

# A SCIENTIST'S SEARCH FOR THE SOUL



Chronicles of a Scientific, Philosophical  
And Spiritual Adventure,  
Looking for Keys to Understand  
The Nature of Matter and Life

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## BOOK ONE: Origin

*About Time...*

## INTRODUCTION

This book and your hands holding it are essentially empty. If they seem solid and do not interpenetrate each other, it is because a mysterious property of the particles of which we are made prevents them from occupying space as they wish: a "Principle of Exclusion" forces them to occupy only the spaces allowed, described by physicists for a century but still mysterious.

All modern chemistry is based on these strange discoveries; all contemporary technology results from them: from the lamp that illuminates you, to your computer, your GPS or even your microwave oven.

But describing a phenomenon does not always mean that we really understand it. Physicists readily notice that if you are not deeply shocked by the results they have been accumulating for a century, it is because you have not really understood what they mean! But do they themselves understand them? Yes and no; it depends on the meaning of the word.

If "understanding" means "appropriating knowledge by integrating it into our image of the world", then the answer is "no": physicists themselves are obliged to navigate between what their formulas describe and what their senses tell them, without being able to make a synthesis of them. But if "understanding" is the result of a logical demonstration in a symbolic language that transcends the limits of our five senses, then it is clear that physicists understand this strange world that they have discovered and exploited since the dawn of the 20th century to create the technology that surrounds us.

It is a world in which particles behave both as diffuse waves in a vast space and as localised point objects. This duality prevents us from accurately measuring their position and speed at the same time: we cannot be sure to find them at a precise place, at a given time; we can only calculate probabilities of presence and speed. Why?

Because "God plays dice" will tell you physicists smiling; probabilities seem to be deeply rooted in the nature of matter! It took them a long time to rally to this discovery, which has always disturbed Einstein! We can't imagine his reaction if he was still among us because today, not only does God play dice, but we are forbidden to see the roll of the dice! Only the result is accessible to us; it is impossible to follow its progress, to observe the behaviour of the dice that roll, in a way!

Nonsense, you might say. Yes... in the context of the world perceived by our senses, but which is definitely alien to the one in which the fundamental building blocks of the matter that constitutes it evolve!

Physicists are amazed, enthusiastic and hope one day to find a way to understand this strange world in a more conventional way than through sophisticated mathematics. But they know that the image left by our common sense is outdated: we are obliged to create another one, compatible with the well-established properties of today's world that must be included in this new representation of the world.

The columns you are about to read tell the story of three friends: a physicist - Axel -, a biologist - Florian - and a historian - Matt. Axel took the initiative of the adventure after deciding to take the world described by modern physics seriously in an attempt to find links

with everyday life. An experience that should have been absurd in the real world has resulted in a result that is as amazing as it is unexpected.... Could there be links between matter and spirit that science could understand? To explore this question, he invites his friends to "get involved" by repeating the crucial experiences of the 20th century physics epic. They try to ensure a solid foundation, to understand the results outside of any mathematical language by bringing them closer to the image of the perceived world. But the world they depict is even stranger than in science fiction novels!

Intrigued by a parallel he draws between the nature of matter and that of life, Florian explains the path of biologists since the discovery of the theory of evolution and then that of genetic engineering in order to present to his friends his rather ecological perception of the nature of living things.

Then Axel presents the work of two of the most brilliant minds of the 20th century: psychiatrist Carl Gustav Jung and physicist Wolfgang Pauli. They have worked together for nearly thirty years with the hope of describing the common source of matter and the psyche. They came up with a successful concept - synchronicity - that Axel used for his original experiment. This process encourages the three friends to explore the sources of intuition.

The chronicles of Axel, Florian and Matt's career are aimed at several types of readers;

- to the curious, interested in the scientific approach and intrigued by its results, which stubbornly confirm the revolutionary models imagined by the creators of relativistic physics and quantum mechanics. These readers will find here an original framework since they will have the impression of carrying out the fundamental experiments themselves with the help of a guide, a CERN physicist, and will only need their curiosity as the only necessary background;

- to readers interested in the biological revolution and its implications on the nature of life. They will be able to easily acquire the tools to undertake a reflection on the nature of man and his place in the biosphere based on new concepts from ecology, an illustrated presentation of the theory of evolution and then the construction of a bridge between chemistry and biology to lead to genetic engineering;

- to philosophical readers interested in contemporary science who would like to understand physics and biology with sufficient clarity and depth to use it in their research: I believe I have succeeded in explaining very clearly and in detail the most important and fundamental results of relativistic and quantum physics based on experimental results and their comparison with our perception of the world, without invoking mathematical language but only contradictory discourse;

- to readers interested in parapsychology who would like to reflect on its implications for consciousness and try to apply new conceptions of physics and biology in the search for models of interpretation of observed phenomena. This seems to be a very good time to look for a synthesis between these areas;

- to readers who have begun a process towards personal development and seek to situate themselves in the material world and the living world through a dialogue with their unconscious and intuition, rather than through cultural concepts that have become foreign to them. They should find here the presentation of practical methods that use the benefits of the experimental method to explore Jung's "individuation".

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A new paradigm based on the facts presented here is published in: “SIMULISM. Are we Living in a Virtual Universe?” (2017) freely available on:

<https://simulismblog.wordpress.com/>

## A.1: GENEVA. MAY: SATURDAY MORNING.

Damn it, the alarm clock! I have to give myself a shake and get up... quickly.... to avoid wasting my time wondering if it's really necessary! Last night Axel looked mysterious and almost solemn when he asked me to join him this morning in his laboratory at the School of Physics. He didn't tell me anything else: just that it was very important and that he was counting on the presence of his two friends: Florian and me, Matt. He didn't want to add anything, except that we had to be free for the whole morning.

Things get better after the shower and coffee. I have to admit, I'm very intrigued. Axel may have just discovered something important. But it is strange that he invites us into his office at the university rather than at CERN where he conducts almost all his research.

It is a very pleasant morning in May. The fresh air, purified by the calm of the night, smells like dewy grass. The sun, still very low, is reflected on tiny droplets hanging on countless cobwebs. Here is at least one gift for the early riser: s/he discovers the immense success of the Spider People! Each tuft of grass, each branch and even the road signs are covered with a thin, glittering fabric that will soon disappear to the perception of late risers when it dries. If aliens were to discover our planet one day, very early on, they would probably give it a name reminiscent of the spider control over the entire environment. In French it could be something like "Arachnée...." » !

I end up on the great descent towards the lake; it unfolds a magnificent perspective on the city that is waking up. Lavender water forms an astonishing contrast to the orange pink of the sky. It's superb and well worth the early awakening! Every day, at every moment, the colours change according to a palette that seems infinite... But the tones are always in harmony. I remember remarking this to Florian, our biologist friend.

- Did it hit you too? "

- I noticed the same kinds of colourful harmonies in the meadows when they are in bloom. The colours of the species that flourish together harmonise, challenge and complement each other. There is never a parallel of tones that strike or extinguish each other! "

It seems as if a gardener with a painter's eye planted soft yellow primroses near pastel violets or white and pink corydalis. The more intense colours herald the beginning of summer. It is then that dandelions, poppies and blueberries compete in brilliance to seduce pollinating insects with whom we share the attraction for flowers, for their perfume and their colours!

If sometimes certain colour combinations shock the view, it is the work of a gardener and not that of nature! It seems that insects have a safer taste than some humans and have gradually favoured harmonious tonal combinations throughout a long evolution... As if insects were attracted by successful colour combinations and more effectively diffused the pollen grains of species whose colours match...

And this morning confirms our observation. The colours are beautiful and diffuse a certain serenity in the mind of whom perceives them.

This serenity fades a little when I park at the School of Physics! The building dates back to a time when buildings should be practical, solid and comfortable. This does not mean that there has been no aesthetic research. The results can be seen on the finely glazed facades of

the stairwells or in some of the timid ornaments above. But it is striking to note that the physicists' environment, at CERN as here, is rather functional, square, and does not attract the eye. Perhaps not to distract them from their thoughts?

I am very intrigued as I walk up the steps to the large metal door of the physics building. I quickly reach Axel's office, at the end of the long central corridor. He's so immersed in his head he doesn't hear me come in! Sitting behind his desk facing the door, he is turned towards the window in an attitude he appreciates: his hands joined by the tips of his fingers spread apart, his elbows stuck on the armrests of the chair, his gaze lost towards the Jura underlining the whole horizon with a band that quickly turns green with the day that is rising.

"Oh, there you are," he finally says: "Florian will probably be here soon and we can get started. But make yourself some coffee in the meantime. It's ready! "

- Thank you! But why are you bringing us here so early? "

- Be patient, you'll understand! I am sure you will be particularly interested in this because you like to teach. "

Now I'm even more intrigued! What does my interest in teaching have to do here? In this office so early in the morning?

It's true that I like to teach. I wondered why and concluded that it was for the love of learning. As an apprentice, I appreciate the courses that bear fruit and, paradoxical as it may seem, there is no better way to learn than to teach! A fruitful lecture is based on a totally digested and assimilated material. It is by building a course that we discover the details that require more attention so that the knowledge really becomes our own, so that it is not a simple repetition of information found here and there, without any real understanding. It is by trying to put ourselves in the shoes of our students to find the illustration that will speak to them best, that our mind turns and returns knowledge until we are really imbued with it. Understanding a phenomenon must make it possible to explain it to someone who does not know it: this is why teaching is the royal way to true knowledge. Sometimes you think you know a subject well, and it's by trying to explain it to someone that you discover the work that still needs to be done! And often this search for understanding succeeds better when we teach rather than when we work alone, as if the two parties - the one who speaks and the other who listens - form a kind of new entity, the one who asks, the other who gives, and together, they succeed in creating something new. Axel also likes to teach: he probably finds the same benefits as me. But I still don't see the reason for this meeting!

## A.2: AT THE ORIGIN OF A PHILOSOPHICAL, SPIRITUAL AND SCIENTIFIC ADVENTURE

Some of the events you will discover are already quite old, but this particular adventure only started a few years ago, when Axel, a physicist friend, called me at home on a Friday evening.

- Matt, I need you and Florian: I'm sure you'll be interested in what I have to offer. Could you come to my office early tomorrow morning, around 7:00 a. m.?"

I was amazed: "Yes, but why is there an emergency? Something serious has happened?"

- No, not at all! Nothing serious, but it's important. It would be a shame to talk about it on the phone. I'd rather talk to you and Florian about the situation in person. Could you come?"

- Of course!"

- So I'll see you in the morning! Ciao."

This conversation only half surprised me. Axel is an experimental physicist. He can be very practical, concerned about developing a clear and defined thought structure. But he can also be in his head and on the moon: he then carries a vague gaze that crosses you without perceiving you: a real schizophrenic! And in that case, you have to know him well to avoid freaking out! He stares at you, haggard, without a movement. The mouth remains ajar because he did not say his last word until the end: he stopped on the way, for an introspection that manifests itself through brief tics on the eyebrows. They suddenly dive behind the frames of his thick glasses before emerging again and participate in his blissful air by their inexpressive curve. He may remain in this state for several minutes before resuming the conversation at the point where it stopped, as if nothing had happened. I remember I had seriously wondered if he was not a little stupid when, as a young student, I had just met him. But no! I quickly realised that these were only the side effects of a prodigious faculty of concentration that allowed him to analyse an issue or situation in a very rich context, turning it around in every way, in the most objective way possible, to try to understand it intimately or to find a solution that fully satisfies him. And since he is authentic, demanding, he goes to the heart of things without the slightest complacency. And this explains his disconnection from the outside world when he mobilises all his intellectual faculties for an analysis that concerns him.

His phone call was supposed to be the result of one of his thoughts and I had learned to trust his conclusions. So I will go tomorrow at dawn to meet him in his office at the School of Physics.

I was happy to see Florian again, whom I had not met in several weeks. I knew he had just returned from a particularly important congress. It was a question, he told me, of reflecting on the possible dangers of experiments in the field, outside the well-controlled conditions of laboratories, which involved genetically modified organisms - GMOs. They are well known today but they did not have the media impact they have since acquired.

Florian is a biologist who seeks to understand the living phenomenon in its greatest intimacy. There are fewer and fewer pioneers in molecular biology who have received training as biologists and have developed a kind of intuition of life, a green thumb that accompanies experiments. He chooses the right questions to ask nature. Those that help us to know it better rather than those that aim to dominate or exploit it.

Florian has joined molecular biologists trained as physicists or biochemists who have not really immersed their hands and brains in the extraordinary diversity of life, seeking to find meaning in it. They mainly deal with molecules by dissecting them with the rigorous and efficient methods of the scientific approach. Florian, on the other hand, was enthusiastic about the discovery of the concept of evolution, which allows us to link myriads of observations by giving them meaning, and which reveals a beautiful and surprising history of life on this planet. He wanted to study the behaviour of life's molecules in order to apply the unifying concept of evolution to them too.

Physicists are looking for a Theory of the Whole that would allow them to explain the universe in its smallest details. Florian taught me that biologists already have their unifying theory. Certainly, it is itself subject to the evolution of ideas! But it is very powerful when it

comes to finding a common denominator to the richness of species' forms and behaviours. So I was curious to ask Florian about the results of the congress. What stage are we at in our understanding of the living environment? Can we start to intervene in ecological relationships knowing what we are really doing...?

I chose to be a historian because I am curious to explore the reasons that have allowed our species to acquire its current characteristics. I am fascinated by the fact that today, at the same time, there are cultures on this planet that have created a very rich, computerised artificial world, and others whose most powerful tools are made of polished stone! Somewhere on the same planet, men have just acquired, it seems, the supreme power to create new living species according to their own designs, while others remain entirely soaked in wild nature, and draw all their food, pharmaceutical, industrial resources... from species they know more in a fusional than intellectual way. What made the difference? How could history help us to understand what happened in one or the other destiny?

### A.3: SUN WAVES

Florian just arrived. He seems to move automatically, only under reflex control, his eye still vague and dull. His attitude reflects a strange mixture of flask and tonic. Strange because it's reversed. What should be toned up is not yet toned up. The features are still heavy with sleep and his skin looks older than him! The muscles do not yet have the respondent they should and seem cold and stiff, much like those of a lizard in the early morning, before the sun has managed to warm it up. He looks like a sleepwalker! Fortunately he has short hair or he'd probably be shaggy!

Florian is even more reluctant of early morning awakening than I am. He has no other time constraints than those imposed by his experiments. He likes to work late at night, in an almost empty lab, inhabited only by the rattling of the samplers who present tubes, one by one, for a given time, under a column that delivers the drops to be analysed. It is also the time when the engines room is buzzing with the hum of ultracentrifuges that run at 40,000 rpm to purify molecules with which researchers explain the links between chemistry and life. Florian feels comfortable concentrating and working without interruption when he is almost alone and his bench lights up under individual lighting that drowns all potential sources of distraction in the darkness. Since he found this way of working Florian progresses much faster! But in the morning, there's no point in hoping to see him in the lab before break time for the others, 10 or 11 a.m. Today Axel changes his habits and, as a loving friend, he obviously accepts to force himself!

Axel straightens up and lead us to a lab at the other end of the long impersonal corridor that cuts the building. He is in an extrovert period, recognisable by his fluid movements and sparkling eyes. In general he can't think and do something else at the same time! His reflexive concentration is deep and compelling. You have to know that to get in touch with him. But this morning he is clearly exploiting the result of his previous cogitations.

He pushes us into the office of his colleague across the way who is not there yet and then closes the door. The room is large, square. A bay window cuts through most of the East wall. Along the North wall run rows of straight books and binders in a light wood library. In the West wall, almost naked, opens the door through which we enter. It is covered with a very

fine-grained plaster, with a pretty egg shell colour. Two desks in staggered rows lean against the South wall which supports small shelves and a large blackboard which must be very useful according its rather grey colour from badly erased chalk. Near the bay window, two armchairs and a small coffee table easily break the office atmosphere that would be austere in their absence.

"Come with me!" Axel leads us to the bay window, obscured by a closed venetian blind. He releases the crank and opens the slats so that the rising sun filters through them and illuminates the West wall with a beautiful orange light.

"I will explain all my approach later, but we must take advantage of the moment when the sun's rays are almost horizontal so that we can make a successful observation, and it will not last very long!"

"Stand by the window and observe. I would like to convince you that light is a wave that has the same properties as the ripples that run across the surface of a pond into which you have thrown a stone."

The shock of this revelation wakes Florian up! His attitude betrays his hesitation. He seems to be wondering if Axel's joking or if he's out of control! But he doesn't have time to express himself: Axel continues. He approaches the coffee table and invites us to look at what is there. It is a rectangular yellow plastic tray about 80 cm wide and 10 cm high. In a corner, on the table, a small metal tripod supports an electric motor connected to a battery. The motor shaft ends with a cam which, by rotating, activates a mechanism that makes a metal rod vibrate in a vertical movement. Axel starts the engine: small wrinkles form immediately on the surface of the water. The ripples do not ricochet against the walls, they seem completely cushioned by a spongy substance all around the pool.

"We're going to do an experiment that can only be done with waves."

Axel seems happy with his setting. He takes advantage of our astonishment to continue: "Only a wave is capable of circumventing an obstacle. Look!"

He stops the vibrator and, while the water calms down, he installs a plastic blade in the middle of the pool. It is surrounded by the same spongy material as the edges of the pool. Its sides are inserted into vertical grooves engraved in the edges of the basin. In the middle, a narrowing of its width allows water to pass over both sides of the basin divided by the blade.

He turns on the vibrator for a moment. This time, a wave train leaves the device, arrives on the obstacle and deforms. Some of the waves are absorbed by the spongy material of the blade. Another part is not stopped by the obstacle and continues on its way. But we can clearly see that the waves cut by the obstacle go around it and then continue their way behind the blade.

Axel runs almost to the blackboard, finds a chalk and draws the following figure (Figure A.1).

"If I were a fish and I swim in the shade of the blade compared to the vibrator, I could see the waves, although I can't see the vibrator!" Axel seems satisfied with his demonstration.

Florian and I slowly emerge from our astonishment and begin to follow his reasoning. Indeed, nothing could be more normal than for the waves to continue their way behind the obstacle! The water molecules raised by the wave will transfer their energy to their neighbours who do not yet have it, whether they are in front of or next to it.

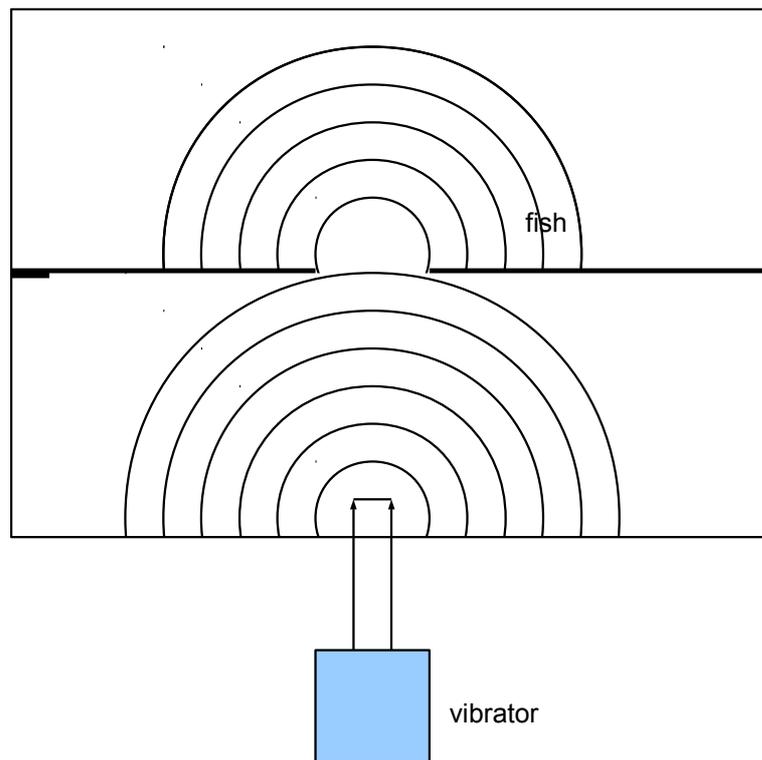


FIGURE A.1: *A fish hidden behind the blade that crosses the basin perceives the presence of the vibrator through the waves it creates that bypass the obstacle.*

Axel draws a wave and explains: "The wave is the result of an energy transfer from one object to another that results in a vertical movement of molecules that do not move horizontally. You see what happens to the molecules that are in the wavefront and those that are in the tail. (Figure A.2)

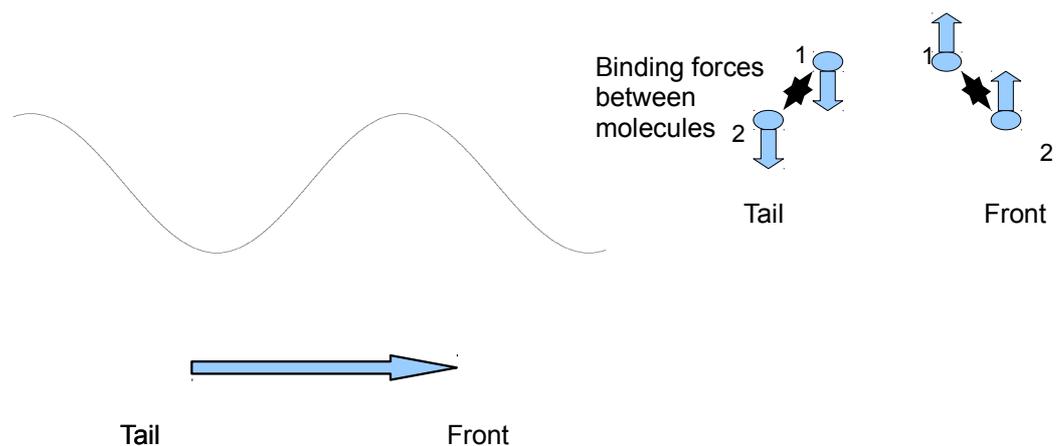


FIGURE A.2: *Molecular movements under the influence of a wave.*

"In the wavefront, the molecule noted "1" will transmit the energy it has received to the molecule "2" and so on... This transfer can only take place in a medium containing close molecules capable of interacting more or less with each other, for example by having a tendency to stick together. If this is not the case, the energy will be conserved by the molecules without being transferred and there will be no waves."

This time we are completely awake!

- All right! Your demonstration is... luminous! Why don't we continue over a cup of coffee?"

Axel straightens up: "Not yet. The most important thing is in front of us: look!"

He returns to the coffee table and the bay window and then plays with the blind crank until the slats are almost horizontal. A soft, calm morning light invades the office. Axel lifts a large white cardboard box that was placed near the window, moves a few steps away and then lifts it to chest height. It faces the bay window. The sun draws wide horizontal orange-pink stripes on the cardboard.

"You see the shadow of the slats," says Axel, "Now I'm slowly moving away towards the back wall. What do you see?"

He steps back, step by step, always with his back to the wall and the cardboard well exposed to sunlight. I don't really understand what he would like us to see. He's almost up against the wall when Florian exclaims: "But you can hardly see the shadows of the awning slats anymore: the cardboard is almost uniformly lit!"

- That's right," Axel exclaims, "I'm starting again so you can follow the evolution of the alternating dark and bright bands."

Axel returns to the window, his back to the wall, cardboard vertical, facing the window. We notice again the shadows of the blades. As he slowly moves away from the wall, the black lines become less dark on their lower and upper edges and thinner and thinner. The light bands lose their intensity. And when Axel reaches the wall, you can no longer see the shadow of the blades. The cardboard seems to be uniformly illuminated with a much less intense light than before.

"How do we explain the disappearance of shadows?" asks Axel.

- If we refer to your experience of earlier, we can imagine that the light goes around the obstacle of the awning slats and, little by little, ends up joining together so that we no longer see their shadow. "

- How do I know if you're right?" Axel asks.

- We should, like your fish in the ferryboat earlier, see the landscape despite the obstacles," Florian suggests.

- The thickness of the slits complicates the analysis of the phenomenon, but take a good look at the texture of the awning slats."

Axel completely closes the blind and we find ourselves in the shadows. But very quickly, our eyes get used to the new lighting and we notice myriads of tiny holes in the slats of the blinds. They let a weak pink light through.

"Approach the blinds and check that the size of the holes only allows you to see tiny little pieces of landscape... Now move away from the window while you look at it."

Florian and I are slowly heading towards the West wall. From a distance of 3 to 4 meters from the bay we hardly see any individual holes anymore. When we get to the back of the desk, it is clear that the landscape is perfectly visible, even though the blind is closed! The light is very soft, the colours are dull, but the shapes and masses are quite recognisable. The sun rises on the Salève mountain surmounted by some mists that evaporate. Even the cable car station is recognisable!

- That's clear! The light is diffracted by the small holes and it thus manages to reconstitute the whole landscape! You have successfully demonstrated! But we already knew that light is a wave! Everyone knows that from school!"

Axel says nothing and asks Florian: "Are you convinced of this too?"

- Well, yes... so what?"

- The problem is that light can't be a wave," says Axel in a mysterious way." You admire a landscape illuminated by the sun. Now there is a void between the sun and us! How do you expect a wave to travel through the void? You know well that sound, which is also a wave, is stopped by vacuum! So how could a light wave transmit its energy to molecules, make them move, when there is almost nothing between the sun and us?"

Touché! I'm trying to find an explanation that would keep up appearances: "Okay, there's no known matter between the sun and us. But who tells us that there is not a kind of particle that is still unknown, subtle, that we should still describe, and that would be the support of the light wave?"

- Matt, you make me happy! That's exactly what the physicists thought! And two of them imagined a very beautiful experience to discover if there really is an ether through which the Earth rushes, turning around the Sun."

Pride must make my cheekbones blush! My ears are even tingling! "But how can we discover if there is matter if we can't see it... if it doesn't react in a perceptible way?"

- Oh, but physicists are very good at working with the invisible!"

- Biologists too," says Florian. "All you have to do is develop an indirect technique."

- Exactly! And that's precisely what makes the experience of two Americans, Michelson and Morley, at the end of the 19th century so beautiful. I would like to propose a new experience now, after having outlined some important concepts to understand the results. Come with me to the lecture hall. I prepared the necessary material. We need a lot of space and in the whole building, only the lecture hall is suitable. We need to take advantage of Saturday: it's only available on weekends."

#### A.4: THE PHYSICIST'S PAINTING BRUSH

The cold shower! I thought I had found an original idea: but no! I have the unpleasant feeling that I was manipulated by Axel to get where he wanted to take us! I wonder what he does with my free will. Upset, I let myself slip into annoyance.

"Axel: Wait a minute! Didn't you bring us all the way here at dawn on a Saturday to give us a physics course?!"

- No, of course not! Uh... Well... a little bit... kind of..."

He seems even more upset than I am! But far from satisfying my need for revenge, his reaction worries me. He doesn't look well!

"Listen! I'd like you to trust me for a while. I can't explain what happened to me yet: I'm still amazed! But know that this is important! Very important! At least for me if not for you too!"

I'm getting more and more worried. Florian too. He questions Axel with his eyes. He already has grey blue eyes, cold, deeply sunken in their sockets and overhanging a nose that takes the wind well: tall, bushy, it simply divides the face into two halves, fortunately well symmetrical. But this morning, his eyes seem even more hidden than usual because he frowns and the darkness only illuminates the light irises.

Axel continues: "Trust me! You will soon understand what concerns me. I can tell you that either I am slowly becoming crazy or I have had an experience whose results are so staggering that I do not dare to present them to you as they are! I would like you to relive with me the main steps of the reasoning that led me to imagine the attempt I made before explaining it to you and to discuss the consequences. I was absolutely convinced that I knew what I was going to achieve and I only tried the experience out of conscience, not to be dogmatic, out of scientific honesty, one might say. But no! I had to admit that I had been deeply wrong... and that I had taken a wrong path somewhere... Not only myself, but all of us when we imagine we know enough about the world we live in!... But enough talk! I suggest that you continue to experiment in order to try to find an explanation together that makes sense. We're going to do a very elegant experiment that dates back to the late 19th century... come and see."

I didn't immediately understand what Axel and Florian wanted to express when they described an "elegant" experience to me. For a long time I attributed to their enthusiasm what I imagined to be a simple language gap. No! On reflection, it must be admitted that the term is well chosen.

Scientists question nature; but they face many obstacles that interfere with the answer they seek. The elegance of an experiment consists in forcing nature to answer their questions: to lock it in a well-composed straitjacket, which constrains and limits it by giving it no chance to wriggle and get out of the prison that the researcher's mind builds for it.

When Axel or Florian describe to me the source of their enthusiasm for an experience, I have the impression to attend the work of the painter who, to transmit his emotions with the most power possible, structures his work, anticipates its effects well before putting them on the canvas. The whole composition of the work is there, but it does not capture the eye at first sight: it forces it to go where the painter would like it to go. A successful painting starts with a strong, powerful composition, which encloses the viewer in the setting that the painter wants him to explore and which will establish a kind of barrier in which emotion can be expressed in a controlled way and even, sometimes, reverberate from one limit to another of the setting, amplifying with each movement.

That's kind of what the researcher is trying to do when he's preparing an experiment. He structures a framework that will define the degrees of freedom of nature: as little as possible, to control all the factors that could influence the outcome of the research.

At the very end of his work, the painter brings his work to life with somewhat magical gestures that, very quickly, following a few precise and brief touches on the canvas, bring out the highlights, guided by his talent and experience. They are the ones who will attract the eye first and give the painting its elegance.

The scientist publishes his result which will shine first, like an enhancement. And the elegance of his work rests on the choice of barriers, on the composition of the experience, on his approach which succeeds in clarifying a facet of nature, as the enhancement brings light and depth to the object he decorates.

In painting, the enhancement is the lightning in the eye that gives a soul to the portrait. It is the subtle touch of light that caresses and animates the fruits, flowers or vases of a still life.

In science, it is the flash of genius that illuminates a part of nature and brings it within reach of our understanding.

The scientist, like the painter, offers us another vision of the world, richer than the one we spontaneously adopt.

Georges De La Tour immerses us in the magic of the light that illuminates - or creates? - objects and characters dissolved in the night. Corot is thrilled for us in front of the landscape that lights up in the rising sun. The atmosphere, free of all dust, radiates a clear and warm light that awakens nature.

Renoir takes us through the reflections that satins pearly skins....

Einstein makes us experience the world in all its four dimensions.

Niels Bohr shrinks us to the ultimate reality and reveals to us the inability of our senses and the cognitive capacities linked to them, to intuitively understand the world we live in!

The scientist, like the artist, invites us to enrich the registers of our perceptions... with elegance.

## A.5: FROM LIGHT COMES...SHADOW

We arrive in front of the lecture hall's door, at the end of the long central corridor that divides the physics school into two equal parts. Axel precedes us by walking down the stairs to the large stage, which is very crowded with disparate material. And now I suddenly feel proud to be a Genevan! There is no need to say: it is good to belong to a society that spends so much money on its universities! Especially when you're a teacher! Luxury and comfort are everywhere. The smooth and shiny glazed parquet floor looks brand new. The moulded wooden chairs have been designed to gently fit the students' buttocks and backs for hours and avoid unnecessary muscle tension. The personal tablets are raised to make the listeners' movements more fluid at the beginning and end of the course. All the walls are richly decorated with fine-grained wood and, at the bottom, on the imposing white rectangle that encloses the amphitheatre, are suspended gigantic blackboards superimposed by batteries of two. The teacher can easily walk a hundred paces to relax while giving his class on the stage, below the arches drawn by the stepped furniture. Currently it is dotted with large tables mounted on wheels. Most of them are cluttered with experimental equipment. Dials here and there are the only devices I recognise at all.

I remember my physics classes at school. The teacher gesticulated around a set of devices and assemblies that seemed totally incomprehensible to us, esoteric! He seemed hypnotised by his goal and danced among wires, screens, adjustment buttons, while talking, without paying attention to us. I would have been hard pressed to tell the difference between what he called an experimental demonstration and the sacred dance of a shaman! Both of them were equally foreign to us, but he didn't notice it! He only saw what he was convinced he would succeed in: to demonstrate to us, through illustration, a concept we didn't need to do anything with, and even less if it was only to find the results of an abstruse mathematical formula!

It was only through contact with Axel that I discovered how interesting and even fun physics can be. It is because he has the gift of bringing ideas within everyone's reach that are not easily accessible when you don't dare to go to the essential. Many scientists remain cluttered with all the precautions characteristic of the Method and often tend to exaggerate. I even wonder if they are not all the more meticulous because they don't really master their material! Even Florian, who is familiar with scientific work, admits that he cannot understand the purpose of an experimental physics montage unless it is explained to him in detail. There are so many factors that can interfere with the result we are looking for that it is impossible to build a simple experience... if we want to remain irreproachable! But why not get to the point by avoiding everything that could clutter the neophyte's mind? Even if it means obtaining less precise but more easily conceivable results? We can always refine the experiences afterwards, once we have properly assimilated the fundamental concepts. This is the approach that Axel develops in his courses. He always tries to make his students understand the experiments he wants them to succeed. And to do so, he illustrates them with examples from everyday life, where possible.

"Here, first we'll discover a new aspect of light."

Axel hands us each a small piece of cardboard, the size of a business card.

"Here are some thin pins. Orient your cardboard by drawing a cross at the top left, then place it on this cork plate and, with the pin held straight, make a small hole on the left side. Now drill two holes very close to each other on the right side of the cardboard. When it's done, go to the back of the room and aim at that bulb by looking first through the only hole on the left, then through the double perforation on the right."

Florian is ahead of me at the top of the stairs. We turn around about fifteen meters from the table on which Axel placed a small desk lamp. He disassembles the reflector so that the bulb is naked and turns on the power. It is a halogen lamp with white light, blinding despite its small size and distance from its source. I look at it through the hole on the left. It no longer appears very powerful.

"It's strange! I can't see clearly the light bulb." Florian tries with both eyes, alternately, without success.

- I see too a clear point surrounded by a luminous circle with diffuse edges." I'm trying to observe the bulb through the two holes on the right.

"It's even worse on the right! The central spot and its halo are interspersed with very thin dark bands!"

Axel doesn't seem surprised.

- Keep looking through the double hole on the right and slowly turn the cardboard around your sighting axis."

The series of dark bands rotates around the axis of the central spot. When the holes are one above the other, the black lines are horizontal.

Florian saw the same thing I did.

"All right! Now come to the bowl full of water to try to interpret what you have seen."

Axel approaches a table with a much larger tank on it than the one with which he introduced his demonstrations earlier in his office. Florian and I go down near it while Axel plugs a motor that operates a long horizontal rod. It dives into the water, near an edge of the tank. The motor drives the rod in a vertical reciprocating movement: it vibrates gently from top to bottom and creates a series of straight waves that travel through the tank until they reach an obstacle, pierced by a slit. The waves are absorbed by a kind of foam that covers the inside of the tank and the obstacle that cuts it into two parts.

Behind the slit you can see wrinkles develop on the water. But they are not straight: they seem to radiate from a point source, the slit!

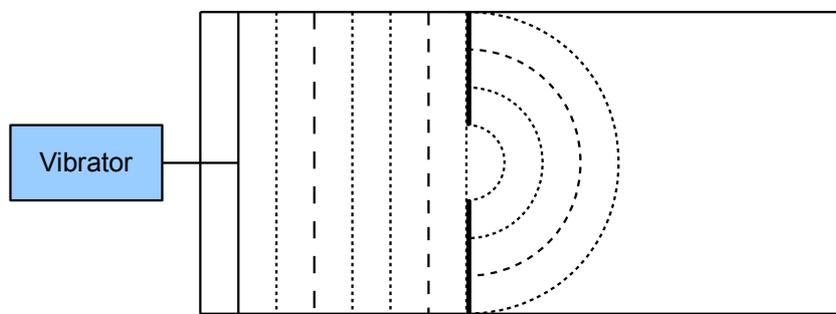


FIGURE A.3: *Straight and parallel waves create circular waves after being forced through a slit.*

Axel comments his drawing: "Put yourself in the place of water molecules to understand their movements! Ask yourself why wrinkles form circles behind the slit when they are straight before the obstacle.

"It will be more and more a question of leaving our point of view to try to adopt the one in which atoms evolve... and you will have many surprises!"

"But here the answer is still simple. Remember that wrinkles are the result of a transfer of movement from one molecule to its neighbours. Those who pass through the slit cannot do otherwise than transfer their energy to the molecules that are straight ahead. But once the slit is crossed, the molecules to the right and left of the forehead will move all the molecules that touch them and are not yet in motion. For example, put yourself in the place of the molecules on the far left, at the exit of the slit. They will not only transfer their movement to those in front of them, but also to those who touch them to their left. So there will be a wrinkle in the shape of an arc of a circle and not a straight wave that will be created at the exit of the slit."

I'm trying to imagine myself as a water molecule. I must confess that it's not so easy... but I think I understand Axel's explanation, who continues.

"Now we're going to replace the obstacle with another one with two slots close to each other."

Axel transforms the assembly, slightly accelerates the speed of the motor, then throws a series of small coloured balls floating on the surface of the water on either side of the obstacle.

"Take a good look at the movements of the balls. They materialise the wrinkles that have become more difficult to observe behind the double slit."

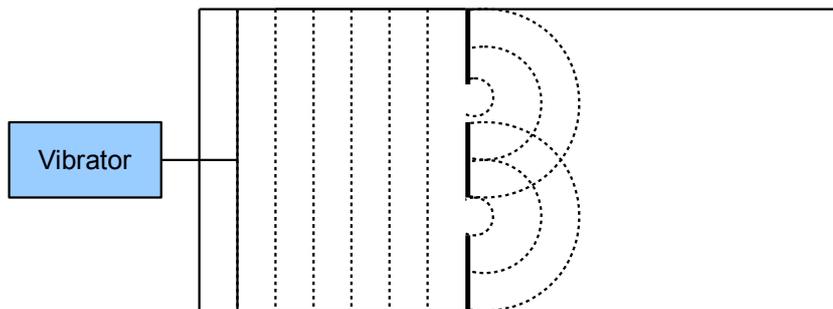


FIGURE A.4: *A train of straight and parallel waves passes through two slits and creates two sets of interfering circular waves. The balls are almost immobile when a trough compensates for a bump or very agitated if two bumps or two troughs add up.*

Indeed, waves cross each other and drag the balls in an amazing way. Behind the slits, some balls are subject to strong oscillations, of a much greater amplitude than before the slits. Still behind the obstacle, other floats barely move, if not at all!

- But you're showing us interference!" says Florian.

- Yes, and they explain what you saw through the two small holes in the cardboard when you aimed at the halogen lamp. In fact, your retina perceived the result of the interference that occurred between the waves coming from each of the holes. In some places a peak of oscillation that came from one hole came exactly at the same time as another, from the second, and they added up to give a single very bright spot. In other places, a wave trough would arrive at the same time as a ridge and the two movements would cancel each other out so that there would be a small dark space."

"That's what you saw! A luminous spot crossed by dark bands."

Florian notes: "If this is true, it confirms that light is a wave capable of making the same kind of interference as wrinkles on water... That's what you'd like us to confirm."

- I'm not imposing anything! I'd just like to go through some discoveries and interpretations with you to see if we understand the same things."

- It seems to me that this is the case! We agree that light behaves like a wave, but we don't really see what the vibrating material is."

- It is to discover if there is such a material in which light propagates, that the experiment we are going to do now was designed. And it was in order to read the results of this measurement that we had to understand the interference patterns we had just observed."

I suddenly realise the absurdity of what my scientific friends are proposing to me!

- Wait a minute! If I understand what you're saying, you'd like me to believe that if I add one light to another, I'll be able to make shade?!"

- Exactly", they reply heartily!

- But that's absurd! We'd see it if it was true!"

- But you just saw it! The problem is that the wavelength of light - the distance between two oscillations - is so small that it is not easily seen. But if you look, you will find many examples of what you call an absurdity, which is very real!"

"Soap bubbles! You probably remember what they look like without us having to blow them out here! Imagine that you have just created a small stream of bubbles in your garden, in the sun. You can see them iridescent, with colours that are those of the rainbow."

- Yes. But I didn't see any black spots!"

- No! But the colours you see are the ones that remain! The others, which make up the white light emitted by the sun, have disappeared, by interference! If you see a red iridescence, it means that the blue, the yellow... have disappeared and that there is only the red left!"

- And what would have made them disappear?"

- Interference, of course! A soap bubble is only a very thin membrane, so thin that the light reflected from one side interferes with the light reflected on the other. And when the thickness of the bubble and the angle of the incident and reflected rays are of a certain value, it happens that waves of a certain length cancel each other out by interference, while shorter or longer oscillations do not cancel each other out! And since the colours of the rainbow are due to lights of different wavelengths - blue being made of short, and red of long ones - you should be able to visualise what is happening in your soap bubble! Or on an oil or gasoline stain that floats on water..."

Amazed... I have to admit: "Okay! Your explanation is... bright! But admit it's weird!"

- I confess! "Axel says with a smile. "But wait a minute! You're not at the end of your astonishment!"

## A.6: THE GREEN OLIVE

*As far as the speeches made by each other are concerned, it was impossible for me to retain the exact text. That is why I have attributed to each of you the words that I have deemed most appropriate to the circumstances, trying to keep as close as possible to the substance of what has actually been said.*

*Thucydides.*

Have you ever tasted an olive? A real one, freshly picked from the tree. You were surprised to discover an unexpected bitterness that makes it completely inedible! How can we imagine that we can get a pleasure out of it for the nostrils and the palate? That behind this feature that protects the fruit from its predators lies an essence that can become so tasty?

How can we make the olive edible? A long process awaits it, discovered for some reason, since the dawn of time. Work of the fruit that brings together the essential qualities. A work of life that ferments and transforms bitterness into flavour. Finally, the work of man, master and conductor of a mysterious alchemy that weaves matter and life. Recipes imagined or deduced from observations patiently and logically gathered to exploit this Mediterranean resource, or the magic of intuition? Maybe a little bit of all this at once.

This is the image that slowly came together, until it became obvious when I reread my notes: the ones you discover. These chronicles show how to work with the matter that the universe presents to us to approach an understanding of its true nature, which is as beautiful as it is unexpected. At first it seems quite different from what it is, deep down. From material, it sublimates itself in stages to finally lead us to question ourselves! In science this slow maturation was born from the long work of physicists curious to understand the physical world in which we bathe, of biologists fascinated by the extravagant richness of the living world in which we participate... It seems to describe a kind of modern philosopher's stone. It is not revealed to the naive eyes: nature must be shaken up to answer our questions, so that it allows us to see parts of reality. Like the olive, which hides a delicious fruit under a rough appearance, which requires human ingenuity to reveal itself.

Paradoxically, I have chosen to focus on themes rather than chronology to gather these chronicles. It seemed to me to be the way to describe as clearly as possible the topics Florian, Axel and I have discussed over several years. This is not without a few repetitions or a few reversals which, I hope, will not disturb you. I alone assume any error in the text because the two scientists preferred to correct only the very serious misunderstandings. They respected the description of my ignorant approach towards the acquisition of knowledge rather than the dry truth of the professional who exposes it, convinced that errors or inaccuracies are a price to pay to achieve greater ease of presentation in all clarity of concepts considered difficult. They have not changed the interpretations or images I have been able to propose to convey what I believe I have understood. They favoured the naive transfer of information rather than criticism and accuracy that could have obscured the purpose or even sterilised the imagination.

## A.7: LASER, MIRRORS AND TELESCOPE

"This is the montage I use for my students. It was a very beautiful experience at the end of the 19th century that showed that light is indeed a wave and that it makes a mysterious matter vibrate, called ether."

Axel is heading towards a large square table with a double top, one above the other. On the upper tray, slightly smaller than the first, are several instruments and mirrors, all equipped with adjustment levers.

"Michelson - the physicist who had this good idea - built this device and called it an "interferometer" because it allows you to create interference patterns with light and use them to make extremely fine measurements. It divides a very pure ray of light into two halves and then makes them travel the same length but perpendicular to each other. Then he reassembles them to make them interact. The slightest variation in the path of one of the rays results in a displacement of the interference lines."

Axel takes a chalk from the desk and draws a diagram on the board.

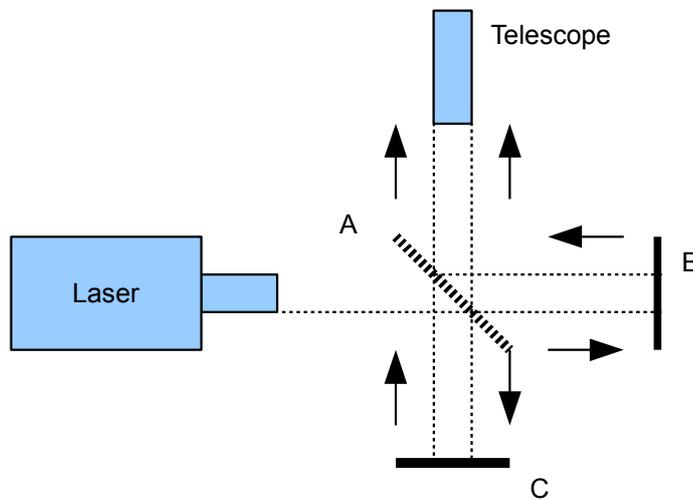


FIGURE A.5: *Interferometer. A laser sends a beam of light onto a semi-transparent mirror "A". Half of the beam passes through it and is reflected on the mirror "B" while the other half is reflected by the semi-transparent mirror before bouncing on the mirror "C". The beams reflected by the mirrors "B" and "C" meet and interfere on their way to the telescope.*

"Look! We use a laser to emit a monochrome wave. The ray arrives on the glass slide "A" which is semi-reflective, like sunglasses that look like mirrors. It lets half the light pass through it and sends the other half back. The first one will ricochet off the mirror "B" to return to "A". The second one will hit the mirror "C" to also return to "A" which now recombines the two light beams. Again, half of each of the two beams continues towards the scope that will allow us to observe the interference lines."

"The device is already set. Here we go! Take a look in the scope."

Axel manipulates a control on the desk to gently lower the light emitted by the ceiling, then turns on the laser, which lights up with a beautiful ruby red colour some dust that float in its path. I look through the eyepiece of the scope. The ray of light is broken down into thin vertical bands, evenly spaced by dark spaces of the same width.

Axel says, "You should see two thin wires in the eyepiece!"

Indeed, two very fine black lines divide the field into three unequal parts.

"Adjust the left thread on the middle of a light strip with this control". He guides my left hand on a wheel that I operate until I am satisfied with the result.

"Now, with this other joystick, set the right-hand thread to the middle of the band next to the one you just chose."

When my two black lines divide two light lines in the middle, Axel quickly checks the result and invites Florian to take a look in turn. Axel continues: "Now I'm going to force one of the two light rays to cross an additional obstacle. He places a transparent glass slide on the table, between "C" and "A", perpendicular to the mirror.

"Look through the eyepiece!"

I notice that the threads are no longer in the centre of the light bands. They must have moved from their earlier position!

Florian observes the same thing and suggests: "The light that passes through the glass you just put down must have been slowed down so that the waves no longer arrive at the same time as those that only pass through air. That would explain why the interference patterns shifted."

Axel nods and then removes the glass slide he had just placed on the table.

"Check that the wires are again centred on two adjacent strips! Now I'm going to turn the whole device 90°."

The upper tray that carries all the instruments must be mounted on wheels because Axel handles it very easily.

"Look again to see if the lines have shifted!"

Florian and I see that nothing has changed: the threads are still fine in the middle of the red stripes.

"Well, this result is not at all what Michelson expected! He was sure that thanks to his interferometer, he would be able to demonstrate the presence of an "ether wind"."

"Indeed, the Earth rotates on itself, orbits around the Sun, which itself leads us towards the constellation of the Lyra, which...etc... If the whole space were filled with a substance that light makes vibrate, we should cross it and undergo the effects of an ether current, just as the runner perceives a breeze when he moves, even on a windless day. And this current should influence the interferometer!"

- I don't see how!"

Axel returns to the table and makes the following diagram (Figure A.6):

"It's easy! Suppose you would like to swim across a river that flows from "C" to "A". If you start from "A" and want to reach "B" as directly as possible, you will have to aim for "D" since the water stream drags you to your left. If you estimate your angle of travel correctly, a bird would see you swimming straight towards "B". But in reality you will have covered the distance AD and not AB, because of the current you have to swim against."

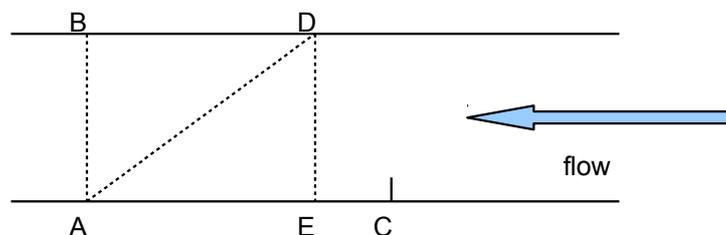


FIGURE A.6: A river flows from right to left (C to A). To swim through it from A to B, you have to aim for a point D, which is all the more upstream of B when the current is fast.

"If you decide to go back to "A", you will have to aim for "E" to travel the most direct distance, always because of the current. In short, to make the round trip between "A" and "B", you will have to cover twice the distance AD."

"Now imagine that you would rather swim from "A" to "C", distant from "A" as "B" is from "A", then return from "C" to "A". How will the time it will take you to complete these two courses compare? Take a specific example to set your mind to it. Let's assume that  $AB = AC = 100$  m, that you swim at 1 m per second and that the river flows at 0.5 m/s."

- You're not going to force us to calculate routes early in the morning: I like physics but not math! Intuitively, I would bet that the crossing from "A" to "B" and back will take longer since AD is longer than AC."

- You're wrong not to rely on math! We will see later, if you don't mind, that they are essential to study phenomena that would otherwise be impossible to analyse. You have the impression that they obscure understanding when it is exactly the opposite that is true! They represent the stick that make it possible to move forward on the basis of something solid. Thanks to them, we use our logic to construct a reasoning that would be very difficult, if not impossible, to create otherwise... We would get lost too easily as soon as the problem becomes important! Look!"

"Let's calculate the time it takes to cross the river and return to the starting point. In a second, you swim 1 m but the river pushes you 0.5 m. How close did you get to "B"? Let's draw your path:" (Figure A.7)

"The AB'D' triangle is a rectangular triangle: and I hope you remember that in this case, the sum of the squares of the two small sides is equal to the square of the length of the long side."

- Yes, it reminds me of the good old days!...."

- We have  $AB'^2 + B'D'^2 = AD'^2$

"From where we get  $AB' = \sqrt{AD'^2 - B'D'^2}$

"And if we replace the terms with their values:

$AB' = \sqrt{1 - 0.25} = \text{about } 0.87$  m.

"To travel your 200 m it will take you  $200/0.87 = \text{about } 230$  seconds.

"Now let's calculate the time it would take to swim from "A" to "C" and back. In a second you'll be swimming 0.5 m. It will therefore take you  $100/0.5 = 200$  seconds to reach "C".

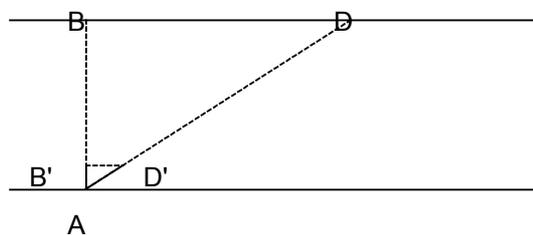


FIGURE A.7: Diagram drawn by Axel to calculate the time required to cross the river.

"To return to "A", you will be carried by the current. Your speed in relation to the shoreline will be 1.5 m/s. You will join "A" after  $100/1.5 =$  about 67 seconds. Your journey will have lasted a total of 267 seconds. Now you see that the calculated result is different from what your intuition suggested! You should always be wary of it and rely more on math when possible!"

- I admit it! It's indeed the opposite of what I had imagined!"

Florian says, "Now I see why Michelson expected to find the ether wind with his interferometer! When turning the device, it is necessary that at some point one of the two rays of light has to go up the current before returning while the other passes through it. The one that goes up the current will be slower than the one that crosses it and the lines should move. But is the device sensitive enough to measure it?"

- Michelson experimented again with a remarkable interferometer that could reveal an ether wind at least ten times lower than the Earth's speed in its orbit around the Sun. And he didn't find anything! He even imagined that it might be necessary to climb to a higher altitude to better feel the ether wind. That up there, it would be less slowed down by the Earth and would shift the interference lines. But even in the mountains, nothing! The rays were stubbornly in sync!"

"After a few years of attempts of this kind, Michelson gave up without understanding why he had failed."

- But then why do you think this experience is great since it didn't work?"

- It didn't fail! It was very elegant and should have flushed out the ether wind, whatever its properties! But Michelson couldn't, like almost all other physicists, imagine the unimaginable! That the ether does not exist and that light is a wave that travels through the void, always at the same speed "c" of 300,000 km/s."

- But what is it a wave of?"

- We'll talk about it later if you don't mind. Now I would like to introduce you to the solution devised by Einstein that turned 20th century physics upside down... and us with it!"

## A.8: EINSTEIN'S EMULATORS

A vision from beyond the grave! Haggard or illuminated? It's hard to know! He is at the very least original, the wacky one who almost hit me at the end of the lecture hall. Imagine a kind of 60-year-old zombie, with short, straight, white but messy hair. A large, aquiline and warted nose. Thick white eyebrows that partly hide the introverted look. An arched back... or hunchback? And, carried by long bony hands at the end of his arms, which one guesses to be thin under the worn-out dark grey jacket, a white plastic tray with four metal containers from which diffuses a very abundant white smoke that gradually vanishes in its wake! It must be dry ice that he takes to his laboratory for an experiment that can't wait until Monday! He will probably spend his entire weekend here: time does not exist for most researchers! They are rarely able to inform you about the date or even the day of the week!

It was in Florian's laboratory that I was able to observe the most remarkable specimens! Many of them are temporarily expatriated from the United States, where culture seems to

have given birth to an archetype of researcher with whom they seek to resemble with varying degrees of success. The model starts with Einstein. Just compare a picture of him with that of an American scientist like Oppenheimer to understand this evolution. The American is neat, shaved closely, his hair well combed. He wears an elegant suit and shiny shoes... while his European colleague obviously doesn't care about elegance! Even his hair isn't cut, just a little brushed backwards so as not to disturb him. The pants, suspended by two wide straps, are probably very comfortable because they are so wide and worn! The sweater is loose but too short... and the shoes dusty. Perhaps the only common point between the two physicists is in their very special look. At Einstein, it is enlightened by intelligence but also by confidence... He has the means to be sure of himself and he remains so, against all odds! Oppenheimer's gaze is particularly clear, reflecting his remarkable spirit. But it was the European who was the media's favourite! It still seems today that researchers think they are getting closer to genius by copying his image!

In almost all professions there is a more or less representative sample of a society: one is not necessarily brilliant because s/he is an academic: there are some who succeed by the strength of will and raw memory! But researchers who reflect the average of the society to which they belong are the exception rather than the rule: we can say that they all have worms in their brain! My friends, whom I love very much, do not escape this generalisation!

Their madness is most often sympathetic: more rarely a little morbid, when it results in sickly introversion. They are obsessed with their passion: able to stay night and day immersed in a complex experiment that takes them beyond time. And since research is difficult, there is always something wrong, a detail that was not given enough importance and that leads again and again to new controls that are essential to get to the bottom of it... And there are the deadlines for conferences that force them to multiply the results they will have to present... And there are credit requests that use precious time... Many good reasons to extract them from the universe surrounding the academic world.

But this life nevertheless has some advantages! First of all, that of awakening a passion so powerful that it often overwhelms the strongest possible drive... the one that makes us born! I wonder if this is not the environment in which there are the most singles - apart from priests or monks, of course! Sometimes their very targeted interest sterilises them in most other cultural or sporting activities. Rarely, when new female technicians or researchers wander the corridors, some zombies seem to wake up from their hypnotic sleep! I have attended discussions between greedy gourmets much more often than between single males! Americans in particular have never ceased to learn to combine good wines with the best cheeses! Biochemists whose experimental protocols often recall cooking recipes, share their gastronomic discoveries, good addresses, details of a particular sauce or the most suitable decoration for a particular dish... when they are not talking about science. I've rarely heard them talk about anything else!

Another spin-off from research seems to have an impact on ageing! I have met researchers after an interruption of about twenty years... they hadn't changed! Of course they had wrinkles! Men regularly had less hair! The belly had blossomed, the step stiffened... But it was the same people, with a curious look at everything, so typical of youth. Most of them remain almost as naive as when they were children. What a difference with the ageing of someone who has lost it, this juvenile curiosity! I remember the shock of the chance encounter with a childhood friend... who had become so old that it was no longer him: it was

someone else... a kind of dry grown-up person, very different from the grown-ups who remained the researchers!

But we arrive in Axel's office who invites us for a coffee before turning to his blackboard, grey with chalk dust.

## A.9: AND EINSTEIN HAS ARRIVED... !

Axel lets us into his office and slides two chairs near his work table. The room is clear now that the sun is higher in the sky. The very bright ochre walls give off a soft glow that highlights the flowers on a corner of the desk. I have the impression that each physicist has his own particular madness, which allows him to express his personality in a very visible way. One would never go out without a bow tie; the other would comb his hair like Einstein; and yet another would not leave his office without floral decoration... May he who has never flattered his ego throw the first stone at them!

Axel sinks into his old armchair, tilts it backwards with a snap of his back and then locks it in balance on two feet by crossing his legs on the table. Elbows firmly fixed on the armrests, fingers of both hands joined in the position he seems to like since it is the one in which I discovered him this morning, he explains:

- Try to imagine the landscape of physics at the end of the 19th century. We had understood our universe with enough precision to draw valuable benefits from it such as thermal engines, electricity, magnetism and their multiple applications... Thanks to geniuses like Galileo or Newton, we were convinced that we were very close to an ultimate understanding of the physical nature of the universe. Galileo had shown that mathematics made it possible to describe the essence of physical phenomena and to control them. He was the first to put the experiment forward in relation to theory and then to seek mathematical formulations that fully explain experimental results.

Florian interrupts him: "Yes, but you don't necessarily understand a phenomenon because it obeys a mathematical law! In biology this is more often the case than in physics! When we are able to draw mathematical curves based on biological or biochemical results, it is because we have managed to control sufficiently well the many factors that complicate our lives as biologists! And then we can say that we understand what's going on! On the other hand, I have often talked to your colleagues who tell me they apply formulas without really understanding what they describe!"

- This has been true since the beginning of the 20th century! But not before! Galileo understood the laws of movement through mathematics. Newton got the gravitational ones from it. He went much further since he himself forged the mathematical tools he lacked to do physics. And since then, his successors have sought to have formulas glued to the experimental results in the hope of giving them, after the fact, a physical interpretation. Another physicist at the end of the 19th century invented yet another new way of doing physics and used it to make a brilliant discovery that brought together forces that seemed very different at the time, electricity and magnetism. Look! You probably had this experience at school, look..."

Axel stands up on his chair and shows us a long copper wire placed on two plastic bases and connected at both ends to a battery and a small bulb. He switches on the current after

placing a compass under the wire. The needle turns abruptly and is placed at right angles to the copper wire!

"It took many years to discover the mysterious relationships between electricity and magnetism... until Maxwell explored a new way of doing physics!"

"He imagined that the universe is filled with an ethereal substance that reacts to fluctuations in electrical current or magnetism, as if tiny sprockets were spun by the current and, without friction, communicated their movement to their neighbours. This mental image allowed him to imagine the influence of an electric current or magnetic field at a certain distance, through the rotations of his hypothetical wheels. But above all, it allowed him to establish the mathematical equations that show that electricity and magnetism are only two sides of the same coin. It is a prodigious discovery because it predicts the existence of electromagnetic waves that were researched and then discovered a few years later: these are the radio waves described by Hertz after Maxwell's death unfortunately!

"Even more amazing! Maxwell's equations involve a quotient of two constants that apply to his waves. The result of this quotient is of course also constant but it has the shape of a speed and is worth nearly 300 000 Km/s! Maxwell notes that this value is almost identical to the speed of light, as measured by the experimenters. He suggests, by association, that light is an electromagnetic wave! A wonderful intuition... also verified a few years later!"

"And that's where Einstein comes in! He greatly appreciated Maxwell's work as a student. He knows the constant "c" and also inaugurates a new way of doing physics!"

- I don't think I understood why you said Maxwell invented a new way of doing physics! Before we move on to Einstein, maybe it would be good if you could be more specific!"

- All right! Well, Maxwell used a mental image, a model, to represent the intimate structure of the universe and build the mathematical edifice that can describe the effects of electrical and magnetic forces... but he did not believe himself in the reality of his model! It was just a crutch that allowed him to move forward in solving his problem. He then uses his results to draw perfectly unexpected consequences that can be verified by experience.

"Einstein continues on the same path but goes even further. He was a strange character! A genius? Probably! But perhaps as much by an association of heterogeneous particularities as by a specific talent! He was extremely confident! Stubborn, able to extricate himself from any concern other than the one he was interested in and to work for years on a difficult subject but that his aesthetic intuition pushed him to explore all sides. He invented theoretical physics based on a physical idea before looking for its mathematical formulation. So he does the opposite of what other physicists did!"

"In the case at hand, he decided that the constant "c" was a physical law and that it should therefore, like any physical law, remain the same, regardless of the frame of reference in which it is measured."

- What do you mean by that?"

- It's simple! But the implications of his hypothesis are staggering!"

"Einstein has several times illustrated his ideas very clearly himself. It had to be because its results powerfully defy common sense!"

"Imagine, for example, that you are sitting on a train that is about to leave a station. You are near the window and watch the train car on the nearby rails. Suddenly, it moves... or is it rather your car that leaves, smoothly...?"

"You have no physical way of knowing at this stage, until you see a third object - the station, for example - to decide whether you are stationary or moving in relation to it. If you throw a coin in the air, it falls back the same way, whether your car is running or stationary. The laws of motion and gravitation remain the same in a stationary train or in a car that runs in a uniform straight line, i.e. that is neither accelerated nor braked and that does not rotate. You have to wait patiently to see the station to see if you have left or if it is the nearby train that leaves before yours!"

- But it seemed to me that it was known from Galileo! Wasn't it he who showed that a stone thrown from the top of a boat's mast would fall on deck in the same place, whether the boat was stationary or moving?"

- Absolutely! Galileo invented relativity, not Einstein! He showed that a movement can only be defined in relation to a reference frame and that the movement is relative to the chosen frame! For a sailor on the boat to describe the path of the stone in the same way as an observer on the dock, the boat would have to be stationary in relation to the dock. If the boat sails uniformly and straight, the descriptions of the movement of the stone will be different, depending on whether they come from the observer who stayed ashore or from the sailor who left with the boat. For the one who is on the quay, the stone follows a curve to fall on the deck while for the sailor it falls straight down. There is indeed a relativity of observations that depends on the context in which you are located, the dock or the boat!"

- And why are we talking about Einstein's relativity then?"

- Because he dared to push this principle far beyond what common sense tells us!

"Maxwell's work had suggested that light is an electromagnetic wave because its speed, measured in the laboratory, is equal to that which emerges from his equations describing the link between electrical and magnetic phenomena. But remember! Maxwell had found that "c", the speed of electromagnetic waves, was a constant, derived from the ratio of two other constants.

"Einstein's genius is to postulate that "c" remains a constant in any frame of reference at rest or in uniform rectilinear motion! Like the laws of mechanics, measuring the speed of light will not allow us to know if the train we are in is stationary or on the move! Einstein postulates that we would find the same result for "c", whether we are on a stationary train or travelling."

- I don't see how this is so revolutionary!"

- Because of the logical deductions we are forced to make from it! And it is here that Einstein invents a new way of doing physics. He begins by reviewing the experimental results and their theoretical explanations proposed by their inventors. He gets an "Idea" from it: I insist on the word! That's the origin of his approach! Then he analyses all the implications and consequences that must logically be verified if the Idea is right; even if they go against common sense! Finally, he draws from it proposals for experiments whose results should decide the validity of his Idea.

"When Einstein applies his Idea to the equations of motion, he discovers that time and space are nothing less than elastic, whereas common sense has always presented us with

absolute space and time. We think we're moving into a fixed space and adjusting our watches to an unalterable time!"

Oh, my... I'm out of my mind!" Florian rubs his forehead!

- So do I! Wouldn't you like to make us some coffee? Don't forget that it's Saturday and you still haven't explained why you brought us here!"

- Excuse me! You're right! But we're getting to the end!"

Axel prepares coffee for us but still doesn't explain his objective.

"Let's take the example of the train again, you'll see more clearly!"

"That's it! Suppose you invented a watch that works with light!"

Axel takes up a chalk and draws two parallel lines on the board.

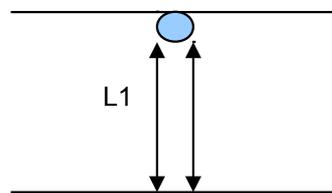


FIGURE A.8: *The photon bounces eternally between two parallel and perfectly reflective mirrors.*

"The skeleton of your watch has two perfect mirrors, one facing the other, absolutely parallel. You introduce a tiny flash of light perpendicular to the mirrors. As they are perfectly bright and perfectly parallel, your flash of light will reflect indefinitely on both mirrors and oscillate between them with a frequency  $F1 = c/L1$  if  $L1$  is the distance between your mirrors and "c" the speed of light.

"Imagine that your train is on its way and a spectator in a meadow sees you pass by with your strange clock. What will be the path of the flash of light he will see?"

"If the train is moving, he will necessarily see the mirrors move along with the train. The lightning will no longer be perpendicular to the mirrors as you see, yourself, who are on the train with your clock! The guy in the meadow would see the lightning reflected from an angle that is all the more acute as the train goes fast: like this: (Figure A.9)

"And if you calculate the lightning path from the meadow, you will see that it will have made a longer path than the one measured at the same time by you on the train. From the meadow we will have  $F2 = c/L2$  with  $L2$  longer than  $L1$ !"

"Now  $F1$  and  $F2$  are equal! In the meadow or on the train, you will see the lightning flash bouncing the same number of times between mirrors per second. Now if Einstein postulates that "c" is immutable, then you are forced to admit that it is time that changes, depending on whether it is measured in the moving train or in the field!"

- I'm lost! And first of all, why did you draw your two mirrors offset from each other? You first drew two mirrors one in front of the other!"

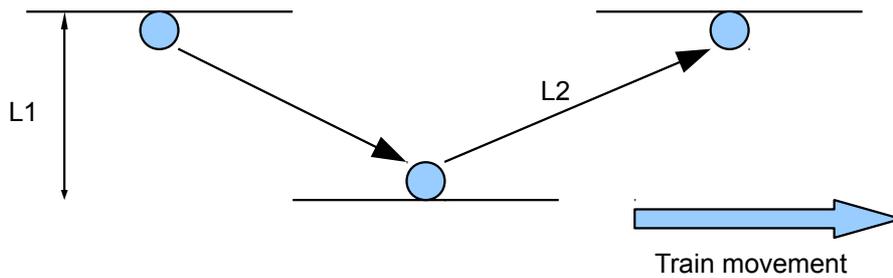


FIGURE A.9: *The spectator standing still in a field discovers that the photon is reflected at an acute angle and not perpendicular to the mirrors as seen by the passenger on the train. For the motionless spectator the photon travels a distance  $L2$  between the two mirrors that is greater than  $L1$ .*

- They are well in front of each other if they are at rest compared to the one who is observing them! But if they are on the travelling train, the spectator in the meadow will see the lightning bounce off a mirror at some point and then the same lightning bounce off the second mirror a little later. But during the time it takes the lightning to cross the distance between the two mirrors, they will have moved according to the speed of the train! The second mirror will therefore be in front of the first, by a distance proportional to the speed of the train!"

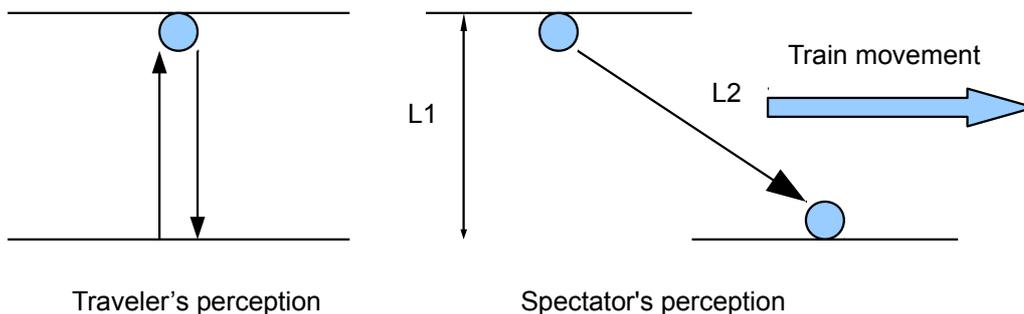


FIGURE A.10: *The traveller sees the photon bouncing perpendicularly between the two perfect mirrors. The device and the passenger move at a constant speed so that they do not perceive any movement: the photon behaves for them as if the train were stationary.*

The viewer in the meadow perceives a completely different image! During the time it takes for the photon to move from one mirror to another, the train has moved... and so has the target mirror! The traveller and the spectator agree on one thing: the photon hits the mirror in its centre. It must be concluded that the spectator sees the photon moving at the same speed as the train and travel a longer distance than that measured by the traveller!

"We have  $F1 = F2$  so  $c/L1 = c/L2$  but  $L2$  is bigger than  $L1$  and "c" is the same in both equations! So something that defines the frequency must be modified by the speed! However, a frequency is a number divided by time! The number being the same in  $F1$  and  $F2$ , it is necessary that the time changes! In other words, a second measured in the train will last

longer than a second measured in the field! This is the only way to check the equation if "c" is a physical law and does not vary!

"Time is no longer absolute! It flows at different speeds in the train and in the meadow! And the faster the train goes, the greater the difference! And if the train approaches the speed of light, time would slow down in the train, relative to the meadow! The spectator would age faster than the traveller!

"Worse yet! Einstein concludes that there is no such thing as absolute simultaneity! Two events that happen at the same time for the traveller, would not be simultaneous for the spectator in his field!"

Axel draws a wagon with a large central lamp that illuminates it.

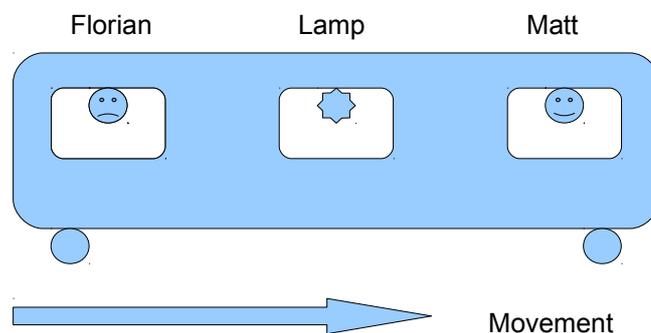


FIGURE A.10: *The lamp in the middle of the car lights up simultaneously for Matt and Florian. But the spectator standing still in the meadow will see the flow of light first illuminate Florian as he approaches the beam when Matt moves away from it.*

"Suppose we light a lamp in the middle of the car. You, Florian is here and Matt is there! You will both see the light come on at the same time since the speed of light is the same from the lamp to Florian or from the lamp to Matt!

"But the spectator in the meadow will see the same lightning strike first at Florian who, because of the movement of the train, is approaching him, then at Matt who is moving away from him! A simultaneous event for you on the train will not be simultaneous for someone else! It's the death of absolute time!"

- This is all too abstract for me! And I still don't see why you're telling us about it!"

Unperturbed, Axel continues...

- Einstein himself stated: *"We must take into account the fact that our judgments in which time intervenes always concern simultaneous events. When I say, for example, "the train arrives here at 7 o'clock", it means that the position of the small needle on my watch on the 7 and the arrival of the train at the station are simultaneous events"*. However, since his theory of relativity, we can no longer speak of absolute simultaneity but only relative to a precise frame of reference! That is why there is no longer any absolute time. The speed of an observer

or what he observes will affect the simultaneity of events! Time becomes relative and depends on movement."

- And why are you telling us all this?"

- All right! You have been very patient and I thank you for that! "

"I have presented these little experiments to show you that physics has changed a lot since the beginning of the century. It is no longer as simple and concrete as it used to be. Physics discovers that the universe is more complex than it imagined, it is subtle and sometimes even outright astounding! Even what we took for granted, an absolute space and time, is not!

"I suggest you stop doing physics for today. We'll do it again later if you're interested. But I invite you to lunch with me at the Tunisian next door and I will explain the reason for my approach."

- Finally some common sense words... Let's get some fresh air and say hello to the Tunisian! "Florian is already up and about and we're all following him.

## A.10: THE CLICK

"L'oasis" is a small local restaurant that its swarthy owner has transformed into a very warm place. His entire and large family participates in the life of the establishment, which opens onto a terrace that is still empty at this time of year. The interior is decorated with hookahs with long twisted pipes, large silver plateaus with hammered and finely chiselled arabesques, oriental carafes whose beaks are surprisingly reminiscent of those of a pelican! All this is a change of scenery and a pleasant break from the workday. But it's Saturday, and the room is almost empty. It is quite different on weekdays, when it swirls with conversations from university staff or the nearby radio and television building, attracted by the boss's royal couscous!

We choose a table away, near the bay window, and order the menu we know well without delay! A brunette who emigrated to the popular district of La Jonction where the Arve melts into the Rhône, offers us the water, so precious in her country of origin, with gestures that we would willingly interpret as ritualising a kind of respect for the crystalline liquid that seems to swell the transparent jug.

The young girl left, Axel explains: "So that's it! My studies in physics have taught me that time and space are of a very different nature from the one we perceive! But learning does not necessarily mean understanding! Thanks to mathematics we can master the description of a phenomenon such as the one we are concerned about today: the nature of time. The predictions of the theories, followed by their experimental confirmation, confirm our convictions. But, on reflection, it appears that it is the form rather than the substance of the concepts that mathematics addresses. There is still a gap between what our equations tell us and the world in which our senses plunge us! And that's always bothered me. Enough for me not to be able to do like most of my colleagues... who are a little schizophrenic! During the day, they juggle with models of reality that are all more stunning than the other... then, at night, gently put their feet back in the slippers of conformity! And then my story may have prepared me a little bit for the adventure I experienced.

"As a young student, I was sometimes invited to spend a few days with an aunt by marriage who had taken care of my sick uncle until his death. He had known her because my grandmother, desperate for the progress of his illness, tried everything she could imagine to support her only son. She even explored unorthodox ways and consulted a reputable magnetiser... who would eventually marry her son and do him a lot of good. I don't know what the magnetism of healers is. I didn't care because I know the amazing effectiveness of the placebo effect. And it is perhaps to its nature that my research would have been directed if I had been a biologist! No! What disturbed me the most was that my aunt was also a valued psychic! When I first met her, she was old and retired from the profession. But she was still regularly solicited. When this happened while I was spending a few days at her house in Juan-Les-Pins, she isolated herself with her client, without saying anything... and it lasted a long time that left me perplexed! I knew what she was doing, but not because she was talking to me about it: it was a kind of family secret. My aunt's abilities or gifts made her a bit of a witch in the eyes of normal people. We admired it without understanding it and perhaps with some semblance of apprehension. What was she able to see... or know?... Was it really Catholic to do this job?..."

Axel stops for a moment while the boss loads our table with several appetising dishes. There is a large circular dish made of thick ochre ceramic filled with a pyramid of blond and smoking semolina, a glazed brown earth casserole dish in which Mediterranean vegetables still simmer covered in tomato sauce and, finally, an oval plate garnished with pieces of poultry, lamb and sausages. It'll probably take us a while to try to get through this!

With our plates full and the Tunisian gone, Axel continues: "I have always been interested in science and the power it shows when it comes to explaining the world. I also knew that my aunt was fine and smart. And that was a big problem for me! How could someone sensitive and reasonable take care of so many esoteric and sulphur-smelling areas?! She probably wasn't a charlatan. I knew her well enough to be deeply convinced of her. But then, how did she reconcile her reason with her so-called talents of magnetism and clairvoyance? I didn't dare to talk about it, but it intrigued me at first. And one evening, quite by chance, we talked about it.

"Tired after a long day of walking in the back country burning with the June sun, I collapsed into one of her old and fragile sofas, which couldn't resist! She must have perceived my great discomfort because she immediately intervened and told me that she knew it had to happen! I was so disturbed that I forgot the family taboo and asked her if it was her gift for clairvoyance that made her say that. She must have felt a hint of irony in my remark because she replied quietly, staring straight back at me. She did not answer my question but said that the psychic should not be mocked without having made the effort to meet it. That it was something very serious... perhaps a gift from heaven to help man, or a widespread and unknown faculty nowadays even if it was valued by all civilisations, including ours... at its origin! Great philosophers respected it, especially Greeks. It had been part of the world for much longer than science... whose qualities my aunt recognised.

"I was embarrassed and didn't answer. But the next day, to clumsily try to apologise, I asked her if she knew of any circumstances that would have demonstrated the reality of clairvoyance. Her answer was sibylline. She made me understand that she did not think that this phenomenon should be demonstrated in the same way as a scientific theory is demonstrated. For her, it was part of a parallel world, which implied a different approach. It

gave me the impression she addressed a pretentious young naive man who still has everything to learn... but who has no idea! I was a little offended, but I don't think I showed it.

"She nevertheless offered me two avenues for reflection: both based on books she asked me to read. The first one was from 1898: it was Morgan Robertson's "Futility, or the Wreck of the Titan". My aunt had ticked the first page of the chapter describing the unsinkable transatlantic ship that was nevertheless going to sink, torn open by an iceberg on its first crossing... At the end of the book was, folded between two pages, a very old newspaper sheet, yellowed by time, that reported the Titanic disaster. It was dated April 14, 1912, fourteen years after Robertson's premonitory novel. And my aunt had added a small figure on the last page of the book that juxtaposed the characteristics of the two shipwrecks, the imagined and the real. It is true that the comparison was staggeringly accurate! I was troubled by it but didn't know what to do with it... how to analyse it, how to exploit it to get something out of it, if that was possible!"

- But these can only be coincidences, come on! "Florian exclaims.

- I can't prove otherwise. I no longer even have the necessary documents to submit them to you,<sup>1</sup> but I clearly remember the shock when I compared the novel and the newspaper article. I don't see how we could calculate the probability that these are just coincidences. But I was - and still am - convinced that this was a serious indication of premonition in the novelist's inspiration."

Florian doesn't seem convinced but continues his meal in silence. Axel continues: "The other book was much closer to my scientific experience, although very difficult to read and use. It was an essay published in 1927 by an aeronautical engineer: J.W. Dunne: "An Experiment with Time"<sup>2</sup> My aunt eventually gave it to me and I still have it. It took me many years to take it seriously enough and to try to exploit the theories it sets out.

"At the time I was intrigued by it but I had not made the necessary effort to decipher the model proposed by the author. I had only learned a few anecdotes about premonitory dreams that challenged our perceptions and beliefs about the nature of time. But I remember sweeping away what I thought were irrational lucubrations. Especially when I got back from my stay with my aunt. I was alone in the car, lost on the Valensole plateau, among the lavender fields well after midnight, and I followed live the epic of Apollo 11 on the Moon, broadcast on the car radio. I was experiencing the triumph of science and rational analysis of the world. And I had no reason to doubt that this method would eventually overcome the difficulties we were still facing in quantum physics. Einstein and others were convinced that it only gave us a superficial insight into the behaviour of matter at the microscopic level and that it was possible to discover more fundamental laws that would put our ideas in order and allow us to describe the universe in a rational and objective way. And, in any case, the quirks about the passage of time are only expressed in circumstances that are often foreign to us. It was quite rare, apart from particle accelerators such as CERN's, that we needed to correct our perceptions or calculations by accepting the elasticity and relativity of time and space... In short, I quickly forgot my questions about premonitions. But a quarter of a century later, the quirks of quantum physics have not faded... quite the contrary! So a few months ago I remembered this childhood reading and decided to play the game and try the experience that Dunne proposes to do.

"The origin of my reversal of position is not clear. But I was increasingly intrigued by the behaviour of several colleagues whose work I appreciated. Some sought to understand the physics behind the mathematical equations by studying Eastern philosophy! Others were

seriously thinking about the possibility of time travel. The formulas showed them that in theory it should be possible to visit the future or the past... My first surprise past, I remembered Dunne's work and decided to read his book with a new eye."

Florian seems to have trouble swallowing his last bite: "You're not going to tell us that you've decided to recycle yourself into psychics?!"

- No, it's serious... you'll see. That's why I would like to share my experiences and suggest that you do it yourself. It's probably the only way to form an opinion!"

- I refuse to buy a crystal ball: you'll have to lend me yours," Florian ironically says.

Axel doesn't seem to appreciate and continues: "I think I have now understood what my aunt wanted to teach me about a demonstration of psychic ability... wait and see! There is indeed a search for personal and reasonable conviction as in science. But it does not seem that it can be as objective, impersonal and reproducible as in science. And there are not only drawbacks to that... But let me tell you about my experiences and you can judge."

- Your difficulties in understanding what your equations tell seem to turn your head, you physicists! Some are even starting to disturb us, biologists! Here: take Fred Hoyle for example. He imagines he has understood biology as well as physics, but publishes misconceptions and even crazy ideas from the top of his prestige as a respected physicist. Your colleagues of his kind seriously complicate our lives when we have to explain evolution! They are spreading misunderstandings that are hurting us!"

- I wouldn't propose a theory to you if it wasn't able to open up practical and verifiable perspectives! Patience!"

I decide to help Axel: "Florian: you've known Axel for a long time! If he brought us here on a Saturday morning, it's because he has a good reason! I don't think it's a joke.... and April has already passed! Then let him talk!"

Florian who has finished his plate, looks at Axel with an amused look but does not answer. Axel continues: "Thank you for your trust Matt. Indeed, this is not a joke. I try to present to you the circumstances that have opened my mind sufficiently to try some experiences that I am very far from regretting and that I would like to share with you. So, if you agree, I'd like to summarise the reasons that led Dunne to experiment with the nature of time."

The restaurant is almost empty now. The Tunisian comes to clear the table and offers us an oriental coffee, which we hasten to accept. As no one talks, Axel continues, after taking a sip of wine.

"In his book, Dunne begins by recounting some events that intrigued him because they might have been reminiscent of clairvoyance or premonition. We realise when we read it that he is indeed an engineer experienced in rational analysis. At first, he is afraid of losing his mind so that he explores various explanations without forgetting psychiatric hypotheses! But the episode that triggered successful research was undoubtedly a premonitory dream of the terrible eruption of Mount Pelee that devastated St Pierre de la Martinique on May 8, 1902. The volcano literally exploded and buried the 28,000 inhabitants of St. Pierre under a fiery cloud. Dunne did not dream of the event itself: he did not see any volcano or sunken city! His double dream was on a volcanic island that was beginning to crack. He saw fumaroles escaping from the slots and was dreaming of the same anguish he would have felt if he had walked on the damaged lid of a huge pressure pot. Still in his dream, he tried to alert the French authorities who ruled the island, but without success: the mayor had left for lunch and

his henchmen asked him to come back the next day! He was looking for a way to avoid the 4000 victims he sensed and woke up screaming: "Listen, Mr. Mayor! Four thousand people will be killed unless..."

"A few days later, Dunne received his newspapers, including the Daily Telegraph, which devoted its first page to the disaster. "An avalanche of fire: probably more than 40,000 victims". The event that intrigued Dunne the most was the reading error he made! Indeed, he read "4000 victims" instead of 40 000. And for many years he has always repeated his mistake by telling his story. It was only about fifteen years later, he wrote, that he noticed its inaccuracy! So he had not dreamt of the real event but of his mental state when he read about it in the newspaper!"

The Tunisian brings us three tiny cups without handles that he places in their saucer, in front of each of us. Then, from a "kanaka" made of beautiful red copper, from which almost overflows a foam of coffee that evaporates a delicious strong aroma, he distributes in several times, in turn in each cup, a little liquid, followed by the coffee grounds that have boiled directly in the container.

Florian intervenes: "But how can you exclude that, long before his dream, Dunne read articles that gave information about the warning signs of the explosion and that he forgot to have seen them? This could easily explain what he takes for a premonitory dream but which would only be the memory of unconsciously acquired information!"

- You're right! Dunne has not explored this possibility or, at least, does not mention it in his book! Perhaps the explosion was so sudden that no English newspaper could mention the danger before the disaster? I can't answer you: but your hypothesis doesn't explain at all the correlation between his misreading of the newspaper (4000 victims instead of 40 000) and his dream!"

- Maybe Dunne also thought he dreamt the event while reading his diary! You see! There is no shortage of rational hypotheses that are much more likely than a premonitory dream!"

- That's right! But he thought about this possibility and it was to exclude it that he developed his experimental protocol! Before going to a psychiatrist, he wondered if dreams were not as much about images found in mental states of the future as they were in the past! The dream would therefore not really be premonitory since it is not an external event that would be perceived before it takes place physically. It is just the activity of the brain, at a given time, located in the future, that would be used by the dream organiser, as well as a memory of the past. This hypothesis, although fantastic, explains why he dreamed of 4000 victims, as his reading error made him believe for a long time, instead of the probable 40 000. Dunne naturally realised that if his model were verified, it would seriously challenge our idea of the nature of time! However, his time predisposed him not to shy away from bold hypotheses because he often quotes the work of Einstein, Lorenz or Minkovski<sup>3</sup> on time and that his mathematical and scientific training had allowed him to know well. You remember the conceptual revolution that the theory of relativity initiated... Well, it gives the impression of continuing on the same path."

Florian, who, like us, has finished tasting his mocha, suddenly turns his cup over on his saucer, makes it turn around a few times, directing it with his fingertips, then straightens it up and contemplates the traces left by the coffee grounds on its edges. He hands it to Axel and asks him: "Here! What can you say about my future?"

Axel laughs: "Laugh it up! But I'd like to be there if, as I hope, you can replicate Dunne's experience!"

Florian puts his cup down while Axel continues: "Dunne, as a good mathematician, has clearly defined his problem. He is not concerned at all with the meaning of dreams, their probable function, or the choice of symbols and their possible meaning... He only seeks to discover if dreams can use mental images from future experience as well as from the past. He knows that these images can be distorted in dreams. If you have been injured in your right hand, you can absolutely dream of an accident in your left hand! You will still conclude that there is a correlation between the dream and the injury. Or, if you have met an acquaintance, by chance, in a restaurant before going to the cinema, you can integrate these two images by dreaming that you go to the cinema and that it is your acquaintance who sells you the entrance ticket! And Dunne wonders if it is possible to have this type of dream before meeting the person in reality!

"He realised that it was very difficult to calculate the probability that such coincidences would only be due to chance rather than premonition. He therefore limited his experiments to short periods of time. If you meet someone once every five years, on average, and see him two days after dreaming of him, you can consider the possibility of a premonition with more confidence than if your dream was several months ago!

"Anyway! Dunne began to write down all the dreams he could remember with attention to detail. And he has convinced himself of the reality of his premonitions of mental states. He saved himself a psychiatric treatment by demonstrating that these were not impressions of déjà vu but images that had been dreamed of and noted!

"He recounts, for example, the dream of a rubber factory fire with many specific details such as a thick toxic smoke, the plan of the factory, the workers trapped on a balcony... and that he made the day before its description in the evening newspapers. Or a dream in which he was chased by a horse on his left while, the next day, he was attacked by a stallion from the right, in a landscape surprisingly comparable to that of his dream!... His experiences convinced him that the dream memory can appeal as well to the future as to the past! Awesome! On the other hand, I have much more difficulty following him when he develops a physical model on the nature of time: I will not describe it to you! But when I read Dunne again, I remembered I had already wondered if I hadn't had premonitory images in my dreams myself! And that's why I decided to be as open-minded as possible and try Dunne's experience!"

## A.11: THE GREAT LEAP

The girl clears our table: no one flinches. Then Axel continues: "I scrupulously followed the experimental protocol that Dunne describes in his book. At first I had difficulty remembering my dreams. But after a few days, I started to find images to put in notes. They regularly became more numerous and rich in detail. I reread them at the end of the day and couldn't help but find some very strange coincidences between some of them and some events experienced the next day or a few days later! But, again, all this is based only on the subjective impression that one can have of it and it is not possible to quantify the phenomenon to demonstrate that it exists. But one day I experienced a real shock!

"The day before, almost upon awakening but still asleep, I heard in my last dream, someone clearly saying "Marguerite, the black and white cow"! Phrase I wrote when I woke up, with other images I remembered. And in the afternoon, while shopping in a supermarket, I came across a cheese package, lost in a corner of the shelf, overwhelmed by other brands presented in a much more aggressive way. On the box in question was a picture of a black and white cow standing in a meadow of grasses and daisies."

- And how do you know her name is Marguerite, your cow? "Florian laughs!

- Because it was the brand of cheese: a big "Marguerite" surrounded a good half of the round cardboard lid!"

- Aren't you going to tell us it's for a cheese that you're making us this whole dish?!"

We all burst out laughing! Axel replies: "I can't explain to you how I felt. But it was very strong! Although, for someone who is listening to this story told by a third party, I understand that this may seem exaggerated. But I felt a real sledgehammer blow! I know the departments of this store well! I've been going there for years. And I've never seen this cheese before!"

- But maybe you ate it when you were a kid! And you forgot it because it wasn't important," Florian replied.

- No, I'm allergic to cheese! But it's true: I can't show you that it's an image from the future! Besides, I remind you, I didn't see a cow in my dream! I heard it said "Marguerite, the black and white cow"! But I see no way to calculate the probability that these two events, the dream and the discovery of cheese, are just a matter of chance!"

Florian seems to be getting a little upset: "Axel, you looked very mysterious and worried last night when you called me. I can't believe it's just your meaningless anecdotes! What really happened?"

- You're right! It has been a long time since I experienced Dunne's ideas. No! What triggered my call is much more staggering! But wait... one thing at a time!

"You're talking about unimportant anecdotes. But the cow Marguerite is only one example among a good dozen others transcribed over twenty days of experience! What struck me most about this one was its free nature! There is nothing to be gained from a premonition of this nature, except the conviction that the nature of time is very mysterious!"

- I agree with you when you say that there is nothing to be gained from your Marguerite," Florian laughs!

Axel, imperturbable, continues: "In the same vein, one evening I dreamt of someone modelling an artificial hen by patiently gluing real feathers on a papier-mâché mould. The next morning, while going to have my breakfast at the village baker's, I discover that his window was prepared for Easter and, between several trinkets, exhibits a large hen made with real feathers! How can we decide that this is just a meaningless coincidence?! How, on the other hand, to calculate the probability of such a coincidence? Impossible!

"In addition to that, macabre! I dreamt of a helicopter crashing into a tennis court I know well, near a shopping mall on the outskirts of Gex. A few days later I discovered, in the newspapers, the report and photo of a helicopter accident on a... football field!

"And again! One evening, in my dreams, I see a Heineken truck - a large green and rectangular box mounted on wheels - rush in front of me from a highway ramp and skid until it rolls over! The next morning, a few minutes after entering a highway for a long trip, I pass a

green "Heinecken" truck that is absolutely identical to my dream! But there was no accident! This time, I was able to estimate a probability of coincidence. It's very weak! I counted the number of trucks I passed throughout the day. There were 379 and no other Heinecken! There is therefore, at most, only one chance in 379 that only chance is responsible for this coincidence. But in reality, this probability is much lower! It is equal to the proportion of Heinecken trucks that are on the highways, compared to the total number of trucks that use them at any given time. I didn't go so far as to do research to get precise figures but they must be in the order of one Heinecken out of several tens of thousands of trucks!"

- Fortunately! I hope you're not wasting your time with these things! How can you stop me from believing that you just remembered that dream because, by chance, there was a Heinecken truck on the highway! Do you have any idea how many dreams you must have had that have nothing to do with images of the future? You can't put forward such an extraordinary hypothesis as that of making jumps through time, without proposing equally extraordinary evidence!"

- I admit that these examples do not convince you... you did not experience them yourself! But I had noted the image of the Heinecken truck before I met it on the road! In this case we can be sure that it is not just a memory due to the circumstances!

"But these examples have destabilised me enough in my previous convictions for me to take the big leap! For me to decide to consult a psychic such as my aunt, who is now deceased."

- No, no kidding! You have too much time to waste! You have no tangible, objective proof of a vision of the future!"

- Of course! If everyone does what you do, we're not about to get that proof! You lock yourself into your convictions without wanting to try the experience!"

- But there is so much to discover and so little time and resources available that I don't see the point of losing them in wrong directions!"

- As you wish! But I decided to take the step and, believe me, it wasn't easy at all! I have my whole past as a scientist that interferes terribly with Dunne's hypotheses and my aunt's gift! But I loved and respected her deeply. Now I had the opportunity to understand it better, even if it was posthumous! And you said it yourself earlier: modern physics troubles us so much that we start to open our minds to many new perspectives... even if they seem far from what common sense suggests to us! A colleague said that if we were not shocked by quantum physics, it was because we had not yet understood it!

"The most difficult thing, once the decision to try the experiment was made, was to find a honest psychic. I know that charlatans are proliferating! Just seeing the ads they put out in the newspapers makes me sick of a visit to them! I didn't dare to ask my entourage for advice, as you can imagine! Just see how you react, Florian! Matt seems more open than you are!"

- Indeed! The consultation of oracles and other omens was the rule for much longer time than science has ever experienced! And even today, a large part of the population is interested in their horoscope! It is even said to flourish in environments that make difficult decisions... political or industrial!"

- Maybe! But astrology doesn't hold water," says Axel, "You read your horoscope more out of play than conviction, I guess."

- Oh, well, Florian notes. "You admit that clairvoyance is just unfounded fun!"

- No, not at all! That's what I think of astrology, although I don't really know it. But I am now convinced that we can have access to mental states of our future: which has nothing to do with astrology! And this conviction - obtained from experience, I remind you - gave me the courage to open my mind and then try to understand what my aunt was capable of doing."

- So that's it! You went to see Mrs. Irma and she impressed you so much that you brought us here today! What the hell did she tell you?!"

- No! It's been a long time since I've had this experience! I tracked down a young friend of my aunt's and asked her for advice. She was able to give me a list of people she called "mediums" and respected for their performance and honesty. She was not at all surprised by my interest in this field so far from mine. She suggested to me that she was happy that I was giving up my sterile dogmatism and finally opening my eyes to what seemed so obvious to her!

"I have made an appointment with the first person on my list; an old French lady who regularly comes to Geneva to give consultations. Then I often hesitated to cancel this visit. I felt like I was preparing to jump over a wide and dangerous precipice! My reason was holding me back! My experience and feelings pushed me forward!"

"When the day came, I was almost shaking in the lobby of the hotel where she is staying when she works in Geneva. Hergé drew it in one of his albums: the owners recall it by presenting a large statue of Tintin in the entrance. As I passed by it, I wondered if I was not falling back into a naive childhood again! But from the door of her suite, she made me feel comfortable with her behaviour and then with her extraordinary performances! Even before I sat down, she asked me, "What are all these pipes you work with? It's strange, I don't feel you being a plumber!"

"I laughed when I confirmed that it wasn't my job! But I had decided not to give her any clues, either in words or in my behaviour. I was trying to be as neutral as possible!"

- But then why so many big pipes? I see them in big galleries... And you are sometimes surrounded by many young people... Do you teach?

"This time I had to nod, dumbfounded by her visions! She described to me the CERN particle accelerator ring and my activities as a physics professor at the university!"

- Yes, but you look like a physicist! "jokes Florian.

- She didn't say I was a physicist! She later told me that she felt I had come to evaluate her and that I was very rational."

- Then we can't say that she was right," Florian ironically says.

- She described my family, without me saying a word to her. The number and sex of my children; their age, with a few exceptions; their character... that of my wife and parents... I had the impression that she had access to a fact sheet collected by a detective!

"Then she approached my past, described some of my emotions at important events... So I was convinced that she had access to information, feelings, in a completely irrational way. But what about the future?"

"There too she amazed me! She predicted a move and a major change in my profession. She saw my neighbours arguing and then divorcing, asking me to testify at their trial. She saw

another neighbour suddenly become a widow... And these events happened well in the months following my visit, despite my belief that they had very little chance of being verified!

- But, again, you can't do science with that! You have no chance to convince anyone in a rational way that your psychic really saw specific past or future events! If that were possible, it would have been known a long time ago!"

- But it's known! The problem is that some people, like you, don't want to know! It is true that it is a question of taking into account subjective and unquantifiable phenomena. And for rationalists, it's prohibitive! They would rather throw the baby out with the bath water than make the effort to open their minds!"

- And why are you trying to convince us?"

- For two reasons. I will share with you the main one, which happens to be the most important one too, but later on. The second one is this: I would like you to help me see more clearly in these reflections and the discoveries I think I have made... I would like you to repeat the same experiences as me to see if you come to similar conclusions. This would be the best, if not the only, way to try to bring these subjective phenomena into the scientific field. I called you because you are my closest friends."

- But I'm not a scientist!" I'm surprised Axel thought of me!

- No! But you're a teacher and you like to communicate what you know. And for that reason you seek to understand it in depth. Your help is invaluable, both to clarify and criticise what we have to say to Florian and me, and also to take notes of our discussions, our experiences... so that we can then use them as a basis for moving forward. And if we succeed in making progress, these notes could be useful to others besides us, to move in a direction that would integrate subjective phenomena into the scientific method... What do you think?"

- And the second reason?"

- No! Later! We still need to do some physics experiments to understand it. And maybe I'm wrong and I was wrong in my analyses. If that were the case, we'd stop this research here and I'd go to a psychiatrist!

" But I would really like you to make the necessary effort to replicate my experiences and monitor their results."

- I'm willing to try to get you treated as soon as possible," Florian says with a smile. "You really need to be a good friend!"

- I'm very interested in your proposal! The stakes are really fascinating and I have often wanted to understand how philosophers, humanists... ancient civilisations, could accept so naturally the use of oracles such as the famous Pythia of Delphi whose success lasted centuries!"

Axel seems relieved. " So I suggest you do Dunne's experiment and then come back to us to discuss the results!"

We get up from the table, ankylosed, to discover that we are alone in the restaurant... probably for a long time! It's already tea time!

## A.12: JUNE: SATURDAY MORNING

The water threads weave an iridescent ribbon that widens as it slides along the polished wooden blade, before breaking into sparkling drops of the colour of the rising sun and reaching the lake from where the Florian oar extracted them for a short time. The observation of his left oar hypnotises me and plunges me into a long, synchronous, flowing movement of his. This morning he is in charge of the rhythm; our four oars break the still smooth and grey lavender surface of the water and punctuate the time with a regular lapping in unison. The ripples they dig interfere with those that our bow strikes in the water and gently move away from it, on either side, in a huge V relative to the size of our boat, a thin needle that runs along the interface between air and water, a blue and pink pastel cocoon with undifferentiated limits in the pale light of the dawn.

Strange sport that quickly leads you to a goal that is... on your back! A target that you must indirectly target; only the relative angles and apparent sizes of your landmarks inform you of your trajectory!

A few mallards oscillate gently, still numb from sleep, under the impulse of the waves we create in the water. A swan reacts and swells its wings and lifts them up by moving them slightly away from its body. It straightens its neck, stares at us with one eye, then with the other, turning its head abruptly, then again with the first... It turns to us: its partner swims gently behind it. It is surely the female that the first one jealously protects at the same time as its territory in which should be somewhere, still brown juveniles.

There are no obstacles or limits to the view from sliding on the water and reaching the sky. A padded steam gently drowns the water in the sky. Axel explained to me, as a physicist who understands everything, that the water on the surface, warmed by the previous day's sun, evaporated during the day and then condensed during the night. The clear sky transmits without reflection the heat rays that radiate from the surface of the water to the infinite space, black and cold. At night, the air is released from the water dissolved in the sun in very fine droplets when it touches the dark surfaces... dew on the leaves in the morning, mist on the water lit by the rising sun.

I can't help but see things differently! I imagine the lake caulking itself for the night, isolating itself from a vaporous down, exhaled in the darkness and that it will dissolve, in gently rising volutes, only when the light has returned... Who is right?

"Are you dreaming?"

- No... Yes, a little bit!"

Florian is surprised at my silence.

- Because I wanted to ask you what you thought of Axel's proposal: "Dream and experiment!" that he asks us! But I'm not a dreamer! I do have some memories of dreams, but it has happened very rarely. Then Axel's experience is quite foreign to me!"

- That's not my case! I became interested in dreams a long time ago, as soon as I learned to remember them. You should try it: you'll see, it's fabulous! We discover a second amazing life, very rich... as full of details as the real life! Perhaps even richer because it leads us into impossible situations in a state of awakening. I even had the chance to live lucid dreams!"

- What do you mean, lucid dreams?"

- Yes, I woke up in my dream, several times! That is, my body was completely asleep while my mind was perfectly clear and aware that it was living a dream! I was so surprised the first few times that I woke up for good, amazed by the clarity and precision of the details I experienced in my dreams! It is impossible to know which world we are in by relying only on our visual, tactile or auditory perceptions, which are as rich and vivid in dreams as they are in a state of awakening!"

- But how do you know you didn't just dream that you were having lucid dreams?"

I feel the irony and guess the mocking smile of Florian.

- Listen to me! I'm not trying to convince you of anything! You ask me what I think of dreams and I answer you from my experiences! Now you do what you want with it! Where I am convinced that Axel is right is when he exhorts us to experiment for ourselves rather than to believe any testimony."

- But what made you have lucid dreams, as you say?"

- Nothing! It happened to me spontaneously. Perhaps because my bedside book of the time related strange experiences of an American whose name now escapes me<sup>1</sup>. He was convinced that he could travel outside his body! He called them "astral journeys"! I remember he described feeling a kind of vibration one night in his bed, then getting up... to realise that his body had remained asleep while he was watching it from the foot of his bed! He, of course, thought he was going crazy: but doctors reassured him. His strange dreams have evolved. He saw his body sleeping while his mind, which he called "his astral body", was floating near the ceiling of his room... And that's what happened to me the first time! I found myself bouncing gently against the ceiling of my bedroom! But I couldn't turn around to see if my body was still in my bed. Nevertheless, I perfectly recognised my room... the one in my main residence in Geneva. And when I woke up, I found myself in the room... of my second home in France! So I suddenly understood that the events that the American had experienced and interpreted as proof that the soul exists and is able to travel outside the body, could only have been lucid dreams! The dreamlike world in which they take place is so amazing that the dreamer is convinced that he really finds himself somewhere concrete! And that's what led me to try experiments on this strange state of consciousness..."

The sun has risen over Pointe à la Bise, the last refuge that nature owes to Geneva's ornithologists. You can clearly see the viewpoint overlooking the swampy reed beds that once bordered the lake entirely with an undulating fabric. Anyone who has driven a pond knows the invasive power of reeds! It is almost impossible to contain them as soon as the three elements essential to life are combined: land, water and air! And yet... our power is such that we must now protect them against the flooding of the concrete!

After completing our U-turn to return to the port of La Nautique, Florian asks me: "So what? What did you do with Axel's proposal? Did you start the experiment?"

- Yes."

- And you found something interesting?"

- No. Not yet. I've lost the habit of remembering my dreams and I'm getting it back."

- How do you do it?"

- There is a simple technique, based on observations by several authors<sup>2</sup> and which allows to exercise the memory of dreams. In reality, there is no memory of dreams and that's fine!"

- Why is that so?!"

- Because dream life can be so rich in numerous and complex perceptions that we would have difficulty discriminating between what has really been experienced and what has been dreamed! Imagine that, in a dream, someone is bad with you and when you meet him in real life, you blame him! Where would that lead us? Good thing we don't remember our dreams!"

- So how do you remember them?"

- A few easy-to-fulfil conditions must be met. First of all, you must be genuinely interested in the memory of your dreams: in the evening, when you fall asleep, you must have a determined intention to do so. You also need to prepare some equipment within reach.

"It is important to know that the dream evaporates as soon as you wake up, especially if you move. The solution consists in staying in exactly the same position as the one you had in dreaming and telling yourself the dream you just had, remembering the dreamed images and then ordering them successively as they appear: one leading the other... It seems that you can pass information from where it was dreamed, to an area of the brain that manages the awakening memory. It is necessary to avoid interpreting the dream in order not to involve the imagination. If you are interested, it is much later that you can try to find the meaning of it, by rereading the report that you will have made in the morning.

"Once you are pretty sure you have memorised the key images, you can pick up the prepared notepad at the foot of the bed, with as little movement as possible. Care should have been taken to obtain a spring notebook that has the advantage of allowing the pages to be easily turned and a tied pencil attached to it at the top of the spring.

"Once the notebook is in your hands, you place your left index finger, since you are right-handed, at the very top of the page, against the spring, and, with your right hand, you place the tip of the pencil against your left index finger. You can then write your first line by guiding yourself with the right little finger to feel the edge of the page coming. Then simply lower your left index finger down a few centimetres along the spring to write a second line that will not encroach on the first... and so on, in the dark and with as little wakefulness as possible.

"Of course, you shouldn't write a novel! Just a few words that will allow you, the next day, to find the dreamed scenes with all the interesting details... Once the dream has been recorded, you have to turn the page and prepare the notebook for a possible second report... I have transcribed up to five dreams in a single night!

"The next day, based on the notes taken, you have to try to remember the dream completely and write it down in as much detail as possible. You'll see, it can be learned pretty quickly... if you really want to learn! You can't cheat with your unconscious!"

We arrive slowly near the wharf and the docking manoeuvre attracts our full attention. Florian seems to be thinking:

"I don't know if I'm really interested. But if I understand what you just explained to me, I'll know soon enough! "

## A.13 : INTERLUDE

You are now close to an original experience: an author will ask you to stop reading his work!

Of course, I cannot prevent you from turning the pages and reading the following ones if I have had the pleasure of interesting you so far! But I strongly recommend that you take a break for practical work!

Axel's work would lose much of its meaning if he did not invite you to convince yourself of the relevance of his results: if he did not introduce you to this new vision of the reality in which we live and which seems infinitely richer than the one we can perceive!

If I explain all this to you, it is - as you can imagine - that I was able to check for myself how exciting it was! You probably remember that I am not a scientist: I teach history. But thanks to the doors ajar by Axel, which I have sometimes been able to cross, I think I felt the emotion that illuminates the researchers' eyes when they explain their discoveries! A kind of discharge travels through the body and leaves you a little stunned for a short while, then it diffuses a kind of fizz into the brain. A smile is finally accompanied by a feeling of recharging with energy for a long time!

Axel has put us on a path that quickly becomes personal to each of us: it is no longer a question of adopting knowledge derived from the intelligence and work of other individuals and that you will understand more or less according to your interest and the efforts made. There is nothing to stop you from using a TV if you don't know how electricity can be transformed into a window so loud and colourful that it is sometimes magnetic! Even if you are curious, the effort you would have to make in order to control the phenomenon sufficiently to understand it would probably be disproportionate to the interest of the result... unless, of course, you made it your job!

But here you can't avoid being directly and personally involved! You are alive in a world you are looking for, more or less, to know! And Axel offers you a way to discover it in a way that is as unexpected as it is rich in new perspectives! And it is not necessary to spend long years of preparatory studies to achieve this! All you have to do is follow some of the advice you will find here, but above all, show a great openness of mind, of which you will be the only master, and also a little perseverance.

It is well after having made the experience I propose below that Florian and I were able to discuss with Axel the psychological and intellectual characteristics that are necessary to do so. I suggest that you expand on this subject later. For the time being, it is enough for us to point out that it is a question of broadening the field in which the scientific method excels - objectivity - by interfering in a region that has always posed major problems for it: subjectivity. This attempt has no chance of success unless the researcher compensates his approach free of sterilising preconceptions, with an always vigilant critical mind! Axel suggested that we accumulate observations without judging them, and then only submit them for critical analysis. This is essential if the approach is to remain a scientific one and not to venture into what would rather be a religious approach. The latter uses faith more than critical reason and does not have the same objectives as science.

But here is the experimental approach that is proposed to you: it is to follow a precise protocol that should allow you to broaden your personal opinion on the nature of time.

First, we must learn to remember at least a few of the four or five dreams we have every night. Then choose a period of about ten days which, preferably, will precede a departure from your habits, such as a trip, a vacation...

Following the advice given above, take note of the dreams you remember by trying to describe their details as carefully as possible. Do not attempt to interpret or compare them with any event when taking notes. It should be separated as much as possible from the analysis of the content of your descriptions to avoid unconsciously changing your memory.

Each evening, review your notes from the beginning of the experiment. Analyse them to find the images or situations that have been borrowed from your experience by the organiser of your dreams. I have chosen to name a concept that is still totally enigmatic, although it has been subject to questions since man first existed! I have no idea what it is, although all kinds of hypotheses exist, of course! But perhaps you will see for yourself how far they are from explaining the extraordinary profusion of images, ideas, situations and above all the richness and "truth" of the details that structure and furnish our dreams! A dream can invite you to the concert and, even if you are far from being a musician, it will recreate for you a whole piece of music with every necessary instrument!... It can make you visit a painting exhibition and bring you all the emotion you would feel in front of the real works of your favourite painters!... It can sometimes make you discover the solution of problems that bother you for a long time!...

Reread your notes and ask yourself about the source of the details chosen by the organiser of your dreams. Are they from the past or the days that closely follow the dream in question? Are they rare and detailed enough to be meaningful?

For this research to be effective, it is necessary to take into account some difficulties that Dunne has described well and that can be overcome.

Do not try to link real events with those described in your dreams. It seems, in fact, that they only trace your mental states that accompany the event and not the precise circumstances that have followed one another in time. Remember that it took Dunne fifteen years to realise that he had made the same mistake in reading the newspaper in his dreams as in reality! So look for the mental states you have experienced that could generate dreamlike images, from the past... but also from the near future!

Remember that a dream can integrate details from different events into the same image. If you have followed a sporting event with an acquaintance, it is quite possible that you may dream of your friend in the equipment characteristic of the sport you have observed, even if s/he has never exercised! It is the details separated from each other that you will have to analyse in search of a single shot at the goal and not the integrated amalgam.

Take into account the blockage that we may unconsciously have with regard to experiences that could be destabilising because they are outside the analytical framework used by common sense: itself the result of a limited mode of perception. To avoid this bias, Dunne proposes to reread your notes each evening by imagining that you will discover the dreams you will have based on the events experienced during the day.

Finally, you must limit the experience over a period of a few days to reduce the importance of chance on what could be a premonition. If you dream, for example, of an air disaster without further details, it is unfortunately very likely that one will happen anyway within a year of taking notes, while a crash experienced in your dreams the day before the event will have a much greater significance for you.

Once you have completed your period of practical work, you can propose its analysis to a third party to check whether you have not failed to recognise certain interesting details, or, conversely, whether you have been too lenient about the correlations you have made between your dreams and reality. Finally, try to estimate the probability that these associations are only due to chance, in order to form a personal opinion on the premonitory faculties of your dream organiser. But unfortunately, it is often very difficult, if not impossible. In this case, count on your feeling when the correlation is discovered! Good work... and see you soon, I hope!

About Time...



*Marcel Duchamp sensed that the nature of time was not the one that seemed familiar to us. He joins the discoveries of physicists when he pulls himself out of our perceived three-dimensional world to try to imagine what it would look like if he had a naked human walking down the stairs from the 4th dimension of space-time!*

## BOOK TWO: Expansion

*About Space...*

## B.1 : THE REPUBLIC OF PHYSICISTS

A state within a state! Or rather a republic straddling the border between two sovereign nations, but who have let go of, these few square kilometres covered with surprising landscapes. Artificial hills that are regularly round, carefully straight roads, stewardship infrastructures, physicists' offices, research, development and manufacturing laboratories..., with simple lines, clean angles, without any frills, sometimes juxtaposed with large towers that emit abundant and silent white steam but which quickly dissolve in the dry air of this autumn morning... CERN is a very special place!

We can see the breath of utopia which, until now, has succeeded in miracles! Physicists have created their small town and have been running it very democratically for a few decades. They have no other resources than those that politicians want to distribute to them, amazed by the military applications that have been made of the discoveries made on the atom, and undoubtedly attentive to possible new contributions... ! But in recent years there has been a sense of donor fatigue. It must be said that the researchers have done very well! They have built prodigious instruments that I invite you to visit. Although the image is outdated, I can't think of anything more evocative: these are indeed modern cathedrals!

The faith of the craftsmen of the Middle Ages is inscribed in the majestic beauty of their works and, above all, in the profusion of details often sculpted in places invisible to the usual visitor. Clearly the artist does not seek to be recognised, does not nourish his ego, but addresses his praises, or makes a kind of prayer to the one who sees everything, wherever it is. The faith of the physicist is expressed just as much in his work, in search of the Grail of Physics, the Equation of the Whole: the one from which we would eventually be able to deduce all the laws that the artisans of research have patiently deciphered for centuries... And his ego is diluted in the project that sublimates his intellectual forces. The artist of the Middle Ages expresses himself for himself and for God. The 20th century physicist works to satisfy his curiosity, spurred on by his philosophy of life, which sometimes leads him to research as one enters religion, by vocation. A deep vocation that only the result motivates.

The cathedral worker does not sign his work. The CERN researcher works in a huge team and his name is so lost, somewhere among thousands of other signatures at the bottom of scientific articles, that he is in fact satisfied with almost perfect anonymity... most often! A downside is necessary all the same! The research population is like any other, heterogeneous. And sometimes implacable ambitious people with a huge ego rage there and are far from being satisfied with a too anonymous signature!

But here reigns a serenity that fills the space of the immense rooms, with a much larger surface area than that of a cathedral and its square combined! Few men and many gigantic structures, beautiful by their geometry although unexpected and incomprehensible to the neophyte. An obvious calm of the technicians working in a tangle of temporary structures, scaffolding, platforms traversed by multicoloured tubes, large beams under which impressive pulleys hang, cranes... At each end of the immense volume, the enigmatic tools that Axel presents to us are slowly and religiously built. Unlikely faceted toroids with a diameter of more than 20 metres, which include several concentric layers individualised by their different colour and texture. Imagine gigantic metal dodecagons placed on one of their facets and composed of three layers, red and orange. Cable twists sometimes slip between the cores and connect them to other parts of the machine, for example a beautiful horizontal cylinder that

appears to be made of large gold bars separated by black wire twists sheathed in transparent plastic. All this is surmounted by lime green scaffolding.

Axel is proud of this and the tone of his voice clearly shows it: "We have just finished installing the crystals that Russia has provided us. It is a material with paradoxical properties that are very useful to us: it allows light to pass through and transmits it, but it stops the particles effectively. It will allow us to capture their energy and drive the tiny flash formed by the shock in the crystal through the optical cables that will be connected up there... look!

"When the calorimeter is finished - it is called that because it allows us to measure all the energy created by the shocks between the particles we are studying - it will be tested, adjusted and then lowered into its final housing, 90 metres below our feet, at the bottom of the large well you saw built when you arrived."

Axel is talkative: he tells us about the challenges that scientists have faced... and that they have met, with elegance, genius and... many means!

"We will have to create magnetic fields so powerful that they were unimaginable a few years ago, and not really available today with the reliability we will need. But we will succeed! The 27 kilometres of the underground ring in which the particles will travel will be cooled to almost  $-273^{\circ}\text{C}$  so that we can use superconductivity... You know! The temperature conditions under which a very high current can be circulated without loss by electrical resistance."

- And what are you going to experience for us today? Florian seems to be getting impatient."

- Yes, we're going to go to another laboratory where I've set up some experiments that I'd like to share with your insight!"

Axel takes us into his car, parked at the beginning of the construction site. While driving, he recounts: "At the end of the 19th century, Lord Kelvin was proud to see that physics had almost achieved its goal: to explain the mechanisms and laws that govern the material world: the one that Descartes had carefully decoupled from the spiritual world.

"Lord Kelvin saw only "two little clouds" in this sky that had become perfectly clear to him. One of these clouds referred to the paradox that Michelson and Morley's experiments had failed to solve... Remember? The problem of the ether wind that remained hidden, that the finest measurements could not detect when it should have been! You know that the solution came from Einstein and that Lord Kelvin's little cloud turned into a hurricane that swept away our classic conceptions of the nature of space and time! Well, the second little cloud of the illustrious English physicist was hiding a cataclysm that was perhaps even more important! That's what I suggest you discover today!"

- What was that little cloud about?"

Axel at the wheel of his car does not answer: he is desperately looking for the essential magnetic card to remove the barriers that block the road. He plagues against the inattention that sometimes makes him put it in unlikely places... even in the fridge, he told me, sheepish! He finds it in his shirt pocket and we enter the physics village!

The buildings are austere. No balconies but large flat, glazed facades that line the streets, named after physicists. The signs indicate: "Rue W. Pauli" or "Rue E. Rutherford" without further details. While in Geneva, the plaque provides information on the time and role of the

notable it commemorates: often lawyers or politicians, sometimes philosophers or religious or even humanist scientists who have made the city famous and, fortunately, very few soldiers! Geneva is not as martial as London or Paris!

"Yes, the second cloud..." Axel comes to his senses.

"Well, it has to do with the nature of light..., always it! Do you remember the interference fringes I showed you at the School of Physics? As early as 1807, they signed the wave nature of light, whereas Newton before was convinced that it was composed of particles. The simplest way to explain these successions of light and dark bands is to apply a wave nature to it, remembering that a trough in the wave can cancel a bump. We have seen how simple it is to understand that by adding two light waves you can create darkness."

- Yes, you even made us see this interference through two small holes in cardboard!"

- That's it. Well, the wave theory did not explain at all correctly the emission of light by an object being heated. You know that! Metal shines brighter and brighter and turns from dark red to white as its temperature rises."

- Yes."

- By applying the theory we found what we had called "the violet catastrophe"! It indicates that the energy emitted by the heated body increases more and more, towards infinity, when the colour of the light emitted goes towards the short wavelengths, i. e. towards the violet part of the visible spectrum, and beyond. However, experience and common sense show that this is not the case! We find a peak of light intensity and the energy decreases even more as we observe shorter or longer wavelengths... But here we are!"

## B.2: THE VIOLET DISASTER

Axel parks in front of one of the soulless buildings in the city of physicists, then invites us to follow him behind the glass gate and precedes us in a long narrow corridor that opens onto the hall. All office doors are closed and alternate with a mailbox in which many papers sometimes accumulate. The atmosphere is very different from that of Florian's laboratory. Here we see no one, nothing but closed doors and, between them, mailboxes at hand height; at the top, portraits of famous physicists. There, the doors are hidden by posters illustrating the biochemical complexity of the cells, or trapped behind devices that overflow onto corridors or reserves of chemicals stacked in their boxes that block them... and all of them, open on crowded and noisy workstations of all kinds of machine rattling, centrifuge humming and voice bursts. There, smells of chlorine, acetone... which are exhaled from the laboratories. Here, total silence: only the sound of our footsteps resonates softly against the walls of the narrow corridor. A strange smell that reminds me of something... but what...?

I found it! That's the smell of the school I drive my young children to! A mixture, probably composed of emanations of paper, colours, pencils, which can also be found in the staff stores of schools, but to which is added the smell of children. Prepubescent children still protected from hormonal disturbances that will later result in other odours, often combined with artificial scents and perfumes. Very strange to find it here again with the smell of primary school! Here where the average age is far from that of my children! Mystery! Would curiosity have a smell that would persist over the years?

But we have arrived. Axel walks in front of us in his office, gently closes the door behind us and, even before we have had time to spot and choose a chair, heads for the blackboard that covers the best part of the left wall, in front of his desk decorated with a pretty bouquet of white chrysanthemums.

"This is what the theory predicts and what the experiment discovers," he says, quickly drawing the next two figures.

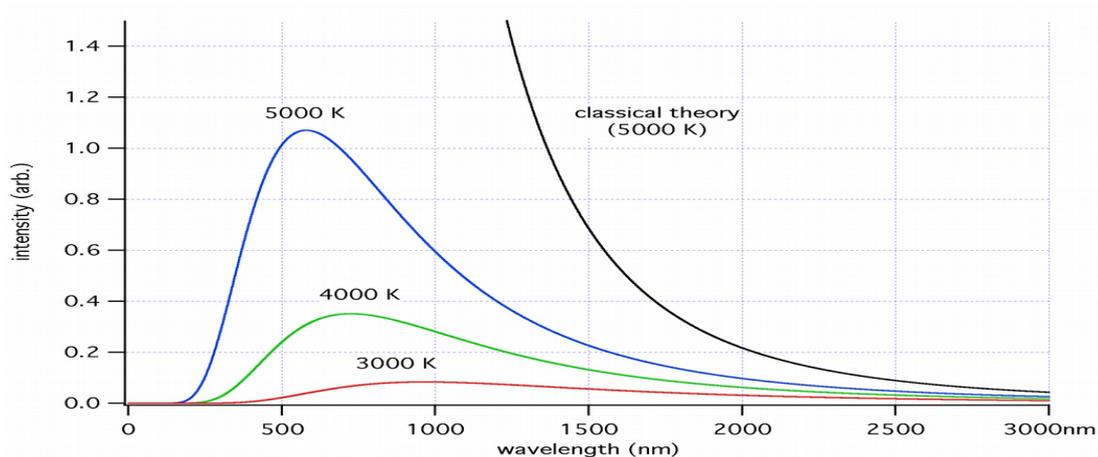


FIGURE B.1: *By heating a black body, we observe that the intensity of the light it emits follows a kind of curve that increases rapidly and then decreases exponentially, whereas the theory accepted at the end of the 19th century predicted that it would increase indefinitely (right curve).*

"This is Lord Kelvin's second little cloud: the huge difference between these two curves! Most often in this kind of situation, salvation is found in mathematics. It is necessary to look for an equation that fits the experimental results and then to start from it to create a physical theory compatible with the behaviour of the explored phenomenon. This was done by Max Planck in 1900 and then by Einstein - again - in 1905. They cleared up this last cloud but at the cost of a discovery perhaps even more intriguing than Relativity.

"Planck has found an equation that forces the intensity of the light emitted by the warm body to decrease faster and faster as its frequency increases, i.e. its wavelength decreases... since one is the opposite of the other. After finding his equation<sup>1</sup>, he had to understand it! Find out why it was used to calculate the transformation of heat into light emitted by the incandescent object. His trial and error led him to discover an equation<sup>2</sup> that measures the energy of light according to its colour and explains very well its formula for the emission of light energy by the body. But it is a very strange formula!.... It is even impossible to translate into a concrete image. It requires the energy of a light frequency to be quantised, i.e. its value must be an integer number of times the multiple of a constant value that he discovers and that has since taken his name: the Planck constant, "h" in the formulas.

"Let's take an object and heat it up. We'll give it some energy. And if it is sufficient, the object will start to glow. Planck shows that the energy of each emitted colour is worth once his constant "h" multiplied by the frequency of the light measured, or 2 or 3 times this

product..., but never a fraction of these values. It is as if the energy exchanges are done in packets that he called "quanta" and that these packets contain only whole numbers of times the value "h".

- I'm not sure I understand why this result is surprising!"

- Oh yes, it is! It's like you're swinging with a very weird swing! Imagine sitting on the board with me behind you pushing you every time you come back to me. You count the frequency of your oscillations... say 20 per minute to clarify the idea. I push you and you go straight to 30 per minute, suddenly, without going through any intermediate value. I push you again and you go to 40 oscillations per minute. I don't touch the swing anymore, the frequency decreases and you go from 40 to 30, then to 20... etc... ! Or another image: it's as if all the roads in the world were stairs... no ramps but only steps everywhere!"

- Yes, I see!"

- It was so surprising that Planck did not believe in the physical reality of these packets: he only found them practical for calculating the energy exchanges between radiation and matter. But Einstein would give them a concrete nature a few years later! Let's see how!"

Axel is heading to a table on which he has prepared electronic devices that remind us of old tube amplifiers.

"I have prepared a series of demonstrations based on the simplest possible devices. I discovered that my students were often overwhelmed by the complications we bring to the set-ups to bring them as close as possible to the ideal conditions. They eventually transformed nature into a series of equations and lost touch with concrete reality. However, I propose to start from the foundations of our reasoning to try to go as far as possible without mathematical abstraction by referring instead to mental images that we can associate with concrete events. I was very pleased to go through the old stocks of the School of Physics and CERN with great pleasure because I rediscovered the days when devices were built without forgetting the aesthetics!

"Look at these old bulbs! We will illuminate the metal plate it contains.

He shows us one of the three bulbs he has in front of him. They are about ten cm long and 3 cm in diameter. They are made of glass and contain a rectangular metal plate, connected to a support that passes through the glass and ends on a kind of pin. A second pin also passes through the glass and comes from a metal grid, smaller and parallel to the plate and therefore does not touch it.

" The bulb is under vacuum so that electrons ripped from the metal plate, will be attracted by the grid that I will bring to a positive electrical potential with a battery."

Axel connects the two pins of one of his bulbs to a battery and then to a small incandescent lamp, all in series. He lights a laser and directs the greenish-yellow beam towards the metal plate inside his large glass bulb. As soon as the light beam illuminates the plate, the small lamp lights up. So there is a current flowing, despite the fact that the metal plate does not touch the grid. It must be admitted that electrons jump from the plate to the grid to loop the circuit and heat the filament of the small lamp.

- Did you prepare a photoelectric cell for us?"

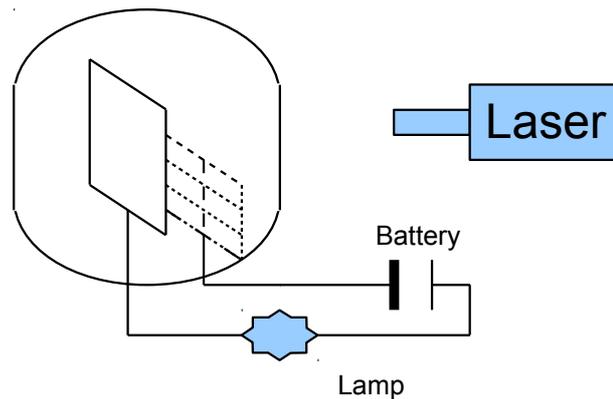


FIGURE B.2: *The ancestor of photoelectric cells: a metal plate emits electrons when illuminated.*

- That's it! This is the prototype of our current cells. The phenomenon had been known for a long time but it was not understood. And here's why."

Axel slowly increases and then decreases the power of the laser beam and the small lamp shines more or less brightly in harmony with the laser beam. I'm surprised: "What's so strange about the fact that the electric current is correlated to the power of the incident beam?"

- Nothing! So far so good. But it's the rest that's weird!"

Axel replaces the laser with another that, when switched on, projects a light red beam and not a greenish-yellow one as the previous one. "This time, look! ". He regularly increases the power of his laser beam. But nothing is happening! The small lamp remains off.

- How do you explain that?"

- Your laser is not powerful enough!"

- No! Look!"

Axel increases the power of his beam which becomes much brighter than the previous one: the lamp always remains off!

- See? It is not only the power of the beam that explains the photoelectric effect: it also depends on the colour of the light, i.e. the frequency of the electromagnetic wave, i.e. finally, the energy it carries. A wave transfers all the more energy when its oscillation frequency is high, when it vibrates more often during a given time. And I'll prove it to you!"

Axel disconnects the bulb and replaces it with another one, which is very similar to the first one. "This bulb contains a plate forged from a different metal than the first one. If all goes well, it should react to the red light."

He completes his assembly and then lights the beam. He's right! This time the lamp lights up as soon as the laser beam becomes visible and it shines even brighter when the red beam is bright. We find the correlation between the power of the light source and that of the lamp.

- You deduce that different metals react to different colours?"

- Not really! I'll replace the red laser with the previous one, but keep the bulb that just reacted to the red."

Axel is once again replacing its light source. And the bulb that responded to the red beam reacts very well to greenish-yellow light! The small lamp even shines brighter than with the first bulb! "That's what intrigued Lord Kelvin and his colleagues! Each metal has a threshold at which it becomes sensitive to the power of light! It is useless to increase the power of the light source if its frequency is lower than the one at which the photoelectric effect is observed: the metal will not react! It will be sensitive, however, to less strong but higher frequency light. And it is this threshold effect that Lord Kelvin and 19th century physicists did not understand. And it is this phenomenon that Einstein explained very simply in 1905, a discovery that would win him the Nobel Prize in 1921! But I suggest you study the phenomenon a little more closely before describing Einstein's model."

Axel makes a slightly more complicated assembly by adding two measuring devices to the circuit: a voltmeter and an ammeter.

"That's it! I put on a bulb that reacts as soon as the light becomes visible in the dark red. He lights the laser that illuminates the metal plate with a beautiful ruby red.

"Look at the reactions of the measuring devices! The ammeter tells us how many electrons travel through the circuit per unit of time, while the voltmeter tells us about their energy. Axel alternately raises and lowers the laser power: the small lamp reacts in sympathy, as does the ammeter. But the voltmeter hardly reacts at all!

"The power of the laser light influences the number of electrons ripped off the plate and reflected back into the circuit, but it has no significant influence on the energy of these electrons! Let's see what happens if I change the colour of the laser!"

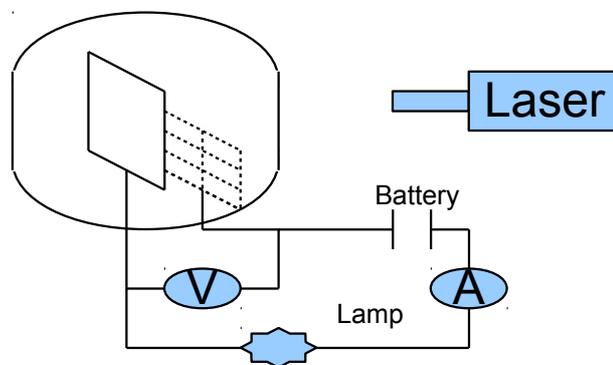


FIGURE B.3: An ammeter (*A*) measures the amount of electrons removed from the metal by light and a voltmeter (*V*) measures their energy.

Axel replaces the light source with another that illuminates the plate with a light red, then with the very first one, which diffuses a greenish-yellow ray. Each time, the voltmeter indicates a higher value. Everything happens as if the energy of the electrons depends on the colour of the light. "The frequency of the light beam that illuminates the plate affects the energy of the electrons that are ejected and not their number! Whereas the intensity of the light directly influences their number, but not their energy! This is what surprised physicists at

the end of the 19th century. We could not see how to explain this phenomenon if the light was indeed a wave, which had been firmly demonstrated since the 18th century!

"However, the photoelectric effect becomes clear if we conceive of light as a beam of small particles that would tear electrons from atoms in the metal plate. To tear them off, they must have sufficient energy, and this would explain the threshold for triggering the photoelectric effect. Planck had shown that the energy of light is quantified and Einstein gives concrete reality to this quantification by creating the photon, a grain of light that stores an energy all the greater as its colour approaches the blue side of the rainbow."

- And what is revolutionary about this discovery?"

- It is because we had demonstrated that light is a wave because it creates interference! Now Einstein is demonstrating that it is made of grains!"

- And why not imagine that these are grains that vibrate like a wave?"

- No! That doesn't explain anything! How would you understand that two grains of light give darkness when they add up?!"

-...

- Note that we tried to understand how light reacts when it is made to cross two slits to create interference, when the beam is so weak that there should only be one photon emitted at a time!"

- I was just about to offer you this experience! "Axel smiles at my remark and continues.

"Physicists have long dreamed of being able to do this experiment, without being able to do it! It is part of what they have called "thought experiments" because they cannot really put them together because of practical difficulties. We will explore some of them that interested researchers for years before we discovered the means to test them for good. Here is one that progress in the development of high-performance optical equipment makes possible today!"

### B.3: YOUNG'S SLOTS

Axel leads us to a metal table loaded with devices of which I only recognise a computer monitor. It is near the wall on which is hung a large blackboard, also grey with hastily erased chalk dust. He describes each piece of his assembly to us, while drawing it on the board.

"The laser, you know it... Here, in front of the beam of light I mounted a polarising filter and then a tiny plate in which two microscopic holes are drilled very close to each other, then, finally, a receiver that will amplify the light received and transmit it to us on this monitor: each light point will represent a photon that will have crashed on our receiver whose shape is reproduced by the screen.

"Let's go back in detail to understand how the experiment will be done. First, the whole thing will be vacuumed and protected from parasitic light, of course. That's why I put everything in a sealed, black enclosure: only the electric cables come out to power the laser, receiver and monitor.

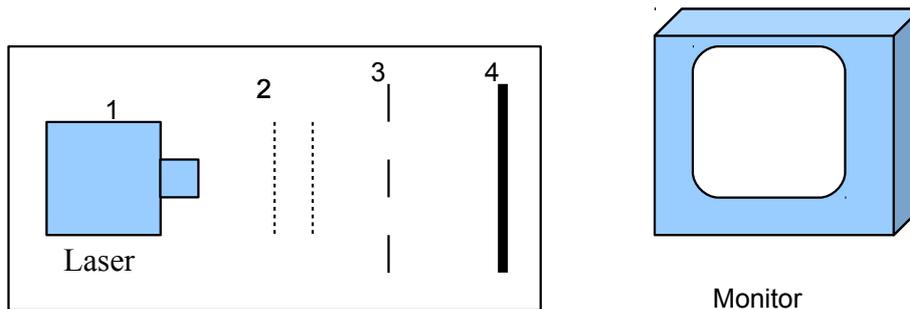


FIGURE B.4: Schematic diagram of Axel's apparatus to reproduce Young's experiment with isolated photons. 1: Laser; 2: Polarising filter; 3: Young's Slots; 4: Photomultiplier screen.

"I will adjust the quantity of photons with a polarising filter on the beam path. You probably know polarised lenses; they are very useful for example, in making anti-reflective sunglasses."

"Imagine that light is formed by waves that vibrate perpendicular to the axis of the light beam. Polarising glasses are made from a screen lens that allows only waves parallel to this screen to pass through: all the others are absorbed or reflected.

Axel draws the following diagram:

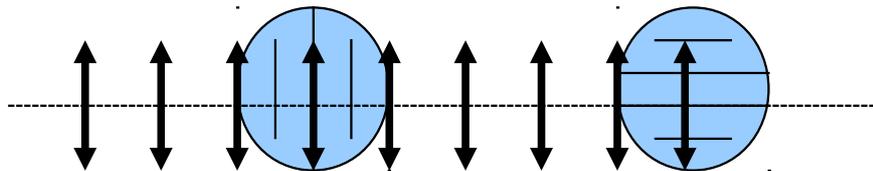


FIGURE B.5: Polarising filter. Only waves parallel to the wefts of the glasses pass through them without loss.

"A light beam can be completely obscured by coupling two polarising filters whose frame axes make a  $90^\circ$  angle between them. It is possible to adjust the light intensity that passes through the device very finely by turning one of the two filters to an intermediate position between  $90^\circ$  and  $0^\circ$ . See for yourself! Here comes the polariser!"

Axel unties and give us the object. Two plastic rings have graduations and each hold a transparent glass slide. They rotate easily around their central axis. When looking through, the amount of light perceived depends on the angle between the two glass slides. When the "0" scale of one is opposite the one indicating "90" of the other, no light reaches the eye: everything becomes black, although each blade alone is perfectly transparent! This is easily verified by setting both scales to the same value. In this situation, the presence of glass in the light path is hardly noticeable. Only a few reflections betray the transparent slides.

"With this filter we can attenuate the light that arrives on our two slots to let only one photon pass through at a time! And to detect such a weak light, that of a single photon, we have a photomultiplier! Many of them are nowadays found in digital cameras and video

cameras. Their internal structure is too small to be visible to the naked eye, but imagine a surface covered with tiny photoelectric cells, each coupled to an equally microscopic current amplifier! "Axel adds a drawing to the board that's starting to get overloaded!

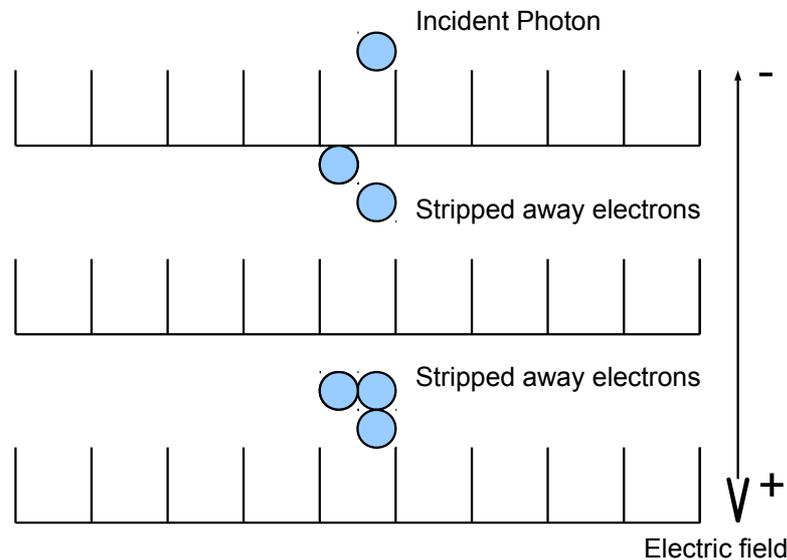


FIGURE B.6: CCD: *Incident photons tear off electrons which in turn tear off other electrons in cascade on the successive plates by being accelerated by the electric field. A light beam is transformed into amplified electrical current.*

"As soon as a photon pulls an electron from one of the photoelectric cells, it is picked up by the amplifier associated with it and then amplified quite easily with current capable of illuminating a point on the monitor screen. The screen surface can be controlled by the CCD receiver surface so that the image seen on the monitor will be a much larger and more powerful reflection of what is happening on the receiver. It's like you become able to see the photons coming, one by one, to a specific place on the receiver!"

Axel replaces the polarising filter in its mounting, then closes the waterproof enclosure and switches on a vacuum pump that hums gently. After a few minutes he turns on the laser source. The monitor screen turns all white.

"It works! Now we will slowly filter the light until only one photon passes through the filter at a time. But before we experience it, let's see what we expect to see!

"You remember that photons, for some unknown reason, interfere with each other after passing through the slits and thus create alternating light and dark bands. If they can no longer interfere since they only cross the slots one by one, we expect to find only two light strips, one behind each slot... like that!"

Axel suddenly erases a corner of the blackboard that becomes increasingly grey and draws.

"A photon that passes through slot "A" will give us a light point somewhere on band "1" and the one that passes through "B" will do the same on band "2". Let's see if that's true!"

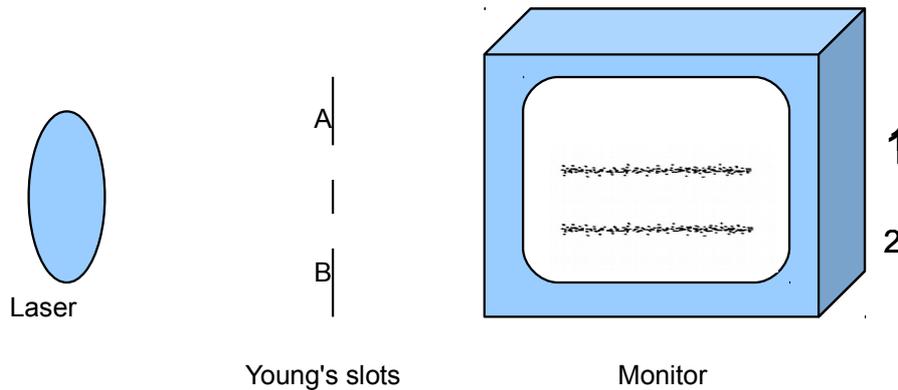


FIGURE B.7: *Isolated photons are emitted from a source and pass through either of the two slots A or B. If traces of the photons are allowed to accumulate on the screen, two light strips composed of dots representing the photons that have passed through one of the two slots are expected to be found.*

Axel turns a joystick that must be connected to a polariser control motor. The screen darkens, turns all black, then small white dots gradually appear on the black surface. They remain bright. Axel explains: "I coupled the experimental device to a computer and software so that the areas of the receiver touched by a photon are represented by a point that remains bright on the screen. This will allow us to avoid noting where they arrive each time there is a new one. Thus a luminous point that appears at the top left of the screen and remains visible means that a photon has struck the receiver, at the top left, before ejecting an electron that allows us to know where it has arrived." <sup>1</sup>

A few minutes pass, during which, in silence, we discover small luminous spots that seem to illuminate randomly this or that part of the screen! No regularity, no visible order! One point lights up here, then very quickly two others, there... then a long time passes before another one illuminates a whole other part of the screen that seems random! The eye is never in the right place! But slowly the luminous spots accumulate and gradually form groups, several bands and not only two, as we expected! (Figure B.8)

"Look!" Axel said softly. "Immerse yourself in the most mysterious result of physics! Although we bombard our receiver with isolated photons, the typical wave interference is there! They seem to have been taunting us for almost a century! No one really understands what's going on! There are many explanations, but they are all far from common sense. We are entering a world that is not ours, although it is at the root of everything: the universe of particles that constitute us, as well as the Moon or the Sun!"

- Wait a minute! Why are you so sure that your photons are isolated?"

- Because they trigger the extraction of electrons in the photoelectric cells and we see them coming, one by one on our monitor! And you didn't see the most amazing yet! I'm going to close slot B. If there are waves passing through slot A I should find a diffraction image on my screen. Remember the experiments we did at the School of Physics with water. Here, this would give me a band centred on A and less and less clear bands on either side of the band 1. Like that!" (Figure B.9 a)

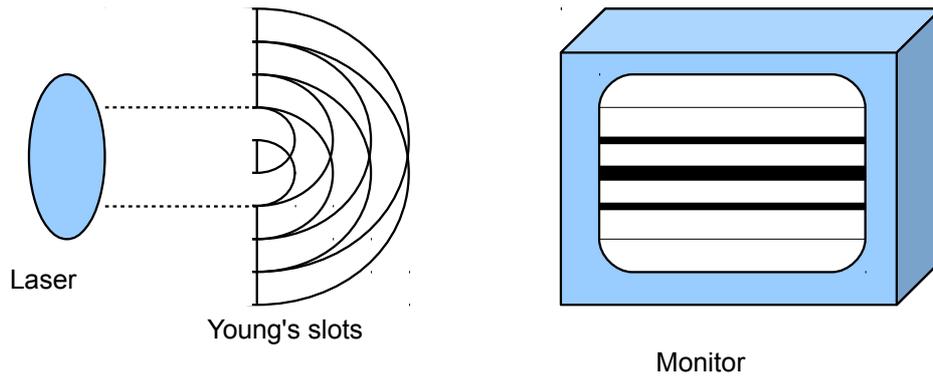


FIGURE B.8: *Despite the passage of isolated photons through the device, the accumulation of their traces builds an interference pattern. Everything happens as if they were interfering with themselves: as if they were passing through the device in the form of a wave rather than a particle.*

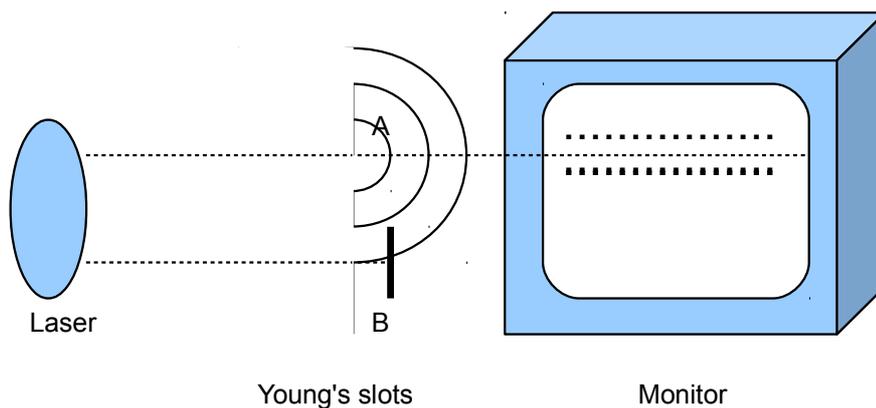


FIGURE B.9 a: *If slot B is closed and the photons pass through the free slot in the form of a wave, we expect to observe a diffraction pattern typical of a wave.*

After drawing, Axel manipulates a switch on the device after resetting his monitor. The screen has gone completely black again. Little by little, new light points appear. But they don't form a figure that looks like Axel's last drawing! There is only one band: it lights up in an increasingly dense way. The photons seem to arrive only in front of the free slit and do not form a diffraction image! (Figure B.9 b)

"That's it! I closed slot B and we only have one strip left, centred on the slit that remained free! They are indeed grains of light, granular photons, comparable to tiny rifle bullets that hit a target in front of the slit!"

- You mean that when there is only one slit the light is composed of grains and when there are two of them it is transformed into a wave? This is crazy!"

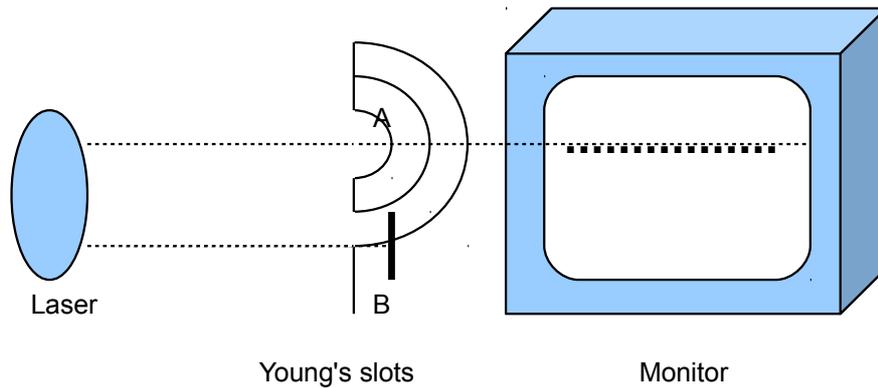


FIGURE B.9 b: *When slot B is closed, the photons pass through slot A as if they were particles.*

- No, I mean that our representation of the nature of light is inadequate! In the 1920s it had to be admitted that it is both wave and corpuscle and that we can't imagine how it achieves this feat!"

- But then I don't understand why it's only corpuscular when it crosses a single slit! The light points should have been seen to illuminate as a result of the shock of the light grains on the receiver, while at the same time being organised into a diffraction pattern to explain its dual nature, wave and corpuscle. Now you told me there's no diffraction image! Even if we wait a long time!"

- That's right! With a single slit we do not see the undulatory nature of light, but only its corpuscular nature."

- Wait, excuse me, but if I understand correctly, the photon that passes through slot A must then know if slot B is open or closed to determine itself! How else would it do it so as not to make diffraction?"

- That's right! And that is why I have described this experience to you, simple in principle, if not in its realisation, as one of the most mysterious in physics! We might be led to think that this tiny photon has a way of knowing the state of the slit B which is immensely far from it, at its scale! There is no reasonable way - I mean that satisfies our common sense, because through mathematics we can explain what is happening in a reasonable way - we cannot understand how the photon that passes through A can be influenced by what happens behind slot B! And God knows if we've been looking! And the photons continue to behave differently depending on whether slot B is open or closed! We even tried to block B AFTER a photon had passed through A! Nothing works! We can't separate what happens in A from what happens in B!"

- You must have some explanation!"

- Of course! But we can't say that it's a really physical explanation, but rather an abstract, mathematical one! I have shown you how we physicists work. We observe, describe, generalise by using mathematics, then give a physical meaning to the laws we discover. This is what we did, for example, to discover the granular nature of the photon after finding the mathematical formula describing its behaviour when it hits metal. But from there we are blocked. We can no longer really give a physical meaning to the nature of the photon and

which would totally explain its behaviour, in a language that is accessible to us and that is not only mathematical. And it's not just the photon that bothers us! In reality, it is all quantum physics that is beyond our comprehension, as is Relativistic physics!

"That's it! We must note that light is both a wave and a corpuscle, but we can never detect these two aspects together. If we set up an experiment to illustrate its wave character, we will not be able to see its corpuscular properties, and conversely, a montage designed to show us that it is made of granular photons will not allow us to do with it what we can do with waves!"

Florian is surprised: "You mean that the contradictory results you obtain depend on the experience and therefore on the choice of the experimenter? And not just the object he's studying?"

- That's right! The principle of scientific objectivity has taken a hit!"

- But then it's magic! It's no longer science! "

- No, I don't agree! It is the principle of objectivity that must be enriched, nuanced!"

- I don't think so, because what got us out of the obscurantism of the Middle-Ages was precisely the obligation to completely separate the object studied from the one studying it! And it has worked so well since Descartes that it has finally been possible to agree on reproducible results and thus base a progress of knowledge on solid foundations! The objects of the universe behave in the same way regardless of the experimenter! Otherwise we're not doing science! It was magic that was supposed to depend on a supernatural gift or ability of the subject. And now you tell me that if he decides to do this or that experiment, an object will behave differently, depending on his choice! That's not possible! It's as if you were telling me that the experimenter influences the behaviour of the objects that form matter only by his choices, therefore by magic!"

- No! I didn't say exactly that! His choices must be translated into a concrete experimental set-up and not only into an idea, a thought that does not express itself materially! What I mean is rather that it is impossible to ignore the entire experimental environment in the analysis of the results..."

I feel like I'm starting to get overwhelmed! "Look, my friends! What if you argue more slowly or calmly explain your arguments to me? I'm a historian and a little foreign to your quarrels over the scientific method!"

Axel calms down: "You're right! That's why I asked you to participate in our experiments! Let's start over!"

"Before the invention of the scientific method, all kinds of ideas were in use and depended on personal convictions that were often unfounded and linked to tradition or to the statements of particularly charismatic personalities... It was common - and this is still often the case today, if we look closely - it was common for a natural phenomenon to be explained in a consensual way and not at all on the basis of critical reflection. It was accepted, for example, that an object thrown in front of you ran a straight line and then fell directly to the ground, precipitated as it was by an impulse to reach the earth! Aristotle had said it: so that's the way it is!"

Florian intervened: "In biology too, consensus prevailed: The heart was perceived as a home that warmed the blood and then sent it into the veins to distribute the heat everywhere. The arteries, as their name suggests, distributed air throughout the body... The thyroid was

used to lubricate the vocal cords since it is very close to them... and as the famous Galen had said! I have plenty like that!"

Axel continues: "And me too!... But let's cut to the chase!"

"The scientific method has been designed to put these images of the world in order and allow anyone who has the material and intellectual means to reasonably convince himself that a given image is a good representation of reality, a good model. And this technique of acquiring knowledge is based on doubt first of all: is this representation well founded? Have objective observations and experiments been made so that I can agree with the analysis of the results and the resulting model of reality? The method is also based on the separation between the subject who observes, experiments, and the object of the observation or experiment. Indeed, just because Aristotle made a given observation doesn't mean you have to be as awesome as him to get the same results! All you have to do is give yourself the means and follow the method! This is the principle of objectivity. The object, its properties and reactions depend on its nature - let's note in passing that it has one! - and not the nature of the one who watches it!"

Florian interrupts him: " But that's it! How is it then that you present us with a model of reality that depends on the choice of the experimenter?"

- Yes..., no... ! Watch out! The result depends on the choice made by the experimenter, but he doesn't need a magician's gift to influence it! Any experimenter will do! Even if it is a machine that decides to open or close slot B! It is therefore objective science, but we can no longer separate the subject from the object as radically as we would like to do... And as we have done since the origin of the scientific method until the beginning of the 20th century, until the invention of quantum physics."

- Speak for physics" grumbles Florian! "We do beautiful and well objective good science! But it's true that you physicists are starting to worry us! Perhaps you have disconnected yourself too much from reality?"

- Or perhaps we are precisely very close to an understanding of reality that is not at all what we imagine! But let me continue!"

- I can't believe there's not another explanation, compatible with the principle of strict objectivity!"

- If you find it, you will delight the minds of a multitude of physicists who have deployed treasures of imagination, cunning, intelligence... to get out of what they considered to be a heresy! We had the same reactions as you did! But we had the experimental results right under our noses! It was not possible for us to deny them on the pretext that the experience was lame! It has been done and redone many times, varying everything that could be varied to try a new lighting... without success! Feynmann, a late genius colleague, even said that anyone who thinks they have understood Young's experience of the slits has understood nothing! And that besides, no one really understands quantum physics!"

- And you've been living with this failure for almost a century? "Florian seems to make fun of Axel!"

- But not at all! On the contrary, we are more and more amazed by what we discover! Well... not all physicists! Because you will see that the results force us to radically transform our ideas about the nature of the world around us. You have to be open and ready to accept the experimental results, even if it means throwing away the old conceptions that seem

inadequate to us today to explain them... even though they have supported us in our vision of the world so far... You will see! But I would like to point out that we have not denied objectivity in our approach! We only adapted it, forced and constrained! Indeed, you could do the experiment again and find the same results as me: the ones we just analysed! The contradiction - or rather the complementarity as it has been called - does not depend on the experimenter alone but on his experimental set-up. Peter or Paul would have exactly the same results if they repeated this experience. But both Peter and Paul will find that the nature of the photon depends on their experience and the choice they make. If they decide to see its granular nature, then they will see it and they will not discover its undulating nature, and vice versa! And we cannot separate the behaviour of the photon from the entire experimental set-up installed to study it. We have become obliged to describe at the same time the behaviour of the particle and the influence of its environment!

- You mean quantum physics is holistic?

- If by "holism" you describe an observation that is on a higher level, that analyses the behaviour of a system and not only of a part of the system, then I agree. We have had to do so because it is the only way so far to build a theory that allows us to predict the behaviour of the microscopic world with absolutely remarkable success. But it is true that this theory is weird! I repeat that we would have liked to find something less strange... but that's it! For nearly a century it has been increasingly verified with an accuracy unknown in other theories, against all odds, despite the efforts of physicists who would like to find a strictly objective path!

"But you are still far from having discovered all the curiosities of the world of particles: it is much more astounding than what we have just seen! Look at this montage instead. It also dates back to the 1920s and its results are still very mysterious today! "

Axel precedes us in front of another table, in front of the blackboard which he now erases with a light hand but which leaves plenty of chalk marks!

## B.4 : STERN AND GERLACH

"The experience I am presenting to you now was imagined in the early 1920s. It dramatically confirmed a prediction made by Bohr who, first, published a quantum model of the atom. He was able to explain very well the surprising observations made so far by quantifying all the properties of the particles of which the atoms are made."

- What exactly do you mean by "quantification"?"

- That their characteristics could only take whole values, per jump... 1, 2, 3 etc... but never an intermediate value.

"Another physicist we will talk about later in a very different context - Wolfgang Pauli - had shown that to describe these particles entirely, it was not enough to know their mass, motion and electrical charge but that it was necessary to introduce into the calculations an additional property - the spin - which resembles a rotation of the particle on itself. We already knew that a rotating electrical charge creates a kind of tiny magnet. It became possible to measure this spin by propelling appropriate atoms between the jaws of a powerful magnet that would deflect them from their course.

"A physicist, not very skilled with his hands, Stern, still succeeded in the experiment thanks to Gerlach, a good handyman. And their adjoining names now describe one of the first confirmations of the amazing predictions of quantum physics. It is a modernised variant of Stern and Gerlach's experience that I would like to show you now if you agree."

- Well, since you've worked hard for us and we're here... why not?!", says Florian, gently ironically.

Axel smiles and guides us through the narrow corridors.

- Very well. I set up the experiment in a room that is better suited for it than my office. Come with me, please.

"I started it last Wednesday already! It requires a very high vacuum and the pumps take time to get there."

Axel opens the door to a large room impregnated with a mineral oil smell. A heterogeneous material is placed on long brown wooden tables. You have to be part of it to find your way around gas bottles, electrical appliances, tubes and wires that are squirming everywhere!

On the left, he presents us the montage he built near a blackboard, again. You can recognise a long glass tube that starts, on the right, from a large cylinder covered with aluminium foil and ends, on the left, with a series of three T-shaped branches, interlocking one behind the other. In some places, other bypasses lead to metal tubes and what appear to be gently rustling pumps or electrical wires. Rings sometimes cut the glass tunnel and seem to join the different parts of the assembly and make them slide or rotate around each other. The tube passes through wooden supports in places that keep it straight. On the far left, a computer monitor and keyboard are placed in front of a desk chair.

Axel goes behind his assembly and draws on the board the diagram of the whole, while commenting on it.

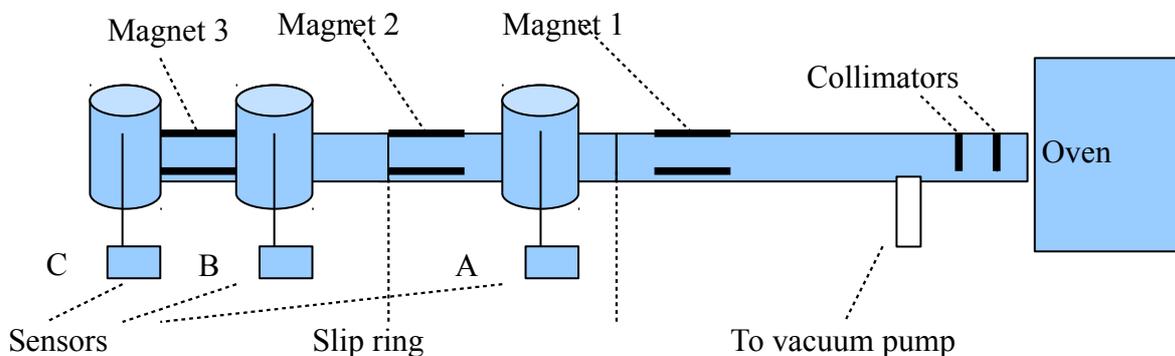


FIGURE B.10: *Diagram of the Stern-Gerlach apparatus. The furnace projects potassium atoms through collimators that select those whose path is parallel to the tube. Powerful magnets are placed on their path. Rings are used to rotate the field of the magnets around the axis of the tube. Detectors are placed behind the magnets. The whole thing is under vacuum.*

He definitely has a weird brain! He is able to manage in parallel tasks that are rarely associated, such as writing a sentence while pronouncing another, or drawing with his left hand while writing with his right hand! Awesome!

"This is the oven. It's a kind of cannon that projects atoms at high speed. Stern and Gerlach had chosen silver atoms but today we will use potassium. It's much simpler because we'll just have to heat it to about 200° while a temperature of more than 1000° is necessary to vaporise silver!"

- But then why did they use silver?"

- Probably because they didn't have a sensitive enough detector. They revealed the silver atoms that were crashing against a plate, much like a silver photo is now being revealed.

"Silver or potassium are chosen because they have a single electron that orbits the periphery of the atom and will give it its spin. The other electrons orbit closer to the nucleus and their spin cancels out two by two."

- Why single?"

- Yes, electrons of opposite spin cancel each other out: the magnetic field they each create also cancels each other out. We have to choose an atom that contains an electron that has no partner to measure its spin."

- I understand."

- So we vacuumed the furnace and I will heat metal chips to 200°. We will select the atoms that are moving in the right direction using two collimators: simple plates with a very thin rectangular slit. They will then pass through the jaws of a magnet, the first of a series I will call "magnet 1".

Axel switches on the oven and then a device that appears to be a thermometer and whose numbers start to scroll on an LCD screen.

"You must now make an effort of imagination and put yourself in the place of a potassium atom!"

- Silly! How should I know what a potassium atom looks like?" I said.

- Don't worry about it! No one really knows! I'm just asking you to try to visualise a kind of small planetary system with the last planet rotating on itself around an axis."

- If that's all it is!..."

- We can imagine that the axis of rotation of the electron points in any direction of space. If the atom passes through a magnetic field, the tiny top will start oscillating around the axis of the field it passes through... like that. (Figure B.11)

"But if the field it passes through varies in power according to a very strong gradient, the atom itself will be diverted from its path, especially since the direction of its axis of rotation is close to that of the external magnetic field... like that." (Figure B.12)

I try to check if I understand his presentation correctly: "If you throw atoms through a magnetic field gradient, you expect, if I understood correctly, to deflect them up or down if your field is vertical. This is because the variation of the field causes a different force at both ends of your atom. And if the axis of rotation of the atom..."

- "Electron!"

- Yes, if you want! Electron! If the axis of rotation of the electron is perfectly perpendicular to that of the magnetic field, then the electron will not be deflected?"

- Absolutely! This is the case represented in "4".
- All right! And since the projection of the electron's axis of rotation can be anywhere on a 360° sphere, you should find your atoms all along a vertical line?"

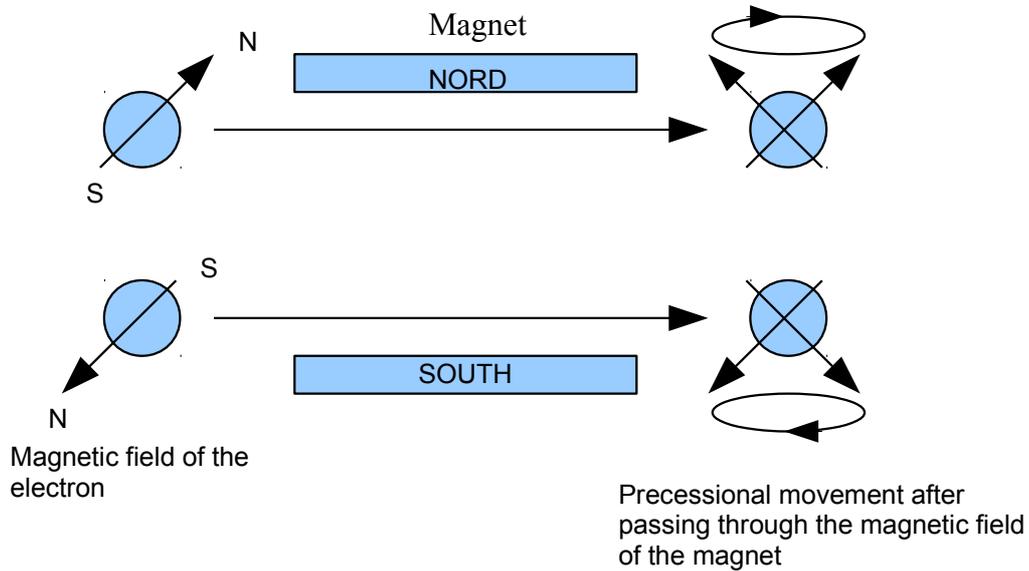


FIGURE B.11: *The rotation of the electric charge creates a tiny magnet whose North pole will be attracted by the South pole of the magnet that is in its path. The axis of rotation of the electron will undergo a precession: it will rotate around an axis perpendicular to the field it has crossed.*

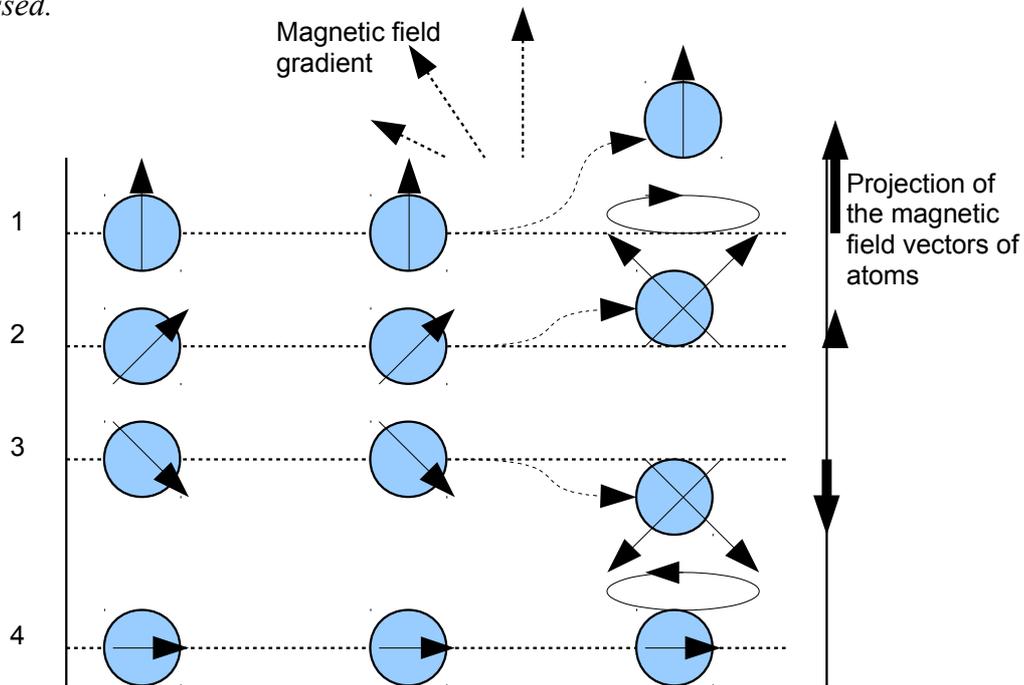


FIGURE B.12: *The deviation of the atom that passes through the magnetic field is all the greater when the projection of its magnetic field vector on the screen is large. Indeed, because of the field gradient of the magnet, there will be a difference in action on one side of the electron compared to the other side.*

- Exactly! And the length of this line depends on several factors, including the strength of the electron's magnetic field that Stern and Gerlach were trying to measure.

Axel draws another figure on the board.

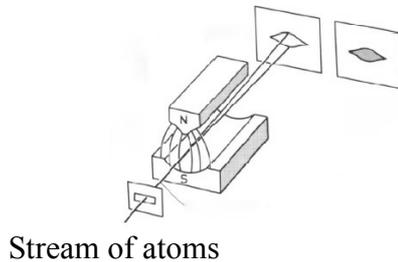


FIGURE B.13: *On the right, the result that common sense expects to observe if the magnetic fields of the atoms can take any direction. On the left, the results predicted by Bohr - and observed by Stern and Gerlach - if the spin is quantified and can only take two values.*

"This is my collimator! It is rectangular: the atoms should be deflected up or down and form an oval spot on my target. But for practical reasons, my target is replaced by a detector composed of a platinum wire heated to 1300° and close to a small electrically charged metal plate and raised to 15 volts... like that.

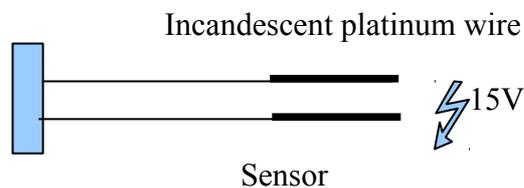


FIGURE B.14: *Detail of the detector connected to micro motors and a computer*

"The potassium atoms that will hit the overheated wire will lose their single electron and become positively charged ions. They will be attracted to the negatively charged metal plate. The very small electrical current will be detected by a micro ammeter connected to the computer here. The same computer will control a system of micro motors connected to the detector. It will be able to explore space in search of potassium atoms and will also draw the shape of the detected spot that the atoms would have formed if they had hit a target.

"We're ready: let's go!"

Axel turns the handle of a device near the oven and comments: "We will first test our potassium gun without activating the magnet. I have started the detector and the computer is in charge of controlling the motors by micro manipulation. As soon as it has obtained enough results, it should draw us a representation of the beam of atoms it has detected." Axel sits on

the far left of the device, in front of his computer monitor, which is not yet displaying anything.

"In the meantime, I suggest you draw the curve you think you'll see later."

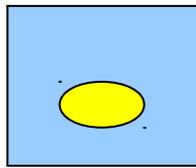
- I guess we'll have a rectangle with blurry edges?"

- And you, Florian, what do you think?"

- I agree with Matt unless the hole in your barrel is circular. If that's the case, I expect to find an oval rather than a rectangle!"

- It's circular and look at it yourself! We do have something that looks like an oval spot. Well done!"

The monitor does display a light yellow oval on a blue background



Axel continues: "Now I turn on the magnet, I reset the computer and we go back to our assumptions: what do you expect to see?"

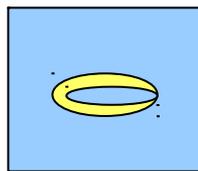
- An oval more spread up and down as the atoms will be deflected."

- How about you, Matt?"

- Yes. An oval higher than wide."

- Well, look at this!"

The screen reveals not a uniform spot, but a kind of mouth with large, half-open lips!



What does that mean?"

- What do you propose?"

- It looks like some atoms are missing in the centre of the stain! Is your barrel well adjusted?"

- Yes, I spent hours settling everything: it's quite complicated! Yes, my barrel is well adjusted! Notice that since 1922 there have been physicists and even students who have done this experiment again and we have always obtained the same results! No atoms in the centre! It was Bohr's astonishing prediction that Stern wanted to verify!

"So how do we interpret this result?"

- Well, if you assure us that your assembly is correct, you have to admit that your atoms have their spin directed either upwards or downwards, without any intermediate position! That's strange! Why don't they randomly rotate around an axis that points anywhere on a 360° sphere?"

- This is even stranger than you think! But Bohr had predicted that the measurement itself created the spin property in a way, and that the result was quantified and depended on the orientation of the magnetic field through which the atoms pass."

- You're talking to us again about magic! How can a measurement create a property of the measured object? It can only reveal a property that already exists, regardless of the measure!"

- In our classical world you're right, of course. But this is not the case in the microcosm of particles and here we are touching one of the great enigmas that we have been trying to solve for almost a century, without any real success!"

- What do you mean? There must be a way to check it out!"

- I'm waiting for that! That's why I'm offering you these experiences! What do you suggest?"

- Just like that? On the spot?"

- Yes!"

- I see you've placed several sensors in a row: you must have an idea in mind!"

- That's right. Many physicists have tried to find a way out by showing that the incredible predictions of quantum theory could not be verified! That's it! I remove my first detector and replace it with another one, behind the one I just removed, which I centred on the upper beam discovered at the exit of the magnet. That is, only atoms that seem to have a spin turned upwards will arrive at it. But before they hit it, I make them cross a second gradient of magnetic field that I can rotate at will around the trajectory of the atoms. Like this!"

Axel first shows us what he plans to do by commenting on his diagram on the board.

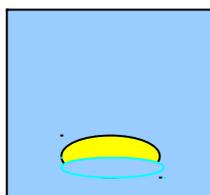
"The detector "A" allowed me to verify that my atoms have a spin directed upwards or downwards. I will now remove the detector from the path of the atoms and let them continue to magnet 2 and detector "B".

"To begin with, I'm going to rotate magnet 2 in the same direction as magnet 1. If I have many atoms with a spin pointing up, what should I find on my monitor?"

- Well, a curve in the shape of an upper lip only and even more inflated upwards than before!"

- Look: that's what we find."

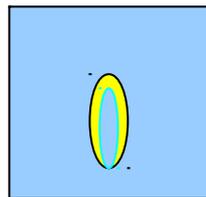
The screen displays a beautiful lip, very pulpy!



- I reset the computer to zero and rotate magnet 2  $90^\circ$  so that its magnetic field is perpendicular to that of the first magnet. What are we going to find?"

- I guess it won't change anything since all the spins seem to be pointing in the same direction that should make them insensitive to the orientation of magnet 2. We should be in the same situation as the one you drew here! "Florian shows the diagram shown in Figure B.12 and points to the atom drawn in 4.

- I agree! If we were dealing with classical physics, that's what we would find! But you will see that the quantum world is very different! Look!"



Indeed: the computer now displays a smaller and less generous mouth than before... but it is vertical!

- So there! I don't understand anymore! You just showed us that all atoms have a spin directed either upwards or downwards and that none of them point elsewhere! And now those who were pointing upwards, no longer point upwards but either to the right or to the left, and again without any intermediate position! That's not possible!"

- And yet that's what we find... and wait! We can go even further, even though the experience is becoming more and more difficult to succeed."

Axel controls the removal of detector "B" from his computer keyboard.

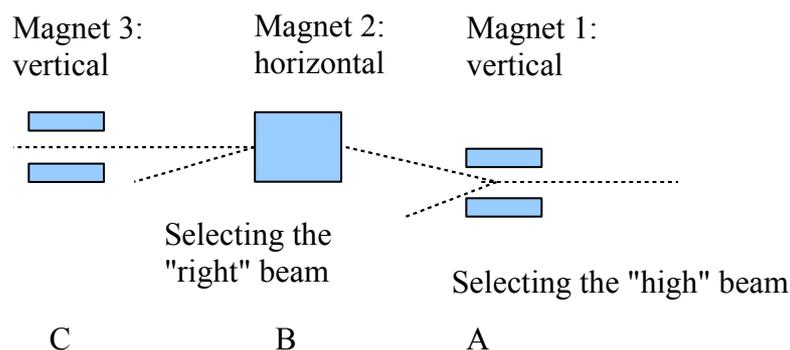


FIGURE B.15: Three magnets in series deflect a beam of potassium atoms. Magnet 2 is placed on the path of the beam deflected upward by magnet 1 and should only be passed through by atoms whose spin was directed upward. Magnet 3 is placed on the path of the beam deflected to the right by magnet 2: it should only be traversed by atoms whose spin is directed to the right.

- I adjusted magnet 3 so that it forms a 90° angle to magnet 2. We will have to wait a while before the computer displays the results because the beam is getting weaker and weaker. I set magnet 3 and detector "C" to analyse the beam that was deflected to the right at the exit of magnet 2 and only this one.

- Yes, I understand the control you'd like to do, but I can't imagine what's going on in your device anymore!"

Florian seems disturbed and continues: "Like everyone else, I've heard that quantum physics is strange, but here...! This is no longer a surprise, but a complete misunderstanding!"

Not being a scientist myself, it seems to me that I remain more serene in front of strangeness! I'm waiting to see where Axel wants to take us.

Florian continues: "I understood that electrons seem to jump from one orbit to another instantly without being caught on the way to their new equilibrium situation. I still admit it! But what you are presenting here goes much further! Are you sure it's properties of your potassium atoms that you're measuring?"

- In fact, I am rather sure that this is a property that involves both the measuring device and the atom. I mean, it is the act of measurement that contributes to the determination of the atom's property!"

- That's what I thought I understood and it's impossible! You seem to be saying that reality does not exist if it is not measured... or that it exists indefinitely to acquire a defined property only when it is measured! I repeat... it's magic and not science!"

- So I repeat myself too... this is what we have been checking for three quarters of a century! And this with ever greater sensitivity and precision. We also put this strange world to work and we do it so well that you enjoy it every day with electronic devices, and you especially with your electron microscope. And Matt when he watches a TV screen or listens to music or when he uses a laser pointer to show his students details illustrated on a projection screen... We continue to use the results of this physics of the microcosm so much so that our entire civilisation is affected! The computer age could not have been born without it... we became totally dependent on it, for better or for worse..."

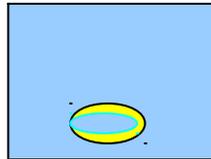
I intervene for fear of being overtaken: "Wait, I don't see how indeterminacy can be translated into tangible property that, through an act of measurement, can explain how my HiFi system works!"

- And yet! All the electronic devices you use are built from the properties of atoms and electrons that obey these laws that you find unacceptable! And these are the most powerful laws that physicists have ever found so far: they allow surprisingly accurate predictions to be made and very often verified to several decimal places! That is, they can describe the behaviour of the microcosm with an accuracy that often goes well beyond the millionth! This is undoubtedly the most powerful theory that has ever been created in physics and perhaps even in science, in a more general context! It explains the chemical properties of atoms and molecules and I have even recently read the work of biochemists who are beginning to wonder - at last - if it should not be applied to biology!"

- Now I'm not following you anymore! " Florian explains: "Our molecules are very real and the cells and then the organisms they form too, thanks God!"

- We'll come to that later if you don't mind. But we are still at the level of atoms and their components and... see for yourself! We waited long enough for the computer to detect enough atoms to illustrate the distribution... what do you think?"

On the screen a new yellow mouth has just appeared on its blue background. It is again a normal, horizontal mouth, with well defined yet thinner and blurred lips than those we first saw.



- But it's a crazy story! Here we are again with spin atoms pointing downwards while you told us that you had selected with magnet 1 those who had their spin pointing upwards then with magnet 2 those who, mysteriously, found themselves with a spin pointing to the right. And now there's half going up again and half going down again! That's not possible!"

- That's right! This is not possible in classical physics. But that's the rule in quantum physics. And if you have a better explanation, I repeat that we are takers! You can imagine that these results seem as astounding to us as to you... and maybe they disturb us even more than you do since physics has always had as its objective to define reality as it is and this new physics suggests to us that it is impossible!"

- Why?"

- You saw it for yourself! I can't make objective a fundamental property of atoms, their spin, that is, independent of my measurements! This property exists because my magnets act on atoms. But it is absolutely not what I can imagine. When I describe it as a kind of small magnetic field created by the orbital motion of an electron, I am only helping my brain to visualise a phenomenon that seems quite out of reach to us physicists despite all our efforts for so long. In a few words, we can describe the phenomena we observe, we can measure and control them beyond any doubt. Our calculations give us a good picture of what is happening in the ultimate behaviours of matter. We are using all these results in an impressive technology. But we have given up when it comes to understand what is happening, to really find an explanation that will eventually allow us to visualise this strange world. It is based on our mathematical formulas. But the abstraction of these formulas, and sometimes the small adjustments that are necessary to avoid obtaining absurd results, make us unable to understand what they describe. Quantum physics is a fabulous success of the predictive qualities of a scientific theory and, at the same time, a sad failure of the explanatory properties of the same theory.

"Or rather not: there is not really an absence of explanation but a plethora of interpretations, all different and all equally astounding, as you can imagine! I was thinking of introducing some of them later, but first I would like to tell you how physicists struggled to get out of this mess... without really convincing everyone so far. How about discussing it in the cafeteria?"

- Nice idea... I'm hungry!"

Axel turns off his machines and then leads us along the corridors to the cafeteria on the ground floor.

## B.5: THE PHYSICISTS' MEAL

That is undeniable! Biologists are good living people and physicists are less so! They do not have a particular penchant for asceticism but rather a lack of know-how when it comes to letting go and having a good time. They seem too complicated: the rational mind is always alert and unable to let intuition work, even for a fleeting moment! This rule of course suffers from a few exceptions, but I have noticed that physicists who appreciate the good food and the environment that suits them, often recycle themselves into the life sciences and work in molecular biology for example! Indirect confirmation of the above rule!

CERN's cafeteria does not have the warm atmosphere of the building where Florian works. It's really sad! Long rows of impersonal tables develop in a rectangular and cold space. There are some warm colours at the self-service bar. But it's only because of the dishes and not because of the talent of a decorator.

The friendly atmosphere of biologists' meetings is very different. Here, solitary people worried, it seems, about finishing as quickly as possible this unavoidable chore of eating to find the necessary calories and hold out until the next interruption. There, tables where more people than expected gather around a colourful space that literally overflows with mouth-watering dishes. Here, a few couples of physicists who either eat silently and worry only about their plates or engage in a dialogue that makes them forget their cooling dish. There, guests talking with their mouths full and laughing while drinking.

When Axel invites us to his house for dinner, it is the lady who prepares the meal. Florian, on the other hand, gloats as he cooks strangely scented dishes that he introduces to his guests. He starts by looking for flavours, often in the nature, in the forest or on the side of the paths that cross the flowery meadows he loves. He collects leaves, seeds or flowers that give an authentic and original character to his culinary combinations. When he cooks, he communicates with nature, which obviously satisfies him. He does not hide it and is always amazed by the close links he discovers with the species that surround him. He treats himself with simple plants that he harvests at the right time and dries with care. I remember his attic covered with poppy petals spread out on the ground. They decorated the space with a strange atmosphere coloured by the blond or crimson reflections that connected the beams or flowers to a few gaps between the tiles through which the July sun crept. Or long leafy stems braided and suspended from the beams of his kitchen, which perfumed the air until it gave it an almost palpable consistency! He is always amazed to discover that he is sensitive to molecules invented by plants that are ultimately much closer to us than we could imagine!

But here it is Axel who invites us to share the special dish of the day, which is very healthy, where everything seems calculated to provide protein, fat and carbohydrates, not to mention vitamins and minerals, but without imagination. Tastes and flavours are secondary.

We sit at the end of a row of tables, against a wide bay window behind which autumn unfolds a serene picture. The warm colours of October are pasted by the mist that takes a long time to dissolve and gives a little joie de vivre on that side of the glass. A few blackbirds pick up crumbs thrown at them by brave physicists sitting at tables outside. The sun is still

reflected in large dewdrops hanging from a few needles of old pines that border the building. But Axel takes me out of my reverie....

"So Matt... what do you think of all this?"

- How strange is particle physics! I'm like Florian, I can't accept that these are concrete properties of the atoms you measure... I prefer to imagine that they are rather strange effects due to the devices."

- I'm glad to hear you're not questioning the results we've been auditing for so long! But I remind you that science does not seek to make us believe anything, but to understand and acknowledge the relevance of models that explain reality in the most satisfactory and convincing way possible...

"But what you said is very interesting. These are indeed "strange properties". But to conclude that they are "created by the measures"... it is debatable!

"And you, Florian, what do you think?"

- I admit that your results are well founded and reproducible, but they remain incomprehensible and seem to me to be more a matter of magic than science as I told you."

- That they are incomprehensible is what Bohr's School concluded! That they're not scientific... that's not true! You get an idea of science that's been outdated for a century! But I grant you all the mitigating circumstances because you are far from the only one. There is really only in physics and perhaps philosophy where we seriously question our conceptions of the scientific method and its results... and the image of reality it gives us."

- And what does Bohr School say?"

- That the universe of particles is not our own. That our brains are not made to understand it and that we should not desperately try to find images from our experience to describe in a way that we can understand what is happening there. It is indeed a scientific approach since the results of the experiment are put first and not the conceptions that are familiar to us... so dear to our minds. The Copenhagen School - the university where Bohr and his colleagues worked - suggests that only experimental observations and mathematics should be used to provide them with an effective conceptual framework. It suggests admitting what we observe and discover experimentally by recognising our inability to understand them other than through our mathematical equations."

I protest: "That's something! But that doesn't help me as a non-scientist!"

- That's right! Even for us, the necessary mathematics is difficult: but it allows us to create an absolutely superb scientific theory because it gives us the ability to predict the results we obtain with amazing precision. And it is very comforting because it means that our abstract equations describe a concrete reality that exists outside them because they describe it so well.

"But Bohr stops here! He thinks that we must remain humble before the results and admit that they will be ineffable forever. The microcosm is composed of objects that are both waves and particles... he calls this phenomenon the "principle of complementarity" that could also be called the "principle of contradiction" since all particles, even those that compose you, Florian, have measurable properties as if they were both well-defined objects in space-time while presenting properties that describe waves, that is, the possibility of being spread in different places in space-time, with measurable probabilities."

- It's incomprehensible!"

- We agree: but that's what we're discovering! Bohr had hung a kind of sign above the door of his house: it represented the law of transformation of the Chinese... you know?... a disc divided into two equal surfaces, one white, the other black, delimited by a line with two curves, with, in each half another small disc, whole and of opposite colour. In Chinese philosophy, this symbol represents the complementarity of everything, white and black at the same time, as well as the law of transformation. In the white half we already see the birth of its opposite, the black disc which will gradually grow in size and eventually make the white disappear... which will reappear in the form of a small disc in its turn... etc... It is also the symbol of the Yi-Jing or "Book of transformations" of Chinese philosophy and which represents the oldest known written tradition. We'll come back to this later, if you don't mind."

- That's what I think! Your science and models seem to lead you towards a new obscurantism rather than an objective universe. "Florian has finished his meal and looks at Axel with a provocative look. But the latter remains calm.

- That's not true! We discover that your "objective universe" is much more mysterious and subtle than you think!

"Let's go back to the 1920s and 1930s. The staggering forecasts of the Copenhagen School are verified with precision and regularity never seen before in physics. The concrete universe whose mechanics we thought we almost understood at the end of the 19th century is totally disrupted by Einstein's theories on space-time and Planck's theories on the properties of particles. Physicists are desperately trying to explain these results with appropriate physical models.

"As far as space-time is concerned, we quickly recognise the impossibility of imagining a four-dimensional universe in an imaginative way. To try to visualise the behaviour of the objects that inhabit it, we must sacrifice a dimension and imagine a space that would only contain 3 to try to illustrate what is really happening in ours. Einstein discovers that gravitation is only a deformation of the texture of space-time by the masses of the stars. But we can only visualise these deformations in a three-dimensional space. This is why it is often represented as a thin sheet of highly elastic rubber deformed by a heavy ball: an image that allows us to easily understand why an object rolling on the sheet and passing near the ball will be attracted by it. It is impossible for us to expand this illustration into a higher dimension to represent what is really happening. Only mathematics can do that...

"In the case of the microcosm it's even more frustrating! We are already unable to visualise how a particle can suddenly change state without us being able to observe it on an intermediate path. Remember Stern and Gerlach's experience: we only observed two states at a time - top-down or right-left - never intermediate states. But what this experience also shows is that our conception of an objective reality independent of us is to be reconsidered! Indeed, it is not possible to admit that after magnet 3 I find again spins pointing downwards, whereas after magnet 1 I had only selected spins pointing upwards! And yet this is what we regularly discover! We must therefore accept, as Bohr proposes, that we must not imagine that there are particles with objective properties. The only thing we can say is that we observe a given result after a measurement, and that this result is predictable if we apply the formulas of quantum mechanics. But these formulas involve both the particle and the device that we use to find its behaviour. In other words, I can't imagine concrete particles, with a "up" spin and that I select to direct them to my magnet 2 and then re-select to go to my last magnet. I can only observe the results of my measurement, i.e. the one I obtain with the "C" detector and which tells me that I have not definitively determined anything in 1 or 2! Or rather that I lost

the determination obtained in 1 because of magnet 2, so the objective reality of the particles is not what I imagine! I can't think that particles have concrete properties if I haven't measured them!"

- Wait, I'm lost! I have trouble following what you present as an objective reality related to a measure."

- Don't worry, you're not the only one! But it is important enough that it is worth trying to clarify the Copenhagen School model. And for that I propose to tell you an exciting episode in the history of physics... the intellectual dispute between two giants of thought, Einstein and Bohr. It lasted a few decades and then turned to Bohr's advantage... but let's take a closer look at what happened... over coffee."

Axel gets up picking up our trays and heads for the bar. I would like to take this opportunity to ask Florian what he thinks of everything we have seen so far.

- Well, I'm as confused as you are! First of all, because of the implications I see for the image of the world we are forging for ourselves, and also for Axel's objective. For almost a year now, he has been preparing some kind of scientific shows to make us think about what concerns him, without telling us what it is about. I'm very confused. Especially since what he teaches us holds up well! I like to provoke him to amuse myself with his ingenuousness, but what he reveals to us is disconcerting!"

- What impresses you most about it? Because I'm finding out a lot more than you are!"

- This is what he has already taught us about the relativity of time and that he links to experiments with astounding results! I made the necessary effort and, thanks to your advice, I finally managed to remember some snippets of dreams. But it is impossible to draw anything conclusive from it: I can't remember anything other than a few images.

- On the other hand, I was able to confirm the impressions I had of my previous dreams. The notes allowed me to have evidence and not just hypotheses.

- Oh!" Florian seems very surprised and interested at the same time. "Can you be more specific? No, later," he adds, seeing Axel coming back. "Let him show us what he's getting at. I'm curious to understand how he's going to do objective science with a reality that isn't, it seems!"

- What do you mean by that?"

- That there seems to me to be a profound paradox between the results that physicists discover and the method they use to do so!

"Objective science studies objects that have their own reality and that do not depend on the experimenter or measuring devices! They would be there, as they are, even in my absence and even if I don't measure them. But what we have just seen is not compatible with this vision of reality and I did not realise this paradox as well as I do now."

- You mean that in addition to the importance of experience and measuring devices to describe the properties of particles, we must also ask ourselves about their nature?"

- Yes, if I have understood the Bohr model that Axel describes for us, we could not talk about the existence of a particle with defined properties, not because our experimental devices or protocols are insufficient, but because their nature is like that: undefined! They would only exist, in other words, with defined and measurable properties, when interacting with them, for example when we observe them."

- What if we don't observe them?"
  - That's exactly what concerns me! I can't help but think that the world exists even when I'm not there to observe it. And Axel seems to want to show us the opposite!
- "But here he comes back!

## B.6: QUANTUM MECHANICS AND SODA

"Here! I brought your favourite sodas!"

Axel offers us sparkling drinks to accompany our coffee. In front of our astonished faces, he continues, smiling: "Yes: soda is closely linked to one of the most beautiful pages in the history of science... Indirectly, of course!"

He continues: "Towards the end of the nineteenth century, a Belgian engineer invented a simple and cheap technique to make the chemical basis of soda. The many applications of his invention earned him a fortune that he used with great wisdom and philanthropy. He began with his own workers, to whom he granted the first paid holidays, social insurance... and continued by creating International Meetings in several disciplines, including physics.

"Ernest Solvay - that's him - invites the most eminent researchers every three years and asks them to talk for a few days on a specific subject. The delegates formally prepare their interventions but as they live together during the whole period of the Meetings they take the opportunity, of course, to discuss in a very free, informal way, sometimes with enthusiasm.

"Fortunately, we still have some autobiographies left, thanks to which we can reconstruct most of the decisive intellectual approaches that marked the birth of quantum mechanics. And so it is that an article published by Bohr in 1949 allows us to relive the contradictory and fascinating debates he had with Einstein since the official presentation of the theory at Como in 1927.

"They clashed with obstinacy but always with class and elegance. Each admired the qualities of the other, while fiercely defending his own convictions. The young Bohr never missed an opportunity to destabilise Einstein by drawing subtle parallels between the quantum revolution and the one Einstein himself had triggered with Relativity. Their mutual friend, Ehrenfest, even compared Einstein's deep reticence towards the quantum model - which he had helped to create in part with the discovery of the photon - with that of his own detractors unable to swallow the new concepts from the Theory of Relativity. From there to imagine that Einstein would have reacted like Bohr if he had been younger...

"But first let's look at what happened in 1927 at the 5th Solvay Physics Meeting.

"So this is Bohr who just proposed a completed quantum mechanics. It fully explains the experimental results known so far and makes it possible to predict and calculate the behaviour of particles studied in new contexts. For him, it is complete and logically coherent. It makes it possible to recover rationality by eliminating the paradoxes discovered so far, for example those that emerge from the corpuscular and undulatory properties of particles. But it has a price... that Einstein refuses to pay! Let's take a closer look."

Florian laughs: "You admit that you were no longer rational!" But Axel continues without blinking.

- Bohr builds his principle of complementarity which lends a nature that is both corpuscular and undulatory to particles but indescribable simultaneously in the same experience. If the equipment can measure typical corpuscular parameters - its exact position for example - then there will be no visible interference patterns. Conversely, if the experiment is able to measure the wavelength of a photon, then we will not be able to define a precise path as we should be able to do with an indivisible particle. The two aspects are necessary, complementary, to know the physical characteristics of the behaviour of atomic objects but they cannot be defined at the same time... as a matter of principle."

- What would stop you from imagining more complex experiments to measure them at once?"

- The fact that Bohr's model poses this impossibility as a fundamental principle of his model! Principle itself derived from the analysis of the results obtained so far."

- It's hard to buy!"

- Einstein refused to buy it! Just as the principle of uncertainty discovered two years earlier by Heisenberg, which shows that it is not possible to know exactly two combined parameters such as the instantaneous position and velocity of a particle or the exact moment when it passes in a given place... Any effort to increase the accuracy of one of the measurements automatically introduces an even greater uncertainty on the conjugated measurement."

- I have trouble understanding why these principles seem serious to you! Not only are they hard to believe, they seem light to me! Why then imagine such exotic principles?"

- Oh no! They are far from light! They are logically derived from experimental results and the mathematical analysis that describes them. But I promised myself that I would not impose this approach on you, which is very difficult and too abstract for anyone who is not a physicist. Nevertheless, be aware that these principles are based on the discovery of the quantification of atomic object states and their wave-particle duality and make it possible to calculate the results that we find when we perform experiments. They are therefore very useful and not light at all!"

- Then why was Einstein reluctant?"

- He didn't question the interest of the model but he was like Planck who never really wanted to believe in the reality of the quantum he invented! Both interpreted the quantum as a temporary device to work and find the results sought but not to really explain them. They were waiting for a deeper theory that would be able to explain the results obtained by going beyond the concept of quantum."

- And Bohr didn't agree with that interpretation?"

- No! Not at all! He admits that his quantum mechanics is symbolic and predictive rather than able to explain the nature of the observed phenomena in concrete terms, but he maintains that it is complete! That is, it is impossible, as a matter of principle, to know more about the microscopic world than we can measure as fundamental parameters. He reminds us that our brains and language are adapted to the macroscopic world but that they are clearly no longer adapted when used to describe the microcosm. He makes it clear that it is not a question of inventing a new appropriate language, but of taking great care when using our own to take into account the particularities of the microscopic world. He calls this precaution the principle of correspondence."

- Again? But your fellow is full of principles!"

- All right! admits Axel with a smile. But he was far from being rigid. On the contrary! He had to show great genius to abandon certainties that seem obvious to us but that do not correspond to the experimental observations of the microcosm.

"But I saved the best one for last and it was the one Einstein didn't like the most. This is the nature of physical reality. Bohr postulates that it is impossible for us to speak, or even imagine, an objective reality without using the devices we have invented to measure them!"

- I don't understand what you mean!"

- Yes, I will take an example. In our world, I can make several observations of the same object in succession: they will allow me to measure different parameters that are specific to it. For example, I can measure the position of the Moon each evening, as well as its appearance, the place of the celestial sphere where it rises, where it lies down... I can then create a model of its trajectory and the variation of its phases that will allow me to predict where it will be in a day, a month... where it was ten years ago... I deduce that the Moon has an inherent objective reality. Even if I am not measuring it, it exists and continues to follow its trajectory as my observations and calculations allow me to be convinced."

- Yes... of course."

- Of course! But this is no longer the case in the microscopic world! Remember the experience we have just had, that of Stern and Gerlach. At the output of the magnet "1" we selected the "up" spin atoms and only those. We guided them through the field of the magnet "2", perpendicular to that of the magnet "1" and found that there were only "right" and "left" spins left. At the output of the magnet "2" we selected the "right" spin atoms and only those. And when they pass through the field of the magnet "3" we find "up" spin atoms AND "low" spin atoms whereas at the beginning we had spread them out! How can we explain their presence?"

- It's incomprehensible!"

- It is irrational: but we find rationality again if we admit, as Bohr proposes, that we cannot speak of the intrinsic reality of an object in the microcosm without including the measure we make of it. Only the results of a measurement have a real meaning and they depend on the device used. We can't say anything about the condition of an object that is not observed, in principle!"

- Another principle!"

- Yes. But let's go back to the Solvay Meetings of 1927. Einstein had missed Bohr's presentation at Como but he tries to show him that his model cannot be coherent and offers him virtual experiences: here is one:"

Axel draws on the table while talking:

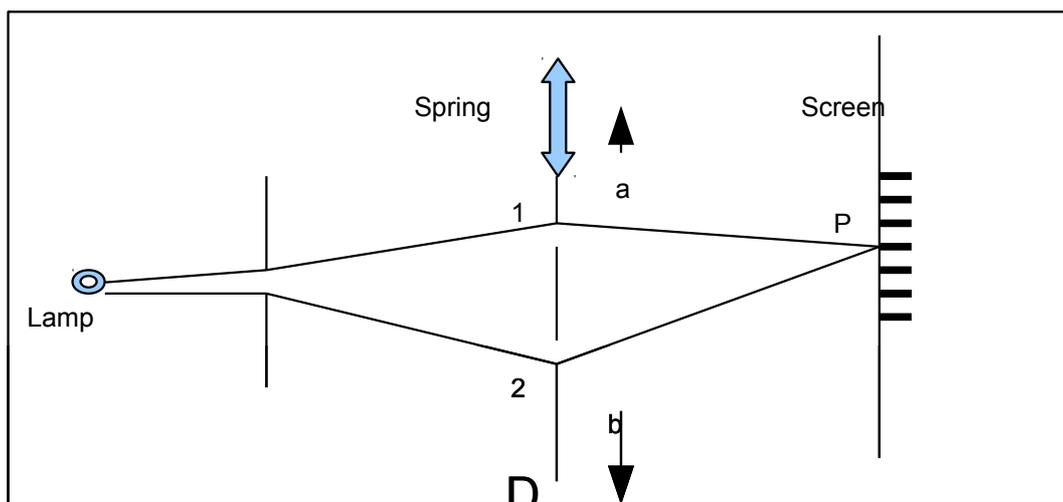


FIGURE B.16: *Einstein imagines an experiment to demonstrate that it should be possible to know through which slit a photon passes by measuring the movement of a spring that causes the photon to hit the edge of the slit. If it passes through "1" the slit will be pushed up (a) and if it passes through "2" it will be stretched down (b).*

"That's it! Einstein offers an experiment that he knows is impossible to carry out for practical reasons but that he imagines possible in theory.

"Suppose," he said, "that we observe an interference pattern such as this one. According to Bohr, I can't know through which slot the photon passed to illuminate the "P" point of the screen because if I put a detector on one of the slots, I lose the interference pattern. But if I hang my diaphragm "D" on a spring, I can measure its reaction to the shock of the photon on the slit it passes through. Indeed, if it passes through "1" it undergoes only a slight modification of trajectory: it will only raise the diaphragm by a very small value "a". On the other hand, if it passes through the slot "2" it will lower the diaphragm by a value "b" greater than "a". I can therefore know both the place "P" where the photon that presents an interference pattern arrived, and its path as a corpuscle. This contradicts the principles of complementarity and uncertainty.

"But Bohr analyses Einstein's proposal in detail, spends the night on the problem and eventually discovers that it is impossible. The next day, triumphantly but with restraint, he demonstrated to his detractor that the whole experience was based on the very accurate measurement of the diaphragm movement. The experimental results obtained so far show that it is not possible to measure both this movement and the position of the slots exactly. What Heisenberg translated and mathematically formulated in his principle of uncertainty."

- Yes, but you just said that Einstein refuses to believe in the uncertainty principle!"

- Oh no! He rejects Bohr and Heisenberg's physical interpretation of it, but not its effectiveness and validity in calculating the experimental results observed. He refuses to allow this to remain a principle. He proposes to keep it only as a useful and temporary tool until we can imagine it better."

- Okay, I see."

Axel continues: "Bohr discovers that the inaccuracy of the measurement of the location of the slots, which is the result of the precision necessary to measure the movement of the diaphragm, is sufficient to destroy the interference image on the screen. He demonstrates - mathematically - that to keep these interference images, it will be necessary to avoid that the diaphragm moves and for that, to fix it firmly on its support... and to renounce any ambition to discover through which slit the photon passed !

"Einstein is obliged to admit the validity of Bohr's analysis. But he can't help but tease him by asking him if he really thinks God is playing dice?"

- Yes, I know this sentence attributed to Einstein, but I don't understand the relationship with the virtual experience you just described."

- You're touching a very sensitive point here that disturbed Einstein for the rest of his life. This is the abandonment of causality in quantum mechanics! No less!"

- How can you keep doing science if you give up causality?"

- Yes, we can! It is just necessary to specify what remains possible of what is no longer possible in this new physics frame of reference. The effect always remains dependent on a cause. In Einstein's virtual experience I can't have any photons on my screen if I haven't turned on a light source! It's obvious! But what I can't do is calculate precisely the path of a particular photon. This concept no longer makes sense in Bohr's mechanics. The only things I can calculate are the positions of the interference fringes. But if I study each photon separately, I will never be able to specify where it will touch the screen. I will only have access to a probability for each point on the screen."

- Doesn't that mean you don't have enough data to know exactly where each photon will end up?"

- That's what Einstein wanted to show, by refusing to attribute to God an interest in gambling!"

- I see! And what was Bohr's answer to his remark?"

- The story gives Bohr two answers. The one he himself published makes him tell Einstein that he must be very careful when trying to attribute to Providence, notions that are incomprehensible to us because they are expressed in everyday language!"

- In other words, he only wants to speak through mathematical formulas?"

- I think this is a good interpretation of his thinking. But in the corridors of the labs there is a rumour that attributes Bohr with very different words. He would have answered: "Albert! Stop telling God what to do, will you?! ".

Our laughter doesn't bother anyone: the cafeteria is empty at this hour! Axel continues: "Throughout these 1927 meetings, it seems that Einstein developed all kinds of thought experiments to push Bohr to abandon his model. He introduced them to him at tea time. Bohr accepted them, very concentrated... asked for clarification, then sometimes isolated himself for the rest of the day, until the next day. But now he was isolating himself again with Einstein and one or other of their colleagues, and showing him the validity of his model. Einstein finally recognised his coherence, its internal logic and no longer attacked him on this level. But he has not given up criticising him. He had still not swallowed this predominance of probabilities over causal certainty.

"Moreover, during these same meetings, physicists wondered WHO decides where the photon will finally crash? Dirac thought that nature decides, without specifying what he meant by that. Heisenberg proposed that it is the observer and the devices he uses that decide, unconsciously of course... This interpretation gives the act of measurement a kind of magic! But Bohr refuses them both! For the following good reasons: one cannot decently attribute to nature a volition, nor to the observer a metaphysical influence on nature! Bohr reminds us that there is no other rational way to get out of this rut than to adopt his principle of complementarity... But it continues to leave many physicists dissatisfied... Einstein first!

"Bohr persists and signs an article in 1929 in which he draws a parallel between the theory of Relativity and his own. The discovery of the finite speed of light requires, he says, that we specify the frame of reference from which we want to describe physical phenomena. "My theory," he continues, "requires us to make the behaviour of particles depend on the reference framework of the instruments that measure them. Bohr does not see what would be really more shocking in his theory compared to that of his opponent.

"And the duel continues at the 6th International Physics Meeting at the Solvay Institute. But I suggest you talk to yourself in my office about it! I need a blackboard and I'd like to show you the drawings Bohr published."

The afternoon is already well underway when we cross the small park that separates the cafeteria from the buildings where Axel works. The light is just as beautiful as it was before, but it turns orange red. The visitor discovers strange sculptures... which are not, but which have taken their attributes!

Imagine a kind of gigantic piston - it must be 2 meters in diameter - attached to a chamber at its size. But no combustion animated the huge bright metal engine! Axel tells us that it was creating a depression in the room that overcame it. This sudden drop in pressure condensed microscopic drops on the path of the particles thrown by the accelerator at unimaginable speeds. It was enough to photograph through the windows of the room to then calculate their properties. A large ball, just as bright as the piston, surmounts a tube in a corner of the park. We could easily imagine an unarmed bathyscaphe. But they are also obsolete particle detectors. Two young girls squeeze together next to the greying man who seems to be explaining the machine to them. We go around them on the narrow path: they listen to their guide with an interest that does not seem feigned: so there are young people still interested in modern physics!

## B.7: DUEL OF GIANTS

Back in his office, Axel rushes to his blackboard before we even have time to sit down! As I sit down, Florian pushes the large vase of yellow chrysanthemums to take his place on the edge of the desk, very close to the blackboard that Axel superficially erases with his left hand: the right is already holding the chalk.

Florian's changed his attitude since this morning. He then expressed a friendly interest that was a little superficial. But he seems to have gotten into the game and wants to actively participate in Axel's presentation. I remain more detached although disturbed by the implications I see on the nature of the world it presents to us. But he quickly leads us in the wake of his demonstrations, perhaps to avoid leaving us the leisure to stumble in front of the

obstacle that would seem insurmountable to us if we had the opportunity to estimate it carefully.

Florian looks intensely at Axel as he begins to draw a kind of comic book clock with a strange mechanism! He explains: "Einstein has admitted Bohr's demonstration well, but he still thinks there must be a way to do physics at a deeper level than the one where Bohr and his team stop. Here is the virtual experience he presented to him at the next Solvay congress in 1930. He is sure of his business because he brings into play the physics he created himself, the theory of Relativity and the famous equivalence between mass and energy that earned him fame: his famous formula  $E=Mc^2$  which shows that matter is ultimately only a very condensed form of energy.

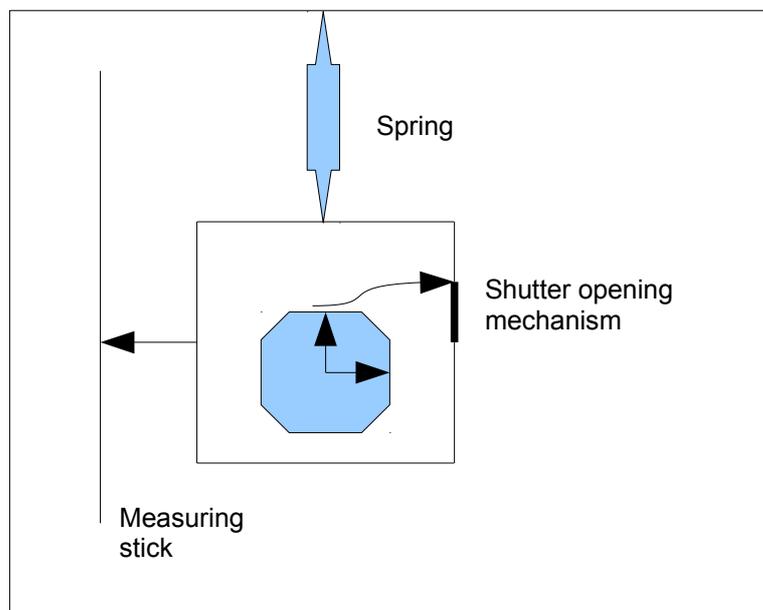


FIGURE B.17: *A clock is enclosed in a tight box containing photons. It controls the opening of a shutter that releases a photon whose energy can be known by the movement of the spring. We know both the energy of the photon and the moment of the measurement, which is not compatible with Bohr's theory.*

"That's it! Einstein wants to demonstrate that an experiment can be imagined to accurately measure both the energy of a photon and the timing of the measurement. However, you will recall that the Principle of Complementarity and its corollary, the Principle of Uncertainty, postulate that it is not possible to know these two attributes simultaneously. Any accurate measurement of the photon energy will introduce uncertainty about the timing of its measurement, and vice versa.

"Imagine," said Einstein, "a box full of photons that also contains a clock. This controls a flap that masks a slit and records the exact opening time that should allow a photon to escape. If the box is weighed before and after the experiment, the weight difference "m" will allow us to calculate the energy "E" of the photon by applying the formula " $E=Mc^2$ ". We therefore have the possibility with this device to accurately measure two attributes that quantum mechanics forbids to measure simultaneously.

"Bohr is very annoyed! As usual, he takes note of his colleague's suggestions and asks for the opportunity to study them carefully. The story goes that he spent the night there but that he was smiling and serene the next day when he invited Einstein for an interview. In the following years, Bohr would not fail to enjoy his hard-earned victory. He inflicts on his rival a stunt that will destabilise him for a long time... five years! And yet Einstein is not a man who is easily impressed!

"Here is the measuring device as Bohr redraws it to show Einstein that he made a mistake in his reasoning as a physicist..."

Axel hands us a magazine of which he has ticked a page. We discover a pretty drawing that reminds us of the style of those I discovered in my physics textbooks at school: a mixture of precision in the line and naivety in the overall result.

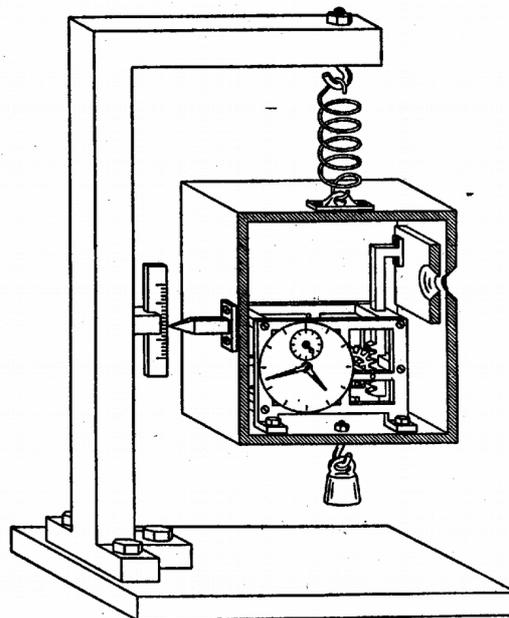


FIG. 8

FIGURE B.18: *Drawing of the mechanism imagined by Einstein as transcribed in Bohr's 1949<sup>1</sup> response. A clock controls the opening of a diaphragm and the spring measures the energy of the photon coming out of the device.*

I give the review to Florian while Axel explains: "Bohr starts by admitting that his device responds well to the proposal that Einstein presented to him the day before: to weigh the photon you will need something that looks like a spring and a reference on a graduated scale! Einstein admits the relevance of the device without suspecting that he has just swallowed a hook that will shove him up to his guts! Bohr gloated as he showed him that the Principle of Uncertainty was once again a winner, and not just anyhow! But by applying an essential discovery that Einstein himself had made and derived from the theory of General Relativity that he published 15 years earlier!

" This theory shows that the rate of time flow varies in a gravitational field..."

- What do you mean?" Florian reacts as if he refuses any new strange proposal: it is true that it is strange!

- Yes, it is! But I prefer not to try to prove it to you. It would be long and not really in line with my point. But keep assured, a plethora of experiments have since been carried out and they have all confirmed Einstein's discovery: time varies in a gravitational field and not only according to the relative speed of objects measuring it. Even your GPS is applying this discovery!"

Florian seems to be making up for it, but remains on guard. He is still sitting on the edge of Axel's desk, his chest bent forward, his arms resting on his right thigh, his left leg hanging so that the tip of his foot touches the ground, as if he were ready to jump on the board to refute or argue Axel's words. I have to admit, I'm amused by both of them!

Axel continues: "Bohr makes Einstein admit that the measurement of the weight of the box will necessarily be done in a gravitational field. So the flow velocity of time when the photon is still enclosed is not the same as that which prevails at the altitude that the box will reach when the photon leaves it... which introduces an uncertainty on the measurement of the moment of exit of the photon, completely compatible with that made possible by the calculation... the Principle of Uncertainty !

"Einstein is beaten! Discouraged, he is surprised that Bohr is satisfied with a theory that is distinguished by the absence of a principle of explanation of nature!"

- What do you mean by that?"

- That Bohr, with his principles of complementarity and uncertainty, refuses any explanation of the nature of the microcosm that would be understandable to us other than through the mathematical formalism of his theory. He reiterated that we should not use the images from our everyday experience to try to visualise what is happening in the microscopic world. Our devices are based on classical physics, the principles of which are understandable to us because we discover them in our daily lives. But our devices are themselves built with these mysterious particles that they allow us to study... Somewhere between the particle and the device, the effects that classical physics has taught us to understand must appear. But we must admit that they are not universal and applicable as such to the microcosm."

- Okay... for now."

- Good. To Einstein's question, Bohr says that when it comes to introduce order into a new experimental field, the only thing to rely on is the elimination of any logical inconsistency in the new theories. He reiterated that it was not a question of relying on principles from past experience, but of being prepared to revise one's convictions in the light of mathematical formalisms when they had showed their logical consistency. A little like Einstein had done for his own discoveries! The latter abdicated but remained very dissatisfied."

Florian doesn't seem satisfied either! "Wait! Explain to me how you can know that a theory gives you a good picture of reality if, from the beginning, you assume that it cannot be used to give you one that is understandable to you!"

- Very good question! But here again Bohr has described well what his theory can help us understand." Axel writes on the board while talking. "That's it! First, he reminds us that:

*a) any theory must be free of internal logical inconsistency;*

"His struggles with Einstein and his like have succeeded in demonstrating to everyone that quantum mechanics is coherent. Einstein finally officially admitted it after his failure in 1930. Axel continues to write:

*b) any theory must make it possible to find the results discovered by experience;*

"This is indeed the case since until today we have not been able to put it at fault... long after Bohr's death himself! In fact, it is even the most effective theory that physics has ever produced!

*c) a valid theory must exhaust all the possibilities offered by the experiments: it must be "complete".*

"Here Bohr is more of an act of faith than a mathematical demonstration. His intuition tells him that his theory is complete, that it fully explains the behaviour of the microcosm... And that's where Einstein will scratch to try to demolish his rival's convictions! His own intuition refuses to subscribe to Bohr's model! He wants to show that there must be a way to objectively measure the attributes of a particle without taking into account the mysterious characteristics of the microcosm."

- For example?"

- He told him that, since it is possible to accurately measure either the position or the velocity of a particle, these two attributes must have an objective physical reality, that is, independent of the observer and his devices! But Bohr retorts that this is not true since these two values cannot be measured in the same experiment. One of them will give a precise value, but no conjecture can be made about the other because it cannot be measured at the same time!"

- The microcosm you discovered is really crazy!"

- And wait... you haven't seen the most amazing thing yet! "Axel seems to have surprised Florian watching him, startled.

## **B.8: AND EINSTEIN CAME BACK... WITH PODOLSKI AND ROSEN**

Axel goes back behind his desk, sits down and resumes: "After the 1930 Meetings, a slight calm prevailed until the next one in 1933. But Einstein doesn't participate in it! Too overwhelmed by his failure in previous ones? We'll never know.

"Bohr met him all the same in Princeton where he took refuge when he left Europe, which was sinking into the tragedy we know. But they don't change their minds: this time, Bohr is bitter! He no longer understands Einstein's reluctance at all and even feels personally touched. Einstein is triumphant in his field because physicists have just demonstrated the reality of artificial transmutations. The alchemists' dream is realised.... with other techniques of course. But his theory and predictions are becoming more and more assertive. Does his success prevent him from changing his mind about quantum mechanics? In any case, he detonated a bomb in 1935 by publishing, with two colleagues, a paper that became famous under the acronym "EPR" based on the initials of its authors.

"This time he is sure to demolish Bohr's convictions as an act of faith rather than a rational perception of physical reality! He finally found a way to demonstrate that quantum mechanics is incomplete: that is, it does not explain all the results that experiments provide us. It is only one step towards the discovery of a deeper theory that would truly encompass all experimental results."

- But how can he be sure?"
- Because it exploits well-known and proven physical laws, and uses flawless logic to imagine an experiment whose result, he says, is inexplicable with quantum mechanics as Bohr and his friends describe it."
- What do you mean?"
- It involves the conservation law, which is well known and very logical. It says, for example, that if an atom that is not electrically charged emits a negative electron, it turns into a positive ion so that the sum of the two charges returns zero. That makes sense! Nothing is lost, nothing is created!"
- All right."
- It also involves the discovery of the finite speed of light, which has also been widely demonstrated over the past half century."
- So what?"
- He states that: "If, without interfering in any way with a particle, one can predict with certainty the value of a physical quantity, then one can affirm that there is an element of physical reality that corresponds to that physical quantity".
- If it's clear to you, I can't say it's clear to me!" As usual, Axel tends to go too fast and I can hardly keep up with him.
- Yes. Einstein simply wants to demonstrate that particles do have an objective existence like the Moon that exists even if you don't look at it! It means that we can measure physical attributes of a particle such as its velocity and exact position..."
- He still hasn't given up on the uncertainty principle?"
- No. And what he wants above all is to show that a particle exists objectively with all its attributes, even if it is not measured."
- That's original! How can you know its attributes without measuring them?"
- It is precisely here that Einstein's subtle genius is revealed. He imagines a very simple experiment - in theory, of course, it will take nearly five decades for it to begin to be technically feasible. But it is an experiment that makes it possible to precisely calculate an attribute by deducing it from a measurement made on another particle that is correlated to it.
- "Suppose, for example, that you excite an atom enough to emit two photons instead of one when it returns to its original energy level. These two photons will be correlated to satisfy the laws of conservation of the physical attributes of the atom that created them."
- For example?"
- If, for example, one photon is ejected in a given direction, the other will be emitted along a trajectory exactly opposite to that of the first, to maintain the balance that the atom had before the emission."
- I see. And then what?"
- Einstein concludes that it is enough to measure any physical attribute of one of the photons to automatically know the attribute of the one correlated to it! We do obtain a physical knowledge without having disturbed in any way the photon that is entangled with the

one we are measuring! The particle therefore has an objective reality even if it is not measured! And Bohr's quantum mechanics does not explain this result. It is therefore incomplete and Einstein is sure to have saved the image of the objective world that science has been exploiting since Newton."

- Wait a minute! Why do you say Bohr doesn't explain this result?"

- Yes, he does! Bohr will explain it, but in a way that Einstein refuses!

"Bohr, with his quantum mechanics, postulates that we cannot say anything about the microcosm when it is not measured: that it has no physical attributes that we could imagine without having measured them! That there is no objective reality like the one we are used to see in the macrocosm... that it does not exist as we would tend to imagine it, as long as it has not been measured... that only the results of the measurements are objective."

- Einstein just proved the opposite!"

- No, because Bohr replies that the measurement that Einstein proposes to make on ONE particle actually acts on BOTH particles at the same time since they are correlated: quantum mechanics defines them in this case as part of the same entity reacting in a deeply entangled way to any event affecting one or the other of its parts. In other words, he says that the experiment proposed by his rival is working as expected because the measurement made on one particle instantly causes the correlated attribute on the second!"

- I don't understand how Bohr can explain that a device located somewhere can have an influence on a particle that can be very far from it!"

- Ah! You're touching on one of the most important arguments for Einstein! Especially since he has shown that no information can travel faster than light."

- I don't see what the light comes to do here!"

- Wait, you'll see! Einstein wants to demonstrate that there can be no instantaneous remote action since the world he has described since 1905 is subject to the laws of Relativity: it has become absurd to imagine that a signal can instantly pass from one place to another in the universe... it cannot travel faster than light.

"Einstein concludes that if the two correlated particles are very distant from each other, Bohr cannot say that they participate in the same measurement experiment when only one of them is measured. It is the principle of locality that an action at a place "A" in the universe cannot have an effect at another place "B" which would be beyond a sphere constructed by all the points that could be reached by the light rays starting from "A" at the time of the measurement." (Figure B.19)

- And what does Bohr say?"

- He maintains his position and reaffirms that we must: "Renounce our ideal of classical causality and radically revise our attitude towards physical reality". He emphasises, for example, that we cannot speak of "physical reality" without involving ALL the devices used for measurement, through space, and even through time!

"Einstein refuses what he calls "a remote action that is more ghostly than physical! »

"Bohr was discouraged, especially after Einstein published an article in 1936 in which he wrote that, for him, the quantum description was only statistically valid for large numbers of

particles. He admits that the theory is logical and consistent, but concludes that his "scientific instinct" leads him to seek a more complete design for particles.

"Nothing will really change until the protagonists disappear: Einstein's in 1955, who died without having discovered the theory he was looking for to overcome quantum mechanics, then Bohr's in 1962, without having succeeded in convincing Einstein's supporters of the intrinsic physical reality of the microcosm.

"Too bad John Bell wasn't born sooner! It would have made it possible to decide between them before they disappeared!

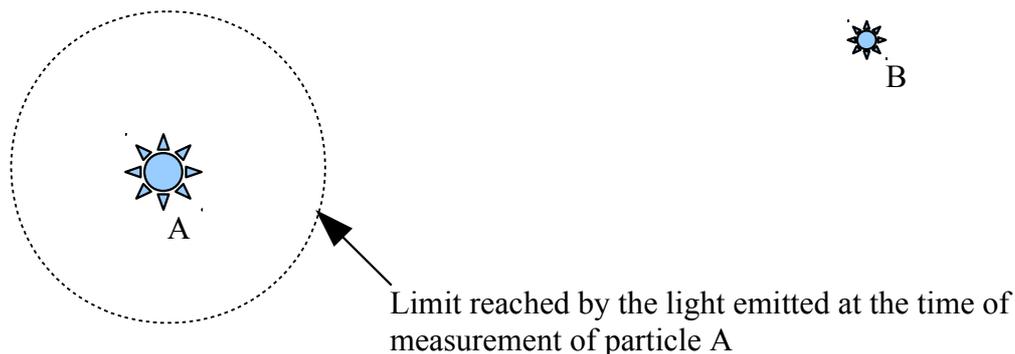


FIGURE B.19: *Let us consider two correlated particles A and B. If the attributes of A are only defined during its measurement, those of B which is correlated to it cannot be defined until a signal emitted by A can reach it. However, the speed of any signal is limited by that of light: it follows that either the attributes of B are not defined at the time of the measurement of A or that a "ghostly" signal faster than light informs B of its attributes!*

" But I will describe his work to you later, when I finish the experimental set-up that will allow me to show you who was right, Einstein or Bohr."

- Because you imagine Bohr might be right? I'm worried about you!" Florian got up and erases the board, maybe to calm down. "You want me to believe with Bohr that nothing actually exists before interacting with a measuring device? This is absurd! How do you explain the world that has been spinning for ages... and that didn't wait for you to invent measuring devices to do it?"

- We'll see about that later. I would particularly like to have your opinion on all this after showing you crucial experiences dating back to 1982. We will have the opportunity to reflect on the image of the world we live in, on the evolution it should have..."

- If I understand correctly, it is not yet today that you will explain to us why you looked so disturbed when you suggested we follow you on this adventure!"

- That's right. But we will soon reach a stage where you in turn will be able to intervene and propose explanations for our discoveries."

Florian turns to me: "Matt! I'd like you to send me your notes as soon as they're finalised. I would like to use them to put some order in my mind. I really need it after what we heard today!"

- For me too," Axel adds, "I'd like to see what you got out of it!"

It is dark when we find our cars and leave each other silently, after a brief greeting.

## B.9 : THE "CRÊT D'EAU"

It's magical! I look at my crossed feet sliding in the soft air and flying over the canopy. Every time you take off, it's the same happiness! Blessed is the inventor of paragliding: an inflatable glider whose ridiculous weight frees us from our own! One could not imagine a simpler aircraft, although its design does not tolerate any inaccuracy.

The sail rushes gently when it passes through a small pocket of warmer air: it slams when the lift surprises it on one side only. No sound, except the intermittent murmur of the sail and the slight whistle of the lines that make me feel connected to it, five metres down.

The yellow canvas hanging in the azure is beautiful! A slight brake application to the left and she enters a nonchalant turn to bring her back towards the slope. I just have time to see Axel take off before turning, to the right this time, to take advantage of the pump that makes me gain altitude, just in front of the takeoff. The air heats up on the dark green of the forest below, caresses the trees by inflating towards the top and then abruptly takes off from the ground at the level of the slope break, on the cliff, at the end of the clearing that serves as our runway.

A small cumulus begins to bud up there, when the rising air cooled by decompression gets rid of the water sweated by the spruces under the midday sun. An astonishing illustration of the water cycle: condensed at night on the needles under the clear sky, evaporated when they warm up, then condensed again at the zenith of the mountain. The whole Jura is a wonderful cloud-making machine! How many times have we found ourselves in their shadows or in the fog at the top when we had left, backpacking, convinced that the perfectly clear sky in the morning promised us a beautiful walk under the sun? The sun was there, everywhere, except on the ridges of the Jura! But today the air seems dry enough to absorb the cumulus clouds before they can meet in a huge street of clouds covering the entire ridge path!

Axel wraps up the ascendancy in which I also turn. The sky is empty of other sails. Only a few kites glide with remarkable ease and tell us where to go to find the hot air columns we are looking for. They must be detecting them from a distance, God knows how! Do they perceive the minute vibrations of the images that pass through the less dense air of the ascents? Or do they see the hot air columns directly? It is not impossible if their brains transcribe the perceptions of different air densities into a form that ours would interpret as colour variations.

I'll have to tell Florian that the heather cockerel still lives on these slopes: I just heard his parade crow, somewhere under my harness: telep... telep... telep... telep..... Unable to see it, I'm already too high, close to the top.

We leave the weakening ascent to fly back and forth in long comings and goings, this time carried by the steeper breeze that has strengthened. The sun heats the whole forest, draws air from the Valserine valley to the summit that we glide along. We just have to describe big 8s to stay in the air, with the leisure to dream and enjoy the site. Although close to Geneva, it is still authentic in its savagery. Even the grey smoke plume that indicates the direction and strength of the wind from the carbide plant that exhales it, in Bellegarde, will soon disappear, remedial measures are required! We will then have to rely solely on ourselves, or perhaps on some brush fire, to guide our flight according to the mood of the wind. But we will not be the ones complaining about the restored purity of the air!

A kite just found a nice pump there, nearby. I take advantage of it and suddenly feel lifted up in the air that smells like resin and undergrowth. We fly together in large circles centred on the ascendancy. It glides effortlessly, black silhouette against the clear sky. It seems to me that it perceives the shivers of his primaries, which it interprets instantly to correct its trajectory and make the most of the wind's energy. At the base of each feather, sensitive cells react to the slightest variations in pressure, calculating short electrical impulses that they send along fine extensions to the spine and then to the brain. It is impossible to imagine the work of the cerebellum that must guide the bird through the three dimensions of space. This is an organ that only perceives the environment through a multitude of short electrical currents! To those that come from the wings, tail or even down on the chest, are added the discharges created by the organs of equilibrium in the inner ear, and those that the retina develops after interpreting the reactions of cones and rods to the photons that struck them... And this ocean of electrical impulses turns into an image of the world that we cannot penetrate. What does it see? What emotion does it feel when it perceives a welcome ascendancy?

It sees the world as only kites can do it.

I see the world as only humans can do, with my senses, but also my experience, my emotions and my mind.

The thin black silhouette transforms itself in my imagination and is adorned with the clouds and blue sky of Magritte's "Promise". Astonishing creation by the artist who, perhaps, perceives before others the evolution of our own image of the world. Here is a bird flying in the night sky, while wearing the day. Space and time change in nature; they intertwine and challenge us on our conception of them. Do the discoveries of physicists not bring us closer to a new Copernican revolution? I confusingly feel that Axel leads me to expand this image that the nature of my senses gives me. Will we have to revise our certainties as we have sometimes been forced to do, with Galileo, Newton, Darwin...?

What were the emotions of the one who suddenly discovered that the Earth is round; or that the movement of the stars obeys laws that are understandable and of the same nature as those that guide us on Earth; or that we share a common evolutionary history with the spruce that I fly over? Perhaps we will soon feel an emotion of the same magnitude?

Axel's green and purple sail has finished flickering along the slopes and is heading towards the valley and the club's airstrip. I turn behind him, regenerated by nature. Axel makes tight turns to lose height, then sinks slowly on the final and lands. He folds his sail back to the edge of the field when I join him, my sail on my back: "Did you hear the heather cockerel!"

- Yes, but I didn't see it. I knew there were a few left around here. We'd have to persuade Florian to guide us in their pursuit.

"About Florian, did he tell you about his impressions of quantum mechanics?"

- Of course! He is very interested in the experiences you are preparing for us... even if he likes to tease you whenever he has the opportunity!"

- Yes, I know."

- He works in a very different way from yours. He almost never handles mathematics but he is immersed in the reality of cells, chemistry, machines that allow him to work... He is very far from the concerns of theoretical physicists and even a little suspicious of them."

- Well, why?"

- But he made us understand it, already. He thinks that physicists are convinced that they understand everything better than other scientists. I saw him get angry with restraint as he read some interpretations published by physicists about biology. He denies you the skill you give yourself when you leave your specialty."

- I see. He may be right, but you have to understand us. We deal with the very basis of all reality. Chemistry and biology naturally take over, but we are the ones who discover the foundations on which they are built. What could be more tempting than to extrapolate our thoughts to the areas that arise from our own?"

- Yes, but you sometimes forget the caution that is required when broadening your vision to foreign questions. Florian told me all the trouble he has with some physicists who have not understood - he says - the basics of the Theory of Evolution and who nevertheless publish nonsense."

- And to return to the image of the world that modern physics suggests?"

- He's interested, and so am I. But he is more involved than I am because he uses the scientific method. Your latest demonstrations encourage him to reflect on the basic principles of his work to try to understand your discoveries."

- And you may not have seen the most amazing yet!"

- You're exaggerating! You've been keeping us on our toes for months. What happened that you don't dare to tell us?"

- Not yet. In fact, we are soon coming to the end of the experiences I wanted to present to you... unless you ask me for more. I'm preparing the last one, you'll see, the result is worth it! Believe me!"

-Credo!"

The sails are folded up in the backpacks. We join the car parked under the windsock.

## B.10 : BELL'S THEOREM

Axel represses a smile when I blow my nose: "You don't have sinusitis by any chance?"

- Yes, and it doesn't seem to sadden you too much!"

- Excuse me," he said, laughing frankly this time. "But I thought you were already reacting to a psychosomatic illness."

- But to what?"

- Yes.... In the meantime Florian I wanted to remind you - very briefly, don't worry - what a sinus is," he says smiling.

- You mean trigonometry, I presume?"

- Yes, of course. Florian doesn't need the little introduction I prepared for you: look!"

Axel shows me the screen of his computer. On a blue background, a large yellow circle is crossed by a radius whose arrowed end rotates regularly in a clockwise direction. The arrow projects itself on two perpendicular diameters and creates on each of them a kind of brown shadow that rises and falls on the vertical diameter while alternating in rhythm from left to right on the horizontal diameter.

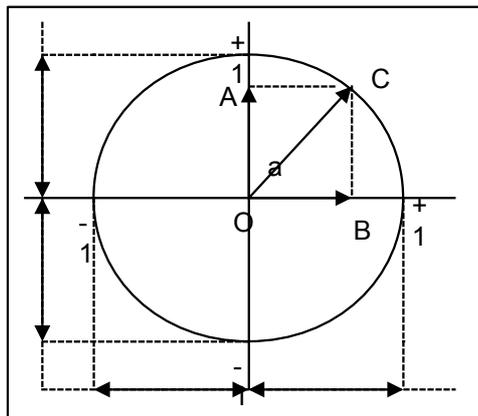


FIGURE B.20: *The OC vector rotates regularly and its projections OA and OB vary alternately between -1 and +1 if the radius of the circle is 1.*

- I see, so what?"

- The AC/OC ratio is called "angle sinus a" and the OA/OC ratio is called "angle cosine a". You grant me that if  $OC = 1$ , we get:

$\sin a = AC = OB$  and  $\cos a = OA$ ."

- All right so far."

- You can see that it's not very difficult. One last thing! The "cos a" is 1 (OA) when the angle "a" is 0 and conversely, it is 0 when the angle is  $90^\circ$ . The sine of an angle varies in the opposite direction of the cosine of the same angle."

- Always agree."

- Well, that's all the mathematics we'll need today! There's nothing to make a sinus infection out of it! Would you like a coffee while you wait for Florian...? But here he comes."

Florian joins us while Axel already erases his blackboard and forgets the promised coffee. I'll take care of the coffee machine while Florian says to Axel.

- I hope you'll reassure us today. I reviewed last night the notes Matt had taken at CERN about the Solvay Meetings and I am worried. I can think all the way round the experimental results and the concepts they involve... I can't make them fit with a reasonable explanation!"

- Don't worry, you're not the only one! It is the opposite that would be original because we are surprised by quantum mechanics endlessly since three-quarters of a century. "

- Because you didn't solve anything?"

- Yes... or not! It depends on your point of view... Wait, you'll understand."

- Ah, finally!" Florian sits in his favourite place, on the edge of Axel's desk, after moving the vase of large blue irises arranged in the middle of a cloud of tiny white gypsophila flowers. But Axel goes back to his chair and says: "I hadn't yet arrived at CERN when an Irish physicist published what could be one of the most important physics papers of the century. He had been hired at CERN for his engineering skills, but it was in theoretical physics that he was most impressive. This is John Bell, a very pleasant personality, fine, elegant, open and friendly... and who unfortunately passed away too young."

Axel seems to have really appreciated his colleague, not only for his scientific skills, but also for his human qualities. He continues: "Bell delved deeply into the concepts of Einstein and Bohr to try to separate them. We were all - and still are - rather schizophrenic because, on the one hand, we cannot help but think with Einstein that quantum mechanics cannot represent the ultimate reality of the microcosm but is only a satisfactory recipe book to describe it. On the other hand, the prodigiously correct results of Bohr's predictions force us to consider that his theory is correct! But Bell did not like it at all and was looking for a method to demonstrate that the world is objective and predictable with confidence, and not indescribable and probabilistic as Bohr would like. And he found a very elegant way to test each of the two world-views and get a clear answer: this is what has since been called "Bell's Theorem"."

- You promised not to do math!"

- We won't make any! We can show what it is without having to solve complex equations, don't worry!

"You remember the polarisers we've already used (see Figure B.5; page 54)."

- Yes! The filter you chose for your experience with Young's slots."

- Exactly! You can imagine a polarising lens as crystallised in one direction so that a photon can only pass through it easily if the plane in which its electric field oscillates is parallel to the rows of glass crystals." Axel gets up and draws on the board. (Figure B.21)

"And the photon is absorbed if its electric field is perpendicular to the polariser frame. But what happens if the photon polarisation makes a  $45^\circ$  angle with the polariser frame?"

- Should it be half darkened?"

- No! Remember that we are talking about a single indivisible photon and not a beam of light. Besides, it's a particle! It obeys quantum logic and not the one we use in our world. In the microcosm the photon will be in an undetermined state: neither vertically nor horizontally polarised, but in a strange and impossible to visualise state which is a superposition of states between the two possibilities!

"Now remember the circle from earlier: For a  $45^\circ$  angle we have  $OA = OB$  in a rectangular triangle  $OAC$ . The Pythagorean Theorem tells us that  $OC^2 = OA^2 + OB^2$  since  $OC$  is the hypotenuse of the rectangular triangle  $OAC$ . And as  $OC^2 = 1$  we can write that  $1 = \sin^2 a + \cos^2 a$ . But as  $OA = OB$  we deduce that  $1 = 2\sin^2 a$  : hence  $\sin^2 a = 1/2$

"The superposition of states predicts that the photon will have a one in two chance of crossing the polariser when its electric field vibrates at an angle of  $45^\circ$  to the polariser frame.

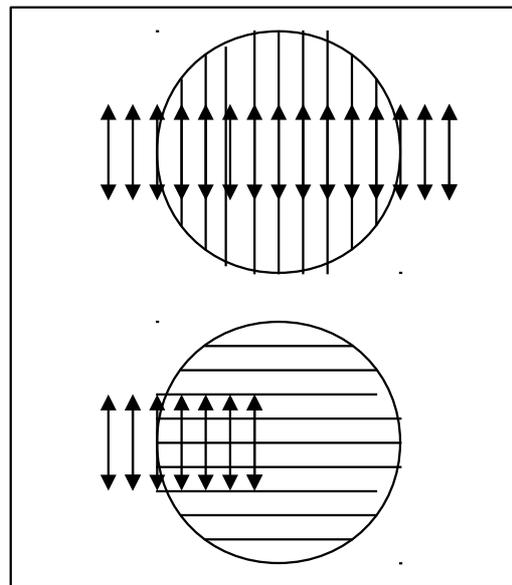


FIGURE B.21: *A photon passes through the polariser if the oscillation plane of its electric field is parallel to the glass frame while it is stopped if the oscillation plane of its electric field is perpendicular to the glass frame.*

- But how can it pass if it is not parallel to the grid?"

- This is because quantum mechanics says that it is undetermined before the measurement and that it is the measurement that causes the collapse of the different possibilities on a single value. And this value will be such that at the output of the filter the photon will necessarily be polarised in the same plane as the polariser frame."

- But then how can you say that the photon is polarised at  $45^\circ$  before entering your filter?"

- I can't say it that way, it's true. I should say that it crosses with 100% chance when the polariser makes an angle of  $45^\circ$  with the vertical and only 50% chance when it is vertical. And I can prove it by adding a third filter after the second. This time the photon passes through it every time if its frame is parallel to that of the second polariser." (Figure B.22)

- If I understand correctly, did you design a machine to transform the polarisation angle of a photon?"

- You could say that. In reality it is undetermined between polarisers 1 and 2 and it is the passage through the latter that determines it."

- How can you say it's undetermined since it just crossed the first polariser? It is therefore polarised at 45°!"

- You're right, I wasn't specific enough! It is indeed determined in the plane of the first polariser, but it remains undetermined for all other planes except the one perpendicular to the first. You will agree that it cannot be polarised at 45° at the same time since it passes through the first polariser and polarised at 0° since it passes through the second! That's illogical! And it is with this kind of experience that we discover the truly probabilistic and indeterminate nature of the microcosm. It really seems that only interactions with the macrocosm are capable of transforming probabilities into concrete events!"

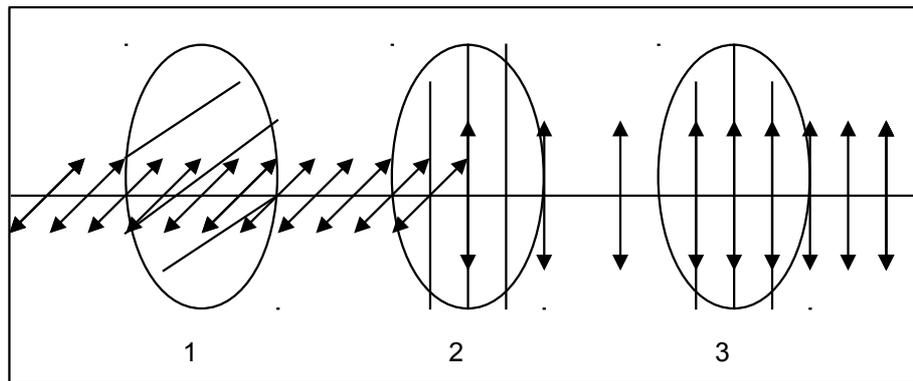


FIGURE B.22: A photon passes through polariser 1 with a 100% chance of crossing at a 45° angle to the vertical. On the other hand, it only crosses polariser 2 with a 50% chance, whose frame makes an angle of 90° with the vertical. It crosses with 100% chance a third polariser parallel to the second one.

Florian doesn't seem to like this explanation: "But what did Einstein think of this so-called indeterminacy?"

- That's the point! He didn't accept it! He claimed that the photon had a given polarisation but that we had not yet found a method to calculate it. He argued that we needed to discover the "hidden variables" that we were not yet able to control and that explained why it seemed to us that the photon remained undetermined."

- I see. The exact same thing happens when you get different results when you are convinced you are repeating exactly the same experiment. This happens when an important parameter has escaped us. I call the phenomenon "the hidden variable at the bottom of the tube" when I try to understand why an experiment is not reproducible. I have just solved a problem of this type! I could do the same manipulations with a strain of bacteria, but they didn't give me the same results every time. Yet it seemed to me that I hadn't changed anything from one time to the next! I finally discovered that the "variable hidden at the bottom of the tube" was the chemical composition of the environment in which the bacteria had reproduced before being stored in the refrigerator to be used as seed for the various manipulations."

- That's it! Einstein was convinced that there were hidden variables to discover, while Bohr argued the opposite. And Bell's theorem has given us the theoretical means to separate them

by imagining an experiment that would necessarily prove one wrong and the other right. Let's see how.

"The theorem is based on the experiment proposed by Einstein, Podolsky and Rosen in 1935, which involves two correlated particles. Imagine an atom being doped so that it emits two entangled photons..."

- Wait a minute! What do you mean by "two entangled photons"?

- This means that their attributes are linked since they both come from an event that obeys the law of energy conservation. If one moves to your left, the other will have to travel to your right to maintain the balance of the emitting atom. They are correlated, entangled in the same story! Remember! It is thanks to this entanglement that Einstein, Podolsky and Rosen were convinced that Bohr was wrong to believe in indeterminacy before any action!"

- Yes, I remember their argument... and Florian's concern about a possible demonstration that would support Bohr's point of view?" I look at Florian, amused, but he doesn't seem to be having any fun at all!

Axel speaks again and illustrates his point on the board.

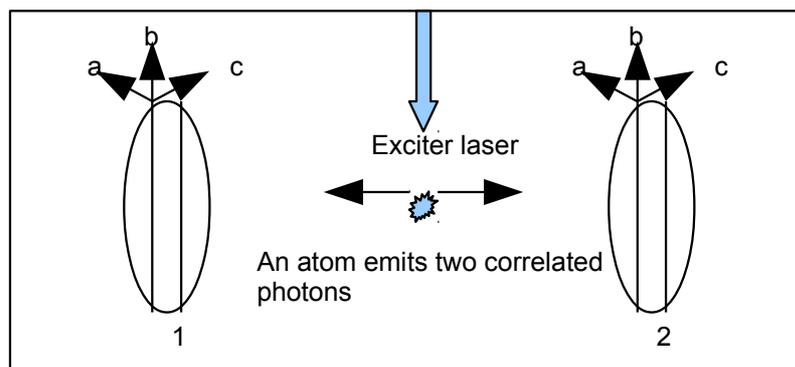


FIGURE B.23: A laser excites an atom and the energy is converted into two correlated photons that flow from either side to two polarisers capable of rotating very quickly between the positions -  $30^\circ$ ,  $0^\circ$  and  $+30^\circ$  (positions a, b and c).

"Imagine that an atom is excited so that it returns to its normal energy level by emitting two correlated photons. Suppose that the experiment allows to measure their polarisation angle. Each of the two polarisers can quickly take one of the three positions I have drawn. Since photons are correlated they will always pass through both polarisers provided they point in the direction of their frame, even if they take their final position after the photons have left the nucleus of the atom that created them. Einstein uses this correlation to infer that each photon has an intrinsic reality, that it exists in a given state before the measurement. And you remember Bohr's answer, who does not believe in this determination but considers the whole experimental material as making only one measurement on the two photons at a time, as if there were no longer any space between them, or as if the effect of the measurement on the photons were non-local, beyond the space as we measure it and therefore instantaneous!"

- Yes, that's what Einstein found impossible to believe and that's my opinion too." Florian almost seems to be making a profession of faith, as if he was afraid Einstein would be wrong!"

- And that's what Bell was hoping for too, and that's why he proposed his theorem. He is convinced, like Einstein, that it is not the fact of interacting with a photon by measuring it that triggers its materialisation in a way..."

- What do you mean?"

- Yes. Bohr may say that we should not try to visualise what is happening in the microcosm, but it is very difficult for us to follow him and ignore that the measurement seems to force the particle to choose among the different possible states. It is as if it exists in an unreal world in which it has no defined value for some of its characteristics such as its position or angle of vibration and that measuring it forces it to become real and concrete, with its attributes.

"Bell, like Einstein, believes that the world exists even if no one interacts with it! In particular, he assumes that correlated photons are well determined but quantum theory does not (yet?) allow us to calculate their attributes without involving the calculation of probabilities."

Axel takes a chalk and draws:" Let's examine all the possible scenarios with the experimental set-up here and see where it leads us.

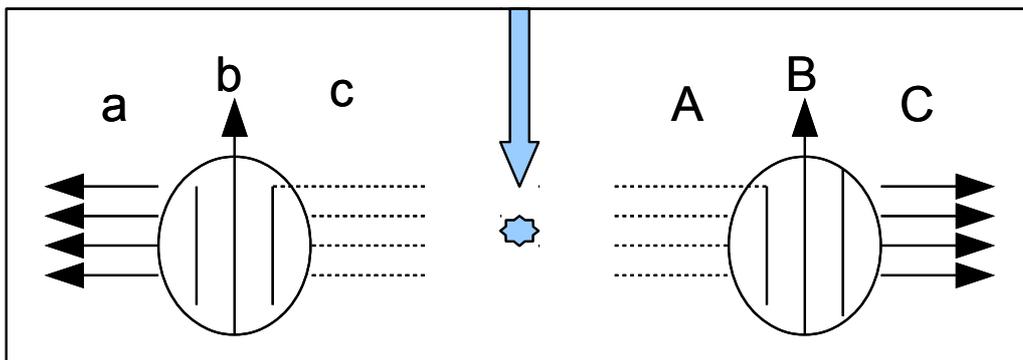


FIGURE B.24: *Four pairs of correlated photons pass through the two polarisers. We can deduce that they are all polarised according to the vertical*

"Let's point the polarisers vertically and measure 4 pairs of correlated photons. They all pass, so we see that they are vertically polarised. So far, no surprise."

Florian stops him: "Wait! You said that photons should be correlated so that the sum of their state is equal to 0 since they are created de novo by an atom! If one is polarised upwards, the other should be polarised downwards!"

- That's right and we're checking it out. Here the polarisers are facing each other and the photons are moving away from each other in perfectly opposite directions. Suppose that the polariser on the left makes a  $45^\circ$  angle clockwise and that the polariser on the right makes the same angle with the vertical but in the counter-clockwise direction. If the photon on the left

sees the polariser to which it is heading make a  $45^\circ$  angle clockwise, the correlated photon will see that the polariser to which it is heading makes a  $45^\circ$  angle counter-clockwise. If they both pass, it's because they are correlated."

- All right."

- Now imagine that polariser "1" points to "a" while "2" remains vertical. On the right they will all cross but on the left we expect only 3 out of 4 to pass since  $(\cos 30^\circ)^2 = \frac{3}{4}$ . There remains one photon out of the 4 that does not pass to the left while its twin has passed to the right. Axel erases the table to redraw the new assembly.

I ask him: "And why  $(\cos 30^\circ)^2$ ?"

- Remind the circle I drew you before Florian arrived. Then remember the superposition of states of the photon: before crossing it is in an undetermined state that includes all possible states between 0 and 1 with probabilities that depend here on the cosine of the angle that OC makes with the vertical. The probability that the photon will pass through depends on the OA/OC ratio, i.e. the cosine of  $30^\circ$ . Then applies the same reasoning as before to predict that it will cross the polariser which makes an angle of  $30^\circ$  with the vertical with a probability equal to  $(\cos 30^\circ)^2$ ". Then Axel comments on his new scheme:

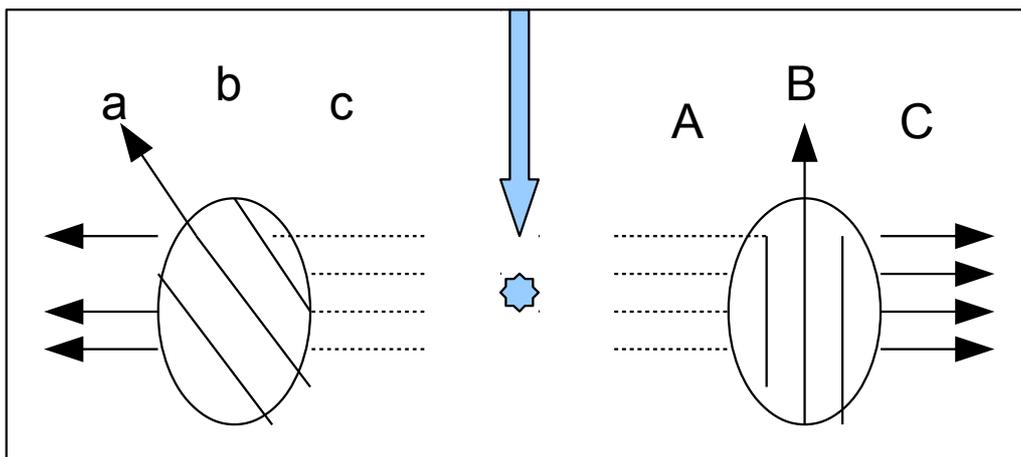


FIGURE B.25: *The polarisers are no longer parallel. The one on the left makes an angle of  $30^\circ$  to the left ( $-30^\circ$ ). A vertically polarised photon will no longer pass every time but with a probability of  $(\cos 30^\circ)^2 = \frac{3}{4}$ . If a large number of correlated photon pairs are measured and all cross the right polariser, only the  $\frac{3}{4}$  of them will cross the left one.*

"Let's formalise this result as follows:" Axel writes:

$$N(-30,0) = 1$$

He explains: "This means that the number of disagreements between the measurements made on the two polarisers is statistically equal to 1 when the first forms an angle of  $-30^\circ$  with the vertical and the second points to the vertical.

- That's clear."

- Similarly we would have  $N(0,30) = 1$  in the symmetrical case."

- I agree."

- Where it gets interesting is when the polariser "1" points to "a" and the "2" points to "C". That is when we will have the most disagreement between our measures. We have postulated that our photons really exist before the measurement with their well-defined physical attributes. And experience has shown us that they are vertically polarised.

"Classical physics predicts that 3 out of 4 will go left and 3 out of 4 will go right.

"If I analyse all the possible cases of correlation, I must conclude that the one that does not pass to the left can be correlated with the one that does not pass to the right, like this:

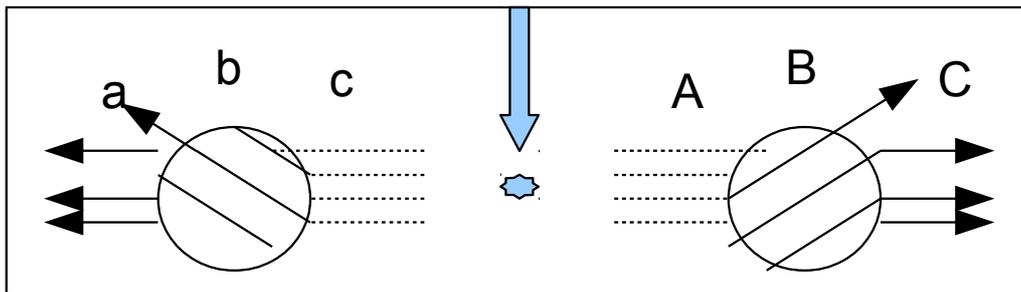


FIGURE B.26 : *The two photons that do not cross are part of the same pair of correlated photons.*

"And in this case I will not have any disagreement between my left and right measurements: either  $N(-30,30) = 0$ . But I can also have the other scenario with different pairs of photons crossing one of these polarisers and not the other, like this:

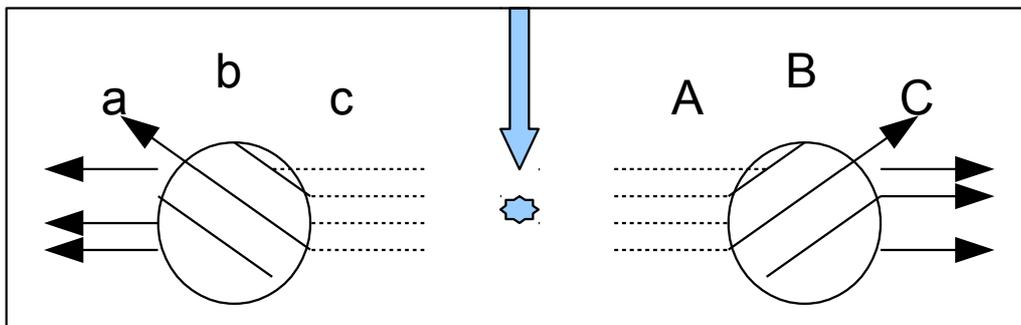


FIGURE B.27 : *The two photons that do not cross are part of different pairs.*

"Here I will have two disagreements between my measurements and statistically I can't have more than 2 out of 4 pairs of photons measured. Indeed, on the left and on the right I expect the  $\frac{3}{4}$  of correlated photons to pass. Moreover, it can only be photons of the same pair or photons of different pairs that pass through. I then write  $N(-30,30) \leq 2/4$  : on four pairs of correlated photons the number of events that will not be symmetrical will be at most 2.

"And here is the very simple formulation of Bell's theorem:

$$N(-30,30) \leq N(-30,0) + N(0,30) ;$$

with  $N(-30,0) + N(0,30)$  between 0 and  $2/4$ , i.e.  $1/2$  in the specific case we analysed. Nothing could be more logical, would it?"

- Yes." Axel reminds me of my elementary algebra classes.

- But be careful! All this reasoning is only valid if the measurement made on one detector has no influence on the determination of the physical state of the photon passing through the other detector. This should be the case if each photon had a concrete attribute before the measurement.

"We should have  $N(-30,0) + N(0,30) = 2(\sin 30^\circ)^2 = 1/2$  since the probability that a photon does not pass is equal to  $(\sin 30^\circ)^2$ .

"But if Bohr is right, we can't analyse separately what happens on each polariser: rather, we must consider the entire experimental set-up as linked to make a single measurement in two parts and not two measurements."

I try to intervene before I lose the thread of reasoning: "I don't see why Bohr considers that the whole experimental set-up is part of a single bar instead of two!"

- Yes: Remember! Quantum mechanics makes it possible to calculate the probabilities of the result of a measurement by finding the solutions of an equation that involves all the devices and objects measured. It is as if we can say nothing about the state of a particle that is not measured and that the only thing we can do is to calculate, with very high accuracy, the probabilities of the different characteristics it could take according to its interaction with our devices. In the case of two correlated particles, the quantum model considers them as a single object as long as none of them has interacted with the measuring instrument. They acquire their precise characteristics - one of those provided by quantum mechanics - only at the moment of measurement, instantly, even if they are very far from each other!"

I think I understand what Axel means. By understanding, I mean his spoken language, of course, and not the ghostly world he seems to describe! He continues: "In this case we can no longer consider each polariser separately and say that it makes an angle of more or less  $30^\circ$  with the vertical, but we must admit that the correlated photons have a probability of crossing each polariser according to the angle they make between them, i. e.  $60^\circ$ ! And then the probability that they will pass through the detectors becomes  $(\sin 60^\circ)^2$  or  $3/4$ .

"In summary, we have two different results to the right of our formula, depending on whether we are with Einstein or Bohr. If Einstein is right, we should check Bell's inequality with  $N(-30,30) \leq 1/2$ . But if Bohr is right, then this inequality should be violated since  $N(-30,30)$  should be smaller or equal to  $3/4$  which is larger than  $1/2$  !

"This is Bell's trick, and he hopes that as soon as the experiment becomes technically feasible, it can be demonstrated that Bohr is wrong to imagine the microcosm as undetermined until we interact with it and that Einstein is right to continue to think that the microcosm has real physical attributes in the absence of any intervention.

"And the experiment became technically feasible in a satisfactory way almost two decades after the publication of his article. And I suggest you reproduce it now!"

## B.11: THE INFLUENCE OF GENEVA BANKS ON QUANTUM PHYSICS

Axel is heading towards the stairs and precedes us to the mezzanine. A long central corridor separates offices that alternate with more spacious workshops. He's getting us into one of them.

"It was in 1982 that a French colleague succeeded in the crucial experiment that had been hoped for since the publication of Bell's theorem. It poses formidable technical problems, or more precisely, it was the case for Alain Aspect, the physicist in question. Today we are lucky to have unimaginable equipment when he built, piece by piece, the equipment he needed. It filled an entire workshop like this one, whereas now a Geneva company is able to market it in the form of the box that is here!"<sup>1</sup>

Axel presents us with a kind of brushed metal shoe box with cables, some of which lead to electronic devices, including the essential computer.

Florian seems surprised: "Marketing what? Everything you tell us is so far from our daily concerns! Who would buy a device to measure correlations between ghostly entangled photons?!"

- Well, you're wrong! Geneva seems to be on the way to becoming an important industrial place in a brand new field, that of quantum cryptography!"

- Tell me about it!"

- Yes, colleagues here have been working for a few years thanks to funds found in the banking and telecommunications sectors. They managed to convince them that they were very close to solving a problem that both of them were struggling with: the secure transmission of sensitive data. They have developed an inviolable technique that allows information to be transported from one place to another without being intercepted en route."

- Pirates have always been able to thwart all the tricks!"

- But this one will remain inviolable precisely because it involves quantum indeterminacy. The basic idea is to use correlated particles to transmit information. As soon as one of them is measured, the other acquires its attribute from an undetermined state. If a hacker tried to get to know the data being transmitted, his intervention would cause the attributes of the correlated particles to be determined and this would be detected immediately!"

Florian seems surprised: "And you managed to convince bankers: now you amaze me! You should have started there: so this is a serious thing you do!"

Axel smiles as he opens the mysterious box on the edge of a large metal table that holds all the experimental equipment. It looks like a prototype because we still recognise transformers, optical cables connecting black objects screwed onto a pre-drilled mounting plate and a string of electrical cables that should be replaced by a printed circuit board or even a chip in the final device. Axel seems very proud of his company: "The researchers of the quantum optics group at our School of Physics are very strong in both theoretical and practical fields. They have achieved a feat! They designed and built a correlated photon source that was practical, robust and reliable enough to be commercialised! Here is how the device works." Axel leaves the assembly table to make a diagram on the board.

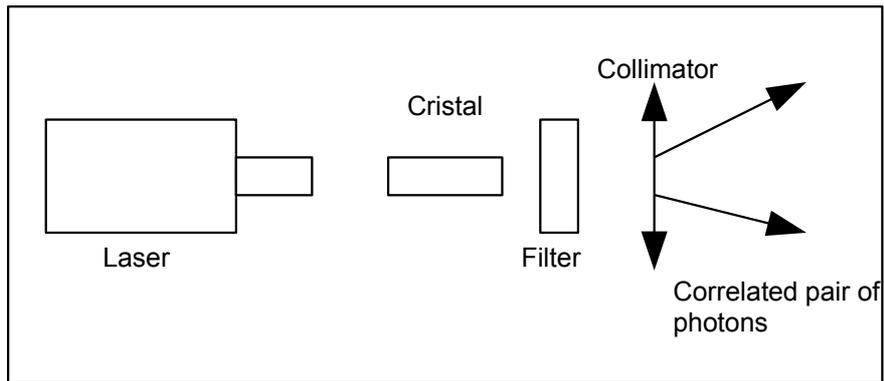


FIGURE B.28: *Schematic diagram of a barrel that shoots correlated photon pairs.*

"A laser sends a strong light on a crystal whose atoms absorb energy. They return to their normal state by emitting two correlated photons that are conducted through a filter, a collimator and then light guides to these two plugs. From there, they can be made to travel several kilometres through optical fibres, while keeping them correlated until they interact with a measuring device. But today we're going to settle for a few dozen metres, that's enough."

Florian gets up, erases the board and draws the following diagram while explaining: (Figure B.29)

"Let me ask a question to make sure I understood correctly. A source will emit pairs of correlated photons in opposite directions. You will guide them to polarisers that can each point in one or the other of three different directions, a, b, c on one side and a\* b\* and c\* on the other side. b and b\* are on the vertical, a and a\* or c and c\* make an angle of 30° on either side of b or b\*."

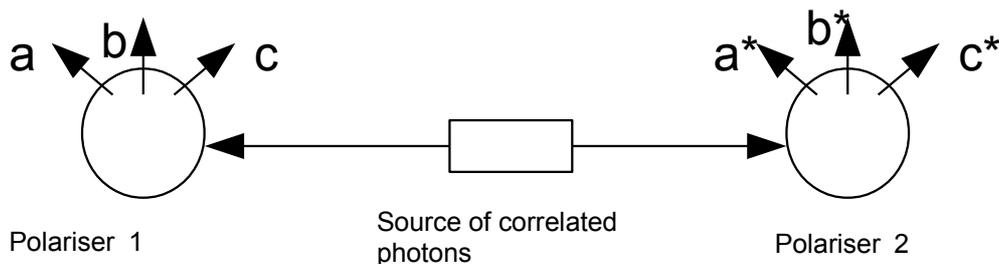


FIGURE B.29 : *Diagram of Axel's experience as seen by Florian*

- No! The calculation shows that the angles that allow Bohr and Einstein to be separated in the best conditions are slightly different: the device is set at 67°5".

- It doesn't matter. But if I try to satisfy Einstein's requirements, I would have to be able to change the angles of my two polarisers at random and AFTER the photons have left the source... during their journey to the targets in a way!"

I intervene: "Why this requirement?"

Axel answers: "Florian is right! Einstein relies essentially on two pillars to build his argument. He reminds us that no information can travel faster than light: this is his first pillar. He then argues that the two photons must have a concrete reality: each with their own attributes BEFORE they are measured but quantum mechanics cannot yet calculate because there are hidden variables that it must still discover and exploit to finally understand what is happening in the microcosm.

"For the results of the experiment to be useful, the measuring instrument must be defined after the photons have separated sufficiently so that the measurement made on one of them cannot have any influence on the attributes of the other. And for this reason they must be far enough apart when choosing the angle of the polarisers so that any information related to a hidden variable does not have time to go from one polariser to another. It is therefore necessary that at the time of emission of the photons the angle between the two polarisers is not yet defined and that the distance between them is sufficient so that the light does not have time to travel before the second photon is measured."

- It seems impossible to me to do! How do you want to manipulate these angles fast enough when photons travel at 300,000 km/s?"

- And yet we did it! Here's how it works! Axel completes Florian's diagram on the board. (Figure B.30)

"Colleagues have invented a switch so fast that no information on the state of one of them can go fast enough to influence a particle that passes through the other as soon as they are a few meters apart! They change state every 10 nanoseconds - that is, every 10 billionths of a second - while light takes 40 nanoseconds to travel the distance between them here!"

- And how is that possible?"

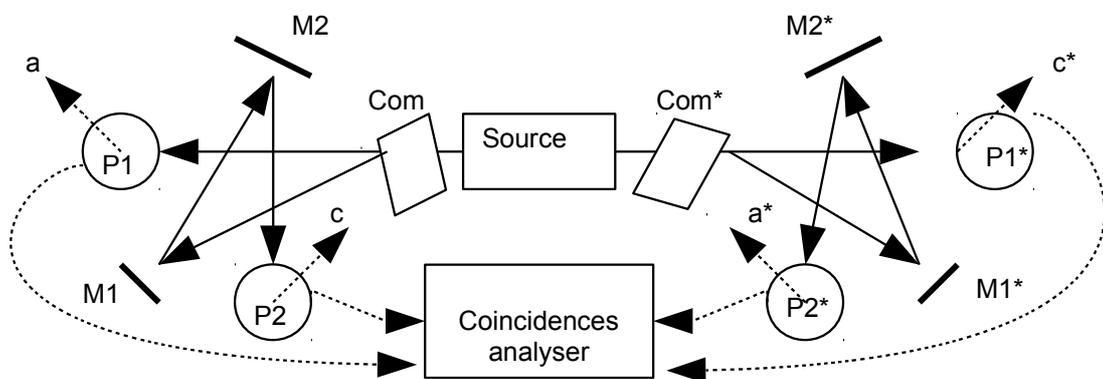


FIGURE B.30 : *Diagram of Axel's experience according to the 1982 Aspect experiment.*

*P1, P2, P1\* and P2\* are polarisers turned according to angles a, c, a\* or c\*.*

*M1, M2, M1\* and M2\* are mirrors that reflect the photons deflected by the Com or Com\* switches to the P2 or P2\* polarisers.*

*A coincidence analyser is used to detect correlated photon pairs.*

- These are optical switches. Imagine a cylinder filled with liquid and with piezoelectric crystals on both opposite sides. Piezoelectricity is a remarkable property that is used in our quartz watches. The crystal vibrates in unison when an electric field is applied to it. We just need to control each of our two crystals with an electric field that pulses and varies at very high frequency to create a kind of ultrasound between them that will form a standing wave. It will go through peaks and valleys about 50 million times per second, like this." Axel draws the switch on the board. (Figure B.31)

"At the point where the photons pass through the switch there will be an alternation of peaks and troughs of liquid density. However, light is refracted according to the density of the medium it travels through and as it changes 50 million times per second, we will have a switch that will either let the photon pass straight through to the first polariser or refract it to the second, after being redirected by mirrors M1 and M2."

- Florian smiles: "You may be crazy but you're still great! It's a great switch!"

- I'll take that as a compliment: thank you!

"So I installed the switches, 4 polarisers and a coincidence analyser that will allow us to calculate photon correlations based on the angles that the polarisers will make between them. The system has been carefully calibrated and tested with or without each polariser and the results confirmed to me that the system is working as expected.

"Unfortunately, the figures we are going to find are very abstract: the statistical analysis that we are obliged to do to take into account the low efficiency of the device is not very common either. So I imagined presenting the results to you in a vivid way... here's how!"

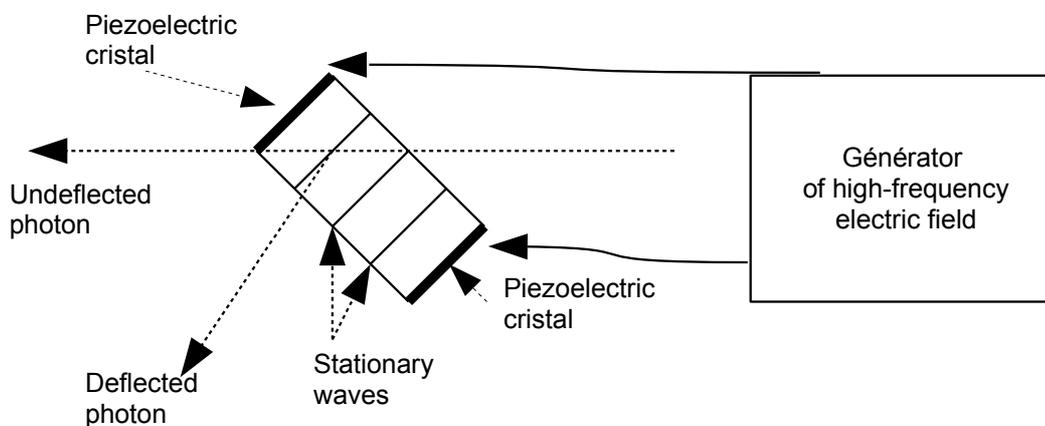


FIGURE B.31 *Switch. An electric field generator provides 25 MHz signals on two piezoelectric crystals that vibrate opposite each other. The waves form a system that passes through a trough and then a hump 50 million times per second and refracts the photon at the same frequency.*

Axel turns on the computer monitor. Two black and white pictures appear. But it is difficult to understand who they represent because their quality is so poor! (Figure B.32)

He explains: "That's it! I have started the experiment itself and we will have to wait about an hour to see the results on this monitor. I wrote a little program that introduced noise on two

portraits, one of Bohr and the other of Einstein. My program will now analyse the results of the correlation measurements. Whenever they are in favour of one of the two protagonists, their portrait will become clearer, and vice versa."

- What do you mean?"

- Yes, when the chance of switching causes polarisers 1 and 2\* or 1\* or 1\* and 2\* to receive the correlated photons, I expect to find that the photons cross them simultaneously obeying a value that classical physics requires me to place between -1 and 0 while quantum mechanics places it above 0 to 0.112. Whenever the measured correlations give us a value significantly lower than 0, my program will introduce additional noise into Bohr's portrait and remove an equivalent amount of noise in Einstein's portrait, and vice versa, of course. This will give us a more concrete picture of the results than a simple table of abstract figures!"

- I see!"

Axel takes a last look at his devices and then leads us to the laboratory door: "Let's have lunch while waiting for the end of the experiment cycle! I invite you to Florian's, in the cafeteria of Sciences II."



FIGURE 32: *The image displayed at the beginning of Axel's experiment to decide between Bohr and Einstein. The computer calculates the results obtained by the coincidence analyser and applies Bell's theorem. Each time it is violated according to Bohr's prediction, its portrait becomes clearer and that of Einstein more blurry, and vice versa when the results are in agreement with Einstein's predictions.*

## B.12: CLASSICAL VERSUS QUANTUM

There are almost no more free tables! The students have just left the amphitheatres and, while a long line is getting impatient in front of the buffet, some are spreading sweaters and jackets over several chairs to reserve a place for their friends. We do the same: Axel and

Florian entrust me with their sweaters, which I ostensibly place on two chairs while occupying a third.

The atmosphere is much more stimulating than that of physicists! We are only 100 meters from the School of Physics and the contrasts of colour, light and noise are all the more obvious! A few teachers or assistants, here and there, temper the exuberance of the younger generation, but the climate remains very lively!

Axel and Florian return with their orange-brown platter garnished with plates in which green dominates: lettuce, watercress form a large cradle where tomatoes and cucumbers are discovered, accompanied by cheeses and strips of dried meat. Soft drinks complete the package.

Axel starts his lunch and asks us: "Since we have to wait, why don't we consider the impact of each of the possible outcomes on the knowledge we can draw from the microcosm?"

Florian notes, "Because you're sure you'll get a unique result?"

- To tell you the truth... Yes, the experiment, although technically critical to be carried out, has already given very clear results! And this is not the first time I've reproduced it! It is almost perfect and convinces a large part of the physicists."

- Why "almost perfect"? What is it that he needs to convince everyone?" Florian worries.

- Never has an experiment, or even an observation, managed to convince everyone! Fortunately perhaps! We would not progress any further if there were not that doubt, that critical spirit or that even slight dissatisfaction that leads us to constantly improve the conditions under which we obtain new knowledge. But there are still two characteristics that some would like to improve in future experiences... perhaps to reassure themselves and postpone the time of the assessment...?

"The first is the efficiency of the switches. Their efficiency is low! It is only when the standing wave reaches a peak, a trough or is just in between that, that the photons pass through without being deflected to hit the polariser "1" or are refracted to the polariser "2". The majority of photons are lost without being detected by either one."

- In this case we know nothing about the characteristics of the lost photons!"

- That's right! But no one really believes that they can be specifically different from those who were captured!"

- That's a reasonable thought," Florian admits.

- The other criticism is when the switches change state. Ideally, they should switch perfectly at random. In our experiment they regularly switch every 10 nanoseconds since they are controlled by a standing wave. But Alain Aspect took care not to set the two switches with exactly the same frequency to avoid that they always switch in a coordinated way. He introduced a slight difference in the frequencies of standing waves to complicate the appearance of the switching and bring them a little closer to a situation that would be pure chance."

- It's not clear why the experiment would fail if they didn't switch at random!"

- That's right. But it would still be better to make an experiment more in line with the requirements of their theoretical designers."

- Let's be satisfied with this one already! "I said emphatically. But our two scientists don't notice the mocking tone.

- Yes, what could we say about the microcosm if Bell's ingenuity confirmed his preferences: the same as Einstein's?" Axel asks.

I let Axel and Florian debate and just take notes while having lunch.

- It would still be very strange, but I guess we would be reassured about the reality of the world when we don't see it". Florian lets a little giggling accent through!

- You mean Einstein and I would have proven that quantum mechanics is incomplete."

- Yes, it would have been shown that a photon has physical attributes of its own that cannot be influenced by a measurement made on the photon that is correlated to it. We expect this result since the two photons are separated in space in such a way that no part of the influence when measuring one of them can be exerted on the other: speed-limit of light obliges us!"

I can't help but intervene before I finish swallowing my bite: "But how can I imagine a reason that would push a photon to send a message to another photon, even if it correlates to the first one?"

Axel smiles: "Listen! Every day is enough with its pain! Let me already try to demonstrate that the concrete reality exists without us having to intervene on the particles! We'll see how and why the correlation between them involves a transfer of information between the two!"

- I would, but your assumptions seem very eccentric to me!"

- Less than the conclusions I would be forced to draw from results that are contrary to my predictions! Or rather to those of Einstein, Bell and many others!"

- If you say so!"

Axel continues: " And what if Bohr wins?"

Florian exclaims: "Don't you think it's a lost cause? Instead, let's try to understand how it is that measurements made on a particle seem to influence its attributes!"

- Oh no! We must remain objective and honestly analyse the two possible outcomes!"

- But that's impossible! This would mean that photons do not exist in practice until you have measured them and they react simultaneously during their measurement, even if they are distant and cannot communicate with each other! How else would you explain a correlation that would violate Bell's theorem?"

- I won't be as definitive as you are! There are other ways to explain a violation of Bell's theorem. But it's true that your interpretation holds water," Axel admits.

- It holds water in theory, but it is not possible because the concrete world is composed of particles: they cannot therefore not exist concretely with their own attributes! They obviously don't rely on your measuring devices to create the universe!"

- Wait a minute! You're going too fast and putting your convictions before experimental observations! That's not good science," Axel reproaches.

- You're right, but how can you imagine Bohr being right?!"

- We can always use hidden variables as Einstein suggested," Axel replies.

- To explain the correlation that violates Bell's theorem I agree. But how would you explain the instantaneous correlations if the photons are separated by such a large distance that they cannot communicate with each other when they are measured?"

- I wouldn't explain it! I would have to admit that where I see two particles, there is only one in reality. Either they are in a particular space-time, or..."

- Yes! Crazy hypotheses than any of them! You can see that Bohr can't be right!" Florian seems to be trying to reassure himself!

Axel doesn't answer: he sips his soda, looks absent, his gaze lost beyond the bay window. It overlooks the wharf along the Arve: the river is accompanied by a very small gallery forest that scars the neighbourhood with a welcome natural intrusion.

- Let's suppose we've gone through the whole thing and have our coffee while we wait for the results: I'll get them." I leave them alone and join the long line under the orange light that baths the buffet. I see Axel and Florian still talking, but it's no longer about physics when I see them again.

Very soon after drinking his coffee Axel gets up: "The results should be clear now! Let's go back and see if everything worked out fine."

The weather that has started to rain is pushing us to run to the Physics School. Is it rain or impatience that stimulates us? After breaking down the stairs to the mezzanine floor, Axel opens the door of the laboratory he had locked, takes a quick look inside, smiles and let us through.

In the middle of the laboratory, on the large metal table that supports all the devices, we only see the monitor! The results are clear! Bohr's picture illuminates the room: he doesn't look triumphant but confident! Einstein's is unrecognisable! A cluster of grey pixels. I am surprised, certainly, but not as surprised as Florian, who seems to be in awe. His gaze does not leave the monitor. He mumbles, "It's not possible! There must be a mistake somewhere!"

Axel hears it: "No, this is the result we have been seeing regularly for two decades! Understand who will, but it was Bohr who was right!"



FIGURE B.33: *The image displayed by the monitor at the end of the experiment to decide between Bohr and Einstein... It's the first one who was right!*

About Space...



*René Magritte may have sensed that space is much more mysterious than it appears to us. His blue bird brings together in the same place what seems distant in time and space, while quantum physics suggests that the multiple may only be a primitive way of perceiving the Unique.*

BOOK THREE: Exploration

*On Mind...*

## C.1 : PHYSICS AND POWER

"And how have you managed to hide all these discoveries so far? I am surprised not to have noticed earlier the tidal wave that physicists are spreading across the borders, hitherto serene, of knowledge about the physical universe.

- What do you mean, hide? We never hid anything, come on! We publish all our results like scientists in any discipline: science forces us to submit them to the critical reflection of our peers! Moreover, the results are only accepted after they have been reproduced by anyone who has the material and intellectual means to reproduce them!"

Axel blushed. I think I touched him on a sensitive point. It is true that physicists publish their results. But they suspect that they are unreadable outside their brotherhood. Axel has always been concerned about this state of affairs and often goes to great lengths to explain to anyone who wants to hear him, what he does and the interest he has in it. That's how I even met him. Already a student, he had been rewarded somewhere in France after an exhibition set up to present particle physics to young people. This success confirmed his taste for communication: he then sought to meet other students who were sensitive to sharing their passion with neophytes. It is also true that his approach today shows that he wants to spread his knowledge!

But we must admit that not all physicists are like him in this communicative aspect! It is true that they certainly do not form a mafia of silence insofar as they would have concertedly concealed the philosophical importance of their discoveries. But they know very well how to unite and persuade politicians to give them the necessary credits to build their titanic devices. They are too honest to make them believe clearly that their research may lead to new applications, but they do not have much difficulty in obtaining satisfaction since the success of nuclear physics.

Nevertheless, I remember having already had the feeling of a tacit and discreet agreement between physicists of different nationalities. A few years ago, I was invited by Axel, whom I had lost sight of for some time. At the table, I was the only stranger to physics and for a while, the three physicists forgot me and gave each other news about the situation in their respective countries. I was not listening carefully to what they had to say and did not clearly remember what they were about. But I had gotten a confused impression from it. I understood that they were convinced they knew important things and wondered to what extent they should disclose them to political and economic authorities. They clearly gave me the impression that they were in power. But the real power! The one which doesn't need to show up to run for the voters' interest! The one which works behind the scenes, which advises and pilots those who go to the fire! Knowledge of the foundations of reality, of particle physics, seemed to give them an assurance, almost an arrogance, that led them to exercise the necessary power to give themselves the conditions for a comfortable life almost entirely devoted to their research. They worked for themselves and made sure that others provided them with what they needed for the Great Work. Their scale of values was clearly based on their passion: they knew how to give themselves the necessary means to satisfy it. Since they seemed to believe that politicians or other economists would never understand what they were doing, they did not bother to popularise what was not directly necessary to obtain new credits.

This behaviour could go far enough! One of the physicists present that day was particularly imbued with himself. He had been a Nobel Prize winner for two years, but I don't think that changed anything in his attitude. I am convinced that he has always expressed an unfailing self-centredness! I had already met him because his wife, Maria, was a colleague of Florian's. He had married one of his students who was younger than his eldest son. He had made her an erased old lady while remaining infantile in some ways. Fresh, lively, passionate about physics, she had become transparent and grey: her back had arched under her undefinable coloured bun, between blond and white. She had put herself in the shadow of her husband's personality, who suffered no concessions. He had given her children, but only if he did not have to take care of them: he had kept his word! I spare you the teenage crises of her children, which poor Maria had to deal with on her own.

I had sometimes talked to him about the work I was doing with some of my students. For them, the aim was to learn about science journalism by meeting researchers involved in an environment-related project. The young people had to approach the experts, persuade them to sacrifice a little of their time, ask them all kinds of questions and then be able to write an article for their peers all over Europe. Maria's husband suddenly cooled me down by telling me that all this was useless! He made it clear to me that he would waste his precious time if he stooped to popularise anything! If those who ask for information were really interested in the answers, he made me understand, then they would have done scientific studies! Having chosen to spend their time doing something else, they had to let the scientists do their work without being disturbed!

This attitude had deeply offended my opinions as a teacher who likes to share his interests. I could not help but point out to him that he was continuing his work thanks to the money of those he was sending back to the pawns! He looked at me condescendingly, without bothering to answer.

I have found this disdain sometimes in the work of physicists. They agreed to describe some aspects of their work but made it clear that it was out of the question for a stranger to the Queen of Science to try to interpret these results in order to seek applications in fields such as philosophy, religion or the paranormal. And this attitude is old and is expressed with more or less nobility according to the authors. Bohr quotes Goethe: *"Tell no one except the wise, for the crowd knows only mockery!"* It is a matter of hiding what can be so poorly understood that it must be protected from the *"gossip and mockery of the multitude"*! But isn't this position outrageously proud?

Heisenberg, Bohr's student, co-founder of quantum mechanics and Nobel Prize winner like his master, castigated the timid positivists who: *"make the mistake of wanting to ignore the great general context, of consciously wanting to keep this context in the fog [...] who encourage no one to think about this context"*. He writes later: *"I have the impression that the younger generation[...] is only interested in details, as if the great correlations were almost subject to a kind of taboo. It seems that we should not talk about these correlations"*<sup>1</sup>. And there is still very little effort by physicists who are publicly interested in both the *"great correlations"* and the *"general context"*.

This lack of interest is not just passive! I have attended lectures or symposiums at CERN where I have seen a group of physicists spontaneously set up to censor interpretations that philanthropists - journalists, for example - could deduce from the work and reflections presented in public sessions! At the time I did not interpret this reflex as I do today. What I thought then was an aid to understanding, now seems to me to be an inquisitor's approach! All

things considered, I have the unpleasant impression that I am rediscovering the Church's approach at the dawn of the Renaissance! She feared that Gutenberg's invention would be used to acquire knowledge that she considered dangerous because it was difficult to interpret "as it should be". Today physicists are jealous of their own and rush to check the orthodoxy of any elaborate attempt at popularisation. They agree to analyse certain interpretations among themselves, lest they be "falsely understood" by the layman.

But the Church has not been able to share its positions in a serene spirit of seeking the truth. She erected herself as the guardian of the "only way" until she burned the heretics who were exploring another way! Let us beware today of apparent good intentions that could hide pride combined with a taste for power!

Of course, a serious mathematical background is essential to get rid of representations from our lived experience and seek correlations based solely on logic. We know today that an atom is not a microscopic solar system in which the star is the nucleus and the planets the electrons! It is well known that this is only an image - slaves of our mental representations - and that only mathematics can describe the behaviour of the particles that experimental physics studies. But these mathematics should not be used as a pillow of philosophical laziness, as a screen that would hide correlations with other fields! There is an increasingly indecent gap between the concrete successes of quantum physics - transistors, lasers, electron microscopes, medical imaging and so many other wonders that we encounter every day - and the poverty of ontological progress - which is the nature of reality - that theory presents to us! I have a better understanding of Axel's discomfort that I have felt many times when he was looking for answers to my questions.

## C.2: UNDERSTANDING AND INSTINCT

Legs... heavy... heavy! But with a clear head and a light heart! This is the result of a long and beautiful day of cross-country ski touring in the mountains of Morgins in the Valais' Alps. Axel mocks me for trying to erase even the memory of a huge dog poop in which I printed my left shoe. But even if the tap is fully opened... it sticks and remains embedded in the sculptures of the base.

"You should take this opportunity to exploit the new knowledge Florian has given us today!" laughs Axel.

Our molecular biologist lost none of his childhood as a naturalist in shorts and introduced us to the subtle science of animal excreta during the best part of the afternoon. What the mother instinctively does when she carefully analyses her baby's diapers to get information about her state of health, the biologist has pushed it to create a new branch of the natural sciences: "comparative analytical poopology"!

It all started when, following the trail of a hare well printed in yesterday's snow - two small slightly offset holes for the front legs, followed by a Y-shaped print for the back legs - we crossed that of a fox: a series of foot holes well aligned in front of each other. And it had relieved itself... of a black dropping, not very big, composite and irregular. Florian examined it carefully, his eye wide open and his eyebrow frowned. With a twig, he teared it up and exclaimed intermittently each time he could define the remains of the animal's meal. Fruit waste clearly recognisable - for the eye of the expert of course - some feathers.... Axel and I

felt that Florian would have wanted to bring it back home for further study. But he didn't go so far as to put it in his pocket by surrounding it with a simple paper handkerchief as I've already seen him do... when he didn't know he was being observed!

The rest of the afternoon provided us with all kinds of information on the precious animal tracks. Florian confessed to us that, even as a child, he had already managed to persuade his parents not to throw away his droppings collection! There were two-coloured bird droppings, shiny hare petolas, duller chamois smoke, wild boar poo, deer dirt, fox droppings, very strawy horse dung, earthworm drops, balls from owls full of treasures such as mouse jaws or hair... and even cow dung! All this well labelled and commented according to the result of the analysis. Humans evolved from tree monkeys, by nature disinterested in their excreta that were quickly thrown to the ground. It takes all the help of science for us to find an interest in this waste, a curiosity that is more widespread among animals that discover the world, with truffles on the ground, looking for all the interesting information that these traces can contain!

"If you had followed Florian's analyses correctly, you should be able to determine the brand of the boxes of food the dog tasted," Axel continues with a laugh. I'm not sure I really appreciate it! But I admit that science can expand the field of humour by opening up new horizons... sometimes unexpected.

With the shoe finally clean, I try to forget the incident by changing the subject: "Axel, you promised to present us with the physical interpretations of the completely unexpected results that concern the world of particles. If I understood correctly, the Copenhagen School is giving up and deciding that we cannot understand this world that is completely foreign to us.

Indeed, Axel invited Florian and I to his chalet to explain some models devised by physicists to try to understand the surprising results of microphysics. He becomes serious again and suddenly answers: "No! Not at all! Rather, there is another way of understanding the world of particles, which is not the way we use to understand the macrocosm.

- How? You mean there are different ways to understand? It seems to me that we understood or not! "

- I'm not sure about that.... We both teach; how do we know if our message has been understood and not just learned?"

- "To the relevance of the questions asked!"

- But if there is no question, is it because the teaching was perfect or, on the contrary, so obscure that it represents nothing for the listener? What could the true understanding of a phenomenon really mean?"

- It must be a profound appropriation of information and not just a superficial learning."

- And how can we appropriate something new?"

- From my experience as a teacher, it seems to me that we must go through an association between the new and a pre-established mental representation. I see my job as an individualised search for images, metaphors that would speak to my interlocutor, which would allow him to create a significant association between what he has already understood, if possible by living it concretely, and the new notion that I would like to transmit."

- You talk as if you only work with one student at a time!"

- That would be ideal, of course! But no, we can work with a whole group and, often, when it comes to answering a question asked by one of its members, I ask the rest of the group to

find an appropriate explanation: precisely to promote an association with an image that is part of their world that is no longer entirely mine: difference in age and experience makes it necessary!"

- Your system only works well if you can use a kind of bank of mental representations, images, concepts, perhaps emotions... But how would it be built? Florian, what do you think?"

Florian has been silent so far. He slowly cooks a soup in the kitchenette of the living space where we have settled. He turns to Axel:" Biology does not yet have much to contribute in this field, although neurophysiology has evolved rapidly since physicists applied their discoveries and created machines that illustrate the brain at work.

- You're thinking about medical imaging devices... ? These are indeed applications of quantum physics that would not have been possible without the concepts of Bohr and his colleagues, however strange they may seem to us today, almost a century after their discovery! At the time they applied only to microphysics but they have emerged from it and are overflowing to invade almost all of our daily environment with all kinds of devices that we know how to create and implement without really being able to associate their mode of functioning with that of the world we live in: the macrocosm."

- I admit that I haven't looked at their insides so far... but only at the results they give... and it's fascinating! We can determine which regions of the brain are most active when they perceive an image, a taste, or when the subject makes a movement or even when they think about an object. If s/he talks or listens, other parts of the brain are illuminated on the machine's screen. Even if s/he does mental arithmetic or thinks about emotions, we can describe certain processes of brain activity that seem to be reproducible. But we are still a long way from attributing a signature to the understanding of a phenomenon with our brain activity exploration machines!"

Axel arranges a red tablecloth on the pine table and then places the cutlery while explaining: "We could have expected it! But let's get back to my question earlier. How can the brain understand anything? I suppose it should involve associations between the perceptions we seek to exploit and those that have been stored in memory at the same time as the events that took place shortly before and immediately after them. New information that comes to us from the environment could be "meaningful", that is, it could evoke something known by association with previous events that have been considered important enough by their effects to be stored and used as a subsequent reference to experience a given situation."

Florian says, "It's interesting what you're proposing! But I think there is a simpler way: a kind of instinctive understanding. Biologists studying animal behaviour have shown that there are associations between genetically inherited innate perceptions and structures that could be interpreted as a kind of very crude understanding, but essential for species to effectively exploit their environment."

- You mean animals understand their environment? I am surprised at the meaning that the word "understanding" is beginning to take on. "I would have thought, a priori, that understanding is necessarily linked to a well-developed intelligence that a slug, for example, does not have!"

- But of course it has it," Florian replies as he comes to serve us at the table. "I'd even say a robot can understand! We must not engage in anthropomorphism, evaluate the world according to the yardstick of our identity, which is very cerebral, to the point of promoting abstraction, the virtual... "

- Aren't you comparing us to slugs? They don't even have brains! Just groups of neurones that don't seem to have a real organ structure. You told me that! Are you provoking? Admit it!"

- A little, that's right! But I am convinced that there are many ways to understand, and not only our own, which is essentially based on mental representations."

Axel puts his spoon back in his bowl: "Were you serious when you said robots could understand?"

- Yes... why not? Robots are no longer programmed strictly to perform well-defined tasks. Machines are built with a minimum of pre-programmed reflexes and a maximum of learning abilities. And I believe that the ability to understand should be combined with the ability to learn. Clearly, learning and understanding are similar because they allow us to adapt to new situations, by associating perception with the memory of reactions we have had to similar events, and then with their consequences... pleasant or not that have been memorised."

- Aren't you in complete contradiction?" says Axel, "You said earlier that there was what you called an innate, genetically inherited understanding that should allow a squirrel to know, for example, that it's supposed to eat nuts without ever having learned it from its parents! "

Florian smiles. "I admit I exaggerated my metaphors a little. But there is no contradiction: there are only several kinds of understandings and the simplest of them seems to me to be programmable in a robot as it is surely programmed by evolution in the nervous system of animals! "

Axel gets impatient: "You are much too vague! What is a robot to you? What kind of understanding would evolution have wired into a slug's neurones?"

- It's simple! Behavioural biology clearly shows us a whole series of instinctive reactions that animals necessarily forge during their evolution. And these behaviours can be perceived as a kind of understanding of the world in which they live."

- For example?"

- There are certainly from birth modules of the nervous system that respond to stimuli important for a given species and that can serve as a starting point for new associations.

"Imagine, for example, a hen and her chicks. You think their chirping is cute... the hen seems to find it rather scary since it looks for the chick and then takes care of it until it stops chirping. The situation might be reversed if a hen's brain was sufficiently developed to be interested in the cries of a human baby. Perhaps it would find charming what is unbearable to us and pushes us to do everything we can to give the child what s/he seems to expect from us!"

- You infer the existence of nerve centres that we would have to activate to trigger a given behaviour from a perception?"

- Yes. A dog is instinctively interested when it perceives the behaviour of another dog and understands its body language and each species has its own. It seems programmed to understand the gestures, the smells... of its kind. We have begun to copy this behaviour by building artificial dogs, robots that imitate them."

- When a mechanical dog wags its tail, do you think it has understood a situation?"

- Why not? I guess there's only one quantitative and not qualitative difference between the flesh dog and the steel dog."

- It's a point of view I don't share; but continue," Axel says thoughtfully as he plunges his spoon into his bowl.

Florian is enthusiastic: "Since the invention of computers, computer scientists have tried to build intelligent machines... without much success so far, I admit! Their journey, punctuated by hopes and disappointments, has nevertheless allowed us to clarify our ideas on intelligence and cognition. The association of psychologists and computer scientists has led to the discovery of neural networks that are widely used today in all kinds of machines."

I take advantage of Florian's silence as he tastes his soup to ask him: "Do you think Deep Blue is smarter than Kasparov?"

- Not at all! Moreover, we are far from a precise and satisfactory definition of intelligence! It is surely multiple and linked to performances of different kinds. The one that Deep Blue could eventually claim is very specialised and involves only greater speed and computing power than ours. But Deep Blue analyses a situation to draw from it all the same what we could associate with a primitive understanding! Especially since it is able to learn through neural networks."

- What do you mean?"

- Probably as does our brain, since neural networks are designed according to its architecture!"

- I didn't know they were using our brains as a model," Axel wondered.

- Yet this is the case, in an infinitely more primitive way, of course! It was a psychologist - Donald Hebb - who suggested in the early 1950s that a learning machine could be built. Electronic neural networks mimic the regular layered structure of our cortex. The latter has about a hundred billion neurones interconnected in five layers, while artificial networks have only a few hundred, arranged in only three layers. But they have nevertheless allowed us to imitate certain properties of the brain such as the recognition of handwriting or faces. Conventional software has proven to be absolutely incapable of achieving these objectives.

"Donald Hebb's intuition was very correct! We recently discovered that our neurones work well according to the premise he proposed as early as 1949! He thought that neurones modify the sensitivity of their connections according to the simultaneity of incoming inflows and that this sensitisation is associated with the analysis of the result."

- But how can a neural network learn?"

- It can be said that it compares an architecture of simultaneously active interconnections to a result it is looking for in its memory or that the computer scientist presents to it during the learning process. Of course, the network must be informed of its performance so that it modifies the sensitivity of active connections according to the results, and this is what learning is all about. If the result is good, the connections that were active will be strengthened and vice versa. We can also strengthen connections that act in retroactive loops to amplify the phenomenon."

Florian is so excited that I can't keep up with him anymore!

Wait, both of you, you're going too fast: I can't assimilate your explanations anymore, Florian."

He smiles: "In reality, these neural networks are difficult to present in a form that would be familiar to us: I even fear that this is not possible because of their complexity. Computer scientists represent them with mathematical formulas that involve the number of simultaneously active connections at the level of a neurone and its reaction. Then they calculate the sensitivity of the junctions based on an evaluation of the result obtained during a learning process."

- It's still not clear!"

Florian gets up and goes to the back of the room: " In this case there is only one illustration on the board that might suit you!"

### C.3 : AXEL'S BLACKBOARD

Axel did not hesitate to equip his chalet with a huge blackboard! Moreover, he has installed them in all his places of stay, most often in disconcerting contradiction with the aesthetics of the decor! I can't imagine my wife's reaction if I suggested that she install one in our living room! But Mrs. Axel is also a physicist, which may explain this... ! In any case, a large black surface adjoins the chimney hood, above a terracotta bench under which logs and small wood are stored.

I understand his interest in the blackboard: you are standing up, active; your whole body is engaged in writing. The features are large; the whole arm participates in the movement and not the hand alone. The brain mobilises a large part of its resources towards the same object: concentration is more natural and the results are affected. Letters and numbers fill the space, attenuate other disruptive perceptions: you immerse yourself in them to be part of them, so to speak. The thoughts are directly transcribed into powdery traces on the grey background of dust, traces quickly destroyed by a gesture of the hand that manages the sponge to be immediately replaced by new creations. If there is any doubt, a few words, a few equations are carefully framed to survive a little destruction... These markers remind me of the painters' taste for their old colour palettes. The new tool intimidates, it does not stimulate the artist's creative thinking. A palette that has lived through evokes past successes, reassures and suggests new harmonies when chance brings the painter's fresh mixes to old coloured paste crusts.

The work on the blackboard is very similar to that of the mind: fast, lively, favourable to associations as well as to the sinuosities of its journey. Moreover Axel is far from being the only physicist I know who can't create without a blackboard..... everyone has their own tools! Other intellectuals often have curious links with their pens: they are able to pay a fortune for tools at a much overpriced cost... why? The pen may represent the link between creativity and its result, between the psyche and matter... In this way, it acquires a special status that is part of a mysterious state of the psyche that cannot be explained and is so precious: the magic of creation.

## C.4: NEURAL LEARNING

Florian hesitates for a moment, with a chalk in his hand: "It is impossible for me to draw anything that does justice to the extraordinary complexity of the neural networks of the brain; I can only schematise in a very rudimentary way the ideas we have about learning and understanding by association." He keeps quiet and silently draws a complex diagram on the board; he repeats it several times, erases some parts of it to correct them... He finally seems satisfied with the result and comments on it.

"I represented a nerve cell - a neurone - by a circle with an arrowed tail. The circle is the body of the cell and the arrowed tail represents its axon - a kind of very thin cable conducting the nerve impulse that it can decide to send to hundreds of other cells. We immediately understand why it is impossible to represent them on the board! Moreover, what I draw in the form of a single neurone probably represents a whole neural network in reality... But let's simplify it!

" Notice that several neurones are interrelated: 1 and 2 for example."

Axel asks: "Aren't you creating short circuits? We can imagine that if neurone 1 triggers a pulse to neurone 2, the latter reacts and stimulates neurone 1 in return."

- But this type of short circuit seems to be important for acting as a short-term memory and the short circuit does not increase dangerously because synapses - the connections between neurones - are more or less sensitive to stimulation so that they do not necessarily trigger a reaction."

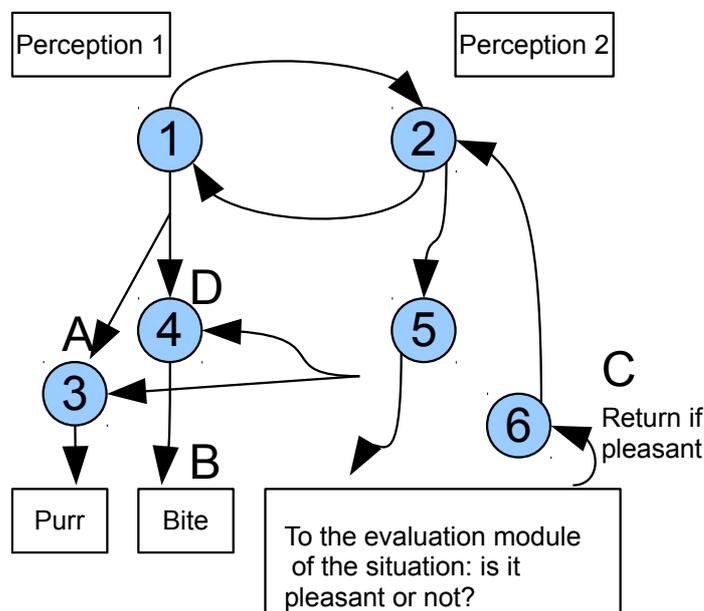


FIGURE C.1: *Extract from the anatomy of a very primitive hypothetical neural network.*

"Neurones 1 and 2 receive perceptions. Neurones 3 and 4 stimulate specific behavioural modules (purring for 3 and biting for 4). The neurone 5 triggers the work of a module to evaluate the general condition of the animal: one can imagine that it gathers the influxes from a multitude of other modules classified as "pleasant", "unpleasant", "stressful", "reward"... The analysis module reacts according to the synthesis of the results.

- You mean if neurone 1 is stimulated it doesn't necessarily trigger a reaction from neurone two?"

- Exactly. The reaction of neurone 2 depends both on the sensitivity of its binding to neurone 1 - a sensitivity that can change according to circumstances - and on the state of neurone 2 when it receives the influx that neurone 1 has sent it."

- All right."

- Suppose that neurone 1 actually represents the culmination of the activity of an entire circuit in a kitten that perceives the presence of its mother, very close to it. Let us also suppose that neurone 2 represents the activity of a network that is activated when its mother cleans it.

"Neurones 1 and 2 will be active and upload influxes to neurones 3, 4 and 5.

"Now suppose that neurone 3 activates in response to the stimulation and in turn sends an influx that triggers the activity of a behaviour module "A". On the right, neurone 5 will send information to a situation assessment module that likely collects myriads of information from all over the brain and analyses and weights them... to give a response such as "pleasant or unpleasant situation, reassuring or anxious, beneficial..."

- But how can you imagine that such complex evaluations could be the result of the activity of a single module?"

- There could be several of them working in a coordinated way. But this hypothesis is true since one of them has been discovered. This module explains how the brain decides whether or not a behaviour should be learned: it is the "reward centre": a tiny nucleus nestled deep in the brain that manages feelings of well-being. It discharges showers of hormones of satisfaction after a good meal, a loving relationship... These rewards encourage the learning of behaviours that are favourable to the individual or species.... It is stimulated by pregnancy, breastfeeding..."

- But why are you talking about learning: it seems to me that these are instinctive behaviours?"

- Yes, but the same centre can be stimulated by new, unexpected situations whose result is pleasant or beneficial. It is as if the centre of the reward is pushing the individual to memorise new situations that are interesting for it. Unfortunately, hard or soft drugs also trigger the activity of this module! We now have a better understanding of the addictive behaviour of an addict. All he has to do is to be in a place that reminds him of his drug use, or with a person who sold him the product, for his reward centre to create a state of withdrawal and lead him to repeat the actions, to rediscover the circumstances that were at the origin of artificial paradise: it is indeed a learning process based on memorised associations."

- Kind of like a robot being stimulated to do a given act?

- Unfortunately, yes, and that's why it's almost impossible to wean yourself off by staying in your usual environment. We must avoid any association that reminds the centre of the

reward of what happened during the drug use because it may take over the reins of behaviour!"

- And if we go back to your kitten?"

- Of course! So we stimulated an "A" behaviour: a purr. One can imagine that the mother is pleasantly stimulated by her kitten's reaction and continues to groom it carefully. The kitten evaluation module has every reason to return a pleasant result to neurone 2 via neurone 6. This situation should last for a while as it is pleasant for both cats.

"Donald Hebb's postulate states that the simultaneous activity of interconnected neurones potentiates their interconnections: that is, they will become increasingly sensitive until they trigger a reaction following a very small stimulation.

"This is what my diagram would look like when it is potentiated: I represent the synapses potentiated by a thicker arrow.

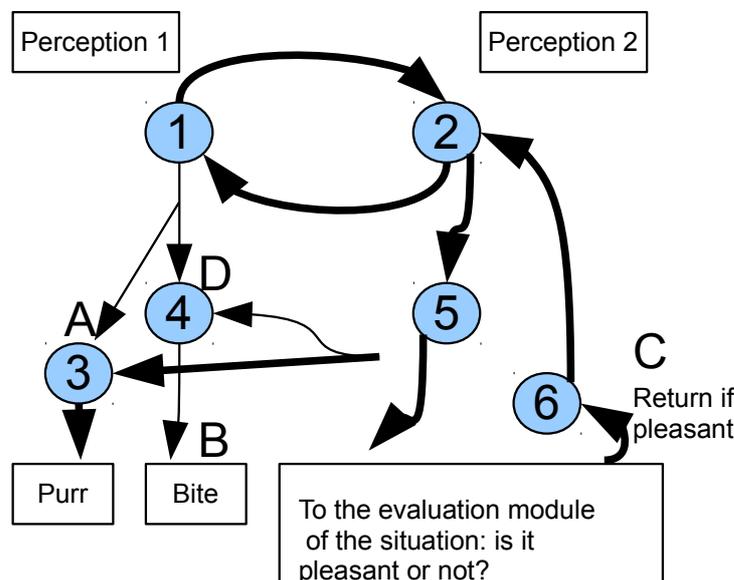


Figure C.2: Potentiation of some synapses in response to the situation analysis. Sensitised synapses are drawn in thicker lines.

"We notice that after a learning process - since that is what it is - the potentiated circuit will be stimulated as soon as perception 1 or perception 2 is present. Synapses have become very sensitive and only one or the other of the perceptions will be enough to trigger the activity of the entire network, i.e. the purring and the feeling of well-being! We can go so far as to assume that the kitten "understands" that her mother is a source of well-being..."

- That would be a very mechanical understanding!"

- But effective!"

- But you didn't explain why the kitten started purring in the first place. Is it an instinct?"

- Maybe. But whatever the origin of this behaviour, it is likely to be associated through learning with new and pleasant situations. Suppose that, by chance, the activity of neurone 1

did not succeed in triggering the activity of neurone 3 and purring, but that it stimulated neurone 4 and behaviour B."

- So what?

- If behaviour B consists in biting, grooming will stop and the synapses concerned will not be potentiated.... The kitten will retain the behaviours that are rewarded and in the vast majority of situations these are beneficial behaviours for it and its species: cats do not take drugs!"

- Oh I'm not so sure," Axel says with a laugh! I knew a cat who was drugged with veal liver! He only condescended to empty his bowl if it contained any!"

Florian also laughs back: "It's a very strange drug! But I recognise that cats are special beings. I only know of two animal species predisposed to be capricious for mysterious reasons: humans and cats! They are the champions of chronic dissatisfaction. Perhaps it is one of the driving forces of our history that has led us to seek ever more progress in order to live more comfortably? But if that were true, the cat should have developed a civilisation of well-being too!"

- But that's what they did," says Axel hilarious! And they do better than us because they stay quietly on our radiators while we work hard to get what they need back home!"

- That's one point of view: but let's get back to our networks!"

- So you think the learning modules of events and the results of our perceptions are the keys to our understanding of the world?"

- I imagine that understanding - taking with - involves meaningful creative associations as you suggested earlier. An association, for example, between the activation of a given neural network following a perception, with the memory of a similar mental event, and then with a representation of the context in which the memorisation of the perceived or learned event took place. These are of course only hypotheses, but they seem compatible with what we know about neurophysiology."

- So understanding would be a kind of association?"

- I think so, yes. Especially since neuro-imaging has just made an unexpected but significant discovery, also based on associations."

## C.5: ASSOCIATIVE UNDERSTANDING

Florian asks Axel: "For you, what does the expression "to be human" means?"

- I guess it describes someone rather kind, who expresses empathy, compassion towards other less happy living beings."

- It is also my interpretation: to be human you have to be able to share the feelings of others, to understand them in a way. That's a moral quality we wouldn't expect to find in an animal, would we?"

- What are you getting at?"

- Just a moment! We agree that a person qualified as human is capable of associating with someone else's difficulties, of understanding them so well that he or she experiences them himself or herself."

- Yes!"

- Well, in that case it seems the monkeys are capable of doing the same!"

- But how can you say that: you can't be in their heads!

- In a way yes... a little bit: thanks to medical imaging that discovers the brain work in real time.

- So monkeys are capable of empathy?

- It seems that yes... and in the process, it becomes possible to imagine much more simply than expected, how an individual understands a given situation!"

- But what are the results you rely on? I can't see a monkey in a medical imaging lab!

- In reality, these studies have not yet been done on monkeys, but the results obtained on us clearly suggest that empathy is not necessarily associated with abstract and complex reasoning, but finds its origin in a simple association with perceptions.

- But you're cheating! How dare you extrapolate observations made on humans that are part of complex concepts?

- But no, our brains are very similar to those of our cousins and that's why we use them so much for our invasive research, when it is not possible to try them on humans! The empathic associations that have been observed could be made by brains even simpler than those of monkeys! Even your dog could show empathy!"

- Enough hypotheses: what are you basing yourself on in concrete terms?"

- On a discovery as recent as it is surprising! We have long known that our brain has specialised areas for defined functions. The entire tactile geography of the skin is projected onto a well-known region of the cortex and builds a kind of miniature image of the body. We can easily identify the brain cells that react when you are touched on your hand, when you pinch your lips... I could make you believe that I touch your finger only by stimulating the area of your brain that contains its image. A nearby area is also well defined and includes the cells that control your movements and I could stimulate the neurones that direct the muscles of your foot for example: it would contract as if you had given it the order voluntarily. Not only would this contraction no longer depend on your will, but you couldn't prevent it!"

- I'd behave like some kind of robot whose controls you'd be in control of."

- Exactly."

- So what?"

- The unexpected discovery is that human volunteers activate the motor regions of the brain without moving a muscle, provided they see someone moving the affected muscles.

- You mean that our brain creates a kind of mirror image of the brain that belongs to the individual who is perceived: it would mimic the activity of the neurones controlling the muscles that we see moving in someone else but without validating the nerve impulses, without sending them to the muscles concerned? "

- That's right, but not only that: the association seems more general... Indeed, neurones sensitive to touch react when a volunteer perceives a human being who is affected but also when he observes an object colliding with another object! His brain associates perception with what he already knows, with what he has felt since birth under equivalent circumstances. But he is able to extrapolate to understand similar phenomena but nevertheless completely different since they involve objects that have no brain, inert objects and no longer a being similar to himself! It is no longer necessary to involve abstract and complex cognitive processes to understand someone else's perceptions and emotions!"

- I understand your astonishment: thus we would have a particularly simple and elegant mechanism to recreate in our brains images of the activity of other brains and even to go beyond! We would be in the presence of an understanding in the true sense of the word: take with you, at home, what is perceived: it is very elegant!"

Suddenly an idea comes to me: "You talk about etymology, what do you think of the roots of the English term "understanding"?" Florian turns to me and answers with a thoughtful look: "under-standing! As if it were a question of supporting a perception, an idea.... Build a representation on existing bases.... Yes. That seems relevant! "

Axel asks Florian: "And what do you get out of it, biologist?"

- It seems to me that these discoveries shed new light on cognitive processes and common sense to the extent that we would tend to make associations with what is known... Everyone sees the Moon in two dimensions as if it were a large flat disc... until you look through a telescope. We discover a new world: mountains, valleys and the light of the Earth on the regions plunged into the lunar night. From that moment on, we see the Moon in three dimensions: it has become spherical. Our perception has changed, modified by our experience. From this perspective it is no longer surprising to be unable to understand the microcosm since it is absolutely not part of any experience of our senses."

I ask Axel: "You who are trying to understand your results, what do you think? Will the microcosm always be foreign to us? "

- Yes and no! Yes, insofar as we do not live in an environment that allows us to build the perceptual foundations necessary to understand it. We tend to think of the spin of a particle as its rotation around its central axis: but it is only a model and not reality! For us, it is what a Braille map represents for a blind person from birth in relation to the real territory! The colours of nature will be foreign to him forever!

"But there is another kind of understanding, more abstract, based on logic and mathematical reasoning... Fortunately, otherwise the physicist's work would be impossible!"

## C.6: LOGICAL UNDERSTANDING

Axel continues: "Many physicists have expressed their admiration for mathematical language: it is full of qualities! First of all, it is perfectly universal and makes it possible to communicate very precisely with representatives of all cultures, better than Renaissance Latin or modern English. And then it only proceeds from logic and abstract constructions that we only need to define correctly to discover their properties without having to rely on the material world. There is nothing to stop us from working with irrational numbers or exploring

the properties of worlds with more or less dimensions than ours! And this work applied to physics gives amazing results! About one of these incredible results, Einstein said of the discoverer: "*he lifted a corner of the big veil*" because one cannot help but be intimately persuaded to discover something fundamental to the nature of the universe!

"Think of the formulas of the type  $E = Mc^2$ : what could be further from our perception? Matter would only be a form of energy in which the square of the speed of light would intervene: absolutely incomprehensible! And yet the logical analysis of Einstein's proposals inevitably leads us to this remarkable conclusion. In particular, we have applied a principle of fundamental symmetry in physics: what happens in one place in the universe must be able to happen in the same way anywhere if the conditions are identical! This guide to logic leads us to the discovery of surprising and unexpected results such as  $E = Mc^2$ ! Here we are discovering fundamental correlations - objects on either side of the sign = - that gradually reveal to us what Heisenberg calls a "central order" that evolves in time and space according to laws that we are able to discover and explain in mathematical language. Thus, quantum physics remains perfectly incomprehensible for everyday language, according to the image of the world that our senses construct for us. But the "incredible effectiveness of mathematics" in discovering and explaining the properties of this same world offers us the intimate conviction that we have really understood fundamental propositions about its nature."

- And that's how you manage to stay schizophrenic!"

- No, I would rather paraphrase Bohr by saying that we are not schizophrenic but that we have developed a spirit capable of complementarity," replies Axel laughingly at Florian, who called him out in a mocking tone.

- What do you mean?"

- Just as a particle is both an immaterial wave and a material corpuscle, we are capable of associative understanding in the perceived world and logical understanding in the abstract mathematical world we create! And, like particles, we express only one of these two contradictory modes at a time; never the two together... which destroys the contradiction!"

- It's a pirouette, not an explanation!"

- If you want.... But I suggest you come back to this fundamental discovery of quantum physics to try to feel its extreme strangeness."

- Its absurdity rather!"

- That's one way of looking at it.... Niels Bohr said that :"*anyone who is not horrified by the results of quantum physics experiments certainly did not understand them.*" I take it you're on the right road," Axel adds, mockingly. "But dress warmly and take your binoculars. I'd like to show you something in the sky."

## C.7 : BACK TO THE PAST

The night is very dark, bright and deep at the same time. The dark vault is punctuated by stars with sparkling flashes: only a few photons shine from the armadas poured into space by these distant suns. The turbulence in our atmosphere diverts them from their trajectory as the refractive index of the air changes, so that the retina receives only one sample of each beam:

the one that has been diverted in the right direction. And the stars twinkle even more as the atmosphere is unstable, which is the case tonight, above the village.

Axel directs the beam of a green laser towards the starry sky: "Look at this great W in the constellation of Cassiopeia."

The pointer clearly indicates the direction it is aiming at: it really looks like the stars are within range of the beam. We easily spot five bright stars that draw a W as wide as two hands stretched towards the sky.

"Are you there?"

- Yes."

- Then focus on the tip of the W, at the bottom right, then point your eyes in the direction it indicates. Stop after travelling a little further than the width of the W and patrol this area with your binoculars until you find a nebula. "

Axel puts his words into action and looks at the sky: we imitate him...

- Here you are! There is a kind of very diffuse cloud... a little lighter in the centre." Florian spots it with the naked eye and then uses the binoculars: "It looks like an elliptical galaxy!"

- It is," says Axel, "the galaxy of Andromeda. It is the most distant object that we can discern with the naked eye in a pure and dark sky, far from the light pollution of cities."

- And how far is it?"

- More than two million light years!..... The photons that hit your retina come at the end of a journey that took two million years at a rate of 300,000 km/sec! "

Axel seems to be enjoying this idea, a little like a gourmet would enjoy a successful sauce! Science is sometimes accompanied by a kind of intellectual jubilation that completes the aesthetic pleasure offered by the eyes. Thus astronomy, like electronics perhaps, addresses both the rational mind and the artistic sense. Here, the perfect rings of Saturn, the turbulent atmosphere of Jupiter, the Martian deserts topped with polar ice caps... so many unforgettable images of mysterious planets, huge interstellar clouds illuminated by the stars that are born from their lumps or clusters of globular or burst stars that glitter gently like large black diamonds... There, well-ordered rows of multicoloured electronic components, carefully distributed along golden trails with a labyrinthine path that is a little hypnotising... Here, a show that opens the doors of the mind to the nature of the universe that the scientific method makes understandable... There, paintings resulting from human ingenuity when she applies the fundamental discoveries that her curiosity offers her... But to the mind and aesthetics, astronomy still adds poetry and philosophy. Indeed, all cultures have furnished the sky with their fantasies and emotions through the drawing of constellations and their mythology; finally, the spectacle of the sky profoundly influences the image we have of ourselves and our place in the universe.

Axel takes me out of my reverie: "Two million light years, that's quickly said! But soak up what it really means! This means that today we are discovering Andromeda as it was two million years ago: astronomy is a time machine!"

- Yes, I understand correctly, so what?" Florian remarks a little vividly.

- So it suggested to Wheeler<sup>1</sup> a thought experiment whose results are staggering because they exploit to the absurd the interpretation of the Copenhagen School: the famous complementarity: the wave-particle duality."

- How?"

- He uses celestial objects to test Bohr's pPrinciple of Complementarity."

- What do you mean?"

Axel leaves his binoculars and looks at me smiling: "Okay! But I'll need the blackboard to remind you of that!... But before going back, I suggest you admire a few remarkable objects... Here we are! Point your binoculars here!" Axel points to a dark place at the bottom of the extension of a line formed by the two stars of the left rising branch of the W, at a distance of about one and a half times the distance between the two stars.

"Enjoy the show... It is one of the most beautiful clusters of stars in the sky: the double cluster of Perseus! We discover here two star nurseries so close to each other that it is possible to easily discern their colours by comparison.

Indeed... what seems uniformly mono-coloured to the naked eye turns into a palette of very nuanced colours in the astronomical instrument. The contrast between several stars visible in the same field of binoculars is superb! Some are yellow, others blue, green or purple...

After a while Axel adds: "Before I go back I will show you where Wheeler located his experiment. Look, it's here!" Axel points his green beam at the Big Dipper: "Somewhere in the constellation of the Big Dipper is a strange celestial object: a quasar! It is a "quasi stellar object or QSO": a light source that looks like a star but shines as bright as an entire galaxy, populated by hundreds of billions of stars! This unimaginable power allows us to see it as it was more than seven billion years ago, halfway between the Big Bang and us! Quasar QSO 0957+561AB - it's its number - is three thousand times further than Andromeda!"

- And can we see it?"

- No! A large telescope is required: one metre in diameter should be enough. Imagine we have one: I point it at NGC 3079 - an elliptical galaxy in the Big Dipper, then I migrate ten arc seconds north and I see a double star, very dimly lit: it's our quasar!"

- You said earlier that it wasn't a star! "

- But it appears to us as such because of the immense distance that separates us from it and its size, which is very small compared to that of a galaxy."

- Why double then?"

- It was this attribute that inspired Wheeler. In fact, it is not a double quasar, but a double image of the same object. Luckily there is a large cluster of galaxies between it and us so that the light it sends us is bent by the gravitational field of a large galaxy invisible to the telescope: the image we perceive as a double star is formed by a beam that passes on one side of the galaxy for one of them, and on the other side for the other. It is the first gravitational lens discovered in 1979: it is one of the consequences of Einstein's Generalised Relativity, but he was no longer of this world in 1979."

- And what does Wheeler do with it?"

- Oh..... Well, he turned it into an instrument of magic!"

Florian and I stare at him, stunned, as he clearly amuses himself with our stupor. He continues: "Thanks to Wheeler and quantum physics I am becoming - you are also becoming - capable of acting on events that occurred more than three billion years ago: the distance that separates the Earth from the galaxy that serves as a gravitational lens!"

- No kidding!" Florian laughs."

- Yes, you will see! Remember the experience we had at the School of Physics with Young's slots? The beam of light that passed through two slits and diffracted in light and dark bands on our screen... I even showed you these strips with a simple halogen lamp and a cardboard box with two very close holes! "

- I remember that. You had obtained incredible results when you did it with isolated photons.... They suggested that a photon is capable of passing through both slits at the same time since there were images of interference!"

- It's an interpretation... but it's absurd!"

- Like everything you present to us," says Florian, offended!

- But Florian... find other explanations that suit you and we would be delighted, provided of course that they obey the experimental results as well as ours! "

- And what are they, yours?"

- Oh, there's a whole bunch of them! I intend to present to you some of them, very different, but which have in common their strangeness, like everything related to quantum physics."

- Their absurdity, you mean," Florian avenges himself!

- If you want" tempers Axel with a smile. "It is true that they are absurd when confronted with our perception of the macrocosm, but it has now been clear for nearly a century that the microcosm has its laws that the macrocosm does not know!"

- Why don't you go back to your magical quasar?"

- No, first of all, you have to remember Young's experience with slits. When only one photon at a time crossed the obstacle, we would find punctual impacts on our screen. After waiting for a few thousand photons to crash on the screen, we observed that the impacts were ordered into regularly spaced bands: these bands recalled the interference fringes typical of waves whose troughs and bumps add up or subtract."

- Yes, I remember, so what!"

- These fringes were formed on condition that the two slits were open and disappeared if there was only one."

- It makes sense if it's interference, doesn't it?"

- But the photon gives a punctual impact on the screen: it is therefore a particle, infinitely small. It cannot go through both holes at once, especially since at its scale these two holes are as far apart from each other as Pluto is from the Sun for us! "

- So what's going on?" Florian asks, very calm.

- It all depends on the interpretation you choose! I suggest that you review four of them and keep this experience of Young's slots as a common thread to introduce them. This is a real

challenge that has been facing physicists for nearly a century! Bohr said that if we ever understood the results of this experience, we would be on the right track to understand what "understanding" really means! And we are still a long way from that! "

- Oh, God, it's a bad start!" Florian murmurs.

Axel continues: "Let's start with the first interpretation that has been published: the one called "Copenhagen's Interpretation" because it is due to Bohr and his students.

"Remember the thought experiences that confronted Bohr and Einstein for years... Einstein refused to digest the Principle of Uncertainty by devising all kinds of technical means to measure both the position and energy of a particle..."

- I remember that.... You told us that Einstein had finally admitted the coherence of the theory but he bypassed Bohr's arguments by arguing that it was incomplete and that the Principle of Uncertainty was due to this gap. He was convinced that we should look for a more fundamental theory that would allow us to calculate both parameters at the same time."

- You're there! That's right!"

- But didn't you show us that Bohr was actually right?"

- That's right: it's about the Aspect experiments. But I would like to come back to a formulation of the Uncertainty Principle: the wave-particle duality. The Copenhagen Interpretation argues that these are two aspects of the nature of the microcosm and that they are complementary rather than contradictory."

- It's again Young's slit experiment in which the results depend on the choice of the experimenter?" Florian looks the same incredulous as the day Axel had experienced it."

- Yes: it is a fundamental result of quantum physics since it betrays both the wave-like aspect of particles when both slots are available and their corpuscular nature when only one slot is open."

- You said it's absurd!"

- Put it that way, I'll give you that. But since the photon impacts the screen in its corpuscular form, it can be assumed that it was also its form when it crossed a slit."

- What about the interference fringes?"

- With this interpretation it must be assumed that when the photon passes through one slit, it is mysteriously influenced by the state of the other slit. When it is open it hits the screen obeying a probability related to its wave function and that is why there are clear zones and dark zones: it is no longer a question of adding the troughs and humps of real waves that exist before the measurement, but of calculating probabilities of presence that obey a mathematical function that evolves in time and space as a wave would. These probabilities can be calculated precisely, but the result of the measurement is not: we know how to calculate precisely the position of the light and dark bands that form when enough photons have impacted the screen, but we cannot predict in which precise band a given photon will crash."

- I feel like you're drowning the fish! How can the photon know if the second slit is open or closed?"

- You do point out a crucial point, indeed! Bohr suggests that we cannot say anything about the characteristics of a particle if we do not take into account the means by which they will be measured. There is no point in asking what a photon really is! It is sufficient to admit that the

result of the experiment depends not only on the particle being measured, but also on the chosen device. If the experiment is built to measure the characteristics of a corpuscle, it is in this form that it will appear to us. If, on the other hand, our instruments are adjusted to measure the characteristics of a wave, then this is how the quantum object will appear to us. It has both the characteristics of a wave and those of a particle but we will never find any contradiction because it is impossible to measure these two characteristics at the same time! He says it is wrong to imagine that the photon passes through a slit to follow a given trajectory before it is measured. He says something like: "*an event that is not measured is a non-event*" or :"*nothing can be said about the nature of the photon until it is measured*"!

- And you think he explained the phenomenon!" Florian laughs.

- I find that he interprets it in a coherent way that eliminates internal contradictions."

- But it doesn't satisfy me!"

- You're in good company! Generations of physicists have devised extremely clever techniques to determine through which slit the photon passes when both are open: the results have never changed! I'll introduce you to one later, but here's Wheeler's cosmic experience first."

"Wheeler realised that the galaxy that lies on the line of sight of the quasar, represents an obstacle similar to the one that separates the two slots of a Young's device! The quasar is a quasi-point source of light since it is very far from this galaxy: it imitates the lamp and its collimator well in a Young's device. We thus have a huge cosmic apparatus that should allow us to carry out the same experiments as with its terrestrial counterpart."

- How is it a magic device then?" Florian asks.

- In that it allows me to act on a past event... to modify the past according to the choice I make today!"

- It's more than absurd, it's crazy!"

- I see you're really starting to realise what quantum physics is all about! ", Axel replies with a smile.

As far as I'm concerned, I'm not sure I see what Axel is presenting: "Couldn't you explain Wheeler's experience more clearly: what he practically did and what the results were?"

- He proposed a thought experiment in 1983, but it has since been carried out with the results he had predicted by applying the principles of quantum physics. But let's go home, a drawing will help me to be clearer."

## C.8: FROM THE UNCERTAIN TO THE INDISTINGUISHABLE

We are back by the fireplace. Axel revives the fire before erasing the board to draw the following diagram.

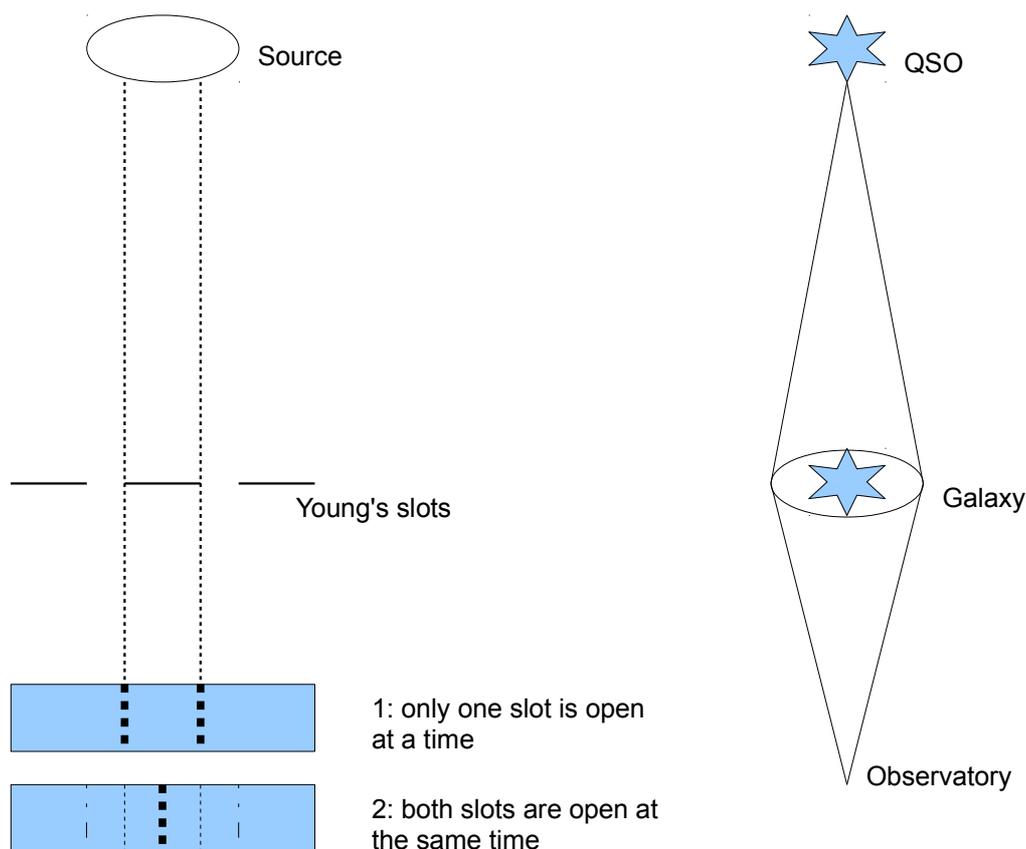


FIGURE C.3: *On the left, Young's slits and on the right, its cosmic counterpart according to Wheeler. The quasar acts as a source, the intermediate galaxy curves the image of the quasar and splits it as if it had to cross two slits.*

"On the left, Young's slits: on the right, its cosmic equivalent according to Wheeler.

"We have seen that if only one slit of Young's device is open, whatever it is, we observe a peak of photon impacts in front of it. Photons behave as particles and follow a straight trajectory from the source, through the slit to the screen. We can imagine that some of them ricochet against the edges of the slit, which explains the spreading of the bell-shaped peak.

"But when the two slots are free we don't find two bell-shaped peaks as one might expect: they are replaced by a series of fringes that we have interpreted as the result of interference."

- And these fringes remain even if only one photon passes at a time: that's what you showed us at the School of Physics."

- Yes. The interest of Wheeler's experiment comes from the enormous distance that separates us from the source of photons - the quasar - and from the obstacle that creates the two possible paths of photons - the galaxy."

I think I understand Wheeler's approach: "You mean that if we manage to discern isolated photons from the quasar, we can block or not the arrival of one of the two possible paths to recreate the same conditions as in Young's device? "

- Yes, but with a serious advantage.... Photons left billions of years ago and we can modify the measuring device long after they have crossed the obstacle that is three billion light years from Earth. I can decide today if the photon I'm about to observe has passed to the left or to the right of the obstacle or if it has taken its undulatory aspect to pass to the left and to the right at the same time: look!"

Axel adds a diagram that represents the devices to be attached to the focus of the telescope to reproduce Young's experiment.

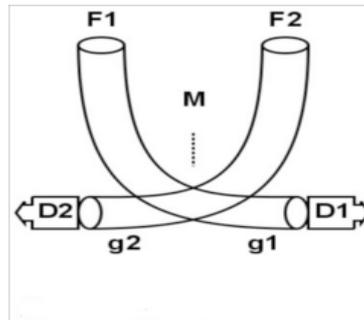


FIGURE C.4: *Detail of the device for detecting isolated photons from quasar. F1 and F2 are filters and collimators that select isolated photons of specific colour. g1 and g2 are optical cables that guide them to D1 or D2 detectors. M is a semi-transparent mirror that allows half of the photons to pass through it and reflects the other half.*

"The ideal assembly is based on two telescopes each pointing at one of the quasar and filters images to allow only one photon of a specific colour to pass through at a time. Optical cables guide the photons to detectors D1 and D2 and then a device allows to introduce or not a semi-transparent mirror on the path of the photon in M."

- I don't recognise Young's device at all!"

- Because it's more sophisticated but the principle is the same, look.... The photon can arrive in F1 or F2 depending on whether it has bypassed the galaxy to the left or right. It will be guided along the optical cables g1 or g2 to the detectors D1 or D2."

- If there are no obstacles, fine."

- Good. We now manage to ensure that the lengths of the optical guides g1 and g2 are such that a wave of the same colour as that of the filtered photons adds up when the two phases arrive together in g1 and cancel each other out in g2."

- In g2 a bump will arrive at the same time as a hollow while two bumps arrive together in g1, right?"

- Perfectly. Suppose that this device is installed in the focus of the telescopes after adapting it to capture both images of the quasar at the same time, a bit like in a Young's device when both slots are open."

- Is that why the two light guides cross?"

- Yes. Wheeler's trick is to introduce a semi-transparent mirror - a kind of one-way mirror - in the middle of the path, at the point where the two light guides intersect. It is built to let half the light through and to reflect the other half. A wave that arrives at both F1 and F2 can be transmitted or reflected to the semi-transparent mirror. If, for example, it is transmitted from

F1 to g1 and reflected from F2 to g1, we will have an addition of the two waves on the path from the mirror to D1 and vice versa of course."

Axel draws the routes with his finger on the diagram and then asks me: "Matt, what results do you think you'll discover when the semi-transparent mirror is in place?"

Axel addressed me: I think about it for a moment after taking a look at Florian. He is of no help to me because he seems hypnotised by the diagrams on the board. Maybe he already understood what Axel would like me to discover. If that were the case, then from the look on his face I'd bet he doesn't like the results at all!

- Well... I guess D1 will detect waves since you built the device for that!"

Florian turns to me suddenly: "Of course! A wave arrives at the same time in F1 and F2 from the same source doubled by the galactic obstacle. The device reacts by triggering detector D1. You could find the interference fringes again if you repeat the experiment with different and appropriate lengths of g1: D1 will be activated provided that the length of g1 is an integer multiple of the colour chosen by the filters. If this length is increased by half a wavelength, then a trough will occur at the same time as a dent at the detector that will not react: we find the interference fringes observed on Young's screen." Florian joins the table to add a graph on each side of the Axel diagram.

WITH the semi-transparent mirror

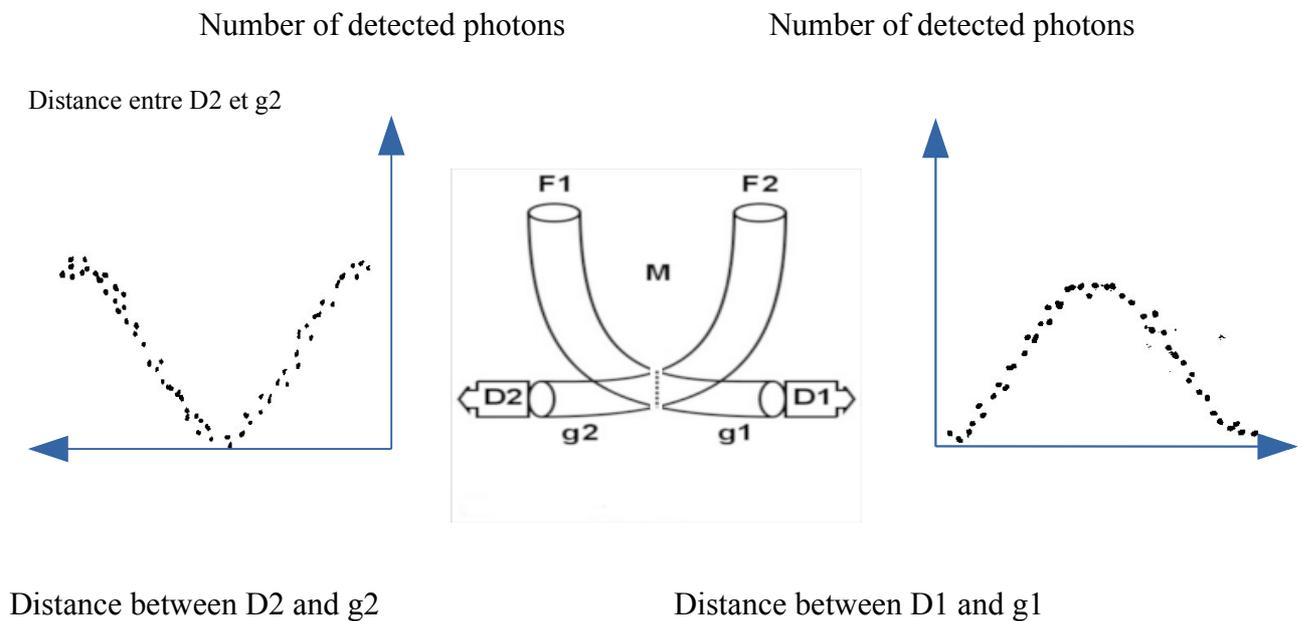


FIGURE C.5: If detectors D1 and D2 are placed at variable distances from g1 and g2, the number of photons they detect varies according to complementary curves: the maximum is reached at D2 when the minimum is measured at D1 and vice versa.

"This is what we would find if we varied the positions of detectors D1 and D2... Each device will detect photons in different but complementary proportions depending on their distance from the objective.

Axel smiles as he listens to Florian: "Amazing! Keep going..."

- I suppose that if we block the F1 path the photon will be able to pass through F2 without being disturbed and will activate D2" says Florian in a strange way, as if he refused to admit what he just said!

- That's what we find."

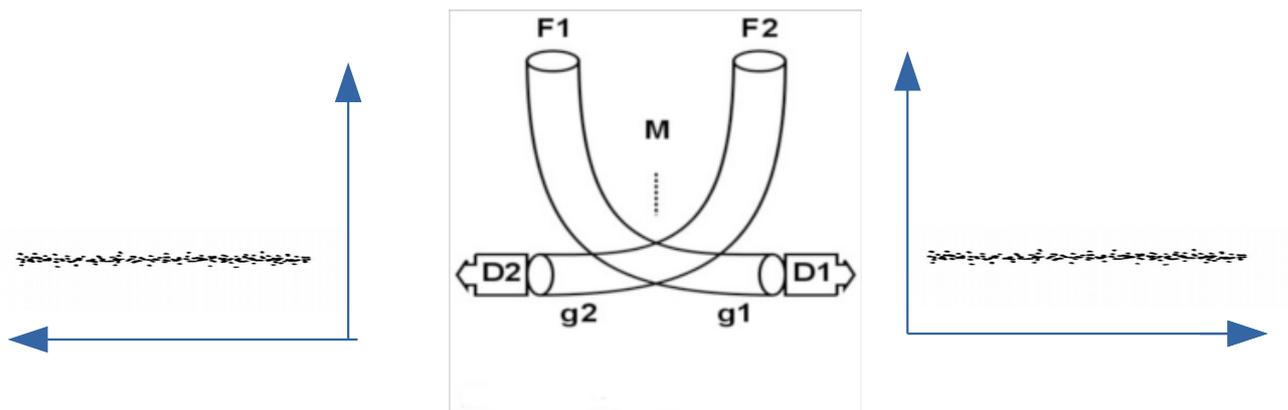
- And if we remove the mirror and the filters allow only one photon to pass through on average at a time, we will have the following results:"

Florian erases the two curves he has just drawn and replaces them with two straight lines.

WITHOUT the semi-transparent mirror

Distance between D2 and g2  
g1

Distance between D1 and



Distance between D2 and g2

Distance between D1 and g1

FIGURE C.6: *If the mirror is removed, half of the photons are detected on D1 and the other half on D2: there is no longer a link between the number of detections and the distance between the detectors and the optical cables.*

"If there is no longer any possible addition of the two images then either D1 or D2 will be triggered depending on whether the photon has reached F1 or F2. The two detectors should not react at the same time if the device has been properly constructed to admit only one photon at a time."

- Superb! You should have done physics instead of biology! What are your conclusions?"

- But it's awful! This means that the isolated photon behaves like a particle if there is only one open slit or like a wave when both slits are free, long after it has been diverted from its trajectory by the galaxy, billions of years ago!"

I don't understand Florian's reaction: something must have escaped me: "I don't see what's awful about this result!"

- But imagine the path of light without forgetting that you are only interested in photons isolated from each other! You can decide today to observe them in their particle form or waveform and your choice influences the path that the photon took billions of years ago!"

- What do you mean?"

- If you observe it with only one telescope it will behave like a particle that has passed either to the left or to the right of the obstacle, whereas if you observe it with both telescopes you will find fringes of interference typical of waves and you will conclude that the photon has passed both through the left and right of the obstacle since it takes its wave form, the only one that allows it to be in both places at once! This is Bohr's interpretation: if the measuring instrument is intended to determine the properties of a particle, then the photon will be revealed as such, whereas an experiment conducted to measure the wave nature of the photon will give results that are consistent with those expected from a wave!"

Florian stops for a moment and then asks Axel: "And what is the distance between the two journeys, on each side of the obstacle?"

- About fifty thousand light years."

- That's it! That's what I was afraid of! If this interpretation is correct, I see only two possibilities, both of which are inadmissible!"

- Which ones?"

- Either anyone is able to manipulate the nature of photons through time, going back billions of years... or free-will does not exist and the choice you think you are making is just an illusion!"

Axel laughs: "We are plunged into the mysterious and confusing beauties of quantum physics! But rest assured... many other interpretations have been proposed."

- I doubt they will reassure me," Florian replies. "But what are the real results of Wheeler's experiment? Are they good enough that we really have to take them seriously?"

- Yes.... No!..... In reality, Wheeler's thought experiment cannot be done technically! On the one hand because telescopes are obviously monopolised by astronomers who have other things to observe and on the other hand because this type of experiment is still technically impossible today, especially because the two paths, to the left and right of the galaxy, do not have the same length: a photon will take about 411 more days to pass to one side rather than the other, which makes it very difficult to design a device that can reveal an interference between the two possible paths."

- But then.... Hopefully it won't give the dreaded results!"

- You're mistaken! There are almost no physicists who question the predictions of quantum mechanics. They have been confirmed for a century, even when they are incredible!"

- I still doubt it!"

- Not too fast! Quite equivalent experiments have been successful and are producing the results expected by Wheeler! Today we have the technical possibilities to replace the quasar by a laser and to place or not the semi-transparent mirror on the photon path after it has entered the apparatus, in a similar way to Aspect's 1982 experiment. We can even order the installation of the mirror with a random generator without changing the results: they still obey this quantum logic so far from ours!"

Florian is disenchanted but remains silent. Axel continues: "Moreover, Wheeler's objective was not to carry out the experiment in concrete terms because no physicist would bet on its failure! His objective was rather philosophical and was based on countless reflections born of arguments published by Bohr, Heisenberg and many others."

"Let us return to the problem of measurement because it is one of the first discoveries that separated quantum physics from the other chapters of physics since here the choice of the observer determines the type of result that will be observed. It causes by measurement what can be called "a collapse of the wave function" since before this measurement a quantum object behaves like a wave occupying a relatively large space to suddenly concentrate as a very small particle somewhere in the space previously occupied by the wave. Moreover, the precise location where the wave function will collapse cannot be predicted with certainty but only with a certain probability: this is the Heisenberg Uncertainty Principle.

"You think we tried to understand what the influence of the act of measuring could really be on the microscopic world... The range of suggestions ranged from the simple inevitable disturbance of a real and independent particle property to the almost mystical intervention of the physicist's consciousness as he experiments the nature of the microcosm!"

- We should be able to test at least a few of them!"

- Of course, but sometimes it's difficult. Let's start with the interpretation that is closest to common sense... the one that applies to the microcosm what we know about the macrocosm. We owe it to Heisenberg and here it is."

Axel erases the whole table and then draws the following diagram.

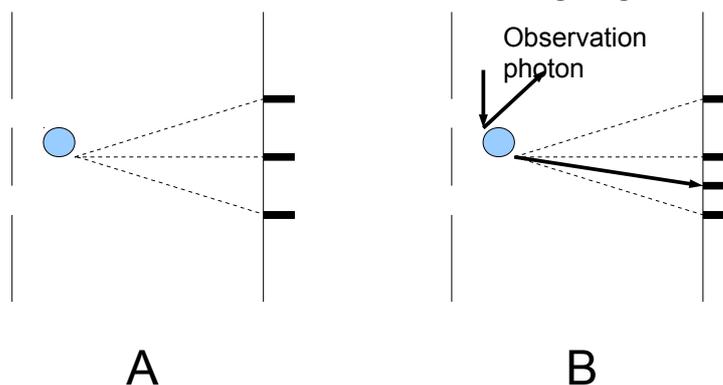


FIGURE C.7: *A particle has passed through a slit and travels to the screen where it is expected on one of the interference fringes. B: If we want to know through which slit the particle passed through Young's device we must bombard it with photons strong enough to measure a result. The shock between the particle and the photon will deflect it in a complex way so that the interference fringes will be destroyed: the result is a spread peak and not light bands alternating with dark bands.*

He explains: "Heisenberg offers a simple explanation to understand the disappearance of the interference fringes observed every time we try to find out which of the two slits the particle passes through. He shows that to make this measurement it must be illuminated with photons strong enough to make the response measurable. This measurement necessarily disrupts the particle's path in a way that is impossible to control, so that interference fringes are lost."

- The wave-particle duality would then only be due to the imperfection of our measuring devices?"

- No! It even survives with hypothetical perfect devices. But this interpretation explains the observer's influence on the nature of the results."

- I'm not sure I understand the difference!"

- So let's keep exploring this phenomenon of measurement and you'll understand.

"If Heisenberg is right, we must be able to imagine an experiment with much more massive objects than a simple particle and a very delicate measuring method so as not to disturb them. In this case we should detect which slit the object passes through without destroying the interference fringes."

- You mean that the wave nature of the object would be revealed by the interference fringes and its point nature by its detection on one of the two slits."

- That's it. The wave-corpuscle duality is preserved and the measurement loses its confusing aspect. This experiment has been done in several ways and always gives the same results..."

Axel stops.... Florian is hanging on to his speech. He continues: "It is now clear that Heisenberg was wrong. It's a pity because his explanation was very practical! It was so reassuring that several physics textbooks, and not the least, were reluctant to dismiss it! No... we must accept the obvious: it is the phenomenon of measurement that seems to create the event. The only disturbance introduced by the measurement technique can no longer be used to explain the observations."

- How can you be so sure?"

- Because we managed to lose the interference fringes without disturbing the measured object. Several teams have successfully demonstrated the wave nature of whole atoms and no longer just particles. However, these atoms are so massive in relation to the disturbance due to the measure that Heisenberg's explanation can no longer be invoked.

- OK, but then? It's too staggering to accept it like this! Are the experiences sufficiently well mastered? Are the results clear?"

- I'll let you be the judge: we put isolated atoms through an interferometer - it's an equivalent of Young's device - to see that they form many fringes of interference as if they were passing through both slots at the same time! Then we built a device to mark the atom at the exit of a given path in order to be able to recognise it. It was either to illuminate it with a laser so that the electron furthest from the nucleus jumps into a higher and recognisable orbit, or to modify the spin axis of the peripheral electron. It is impossible that such small disturbances can destroy the interference fringes as Heisenberg imagined.<sup>2</sup> By way of comparison, assume that the atoms are large enough to be easily visible to the naked eye. In this case the experiment would be to stand just behind one of Young's device slots to monitor

the atom's passage in order to mark it with a little paint in order to recognise it when it hits the screen. To avoid disturbing its trajectory, you give a very slight brushstroke on its peripheral electron as it fuses in front of you at full speed. All the atom's energy of movement is practically concentrated in its nucleus, which would be the size of a golf ball and weigh about ten billion tons. You can't reasonably believe that it's your light brushstroke on its peripheral electron orbiting 1 km from its nucleus and weighing only half a milligram that can disrupt the atom's path to the point of removing the interference fringes!"

- But then what? How do you explain the loss of interference fringes? "

- The current interpretation maintains that just being able to determine where the particle has gone is enough to lose the interference fringes!"

- But that's not possible! This would require a god or a malicious demon to have fun constantly scrambling the cards simply to prevent us from knowing where the particle is going before it is measured! We have the impression of playing a game whose rules have been arbitrarily determined by its creator according to a logic that is incomprehensible to us!"

Axel laughs: "Indeed, the Lord's ways are impenetrable... and we have to deal with them! I hadn't thought of that one! But nothing prevents you from believing it: it's a way of explaining the results! But it's not scientific because I really don't see how to falsify it!"

Florian doesn't seem to think it's funny... Axel continues: "On the other hand, it is now clear that the uncertainty principle must be renamed the "Principle of Indistinguishability": many experiences attest to this."

- For example?"

- Describing some of them would take us too far.<sup>3</sup> But I can offer you a simplified experience derived from a real experiment.

"To begin with, it is interesting to know how Heisenberg discovered the Principle of Uncertainty: he had the intuition to do so while trying to resolve contradictions between observations and mathematical formulations of quantum mechanics. He tells us that he suddenly realised that we had to correct our interpretation of observation! A particle seems to us to pass through the measuring device - a bubble chamber for example - since it leaves a continuous trace materialised by the bubbles. We imagine it arriving through air, crossing it and then leaving at the other end. But there is no confirmation that it is the same particle! We would make the same observation if a mathematical function determined the properties of a particle at different places and times. There is no reason to admit that it is the same particle that is observed throughout the trajectory! In reality, we cannot identify a particle, mark it in a way, to be sure that it is the one that entered that we find at the exit! Each bubble that marks the passage of the quantum object is an act of measurement: as such, it somehow creates the event and obeys the mathematical formulation that we interpret as the trajectory of a particle with defined properties. But we have no right to say that it is indeed the same object that creates each bubble: we could not mark it with a brushstroke to be sure that it is the same one that runs the entire trajectory!"

- You mean there is a creation of different events that we interpret as the trace of one?"

- If you will, yes. We cannot individualise a given particle - call it "Bob" for example - when it enters the measuring device and check that it is the same Arthur who leaves it!"

- And this has been demonstrated?"

- Yes! Shimon Malin has published a simplified version of the experience: here it is!"

Axel draws four double trajectories on the board and then comments on them: "Suppose that we measure the spin - the axis of rotation around itself, if you will - of two photons travelling together in the same direction. It is decided to measure it in the axis of movement. Quantum mechanics only provides for two possible values: either the spin points forward in the direction of motion or it points backward. I identified each photon by giving it a name and now I ask you what is the probability of finding one of these combinations?"

Florian is much faster than I am: "Have we shown that all combinations can exist with the same probability?"

- Of course! We also made sure that the spin of one photon does not influence the spin of the other."

- So in this case it is obvious that each combination represents a quarter of the possibilities!"

- That's right... but that's not what we find experimentally!"

- And how is that possible?" asks Florian, worried.

- Precisely because we do not have the right to give a personal name to each particle: there can be no Quantum Alice and Bob! Possibilities 2 and 3 are not identifiable from each other."

- And what are the results?"

- Well, we find that combinations 2 and 3 are indistinguishable so that there are only three possibilities left: the photons both have their spin either in the direction of motion - this is the case 1, or in the opposite direction, this is the case 4, or their spin points in the two different directions without being able to differentiate case 2 from case 3. Consequently, we find each combination with a probability of 1/3 whereas we imagined finding 1/4 if it was possible to individualise the particles!"

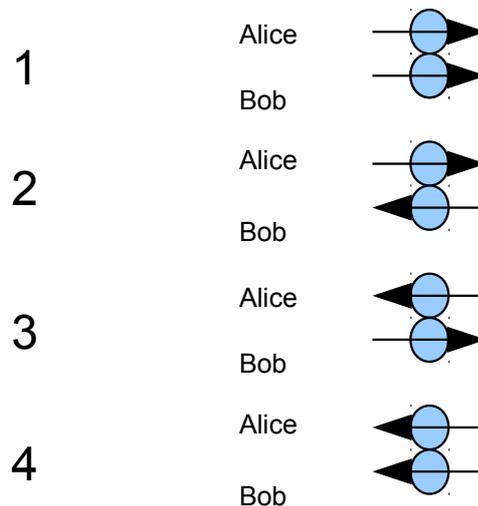


FIGURE C.8: *The spin of 2 particles travelling together is measured. Quantum mechanics predicts that if the measurement is made in the axis of motion, the spin points in the same direction or in the opposite direction. If each particle is identifiable, we expect to find 4 different possibilities, each with a probability of 0.25.*

- But it's extraordinary!" For once, Florian seems to appreciate Axel's explanations, who is very surprised!

"Yes, I think of a nice parallel with the living world: the form, the information is perennial, the material that constitutes it, is not!"

This time it's Axel who seems borrowed: "Can you be clearer?"

- Of course! You can imagine seeing the same guy in your mirror every morning, but it's just Axel's shape! The cells that determine this form are not the same from day to day: every second millions of them are replaced by new ones that look almost perfectly like them so that we imagine ourselves remaining the same as ourselves. In reality, only the information that allows the young cell to look almost perfectly like remains - except for the ageing - the old-fashioned way. The material that concretised dead cells is recycled into all kinds of new structures!..... If, for example, you were an aborigine from Kalimantan living in a community house on stilts under which pigs take refuge, the material that makes up your cells may well find its way into one of them... no offence, of course! I'll have to draw this parallel... but keep explaining!"

Axel takes a moment to regain his senses. He returns to an armchair, concentrates for a moment and then continues: "When Wheeler published his thought experiment, the results I have just presented to you did not yet exist: they are recent. On the other hand, Alain Aspect's had just been published."

- The ones you introduced us to at the School of Physics"?

- Yes, these experiments are clear: we must abandon one or other of the concepts that Einstein had described in an attempt to demonstrate that quantum theory was incomplete. He never accepted the Principle of Uncertainty. It was to challenge it that he imagined an experience of thought that would demonstrate that there is a knowable reality without any disruptive measures. This is the EPR argument I presented to you in the introduction to the Aspect experiment. If Einstein was right, then quantum theory would not be complete and there should be hidden variables that, if known, would allow us to calculate precisely where the impact of a quantum object on a screen would be: we would no longer have to invoke probabilities and a collapse of the object's wave function and the uncertainty principle would no longer be a fundamental principle of quantum physics but a reflection of our ignorance."

- And Aspect showed that Bohr was right."

- Yes. As a result, we need to take a more serious look at what he was thinking. Bohr said that it was impossible for us to know the properties of a quantum object before measuring them. Although he was very talkative, he never went so far as to propose an interpretation, an image of his mental representations. He was probably right because there was no way to test them, but his words could suggest that realism is an illusion."

- What do you mean?"

- Put simply, this would mean that the microcosm is not filled with defined objects, with their own properties, independent of our measurements, but that these properties are somehow born during the measurement. Wheeler seems to be in agreement with this vision and that is why he suggested his thought experience. It shows very strongly that either time and space are very different from what we imagine, or that the act of creating the universe is not - or not

only - part of a distant past but that it is revealed at any moment, whenever a quantum object acquires the properties we measure!"

- But that's absurd! "

- With our classic concepts, surely! But we must accept the evidence of the experimental results! Wheeler stigmatises the difference between events that take place in our classical universe and those that are part of the quantum microcosm. The former obey our current concepts of time and space but it shows, in agreement with Bohr, that these concepts are not appropriate as soon as we are interested in the microcosm. We are wrong to imagine that the photon really left a quasar billions of years ago to travel towards us during all this time and over an immense distance! Before the measurement we can say nothing precisely about its nature or properties: they are not part of our universe as our senses reveal it to us: they are somehow outside the time and space we perceive and that is why we discover what we are obliged to describe as a-local and a-temporal characteristics! Wheeler is very impressed by the act of measurement: he attributes it a kind of creative power since it seems to determine the properties of the microcosm underlying the macrocosm we know."

- Good Lord... I'm getting a headache," Florian complains.

- So let's stop here for today," Axel laughs.

- With pleasure and relief," Florian whispers as he gets up slowly.

## C.9: SCHRÖDINGER'S CAT REVISITED

Skiing is over for this weekend: here we are back when it's not even noon! Perhaps he was too absorbed in his discussion with Axel... Still, Florian inadvertently stepped on a plate of ice. His right leg suddenly moved forward, dragging the unfortunate man behind her until he found himself lying on his back before he could realise what was happening to him. His occiput violently struck the edges of the skis he was wearing on his shoulder, so several stitches were needed to repair the damage. Two hours later and a big bandage, Florian, still stunned, sits in an armchair while we prepare hot drinks for ourselves.

"Something bad is good!" ruminates Florian. "Axel, you're going to be able to explain the whole story to us since we have all the time we need now!"

Axel takes a doubtful look at him: "Maybe... we'll see where we stand. I would like to explore with you some interpretations proposed since the 1950s that are still interesting today."

He brings us a tray with bowls of steaming broth that we share: "You know Schrödinger's cat, don't you?"

- The one who is both dead and alive:" mocks Florian. "Here's another physicist's invention!"

- Precisely, I wanted to propose a version that doesn't require your discipline.

- Wait a minute! I have heard about this cat but before proposing a new version, could you summarise the argument for me? He probably doesn't look as familiar to me as he did to Florian."

- Summarise it to him, Florian!
- No! After all, this is your domain: this cat is nothing biological!"
- If you say so!"

"Schrödinger - and Einstein - didn't like the Copenhagen interpretation we were discussing last night. In particular, he rejected the notion of complementarity or wave-particle indeterminacy of the quantum object. It can be described as an overlay of all possible states until it is observed. During the measurement, the wave function collapses to give way to only one possibility by obeying the probabilities it describes.

- It's indeed an unbearable concept, especially for a poor cat," Florian laughs.

- Schrödinger wanted to stigmatise the strangeness of this interpretation by appropriating the mysterious concept of the living state: one is alive or not! There is really no way to imagine a cat that is both dead and alive in a superposition of states as the Copenhagen interpretation would like! And to illustrate this absurdity, he imagined correlating the life of a cat with the mechanism of a kind of infernal machine locked with him in an opaque and soundproof box. The mechanism breaks or not a deadly cyanide capsule depending on the result of the measurement of a quantum particle in superposition of two states, measured at the time of opening the box. Schrödinger ironises by concluding that if Bohr is right and the state of the particle is undetermined before the measurement, then the infernal machine also exists in the two superposed states just like the cat whose life is correlated to it! The cat should be both dead and alive until the moment the box is opened: only when it is observed will it be dead OR alive and no longer dead AND alive!"

- And this shows that the properties of the macrocosm cannot be directly deduced from those of the microcosm," Florian adds with a sententious tone.

- ... I'm not sure I agree," says Axel after a moment of reflection. "But it doesn't matter! Schrödinger may have ironised, but it didn't change anything since all the predictions of quantum mechanics have been verified experimentally and we have to do with it! But here is another illustration of the problem, proposed by David Lindley<sup>1</sup>. He imagines another version of the box: it does not contain any infernal machine but it involves two boxes. Each one contains a glove from the same pair but no one knows which one of the boxes contains the left or right. One of them is kept in Geneva and the other one is sent to Arthur's in Tokyo. According to classical physics, each box contains a specific glove. According to quantum mechanics if no one looks in the boxes the gloves are in a state of superposition: the two are both left and right! It is only when one of the boxes is opened that the two correlated gloves collapse their wave function so that each takes one of the two possible complementary states."

- You're right, I prefer this version to Schrödinger's," Florian says with a smile.

- I thought so! But this is getting even stranger! Florian: You open the box and discover a left glove! How would you use quantum mechanics to explain what happened?"

Florian gets caught up in the game and answers: "I suppose the glove was instantly determined as a left glove when I opened the box and that it communicated its condition to the Tokyo glove so that it would become a right one!"

- All right! The Tokyo glove collapses into a straight glove even if the box is not opened. The effect is instantaneous, so a-local, and that's what Einstein disliked so much and led him to conclude that quantum theory was incomplete... wrongly, as we have seen!

"But let's continue the reasoning! Matt! Do you think there's a way to transmit information instantly from one end of the planet to the other, faster than light?"

- You're taking me by surprise! But it seems to me that it is, since the determination of the left glove is instantly correlated with that of the right glove from an undetermined state."

- But how do you know if Florian opened the box first? Perhaps it was Arthur in Tokyo who had already opened his and caused the collapse of the superposition of states of his glove!"

- ... That's right!"

- There seems to be an instantaneous action between two correlated quantum objects but it cannot be used to transmit information faster than light! In our case, I would have to call Arthur to compare the opening hours of the boxes to find out who caused the first collapse of the superposition of states. And of course, the phone doesn't allow information to be transmitted faster than light!"

- I see!"

But that's not all! Remember that Einstein demonstrated that the simultaneity of two events was relative. We saw that two events A and B could be simultaneous for one observer but not for another who travels very fast compared to the first."

- The consequence of the finite speed of light, regardless of the observer's speed: yes, I remember," Florian replied. "So what?"

- So how do we know if you or Arthur opened the box first?"

- Just compare the opening hours," I said hesitantly.

- But time passes at different speeds depending on the relative speeds of the observers! An observer standing still in relation to Florian and Arthur could see the two boxes open simultaneously. But this would not be the case for a traveller who would move very quickly to Florian or for a third who would move very quickly to Arthur! Everyone would see the box in their direction of movement open before the other!"

- But then who is right?" exclaims Florian, very interested.

- We are led to another interpretation imagined in the 1950s by a student of Wigner who made it his thesis subject but who has since abandoned physics: Hugh Everett and... behave yourself because it takes your breath away!"

- At this point you can keep going!" Florian says with a smile.

- Everett had the nerve to propose the simplest solution in theory, the most logical and economical... but also the most disconcerting! He proposes that the three observers must be right... but each on his own side!... in their own personal world in a way! From the relativity of time we move on to the relativity of consciences!"

- It's the theory of parallel worlds! What nonsense!" Florian regains his critical mind.

- If you want. But here is an interpretation that satisfies the rules of the scientific method. It is the most economical in terms of principles or assumptions and is based on what we know and observe without introducing anything new. It admits realism - each object exists with its own properties - but resolves the contradictions with which we have been confronted by multiplying the results of the observations according to the number of observers. What we

interpreted as the collapse of a wave function on one of the possible states becomes the separation between several worlds, each with one of the states predicted by quantum physics. The universe becomes local again since we no longer need to invoke the instantaneous transmission of a state regardless of the distance between two correlated particles.

- You mean if I think I'm making a decision among several possible choices I'm only the victim of an illusion and I split myself into as many different myself as there are possible decisions?"

- This is one of the consequences of Everett's model if you want to extend it to the classical world instead of confining it to the microcosm.

- This is even crazier than Bohr's interpretation! Don't you have anything else to offer?"

- Yes, there are many others... for example David Bohm's, still in the 1950s.

"David Bohm has built a whole realistic but hidden variable quantum mechanics: quantum objects have many defined properties even if we do not measure them. But these properties are the result of interactions that we do not control. It satisfies Einstein's intuition and our common sense by arguing that particles are real even if we do not interact with them. There is no longer any wave-particle complementarity but rather a very strong association between a particle and a wave that drives it through space and time. The photon passed through only one slot of Young's device and it was his pilot wave that passed through both slots so that it steered his photon to a localised impact on the screen in accordance with the condition of the device. If only one slit is opened, the wave will drive the photon to a band located just in front of the opening, while if both slits are open, it will drag it onto one of the bands formed by the interference patterns. David Bohm has built a whole mathematical edifice that is perfectly compatible with the experimental results.

- But that's good news," says Florian. "We find realism and objects that behave in better harmony with common sense!"

- Don't go too fast.... There's a price to pay!"

- Damn it! Explain it!"

- To take into account the experimental results, Bohm is obliged to postulate that his pilot wave is a-local and a-temporal: that it is capable of reacting instantly to the state in which the universe is in, and this, without losing energy. Otherwise, we would have noticed a loss of energy due to the work of the pilot wave a long time ago!"<sup>2</sup>

- Oh, that's right. But perhaps the properties of this hypothetical energy have not been sufficiently defined to enable us to measure it?"

- This is not enough to satisfy physicists. Besides, Bohm didn't seem to believe it too much himself because he published ideas on a kind of Order already inscribed in the whole universe and the course of his story to avoid this problem of ghost energy."

- Does he mean that the events are predetermined? That's impossible," says Florian.

- He was never very clear... but he became more and more mysterious and even a little mystical towards the end of his life!"

My head is spinning: "But Axel, what is your own idea? How do you interpret quantum mechanics?"

- Oh me!..... It is well for you to help me to get an idea that I proposed this adventure to you! But hope has been reborn in recent years with a new interpretation which, I believe, has many interesting aspects. It's about decoherence!"

- The incoherence you mean" interrupts Florian maliciously, who no longer seems at all concerned about his injury.

- Florian, you're disgusting," Axel replied with a laugh. "No, it's decoherence, that's what it's all about! This interpretation seeks to reconcile the results of quantum mechanics with our experience of the objective world. It seems to exist to us of course outside the interactions it has with each of us and we all agree to discover it in the same way: we all attribute it the same properties although quantum mechanics seems to indicate that the results depend on each observer!

Could you illustrate your point?"

- Yes, in classical physics I can easily predict the position of the Moon tomorrow, Monday, based on observations and measurements I have made since last Monday, every day, until last night. And anyone would find the same results.

- You wouldn't even need to use Newton's formulas because you could make an extrapolation!"

- Yes. But according to quantum mechanics, I shouldn't get the same results!"

- That's original! Explain yourself!"

- Remember! The microcosm is undetermined until I observe it. Moreover, if I interact with it it acquires properties that could influence a later observation.

- So what?"

- So if I measure the position of the Moon on Monday and Tuesday, I can predict its position on Friday. But theoretically, this Friday position could be different if I decided to observe it on Wednesday!"

- I'm lost!"

- Remember that the measurement determines the properties of the measured object from an undetermined state! If I observe the Moon on Wednesday I can no longer rely on my Tuesday results to predict its position on Friday since its properties are now defined by the new measure made Wednesday!"

- Enough is enough," says Florian. "What's your point?"

- The theory of decoherence allows us to explain why the Moon seems so predictable to us even if we do not observe it. Indeed, the mysterious quantum state only exists if there is no measurement, that is, no interaction with anything, no other particle, no other force field. For the behaviour of quantum particles to remain correlated, coherent, they must be protected from any interaction. However, as early as the 1970s, a mathematician, Dieter Zeh, discovered that superimposed states that can collapse into a state that seems very random to us, evolve very quickly into less and less complex states as they interact with the environment. It becomes possible to explain why a macroscopic object never seems to us to be superimposed: it is because the particles that make it up interact very quickly with each other and with their environment so that only one state remains very quickly".

- That's reassuring! The microcosm retains its quantum peculiarities but the macrocosm regains its colours! At last!"

Axel smiles at Florian's remark: "If you want! Decoherence is a very satisfactory answer to the problem of measurement. But it does not explain our inability to define a reality on which everyone can agree: why is it that we all agree to give the same properties to reality when quantum interactions give different results for different observers? How is it that reality seems objective to us - independent of our relations with it - while the microcosm seems to be linked to the interactions we have with it? Nor does it explain a-locality and a-temporality... There are still difficulties because, although each particle interaction defines a certain future and excludes another future, we do not know which one will actually take place! Research still has a bright future ahead of it! "

## C.10: AND THEN: WHICH INTERPRETATION TO CHOOSE?

"But what do you do with common sense in all your assumptions?" worries Florian.

- But I am convinced that the scientific method we use is the sublimation of common sense, its generalisation to the questioning of the world after an elaboration, a purification by abstraction! Common sense is based on the perceptions provided by the senses and our logical analysis skills that we inherited during our evolution. But our senses don't tell us everything!"

- Now I'm following you," says Florian. We even know that they can mislead us by interpreting the world for us, surreptitiously!"

"Perhaps the great success of science consists in the discovery of the limits and imperfection of our senses. Logic and intellectual honesty lead us to go beyond everyday common sense to apply the method without compromise. Philosophy can no longer be a matter of common sense alone, but must incorporate the results of the scientific method.

- And what would be your conclusions about what physics teaches us?"

- I have the impression that physics has been struggling for nearly a century to preserve its reductionist and rational roots that built it three centuries ago... but it does not succeed! No one is happy and satisfied with the current situation, not even the authors of the interpretations of quantum physics: they all experience a kind of deep uneasiness from the gap that separates the microcosm from the perceived macrocosm and from which we have built classical physics.

"What do these interpretations imply? Nothing that can really satisfy the paradigm in which we have lived for three centuries of rational science!"

"First the Interpretation of Copenhagen. At first sight it is not really an interpretation but rather the abandonment of any desire for ontological explanation in favour of objective pragmatism. "Let's not try to describe what we don't see: let's just use the results of our discoveries" seem to say Bohr and his disciples! But that's not really the end of the story! We have to admit that the intuitive model Bohr uses to build his theory works perfectly! It is the most extraordinary discovery of science since it was born, the most precise, the most fruitful! It has never been faulted for nearly a century while generations of physicists - and not the least - have never stopped showing that it suffered from internal contradictions or that it was incomplete... without any success so far!"

"What is this Bohr intuition so fertile and exceptional? He was too good a scientist to reveal it to us: he only exploited it, perhaps because the knowledge of the early twentieth century did not allow him to go any further. But now that we know much more than he does, what can we say about the basis of the macrocosm? The analysis of Bohr's remarks concludes that the nature of the microcosm is fundamentally foreign to that of the macrocosm. It is neither realistic nor causal. It is not local or temporal in the sense that we understand it in classical physics. We can see that Bohr describes well what the microcosm is not, but does not venture to say what it is!"

"But admitting what it is not already forces us to deeply reconsider what we think we know about the macrocosm and its properties since, of course, it is the result of a construction derived from the microcosm."

"If Bohr doesn't really help us, what does Everett have to offer? An interpretation completely in the wake of Occam's scientific method and razor, since it is the one that is the least greedy in new principles... but at what price! An immeasurable infinity of worlds that not only separate us forever from each other on different trajectories, but multiply our own consciousness into a multitude of me, at least part of which would seem profoundly alien, if not detestable to us! Perhaps one day we will be able to exploit Everett's Multiverse by building computers that take advantage of its properties. But I'd be surprised if it really satisfies our aspirations to understand the world!"

"And Bohm's other realistic interpretation: what does it bring us? The microcosm, he says, exists with its properties even if we do not interact with it. That would make Einstein happy! But what is the price? It is very heavy because it pushes us to admit the existence of what Bohm elegantly calls "the pilot wave" and which in reality is a concept perfectly incompatible with classical physics! The pilot wave is the result of a kind of interaction of each quantum object with the whole rest of the universe! And all this information is obtained instantly and without any loss of energy! This is a tribute that very few physicists accept to pay at the altar of realism! Especially since a more in-depth analysis of the model seriously endangers free-will! Didn't Bohm finish his almost mystical life after designing his Implicate model of Order - quite obscure, I must admit? So not much hope of finding satisfaction here either."

But decoherence seemed to satisfy you!"

- Yes and no! Yes, insofar as it explains well what we know about the microcosm and the macrocosm. It shows why the macrocosm seems realistic, local and temporal to us based on the evolution of the microcosm that we have learned to describe and predict, if not explain! However, the nature of the microcosm is deeply confusing and incomprehensible according to our perceptions of the macrocosm. This interpretation makes us recognise that the world is in perpetual creation through an underlying process of particle travel into and out of our world. It allows all kinds of strange things as long as they are very unlikely, they don't last long... but don't exclude them! Nothing prevents a particle from crossing a perfectly impassable obstacle, or a black hole from evaporating when nothing can get out! The continuous process of creation frees the microcosm from all these limitations and allows the prisoner to find himself outside his cell, which has remained sealed, by the miracle of quantum phenomena. It is only very unlikely because all the particles that make up the prisoner would have to react in the same way at the same time... but it is not impossible in theory! Can we accept this model of decoherence as satisfactory? I'll leave you to judge! On my side I learned to doubt my prejudices and decided to re-evaluate them with the greatest openness of mind I can have!"

- In short! We didn't get out of the woods," Florian concluded.

- Yes. We know that the world Newton imagined and perceived by our senses is not suitable. We do not know how to synthesise the two great physical descriptions of the world: Relativity for the macrocosm and quantum mechanics for the microcosm: they remain incompatible although both describe with great elegance and precision the world to which they apply! We are obliged to admit that the world as we perceive it is not the right one, but we do not yet know how the next one will be. And that's why we have to check our certainties!"

"But enough of this! Let's get down to business!"

## C.11 : PREMONITION ?

"Because for you we've had fun so far?"

- No Matt! Axel smiles and relaxes. I meant we're swimming in hypotheses and I'd like to move on to more concrete things!"

- We're listening to you: we've been waiting for months for your explanations!"

- Before explaining myself, I would like to take stock of the experience on the time I proposed to you based on Dunne's work... Let's start with Florian?"

Axel looks at him with an interrogating look: Florian hesitates, embarrassed.

- Listen.... I really tried hard... But I don't have to be a friend of my dreams because I couldn't remember them in enough detail to get anything out of it..."

- You probably haven't been able to put your prejudices aside," Axel replied, disappointed.

- No. Honestly, I believe I am an authentic scientist and have the open-mindedness to do so.... But I'm not a dreamer... literally or figuratively! I am willing to prove my good faith by admitting the reality of your own experiences. In science, any acceptable observation must be reproducible by anyone who can afford it... let's assume that I haven't been able to find the necessary means!"

- It's a pirouette!" Axel is disappointed.

- No: let's just say I've learned enough so far to no longer be tempted to take you to a psychiatrist," Florian concludes by friendly tapping Axel's shoulder. His smile seems less mischievous than usual.... more friendly too.

After a moment of silence Axel looks at me with a questioning mood.

" Oh, I'm willing to describe my results to you, but I'm not sure it's very useful: you really have to experience this kind of episode yourself to draw valid conclusions."

- That's right... that's why I asked you to do these experiments. But it is also true that sharing them, submitting them to criticism allows us to draw the most objective conclusions possible..."

- If you want.... I must first reveal to you that I approached this experience with great interest, having already experienced several situations evoking premonitions. Axel's protocol has the merit of framing ideas, creating a rigorous structure that is useful when working with the subjective psyche."

- So you got any results? Axel seems to be getting interested again."

- Yes, on many occasions. But I repeat that they are difficult to share because it is not possible to transmit the emotion, the shock sometimes felt when we discover the phenomenon. I think that these feelings should be an integral part of the experience."

- Try it all the same!"

- Then I will choose one: the one that touched me the most because it was very meaningful. I don't know what it will do to you, but I can assure you that it has deeply upset me and convinced me of the interest that the phenomenon deserves.

"That's it... You know that my mother died a few months ago, after a disabling illness that was difficult for both of us to live with. Her strong personality, her independence, prevented her from living anywhere but her home. But she needed help, she was forced to rely on others.

"One afternoon her nurse called me in because she was very ill. A doctor called urgently to replace her own on vacation clearly told me that she was far from being in agony, although she was very handicapped. The remark was relevant because my mother had had enough of this life and only her faith prevented her from taking the necessary steps to end it. The nurse who knew her well confirmed the prognosis so I came home to take care of my family, relieved to know that a night shift was taking over.

"In the middle of the night, around three in the morning, a doctor called me to let me know that she had died when no one expected it. I dressed in a hurry, in a second state, taking what was at hand and went to watch her the rest of the night.

"Sitting in front of the body I was filled with many feelings including the guilt of leaving her to die alone. After a few hours of vigil I see my notebook on my lap: I had taken it without thinking about it, whereas it usually only accompanies me when I attend a conference or when I think I have time to work...

"I open the notebook and it's a shock! I come across notes taken four months earlier while I was on holiday in Italy. It was the memory of a dream from the previous day that I transcribed as part of the experience you had proposed to us. In that dream a stranger came into my room and woke me up to tell me that my mother had died."

- You'll admit there's nothing very amazing about it since your mother was seriously ill! Florian immediately regains his critical mind, even though he promised to trust us!"

- That's absolutely right! I already felt guilty about being on vacation away from her when she was not well. But that's not all: in my dream I quickly put on beige pants and a mercerised cotton polo shirt of the same colour and, according to a logic specific to dreams and perfectly illogical in the real world, I was convinced that the very fact of having chosen this beige polo shirt had caused her death!"

- The details you remember amaze me, but I get nothing more out of it," Florian mutters.

- Wait a minute! Reading my notes I suddenly realised that the clothes I had taken in a hurry were exactly those of my dream... and I felt guilty, just like in the dream... !"

Florian seems to be thinking. "I understand better what you meant about the importance of the experience: you could interpret it as a series of coincidences, unless you live them yourself." He turns to Axel: "Let's say it could be a premonition: how would you explain them? How could you understand that something like that is possible? If that were true, it would upset everything we think about the nature of reality... it makes us dizzy!"

- I can't explain them, my goodness! But that doesn't stop me from accepting them, knowing that the real nature of our universe is far from being understood and much more mysterious than we imagine!"

I'd like to get more details: "Axel, you're not the kind of person who just makes observations... you probably have some explanations!"

- That's true, but they're all equally incredible! Moreover, they are not mine: they logically follow the discoveries of 20th century physics and in particular those of Einstein: it is he who has shown us that the nature of time is not at all the one we perceive."

- And what did he think?"

- In the context of physics, his discoveries are amazingly elegant and cohesive: they demonstrate very clearly that time is only one aspect of a dimension that we do not perceive as it really is. As for the applications of these discoveries on the nature of time, he was never very talkative about it. But on a few occasions he said enough to allow us to imagine his conclusions. He thought that the distinction we make between past, present and future are only persistent and obstinate illusions!"

- Yes, but still? What is the concrete basis for thinking that?"

- But on all its equations and the confirmations of the predictions they propose! For a century, no result has called into question his concept of space-time: on the contrary, it is used for a plethora of applications that he has never imagined himself... GPS for example! Einstein's formulas are necessary for them to give accurate results!"

- This remains very abstract for a non-physicist! Isn't there a way to illustrate the nature of time according to Einstein in a more concrete way?"

- Not really because time is only one of the components of a dimension that also involves space. We are only able to perceive three dimensions of space, the fourth one is impossible for us to imagine: only mathematics really allows us to understand it through symbolic logic. We understand the equations and their results but we cannot visualise the true nature of a four-dimensional universe.

"Fortunately, it is still possible to get an idea of the gap between reality and the image that our perceptions give us: it is possible by trying to put ourselves in the shoes of an organism that would live in a universe with one or two dimensions of space and that would perceive time with the limitations that are ours. By analysing his way of seeing the world from our higher perspective, from our three-dimensional perception, we can understand why this fourth dimension is so strange to us. Then, from there, we can better approach the study of the characteristics of this universe which seem absurd *a priori* to us and which nevertheless become unavoidable... such as the contraction of an object which moves very quickly, the ageing slows down of a twin brother while the other takes age normally and so many other strangeness... !"

- And premonitions could be integrated into this new perspective?"

- I'm afraid you're very disappointed.... many ideas have been published but there is no way to understand how a premonition would be possible... largely because we don't know much about consciousness! But let's start by putting ourselves in the shoes of organisms that are even more disadvantaged than us: follow me!"

Axel precedes us at the other end of the room, which he illuminates from two spots screwed onto a beam of the ceiling. In the corner is an old walnut clerk's desk with a comfortably inclined flap for writing. At the top of the cabinet, in a groove provided for pens, he picks up a chalk and heads for the covered wall for a good three meters of his obviously handcrafted blackboard.

## C.12 : FLATLAND

Axel draws a horizontal line on the left of the blackboard: "We perceive a three-dimensional world; each dimension allows us to travel through space in a different direction: from left to right, from front to back and from top to bottom. You notice that every time I add a dimension, it is as if I were stacking an infinite number of additional universes in a direction perpendicular to that of the movements allowed in the original universe. By doing this I also introduce the freedom to move perpendicular to the movements allowed in the lower type universe.

"Now suppose that there really exists somewhere a one-dimensional universe that we could call "LineLand". Let's try to visualise the world as it would be perceived by an indigenous person."

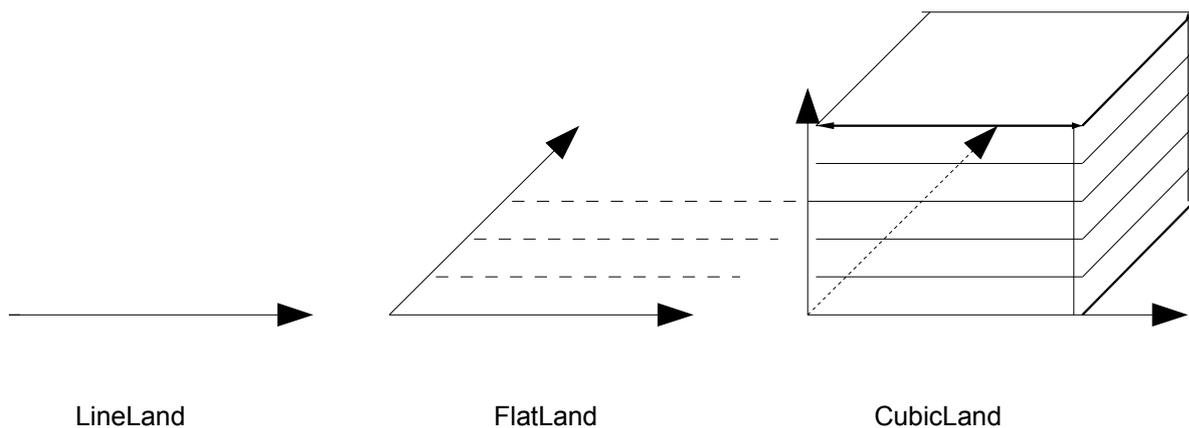


FIGURE C.9: *The LineLand is a one-dimensional imaginary universe. Its inhabitants can only move to the left or right.*

*The FlatLand stacks an infinite number of LineLands in a direction perpendicular to the possible movements in the LineLand. Flatlanders can move to the left or right but also to the front or back. They live in a two-dimensional plane.*

*The CubicLand in turn stacks an infinite number of FlatLands in a direction perpendicular to the FlatLand's plane. Its inhabitants, like us, can move in three directions in space.*

- The poor should better get along well with his neighbours," says Florian, looking mockingly !"

- Why, I said?"

- Because the unfortunate LineLander is condemned to spend his whole life between them since he cannot step over his neighbours to find others!"

- Yes," Axel adds, "this world should be terribly frustrating!"

- On reflection, I'm not so sure anymore," Florian replies. Evolution being what it is, he should be well adapted to his universe and should feel no more or less free than we do: and thus, not feel particularly frustrated!"

- It's interesting... thinks Axel out loud. "In fact, you may be right: going up or down should seem as absurd to him as time travel is to us. This possibility is not part of our universe, whereas Relativistic Physics suggests that it is possible because time builds an extra dimension through which we could travel, at least in spirit."

- It's hard to admit!"

- True: it is very difficult to imagine a world so fundamentally different from the one we perceive, although our intellectual faculties have allowed us to discover a 4D universe in which time is no longer that ineffable river that inexorably takes us with it but where it becomes a key aspect of the fourth dimension: space-time.

"To feel the limits imposed by our senses adapted to a 3D universe, we must imagine the one that an inhabitant of a one-dimensional LineLand or a two-dimensional FlatLand would perceive, and then extrapolate our discoveries into the 4D universe.

"Let's start with FlatLand: the two-dimensional universe of space. Imagine that Matt is a FlatLander and decides to explore his miserable universe in a rocket capable of reaching speeds close to that of light "c".

Axel draws two superposed planes crossed by a rocket and then adds additional planes inclined with respect to the first. (Figure C.10)

- It looks like a comic book. You represent a rocket at different successive moments, each moment is represented by a plane above the previous one?"

- Yes, we can represent the flow of time as a series of nows that stack one on top of the other: in each of them we draw the rocket taking into account its possible movements according to dimension D1 or D2."

- If I understand correctly, the rocket takes off at time 2 and moves in the direction of D1. But why are you tilting the whole plane to the right? I would have moved the rocket in a series of shots that remain parallel to D1!"

- No. Remember our discussion on the Principle of Relativity of the movement."

- Einstein?"

- First Galileo! When you travel by plane, you only notice your way by looking through the window to perceive your way according to objects that don't move with you. Without the vibrations and noises of the engines you would feel perfectly motionless in the plane. You don't move in relation to your frame of reference: it travels with you. If you drop an apple, it will land at your feet, unless you are in the acceleration or braking phase. Your rocket and everything it contains is part of a universe of its own in which everything is motionless. If an object external to your rocket travels with it, it will also be part of this universe. All other objects will give you the impression of moving while you yourself will not feel any movement. So I have to draw Plane-Universes in which your rocket and everything in it does

not move for you as long as it moves at constant speed, even if it is very fast compared to other reference frames: here, the direction D1. The only solution is to draw my inclined planes to stay perpendicular to the direction of your journey and these planes will be those that contain all the objects that travel with you, in the same direction and at the same speed and that you will perceive as immobile.

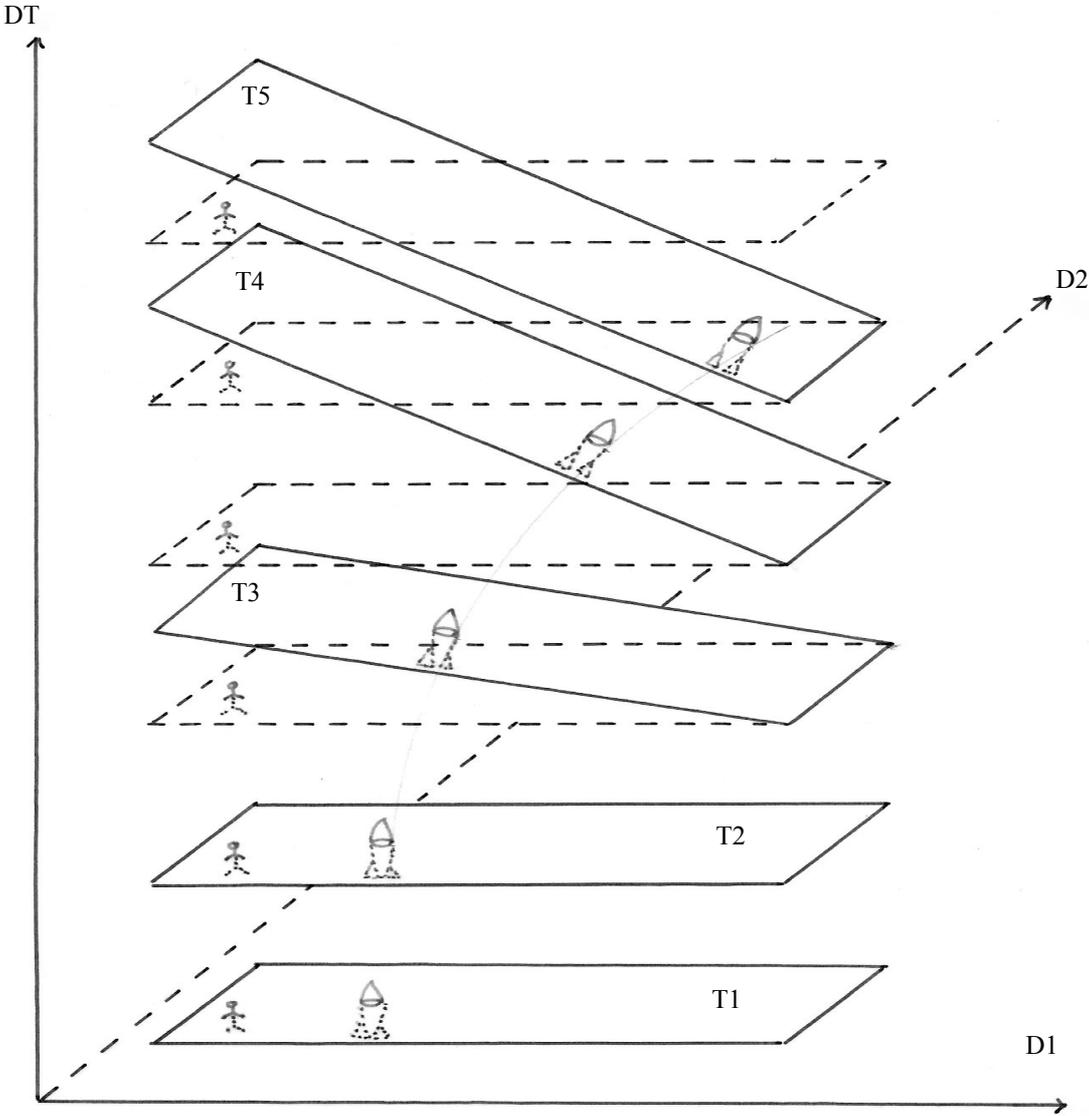


FIGURE C.10: Matt takes off from FlatLand at time T2, accelerates to time T4 then continues at a constant and very fast speed. The Plane-Universes contain Florian and Matt's rocket as they probably perceive themselves and not as an observer in the third dimension would perceive them: for him they would be entirely included in the Plan-Universe and would not exceed towards the third dimension.

"In our current world our speeds are so small compared to "c" that the planes will hardly be inclined: we will not perceive the strange things that we will describe for speeds close to "c". To try to visualise this phenomenon you can imagine that we draw a new plane every second: in this case they will be 300'000 km apart from each other along the vertical axis DT ! Suppose Florian attends the takeoff of your rocket which is released from the Earth by travelling, say.... 20 km/sec; you will not perceive the inclination of your universe plane with respect to that of Florian since the angle they will make between them will only be  $0.006^\circ$  that is to say the apparent angle that the diameter of a coin would have seen from a distance of three kilometres!"

- I see. And where the planes are turning I should feel a variation in speed and objects that wouldn't be attached to the rocket would move relative to me."

Florian suddenly intervenes: "Wait a minute both of you! Matt, you're very quickly satisfied: I'm not! I understand well this way of structuring time by drawing successive planes along the vertical axis, but I claim that we can obey the Principle of Relativity without tilting the Plane-Universes: it is enough to draw Axel's rocket entirely drowned in its plane and to make it travel along the D1 axis." He gets up, erases the board and draws while commenting: "I can even accompany him in a rocket set at the same speed so that neither Matt nor I observe any relative movement with respect to each other!"

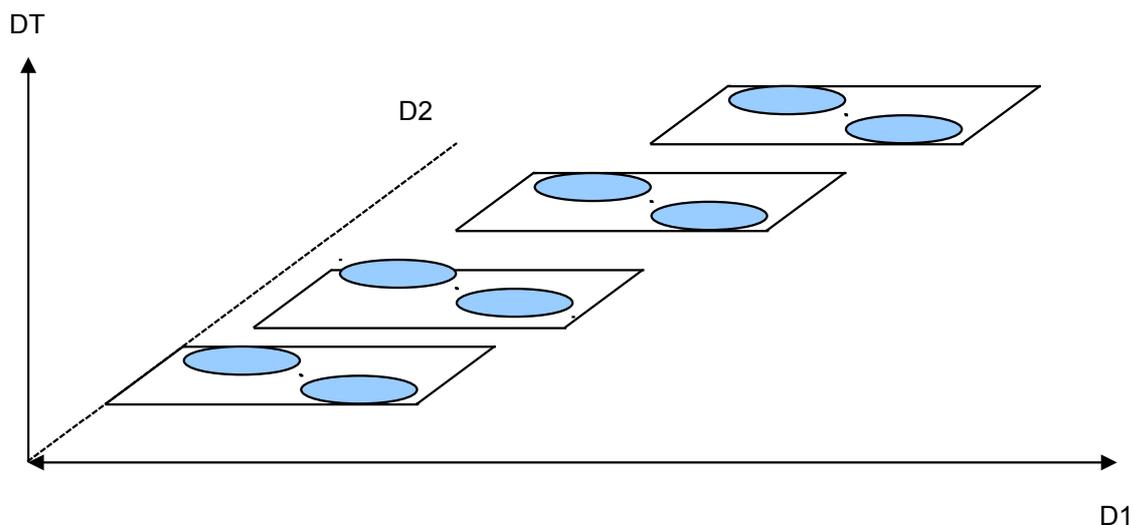


FIGURE C.11: *Florian suggests keeping the Plane-Universes parallel rather than tilting them in the direction of their movement: this preserves Galilean relativity without introducing distortion.*

Axel watches him do it without saying anything and then smiles: "You are absolutely right... until 1905! I see you haven't grasped all the subtleties of Einstein's discovery. It's true: you find Galileo's relativity, but not Einstein's! To do this, you have to find a way to force time to flow in the same direction as your movement! Remember.... Einstein decided to rely on the theoretical and experimental results of physics rather than on our perceptions. This perspective has led to the revolution that we know. The theory, with Maxwell's equations, suggested that the speed of light was a constant and the experiment confirmed this consistency while our common sense led us to predict different results."

Remember the thought experiments proposed by Einstein and which have been very regularly confirmed by the experience since then."

- For example?"

- GPS uses the constant speed of light to calculate your position in space."

- And how?"

- They are listening to a battery of satellites rotating at 20,000 km from Earth that contain very precise atomic clocks. They regularly broadcast their identification and time. Your device will receive information from half a dozen satellites and compare the times they display. As the signals they send to your device all travel at the same speed "c" regardless of the satellite speed, it will take them longer to reach you because they are far from you. Your GPS knows where they are: it has the coordinates of their trajectory, so it can calculate its own position taking into account the delay between the time a satellite emits and its own time when it receives the signal.

"Remember again the thought experience I proposed to you: the train crossing a meadow..."

- The car that was lit by a lamp?"

- Yes. Here is a lamp in a very fast car. The lightning flash reaches Matt's retina and the cow's retina at the same speed "c" while common sense tells us that it should reach the cow's retina at a speed equal to "c" increased or decreased by that of the train depending on whether it approaches or moves away from the animal."

- So what?"

- Since the speed "c" always remains constant, Einstein logically concluded that it is time that passes at different speeds for the train passenger and the cow."

- It may make sense to you, but it doesn't make sense to me!"

- Yes, look! Axel draws a wagon and a cow. (Figure C.12)

"We measure the speed of the light rays that reach the cow's retina and yours. To simplify, let's take this measure when a brief flash from the lamp reaches your retinas at the same time when you are both exactly the same distance from the lamp: the distance between Matt and the lamp = the distance between the cow and the lamp."

- So what?"

- We find that the speeds of the light rays are identical while common sense suggests that this speed should be added to that of the train on your retina and decreased accordingly on that of the cow, if we do not take into account the different angles."

- Of course."

- But that's not the case! It's the same on both retinas! We are forced to conclude that, from the cow's point of view, it took more time for the lightning to travel the same distance in the train as the distance between the cow and the lamp. So time flows more slowly in the train than in the meadow. The simplest way to illustrate this phenomenon is to switch the planes that contain the objects in relative motion in the direction of their motion.

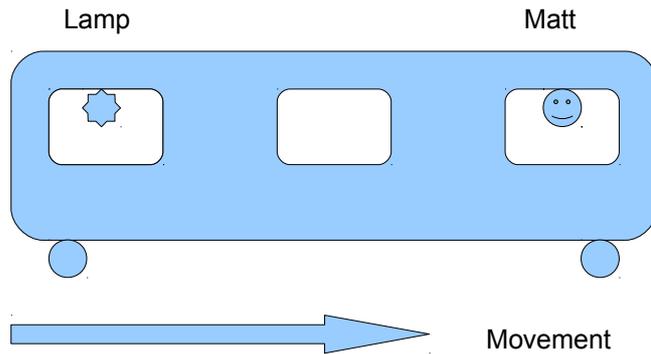


FIGURE C.12: *Matt in a very fast wagon, meets a cow standing still in a meadow. A lamp in the car is at the same distance from Matt as from the cow. The speed of the light ray measured at Matt's retina is the same as that measured at the cow's retina, whereas it is expected to be higher since the speed of light should be added to that of the train. From the cow's point of view, the light beam took longer than it reasonably would have taken to reach Matt's eye. As a result, time flows slower in the train than in the meadow.*

"Reality is much more complex and impossible to draw: we travel on the wings of time in a 4-dimensional space whose projection in a 3D space is all we perceive. The consequences of this projection are satisfactorily illustrated by the tilting of the planes: each observer will have the impression of being motionless in his own universe and will see the time and space of the other deformed all the more so as their relative speed is high.

Florian admits: "Yes... I remember now. And this difference in the speed of time flow is relative, that is, for me in the train, it is the time of the meadow that passes more slowly."

- This is true because, for you, it is the cow and the meadow that are in motion while you are still in relation to the lamp. There are many other very surprising consequences that I will not develop<sup>2</sup> but I would like to insist on one of them because it could have an importance on a possible understanding of premonitions."

- Are you going to make us believe that time travel is not as absurd as it seems?" Florian laughs nicely: "Notice that after being introduced to a travelling meadow and a cow who has her point of view, I expect almost everything from physics!"

- Laugh if you like it, but you'll see it's even stranger than you think!"

### C.13: FROM FLATLAND TO THE BLOCK-UNIVERSE

Axel erases his blackboard: "Let's take the example of FlatLand again but let's add Florian and make him travel in his rocket... like that." (Figure C.13)

- Don't you think it's getting too complicated?" Florian doesn't seem ready to ride his rocket, even virtually!"

- I will use different colours for each of you: it will be clearer. Let's see... Matt will be brown and Florian green!

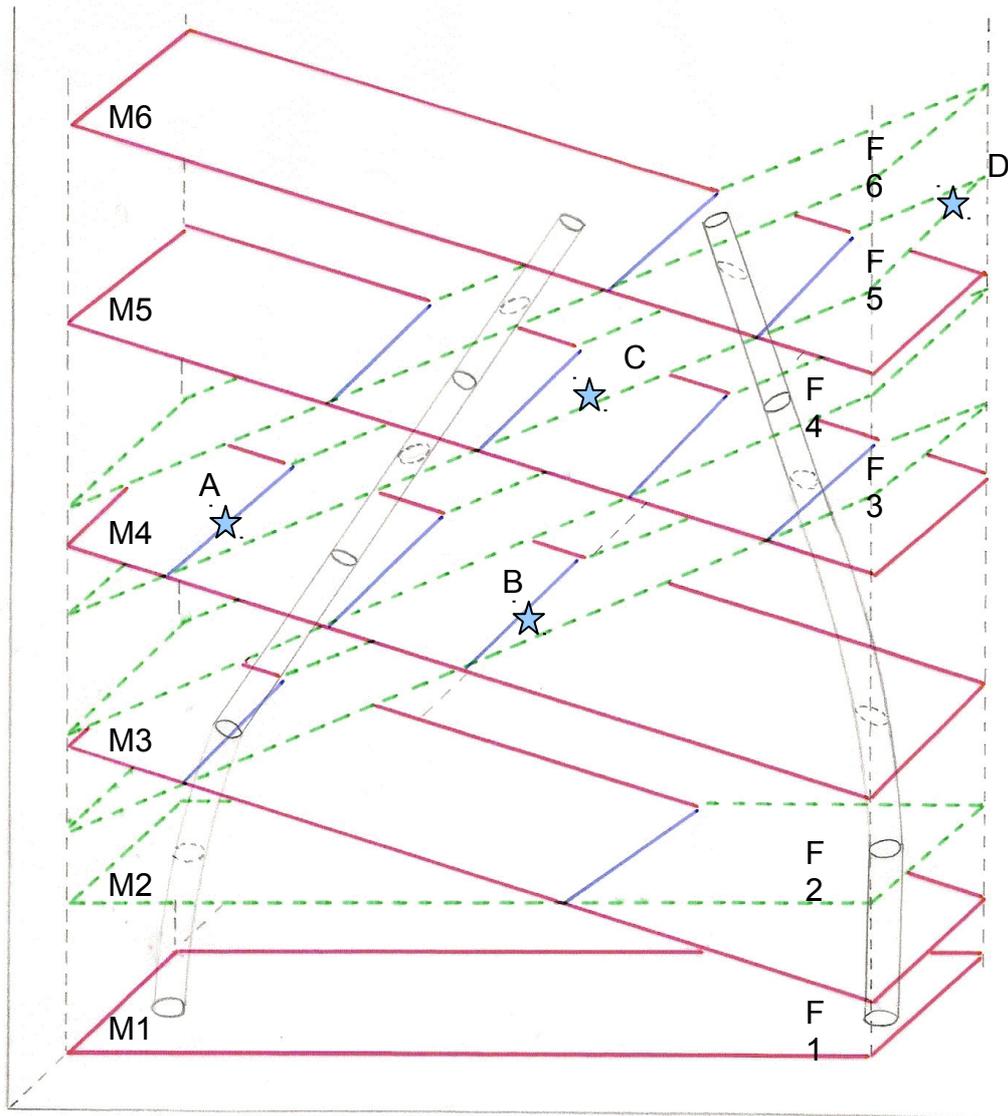


FIGURE C.13: Matt takes off at time  $M1$  and then continues his journey at constant speed from time  $M3$ . Florian takes off at time  $F2$ , accelerates and then continues his journey at constant speed from time  $F3$ .

For the motionless observer in the 4th dimension that we are, stars  $A$ ,  $B$ ,  $C$  and  $D$  explode simultaneously. But for Matt only explosions  $A$  and  $B$  are simultaneous at time  $M4$ : stars  $C$  and  $D$  explode later because they are further away. Indeed, Matt passes exactly between  $A$  and  $B$  at time  $M4$  while the light emitted by the explosion of the star  $C$ , further away, will only reach him after  $M4$ .

For Florian it is the explosions of stars  $C$  and  $D$  that are simultaneous at time  $F5$ . For him, star  $B$  exploded well before  $A$ , shortly after he passed through  $F3$  and well before the simultaneous explosion of  $C$  and  $D$  in  $F5$ . This difference in simultaneous events according to

*the observer who perceives them strongly suggests that all events exist in a Block-Universe whose different slices are perceived by different observers moving relative to each other.*

"Matt takes off after Florian. You accelerate and then run a constant speed. For Matt, from time M3 and for Florian from F3.

"Notice the variation in the shapes of the rockets according to whether they are in the green or brown planes.

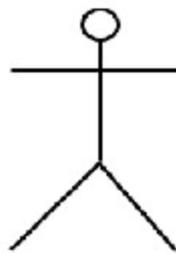
- Yes, so what?"

- This is one of the strange consequences I mentioned earlier: the deformation of lengths in the direction of relative speed."

- And in good English, what is it about?"

- Well, Matt you will appear to Florian shorter, thicker and deformed to the right while Florian will be for you just as short and wide but distended to the left, a little like that!" (Figure C.14)

Axel laughs while he traces caricatures that don't really benefit us !



Matt seen by Florian

Matt seen by Matt

Florian seen by Matt

Florian seen by Florian

FIGURE C. 14: *Although Matt or Florian do not change shape inside their rocket, they appear all the more deformed in their comrade's telescope because they are in rapid movement with respect to each other.*

- I don't see why we should be so ugly at all!"

Axel laughs and then adds a drawing. (Figure C.15)

Florian calls us to order: "And the time travel you promised us, what does it have to do with these deformations?"

- I mention this effect so that you can understand why I called the vertical axis DT and not only T: it is a dimension that involves time and space in a synthesis that is completely foreign to us because our speeds are not sufficiently high compared to "c", but which is a logical consequence of Relativity.

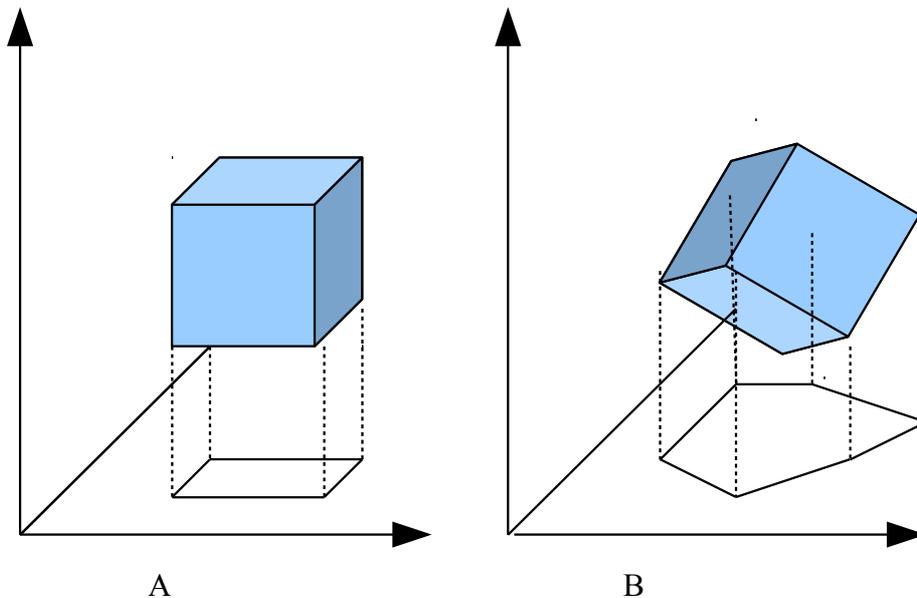


FIGURE C.15: For a FlatLander that inhabits in the horizontal plane, a cube from the Block-Universe and that crosses FlatLand will be perceived as a solid body in the shape of a diamond (A) or in a more complex shape (B) if the cube has undergone a rotation in the third dimension that he cannot see.

"But it is the relativity of simultaneity that interests me most. It will lead us to even stranger discoveries. First of all, I would like to point out that, in your rockets, you are travelling in a two-dimensional space universe, D1 and D2 and a space-time dimension DT. "

- All right. And you observe us from your world that is imperceptible to us, from your sky with three dimensions of space and one of space-time," Florian says smiling.

- Exactly: I am a god for your FlatLand! For me the four stars I drew in A, B, C and D explode simultaneously... Florian! How will you perceive them in your rocket?

Florian thinks for a moment: "I guess for me only the explosions of the stars C and D will be simultaneous since they are at the same distance from my trajectory and in my reference frame F5."

- How about you, Matt?"

- I'm not sure I can imagine the situation clearly, but if I imitate Florian's reasoning, I should conclude that stars A and B explode simultaneously for me," I hesitated.

- But you'd be right! For you the explosion of C is in your future, then that of D will be even later while for Florian the star B exploded well before A. Meditate this conclusion, it's worth it!"

We remain silent for a moment. Then Axel asks: "The discovery that a given event can be found in the past of one observer and in the future of another is staggering, don't you think?"

- Of course," says Florian. And what conclusion do you draw from that?"

- I don't see how we can avoid thinking that all the events already exist in what could be called an unchanging Block-Universe, where nothing moves and that I drew on the board by the volume in which I represented your personal frames of reference."

We remain silent for a long time under the shock of this conclusion. Then I ask Axel: "But if you're right, the past and the future become relative."

- Yes."

- But then one could imagine that the effect occurs in the past of an observer before he perceives its cause that would be in his future!"

- Fortunately not! The cause will always come before the effect, whatever the position and speed of the observer, as long as he does not travel faster than light! In order for the effect to be observed before the cause, the observer would have to go back in time, i.e. travel faster than "c", which is fortunately impossible."

- But you were suggesting earlier that time travel would be conceivable.

- Not a trip like this. On the other hand, travelling to the future would be possible. Imagine two twin brothers: they could age at different speeds if one of them makes a trip in a rocket whose speed approaches "c". He will return to Earth in his brother's future because time would have passed more slowly for him than for his twin on Earth."

- You reassure me," I said.

- But I'm not reassured at all," Florian says. "If we follow your reasoning, everything would already be written and we couldn't change it! We would only be proud puppets convinced that we are their own masters, that we have free-will that is just an illusion! That's impossible!"

- This question is as important as it is difficult to study! Many philosophers have discussed it... and so have physicists. No one really has a definitive answer to offer. But there are possible answers that I don't want to detail because it would take us too far and it's not my major concern right now."

- Could you at least explain how they allow free-will to be saved in an unchanging Block Universe?"

- Very quickly then. First of all, we can imagine that the future is only determined in a finite volume limited by the speed of light, that would be enough!"

- That's not enough! I need a future infinitely close to my present and perfectly undetermined to be reassured on my free-will!"

- Then you should fall back on another solution. Remember Everett's model, one of the interpretations of quantum physics I presented to you."

- And which one of your mind-boggling fantasies was it?" Florian asks.

- It was the simplest model because it was the most economical: the one that presupposed nothing other than the experimental results and drew the direct conclusions. In particular, he proposes that there is no collapse of the wave function and that the perception of events is relative because it depends on the observer. Finally, he suggests that quantum mechanics is not probabilistic as we perceive it in our experiments, but that all possible results exist at the same time... but in different worlds!"

- The Multiverse theory?"

- Yes. With this concept you can save your free-will... to a certain extent."

- How?"

- I can't help you much, but you could imagine that your free-will allows you to mysteriously activate the Multiverse switches so that you consciously live in the parallel world you have chosen."

- But then another myself would be in another world?"

- Maybe... His free-will would have made him choose this other world!"

- You're not really reassuring me!"

- I'm sorry, but that's all I can offer you: the world is far too strange for our limited imaginations!

Florian sits in his armchair, elbows on the armrests, head bent forward, chin resting on his two thumbs together and remaining silent for a moment. He straightens up and asks Axel: "Do you realise what you want me to swallow? Let's start from the beginning. Your premonitory dreams would suggest that our consciousness - or our unconscious rather - would be able, God knows why, to take a look at the future, then come back and share it with us. But that's not all! You suggest that other consciousnesses, those of the visionaries, would be able to probe ours to find past... and future memories!"

- Yes, I know, it's impossible... How impossible it was for the speed of light to be constant in all cases! As it was impossible for two objects to remain correlated even if they are too far apart in time and space for them to communicate with each other... But these premonitions - if confirmed, of course - force us to change our frame of reference as Einstein did.

"You refuse to imagine a consciousness that goes and returns through time to explore multitudes of worlds that already exist... But if the notion of time is only a human conception and in another dimension the past, present and future are similar, it is no longer unimaginable to come and go from one to the other!

"You refuse to imagine a communication between two separate consciousnesses in space that would not pass through our senses. But what if this separation is only an illusion due to our limited perceptions? Imagine, for example, that our unconscious has a certain thickness in the fourth dimension that is not directly perceptible to us..."

Axel erases a piece of board and draws FlatLand populated by more or less swollen cells: some with some kind of antennas. (Figure C.16)

Florian gets up: "Well, I've had enough for tonight, we're swimming in science fiction; we can't get anything good out of it!"

- I don't entirely agree," Axel says. I admit that it is not possible to accept these interpretations if we have not personally experienced events that lead us to question our perception of the world. You did us the honour of admitting our experiences since you didn't have any yourself. But I remain convinced that you should persevere: it is worth it!"

- To lose my free-will? No, thank you!"

I answer Florian in turn: "Maybe I have less reluctance than you to change my mind: I'm less rooted in critical doubt than yours. Perhaps this has allowed me to be more free and to accumulate interesting observations. Why don't we stop speculating and resume this discussion another time, maybe with new observations?"

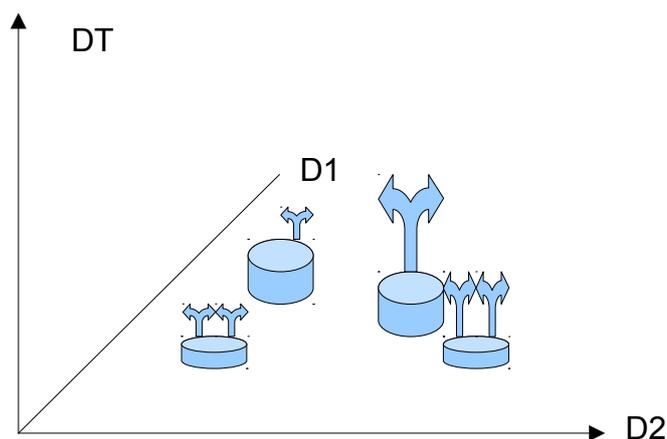


FIGURE C.16: *FlatLanders with a certain thickness or antennas projected in the 3rd dimension DT could perceive a larger slice of space-time or share information without their consciousness being confined to the 2D FlatLand, the only reality accessible to their senses.*

- If you want," Florian says. But you still haven't explained to us what triggered this whole adventure," he adds, turning to Axel.

- We are getting there.... First, I wanted to present to you the astounding perspectives that our discoveries suggest."

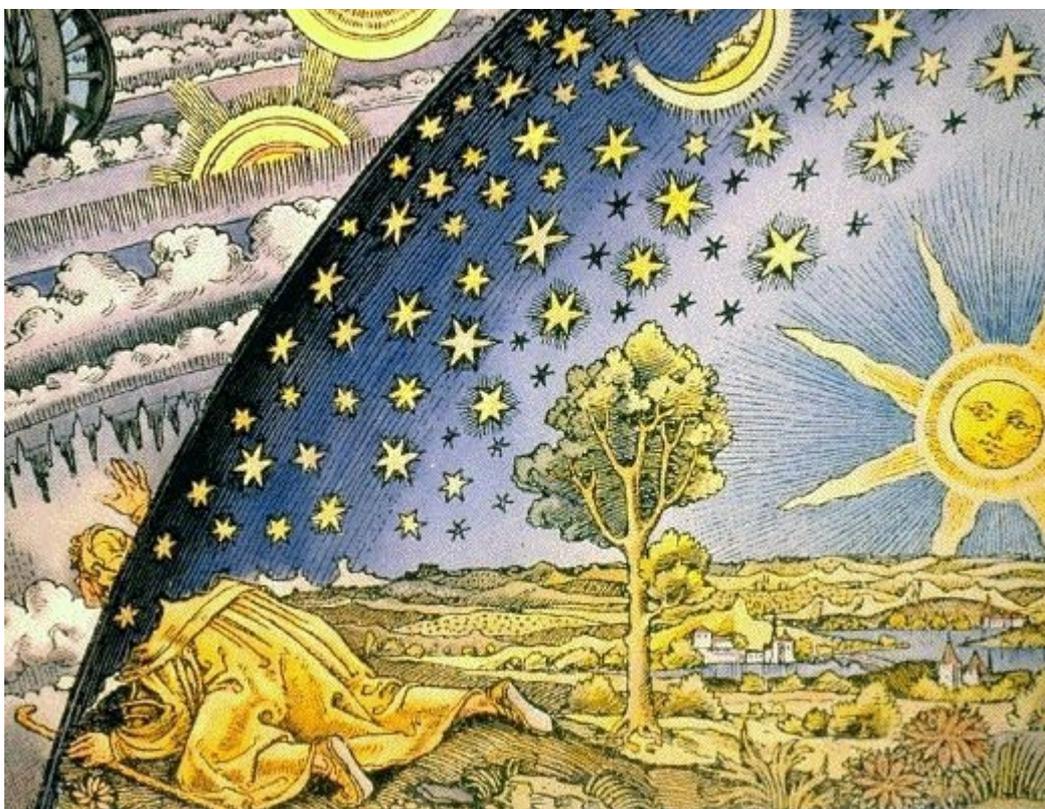
- I expect the worst," says Florian. "Amazing... that's an understatement! On the other hand, the interpretation of your results, which involves decoherence, seems to me to be prodigiously interesting insofar as it provides a complementary and fascinating insight into biological problems. I'll think about it.

"The more I study life, the more I am convinced that it is an interactive phenomenon rather than a reality confined to the level of the isolated individual. That is why I was very struck by the discovery of the importance of interactions in the microcosm that seem to determine the properties of the macrocosm as we perceive it.

"I suggest you come and spend a weekend in my cottage and talk about biology this time! We will finally return to Earth to explore the importance of interactions in the context of living things: I would like to present to you why interactions seem to be as fundamental in biology as they seem in physics."

Axel looks thoughtful but rather relieved: "But I'm sure Matt would be as interested as I am to hear from you!"

About Mind...



*The author sensed that the nature of the universe was not the one that seemed familiar to us. He joins the discoveries of physicists when he emerges from our world as our mind builds it to try to imagine the vision it would have if he were able to pierce the shell of our representations!*

*It is curious to note that he seems to have encountered the tree of life during his peregrinations....*

BOOK FOUR: Implementation

*About Life...*

## D.1: AN OMELETTE WITHOUT BREAKING EGGS

"Here, lower the flaps by 15%, will you?" Florian sometimes offers me the opportunity to be his co-pilot during the flight phases without any worries. I push the lever to the left: the flaps lower and brake the plane as Florian chooses to start his approach on Megève, all white under the snow. Already the Glacier Armancette is pointing its dazzling peaks of sunshine well above us. We can see the large snowfield that will welcome us to the "Cote 2000". To the right, below, is the old Megève with its dark wooden chalets, gathered around the superb Hôtel-de-Ville square. And all around the village are scattered more modern chalets along roads betrayed by dirty snow. Their colour is lighter: glazed windows cover most of the southern facades, while the old buildings have only small multi-pane windows. The reflection of the winter sun, low on the horizon, jumps abruptly from one chalet to another while Florian completes his last turn and begins the final.

"The flaps at 100% please!" The aircraft slows abruptly and enters gliding flight when Florian lowers the engine speed. We can better perceive the wind whistling around the red wings above our heads and all around the cabin. I set the flaps and then leave Florian for the next part: landing in the mountains is a matter for an experienced pilot! And the snow makes it difficult for him to appreciate the height that remains under the skis. But he's good at his business! It was in Megève that he looked for a chalet precisely because it is possible for him to come very quickly from the Geneva Aeroclub.

The plane gently sinks towards the field at the end of which the altiport building stands out, just below the ski trails that line the mountain in front of us. On the flat ground along the runway, cross-country skiers look up as our plane passes by and then, very quickly, the skis gently touch the snow while Florian raises the aircraft and slows it down. Some engine power is necessary to reach the building and park the aircraft. A taxi is already waiting to take us down to the chalet, which we reach a few minutes later.

It is very different from Axel's. It is an old sheepfold that has inherited from its history only very dark wood carved by the bad weather and whose veins draw lighter blistered undulations on the brown-red background. It is placed on a masonry base in the stone of the mountain. The slope is such that there is a level difference between the entrance door on the Northeast facade and the one opposite which opens onto a wooden terrace, built above the old cellars transformed into bright and comfortable rooms. It overlooks a large meadow on a gentle slope that makes children happy on their sled. Lined with forests, it is crossed by traces of savagery: hares, foxes and even wild boars that we have sometimes observed in the evening.

Helen - the companion Florian brought back from his internship in the United States - has succeeded in blending local traditions with her country's brief history. On a tall chest of drawers in light wood, a santon in a shepherd's outfit - cape and hat with a wide brim - seems to discover a navigation map on Lake Erie nailed on the wall opposite! Watercolours of American folklore hang above a large copper cauldron, discovered perhaps during the renovation work on the sheepfold... The whole thing creates a very warm atmosphere, especially since the comfort is comparable to that of a contemporary American house, especially in the kitchen where Florian prepares a lunch for us.

"Here," he says as he take the eggs out of the fridge. "I just figured out how to make an omelette without breaking eggs!"

- What do you mean?"

- Exactly that! You can make an omelette without breaking an egg!"

- You're kidding!"

- No, I'm not! Nature is overflowing with amazing resources! For example, it can develop mechanisms that are both reliable and sensitive: two qualities that our engineers cannot reconcile. An alarm system like the one I unfortunately had to install in the chalet must, to be reliable, be activated as soon as its sensors detect a sudden temperature change. But if I adjust it too carefully, it may scream as soon as a ray of sunlight hits the window. And when I try to avoid an accidental activation, I risk being robbed without my camera reacting! For engineers, sensitivity is the enemy of reliability."

- And nature is both sensitive and reliable?"

- It is subtle and complex. It must be said that she had plenty of time to improve!

"Look at a synapse, for example: the junction between two neurones. It must be reliable to avoid serious problems and sensitive to avoid others! Imagine if it wasn't reliable and went off when it shouldn't have! It is becoming impossible to imagine that billions of neurones can work in an efficient and coordinated way! Even the simplest animal would quickly succumb to a horrible mixture of paralysed muscles and irrepressible tics! And if the synapse reduces its sensitivity so as not to trigger wrongly, it would create serious problems for its host! It couldn't adapt fast enough to its environment: and if it's a predator approaching...!"

The omelette is ready: Florian couldn't help but flavour it with herbs, even though it's the middle of winter. He uses his supply of frozen basil, chives and parsley, to which he adds a pinch of garlic salt. And it is with closed eyes that we could follow him to the scents he spreads by carrying it to the large table surrounded by simple wooden benches, at one of the ends of the living room that occupies almost the entire ground floor.

Sitting at lunch by the bay window, we have a view that nourishes the mind by immersing ourselves in our natural roots: the mountain, the meadow, the forest, the valley at the bottom of which we can see the sun's reflections on the swirls of the river.

The bread-knife crunches on the brown crust of a large loaf pressed against Florian's chest, who explains: "When an engineer wants to control one electronic module with another, he connects them by a solder that transmits the electrical impulses directly. But two neurones don't touch each other. The nerve impulse is transformed before influencing the second. It is not electrical charges that connect the cells but complex molecules secreted by the first and whose shape is specifically recognised by the membrane of the signal-receiving cell."

- I don't see how this complication makes you think you can make an omelette without breaking eggs!"

- No, it's just a typical example of a successful biological mechanism! In the case of neurones, we discover a whole functional structure that is not a simple addition more or less useful to the basic structure, but which creates a kind of new dimension much richer in possibilities of control."

- How does the translation of an electrical nerve impulse into molecular movements do anything other than delay the transfer of the signal between the two cells?"

- It makes it possible to add a new high-performance control stage. The receptor cell is sensitive to the shape of the emitted molecule and this allows a quick and appropriate response because it is specific to a given shape, a bit like a specific key is needed to operate the lock that triggers the activity of the receptor neurone. An electron is the exact copy of all the electrons in the universe while each species of neurotransmitter molecule has its own personality and will be recognised without error. This system is very safe while remaining sensitive thanks to another trick!

"It is very unlikely to trigger a downstream reaction without an upstream order, although it certainly happens that some neurotransmitter molecules perspire by mistake. Indeed, the space between the two neurones contains enzymes that destroy them and recycle them immediately to the upstream cell. For the downstream cell to react, these enzymes must be submerged by a stream of neurotransmitter, which cannot happen by mistake. And that's how our brains allow myriads of neurones to communicate sensitively and safely at the same time."

- I still don't see how you can make your omelette without breaking eggs!"

- It is quite simple, though. All you have to do is transform your point of view, change your perspective, add a layer to your representation of the problem."

- My egg remains a hermetic egg with what interests me well protected from its shell, whatever my perspective! Besides, I notice you broke your eggs to make us this omelette!"

Florian smiles: "Axel would say you should change your dimension... develop your antennas in the next dimension."

- Is it in the fourth dimension that you're going to cook your omelette?"

This time Florian laughs frankly: "Yes and no, you are on the right track. A little more imagination please!"

- I still don't see where you're going with this. That being said, your omelette is very good!"

- But it's the chicken, of course!"

- I still can't see."

- Change your dimension! Rise in your imagination above your egg on the table in its usual space, the only one we perceive with our five senses, and look at it through space-time, the 4D block that Axel presented to us. You see it being born, you let it live and turn into a chicken. You didn't break your egg, and now it allows you to harvest many more that you can turn into an omelette!"

Florian suddenly changes his tone: he looks like an old wise man who talks: "Change level; rise in your imagination above the perceived world and you will sometimes discover amazing things! What is antagonistic or contradictory can become complementary in a higher perspective!" I'm surprised at this speech, which is closer to Niels Bohr than to the familiar Florian.

- But..."

I'm interrupted by the doorbell. Florian will open and let Axel in who is coming with our families and luggage for the weekend. They preferred to come by car: there was not enough space for everyone in the aircraft anyway.

I meditate on Florian's proposal: I am not convinced by his idea. What if his egg were to produce a rooster?! But I'm sure if I made the remark, Florian would take a compassionate look at me and say something like, "But Matt... it's just a metaphor!"

## D.2: WHAT IMAGE OF THE WORLD?

The children joined the playroom in the basement at the end of dinner. Their mothers went for a walk in the village, illuminated all year round as if time had stopped on Christmas.

Florian prepares us a coffee and then joins us by the fireplace. Axel, hypnotised by the flames, mechanically caresses his dog lying next to him, his snout on the ground towards the fire. Apart from the flames, only a lampshade in our back lights up the background of the room with a soft orange light. Armchairs, carpets, library, curtains and decoration all contribute to create a warm and relaxing atmosphere.

Florian brings his armchair closer to the fireplace and brews the embers: "I invited you to join me to discuss some associations of ideas suggested by Axel's remarks on the interpretation of modern physics. To be honest, I have a hard time taking most of these models seriously because they seem so cut off from everything we are used to perceiving. But by rereading my notes, I can't completely exclude them because the experimental results are well documented. On the other hand, I am not competent to participate in the search for more reasonable models, but the approach of physicists has challenged me in several ways; it suggests associations with at least three fields of biology that interest me particularly: it is the evolution of species, genetics and ecology."

- You see that you will always need physicists," says a sarcastic Axel with a smile.

- We'll talk about it again when you finally understand how species evolve," says Florian. But it is clear today that we do not all share the same image of the world. Very elegant research has allowed us to somehow get inside the heads of other animal species to understand how they perceive the world, and, proportionately speaking, the results are almost as surprising as yours!"

- You mean animals that have senses we don't have? "asks Axel.

- Yes, but not only that. Some species live in a world of smells: your dog for example. For others, the universe is perceived almost entirely through the ears. Still others only see what moves; the motionless object is not part of their universe... not to mention the temporal rhythms that seem to vary from simple to hundredfold..."

- Wait, which way are you talking about more precisely?"

- Oh, there are many of them," says Florian. Think, for example, of electric fish; all these species live in an environment that is always dark, full of dirt that seriously limits the effectiveness of their vision. These fish have adapted by developing a perception system capable of giving them an image of their environment completely independent of light. From muscles and neurones they have tinkered with a new device that we don't have: a kind of electric field transceiver. The fish is surrounded by an electric bubble whose shape is modified by environmental obstacles. These variations are perceived by fish to form an image of the

world around them that their sight cannot give them. They swim, live and exploit without difficulty an environment in which other species could not thrive.

"There are many other examples related to the perception of lights invisible to us, infra-red or ultra-violet, sounds inaudible to us, infra-sounds or ultra-sounds, magnetic fields..."

- What are you getting at? "asks Axel.

- To the conclusion that the image of the world we live in today is only an image, and that it would be useful to put it into perspective when physics seems to show us that it does not correspond to the discoveries it makes. Species, like us, have each developed an image that is well adapted to their way of life and that can be very different from other ways of perceiving the world !! What seems to us to be common sense may not be so common sense for another species that has adapted to a different way of life than ours."

- Isn't common sense the same for everyone?"

- Beware of common sense; remember the omelette from earlier!"

- I don't want to offend you, but your omelette left me very confused! Don't you have another example?"

- Of course! First of all, it is obvious that it is the Sun that revolves around the Earth and not the other way around!"

- What do you mean?"

- That common sense almost led poor Galileo to the stake! He was right, of course! But to admit it, it was necessary to be able to change the level of analysis, to rise in spirit to discover the solar system from a higher perspective. From the new point of view, the same common sense of everything will lead us to choose the simplest model capable of explaining and give meaning to a multitude of observations and measurements with the least number of assumptions possible. And it is from such a perspective that Copernicus' system appears much simpler than Ptolemy's that common sense had favoured until then."

- But you talked about different common senses for different species: they can't change their level of analysis!"

- Individuals of the same species have shared the same world experience and common sense for ages. But for a given species, what makes sense based on its lived experiences may be very different from what seems normal to another species!"

- I can't believe you!"

- Imagine a bat having fun studying your behaviour! It won't understand why, as soon as night falls, you keep stumbling over the obstacles that are so visible to it, who perceives the world with its ears and sonar!"

- Don't you think it'd make the difference between my daytime and nighttime behaviour?"

- No, because there is no difference for it who has always perceived its environment in the same way, whether there is light or not! What is common sense in its representations does not necessarily reflect the experiences you have had in your personal representations since you do not live in the same world!"

- I see."

- And it would be your theory of evolution that would explain why we perceive the world as it appears to us and not as physics describes it to us?" Axel asks.

- Of course! Life is diversifying, exploring all kinds of ecological niches over the past four billion years and adapting by developing some perceptions while losing others that would have become useless. Since Darwin we no longer have any fundamental problem to understand the processes that underlie its adaptations; we sometimes have to discover the details of the mechanisms that work to create this biodiversity but the heart of the process is well understood!"

Florian's enthusiasm reminds me of the one he had when he illustrated Darwin's theory to me a long time ago... It was on the Mediterranean coast, in Monaco. Memories flow...

### D.3 : MONTE-CARLO

"It's a frangipani tree! ". Florian reacts to my surprised look when I pick the flower on the grass, at the foot of a strange shrub. He looks at me with his clear eye, perched high. The other eye is almost hidden behind his eagle beak nose.

Weird!... I just felt a deep interest in this shrub! By far, it doesn't look like much. Its architecture is rather regular like that of the primitive trees still centred on themselves and growing according to their genetic program, whatever the constraints of the environment: fir trees for example. Whorls of 3 rather thick shoots lay along the main trunk and the main branches. From bright green when they are young, they evolve towards an elephant grey to such an extent that the trunk recalls a pachyderm's leg, a pillar that supports the rest, naked and scattered with scars, where the leaves should be. You can only find them on the top of the branches: they are ephemeral but magnificent, very large, as long as a forearm and wider than the palm of the hand, of a bright green that shines in the sun of Monaco.

But neither the trunk nor even the leaves explain my reaction: it's the flowers!

They bloom into cushions at the top of the branches, protected by young leaves from adventitious branches that reflect a light green on their silky white. The eye is attracted to the centre of the flower by a progressive evolution from the white of the petals' tips to a warm butter yellow in the centre of the corolla. I admire between my fingers a large regular propeller whose 5 interlocking blades diffuse an elegant scent in the soft air of this April morning. Each petal, as long as two phalanges, is twisted on one edge: the one above the neighbouring petal. This helical flower diffuses a fragrant whirlwind of rare sweetness. In short, a success of nature!

"Do you wish you were a bee?" laughs Florian!

I am intrigued by the emotion that this flower arouses in me! "How is it that we have the same affinity for flowers as bees, butterflies... and many other insects?"

- This is one of the few questions to which the theory of evolution does not provide a direct and satisfactory answer! But I have some ideas: we are the descendants of tree primates who may have discovered in flowers the promise of edible fruits, if not a sweet and fragrant appetiser... But in reality I don't know!

"I don't know why we find most flowers beautiful and attractive... why we use them to perfume ourselves... why we decorate our interiors with bouquets or wall papers, textiles that represent them..."

- Yes, but evolution is just a theory, isn't it? No wonder it doesn't explain our attraction to flowers!"

Now I wonder if I didn't go too far! Florian gets excited and his eyes become colder as his cheeks warm up! I know that Darwin is one of his favourite scientists, but I sometimes hear criticism of his work... So?!

Usually, Florian is reserved, perfectly in control of his emotions. The nervous impulses they generate in the depths of his brain - the one we share with the most primitive vertebrates: crocodiles and other reptiles - do not cross the barrier of his rational cortex, the one that distinguishes us from other vertebrates and gives us our specificities. Florian usually analyses carefully, weighs his emotions, before sometimes allowing them to trigger a well-controlled reaction.

Presently, his hard look reflects the intense work of the rational barrier and his red cheeks, that of his emotions! And if the dam breaks, the look changes too: it becomes lively, mobile, penetrating. And it is another Florian that is discovered when his emotions overwhelm and take away the control he has carefully put in place over time. It becomes as dual as a stutterer transcending his disability on stage where, as an actor, he develops a fluid and confident speech. The usual Florian chooses his words: he often seems to search for them, sometimes with a little difficulty. The liberated Florian exalts himself and becomes charismatic: convinced, he becomes all the more convincing! Voluble, his stream of words overwhelms his interlocutor when he is called upon to discuss a subject that fascinates him enough to trigger the phenomenon. He then speaks with his whole body... That's what he's starting to do now!

- A scientific theory is not a hypothesis! You're not going to make the same mistake as the anti-evolutionist sects, come on! Darwin's theory is so logical and obvious that some philosophers have criticised him for not really discovering something original! It argues, in essence, that organisms that happen to have favourable personal characteristics in a given environment survive longer than others and conceive more suitable offspring than the rest of the population to which they belong because they transmit to them the genetic factors responsible for their success. How can we refuse this evidence?"

- Wait a minute! You talk to me about chance and genetically transmitted traits... there's room for doubt!"

- No, not anymore today! A scientific theory is not a hypothesis but the model that most convincingly explains the largest possible collection of observations and does so with economy. And that's exactly what Darwin's theory does! A scientific theory allows us to give meaning to our observations, to understand the world in which we live. And I affirm that Darwin deciphered the Rosetta Stone of Life! The innumerable and admirable manifestations of life acquire meaning through the associations and links that scientific theory allows us to forge between them. Darwin's discovery is one of the richest in this field: it gives meaning to myriads of observations that would not have any without it! And I can prove it to you! But don't forget that the Theory of Relativity is also a scientific theory... and you can't say that "it's only a theory, only a hypothesis", since it has widely demonstrated its effectiveness, not only to explain observations that were not understandable without it - the constancy of the speed of light for example and many others - but it is at the origin of predictions that have led to the

discovery of nuclear energy. And bombs or power plants are real... although they have their origin in a theory! No! Don't fool around and confuse scientific theory with free hypothesis!"

Florian is fulminating, he's right in the middle of his liberated appearance!

- But if you're so sure of yourself, why call them theories rather than laws?"

- We can also call them laws, but that's not the point! It is a matter of remembering that a scientific theory, a natural law as well, are only ways of understanding the world and that there are certainly better ways of explaining it. These approaches must be placed in their historical context: the scientific quest is a perpetual quest, although some may think differently. It is true that sometimes scientists let themselves be overwhelmed by complacency and proclaim that our quest is very close to ending in a particular field! Remember Lord Kelvin about whom Axel told us: he could only see a few little clouds in the great blue sky of physics. And these clouds have turned all certainties upside down and continue to do so, more than a century later! We also have our Lord Kelvin in biology who boast to anyone who will listen to them that the molecular biology of our genes will soon allow us to understand all the mysteries of life... We will probably never be able to finish, but our models will be more and more efficient. They will explain more and more observations at the same time, in an increasingly elegant and economical way...

"That's the spirit of a scientific theory! It must remain constantly subject to criticism of reason as well as the results of observations or new experiments. It is nevertheless firmly established by myriads of facts of nature that make sense through it. The more we learn, the more subtle and efficient these models become. That is, able to predict the result of an observation never before made or an experiment never before carried out. And you will agree that the discovery of results predicted by theory, long before the experiment, leads us to be very reasonably convinced that our model of the world is at least a reliable image, if not a real image.

"But there's a difficulty!"

- Ah all the same! "I find it hard not to make fun of the character: but he continues, unfazed!

- It is that models often become more difficult to understand, even for research actors... They require more and more efforts to become usable in our quest for an understanding of the world because they are based on observations that accumulate, work, reflections, creations that jostle... As a result they become more abstract, more distant from what our senses have taught us to master without difficulty! But anyone who allows himself to throw away the result of so much work without taking the trouble to really understand what the creators of scientific models meant has not perceived the astonishing power of the method they use. He has understood nothing of the source of its effectiveness to decipher nature, to control it and to derive benefits for our species... control and advantages from which he naturally benefits, unaware of their real origin... It is a pity!"

- But it is not only science that allows this learning! All the cosmogonies are there to explain the world: each culture is based on its founding myths in which it believes with much more conviction than your science could awaken! We are beings of belief more than beings of reason! I am convinced that you yourself believe in certain things because they come from the scientific approach you recommend, without really having confronted them with the work of criticism and reason! Isn't that right? You believe in science like a religious man believes in

his God!" Florian definitely attracts teasing because he falls into almost every trap when he is exalted!

- Good God no," he replies with a mischievous smile: this time he noticed the scheme!

"It is true that no one wants or can repeat all the intellectual steps of the discoverers to ensure that they agree with their work. But the scientific method dispenses you from doing so systematically as soon as it is based on the reproducibility of the results by anyone who gives himself the means to duplicate them. When I am assured that a phenomenon is scientifically proven, it precisely means that it has been subjected to the test of reproducibility as well as to criticism by competent people and towards whom I see no reason to be suspicious: it is therefore not at all a blind faith without a thorough analysis. If it is not done by me and I know that it has been conducted according to the rules of the method, then I admit the very likely relevance of the analysis and, until proven otherwise, since the method is always open to improvements and even revolutions, I rely on these discoveries to seek to understand the world and conduct my own work."

- What is the difference with the theologian who relies on the reflections of his predecessors..."

- Matt, stop it! Look! I will illustrate my point precisely with the theory of evolution! Darwin has given us the means to truly understand the living world around us. It even allows us to realise that we are intimately part of it... that we share its history... We are going to visit the Oceanographic Museum and I will show you how, thanks to Darwin, we can find meaning in observations that otherwise would have none!"

- I don't agree with that! I remind you that each culture gives meaning to objects and events through the beliefs it inherited from its predecessors..."

- Matt, that's enough! You're not going to compare... But wait! You'll see for yourself!"

I shut up, slip the frangipani flower into my shirt pocket to stay close to its scent and follow Florian on the clear sandy path that crosses a carefully maintained park linking the old town of Le Rocher to the Palace that houses the Oceanographic Museum.

## D.4: THE OCEANOGRAPHIC MUSEUM

We arrive very close to the large light ochre palace set in the cliff which plunges straight into the ultramarine blue swell. The sea breeze is already in place, fuelled by the depressions dug by the sunny hills. The air vibrates with heat on the old city of Monaco and the rocks that overlook it.

Gulls glide with astonishing virtuosity over the museum terrace, carried away by the breeze lifted over the continuous walls of the palace. We suddenly understand the pilots' passion for their flying machines: it is exhilarating to evolve in all three dimensions by taking advantage of natural energies: the strength of the wind and the sun!

The visitor is led onto the square in front of the palace and discovers a majestic staircase leaning on a long facade decorated with sculptures and inscriptions to the glory of the princes of the place. It is indeed a palace: it seeks to impress the visitor! And for that it takes its ease, spreads out, raises its ceilings, adorns itself with immense rooms, monumental stairs, in a

place where space is so rare that in town the buildings cling to each other, stretch as they can towards the sky, clinging to the rocks that outcrop here and there... This museum secretes a serene atmosphere of quiet force.

There may not be more dissimilar architectures than that of a palace compared to that of a School of Physics! And yet we feel the same feeling of controlled power when we approach it! Perhaps it is the result of the power that transfuses from the prime contractor to the architect. Power of the creative reason of understanding in the physicist: power of money creating goods and culture in the prince.

Inside we discover the passion of its creator: oceanography. Intellectual excuse for leading an adventurous life on the water? Hanging on the walls, large photos illustrate the precarious conditions that were those of the sailors of the last century. They proudly pose in front of the photographer's camera but their clothes are dusty and wrinkled. The features are rough, the hair poorly shaved: you can almost feel the calloused hands and the smell of their work!

In the large central room with its glossy floors, a large boat, under a collection of whaling harpoons, commands admiration for the courage of these men. They were still living at a time when the Earth was immense and the ocean mysterious and almost infinite! The whale killer was a hero who expressed the supremacy of our species over all the monsters that the Earth could harbour and whose illustrated representations can often be seen on maps of the world or in geography books of past centuries. Monsters with an oversized, worrying face...! Today the bladder has deflated: whales are gentle giants that must be protected from extinction against barbarian hunters! Other times... other paradigms!

On either side of the central part of the building there are two huge, very bright rooms, of a height more appropriate for the naves of cathedrals than for modern museums! Large bays diffuse a golden light on the collection of cetacean skeletons - whales, rorquals, sperm whales, porpoises - recognisable only by the panels that represent them with their flesh. The very white bones are carefully assembled with almost invisible wires.

Florian points out to me that inside all these skeletons, we discover two small slightly twisted bones hanging in the middle of the body, in the lower third of the beast. They are not connected to anything at all except two wires that cling to the bones of the spine. (Figure D.1)

"What could be the role of these bones?" asks Florian.

You tell me, you're the biologist!"

- I'm a biologist, but I can't tell you what they're for! I'm even convinced they're useless!"

- But then why do all these skeletons possess them?"

- Well, this is one of the mysteries that the theory of evolution elegantly explains. It is one of the myriads of observations that would have absolutely no meaning without it, but which enlighten and stimulate reflection that reveals the history of species and that of life at the same time. These bones are relics... remains of an abdominal belt that connected the hind legs to the bones of the spine... the hips in a way. We have a better understanding of why cetaceans are so different from the fish they imitate and live alongside. They are mammals like us. And like us, they had four members a long time ago, tens of millions of years ago when their ancestors ran on land and fished in coastal waters as sea otters do today."

- You expect me to believe that the whales' great-grandmother was an otter?"

- Horror! No! You're not going to use creationist arguments against me! What did I do to the good Lord to have a friend like that?!"



FIGURE D.1: *Cetacean skeleton with strange bones suspended under the spine.*

*Source: Oceanographic Museum of Monaco.*

The visitors closest to us turn around to try to understand why we laugh so loudly and smile in turn: good humour is contagious!

- No! Otters didn't exist yet when a funny animal... But funny is perhaps not an appropriate adjective for this kind of river wolf! Imagine instead a kind of large muskrat that lives near waterways and has a crocodile jaw, bristling with sharp teeth to ensure the success of its fishing. A nightmare creature!"

- And it was in your nightmares that you discovered it?"

- Don't make fun of me! It is a very beautiful story that its discovery! To appreciate it, we would first have to discover how well whales are adapted to their way of life and then try to put ourselves in Darwin's shoes to imagine their history.

"But look here at the representations of all these cetaceans: they have a superb hydrodynamic shape and I was told that soldiers were studying the texture of their skin in order to get inspiration for their submarines. They discovered that it reacted to the pressure waves of the water at high speed so that there was no loss of energy due to turbulence: cetaceans are able to swim fast and long without great fatigue."

Florian approaches a skeleton of a high contrast white on a waxed parquet floor. Tendons and muscles are elegantly replaced by a discreet architecture of wires and metal tubes. The imposing long spine immediately suggests the power and flexibility of an undulating swim now frozen in the curves of the skeleton.

"Darwin proposed that this animal is the descendant of a land mammal. You are a land mammal: so try to put yourself in the place of this ancestor to discover the adaptations you should have developed throughout your evolutionary history to become a whale!"

- You're cute! First of all, I'm glad to be more wrapped up than all these piles of bones, no matter how much you admire them! And I intend to stay that way for a while!"

Florian smiles: "but still?"

- I'm surprised! There are many myths that transform people into animals, especially in shamanic cultures: I have met some that transformed them into wolves, bears or ravens... but never into fish... sorry, whales!"

Florian's expression prompts me to correct myself immediately. He's relaxing.

- Try to imagine what the changes should be that would allow you to live their lives!"

- I would probably start by practicing dolphin swimming: the two legs gathered horizontally that would wave from top to bottom following impulses initiated by the upper body."

- Suppose then that you have an immediate gift for malleability, a little as if your body were made of clay. What would be the metamorphoses you would like to experience to make it as effective as this whale?"

- I guess I'd have to wrap both my legs in a mermaid's tail."

- Kind of like a seal would do?"

- I hadn't thought of that, but you're right! I would then have to lie down my toes and attach them to a skin to imitate a fish caudal. This solution has the advantage of still allowing occasional land transport."

- But it is less effective in water. The ancestor of the whales probably had a powerful tail, such as that of an otter or beaver and hind legs proportionally shorter than our bipedal legs. From this anatomy it is easier to rely on the tail rather than the hind legs to develop a powerful aquatic locomotion: watch an otter or a beaver swim and you will understand! But I remember that you assume an intermediate step with webbed feet. And what would you do with your arms?"

- As they are there, long and cylindrical, they would not be of much use to me. I would modify the hands whose flattened shape could be more easily used to make a fin. I would have to shorten my arms, flatten their bones, lengthen my fingers and connect them to turn them into a swimming pallet."

- And you'd stiffen the joints to make your pallet more efficient! This is exactly the solution found by whales! Look at this porpoise: you can recognise the arm bone, the two forearm bones and then the fingers, very long and connected to the rest by the wrist bones. It's all there! It was noted that the joints between these bones were still soft in whale foetuses but that they bonded well before birth! Their fins thus become as effective as those of the sea tiger, the predator that has been refining its performance for hundreds of millions of years: the shark!

"Now what do you find in the shark fin? Nothing that reminds us of our bones and those of whales! But long rigid and one-piece cartilages, articulated only at the level of their connection to the skeleton of the body! Why then do cetaceans have such a complex structure of their swimming pallets and have the same bones as those of our arms if not because they share with us a common ancestor who had these bones in its forelimbs?" (Figure D.2)

- That makes sense, I'll give you that."

- Isn't that right? Let's keep going! You live in the water but you breathe air: you have to dive long and deep to fish. How would you direct your adaptation?"
- I'd stop breathing to convert to gills!"
- That's a good idea, *a priori*."
- Then why don't whales have any?"



FIGURE D.2: *Cetacean swim pallet.* We recognise the same bones as in all tetrapod vertebrates: humerus, ulna and radius as well as ossicles and phalanges. But all these bones are stiffened and give an effective swimming palette. We also notice that the ribs are articulated at their junction with the vertebrae. This is an adaptation to deep diving.

Source: *Oceanographic Museum of Monaco.*

- Because they were already too advanced to be satisfied with it! They are very active like all mammals. All their cells work intensely because they are bathed in a constantly regulated environment to provide them with the optimal conditions: this is not the case for fish whose temperature varies with that of the water that hosts them. The life of cells is all the richer because the innumerable chemical reactions that are the basis of them are carried out quickly. And their speed depends on the ambient temperature. We mammals are very active regardless of the temperature of our environment because we constantly create and regulate our internal heat. But there is a price to pay! We are very energy hungry and to make it we use a lot of oxygen, much more than the little that is dissolved in water! All warm-blooded animals living in the ocean are condemned to breathe air to find the energy they need."

- All right. In this case, I would do well to open my nostrils on the top of the skull to breathe more easily: this is what happens with cetaceans!"

- Yes. But there are still several adaptations to be found to dive successfully. Pressure, for example. The water is dense. For every metre of depth every square centimetre of your skin is subjected to an additional 100 grams of pressure!"

- Yes, but apart from the ears, it's not a problem since I'm not compressible!"

- You don't, but your lungs are, because they're full of compressible air!"

- Then I would develop a way to store air in dissolved form and give up my lungs!"
- It's still a good idea that's impossible to put into practice!

"No, that's not quite right! Maybe the sperm whales are using part of your idea. They are the champions of long and deep diving: more than an hour at more than a thousand meters! Some biologists think they have found a way to store dissolved oxygen in the huge mass of fat that gives them the unique anatomy of their heads. But their physiology is still mysterious to us! However, they still need lungs to allow the air to dissolve in the blood. Don't forget that you are an aquatic animal adapted to terrestrial life and not a real organism independent of water!"

- What do you mean by that?"
- That you live in a private aquarium where your skin is the glazing!"
- Tell me about it!"
- Yes, it is! All your cells live in water and can only consume dissolved oxygen: they would all die dried if exposed to the open air!"
- So how do you keep yourself fresh?!"
- We have invented a skin made up of cells that sacrifice by filling themselves with a waterproof protein that condemns them! The only living cells you see in me are those of my eyes: they are constantly humidified, otherwise they would also die!"
- Oh, my gosh! I feel closer to a fish all of a sudden! And how do the lungs live in the air?"
- These are bags kept moist so that gases can pass from the dissolved state to the gaseous state and vice versa depending on whether it is carbon dioxide from the blood that must be released into the air or oxygen gas that must pass into the blood. To convince yourself of this, you can have a cruel but demonstrative experience.

"Take two earthworms of comparable size from your garden and place them on the slabs of your terrace after carefully drying one of them. You'll see that it'll go to sleep long before the one who stays wet. It has no lungs and can only breathe through its skin. But for that it must stay wet! Paradoxically, you would find that its blood is much poorer in oxygen if you let it in the air than if you immersed it in water that contains forty times less oxygen than air!"

- We're a long way from the whales!"
- No: I'm explaining why they had to keep lungs although they have a problem diving!"
- And how did they solve it?"
- Come and see the ribs of this sperm whale."
- I don't notice anything in particular."
- They are articulated at the vertebrae while yours are not. The sperm whale's rib cage can compress without breaking!"
- I wouldn't say it's a very elegant solution!"
- Try to find another one!"
- ...

- But you mentioned your eardrums earlier. How would you change them to become a whale?"

- I don't know. If I choose to thicken them to resist pressure they would no longer vibrate and would be useless."

- The whales have something that looks like a useless vestigial eardrum, a thick ligament that is no longer even connected to the outside through an opening."

- How do they hear?"

- With their heads! Sound vibrations are transmitted to the inner ear after being picked up by cranial bones. And it is a bone particular to cetaceans that takes care of this work. Come and see, there's one on display upstairs."

Along the gallery that overlooks the life-size reconstruction of a sperm whale, Florian leads me to discover two large kidney-shaped bones, placed on a wooden shelf in a large, slightly outdated glass cabinet. A nearby label states that they are "tympanic bubbles" of a harpooned whale off Monaco on 26 May 1896. It's a very curious object! It looks like a kidney more than ten centimetres long, partially fused to a bone whose shape suggests a large phalanx. It is not at all obvious that it can be useful to hear!



FIGURE D.3: *Whale tympanic bubble.*

Source: Oceanographic Museum of Monaco.

- I don't see how this bone can replace a eardrum!"

- We need a thin, lightweight membrane to react to low air pressure waves. But the water is dense! Vibrations circulate in the water and are transmitted very well to skin cells, which are largely composed of water, and then to the bones, which are even denser. The tympanic bubbles concentrate these pressure waves captured by the bony structure of the skull which acts as an antenna: it replaces the auricle of our ear. The bubble transmits sounds to the nerve cells of the inner ear."

- And what makes you so sure of your case?"

- The comparative study of vertebrates! In particular, it tells us the history of each skull bone and the various uses that different species have made of it. Thus the ossicles of our

middle ear can be related to bones that articulated the jawbone of an ancestral fish... Come and see this one!"

## D.5: A DREADFUL GREAT-GRANDFATHER

I go down the stairs again after Florian to the second room, on the other side of the entrance hall. There, at the foot of a wide bay window, at eye level, he stops in front of a large naturalised fish. It's really very ugly: blue-grey with very large scales!

Florian laughs: "Don't look so disgusted with your great-grandfather!"

- What do you mean? You always told me we were descended from a monkey, not a fish!"
- But the monkey itself has this fish as an ancestor! So... !"



FIGURE D.4: *Latimeria*, a living fossil of the coelacanth, which is itself related to the fish that created the first terrestrial amphibians, with fins mounted on bone appendages. Pectoral and pelvic fins are the ancestors of the arms and legs of terrestrial tetrapods.

Source: Oceanographic Museum of Monaco.

As a result, I observe the creature more carefully. Apart from a few horrors fished deep in the depths of the abyss, studded with awful long, thin teeth that stand on end two jaws much longer than the rest of the body into a grin from another world... apart from these predators of the abyss, I have not seen anything uglier! And Florian tells me the horrible news... we would be related to that thing!

You may be surprised to learn that your great-grandfather lived blissfully under the waves, that he was covered with large nested scales, grey with blue reflections, sometimes light grey in large irregular spots scattered over a stocky body. That he had a huge rigid mouth lined with thick, beaded lips, a bit like those of a grouper but even less expressive! His big, glaucous green eyes don't make it any more attractive! What seems to differentiate it best from a failed grouper is the impressive number of fins and especially its very muscular tail: a large diamond covered with scales and bordered by a narrow membrane no wider than the palm of the hand for this animal that borders the meter of length.

"How can you say something so extravagant? And then, if it was the ancestor of all of us, how come it's naturalised when he should have been gone for ages?"

- One question at a time! But you're right: it's not your great-grandfather because it was caught alive a few years ago. But it is a living fossil: that is, a species that has hardly changed its fundamental anatomy in hundreds of millions of years."

- So there are species that do not evolve?"

- No! It is not the same species as the one known to us from 350 million years old fossil traces. Moreover, its ancestor was called "coelacanth" whereas this one is a "Latimeria". There has been an evolution, but it is not noticeable in the animal's overall architecture: only in details."

- How can you be sure of that? And this should be a blow to the theory of evolution since it obviously does not apply to all species in the same way!"

- That's exactly not the point! Moreover, biologists had predicted that there must be organisms that have remained almost unchanged since the dawn of time. The theory of evolution assumes a continuous adaptation of species to a changing environment. But if it is stable they have no reason to change what is already well adapted! And such an environment exists: it is the deep ocean. It's always been dark and cold there. But not more or less black and more or less cold depending on the seasons or climatic variations: no! Still as dark and as cold as ever: only a few degrees. And that's where we discover living fossils! They are very precious because they reveal their organs and especially their behaviour, impossible or almost impossible to study on fossil traces."

- But none of this explains to me why you recognise it as your ancestor!"

- No! It's not your great-grandfather since it's still alive today, but it looks a lot like your ancestor who lived 350 million years ago."

- And how can you say we could have anything in common with this... thing?"

- We have a lot more than you might think. But to discover it, it is necessary to take the trouble to take an interest in the comparative anatomy of animals. You'd see that you share with all the fish an internal skeleton with a spine..."

- But his has bones and mine has ribs and hips!"

- Like the one of the monkeys...! It took time for this skeleton to evolve and adapt to all kinds of lifestyles. But if you analyse it objectively, you will be forced to admit an inescapable relationship with other vertebrates, frogs, birds or lizards! Comparative anatomy makes you relive the history of most of the bones found in all these species, living or fossil. You would discover the genius of nature when it comes to tinkering with a new structure to meet a new challenge; it most often tinkers with what it already has, modifying it to redirect

its use. And this is especially true of this type of fish and that's why I honour it by attributing it a relationship with you!"

- Thank you, but I'm not sure it's really a gift!"

Florian smiles: "You see, if all the terrestrial vertebrates have four limbs - two arms and two legs for you - it's because a fish that looked like this one started crawling on its two pairs of fins to explore life out of the water!"

- I heard that like everyone else. But you have no proof of what you're saying!"

- Proof, no! But a reasoned conviction, yes! Because a multitude of observations can be firmly linked together and acquire meaning thanks to the theory that links us to this fish! It is in its group and a few others close to it that we find fins mounted on stilts of some kind. Take a good look! Almost all fins are on a small limb and the rays that stretch them do not come directly from the body, but from bones that indirectly connect them to the spine."

Indeed, except for the anterior dorsal fin, all fins are mounted on a kind of stump. Even the ugly caudal ends in a small growth that draws the tip of the diamond and must be able to move independently.

- We only have four members, he has many more!"

- We have two pairs of members like it. The others, odd, left no trace in our house except one: the tail!"

- In the reptiles?"

- No, in all vertebrates, even you! But it can only be observed in the human embryo. It develops as in reptiles and other vertebrates, but instead of growing with other organs, it is caught up and then largely overtaken until it disappears in all great apes. But it is not the only vestigial organ we have. Our embryos even develop cracks in what will become our neck, like those found in fish embryos. But in their case they remain and protect the young gills, while in our case they disappear without any gills developing behind them. How would you like to give meaning to this type of observation without involving a common ancestor between the fish and us?"

- But it looks so little like us!"

- At first sight, certainly! But you can see that a finer analysis brings us closer to it as it applies to smaller dimensions. It is difficult to find big differences between fish and us when we analyse very young embryos. It would be impossible for you to choose with certainty a set of cells that I would have taken from either species and examined under a microscope. And you'd be even more confused if I confronted you with even more microscopic structures! You couldn't even recognise a nucleus from one of your own cells from the one I extracted from a nettle cell!"

- But aren't these similarities simply requirements to meet the contingencies faced by all living species?"

- No! And for several reasons. First of all, there are species that do not have a nucleus in their cells and are nevertheless capable of living. And then, since it is possible for us to analyse DNA, to read the sequences of molecules that constitute it as we would read words in a book, we find genes that are all the more similar in detail, as the cells from which they were extracted come from related species, although their role is the same as that of homologous genes, analysed in species that are not at all like us!

- I'm lost!"

- Your cells breathe oxygen like chimpanzees, whales or morels! To breathe they make enzymes and we can read the genes that control their production. All these enzymes do exactly the same job: they are adapted to the same contingencies. And yet, they are all the less similar in their structure because they come from dissimilar species. How else can we explain this than by admitting that they all come from common ancestors?"

- You're taking me back to the morels now! This is ridiculous!"

- Not at all! The morel is far too evolved to be your ancestor!"

I must look very upset because Florian laughs and says: "But no! You misunderstand me! I didn't want to judge your ancestry! I just want to point out that the morel lives with us today: it means that it has evolved as long as our species has, but on a very different path and in an environment that has not forced it to become as complex as we have. Nevertheless, we share a common ancestor with morels and whales, but one that lived so far back in time that the enzymes we inherited from them could accumulate differences all the more numerous as our lines separated a long time ago! In this case, they are about 64% between the morel on the one hand and the whale or us on the other hand! And then, after the separation of the branches that gave the animals on one side and the mushrooms on the other, another common ancestor is to be found at the branch that separates the whale from the primates. And since it is less old than the previous one, the enzymes of monkeys and whales are only 16% different. And between the chimpanzee and us it's almost a total identity!"

- I'm not sure I follow you. On the one hand you tell me that there is an adaptive evolution of species to respond to variations in their environment, and on the other hand, you try to show me that enzymes evolve, although they respond to exactly the same contingencies from the beginning!"

- Yes, they do the same work but under conditions that have changed significantly over time between the species in which they are found. But be careful: evolution is not necessarily an adaptation to a new environment. In Darwin's theory, variations are not directed towards any goal. They appear at random and it is then that natural selection will eventually act on them. But neutral differences can very well arise, which are neither advantageous nor harmful and which will be able, by the simple fact of probabilities, to establish themselves in a lineage without modifying their adaptation. Advantageous variations will of course be favoured, those that are harmful will disappear without leaving descendants, but neutrals can last for a very long time and sometimes settle in an entire population."

- It's very complicated!"

- On the contrary! Here is a theory that allows you to simply explain a myriad of observations that would not be related to each other if the theory did not exist. And I'm a long way from showing you its full potential!

"Look at those big eyes!

Florian approaches the fish's head.

- Yes. Didn't Darwin say he couldn't explain the evolution of such a complex organ?"

- That's right! But the discoveries we are constantly making today allow us not only to have a very rich picture of what the history of the eye has probably been, but also to understand why we have inherited the wrong formula!"

- You're not answering my question!"

- Simply because I have no eyes to show you at hand when I can exploit these magnificent specimens! But Darwin couldn't have an answer for everything! Besides, he wasn't even a biologist! Biology did not yet exist as a discipline distinct from the natural sciences."

- What do you mean?"

- At that time, there were only beetle and herbalists collectors, no physiologists or neurobiologists and even fewer geneticists! The poor man could not imagine what we have discovered since then, which gives us a very beautiful picture of what the evolution of the eye could have been. Besides, he was a self-taught naturalist of sorts! He did not even complete the medical studies that his father had chosen for him: he ended up laboriously completing a degree in theology..."

- Darwin was a minister?"

- He never practiced, but he was a theologian, yes! It was only as part of his theological studies that he took some courses in the natural sciences. He trained on the job, driven by his own interest in nature and then, later, travelling around the world as a young naturalist invited free of charge on a British Navy ship."

- And what could he have proposed today for the evolution of the eye?"

- For the evolution of the eyes! We now know that it is an organ that appeared independently in separate lines. He would have had no difficulty describing this story based on the discovery of the many ways used today to perceive light and images. Primitive organisms are satisfied with a few photosensitive cells that only provide information on the intensity and approximate direction of light. Others, who need more precise information, collect their photosensitive cells at the bottom of a spherical pocket so that the direction of light can be perceived with greater precision. Others finally replace the water that fills the pocket with secretions that act as lenses... We no longer have any difficulty imagining a slow and progressive evolution of the eye, whereas in Darwin's time we did not see how it could have evolved by gradually acquiring one piece after another, which is absurd since it needs all its parts for it to be useful ! An eye without retina, lens or pupil would not have given any advantage to its owner, until it became complete and operational! (Figure D.5)

"So that's no longer the problem. But rather try to understand why our eye is not perfect!"

- I thought, on the contrary, that it was an irreproachable organ!"

- No, it has flaws that an engineer could have avoided, if he had created it from scratch!"

- Cataract? But this is the lot of old age!"

- No. Retinal detachment and blind spot are clearly the result of an evolutionary history punctuated by adaptations to very different and contradictory lifestyles rather than an *a priori* conception. Octopus eyes do not have these defects: probably because they have evolved more directly than ours. Their retinal cells very logically face the light that passes through the pupil and then sends nerve impulses to the opposite side, to the brain. In our eye, things are the other way around. Light-sensitive cells look at the back of the eye and then send their nerve fibres to the wrong side, to the pupil! Each photon must pass through transparent neurones, transparent nerve fibres, before reaching the photosensitive cell! The nerve impulse will take the opposite path, leaving the cell that has been stimulated by light, moving towards the pupil, towards neurones that will gather information from several cells before leading

them, always in the wrong direction, towards the future optic nerve. It will have to pass through the entire retina to the brain and, of course, there will be no light-sensitive cells at the place of this crossing: it is the blind spot."



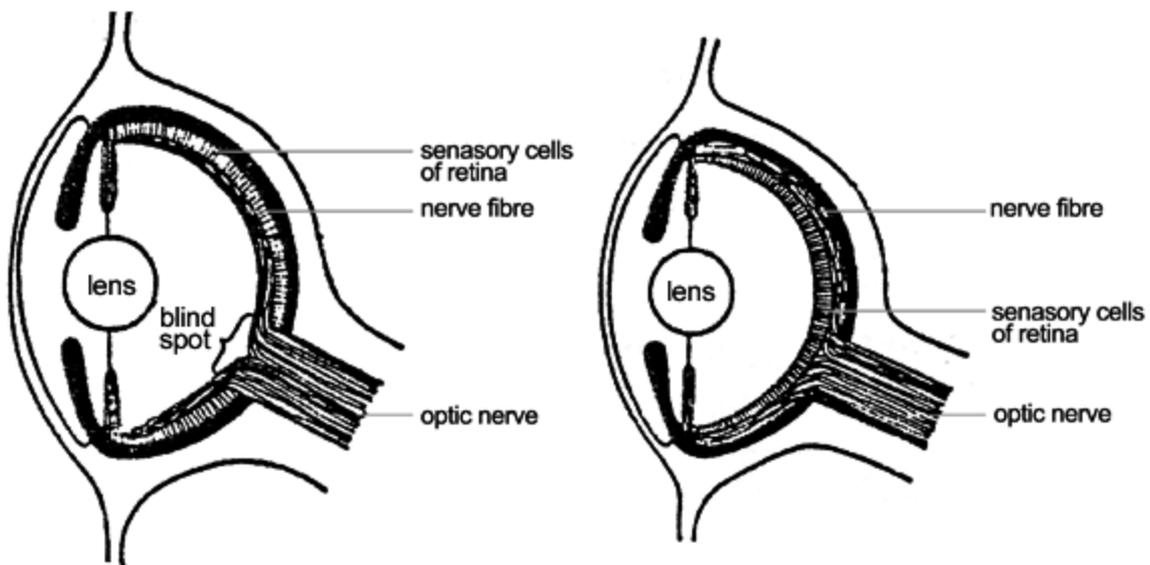
FIGURE D.5: *How the eye could have evolved in small steps from a few photosensitive cells like those found in some flatworms, through the digging of a depression like the starfish, then through an almost closed chamber like the nautilus, then through a closed chamber...*

Source: Matticus78 de en.wikipedia.org, CC BY-SA 3.0,  
<https://commons.wikimedia.org/w/index.php?curid=2748615>

- But we don't perceive it, it doesn't bother us at all!"

- That's true. The brain reconstructs a complete image based on the information perceived all around this blind spot. But it is still less elegant than the solution found by the eye of the octopus!

"That's not all! This assembly despite common sense has another defect, it is that the retina is too easily detached since it is not well secured to the back of the eye by the nerve fibres! This is also much worse than in molluscs! So how do you explain that we have poorly designed eyes when octopuses are the living proof that it is possible to make much better ones?"



*FIGURE D.6: The vertebrate eye (left) is built upside down since light must pass through nerve cells before it reaches the photosensitive cells. The departure of the optic nerve to the brain creates a blind spot. The retina is easily removed from the back of the eye that supports the nourishing vessels. All these defects are absent in the cephalopod eye (right). Source: Wikipedia ([http://upload.wikimedia.org/wikipedia/commons/a/a5/Evolution\\_eye.png](http://upload.wikimedia.org/wikipedia/commons/a/a5/Evolution_eye.png))*

- And how do you explain it?"

- Oh, very simply, by exploiting the theory of evolution, of course. It is enough to postulate a first ancestor adapted to the night life or to a very dark environment most often, as the coelacanth, precisely. If it is advantageous to exploit the slightest photon, it becomes very interesting to mount the sensitive cells upside down so that each photon has two chances rather than one to be perceived."

- Yet we don't have a good night view! There are many animals that see better than us at night!"

- Yes, because they have kept the reflective mirror that covers the back of the eye and without which it would be absurd to spill the retinal cells. A dog's, cat's, fox's or owl's eye shines when it is lit at night because the photons that pass through the cells without being absorbed are reflected, while the bottom of our eyes have lost this mirror and are only red, the colour of the blood vessels that line it. Night predators derive a benefit that compensates for

the defects of this inverted construction, but we are not night predators and for us, it only brings disadvantages."

- And why would our ancestors have lost their reflective mirror when it increased the performance of their eyes?"

- By night only, not by day! The eye is more sensitive but becomes less precise. Imagine a photon that has not been absorbed when it has passed through sensitive cells and is reflected by the mirror. It ricocheted and went back. It does have a second chance to be absorbed by a nerve cell, but it will not be the one that would have allowed the brain to build a clear image! When the photon ricochets, it will only very rarely resume the same trajectory as when it arrived in the eye. Most often it will be diverted and will stimulate a cell close to the one that has been crossed without triggering nerve impulses. The brain will perceive an image well, but it will be blurry. And it was probably to maintain a clear daytime image that our ancestors lost their reflective mirror."

- If I understand correctly, it's because of this awful grouper that we inherited a reverse eye of common sense!"

Florian smiles without answering as I take a disgusted look at this awful great-grandfather.

## D.6: THE HUNT FOR WHALES' ANCESTORS

The cafeteria table is submerged in warm colours under the large ochre-yellow parasol. The tables on the flat roof of the Oceanographic Museum are already almost all occupied. They are obviously of interest to gulls: especially since some children have been playing with their prowess in flight to catch some bread crumbs they throw at them.

Florian pushes one of the four cutlery to the side and delicately places a laptop in front of him that he has just borrowed from a fellow student on an aquariology course in the museum's basement. I know he's prolific when it comes to evolutionary biology, but it amazes me now! After having served me as an impromptu guide for the visit of the museum, here he is, filling up by inviting me to follow him on the Internet!

- Here, would you like to order me the dish of the day while I look for the sites that interest us?

"Palaeontology has inspired many enthusiasts who travel the world with an energy that would have nothing to envy that of Indiana Jones! And unexpected adventures are no stranger to them either. Many have had the good idea to create websites that they transform into showcases of their discoveries and works. It must be said that competition is strong in their community and that they find a good opportunity to attract patrons."

I place the order while Florian is working on his machine. He continues: "Darwin had a bad experience with whales. In the first edition of his book, he suggested that they had had a land mammal as an ancestor and proposed a kind of polar bear to play this role. The criticism was so strong that he withdrew his suggestion from subsequent editions without replacing it. And the origin of whales remained a deep mystery until very recently.

"Well, here's Gingerich's website <sup>1</sup>."

Florian turns the screen a little towards me. At the top right, there is a portrait of a jovial man with a rather round face, a large pair of glasses and a well-shaped moustache.

"Gingerich is a skilled hunter of fossil mammals. He is looking for the longest possible successions of related species in the hope, which I think is illusory, of finding a mathematical formula that would describe their rate of evolution. In the 1970s he explored beautiful fossiliferous strata at the foot of the Himalayas in Pakistan, and sometimes discovered bones that he attributed jokingly to "legged whales"! They were fossils of pelvic vertebrae and bones that had characters similar to cetaceans, but since whales have no legs and he was interested in other mammals, he made little of them... But one day he found an almost complete skull and there, no doubt about it: it was a very primitive cetacean because it had characters that were found only in this family. It was the enlightenment! He suddenly realised that he was wrong to joke about legged whales and has since turned into a whale ancestor hunter! But despite all his efforts, he did not discover a skeleton complete enough to correctly describe the Pakistani cetacean he had found and named Pakicetus. In the early 1980s he was driven out of the area by the war in Afghanistan.

"He decided to continue the quest for the ancestral whale and turned to an Egyptian site that had already delivered whale fossils in the middle of the desert."

Florian explores the Gingerich site and presents me with some great desert photos.

"This is the site. Surprising whales have been discovered there since the 19th century! One of them was first mistaken for a sea snake, hence its name: the Basilosaurus or king of lizards. Gingerich worked for about ten years on this site and discovered fossils well enough preserved to prove that these whales had legs! Look at this!"

Florian presents me with an image of a Basilosaurus fossil that represents the reconstituted animal. No wonder it was mistaken for a sea snake. It is immense: at least 15 m of spine with, in the lower two thirds, tiny legs!

- But it couldn't use its legs!"

- Certainly not! Especially since the swim paddles are not articulated like those of seals and the hind legs are far too small to support the weight of the body. Besides, the pelvic bones are not even fused to the spine! And the foot is only four inches long, look!"

Indeed, a photo details a tiny leg that ends with three fingers. Florian explains: "It is clearly a vestigial organ that proves that its ancestors were indeed quadrupeds. But was it a bear as Darwin imagined? Certainly not! At the time, specialists were divided into two schools: bone and molecules."

Florian stops to let the waiter fill the table. He has probably seen many eccentrics before and does not seem intrigued by the computer while arranging the dishes on the free surface. As soon as he moves away, Florian picks up again while mechanically swallowing bites of his fish: "palaeontologists trust too much in the bones they discover..."

- What else could they believe in?"

- But to the molecules of course! Wait a minute! You'll see.

"Gingerich and other bone collectors were convinced that cetaceans were related to a now extinct family of mammals that looked like wolves. Besides, you can understand their arguments: look!"



FIGURE D.7: *Skeleton of Dorudon, close to the Basilosaurus but smaller. We notice the remains of the hind legs.*

Source: Gingerich P.D.

The screen displays a picture of three aligned skulls. They are very similar and legend has it that they are attributed to Pakicetus in the centre, a Mesonychid on the left and a coyote on the right.

" But biochemists who analyse the structure of molecules, DNA and proteins, were convinced that whales are not related to the Mesonychidae, which looks like a coyote, but rather to the hippopotamus."

- How do they propose that?"

- Several methods are available and all say the same thing, hence the confidence they have in their hypothesis. You can even check it for yourself by searching the databases available on the Internet. Switzerland is very well developed in bioinformatics!"

- And anyone can work with these databases?"

- Of course."

Florian is leaving the Gingerich site. The screen is much more sober and only displays text, a little obscure for me. But Florian pianos on the keyboard, slips a finger on the tactile surface while explaining: "The Expasy<sup>2</sup> bank stores a very rich information on the nature and order of amino acids of many proteins chosen from all over the living kingdom. We can compare a particular whale protein, such as red blood cells, to the same protein from a fish, coyote or hippopotamus and measure their degree of kinship."

- How can proteins be related?"

- If whales and coyotes share an ancestor, their proteins should have more amino acids in common than those of fish or hippos. Remember what we discussed about common ancestors earlier.

"I can choose the haemoglobin of a whale and compare its structure with the haemoglobin of a group of other species. Look! The program automatically calculates the degree of similarity for me."

Florian scrolls through his comparisons. He finds 35.6% similarity between the whale and the shark, 86.3% with the coyote and 88.4% with the hippopotamus. He continues: "Of all the animals that are not cetaceans, the hippopotamus is the closest to the whale. And that is why biochemists thought that the ancestor of the whale was an Artiodactyl, an animal of the hippopotamus, cow or pig family but not a Mesonychidae.

"This was known in the late 1980s, when the political landscape allowed Gingerich to resume excavations in Pakistan. Try to put yourself in his shoes and predict what the characteristics of the fossil you would like to find should be to clearly prove the genealogy of the whales."

- A complete Pakicetus skeleton to discover its legs. And then other more recent fossils to discover their regression."

- Gingerich searches again and again, but his luck seems to be exhausted: he does not discover a complete Pakicetus. He does, however, dig up a new interesting species: Rhodocetus. It is younger than Pakicetus, clearly aquatic, with a regressed basin that was supposed to allow it short trips on land, perhaps just to breed like elephant seals today. He is both happy and disappointed. His luck came back later when he found a very well preserved leg in 2001: look!"

Florian shows me a picture of three sets of bones that are incomprehensible to me. They look like pieces of joints: the one in the centre is clearly fresh: the other two are fossils. (Figure D.8)

- What should I see?"

- The astragalus, of course! It has a double pulley and that's the characteristic of Artiodactyls!"

- Tell me about it!"



FIGURE D.8: *Fragment of an American goat's foot in the centre compared to those of two fossil whale ancestors found in Pakistan.*

Source: Gingerich P.D.

- The ankle bone is very typical of Artiodactyls. Both fossils are ancestors of the whales discovered by Gingerich and confirm the biochemists' hypothesis. The ankle in the centre is that of a modern Artiodactyl! Whales have many Artiodactyls and not Mesonychids as ancestors and that is why the molecules of the hippopotamus still resemble those of whales.

"In the 1990s another researcher embarked on this exploration and his discoveries were superb!"

Florian goes on to another highly illustrated website. Its author is very different from his colleague: serious and emaciated face.

"Thewissen also went to Pakistan and discovered a superb whole skeleton of Pakicetus, which allows him to reconstruct the animal in much more detail."

Indeed, the top of the page is crossed by the cartoon of a kind of big rat. There's nothing aquatic about it! Below, a picture of its skeleton next to a hammer that serves as a length reference allows us to imagine an animal about 1 m long with a very powerful tail.

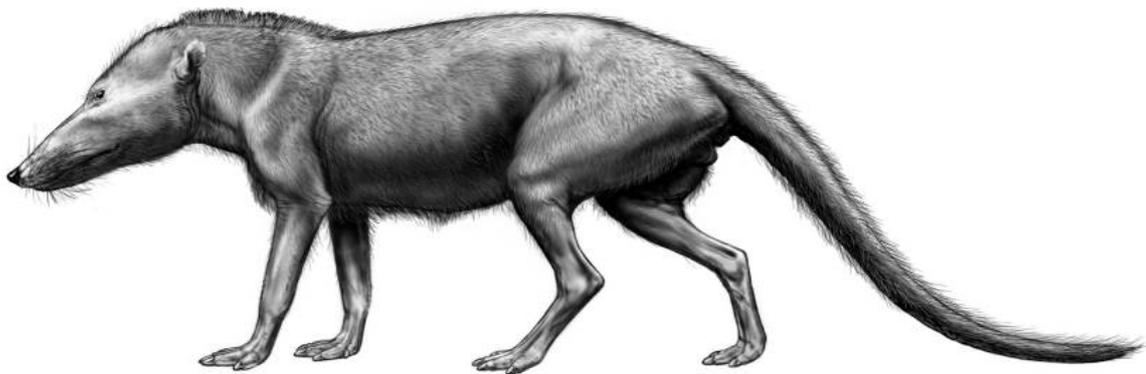


FIGURE D.9: *Reconstruction of Pakicetus, one of the first ancestors of cetaceans.*

Source: Thewissen and the painter Carl Buell.

"Pakicetus had four legs as functional as those of a coyote, but it had to have a hunting technique closer to that of a crocodile. Like it, it had to use its long lower jaw as an antenna sensitive to ground vibrations. This would alert it to the approach of potential prey near the stream or pond that was to be on its hunting territory."

- How can you know that?"

- Because it has a tympanic bone that can transmit the vibrations perceived by the jaw to the middle ear and it is precisely the ancestor of the bulla so typical of cetaceans. Today this bone concentrates the sound vibrations collected by the skull of cetaceans and transmits them to the ear, which no longer communicates with the outside world."

Florian displays on the screen the painting of a powerful aquatic monster with powerful legs who has just surprised a kind of dog that it holds in a huge mouth.



FIGURE D.10: *Reconstruction of Ambulocetus, the missing link between Pakicetus and Basilosaurus.*

Source: Thewissen and the painter Carl Buell.

"There's your fossil: the one you would have liked to discover to prove the genealogy of whales! It has all the characteristics of a terrestrial tetrapod that adapts to aquatic life and its age places it after Pakicetus and before Basilosaurus: exactly as Darwin had imagined. Thus the history of whales, which was one of the most mysterious in Darwin's time and remained so until the 1970s, is now becoming one of the most beautiful proofs of evolution!"

Florian's enthusiasm is communicative, but still!

- But how can you be so sure of yourself? The reconstructions you presented to me are impressive, but on what basis are they based? How do we know what part of the imagination is and what part of reality is?"

- There is very little room for imagination in these reconstructions because they emanate from a plethora of independently acquired information, all pointing in the same direction. Of course, it is impossible to know what colour the animal whose fossil is found was, but its environment can be reconstructed by analysing the associated fossils.

"Pakicetus is found among the remains of rodents, bats... in sediments typical of running water. Ambulocetus - the flagship fossil of Thewissen - is surrounded by typical remains of a shallow sea: marine snails... Rhodocetus is removed from typical clays on the edge of the continental shelf amid skeletons of ocean plankton. We are seeing a progression towards marine life that is increasingly liberated from the coasts.

" And Thewissen had the idea of analysing the enamel on the teeth of his fossils to determine what was the source of water they drank."

- Can you see that in your teeth?"

- In the proportion of light oxygen to its heavy isotope. Indeed, the light isotope evaporates a little more easily than the heavy one. Since the surface of the oceans is much larger than that of fresh water, salt water is enriched with heavy oxygen, which remains after the loss of light oxygen because part of it is precipitated as rain on land where it enriches freshwater bodies. And Thewissen found that Pakicetus drank fresh water, Ambulocetus lived on the coast because he drank both fresh and salt water while Rhodocetus was a sailor. Do you need any more proof of evolution?"

- No, thank you!"

- I'll give you some anyway. Or rather I suggest you discover them yourself!"

Florian heats the waiter and orders two coffees from him. Gulls hover over the terrace and seem to like it: there are no more children throwing crumbs at them.

## D.7: DARWIN AND FOOT FETISHISM

Florian observes me with a mischievous look: "I was arguing earlier that the theory of evolution gives meaning to myriads of observations; I suggest you discover it yourself, perhaps to your defending body by the way!"

Now he's downright mocking: "What would you say if we tried to explain foot fetishism through Darwin's theory?"

I must look totally stunned because Florian laughs...

- You're kidding!"

- No, I'm not! The theory allows us to imagine a plausible origin even for this kind of subject, you'll see!"

- Are you sure you're still doing science or are you offering us the 15-minute break?"

- But I'm serious... maybe not as you imagine, but I remain convinced that by reflecting on the circumstances in which our evolution took place, it becomes possible to understand certain observations in a completely plausible way, even if they are obviously not... or not yet, scientific truths!"

- So let's see what you have to say about the evolution of foot fetishism."

- Ah no! I'll just set the scene and you'll make the characters evolve!"

I must look stunned because Florian burst out laughing unabated: "You will see, I am convinced that you can do it... even if your education with the Jesuits makes you feel a few gaps and even a few flaws..." he adds, hitting his thighs while laughing with his throat outstretched. I wonder if I should be offended....

He finally calms down a little and adds with a smile: "Don't worry, you'll get there!"

After a short moment of silence to let the waiter arrange our coffees on the table, he continues: "Here... the story begins a very long time ago... six to eight million years ago. We are in Africa. At that time no man, no chimpanzee either; only a population of our common ancestor is struggling to adapt to the climate change that has been raging for a few hundred

thousand years: forests are shrinking as drought invades East Africa and the places available for tree life become very coveted..."

I stop him: "I see you coming!"

- Oh, well, you amaze me! Then explain to me the foot fetish!"

- No, I was thinking about our evolution from the monkey! But don't we still have a special status? There are controversies about the nature of fossils that biologists determine like our ancestors! Your critics argue that there are many monkey fossils, they also admit the existence of human fossils, but not forms of monkey-man as you say."

- Yes, I know, but that's totally false and it's even an argument of perfect bad faith! I will give you just one example: we have a whole impressive series of fossils that are clearly monkeys by the size of their brains and just as clearly human ancestors by their bipedal gait and especially by their teeth totally human type. Why would a monkey have our gait and teeth if not because it is part of a bush of species from which our direct ancestors emerged? There is no doubt now that we come from monkeys that disappeared long after leaving us the characteristics that distinguish us from contemporary monkeys. Because it must be added that these fossils are not missing links between the monkey and us as some people mistakenly think, no! It is a common ancestor, not only less evolved than us, but also less evolved than the contemporary chimpanzee which, I remind you, has also evolved over the past six to eight million years like us, but on another road!"

- You mean the chimpanzee is as evolved as we are?"

- Of course! Our species is the same age as its own, but ours has specialised in living in its own ecological niche in the Savannah, while the chimpanzee has chosen to remain in the tropical forest."

- So our ancestors would have come down from the trees to leave the chimpanzee ancestors there?"

- If you want! And we would have inherited a bipedal approach and the type of dentition we have today on this occasion, for reasons that are still mysterious."

- Wait a minute! You mean you can explain to me the origin of foot fetishism and you admit defeat when it comes to explaining our bipedalism?!"

- Don't be so serious, Matt... let go and you'll see that even you can find meaning in some of our strange behaviour!" Florian mocks gently but it is not enough to shake my conviction.

- Keep going, I'm curious to hear what you can say about our evolution but I remember that you ducked out about a particularly important character!"

- That's the way it is! So here I am, replanting the scenery: we are in Africa... We see a strange monkey by our current criteria: he is not a man but he is not a chimpanzee either, he is more primitive. Some populations of this species are found at the edge of forests that are constantly retreating. They are forced to exploit the Savannah in search of food while taking refuge as much as possible in the forest. Over time this population adapted to the bipedal approach, helped by its brachiating history - you know... this way of travelling by hanging from the branches like the anthropoid monkeys still do today. Baboons have remained quadruped by adapting to life in the Savannah because they do not have brachiating ancestors like us. In the case of our ancestor, the most effective approach in the Savannah was

bipedalism, more profitable than the current chimpanzee or gorilla approach, which was probably his at the beginning."

- Let's say so."

- His teeth also adapted to their food: seeds and tubers harder than the leaves and fruits of the forest."

- And the theory of evolution is enough to convince you of the origin of these adaptations?"

- Of course! Individuals who have inherited mutations that allow them to travel miles in the Savannah in the most cost-effective and safe way would be favoured. Those who would have inherited the thick enamel that is characteristic of our molars could have been nourished with food too hard for chimpanzees..."

- All right, let's say you're right..."

- And so we come to the problem I propose you study. On one side we have a population of monkeys well adapted to tree life, the ancestors of chimpanzees. On the other hand, on the edge, we have populations that develop physical characteristics more appropriate for Savannah life. But both populations are part of the same species and are still able to crossbreed and have offspring."

- So what?"

- Then the hybrid offspring may be unsuitable for both Savannah and forest life!"

- She'd be out of luck! Why not imagine the opposite: that it be adapted to both environments?"

- It is much more difficult, especially when the two lifestyles are separated: hybrids are much more likely to be less well adapted than each parent."

- Why?"

- Because they must maintain a set of characters adapted to the specialised lifestyle. In a hybrid there will be a lot of risks of losing some of them.

- All right. So what?"

- So it's up to you to keep imagining their evolution: you're dealing with two groups of monkeys. Each relatively well adapted to one of the two environments that coexist, capable of having hybrids but the children of two edge monkeys or the children of two tree monkeys manage much better until the age of reproduction than those of hybrid couples... How would you assess the evolution of this situation?"

- Perhaps individuals who reproduce only with a spouse from their population will have more descendants."

- With the conditions we have specified, this is not an assumption but a basic fact! I ask you to imagine what behaviours are likely to be selected."

- Are you thinking about the ones that lead to the choice of spouse?"

- Exactly!"

- The foot fetish, I say, mockingly?"

Florian smiles: "Not so fast, but you'll get there! Let's start by asking ourselves what is the driving force behind the formation of a couple."

- Seduction?"

- Yes! I argue that by analysing what today seduces men in women and women in men is, in part at least, inherited from the time when the common ancestor we share with chimpanzees had to choose sides! In other words, our ancestors would have been seduced by the specific characteristics of our adaptation to Savannah life and, of course, those of chimpanzees would have done the same with adaptations to tree life."

- Original! And what are these seductive characters?"

- Oh no, you're cheating! It's up to you to find them: it's easy! Just imagine yourself in front of an attractive representative of our species and ask yourself why you find her attractive. Close your eyes and visualise a beauty: why not a model? Look at her and let yourself be overwhelmed by emotion... She's parading to seduce you.... Imagine her naked as our ancestor was....

"Be careful, get a hold of yourself, you're all excited!"

- You are incorrigible," I said, reopening my eyes. But it is true that the image was disturbing!

- Try not to let your consciousness disappear under the emotion; remain lucid enough to analyse the sources of your emotion... What seduces you? Help yourself by discovering her seduction tricks, what does she highlight? Let your eyes glide over her shapes.... She evolves in front of you, moves in profile... caress her with your eye... admire her from behind... Look at her gait, her swaying, her long legs on uncomfortable and dangerous heels... her straight walking style. The torso and head move little; the hips and legs attract your attention... especially her movement of legs that remain excessively close together, to the point of crossing each other with each step. Her hairstyle is opulent and undulates on her shoulders....

"All right! Now she turns around and comes back to you, but she's not alone anymore: a monkey walks by her side!"

I suddenly open my eyes again, which makes Florian laugh again: "Calm down and analyse the two figures. How does the monkey walk? What are its shapes, its particular anatomy and what does it do with it?"

"Imagine the monkey standing up on both its legs: it waddles with every step: its short straight legs very far from each other. Look at the mannequin again; her long legs are not straight and separated but converge from the hips to the knees to ensure a comfortable bipedality. And the seductress accentuates our specificity by crossing her legs at every step, at the risk of making a paw hook, which is no longer comfortable at all but interests the male of her species!

"Don't you think that what seduces us are shapes, anatomy, gaits and tricks that caricature the differences that separate us from our simian ancestors? Why do our companions take so much care of themselves when they wax? To make up their eyes, to take care of their hair...?" Keep comparing her to the monkey that's marching with her.

- And the foot?"

- But it is one of the fundamental characteristics that has allowed us to be better adapted to life in the Savannah; that is why the foot can also be attractive, provided of course that the big toe is not opposable to others as is the case in monkeys," Florian adds with a laugh.

- If you were right, we should reverse your argument and find in the man what seduces the woman; then why didn't I meet any woman who looks at my feet?"

- Oh, yeah? It's strange because all my girlfriends love mine! Maybe your feet are particularly ugly..." offers a hilarious Florian.

- Because you think you have enough experience to be sure of yourself? You amaze me! Don't run away: what do you have to say?"

- That this is more of a game than a real analysis! A serious study should include the characteristics that make it possible to differentiate between the sexes, those that derive from the roles assigned to each sex... not to mention the effects of cultures and fashions! To be simple, I could answer you that women are often seduced by our hands, perhaps because our social role is incompatible with a thin foot, mounted on a stilt and because our hands also distinguish us from monkeys: our thumb is much longer and more mobile than theirs..."

- You're not convincing!"

- I remain convinced that the analysis of our seduction criteria would allow us to reconstruct the conditions in which the founding event of our lineage took place: the separation from the common ancestor that we share with the chimpanzee. Here, continue your exercise and ask yourself what are the male anatomical characteristics that seduce women by trying to avoid those whose main role is to differentiate between the sexes, such as hairiness for example."

- I'm sorry, but I can't see!"

- The ass!"

He's definitely strong enough to surprise me! He continues laughing: "The ass!..... It's their ass they're looking at! I assure you!"

He insists in front of my dubious and shocked look.

- How can you be so sure?"

- Okay, I didn't do an investigation..... But I have two girls at home inviting girlfriends and, believe me, things have changed a lot since we were their age! They express themselves very naturally and act just as naturally. The other day I was surprised to see them wallowing in front of the television, which was broadcasting a rugby match live. Apart from dancing, horse riding and gymnastics, they are not particularly interested in sports, especially on television! In reality, they were not following the game at all. Moreover, they were not interested in the rules of rugby, but they enjoyed the melee that allowed them to exchange opinions on the protagonists' buttocks and muscular thighs! And, believe me, they seemed very interested in the show!"

- So what?"

- Well, look at a chimpanzee and you'll see that our bipedalism requires characteristic buttock muscles and long legs that they don't have!"

I remain silent for a moment: "And it doesn't depress you to imagine that all this behaviour could have such an animal origin?"

- But not at all! On the contrary, because when we discover nature it forces us to admire it: it is prodigiously inventive and the behaviour of species is extremely interesting, especially when we study them in terms of their adaptive value!

"No, I don't find this approach degrading. Our extreme specialisation in intellectual and cultural faculties separates us from the rest of the living world to the point that we feel orphaned, alone of our species. But by discovering our roots we find ourselves in a large family made up of all the living species, all as interesting as ours, although from other points of view, of course!

"You see, I wonder if I'd rather spend an afternoon trying to converse with a chimpanzee than a fanatical sectarian!"

- Maybe you're right.

## D.8: GENES AND ATOMS: THE SAME STORY?

The sun of Monaco returns to my memories as here in Megève, Gold, Axel's dog, suddenly rises and puts his snout on Florian's thigh. Our biologist has been of prodigious interest to him since he started shelling chestnuts that were roasted in a chimney fire. Their aroma adds further warmth to the room atmosphere, as do the reflections of fire on the golden retriever's golden coat.

This chestnut is for Gold who swallows it almost without chewing it, after having checked with a quick blow of truffle if it is indeed what he hoped. Florian notices Axel's annoyed look, who has to fight the bulimia never satisfied with his dog and tries to change his thoughts: "Evolution explains in a very satisfying way why the species we are studying perceive the world differently than we do. But until you explained physics, Axel, it seemed quite obvious to me that our own image of the world was the right one... Besides, I had never really wondered about its value. But today I am no longer so sure of its relevance and I fear that our pride will take another blow!"

- I don't see what our pride would come here... and what pride is that?"

- The one of our species. We are all convinced of our supremacy at all levels. Our pride has already suffered a lot with Copernicus, then Darwin... and Freud..."

- I see. But I don't follow you," Axel replies, pulling Gold towards him. The dog sits at his master's feet but always looks towards Florian who is shelling other chestnuts.

- Maybe you're too proud yourself, like most of your colleagues, by the way!" Florian mocks Axel with a smile.

- I am proud of our results, it is true and justified! Our image of the world may sometimes be less rich than that of other species, but we more than compensate for our limitations by the very honourable performance of our senses and especially by our intelligence. It has allowed us not only to discover our limits, but also to build devices that extend the performance of our senses to areas inaccessible to all other species!"

- This is the pride of physicists," Florian continues, throwing a chestnut towards Gold but which Axel catches up with in flight. "But my perplexity goes further! The fact that my senses are limited does not disturb me too much, especially because I know how to compensate for

their inadequacy by technique: no! What challenges me is a much more fundamental question about our perception of the true nature of reality! I have the impression that the more we explore the microcosm, the more we miss it... Or, more precisely, the more we explore it, the more we are led to question our fundamental conceptions of the nature of reality."

- Now I agree! The physics of the twentieth century is full of surprising discoveries and not only at the level of the microcosm! Astrophysicists can only explain about 5% of the mass energy observed in our telescopes. The rest, the 95%, we can measure its effects well, but it remains perfectly invisible and mysterious!"

- Dark matter... yes. In biology too, we are discovering all kinds of unexpected phenomena... This is the second theme I wanted to discuss tonight.

"In the 1950s, with the first works of CERN in particular, you built increasingly powerful machines to break matter in the hope of finding the ultimate particles... without success! The fundamental brick of the material you dreamed of seems to escape you as you discover a whole zoo of strange particles. You are building increasingly insane machines by holding out to politicians and taxpayers the hope of ultimate discoveries... and this for half a century!"

Axel diverts his embarrassment by scratching his dog's neck with renewed vigour: "You're hard! We have made extraordinary discoveries, both in microphysics and astrophysics! But it is true that nature is not as simple as we had hoped at the beginning of the twentieth century. Nevertheless, our discoveries have been numerous and often put to good use by technicians for the greater good of all!"

- That's true. But what strikes me is that in biology we are discovering the same limits as you do! We too thought we were close to the goal: the physicists and biochemists who came to lend their talent to biologists to create molecular biology and genetics naturally applied their fundamental concepts when it came to creating models of life. Materialistic and reductionist paradigms have been transposed from physics and chemistry to biology. With great pride, the young researchers postulated that it would be possible to understand all the mechanisms of life by analysing the properties of the molecules it uses. Physicists set out in search of the fundamental brick whose properties would gradually explain those of the entire universe: biologists set out in search of genes, convinced that they could understand the construction of an entire living being based on the properties of its genes. And it worked... at first! But it seems that the situation we find ourselves in today is similar to yours. A parallel can be found in the history of discoveries in physics and molecular biology. Is it a method artefact or a significant association with the nature of reality? That's a question that bothers me!

"Physicists who set out in search of the fundamental brick of matter have seen it explode into myriads of increasingly esoteric particles and then into immaterial waves that are capable of infusing the entire universe and interfering to make what we call matter a reality. Biologists in search of the fundamental brick of heredity believed they had discovered the gene and then, trying to define it more and more finely, they saw it gradually escape to get lost in what seems to be also a world of interactions!

"Here Matt! What is a gene to you? How do you represent it to yourself?"

## D.9: WHAT IS A GENE? FIRST ATTEMPTS.

"What is a gene," asks Florian! I suddenly remember many years ago asking myself the same question in high school, in the amphitheatre on the first floor of the Villa des Sciences. And the answer, I didn't have it! At least not clearly.

The teacher of natural sciences, a very brave priest who sought to transmit his enthusiasm for the harmonious and rich beauty of nature, was suddenly cluttering himself with jargon behind which he probably hid his discomfort when it came to genetics. We felt he was reserved, obliged to cover the program on which we would be evaluated, but passing like a cat on fire through the chapters he had to consider shamefully mechanistic. He was a naturalist: very competent to communicate his love of nature as we discover it through the amazing adaptation of species. Much less comfortable when it came to analysing the intimate mechanisms, the mechanisms that Descartes believes would constitute the nature of individual machines. And this gene was incongruous in the serenity of our beautiful class bathed in the sun as light passed through the glass facade on our left. The light gilded the long oak benches that had turned brown with time and cascaded down the steep slope on which they followed each other to the large table, at the very bottom, also in oak, around which our master wandered. And all his definitions cluttered our minds instead of helping us structure its work: gene, allele, haploid, meiosis, zygote... and more!

Much later, Florian introduced me to the revolution in biology through genetics. He had shown me how another priest, an Austrian one but also a high school natural science teacher, had created this new branch of biology, all alone in his garden, misunderstood and ignored until his death at the end of the 19th century. His skills in statistics - he also taught mathematics - and his scientific probity had led him to set up experiments of high quality, well ahead of his time. His religious status prevented him from working with animals - at that time he would have been quickly accused of being a vicious man if he had dared to mate mice, for example! So he had chosen the pea! And it was by crossing 14 selected varieties of this common vegetable that he discovered an order underlying the apparently chaotic diversity of the couples' offspring. The laws of heredity he discovered met, at best, only a polite interest. His readers could not imagine that discoveries made with peas could be of interest in understanding animal genetics, and even ours! Mendel himself has been influenced by critics. He tried to understand the transfer of characters to the only animal that can be raised in a convent without raising suspicions: bees! It couldn't have come at a worse since they have very particular characteristics very far from those of other animals! He was unable to extract from his observations on animals, concepts as clear as the first ones, a comprehensible schema. He gave up research and took on administrative responsibilities until he disappeared.

And yet, the first geneticists of the twentieth century discovered, very amazed, that the laws governing the heredity of peas also regulate that of animals! And that's when we discover the gene.

A few years after the moment chosen by Planck to create a concept to which he attributed no reality but only the advantage of being a good research tool - the quantum - a biologist also creates a concept - the gene - in order to benefit from a functional image to simplify the analyses of the results obtained. He too did not really believe in the concrete nature of the

gene: he considered it as an artifice, a transitory and imaginative concept on the road that would lead to an understanding of heredity.

Mendel - our Austrian monk - had already shown that, against all odds, genetic information is granular, quantum we might say: this discovery was unexpected! Expressions such as "blood mixing", customs such as the prohibition of non-caste or out-of-class marriages, showed how much the origin of hereditary characteristics was supposed to be fluid, soluble and non-solid and durable. Mixtures were not recommended because they could dissolve the root causes of hereditary traits irreversibly: a bit like diluting milk in a cup of tea and no longer finding pure milk or tea. We better understand the barriers that some ego put to the choice of the spouse: they sought to find their own characteristics in their descendants, intact if possible.

But these preconceptions are wrong: Mendel discovered why certain characters could "skip a generation", find themselves intact in the offspring of hybrid parents who did not express them! They are not denatured by the mixture but remain, sometimes hidden for a long time, until they can express themselves again in an environment that suits them.

It was an important discovery but Mendel went further: he showed that we both have copies of each of our genes, a legacy of each of our two progenitors. Each egg, each sperm, contains a copy of all the genes necessary to build and animate an individual. Then, after a successful fertilisation, one, two or both copies can be expressed according to specific conditions that only the experiment can reveal. Thus, sometimes, a gene goes unnoticed when its copy expresses itself alone, and then finds in the next generation a new environment that is suitable for its expression.

Florian told me about the saga of genetics since the explorations of the first researchers of the twentieth century, contemporaries of the discoverers of quantum physics who, like their fellow physicists, developed techniques to work with the invisible, the too small to be seen, even under the most powerful microscope of the time. But while some discovered the Principle of Uncertainty, others gradually ensured themselves of the astonishing characteristics of heredity. Very quickly the genes are located on the chromosomes that we see leading an elegant ball during each cell multiplication. Then they become concrete when we succeed in locating them, one by one, on the chromosomes that we map like a new territory that we explore. The virgin areas of genes are thinning as the family of researchers grows.

To explore the nature of matter, physicists explode it into smaller and more easily studied particles, with the reductionist and mechanistic hope of later being able to understand it while reconstructing its parts. A little like a curious person intrigued by a watch might be tempted to take it apart entirely and then rebuild it to understand its mechanism.

Similarly, biologists at the beginning of the century break genes to try to understand their attributes: they collect mutants that have become incapable of expressing a particular hereditary trait to study its genetics and effects on other traits. With the reductionist and mechanistic hope of understanding life by reconstructing the individual from the added characteristics of all his genes.

And then it is the explosion of discoveries that leads to the premises of the biological revolution. Plethora of profoundly significant results, whose paternity owes much to other explosions, sinister these ones, in Hiroshima and Nagasaki! A generation of physicists, horrified by the consequences of their work, left physics to work on life. And they take with

them their technology, but, of greater importance, their methods of analysis and their pride which ensures that they find answers to the increasingly precise questions they ask nature!

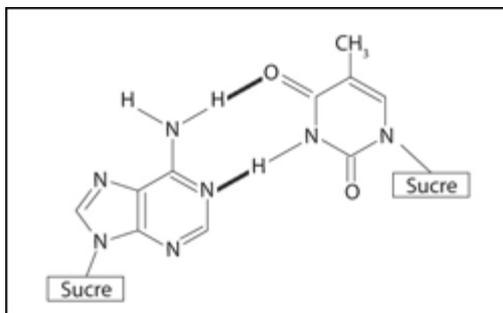
It is indeed a source of pride to believe that we can unravel the most intimate mechanisms of life, those that bring us all our inherited faculties: a little like the psychiatrist who would seek the mind under his scalpel. It is not surprising that the surgeon did not find the mind. That new biologists have discovered the physicochemical nature of life has not yet produced all the surprise that this event deserves, perhaps because its implications are not always well understood. Here again, a parallel is drawn with physics! Quantum concepts are not yet taken seriously enough by the neophyte to surprise us as they should!

The first beacons of the new biology were put in place well before the war, as early as 1928. During a pneumonia outbreak, we discover why certain strains of bacteria resist our defence system: they surround themselves with a greasy coat that protects them from white blood cells responsible for digesting parasites. A brilliant but insufficiently exploited intuition leads Griffith to discover for the first time that a gene is manipulable. He kills virulent bacteria - those who know how to make their protective coat with a given gene, Griffith reasoned - and mixes the juice of killed with live bacteria of the same species but unable to invade us because all naked, without greasy coat and completely digestible to our white blood cells. The result is breathtaking: from the mixture, new virulent bacteria are born, very much alive and able to proliferate to give birth to other microbes, all as virulent as their progenitors! A hereditary character, the one that makes it possible to make the protective mantle, had passed from one dead bacterium to another, living, and transformed it! A gene is therefore capable of transcending death! So it is not alive... or dead: does the question make sense at its level? But Griffith doesn't go any further. We have to wait for another biochemist and 1944: second beacon on our way.

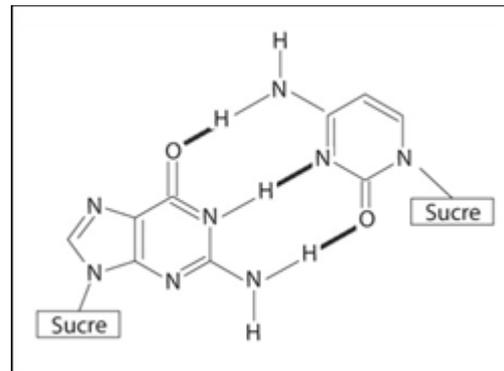
Avery finds Griffith's work and realises that it can be used to determine the chemical nature of a gene: the presumption is not limited to the physicists' clan but it has paid! A series of elegant experiments led him to discover that the transformation of harmless bacteria into killers protected by their fat armour was triggered when they acquired a piece of a molecule whose importance had been underestimated until then. At the time, we swore only by proteins whose infinite diversity largely justified the geneticists' convictions on the chemical nature of genes. No! Our heredity was embedded in a curious molecule much simpler than a protein. A long, very long chain composed of only 4 different forms of smaller molecules, attached to each other, while for proteins we find twenty different types. And this molecule of heredity we all know today: it is DNA!

The following beacon marks 1953. This time it is the official birth of molecular biology, led by many physicists who, after reading one of the founders of quantum physics - Schrödinger - are also interested in the fascinating mysteries of biology. Schrödinger with a prodigious intuition had proposed as early as 1944 that heredity should be stored in coded form in an aperiodic crystal<sup>1</sup>! Crystal to be durable, resistant to time: aperiodic to allow the infinite variations observed. A salt crystal looks like any other salt crystal because the atoms fit together in a strict periodic order. A DNA molecule can store information because the order in which its 4 basic molecules follow each other is not predefined in any way. Each of them has as much chance of finding each other as any other. And while a large salt crystal will not store more information than a smaller crystal - it will only contain repetitions of what constitutes it - the DNA molecule, often gigantic, becomes capable of containing an enormous amount of information.

Molecular biology was born with the discovery of the three-dimensional structure of DNA. One could not have imagined a more elegant structure, richer in explanatory potential! Just by looking at it, we can guess how a simple chemical molecule can do what we thought was only related to life: reproduce! A superb double helix, prefigured into a majestic staircase of the Château de Chambord built 5 centuries earlier! Each DNA helix secures the information first by protecting it in the centre of the structure, protected from solid amounts of a skeleton whose vertebrae are phosphoric acid molecules (DNA's A) and a small sugar (DNA's D). Then by duplicating it: indeed, each spiral is complementary to the other. It is not a mirror image but the result is the same. If a damaged molecule needs to be repaired, the necessary information can be found on the spiral opposite. The result is an astonishing security since we find only very few errors. Much less than the best typographer can ever succeed: an average error in a billion!



Adénine and Thymine



Guanine and cytosine

FIGURE D.11: *Nucleotides: fundamental molecules for storing genetic information.*

*Adenine and thymine spontaneously join in a mixture of molecules because their shape promotes a sharing of hydrogen atoms in two places (thick bonds in the diagram on the left)*

*For the same reasons, guanine and cytosine bind and share three hydrogen atoms.*

Source : [www.ogm.gouv.qc.ca/images/img\\_nucleotide.gif](http://www.ogm.gouv.qc.ca/images/img_nucleotide.gif)

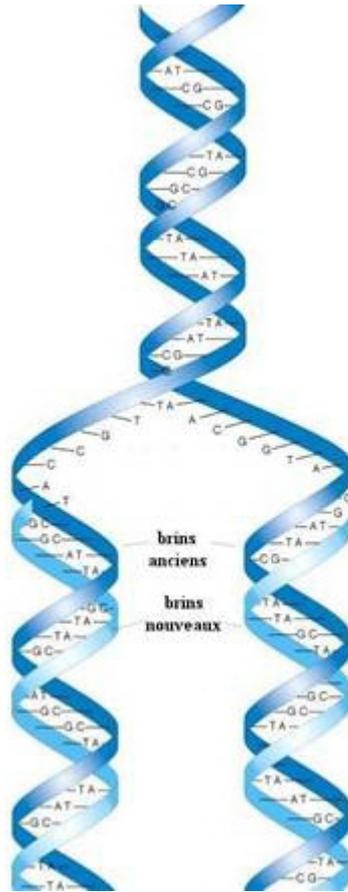


FIGURE D.12: *DNA is formed by two intertwined spirals of complementary nucleotides: in front of the adenine is a thymine while in front of a cytosine is a guanine. As these nucleotides bind spontaneously, it is sufficient to separate each nucleotide chain to let the complementary nucleotides recognise their neighbours. A simple chemistry, based on the properties of nucleotides, makes it possible to understand how a molecule can reproduce itself without invoking any "vital force".*

Source : [http://www.edu.upmc.fr/sdv/masselot\\_05001/introduction/images/pic009.jpg](http://www.edu.upmc.fr/sdv/masselot_05001/introduction/images/pic009.jpg)

## D.10: THE NOBEL PRIZE WINNER IN THE BASEMENT

A Nobel Prize for Geneva! Who would have thought that such a distinction would crown the young professor who worked in the basement of the School of Physics, at the end of the corridor, to the right, at the bottom of the stairs on the Jura facade?

Not that a Nobel Prize was unlikely for the Department of Molecular Biology: it remains one of the best even today! But no one would have imagined him to earn the Prize: an atypical behaviour within a team that is largely committed to the Anglo-Saxon model. A German-Swiss with a strangely matte complexion, powerful stature and who had kept all the restraint of deep Switzerland, isolated among other Germans and a few French-speaking people, all of

whom had acquired the feverishness of a good reputation in the laboratories. The one who shone with his nervous energy, his impulsiveness, his eccentricity and total indifference to social conventions, the one who ignored any attention at the hour of the day or the day of the week, was fashionable. The future winner was discreet and independent, even taking his snack alone, rarely rewarding a student, technician or assistant of a cookie taken out of a metal drawer in the middle of his archives. We could have set our watch based on the sound of his footsteps along the corridor!

But it was perhaps this independence of mind that made him successful! Engaged in a project well defined by his thesis supervisor - the exploration of the effects of nuclear radiation on bacteria and viruses - he could not help but explore a chance observation and satisfy his desire to get to the bottom of things to understand them as well as possible. He had no idea that he was going to abandon his primary subject to spend the rest of his professional life exploring the consequences of the discoveries he was going to make, guided by his curiosity.

Other researchers already knew that there was a strange impregnation of the virus after its victim. The predator can attack several breeds of bacteria but its effectiveness depends on both the type of prey it has just infected and the one it attacks immediately after. If it is the same race, then it is able to fully develop its virulence: each prey will be destroyed by giving birth to a hundred new viruses. But if it tries to enter a new breed of bacteria it will be severely restricted: only one virus among a multitude of attackers will have the chance to escape the system of protection that bacteria erect against their parasites. But the winner's offspring will be impregnated by its bacterial victim so that it can now develop virulently without any further restriction. On the other hand, it will have lost its effectiveness as an infection for the ancestral bacteria race. The parasite is modified by its prey so that it no longer has any restrictions on it. But it becomes sensitive to that of all other bacterial strains, even if its distant ancestors were able to attack them.

Our young professor knew all this, but he made an interesting parallel with his research project when he analysed why viruses that were not properly modified could not reproduce in a new strain of bacteria. He discovered that they were victims of the same fate as those who had been heavily irradiated by nuclear radiation: their chromosome was broken into pieces! In one case, the radiation directly broke their DNA: in the other, sentinels nestled in the walls of the bacteria cut them up.

He named these border guards "restriction enzymes" and this discovery won him the Prize. Not because the Swedish Academy found a direct use for this discovery in medicine, but because a few years later, biochemists succeeded in exploiting restriction enzymes to create the techniques of genetic manipulation universally used today. These enzymes analyse a DNA molecule at full speed in search of a specific nucleotide sequence: each bacterial race recognises what constitutes a kind of personal signature and accepts DNA from a congener during mating because the target sequence is chemically modified in a recognisable way. If this is not the case, its restriction enzymes cut out DNA that is not impregnated and most often comes from potential parasites or unwanted mating. (Figure D.13)

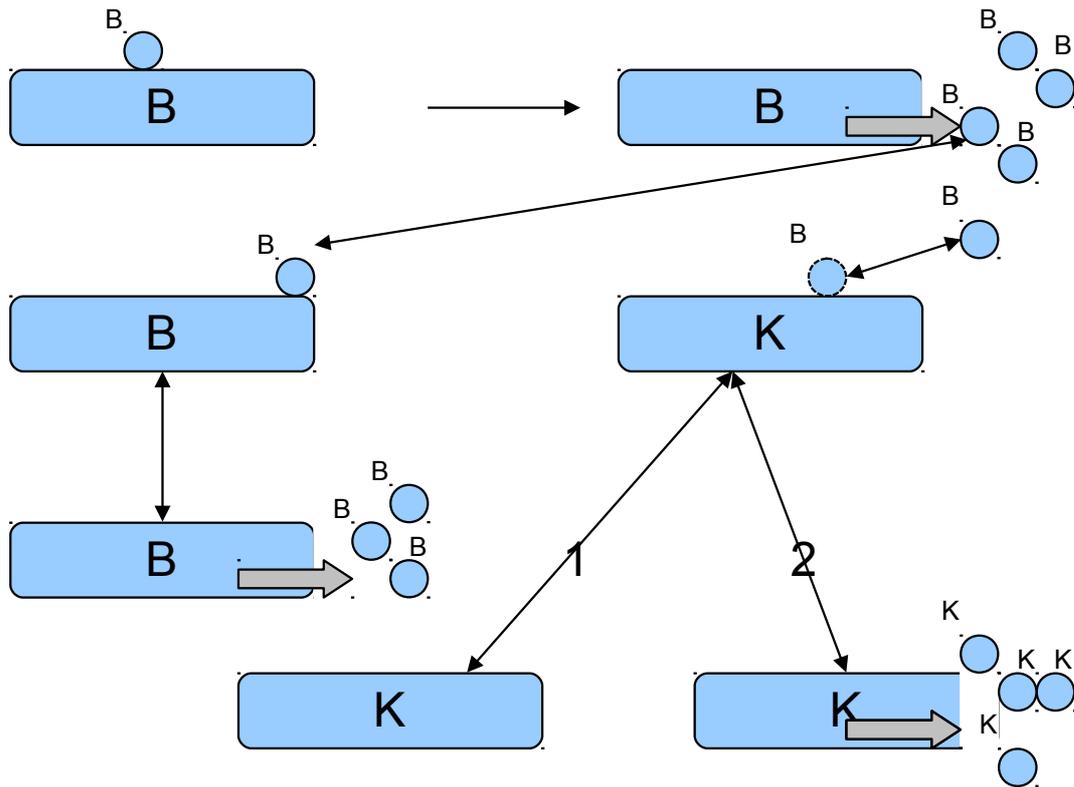


FIGURE D.13: Restriction and modification of viruses by bacteria: the mechanism that is used to invent the tools of genetic engineering.

A virus that has successfully parasitised a strain of B bacteria is able to parasitise new ones with high efficiency (left). But it is unable to infect a type K strain: the bacteria recognise the virus as a parasite (1) and cut out its DNA when it tries to penetrate it. But one virus in a million manages to cross the restriction barrier without damage (2). Its offspring become capable of infecting type K bacteria with high efficiency but have lost their virulence against type B bacteria.

The precision of the restriction enzymes has earned them the nickname "molecular scissors" because they are able to simplify a monstrously long DNA molecule into perfectly manipulable pieces and always cut cleanly in the same places: those with the signature of the bacterial strain from which they were extracted! Thus, it was quickly possible to cut the human insulin gene and transfer it to a bacterium so that it could express it as if it came from its own heritage and produce a large quantity of human anti-diabetic hormone. Thus it became possible to hope to properly extract an active gene from a healthy donor to transfer it to the cells of a patient with a disability of hereditary origin and try to cure it, whereas until then one could only hope, at best, to treat it. The Nobel Prize for Medicine was perfectly justified!

It is to Florian that I owe it to myself to have lived in part the heroic era of biophysics underground! A contagious enthusiasm inflamed all the Institute's staff and I liked to find this pioneering atmosphere again when he was a young assistant very committed to his studies.

The comfort of the place was limited but it was considered useless! Florian and an accomplished technician and researcher shared a large square room that served as an office, laboratory and archive room. The room received only weak daylight through a little window

exposed to the North, just above Florian's bench. But a plethora of fluorescent tubes on the ceiling and old office lampshades were enough to warmly light up the room. Some machines - centrifuges, water baths to cultivate bacteria - provided a constant but not unpleasant background noise. To the point that Florian sometimes spent the night at the foot of his work table, lying on an air mattress, near the alarm clock charged with punctuating his night with bells aggressive enough to wake him up when a timed manipulation required his intervention.

Because since physicists had converted to biology, work on plants or animals considered far too time-consuming was over! Even the smallest fly needs 21 days to create a new generation! The analytical and reductionist approach of physicists has pushed them to work on bacteria and their viruses which only need a few minutes to give birth to their offspring to the point that in one day as many new generations of microbes are born as in several centuries for us!

The results are quickly achieved, but at the price of protocols set to the minute! And I sometimes helped Florian when he was preparing experiments for biology or medical students. He used me as a guinea pig, which allowed me to understand the basics of the biological revolution, then in an explosive phase since the discovery of the structure of DNA.

## D.11: WHAT IS A GENE? THE ERA OF DOGMA

"We have found the secret of life!" said Francis Crick to anyone who would listen to him in the pub near the laboratory where, that very evening, he had just understood with James Watson the structure of the magic molecule: DNA. Indeed, their discovery made it possible to build a large bridge between the world of chemistry and its molecules on the one hand and that of life and its mysteries on the other! No need to invoke a hypothetical supernatural life force to understand how a cell reacts to the aggressions of its environment and rebuilds its molecules, whereas a crystal is incapable of doing so, although it too has an ordered structure. The laws of chemistry, themselves daughters of quantum physics, are now building an avenue that links the world of inert matter to that of the living world. Laplace replied that he had not needed the hypothesis of a God to build his model of the Universe; he could be paraphrased by the two researchers who no longer needed to invoke a supernatural force to explain one of the most fundamental qualities of living matter: reproduction.

Who could have foreseen the extreme elegance of the solution found by nature to imagine eternity: reproduction that transcends wear and tear and accidents, which is the only true response to the eternity of time that passes with its share of potentially destructive difficulties? Since 1953 the little note that Crick and Watson had added to the bottom of their publication has been widely demonstrated. It stated that "it had not escaped our attention that the analysis of the DNA structure strongly suggested a mechanism for self-replication of the molecule".

Followed by a golden decade. Major discoveries are accumulating. Models abound and experiences confirm some of them, often the simplest: nature seems to be very economical in terms of resources. Concepts are affirmed and transformed... into dogmas! To the question "what is a gene?" the answer is clear: it is a well-defined piece of a chromosome that contains the construction instructions for a given protein. And when we know that proteins are the building blocks of any cell and the molecules that give it life through their enzymatic

properties, we feel very close to a physical, mechanistic understanding of living processes. It is still necessary to discover how the gene is expressed to direct the construction of proteins!

It was on the paper tablecloths of the pizzeria next to Florian's lab that I discovered the language of life! We often met there in the evening with a whole team of friends to relax and play electric billiards before enjoying Italian cook. Florian, enthusiastic, scribbled between the oil stains to explain the expression of genes as predicted by the most popular models. And little by little, we participated in the astonishment that was the lot of any researcher involved in this race: nature was understandable! Moreover, the solutions she had found were much simpler than those devised by the researchers. The language of life was discovered in bits and pieces and in the 1960s the most unexpected discovery ever took place! Only the fact that it took several years to reveal it can explain why it did not have the effect of a bomb!

The language of life is universal! Regardless of the species being studied, the genetic code that allows it to store its hereditary information and then translate it into the form of precise molecules is the same! It is as if, everywhere on the Planet, we speak exactly the same dialect, with the same accent, whether we live in Kamchatka or Melbourne! No one would have imagined such a thing! Because it is indeed a coded language: a series of symbols that require a dictionary to take on a meaning, just as a series of letters symbolises the meaning of a word in a language without any reason other than their history to link a given word to a specific meaning. Moreover, in another language, the same word could very well have a different meaning if it were written with the same letters! Any transmission of information requires a symbolic code, whether it involves transforming the sequences of bumps and hollows of a CD into musical tones, or the orientations of magnetic micro-particles stuck on the plastic matrix of a magnetic tape into images and television sounds. It is always a language that requires a dictionary to be understood. The same is true of the genetic code and the dictionary is the same everywhere, from the virus to the baobab, including us of course!

Awesome! And it is the very heart of the biological revolution that allows us today to extract a gene from one species and then graft it onto another, in which it will be integrated, understood, deciphered, as if it had always been at home, without any difficulty of understanding. Genetically modified organisms are the consequences of this universality of the genetic code. This is why the human insulin gene is recognised as one of its own by the bacteria into which it is inserted. This is why the bacteria that express it becomes capable of building a protein of human origin from instructions extracted from our hereditary heritage.

All living beings on this Planet share the same type of molecules that they assemble and reassemble to build their specificity, a little like a child deconstructs and then rebuilds its compositions from standard reusable parts such as those of a Lego for example.... And nature does not deprive itself of sharing the genes of one species with other species: it invented genetic engineering long before us and makes fun of the barriers between the different species that we thought were impermeable! This is what Florian told us in the late 1960s and today... what will he teach us?

## D.12: THE FLY, THE POPLAR OR MAN: WHICH IS MORE COMPLICATED?

What is a gene for me, Florian asked me while peeling chestnuts that Gold lovingly looks at and Axel watches over while keeping the dog glued to his legs, looking severe.

- Well, I imagine it as a series of molecules well described today, located at a specific address of a given chromosome and containing all the information necessary to make a hereditary trait."

- Your definition sounds precise but it's too vague," Florian replies. "What is a hereditary character then?"

- Information necessary to build a molecule: a plan of sorts!"

- It's not enough: how do you know where and when the molecule should be made?"

- You're the biologist! But I suppose there are regulatory genes that are responsible for determining the timing and extent of expression of other genes."

- This is the path explored in the 1960s. The discovery of regulatory genes has been fruitful, but are they still really "genes" in the primitive sense? It's not sure! Genes have been found to be more or less expressed in relation to DNA sequences that do not code for the manufacture of molecules and that may be quite far from the gene whose expression they control: are these regulatory sequences genes or not?"

- It all depends on your definition!"

- This becomes a problem: as discoveries accumulate and become more precise, the concept of the gene loses its relevance and is diluted into a set of interactions, some of which were surprising and completely unexpected."

- For example?"

- For example, the discovery of DNA sequences that do not appear to be useful, that do not contain the information necessary to build a molecule and that are interspersed in the sequence of the gene that stores the information to build a molecule. It is as if you discovered that you have just bought an unreadable, incomprehensible book, because sequences of letters that mean nothing are interspersed in the middle of sentences or words and you would have to find them to erase them in one way or another in order to be able to read your book. These introns - that's their name - often have lengths much longer than exons - the part of the gene that we can read and that stores the information to build a molecule."

- And what are these introns for?"

- In fact, we don't know... more than a quarter of a century after they entered the world of molecular biology researchers! Some even think they are useless. But this is certainly not always the case: we have sometimes discovered that they were essential but we still do not know in what way! But that's not all!"

Florian turns to Axel, with a deadpan look on his face: "Axel, are you more complicated than a worm?"

The person concerned looks at Florian without answering, eyes wide open!

"Matt, are you more complicated than a poplar tree?" Florian asks, turning to me and smiling frankly this time.

- Of course, what's your point?"

- It's not that clear! We thought we were the result of the expression of at least a few hundred thousand genes... And we found only about 25,000, not even more than those of a tiny fly, not much more than a miserable worm invisible to the naked eye!"

- Maybe you still have something fundamental to discover," Axel says. A little like in physics when we are looking for the 95% of the mass energy that we lack to explain our observations!"

- Maybe you're right. But a recent discovery has put us on a path that also shakes the concept of gene.

"Introns scatter genes and must be excised before the cell can make a molecule from its genetic information. But it has been discovered that a single gene can give hundreds, sometimes thousands of different molecules, as a result of intron excision. This can be done in different ways so that the excision of a given intron may or may not involve the excision of one or more exons of the gene concerned... upstream or downstream! Not to mention possible interactions with a series of molecules capable of modulating the extent of expression of each exon as well as its probability of being excised or not."

- But these discoveries could then explain why we can be much more complicated than flies without having many more genes than they do!"

- Not really because poplar has almost twice as many genes as we do, why?!"

- And it seems much less complicated than a fly... it's weird, Axel answers. You should really look to broaden your gene concept!"

- This is what I was getting at: we started out a little like quantum theorists, creating a functional concept and then discovering that after all it was concrete and finally we discover that reality is much more complex than we imagined.

"Another example: a Bernese researcher transferred a mouse gene into a fly egg and the mouse gene was expressed!"

- What surprises you since the genetic code is the same everywhere?"

- This gene controls the production of a functional mouse eye. And in the fly that should have been born blind because it carried a mutation that prevented it from making eyes, the mouse gene is able to restore the function of the mutated fly gene and direct the production of a perfectly normal fly eye."

- So what?"

- Then the fly's eye has nothing to do with a mouse's eye! How can we explain that the product of the same gene is able to trigger the expression of a mouse eye here and a faceted eye there?"

- ...

Florian answers for me: "It is probably an architectural gene: it does not directly produce a structure of the eye but directs the expression of hundreds of other genes which, in turn, produce an eye adapted to the environment in which they are found."

- You highlight the importance of interactions between the gene, their product and their environment," says Axel.

- Yes, the concept of the gene loses some of its specific nature to acquire properties related to interactions: they become more and more important, a little like it is the case in physics! We are gradually discovering that a gene is more a way to store information and not really a creator of hereditary character."

- But isn't your architect gene an eye creator?"

- Not at all! What creates the eye is the interactions it allows; it is incapable of creating it because in one case its role is to order the construction of a mouse eye and in the other, that of a fly!"

- There's a subtlety there that escapes me!"

- So let's see what we discovered with the knock-out mice."

## D.13: THE MYSTERY OF KNOCK-OUT MICE

I have a crazy pain in holding back from laughing out loud! Florian has found a way to thwart Axel's vigilance; he peels his chestnuts and then gently slides them towards Gold's jaw. The comic of the situation lies in the dog's attitude because he seems to be perfectly aware of the game! He, usually so exuberant when it comes to food, remains very discreet as if not to arouse his master's suspicions. He is spread out all along, his flank glued against the supervisor's leg but his body and snout stretched towards Florian. He barely sketches small mouth movements to catch up with the fruit and swallow it silently!

Florian is no less comical with the contrast between the seriousness of his words to focus Axel's attention and the lightness of his behaviour! He says: "As we tried to circumscribe the notion of gene, we discovered completely unexpected results in the mechanistic and reductionist conception we inherited from physicists. Half a century later, we were also discovering the importance of a more global vision of genetic phenomena. The all-powerful architect gene, the gene that chiefly builds anatomy and creates the adaptive functioning of the individual, escaped attempts at precise description.... And then the techniques have progressed so much that it has become possible for us to work on a few cells at a time, and even on a single cell in the most favourable cases."

- And what is the advantage?"

- There are many of them! Imagine, for example, that you would like to understand why certain cells in your toes make hair rather than a retina."

- That's the kind of stupid question I'll never ask myself!"

- It is not stupid because all your cells have the same genes, whether they make eyes or toes! How do you explain that the genes needed to make eyes are only expressed in the right place and not in your toes?"

- I don't know!"

- Neither do we, but we're looking for it! We now have techniques for analysing gene expression in each of the cell types: and the fewer cells we need for these studies, the more revealing our results should be of the fundamental mechanisms."

- And what do you discover?"

- That many of our preconceptions were wrong! For example, something that reminds me of the intrusion of randomness into quantum physics.

"Many biologists were convinced that all cells in a tissue expressed themselves in the same way, at the same time, under the orders of the same genes. Well, no! The image that is gradually created with the discoveries that accumulate, is that of a random process in which a given cell is more or less likely to express a given gene according to its environment and that it is a kind of natural selection of cells that express the genes most appropriate to the circumstances that guides their adaptation and even the development of an embryo: it will produce a given specialised tissue according to their environment more than following the direction given by the genes in power. Interactions with the environment become the main actors in the expression of genes, which are gradually relegated to a role of storing information, whereas they were imagined to be capable of directing all the bases of life."

- You're not going to make me believe that if I have an eye in the right place instead of a toe in the middle of my face, I only owe it to my luck!" Axel laughs.

Gold gets up suddenly, surprised by the big bursts of laughter! Florian finally replies, continuing to laugh: "I recognise the physicist there! One biologist said that if physicists are able to mathematise their science, it is because it is so much simpler than biology!"

This time I'm the one who's surprised: "Do you think mathematics is simpler than biology?"

- Not really: he meant that the objects that physicists study behave in a much simpler way than a living organism. He gives the following example: if you throw a dead bird into the air, a physicist will be able to calculate its trajectory by applying a mathematical formula. But if you release a live bird, no physicist can predict its trajectory with an equation!"

- I don't see the connection at all! "says Axel.

- There is one though! It is the emergence of orderly or complex behaviour based on simpler laws that are rich in potential effects.

"Biologists have been able to simulate the ordered organisation of cells from the random expression of a few properties. And that's when it gets very interesting, because the main thing is back in the interactions! They have simulated interdependent cells insofar as they cannot survive on their own: which is the case for all normal cells in an organism: only cancer cells seem to escape this requirement! Suppose that a cell specialised in one type "A" secretes a molecule that is necessary for the survival of a cell of another type "B", while the latter returns the same. In addition, molecules "A" and "B" influence the development of cells that have not yet chosen their specialisation by promoting the expression of the gene that expresses them: the molecule "A" that enters a cell will cause a greater expression of the gene that expresses "A". Both conditions are necessary: each cell type must depend for its survival on molecules made by others and the molecules act on their own expression that they stimulate, while influencing cells that have not yet chosen their development type. If you program your computer model with these instructions, you will gradually see layers of cells

appear on your monitor that evolve in a way that is very similar to what you see in an embryo  
2!"

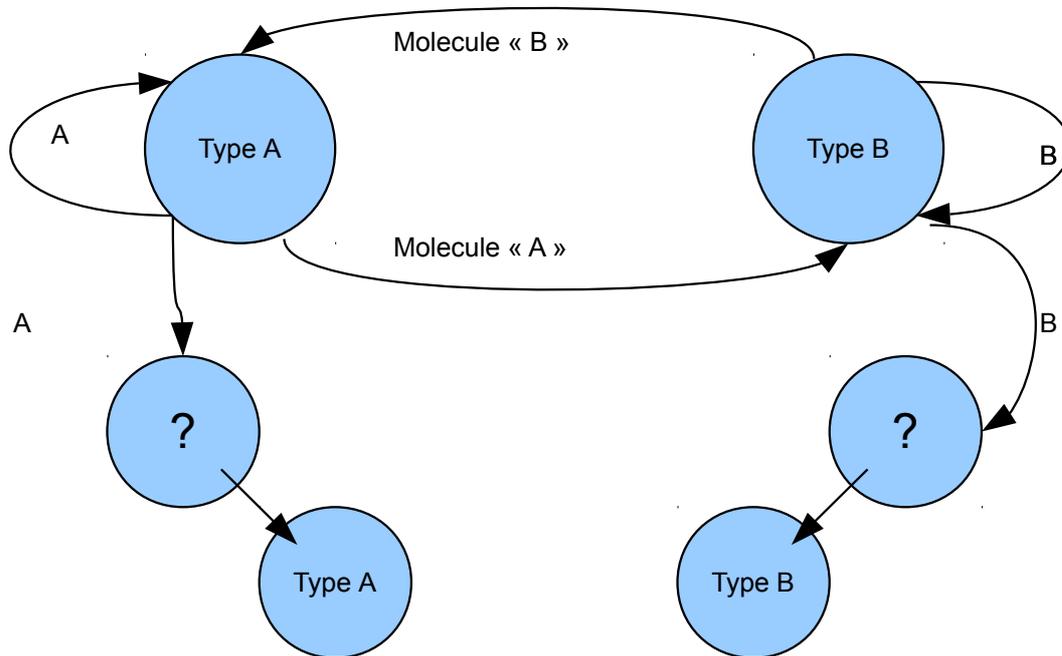


FIGURE D.14: *Experimental model of intercellular interactions that explains the specialisation of embryonic cells in differentiated tissues.*

*Type A cells secrete a protein A necessary for the survival of type B cells and which stimulates its own expression. It also triggers specialisation towards type A of cells that are still embryonic. The situation is the same but reversed for type B cells.*

- But you are far from understanding the highly ordered organisation of embryonic development!"

- That's true, but the emergence of an order despite fluctuations in gene expression was unexpected and indicative of the importance of interaction networks."

- You mentioned mysterious mice earlier..."

- Yes, knock-out mice! This is one of the latest unexpected discoveries that challenges our fundamental concepts.

"The story begins a few years ago with the development of techniques capable of manipulating genes to put them exactly where you want them, which is rarely the case, even today. This is the technique called "knock-out" because it destroys the expression of the target gene by replacing it with an artificially inactivated copy."

- And what is the advantage?"

- We thought we had a particularly powerful way of finding the role of genes that genomic analysis makes us discover. By inactivating a single gene precisely, we were convinced that we would discover its importance, the moment when it is expressed, the tissue or tissues in which it is needed, the products whose manufacture, expression or activity it directs..."

- And you were disappointed?"

- No, the technique is very powerful but it has sometimes given extremely surprising results! For example, we discovered cells that remained completely normal when we had destroyed the expression of a gene that seemed vital to us! And sometimes there were many visible effects, but not at all related to the ones we expected!"

- For example?"

- The inactivation of a single gene involved in the cell multiplication cycle did not prevent cells from reproducing, or even giving birth to normal mice. But when they reached adulthood, it was discovered that females had lost all maternal behaviour! Why? No one knows why!

"Another example: the inactivation of the gene that allows certain nerve cells to communicate with each other did not prevent mice from developing normally. The only visible effect was to accelerate their ability to learn new behaviours!"

- And what are your conclusions?"

- It is the organisation of their expression in complex networks that makes them participate in multiple tasks within the body, sometimes without any logical or even functional relationship between them! These networks are robust and resistant to accidents, to the alteration of some of their components... This is a discovery that brings us closer to quantum physicists when they describe the importance of interactions between particles and the globalising framework within which these interactions must be analysed. Here are mice born from interactions between genes and with their environment so numerous and important that it becomes difficult to know where one stops and where the other begins! It is the network that matters and not the node. A few nodes can fail without affecting the network, much like an ecological system that can lose some species without collapsing. And that brings me to the third association I wanted to talk to you about tonight: interactions are as fundamental in ecology as they seem to be in quantum physics!"

#### D.14: IS A GENE ALIVE ?

Florian calls Axel: "Tell me! There are people who believe that genes can be dangerous, that it is irresponsible to release genetically modified organisms into the environment. They are afraid of genes extracted from one species to be introduced into another. And of course they horribly refuse the possibility of swallowing the result of such manipulation! What do you think: do you think a gene is alive and able to act in a pernicious way on the body of the person who swallowed it?"

Axel looks at Florian with a surprised look: "Of course not, let's see! A gene is only a part of DNA, a very common large molecule: how can you attribute some vital property to it? This is absurd!"

"And you, Matt, what do you think?"

- I won't be as categorical as Axel because I don't trust certainties. But intuitively, I don't like eating manipulated organisms, just as I don't like swallowing artificially raised organisms, above ground, stuffed with chemical junk food."

- I understand that you don't want to swallow chemical, but suppose you are served a superb corn cob from an organic crop but of transgenic origin: would you eat it?"

- I don't think so. And if I ate it, it would be with much less pleasure than if it were natural."

- But the transgenic epic is just as natural as any other!"

- So we don't agree on the definition of natural!"

- Indeed. But I remind you that the gene introduced into corn was not invented, nor even artificially manufactured! We found it in the genome of a bacterium and simply moved it from one place to another, transferring it to a corn strain."

- You just explained to us that a gene seems less important in itself than the interactions it participates in with the other genes in the cell and with its environment! So you created an artificial corn strain with a new genetic environment that owes nothing to its natural history but is the result of a perfectly artificial manipulation! You also told us how surprised you were to discover unexpected and incomprehensible results that regularly raise the importance of a global set of interactions rather than the expression of particular genes. That's why your corn is no longer organic even though it was grown according to organic standards!"

- Shot down! You're absolutely right. But let's get back to the fundamental question: is a gene alive?"

- ... I'm sorry, but I can't answer you. I wonder if the question is well asked: can you really invoke the life or death of a gene? Besides, what is the definition of the living?"

- Shot down again!"

Florian remains silent for a moment, his gaze directed towards the fireplace but without apparently seeing it. He mechanically scrapes Gold's occiput, which has come to sit next to him, as full of chestnuts as a Christmas turkey!

"Life is a bit like time: everyone knows what it is... until the moment it comes to finding a definition for it. I will tell you a story: another completely unexpected discovery that opens up amazing perspectives. But before I tell you about it, I would like us to clarify a little bit what we really mean by the "living" attribute.

"Axel: if you had to choose a fundamental characteristic that you possess that allows you to be alive, which one would you choose?"

- Certainly not some kind of vitalism, if that's what you're thinking about!"

- So what?" says Florian.

- I intervene: "Axel, what exactly do you mean by "vitalism"?"

- A kind of naturalistic or acupuncturist whim, the conviction expressed by some - admittedly less and less numerous - that a kind of vital energy unknown by science, perhaps of supernatural origin, a kind of living breath whatever that might mean... is essential to give life to an organism. It is the subtle energy that passes from God's index finger to Adam's for Michelangelo, the Promethean energy that the mad scientists of novels or science fiction films, like Frankenstein, try to master... An energy that has nothing to do with physics and that acupuncturists call the "Chi" supposed to circulate in equally subtle and invisible channels, the meridians..."

- I see. So what would you say to Florian?"
- Let him take me by surprise! But I suppose that the fundamental characteristic of life is the ability to express a gigantic network of coordinated and self-regulated chemical reactions so effectively that it appears to us as a closed, self-sufficient whole."
- I'm not sure I understand what you mean, but I'm sure you haven't found the really fundamental characteristic of life," Florian says.
- And what is it then?"
- It's very simple: try to imagine yourself totally cut off from the world and you'll find it!"
- ... No, I don't see it."
- Imagine yourself locked in a big, waterproof jar: could you stay alive?"
- Of course not if there is no air change! I don't see what you're getting at."
- What if I gave you some fresh air: could you live?"
- As long as I don't run out of water and food, certainly!"
- But the water, air, food that are absolutely essential to you, you find them through continuous interactions between your environment, other living species and yourself! Here they come again, the interactions! You described to me a fundamental characteristic of life today that seemed to lock it inside the cell membranes or under the skin of a multicellular organism. But it is by no means a really fundamental characteristic of life: on the contrary! We cannot imagine any living being that is not continuously, at every microsecond, in more or less direct interactions with other species and its inert environment. A total interruption of these links would be fatal, even if it were brief."
- Isn't that very exaggerated? I could see myself surviving at least a moment without interaction with my environment."
- You're mistaken! You mentioned chemical reactions earlier: chemistry essential to life processes. But the energy and oxygen you need to maintain them, the basic chemicals, atoms and molecules, all this comes from your environment or from the work provided by other living species, whether it is the oxygen released by green plants or nutritious molecules also made by plants or animals. Interrupted in imagination these contributions and the laws of chemistry and physics would instantly apply to degrade the extraordinarily well-ordered structures characteristic of life. Wear and disorder would immediately take over and there would be no more life possible."
- I still think you're exaggerating! But what are you getting at?"
- To the recognition of the interactions that are fundamentally at the base of life. And this is also what an English chemist discovered in the 1960s, a brilliant and very original inventor, eccentric, even for the Englishman: James Lovelock."

## D.15: THE GAIA HYPOTHESIS

Florian makes us some tea: he comes back from the kitchen carrying a loaded tray, followed by Gold who never takes his eyes off him. Florian tells the story while serving us:

"Here is a chemist who asked himself the right questions: he made us discover that trees were hiding the forest from us, even from us biologists!

"Lovelock invented a measuring device capable of analysing tiny gas samples and has made his fortune, he is one of the few researchers who lives off his rents and experiments what he's interested in, without worrying about producing at all costs to get research grants.

"His discovery was so effective that he was hired in the early 1960s as a consultant by NASA to prepare for the search for a hypothetical Martian life: the Vicking program. Lovelock's detector would be perfect for analysing the atmosphere and soil in search of signatures of a Martian life. His colleague, a biologist, offers him a series of experiments to detect extraterrestrial life that leave him perplexed because he is not convinced that life on another planet should necessarily resemble the one we know here, with its characteristic biochemistry based essentially on that of carbon, which uses optically active organic molecules... "

- What do you mean by that?"

- It was Pasteur who already discovered this property of organic molecules. As soon as you try to artificially make large molecules, you discover that they can have different configurations: a little like gloves that are the mirror image of each other, the left and right gloves have quite the same structure, they are composed of the same molecules, but you can't superimpose them. Pasteur found that molecules important for life were of only one type: either the left type or the right type: never both. This discovery gives us a simple way to decide whether or not there is life on Mars: simply take molecules from the soil or atmosphere and look for the left or right form rather than a mixture of the two. If extraterrestrial life exists, one would expect to find an imbalance between the two mirror forms of the molecules it would use."

- And what did we find?"

- Not so fast! Lovelock was not really convinced and asked the biologist the fundamental question: "What is the definition of life? It is from this definition that we should create detection tests, rather than looking for terrestrial lives!" To his great surprise, his colleague, Dian Hitchcock, is unable to provide him with a definition that satisfies him! He's looking elsewhere... without success! Even biology dictionaries do not offer a fundamental and consensual definition!"

- And for you, what is life?"

- I hadn't really asked myself that question, but today I'm convinced that Lovelock has found the right track. Indeed, a first flash of genius pushed him to look for this definition from "top to bottom" rather than "bottom to top" as do more traditional scientists. He seeks this definition by observing the planet from space, with the eye of an alien approaching it for the first time. While all scientists propose definitions based on their limited experience as particle physicists, molecular biochemists or specialised entomologists...

"Here's Matt: imagine you're in your flying saucer: you're an alien biologist, green and full of tentacles. You discover the Earth by approaching from very high up. How would you know it contains life?"

- I'm grateful you didn't cover me with purple pustules... but I don't think I'm competent to define what a living planet would be!"

- Oh, you're not the only one! If we have difficulty defining life, it is also because this definition seems obvious to us: probably because we recognise it instinctively! Very early in the evolution of animals, we can imagine that a species capable of distinguishing between a living organism and an inert object will be favoured by natural selection, since it will be able to manage its environment more successfully! It will be more effective in the search for food - alive! - or in the avoidance of predators - alive too! Our ancestors probably developed an innate ability that allows us to intuitively feel the fundamental differences between an inanimate object and a living being, but without really understanding them, without even being able to express them objectively!"

- Maybe."

- Nevertheless, Lovelock assumes that life is a complex process that creates order from disorder by using matter and energy. But this definition seems too general to him because it can be applied to hurricanes, whirlpools in a torrent or to most of the machines we manufacture: a refrigerator for example! Nevertheless, this research opens up a very rich path of discovery for him: the one that starts from the general to the particular. He wondered whether it was not in the global atmosphere of a planet that we should look for the signature of life. It must necessarily exchange matter with its environment (construction materials and waste) and this exchange must at one time or another pass through the atmosphere of its planet. "

- Why is that so?"

- Because it is the fastest way to make exchanges and the chemical reactions at the base of life must be very fast so as not to be overtaken by wear and tear or messy processes. Lovelock understands that an inert planet must have a stable equilibrium atmosphere, much like an engine's exhaust gas, which no longer contains gases that can interact and provide energy. While a "living planet" would be recognisable by its atmosphere far from chemical equilibrium, with gases capable of reacting with each other and releasing energy, such as the mixture that enters the carburettor of a gasoline engine.

- Wait a minute! I don't understand why the atmosphere of a planet that supports life must necessarily contain reactive gases.

- No. Lovelock does not make it a prerequisite for life, but he thinks it is the consequence. He uses this signal as the signature of cyclic and self-sustaining chemical reactions, proof that something - that he imagines alive - is capable of maintaining a stable concentration of a product in the atmosphere that would otherwise disappear very quickly. Continuing this reasoning, we discover that in the solar system, the Earth is the only place that fulfils the fundamental condition of a planet that hosts life. Its atmosphere is in dynamic equilibrium and not static. It contains, for example, both oxygen and methane, while these two gases react to produce carbon dioxide and water very quickly. This requires mechanisms - sustained by life - that constantly replace the lost oxygen and methane. Lovelock calculates that each year, life must inject about a billion tonnes of methane into the atmosphere to explain why it constantly measures 1.7 ppm. If life were to suddenly disappear from the Earth, the atmosphere would quickly return to a stable chemical equilibrium and resemble that of Mars or Venus, with a lot of carbon dioxide and no, or very little, nitrogen or oxygen."

- So you condemn Mars and Venus! Are they inert planets?"

- This is what Lovelock concluded in the 1960s: but NASA doesn't like it at all and would like to send its robots to Mars!

- But what is the point for the species concerned to inject so much methane into the atmosphere?

- That's a good question! Wait and see that it led Lovelock to a conceptual revolution, no less! I'm getting there.

"Lovelock continues his reflections. He knows that our atmosphere has been stable and conducive to life for a very long time, while its chemical composition reflects great reactivity, a chemical state far from rest! A second brilliant idea shakes him deeply: what if this dynamic equilibrium was the result of a planetary homeostasis? Lovelock and Hitchcock discover that the only way to understand the highly improbable chemical composition of our atmosphere is to admit that it is controlled, day after day, from the surface of the planet! And that the manipulator is life itself, inextricably linked to its solid, liquid and gaseous environment!"

- And why this homeostasis, this balance would be so important for life?"

- Every living organism is fundamentally homeostatic. The slightest bacterium is able to maintain surprisingly stable concentrations of nutritious materials and wastes, while they can vary in very large proportions. It will even swim at full speed to escape high concentrations of toxic substances or to search for food, oxygen or light. We mammals are probably the champions of homeostasis! Not only are we able to maintain intracellular chemical conditions favourable to life, but we can also regulate our temperature very finely, to within a few tenths of a degree! Lovelock wondered if we could not consider the whole planet as a gigantic homeostatic machine. Indeed, the Sun has not always heated the Earth as it does today! Astrophysicists tell us that today it is 25% brighter than it was 4 billion years ago, when life appeared on Earth. But since then living conditions have remained very stable, although they have had to adapt to a much warmer Sun! How?"

- But how do we know that these conditions have really remained stable?"

- Oh, there are all kinds of methods! From geology, which allows us to estimate the average temperatures during the formation of a given deposit, to palaeontology, which allows us to discover datable species that only live in well-known climates.

"Lovelock suggests that the planet as a whole is capable of actively influencing climate parameters to maintain the best conditions for life to flourish! He creates a "geophysiology" that complements geophysics. He imagines, for example, that life and the planet are able to regulate the average temperature by adjusting the proportions of greenhouse gases. Too hot? So we reduce the amount of carbon dioxide, methane and increase the amount of clouds that reflect part of the sunlight before it is transformed into heat on the ground. Too cold? So greenhouse gases accumulate and restore the conditions that are more conducive to life.... He was looking for an imaginative name for his new theory and a neighbour suggested the "Gaia Hypothesis" of the name of the Greek goddess who managed harmony on Earth.!"

- But it's perfectly ridiculous," Axel says! "How can he imagine such a thing?"

- A lot of scientists reacted like you! But after a long journey through the desert, it now seems that this is no longer a hypothesis, but a theory<sup>2</sup> !

"The first difficulty comes from the fact that we are not used to working in a transdisciplinary way. We favour reductionism over systemic analysis beginning with Descartes: we break down a complex problem into simpler parts in the hope of understanding it while reconstructing the puzzle. Lovelock does the opposite: he studies the complete system

to define its systemic qualities - those that emerge from the interaction of the parties - and that can escape reduction analysis.

"Lovelock uses notions of biology, chemistry, physics, meteorology... and misunderstandings accumulate. Biologists, for example, do not understand how Lovelock can imagine the evolution of species capable of managing the atmosphere of a planet in a symbiotic way. A Canadian biologist, Doolittle, giggles that the Gaia Hypothesis would require a parliament of delegates of each species to decide together who would do what the following year to set the temperature of the atmosphere to the chosen value! An English biologist, Dawkins, notes that there can be no evolution of Gaia since it does not reproduce and that natural selection only acts on species capable of reproducing...

"Lovelock realised then that he wasn't precise enough, so these misunderstandings were inevitable! He never meant to say that Gaia was alive! Just that the entire planet was capable of automatic homeostasis: a little like a very complex machine is capable of doing."

- Yes, but a machine was created by us!"

- And Gaia could have been the result of an evolution! "

- But you just pointed out your English biologist's remark against this idea of evolution."

- I know, but I do not agree with him at all: I am convinced that an evolution can take place in the absence of the criteria specified by Darwin on the condition that it is placed on a higher level of analysis than that of the individual. Aren't galaxies, our solar system.... the result of evolution without having to imagine competition between galaxies to select the most suitable? We could discuss it later if you're interested. But back to Lovelock: he clarifies his model by creating "DaisyWorld", a computer simulation of a very simple fictional planet populated by two species of daisies: one is white and the other is black. It seeks to show that there can be homeostatic interactions without necessarily going through the natural selection of a progeny, nor by calling on an absurd parliament in which species would legislate!"

- And it works?"

- Very nicely <sup>3</sup>! DaisyWorld is a planet that revolves around a star identical to our Sun. Its temperature depends on several factors, including its "albedo", which is a measure of its degree of reflection or absorption of light. If the albedo is high, the planet remains cold because sunlight is reflected rather than absorbed and transformed into heat. The albedo varies between 0 for a black hole that absorbs everything and 1 for a perfect mirror. DaisyWorld has an intermediate albedo of 0.5 at the beginning of the simulation.

"We must imagine that we have sown daisy seeds that germinate and grow from a temperature of 5°C. "

- You're cheating! Who would have come to sow seeds on Gaia?"

- I'm not trying to explain the origin of life, just to show that once on a planet, life will automatically set up homeostatic systems from which many interactions emerge, often in loops, without having to involve anyone!"

"Daisyworld daisies vegetate and reproduce according to a curve whose maximum is 22°.5 C and then decline to 40°C. The DaisyWorld star has the same properties as the Sun, i. e. it evolves by increasing luminosity according to a curve described by astrophysicists. At first, the temperature is too low for the daisies to germinate. It is necessary to wait until the star heats the equator enough for them to start living and reproducing. The evolution of the global

temperature will depend on that of its albedo, itself linked to the quantity of daisies and their colour. The properties of the daisies will have an effect on the temperature, which in turn will have an effect on the daisies! This is an example of "feedback" that seems to be essential for any homeostatic process. Negative feedback is the basis for all regulatory processes, such as a thermostat. The higher the temperature, the more it closes the radiator valve, and vice versa. Positive feedback leads to an explosion following exponential growth. For example, a neutron that breaks a uranium nucleus releases 2 neutrons, each capable of breaking a new uranium nucleus... But several complexly interrelated feedbacks can, on the contrary, be at the origin of a regulation such as homeostasis discovered with Lovelock's simulation. By playing on several parameters, we understand how a system composed of living species and inert objects can evolve towards what can well be called a "geophysiology" capable of homeostasis, just as our own physiology ensures stable internal conditions favourable to cell life."

- And where would you like to go with this simulation?"

- I see again how important interactions are to explain what we observe, the very properties of life. And I also see how interesting the global approach can be! So much so that I wondered if we were really alive?"

- Are you kidding?"

- Not at all!" Remember the gene from earlier? When we try to find out if it is alive or not, we discover that the question is probably incorrectly asked: that is what I mean now at the level of the individual. I wonder if it is really relevant to describe an isolated individual as "living". Shouldn't we change the context in which we analyse life? Discoveries are accumulating and lead us to broaden our concepts. Remember our discussions on the notion of a super-organism and the ecological integration of species into ecosystems. These are two ways of thinking that relativize the importance given to the individual when we go in search of a definition of life!

Ecology.... The super-organization.... I remember, indeed.....

## D.16: A WALK TO THE MONT-SION

Not the one in Jerusalem but ours, the one who dominates the Savoyard village of Chaumont! Spring botanical walk led by Florian to admire an impressive *Erythronium* station, a pretty Liliacea with long leaves decorated with irregular reddish-brown spots that earned it - God knows why - the curious vernacular name "dog tooth". At the foot of the mountain the meadows are already well coloured but at altitude the colours are just beginning to blossom.

The path turns behind the church, runs a wide loop through the meadow to a farmhouse nestled at the edge of the woods at the foot of the mountain. Three cows stop grazing and gently lift their heads to observe us from this strange air, both curious and disillusioned, probably a reflection of the serenity of the herbivore when it has felt protected from its natural predators for so long.

Florian kneels down and uproots a clover by cutting a small square of earth with his penknife. Without saying a word, he carries the little plant to the drinking trough and vigorously shakes the tuft in the water. I am not surprised, used to the long digressions scattered over the walks guided by a botanist. He carefully crumbles the soil that still sticks to

the roots and then waves at me to open my hand: "Look," he says, placing a few rootlets covered with tiny reddish galls on it. Then he adds with a serious look: "This is your body!"

He regales himself for a moment with my amazement and keeps the serious, emphatic look with which he has just expressed himself. After a while he laughs: "Don't look so stupid: I wasn't thinking of a supernatural transubstantiation, only of a most natural transformation!"

- Is it the name of this mountain that inspires you? Explain yourself!"

- Your body, like that of all living beings, from the smallest microbe to the largest whale, is made of proteins... and these proteins are made from materials that only a few species of bacteria are able to provide to the living world. And these bacteria are there... in your hand!"

- You mean my body is the result of the activity of these germs?"

- Yes, all the nitrogen atoms in it have been made available for life by these bacteria, from the atmospheric nitrogen that only they can fix in their cells. Each nitrogen atom that contributes to the structure and activity of your proteins comes from your plate after a more or less long and complex series of interactions that start here, in the cytoplasm of these bacteria or their analogues. Without them, there can be no life on this planet!"

I look at the tiny spherical growths stuck to the roots with a new eye: "It is the bacteria that make these galls?"

- Not really: it's a symbiosis. And as is often the case with symbioses, it is difficult, if not impossible, to know where one begins, where the other ends or who benefits most from the relationship. It seems that rootlets react to bacteria that signal their presence and then respond in turn to establish a long-lasting, profitable relationship for all and often mandatory. Here it is the plant that makes the nest in which the microbe grows. It protects it from oxygen with a red pigment very close to the one that colours our blood: another proof of kinship between plants and animals!

"Moreover, these bacteria are far from being the only ones whose life is essential to us. Without bacteria no life would be possible! They are the oldest and simplest living beings - at least in appearance - that we know: it is clear that they invented life. It is from bacteria that evolution has built all the other living groups, including ours, of course."

- How can you be so sure of yourself?"

- Because we all use the same chemical language invented by bacteria some four billion years ago: the genetic code is universal! All life on this planet uses the same language to transmit and express genetic information. How can we explain that all the cells speak the same dialect without imagining that they all have a common history?"

We sneak through the barrier that separates the meadow from the forest. The path quickly starts to climb seriously and becomes rocky. We walk in silence for a moment, attentive to choose where to set foot. As the path widens and becomes more comfortable, I suggest: "Perhaps chemical constraints force all cells to use the same genetic code without evoking a common origin.

- Of course we tested that hypothesis! But it does not hold up because other genetic codes can be artificially constructed that work perfectly well. We must conclude that if all living beings speak the same genetic language it is because they have a common origin! In the same way that a baby born in England will speak English whereas if he had been born in China, he would have spoken Chinese!"

- If, as you say, the bacteria gave birth to all of us, then how do you explain that they are still there? As simple as they were billions of years ago!"

- I never said that! You're wrongly extrapolating my words. I did not say that they were as simple as they were originally, but that today they are the simplest organisms. I don't know what the first living beings were like, or even when you could say that a structure is alive or not; it's not that easy. And to make matters worse, some even think that life appeared on Mars before it was projected onto our planet with meteorites torn from Mars in apocalyptic collisions and used as vehicles for Martian bacterial life!"

- I see, but why is it that we cohabit today with such primitive beings if there has been a bushy evolution from common ancestors? They do not live like the coelacanth in environments that have not changed for millions of years. And my ancestors have disappeared! "

- My God, there are so many misconceptions in your conceptions of nature! I could give you two answers: the first applies to the very mechanism of natural selection and the second is the very particular biology of bacteria, very different from ours.

"Natural selection does not necessarily replace one species with another as you replace your ancestors in a way. Species constantly interact with each other and with their environment by exploring all possible combinations in an exuberant creativity characteristic of the living phenomenon. The "tricks" sometimes give aesthetically interesting results...." adds Florian as he admires the meadow.

We have left the forest and crossed a sunny green universe, lined with primroses whose subtle pale yellow flowers harmonise with the deep blue of the periwinkle. Florian turns around and remains silent. Behind us the view of Chaumont is superb: the church tower dominates the village and its facade stands out nicely against the dark green of the hill forest in the background. The village's bright ochre-coloured facades are covered in gold by the sunny mist that has not yet evaporated.

"Look", says Florian, "life is everywhere, even where it is not easy; lichens clinging to stones, tiles... the plantain with flat leaf rosettes on dry and trampled soils... life develops a remarkable colonising energy and this faculty is most often expressed in the creation of new species, more specialised, better adapted to lifestyles still free of inhabitants and that it hastens to explore. And these pioneers are the daughters of species that perpetuate the ancestral way of life and have no reason to disappear! Life diversifies by enriching itself, by continuously creating new things, without necessarily replacing one species with another."

- And that's why we still find our ancestors from so long ago today?"

- Yes and no: it's more complicated than that!"

We are resuming our walk. On the right, the forest blocks the view of the Rhône plain and Lake Geneva, while on the left, the view travels from hill to hill until it gets lost in the mist on the southwestern horizon.

Florian continues: "Moreover, the notion of species is artificial: today we are far from considering them as natural and stable categories as we imagined in the 19th century. Bacteria in particular have blown up these rigid conceptions, they in which the very notion of the individual is not really relevant since each bacterium is capable of cloning itself explosively, of exploring all kinds of situations through the myriads of twin sisters who are as many copies of the parental individual. Each microbe can participate in exchanges of genetic material with

its congeners and even with other species. And that's my second answer to your question earlier: bacteria have a much more diversified sexuality than ours, which is limited to the female and male genders. We can't even be sure how many different sexes they can take and this allows them to evolve so quickly that we are losing the war against bacteria that are dangerous to us. We are no longer able to create new antibiotics fast enough to counter the evolution of their resistance mechanisms! They manage to find - God knows where - resistance genes and pass them on at high speed from one individual to another and even from what we take for a given species to what we think is another species!

"By analysing their way of life in a more global way with an objective vision, we even discover that it transcends the notion of individual and species from our own way of life, a little like an anthill that can also be considered as a super-organism in which ants resemble more our cells dependent on other cells than autonomous and independent individuals."

- But an ant is unable to live alone while a bacterium even grows alone!"

- This is true only in the short term. Very quickly mutations will differentiate the countless descendants of the clone and will allow to diversify the characteristics of what becomes a population. As soon as one or the other member of the clone is the depositary of a variation interesting for the others, it can be shared quickly by all.... Bacteria are constantly evolving much faster than we are."

- Then I don't understand why they stayed so simple."

- But because your perspective is biased: you don't observe them from the right level. They seem simpler to you because you are comparing a bacterium to a human being and this connection doesn't really make sense. We are in fact only one of the evolutionary pathways discovered by bacteria during their evolutionary history!"

- I didn't expect that! I know you like your bacteria, but to relegate us to the rank of dispensable experience as you suggest?"

- That's the reality! We imagine being free and independent. And yet we would be nothing without the bacteria! They are by far not as simple as you might think! The Biosphere's fabric is woven by bacteria! All the other species are only its decoration, impressions of aesthetic shapes and colours, certainly, but quite dispensable from the weft of the living<sup>1</sup> !"

Taken by the conversation, it is only now that we notice the flowers we have come to see. At the edge of the forest, the yellow of the daffodils is combined with the pinkish-purple tone of the dog- teeth and replaces the primrose-periwinkle association of the plain. We quit the path to let down a group of well-behaved elders, their hands unfortunately full of daffodils, who are nevertheless so much more beautiful in their homes than in a flowerpot.

- You said we should be indebted to the bacteria..."

- Of course," Florian replies, lying on the floor to photograph a bouquet of flowers. "They are the ones who invented the ancestors of our cells two billion years ago by learning to live in symbiosis. Even today, their descendants proliferate in all cells and allow them to breathe. If you had the curiosity to look at any of them under a microscope, yours like those of this daffodil by the way, you would find a few hundred organelles that look like bacteria. We are now sure that the resemblance is not accidental: they are descendants of bacteria that have their own chromosome and reproduce in our cells. They could no longer survive elsewhere and our cells are also entirely dependent on them. From what was a symbiosis two billion

years ago has emerged new inseparable entities capable of better performance, of greater independence from their environment: the cells that are holding them today."

- You mean I'm full of bacteria?"

Florian laughs when he gets up: "Of course! But not as you think! Your cells have inherited descendants of bacteria but they have changed so much that they can no longer be classified as such. On the other hand, we are discovering that we are super-organisms and this is new!"

- That I'm a super-organism doesn't surprise me as much as you think, but that you are one, too..."

Florian smiles: "That's right! As I mentioned earlier, the boundaries that we thought were well defined, well sealed between species, are in crisis: they are gradually losing their importance and new concepts are emerging, including the concept of super-organism.

"A few years ago the development of a powerful microscope introduced us into a whole new unknown universe. It can explore microbes without killing them by dehydration as do conventional electron microscopes. We discovered that bacteria were social beings who enjoyed living in communities of different highly organised species. They are not only the simple cells capable of living on their own that we have known until now. We found that they are building what would be for us an agglomeration with specialised neighbourhoods. Just as in a city we would have the hall district, the textile district or the jewellers' street... different species of microbes join forces to create specialised and complementary structures in interaction from which unexpected properties emerge. This way of life allows them to respond even more effectively to the weapons we are trying to oppose them. I myself experienced a typical case: a doctor friend did not understand why the cultures of pathogenic bacteria he made from samples taken from his patients were very sensitive to antibiotics while his patients did not heal when he administered the same antibiotic."

- And did you find out why?"

- Yes, until now it has been obvious to test antibiotics on purified samples in which the different bacteria are separated on culture boxes that only grow those of interest to us. In these boxes the pathogenic strain is very sensitive to antibiotics. But it was enough to cultivate the sample under conditions that allowed all the species in the sample to reproduce to find that the antibiotics were no longer effective."

- An illustration that sometimes the whole is different from the sum of the parts?"

- If you will! It has been discovered that bacteria build gelatinous biofilms in which they protect themselves and cooperate to live: the waste from one becomes the food for the other according to very efficient interaction networks. Antibiotics are degraded by some species that populate the biofilm and the very physiology of sensitive species changes: they produce new products when they live in combination, modify the properties of their membranes and this is what can make them resistant to the drug. We are dealing with a super-organism that is much more efficient and potentially dangerous than each species alone."

- And why would I be a super-organism myself?"

We arrived on the rocky summit of the mountain Vuache. After having placed our backpacks we spot a small white limestone circus in the middle of a meadow that plunges into the trench dug by the Rhône at the very bottom. It has remained wild on this side of the

Vuache and we do not regret too much the blocked view to the North on the plain and the lake.

Florian continues while attacking his snack, with his back against the rock: "Yes, we have more bacteria than we ourselves have cells in our body, not to mention the organelles that live in symbiosis in all our cells and that I presented to you earlier. Recently, biologists have discovered that our intestinal flora is a real microbiome that contains a hundred times more genes than our cells. In other words, it seems that the properties that are ours - which seem to us to be ours, I should say - do not only come from the genes we have in our cells but are sometimes due to the genes in our intestinal microbiome. Foods are digested with their enzymes.... Vitamins vital to us are made by it.... It protects us against potentially dangerous bacteria and even against certain diseases of genetic origin that do not express themselves if the intestinal flora is rich and diversified... It is from these discoveries that the concept of super-organism emerged that takes into account the emerging properties of the human-microbiome unit!"

- But we could live alone in our intestines?"

Florian laughs: "Of course! But we couldn't digest our food properly, we would lack vitamins and get sick much more easily... Believe me! Keep your bacteria; you're not much without them!"

"Remind me to introduce you to a little super-organism I'm raising at home on your next visit!"

I, in turn, comfortably wedge myself against a rock and think of the bacteria that will soon be eating my snack! Strange day that saw me climbing a mountain to discover myself as a bag of bacteria!

## D.17: A DOOR OPEN TO SUMMER

A solid white gate closes the green tunnel that leads to Florian's house. A few meters to walk under a green shade to reach the large, ajar door that lets a column of golden light filter through. There is no feeling of a barrier to prevent access but, on the contrary, a door open to summer, a border between two worlds: here, nature more or less developed by the municipal road network, there, a space created by a nature lover, unable to restrict the style of his garden and which builds spaces that blend harmoniously to surreptitiously lead the visitor through the horticultural discoveries of different cultures. A haven of life created by Florian, conductor rather than gardener.

First of all, a tiny space of Japanese inspiration: a philosophical garden. To the right of the path, a few square metres create a very special atmosphere that can be enjoyed as it is, but which deserves to be completed by the speech of its creator. Towards the centre of the square, an oval surface covered with white and coarse sand covers a small half of the whole and comes up against the flat stone path that runs along one of the two sides of the rectangle. From the sand, a kind of rocky island emerges which, very quickly, takes on the appearance of cliffs, steep on one side, soft on the other, until it merges into the sea of white sand. The visitor's imagination naturally shrinks him down until the little Japanese maple tree, alone in the middle of its island, turns into a majestic century-old tree. Its finely cut webbed leaves are

intertwined in a few bright green layers on long, horizontal and winding branches, the greyish brown of which accentuates the fresh, tender green colour of the leaves.

On the other side of the path, the sandy sea is bordered by large stones and then low or crawling plants, against which one or two floors of taller plants rest. The other two sides of the square contain two groups of plants separated by a fine canal at the end of the sandy sea. The plants come up against the blocks of stone that each suggest a dangerous cliff, the end of a world. Each of the green ensembles revolves around the central sand to stop against the path. We can guess that the sand channel opens up behind to what seems to be a different world, but the garden suddenly ends with a wall of dry reeds.

The plants that the visitor encounters on his right, just at the entrance to the garden, are of remarkable vigour. A dozen species, each represented by a single individual, seem to be struggling for space and light: not a single gap between the leaves! On the other side of the sandy sea, the other group of plants seems much wiser. Species are less numerous and represented by several individuals gathered together. All the shrubs in the garden are evergreen except the Japanese maple, alone, at the centre of gravity of the whole. It's the only one that looks dead in winter... but it's only an impression of course. And for Florian it paradoxically represents "the tree of life"!

To compose this sculpture combining minerals and plants, Florian was inspired by some characteristics of life and its history: at the beginning, an explosion of attempts more or less suitable to develop, in competition to live the longest possible history. Today, a calmer nature, adapted to avoid destructive conflicts, oriented towards mutually beneficial interactions. And, in the centre, in another dimension it seems, the tree of life that synthesises the qualities of the whole: longevity through renewal.

But Florian's passion for the things of life is not limited to Japanese art alone. Certainly, it satisfies its search for a deep bond with each species it cultivates and that it must be placed in a mineral and plant environment that allows it to express its full potential for life. The Zen garden brings him this meditative and philosophical research that reintegrates the human being into a nature that he recognises as being very deeply his own, after a journey, sometimes tortuous, through his specificities, especially intellectual, and which tend to make him lose his roots. Finally, Zen art allows him to create an aesthetic that integrates stones and plants in a harmony recreated by man, but in which the real success consists in no longer noticing his influence. Florian particularly appreciates the comments of his visitors when they think they are discovering pieces of wild nature when it comes to his own facilities.

Florian's garden is a world in itself, with its deserts, oases and even tropical jungles! An astonishing variety that benefits from its installation on a slope that is favourable to the design of terraces and nooks and crannies that are more or less enclosed and separated from each other. The desert of paved stones, gravel or grassed floors highlights the oases of groves or English-style massifs. There, Florian satisfies his research on the exuberance of life when the right conditions are met: fatty soil, pure water and full light. Here too, the gardener's art consists in erasing himself to suggest that a natural ecosystem in dynamic equilibrium lives its natural life without his help, that pieces of flowering meadow explode on the obstacle-free land in a profusion of sizes, shapes and colours that interfere to bring out a particular personality for each space. And the gardener's art consists in walking the visitor from corner to corner in a subtle discovery of his creations to slowly build a coherent story.

From the art of the French garden Florian has retained the strict control of the desires of vigorous natural species and the enhancement of those that seem fragile and soft to us. And it

is the severe size of the former that is the hallmark of the latter. There, the tight foliage of the pruned boxwood cannot smother the grasses that bloom under its guard. Here, graceful plants contrast with the hardness of strict cut stone walls.

And even the Moorish-inspired garden is suggested on a terrace sheltering a rectangular basin populated by a few water lilies and small carp, bordered by a large flowerbed of low and very fragrant flowers. In winter and spring, horned violets decorate the place of their colourful faces, while in early summer marigolds, cloves or dwarf sweet peas take over until carnations, heliotropes or resedas replace them until late autumn.

But the highlight of the garden is undoubtedly the tropical greenhouse. Under a high glass roof leaning against the South wall of the house, Florian grows all kinds of species in a warm and humid atmosphere that he loves. The Northeast front is almost entirely built of large granitic rocks between which epiphytes, bromeliads, orchids or ferns cling. A small spring gushes out above a large block of stone, from a large crack that separates two large rocks. The water first flows on the upper surface of the granite before sliding off the steeply sloping stone. Mineral or vegetal obstacles force it to sneak down the small cliff, then the water plunges into an irregular pond lined with stones and mosses before gently undulating into a small stream quickly submerged by beds of large plants with sometimes gigantic leaves, often cut off. Some species have leaves with unexpected colours: bright red or bright yellow. Here and there, shrubs grow flowers with unusual shapes, facing the light of the South or the zenith. The Southwest façade is entirely glazed and covered with vines and voluble species, including the tropaeum's charming yellow-butter petal daisies and reddish-brown heart, and the broad-brimmed, sky-blue flared cups with the white edges of the ipomeas. Under the green wall that lets the light from the West filter through, Florian has nested two small wicker chairs that he sometimes uses alone when he comes to work in his private jungle: a way of immersing himself in the world he really loves when his profession - the biology of molecules - forces him to be too abstract.

A small round table with a marble top on a central foot separates the two armchairs. Florian has prepared a breakfast but, even before we sit down, he draws my attention to a large jar of old-fashioned preserves. It is all glass, with a metal ringed cover to properly seal the contents by pressing a protruding white rubber seal. But it is quite incongruous near the coffee pot that smokes gently and croissants, especially since it contains nothing that seems edible: just water on a kind of greenish and suspicious mud that fills the bottom of the jar to a height of about four centimetres. A few small stones emerge from the green mass... nothing else.

"This is the super-organism you came to discover! "

No matter how closely I check, I don't see anything that looks like an interesting organism, even from a distance!

- I can't see anything!"

Florian laughs at my perplexity: "You see, but you don't know what to look at!"

- Then show me your super-organism!"

- But it's the jar!"

- You're kidding!"

- No! Look in the water: you'll see little crustaceans swimming. They hunt algae and breed in their closed universe for more than two years."

As you open your eyes, you can see a plethora of small blackheads swimming gently everywhere: "And why do you call them super-organisms!"

- No, it's the whole jar that's a super-organism, not the species that inhabit it! Each of them, taken in isolation, could not survive in a watertight jar where neither air nor food can enter, from which no toxic waste can escape. Crustaceans would suffocate before they even starved to death or poisoned by their waste; algae would deplete the mineral resources they need to live and reproduce; each species of bacteria that form the thick mat at the bottom of the jar would also eventually die. What is particular is that, put together, they build an ecosystem that, although very simple compared to those we are used to, is far too complex for us to fully describe it and understand how it works. But it lives! It no longer depends on the external environment for air and mineral or organic materials. Only energy is needed in the form of light and adequate temperature."

- But why do you call it a super-organism?"

- Because it achieves an autonomy that we usually attribute to life when in reality almost no species is truly autonomous on this planet, at least in the long term. It is only through interactions between different species that life acquires the autonomy and ability to reproduce and evolve that clearly distinguishes it from inert objects. Here we have an organisation, a super-being organised by the association of species that are complementary in their specialisation and that reminds us of what we are used to considering, wrongly, as an autonomous organism composed of specialised organs, tissues and cells that are also unable to live separately from the whole. This one is not as autonomous as we imagine... this one only needs energy to live and that's why I give it the prefix "super". "

I look at Florian with a doubtful look, but he seems quite serious." Here, pour me a coffee before it gets completely cold!"

## D.18 : THE PRICE OF THE SPARROW

Florian pours coffee into two small cups and then unpacks golden and belly croissants. We have just begun to feast when two sparrows perch on the edge of the table, looking at the pastries with insistence, which makes us laugh. We sacrifice a few crumbs that they pick in the middle of the table: it seems they are regulars! Florian renews the crumb stock and then becomes more serious: "I learned that sparrows are disappearing from cities. Ornithologists are all the more concerned because they do not understand the causes: how to stop the process and what could it tell us about the state of our environment? Are we in danger too? "

- At least these sparrows look very healthy!"

- What would be the price of keeping our sparrows? Matt, how much would you pay for a sparrow?"

- But nothing at all, it would be of no use to me, it is very well in the wild!"

- Are you sure it's really useless to you? Think of the super-organism of which we are a part!"

- If you insist... Maybe it would be useful for my cat. It sometimes brings me some home and still plays with these unfortunate ones before eating them. It prefers them to the boxes I give it. Perhaps we could add sparrow to cat food and find a way to enhance this resource!"

- I hadn't thought of that, but on reflection, your idea is interesting. So how much would you pay to put a sparrow in your cat food?"

- Of course, we would have to do a market study", I say with a pedantic look. "But I can make an estimate if you tell me the weight of the animal."

- It weighs about 25 grams."

I simulate a sophisticated calculation aloud, looking as serious as possible: "Let's see... I give on average one and a half boxes of food per day. They cost me about 1 franc eighty and weigh 150 grams... That's it! I'll give you 0.3 cents for your sparrow. Are you satisfied?"

- That's what I was afraid of. The unfortunate beast has no value, a price - that is, an importance for you - except through the supply and demand of our market. It represents nothing at all outside this system that we have created to manage our relationships with our environment and with ourselves."

- Yes, it is! It has a value that does not enter into economic life and that I cannot therefore quantify! It can please the ornithologist, the lady who has fun feeding it on her balcony... But all this is not part of a concrete economic calculation."

- I'm not so sure about that! Imagine you're a big hit with your cat sparrow food. You're going to hunt them more efficiently. You will exploit new regions to satisfy demand... until you overexploit the natural resource. You will hunt so many that the reproduction of the species will no longer be able to compensate for the losses. What will you do then?"

- Ah, but the economy is perfectly adapted to that! If supply decreases and demand remains, the price of the sparrow will take the elevator."

- And you think we'll find an economic balance that will satisfy everyone: sparrow hunters, feed manufacturers and cat owners?"

- But of course! That is the beauty of the system: it balances itself, provided that we do not interfere with restrictive regulations. We must follow the laws of the free market and we will all benefit as much as we can from the system. The services will be subject to competition and not to monopolies or customs protection. They will evolve according to supply and demand and nothing else."

- I see! Don't you think the sparrow will disappear, like the sturgeon for example, which is becoming very rare?"

I smile as I rest my empty coffee cup: "You give me an idea for my advertising: Sparrow caviar: your cat deserves it! "

"But to answer your question: no! There are risks that it will disappear, but it is not inevitable and in any case it would not matter much."

- Then that's where you're wrong!"

- Not at all! Sparrow production would be relocated! I'm sure there would be many countries that would be happy to send their sparrows to Geneva!"

- That's how you see the problem! Not me. But at least you'll admit you've put the Geneva hunters out of work!"

The conversation takes an unexpected turn, everyone takes part in the game of biological or economic argumentation! I took the side of the liberal economist, I develop it: "They will of course have to retrain. A healthy economy is a living economy, which continuously adapts to circumstances, to the changing environment, to discoveries... as well as to disappearances. In nature, it is natural selection that manages its economy. In our society, it is career guidance and continuing education that adapts to potential opportunities and fulfils this function."

- I see. But I still believe your system is flawed. It does not take into account the ecological reality of the super-organism but only the economic reality. However, the economy is centred on man and him alone, while ecology is not centred on any particular species. On the contrary, the health of an ecosystem is all the more assured when its biodiversity is rich."

- You asked me the price of a sparrow, not the price of an ecosystem!"

- Precisely, we can't - we shouldn't - calculate the price of a sparrow without taking into account the ecosystem that hosts it!"

- And why is that?"

- Because changes in the size of sparrow populations will have many repercussions on other parts of its ecosystem. These effects could cost us much more than we would have earned by selling sparrows."

- For example?"

- What is disastrous about this case is that no one can guarantee that they are able to predict all these repercussions. We can only make more or less well-founded assumptions, without any assurance that we are right, a little like climate models and assessments of the impact we could have on its evolution.<sup>1</sup> "

- And it's with assumptions that you'd like to prevent me from making the sparrow profitable? In economics, assumptions are not worth much. Which is likely to happen in the long term, either! We deal with statistics and probabilities, not assumptions. What matters is, of course, the return on investment or the savings made quickly through an effective strategy! According to the laws of economics, it is not healthy to make expenditures, or even to limit oneself to short-term investments, if one has only assumptions to offer! It is up to the economy of tomorrow to manage the problems of tomorrow!"

- I don't think I agree with you."

- I will take an example. You know, of course, that some people suspect that the carbon dioxide we release into the atmosphere is changing our climate."

- Because you doubt it?"

- That's not the point. But imagine if environmentalists can persuade politicians to spend a certain amount of money to limit gas emissions."

- It's about time!"

- Well, that capital would be lost to the economy!"

- What do you mean? It will have enabled us to avoid a disaster!"

- It's not safe! It's just a hypothesis. And moreover, if that were true, the disaster would not occur, so the capital would have been immobilised in pure loss since it would not have produced anything!"

- But it's terrible what you're telling me! Your capital would have saved you a lot of destruction! Look what happens with hurricanes!"

- No, this capital will be more productive for our economy if it is used profitably, for example to rebuild a destroyed city, rather than if it were immobilised in the short term, just to respond to a hypothesis."

- But you're an unspeakable cynical!"

Florian seems to have really gotten into the game and I'm enjoying it!

- No, I'm not! This time it's you who's not thinking about the interactions needed to keep our economy healthy: I'm realistic and concrete... not cynical!"

- So now I see two kinds of disastrous consequences of your economic laws. Let me first propose the example you were asking me to set. The sparrow, like many birds, participates in the demographic regulation of insects, especially to feed their young. Without sparrows, farmers would have to spend more to buy insecticides, get them to the fields, spread them... There would be risks of soil and groundwater pollution, which would be expensive, if not impossible to clean up..."

- Here you are painting the devil on the wall! You can't make me believe that your sparrows are essential for me to drink clean water! That's what ecologists typically do: exaggerate and make you feel guilty!"

- And yet the water you drink is healthy because many species are involved in nature's economy. It is an entire ecosystem that is responsible for our life and its quality!"

- These are the arguments of eco-dreamers: we need competent economists who have their feet on the ground to run the machine, not sweet freaks who are only sure of their faith in mother nature!"

- The utopian simplifiers are you: not us! Economists have not yet made their Copernican revolution! They believe that the Earth is an infinite, inexhaustible resource, which has no value except for what interests our species and only it. An object only acquires value to the extent that they find a place for it in the system we have created and which now seems to lead us straight to where and how we do not know! This is the second dangerous consequence I was telling you about earlier: we are driven by the economy we have created, we are not the ones who run it!"

- Bullshit! Now here are the anti-globalisationists' ritornello! Come on, be serious!"

- Are you serious? Some have tried it, with the pride that characterises us. And the failure was so bitter that we try to forget this misadventure!"

- What are you talking about?"

- Of Biosphere II. In 1991, in Arizona, we created a gigantic enclosure in which we wanted to make 4 men and 4 women live in total self-sufficiency, cut off from our biosphere which makes us live without us realising it, and you, the economists, even less than the others! We have created a simplified copy of our biosphere that is supposed to provide them with absolutely everything they need for life: clean air, clean water, a variety of foods... all in a

sustainable way, that is, without creating unrecoverable waste but by offering a natural system for recycling all waste."

- They tried to create a super-organism like your jar, in a way?"

- Exactly... but it was a total disaster! We quickly realised that our biosphere is infinitely more complex than we understand it today. Despite the capital sunk into the project, the efforts made to recreate several ecosystems, from a miniature ocean with waves and reefs to the dry Savannah fed by fog, vegetable gardens and orchards in a closed economy... Despite the financial and intellectual resources invested, it has not been possible to create a haven of life capable of turning autonomously without any relationship with Biosphere I, the only one able to ensure our existence! The atmosphere was not regenerated properly: it was becoming unbreathable and only ants seemed to have taken advantage of this atmosphere!"

- So what? I don't see how this failed experiment would prevent me from feeding my cats sparrow caviar!"

- Definitely economists - and you with them - are part of another planet! You do not understand - or do not want to - that all these species in the middle of which we live, in the same environment, embedded in the same evolutionary history, work for us in the sense that economists, give to the word "work". "

- What you call "work" of a species is its way of life? Why are you talking about work?"

- Because it ultimately has its role. Each species exploits a niche of life that includes a particular habitat, a type of food, a specific strategy for obtaining it, complex and numerous relationships with other species... everything that corresponds in our society to a profession, that is, a role in the social fabric.

"Ecology is a very interesting scientific branch because it gives meaning to the objects it studies: we understand the role of each individual in the immense interactive network of life: few scientific activities are capable of this!"

- I see! And what work do you think we're benefiting from?"

- It is thanks to other species and only them that we can live, breathe, drink and eat! We are completely unable to purify the air we need. We only know how to pollute it and there are countless species of decomposers that allow us to drink pure water even though it has been drunk many times before us! The air we breathe already passed through the lungs of dinosaurs and it remains as breathable for us as it was for them, thanks to the free work of myriads of species to which you refuse the status of service providers. Ecosystems work for us and we do not include this work in the price of the objects and services of our own economic system. <sup>2</sup> "

- Your love of nature is respectable but it pushes you to exaggerate its importance. We are perfectly capable of purifying air and water as soon as it becomes profitable!"

- You're wrong! Find out more about the purification techniques and you will discover that they most often depend - at least for those that are effective - on biological species that do all the work for us. In the factories that we pompously call the Water Treatment and Purification Plant, the main work - and by far - is done by myriads of micro-organisms whose Plant only promotes life by providing them with a habitat, air and food, our waste. I repeat: by relying solely on ourselves, we are completely unable to ensure not only our quality of life, but our very lives. Nature does a huge job for us, whose economists do not know how to calculate the salary it deserves, but whose importance they are still unable to measure. That's why I'm

telling you, they haven't made their Copernican revolution yet. They base our entire system on man. They are entirely anthropocentric as medieval man was geocentric, convinced that the Earth was the centre of the universe!"

- You're exaggerating! Adam Smith long ago recognised the "invisible hand" of nature that works for us: we know that nature is a capital of essential resources and services."

- No, I'm not exaggerating! The unfortunate experience of Biosphere II reveals our powerlessness when it comes to copying nature and you persist in imagining that we can do so as soon as it is profitable. You say that we will be able to manage our resources if they are scarce, that we will be able to purify water, air, soil if it becomes profitable... Note that you are only making assumptions! And I consider them to be much less well-founded than the ones you accused me of doing earlier!"

- You are very severe when you judge our industrial and economic capacities. There are already high-performance, environmentally friendly industrial complexes. Industrial basins bring together interdependent companies that make much better use of their products by participating in networks for the exchange of raw materials, finished products and intermediate waste. The waste from one is the raw material for another. It is precisely by understanding the functioning of ecosystems in which some species' waste is used as food by others that these industrial networks have been created. You can see that the fundamental principles of ecosystems are known and useful to us. Besides, their interactions reminded me of the ones you described earlier with your super-organism jar. "

- I have heard about these eco-industrial complexes. It is true that this is a step in the right direction. But the question is not only there. Your ecological industrial network probably degrades the environment less than a conventional complex. But the fact remains that it is based on a mistaken paradigm: that of an infinite planet, with unlimited resources and the ability to dilute all waste without it coming back to pollute our lives!<sup>3</sup>"

- What are you talking about?"

- The reality! The laws of the market, the economic system that manages our relationships with our natural resources, our work and our production, were developed at a time when vast territories were not yet mapped! We knew that the Earth is round and limited. But our power of action on it and the size of our population did not seem to us to be dangerous for our quality of life. A forest was disappearing? No need to worry! There were many others to exploit, a little further away. And the cleared land was freed for our own use, to the detriment of a multitude of wild organisms that no one would have imagined saving at the time. All species that were not directly useful to us as food or production aid were considered useless or dangerous and destined for eradication! The seas were full of inexhaustible resources. A valiant fisherman, considered a hero, could make a fortune by harpooning dozens of whales in each fishing season... But with the increase in supply, prices fell. The shipowner who had to make his investment profitable had no other solution than to intensify his production...

- I see you coming! You want to convince me that the free market needs regulations."

- Would you like another coffee?"

- With pleasure! "

Florian serves us and continues: "Of course we need regulations! Our power of action is such that nature can no longer follow! The whaler will have to bring more back to each fishing season to earn just as much as he did in his early days, when the whale's price was

high. He will be confronted with competition and will have to search further and further for his prey, and sail longer and longer to find it. This is a vicious mechanism for the free market! Production costs increase while work efficiency decreases!"

- That's true. But the economy is fully aware of this problem. In our reflections we use these retroactive loops as externalities. In the example you mention, the cost of production increases because the resource does not reproduce fast enough to compensate the fisheries and it is this rate of reproduction that is an externality of the economic system: it is not part of the market but influences it indirectly."

- It is not enough to give a name to the phenomenon to solve the problem it poses; cetaceans risk disappearing if there is no strict regulation of their fishing!"

- But if we accepted regulations to restrict the free market, we would have an economy that wastes resources, maintains poverty and unemployment."

- You should admit that good economic management should internalise what you leave out in your system."

- And how?"

- Ah, it's up to you to propose a method if you think the regulations are dangerous. You must admit that the planet is limited, that resources are not inexhaustible and that our quality of life depends on the services that nature provides free of charge but that it is increasingly struggling to make available to us. You must find a way to ensure that it can continue to provide us with the services that keep us alive!"

- I don't understand your interest in regulations since nature doesn't have any as far as I know! It manages well on its own to ensure its balance without referring to anyone!"

- You're mistaken! Nature has many laws but they constitute its very essence, its skeleton: it is built around it! A species that exploited its natural resources as much as we did, that created so much unrecoverable garbage... simply disappeared after it had finished sawing the branch of the tree of evolution on which it was sitting. They probably existed in the past, but they didn't last long. They have disappeared and given way to species that are able to integrate into a sustainable system, compatible with the qualities and quantities of available resources and whose waste constitutes resources for other species, in a balanced interaction. This is evident when an ecosystem is severely damaged. When a mountain area collapses, a forest burns or a volcano explodes, renaturation involves a succession of species that each live for a period of time on the remains of the disaster, modify their environment, compete with other species... until they are themselves displaced. And gradually a balanced, sustainable ecosystem is being established when species complement rather than compete with each other. Each one rediscovers its brands and contributes to the new sustainable balance. There is no need for artificial rules!"

- You just described the ideal free market to me!"

- Oh, no! My ecosystem only includes species of the same nature, i.e. they are based on the same biochemistry. They make discoveries that they submit to natural selection at the speed of their reproduction, that is, slowly. You can't compare this economy to ours, which is changing so fast that natural selection can't catch up. We are constantly inventing new ways to avoid it. But how long will this be possible? The biosphere may no longer be able to provide us with the services you are not yet sufficiently aware of!"

- I hope you're too pessimistic, but at least here I'll know you'll give us a nice piece of nature!" My compliment doesn't seem to convince him. The game has taken a too serious turn: I change the subject: "Well, you see, I feel better as an ecological super-organism than as a bag of bacteria! It's still more rewarding!"

Florian relaxes and feeds the sparrows that have not left us since the beginning of our conversation.

## D.19 : A SHORT HISTORY OF THE INDIVIDUAL

Gold spreads out all along his left flank at Florian's feet. It's dreaming ! We notice it with the irregular quivering of his right chisel, free for its movements. We discover that a man dreams when his eyes move behind the closed eyelids while all his muscles are relaxed. In the dog the sense of smell replaces the view to discover the world and it is to the jerky movements of the tactile hair planted in the chops that it reveals its state. What is it dreaming of? Science cannot tell us yet.

Axel addresses Florian: "You are inviting us to modify our usual perspective to imagine the world from interactions rather than the objects it contains. That's what quantum physics does, and you suggest that biology could do a good job. to adopt this point of view? "

- Yes. It reveals fundamental properties of life that are underestimated when one focuses on the individual rather than on the living process itself. To over-emphasise the organism, we neglect the organisation: the tree hides the forest! And life seems to me to be rather a phenomenon of organisation of matter than of making individuals. On reflection, I even think that the individual is only a very powerful means discovered by evolution to build an organisation able to adapt better and as quickly as possible to its environment. "

- You're going too fast for me! If I understand you correctly, would you even try to define life from relational properties rather than individual characteristics? "

- If you like. The idea came to me when you presented the theory of decoherence. I continue to think that all the theories you propose to explain your experimental results are not satisfactory. But that one at least gave me ideas! "

- You see me delighted," says Axel with a mocking air: "I am happy that physics can be useful to you! So let's go back to your reasoning and first of all, what are your reasons for privileging relations rather than parties? "

- Oh, there are many! There are already the difficulties encountered in trying to find a definition of the living from the individual: it is perhaps the revelation that the question is badly asked; it is all the same curious that biologists are not yet in agreement to define the object of their science! "

- At least you admit our superiority!" quips Axel. Florian continues without answering:

- And then there are all these discoveries that accumulate and which all point in the same direction! "

"At the macroscopic level the individual is nothing without the interactions that bind him to the rest of the living world: only the whole actually expresses the properties that we would like to attribute to a living organism."

- And what are they for you?

- It seems to me that the fundamental characteristic of life is the duration, its formidable ability to maintain an organisation on several levels. From that of biological molecules that can repair damage and reproduce identically, up to the biosphere that maintains the necessary conditions to last, passing naturally by the individual - a short crystal of life received then given, during a very long story that seems well capable of eternity! "

I think I understand Florian's point of view but I find it hard to give up the individual as quickly as he does: "Wait, I know that the characteristics of living individuals such as breathing, digestion, locomotion ... are useless because of many exceptions; but we can see a difference between an individual living or dead! So where does it come from? "

- It's not simple. Biological molecules alone can do nothing without the cell, which itself depends on the individual in the midst of a formidable network of interactions. But the individual is also the emergence of cellular interactions and he himself no longer lives if he is separated from the rest of his environment. We privilege the analysis of the living phenomenon at the level of the individual because we are ourselves individuals. But it is a subjective choice, more emotional than rational. Objectively I do not see any real reason to limit ourselves to this level. On the contrary ; the more I think about it, the more I am persuaded that we have to change the scale of analysis. Remember the fable of the egg and the hen this morning! "

- What's the hen doing here?" exclaims Axel.

- Oh nothing. It was just to show Matt that a problem sometimes seems insoluble because it is not analysed in a proper framework. Here too we should ask ourselves what life is by observing it as a whole: the Planet!

"Is a virus crystallised at the bottom of a vial alive or not, is an embryo frozen in liquid nitrogen alive or not?" To find the answer, it is necessary to bring in Time: to move from Space in a strict sense to Space-time to observe the thread of life of the object studied, and the answer becomes possible: they are alive because they are inextricably included in the history of life, from its origin to eternity perhaps! "

- But that's ridiculous! If I understand you correctly, a dead organism would be alive for you! "

Florian smiles: "In a sense, yes, just as you are alive yourself when every second millions of cells die and are replaced by their clone, you do not even notice it. You recognise yourself every morning in your mirror while shaving without realising that, materially, you are no longer the same! Your form is preserved but the molecules that constitute it change. They are ordered according to the instructions given by your heredity and your story, but they have changed! You are not the sum of your molecules but your individuality is in the information they contain and who organises them: information they have inherited and will transmit themselves in turn. This information does not wear out, does not get old: on the contrary! Globally viewed as it should be analysed, in the context to which it really belongs, it evolves over time enriching itself in the middle of a gigantic river that takes its source in the origins of life ... if not in those of the entire universe! "

- In this case I guess we do not define life at all in the same way: we are not talking about the same thing! So what would be your own definition of life? "

- Let's start from the proposition that Axel made just now." Florian turns to Axel: "The fundamental characteristic of life for you would be the creation of a self-sufficient network of coordinated and self-regulated chemical reactions, to order matter by consuming energy."

- Something like that, yes."

- It's very vague! Where is the individual in your definition? "

- In self-regulation and self-sufficiency."

- But the analysis shows that self-regulation permeates everyone alive, from the fundamental molecular mechanisms inside the cells, to the biosphere as a whole! Why privilege the individual if not because we are individuals? In reality it is only one step - important, certainly - but not really fundamental in the development of self-regulation in the course of life's history.

"As for self-sufficiency, it's an illusion, only the biosphere as a whole is really self-sufficient and needs only solar energy to thrive. All species depend on each other and their environment to live!"

- And what definition would you propose for life? "

- Wait, I would first like to clarify some aspects of the living phenomenon that seem to me unrecognised.

- Which ?"

- I would like to persuade you that the individual does not have the importance you attribute to him in the living process. And for that we could imagine what could have been his story through the different ways of life that we can see today. Life hesitated: it did not follow a direct path to create the individual we have become! And this hesitation, the path it followed on various ones relativizes the importance of the individual in the search for the fundamental characteristics of the living!

"Let's start with bacteria: for us, the individual forms an indivisible, unique and recognisable whole: he has his own characteristics, but a bacterium can exist in billions of copies and rarely has attributes of its own. These individual characteristics are modified according to the circumstances and the interactions that it can have with each other and its environment, it can even change sex, integrate new genes or lose some of them. When we try to identify a bacterial individual we are in the presence of a clone rich in myriads of cells in simple artificial environments. And in their natural environment it becomes illusory to attribute to one cell a great importance because it participates in the history of an entire population. By focusing on the bacterial cell in a natural environment it becomes unclear what makes the true characteristics of the group. That's what we did when we imagined curing all infections with antibiotics. Today the situation is catastrophic: we cannot create new weapons fast enough against some strains! They find a way to resist all our inventions by constantly and quickly changing their individual characteristics. "

- Nevertheless, we cannot imagine bacterial life without going through the individual cell!

- You're right ... in a way. But we cannot imagine the evolution of bacteria without passing through the population and even by super-organisms that associate several species in the same story. The majority of species are not cultivable alone: they die without breeding! Only an

association with a series of other species creates a new entity that lives and reproduces: each bacterium collaborates vitally for the prosperity of the whole. "

- We turn around !"

- Which suggests that the problem is badly addressed! And that does not stop there. About two billion years ago, some bacteria invented such close symbiosis that they profoundly changed their individual characteristics: they became unable to live without each other. This is how the ancestors of our cells inherited bacteria to breathe; and plant cells have inherited bacteria to use solar energy ... and examples are multiplying. "

- The creation of new types of individuals seems to me to indicate that this is an important step for life precisely! "

- Yes but it goes through interactions and does not survive without them! And then the story of the individual arrives at a turning point in its history a few hundred million years ago: cells learn to live in colonies rather than alone and start to specialise to share tasks and end up to depend entirely on each other for their survival ... It is the colony of cells that gives birth to the multicellular organism ... the indivisible individual.

"Before the association, each cell was content with intermittent interactions with other cells but the colony that evolves towards the multicellular organism is composed of cells which have lost all autonomy: only the interactions between the members of the colony-organism allow the whole life!

"These are not isolated phenomena since parallel to the evolution of colony-organisms we observe the creation of new entities from symbiosis between colonies of different species: lichens or sponges are their descendants today. These are clearly seemingly autonomous associations of cells that have lost their original autonomy. "

- For example ?"

- Look at a lichen: it grows everywhere or almost. It colonises the surface of rocks, the tiles... But under the microscope you discover an association between a unicellular seaweed and a mushroom. The seaweed, protected from drought and provided with minerals by its companion, shares with it the food that it makes with air, water and sun. That's all the lichen needs to live but it's the result of an interaction! "

- I am not convinced because you have just described an organism that lives all the same in the form of recognisable individuals on their rock! "

- They appear to you so because you do not observe them closely. When a lichen breeds it forms pretty little microscopic sections in which are formed some kinds of eggs able to spread new colonies where the wind carries them. But it's not about eggs at all! These structures are made up of a few seaweed cells surrounded by mushroom filaments: we can clearly see that this is not really an autonomous individual but an association! "

- I think you're naughty! You said yourself that lichens are self-sufficient! "

- Relatively autonomous! If there were no other species on Earth even the lichen could not survive. Remember the Gaia Hypothesis! The biosphere alone seems capable of maintaining the necessary conditions for life in a homeostatic way. Without other species the Earth's temperature would have evolved catastrophically even for lichen!

"But I have another example to show you: Dickie!"

Florian gets up and goes to get a petri dish placed on a shelf of the library that covers the back wall. It is a small circular container of transparent plastic about twelve cm in diameter and two cm thick. Florian passes it to me: "Do you remember Dickie?"

The bottom of the box is covered with a blotting paper on which some oat flakes are thrown into pasture to a bright yellow gelatinous mass. Enlarged a thousand times it could star in a movie series B chasing nice people to engulf and digest them: I wonder if I have not already seen stinkers of this type.

- No, I do not remember! What is it about?"

- But I already cultivated it when I was a student: I'm sure you saw it at home! "

- But Florian, your room was full of all sorts of animal and plant curiosities, not to mention your collections of bones, nests and even dung! How do you want me to remember your Dickie? "

- But it is very particular! I had filmed its reproductive cycle ... "

- Indeed, it is particularly awful ... but I do not remember! "

- So let's watch the movie! Florian manipulates a remote control: a screen slowly descends from the ceiling in front of the chimney hood; a video projector fixed to the ceiling and camouflaged in the library lights up while Florian lowers the ambient lighting. "

- This is a species that defies our classifications explains Florian. I filmed it in accelerated because for it the time is slower than for us. "

- What do you mean, intervenes Axel?

- For biology also time is relative. Some species seem to be very slow, slugs ... or even plants that move their leaves, their petals or their twining stems. But I am convinced that for them time passes more slowly than for us. If they have eyes they probably perceive us as febrile species, a bit like we perceive flies or ants! For these insects time goes much faster than for us: a month of life of a fly is as long for it as a year for us. But Dickie - its real name is Dictyostellum - is a representative of a group straddling mushrooms and amoebae and living in slow motion ... But look at its behaviour when adjusting our temporal perceptions to theirs. "

The screen projects a faint greenish glow into the room. There are a few dozen small black marbles: "These are spores filmed under the microscope in accelerated, watch them sprout."

Here and there, a spore bursts abruptly: a kind of amoeba comes out and crawls nervously with pseudopods that retract or develop quickly, much like exploring the environment before choosing the right direction.

"That's how Dickie was born, with a microscopic spore, watch them feed," adds Florian, with a paternal air that surprises me ... especially at the sight of the offspring! Small amoebae vigorously hunt for bacteria. The hulls and sticks are engulfed by the protean mass of amoebae and disappear as their predators grow slowly.

All of a sudden the field becomes wider: the amoebae are nothing more than tiny little bright dots that zigzag feverishly ... until ...

- But what happens to them?" Asks Axel. Amoebas seem to coordinate their movements: the small light spots converge spiralling towards some centres of attraction that gradually grow as the amoeba clusters.

- It happens that amoebic individuals are in the process of profound transformation to another type of individuality. When there is no food or the conditions are degraded, they emit chemical signals and gather towards the most concentrated sources, much like gravity attracts dust from interstellar clouds and forms more and more bigger lumps. Here emerge organisms that deserve a new name since amoebae lose their membranes and their individuality at the same time to merge into a single gelatinous mass: a plasmodium. And that's the one you see in the box: watch it live when you watch it at its own pace! "

This time the creatures are filmed under the magnifying glass: they are too big for the microscope. Lateral illumination reveals five somewhat frightening plasmodia. They emit pseudopodia from everywhere until one of them encounters an oatmeal. It stops on it, completely covers it and gradually the protuberance formed by the prey disappears while a pulsating current animates the pseudopodium, quite as if there was a heart hidden somewhere in this yellow mass!

After a while, the plasmodia calm down and eventually stiffen. Then, very slowly, black hairs, each surmounted by a capsule, emerge as a group of the yellow mass. They grow in unison, freeze and capsules burst.

Florian comments: "This is the end of the plasmodium, it has produced sporangia typical of fungi while it was formed of amoebae just now! They burst and release myriads of microscopic spores that will remain in lethargy for some time before germinating and resuming the cycle. Axel, you can see that what seems to us to be an autonomous individual and that expresses all the characteristics of the species at a point in its life cycle has nothing to do with another type of individual a little later and who looks just as autonomous! "

- But you present us an exception, a monster! "

- It is the study of exceptions that best informs us about the fundamental characteristics of life, a little like the examples of incomplete evolution tells us how species are gradually adapting to their environment! And the plasmodium is far from being so exceptional that you think it is. A few hundred million years ago, life hesitated between two ways of acquiring multicellular individuality and today offers us two very different solutions. On one side corals and jellyfish, and ourselves on the other side! "

Florian gets up, changes the DVD and looks for specific sequences. The screen is black and dotted with clear dust animated by a fast movement. Two metal arms with large claws appear in a beam of light: we are in a bathyscaphe, far from the surface, in the permanent darkness where species are so strange that we would imagine them on other planets rather than on ours ! We see it appear and then disappear very quickly because Florian runs the film in accelerated in search of a precise sequence. A pink octopus with curious soft fins crosses the screen, followed by a sort of transparent streaked rows of eyelashes that waves in iridescent synchrony of all the colours of the rainbow. Florian slows the film when a column of pulsating bells surmounts a transparent dome trailing a long colony of tentacles that runs in regular spirals. The light beam illuminates a strange colony of redundant organisms associated by specialties it seems. On one side the engine, composed of bells jellyfish movements, grouped on a rod held more or less right by a top air pocket; on the other, what looks like hundreds of fishing lines loaded with cream-yellow bait and, along the central axis, a series of transparent and bluish bags. The whole is so diaphanous that it would be easy to imagine that it was born of water, that it emerges alive from organised water thanks to the mysterious properties of the living and some molecules responsible for stabilising the ordering of water.

Florian comments on the film: "The group of jellyfish and corals are made up of very different individuals from us, look at this siphonophore: it seems strange to us because it is a community we are just beginning to explore. It is itself made up of sub-individuals - named "people" by biologists, what appears to us as a colony is not really one. The whole is born of a single cell like us, but while our embryo is developing by specialising some groups of cells into organs like the stomach, the lungs ... the siphonophore embryo produces a series of identical people similar to the polyps of a coral colony, all from the same cloned larva. It assigns particular roles: locomotion for bell-shaped people, fishing for people with stinging cells, digestion for stomachs which ... look at this one! It digests prey." Florian points to a little squid whose coat is half-engulfed in one of the colonial stomachs. It seems to look at us with its big dark eye while its paralysed tentacles wave to the rhythm of its predator.

Axel remarked: "I do not really understand your point of view, whether an individual is made up of specialised organs or people does not change much in the business!"

- Yes ! The hiccups of evolution suggest that the individual is no longer really the fundamental characteristic of life but only the means to evolve towards performances inaccessible to isolated cells, even when they are in close interactions as in bacterial populations."

I do not think I have an excessive ego, but Florian's opinion of the individual makes me feel uncomfortable: "One moment, it is the individual who is clearly alive or dead! The fundamental difference between these two states should be defined just as clearly, and thus characterise life, is it not?"

## D.20 : LOOKING FOR THE CHARACTERISTICS OF THE LIVING

- Let's try! What are for you the fundamental differences between a living being and its dead counterpart? "

- The living perceives the environment and responds appropriately; it organises itself continuously by consuming matter and energy; it reproduces itself; it is capable of evolution ... It is clearly different from a dead individual! "

- If it were so clear, you would have found only one fundamental characteristic! Admit that your list hides your perplexity! "

- ...

- If it were necessary to analyse each of your proposals the night would not be enough for us! But let's start with the organisation; I'm going to show you that inert matter is capable of it, as well as a super-organism like an ecosystem, but with one interesting difference: information management.

"Prigogine has shown that inert matter can self-organise in a way that is strangely reminiscent of life: suppose that you are a very small ... of a size comparable to that of molecules; hardly a hundred times greater than a molecule of water.<sup>1</sup> "

- Definitely I must hang on! Just now you turned me into a gooey extra-terrestrial and now into a molecule! But ... ok, I'm ready! "

- Well. You are in a saucepan full of water and its owner has put it to heat. Reassure yourself, you are insensitive to heat: you are only able to see and analyse what is happening around you. So what do you see? "

- I imagine that I would see molecules of water more and more hot, that is to say, which vibrate and clash with frenzy.

- Yes, but there is a gradient of energy: the plate is hot and the surface is cold. The molecules gain speed at the bottom of the pan and then lose on the surface ... "

- I see. They rise to the surface and create eddies. Some change their state: they vibrate so much that they stay away from each other and form bubbles of steam that burst on the surface.

- But if the heat gradient is not very contrasted the surface is not chaotic! "

- Okay ! There are whirls, well-organised convection zones. "

- And how do you perceive this organisation since your place, in the bottom of the pan?

- A multitude of molecules that moved in all directions spontaneously organised in convection cells: they seem to interact to form huge ordered columns that load energy at the bottom of the pan and transmit it to the surface, before they plunge again. "

- A convection cell is organised as a result of interactions and seems to have a purpose: to dissipate energy. If you are blind to the environment around the pan you have the impression of dealing with a mysterious mechanism: a self-organisation of matter capable of creating an identifiable structure. Chemists have discovered associations of molecules capable of forming much more surprising structures: all have in common the interactions between molecules and the transfer of energy at the origin of a self-organisation which suggests a behaviour directed towards a goal. "Either it's alive, or it's been built by an intelligence" would say a naive observer who would discover somewhere on an unknown planet, a set of molecules in the middle of dissipative behaviour - Prigogine called them indeed "dissipative structures".

- But it is! You are responsible for the dissipative structures since you have gathered the molecules in a proper environment for them to organise. "

- Pouring them in a saucepan to heat them, yes ... obviously. But the Sun provides us with all the energy necessary for processes of this type to gradually create life without outside intervention, from the properties of matter and the propitious physical conditions. "

- In this case the peculiarity of the living would be the ability to evolve towards more and more efficient structures to take advantage of the available energy? But to do what?" asks Axel.

- To create an organisation from dissipative structures: an organisation able to preserve its structure maybe, then to make copies ... I have no difficulty to imagine a natural selection of molecules resistant to erosion ... "

- In this case why not select very hard crystals, diamonds for example? "

- Because it is very unlikely to make diamond. The availability of carbon is not enough: it takes enormous pressures and temperatures so high that it is unlikely to be encountered on the surface of the Earth. Thus a carbon atom released by erosion will have very little chance of participating in the growth of a diamond crystal. But imagine that it finds itself in an environment conducive to multiple interactions ... it will have a chance of finding itself in a

less hard structure than the diamond, but perhaps capable of catalysing copies of itself and, thereby, to consume all the carbon atoms it encounters! "

- If it were true, there would be no more definite boundary in the life story between the inert and the living?"

- I would see the story of life that way, but it would not hang on the individual: it would continue to self-organise to the ecosystem ... and even to the biosphere!

"A dissipative structure organises either the movements of the inert matter in the convection cells, or the chemical properties of the molecules in the self-organised reactions discovered by the chemists: in both cases there is creation of order from disorder. thanks to the transformation of energy, properties of matter and interactions, but there is a fundamental difference between convection cells whose properties are only in classical physics and dissipative structures in which chemical reactions take place that is to say quantum physics? We can clearly see that this is an organisation based on interactions, but in one case it is only a matter of statistical and additive interactions: water molecules do not change in nature by interacting to form convective cells, whereas the chemical dissipative structures are much more interesting. Do the molecules enter into chemical and not only physical interactions: and thereby change their nature? We are much closer to the living phenomenon! "

- It's interesting, says Axel! If you're right, we could only find life in environments that are very rich in chemical interactions, water for example! It would explain why life appeared in the ocean. "

- Indeed, water dissolves almost everything; it ionises all kinds of atoms and molecules and allows them to interact by forming chemical bonds from which new properties of matter emerge. "

- What did you mean by "change of nature"?

- Of course! It is too easy to forget that whenever we add or subtract even one atom from a molecule, we can profoundly modify its properties. Water for example is so different from its two constituents, hydrogen and oxygen! This is the kind of interaction from which new properties emerge that are very difficult to predict. And I'm convinced that life is an emergent property of matter when it is subject to conditions that allow it to interact. "

- So how would you define life? "Asks Axel.

- I admire too much the richness and exuberance of the living phenomenon to enclose it in the yoke of a definition! "

Axel and I are stunned ... Florian looks at us mischievously and seems to enjoy our reaction.

- You're awful, "Axel replies with a smile ... "but you will not get away with a pirouette!"

- Generations of naturalists followed each other without finding a definitive definition, so why should I be able to?"

- You owe us at least some suggestions! "

- But I did! When I presented to you my doubts about the importance of the individual for example, or when I showed you that we underestimated the role of interactions in the living phenomenon. I am convinced that life is inscribed in the fundamental characteristics of the universe. But to emerge it needs an environment in which rich interactions can occur for long

enough for natural selection to favour some molecules at the expense of others. It would enrich the ocean with erosion-resistant structures as part of a competition for atoms. "

- When you talk about natural selection, you do not think about Darwinian selection, do you?" asks Axel.

- At first, no! It would be a simple competition between molecules to appropriate the available atoms and thanks to them, acquire new properties, subject to the same selection in their turn ... But as soon as a molecule has become able to create copies of itself, if only by breaking down to release a more or less long repetitive structure, we can evoke the Darwinian selection based on the reproduction of the structures most likely to create copies of them, sometimes with slight errors subject to selection."

- I think I see how you imagine this competition between molecules. But there are still many obscure points. And first of all, what exactly do you mean by "life is inscribed in the characteristics of the universe"?

- I think Axel will explain it to you!" Florian looks at Axel who seems embarrassed before answering:" Do you think of emergence? "

- Yes!"

- There is an old debate about the meaning that should be given to emergence: is it written in one way or another in the fundamental characteristics of the objects from which it is expressed when the conditions are met? Is it in other words, a pre-existing property but that did not have the necessary conditions to express itself? Or is emergence a de novo creation that is in no way inscribed in the properties of the objects from which it appears? In this case, chance - with all the uncertainties about its true nature - would intervene and crystallise one way of evolution among others possible<sup>2</sup>.

"If the emergent properties are reproducible we can no longer invoke chance, of course, but life appeared only once from what we know today ..."

- And I believe less in the importance of chance in the emergent phenomenon because quantum physics allows us today to explain the emergent properties of simple molecules such as water, while at the end of the nineteenth century it was impossible to predict them from the properties of its constituents", adds Florian. "In the same way that the primordial characteristics of the universe seem to lead it along a rich evolutionary history, they would also be capable of pushing up the appearance of life and its own ways of evolution; an evolution able to create intelligence and then culture, the summit of the creativity of matter-energy! "

"Don't you think you're overly materialistic and presumptuous? Do you really think science alone can explain everything? "

- The question is not there!" reacts Axel. "The scientific approach seeks from the outset to understand the universe from the only objective data that we discover and our intellectual faculties."

- One can even add that the scientific approach seems to have objectively discovered the anthropic principle, isn't it Axel?" points out Florian.

- If you want!" Axel looks embarrassed again.

- What is it about?"

- Well ... Astrophysics and quantum and relativistic physics have come to a model of evolution of the universe quite extraordinary: we can understand its evolution from pure energy, moments after the Big Bang. .. until the creation of galaxies, solar systems ... But this whole story depends absolutely on the values of some fundamental constants such as the charge of the electron, its mass, that of the proton ... etc... "

- So what ?"

- We realised that these values are not modifiable!"<sup>2</sup>

- You said that these were fundamental constants!"

- Yes of course! But if we create universe models, computer programs that simulate evolution, the history of matter ... we realise that it is impossible for us to calculate the values of these constants from our theories and that it is equally impossible to modify their value, even in an infinitesimal way, without destroying the evolution of the universe as we know it!"

- You mean that these values have been chosen so that the universe can evolve to what it has become."

- I mean that if we try to change these values, the simulations only give catastrophes unable of creating sufficiently complex and stable conditions in time so that life can appear! But there are physicists who explain this discovery by imagining that there is an infinity of universes and that we find ourselves, by chance, in the one that allows life! "

- Decidedly physics will always amaze me! If I understand, life would be inscribed in the values of the fundamental physical constants from the beginning of the history of the universe ... then biology proposes that it does not stop after having invented the individual but continues to organise the material on a larger scale! "

- It's a nice shortcut," says Florian. "Indeed, in an ecosystem we find several characteristics that can be attributed to life. The organisation of an ecosystem is similar to that of an individual: energy flows through a set of organisms. An ecosystem self-organises through the properties of the species that make it up and their interactions."

- Do you mean that it is not the individual per se that matters, but rather the properties that it expresses through its belonging to a given species? "

- Exactly; the ecosystem self-maintains over time, it evolves by adapting ... as a kind of living super-organism. The individuals that compose it are important only because of the role they play in a specific tissue carrying defined and vital functions for the whole. The cells of our tissues compensate for wear through reproduction: individuals in ecosystems reproduce and die ... the fundamental properties of ecosystems are not so different from those of the individual! "

I persist in defending the individual: "The individual can reproduce, evolve ... the dissipative structures are not capable of it, neither the ecosystems!"

- You put your finger on a difference that may be fundamental: dissipative structures and ecosystems do not seem to store information in symbolic form to reproduce: only interactions with other appropriate molecules can extend the organisation from the whole. In the same way, an ecosystem does not have a specific way of storing information: it is the reproduction of individuals and the evolution of species that are at the base of its organisational properties."

- So here it is the fundamental characteristic of the living: the capacity of reproduction and evolution! And it is in the individual that we find them! "

- Interesting, but not so simple! In reality, these reproductive and evolutionary abilities are widely proposed by biologists to qualify the purpose of our research. But I can show you that these qualities are not satisfactory to describe an individual as alive and that ultimately they apply better to the biosphere than to the individual!

"The biosphere evolves very clearly, although it is not strictly speaking a Darwinian type of evolution since it does not multiply and is not subject to natural selection as an individual is. We will see later if it interests you, how to imagine its engine of evolution ... But let's start with the individual.

"You propose to attribute to it the qualifier of living if it can reproduce and evolve. Thus according to you, a sterile individual would not be alive: it is absurd! On the other hand, even if it is fertile, it is not itself who is able to evolve, but its descendants! You are obliged to conclude that the individual is not really alive: it is his lineage that is alive! "

Axel questions: "Do you really think that only the lineages of individuals are alive?"

- If I continue my reasoning from your proposals I am obliged to answer you "yes" to the extent that the lines have the capacity of adaptive evolution, and "no" because it is not autonomous to self-organise: it is part of a super-organism that is only able to self-organise! In addition, a lineage is an oversimplification of reality: we must rather evoke a network of links that are wider and wider and that eventually encompass the whole species! It is not clear where to place a border!

"Is speciation the real creative event of a new life? This is unsatisfactory either: why give priority to speciation when it is happening in an ecosystem that is able to self-organise and to evolve even if it is not a classic Darwinian evolution."

## D.21 : AFTER THE NATURAL SELECTION: CO-EVOLUTION

Florian has everything about the iconoclast and I point it out to him: "You have just put into serious perspective the importance of the individual in the search for the atom of life and you are now attacking that of the species ? "

- Of course; a species separated from its ecosystem will not survive. It manifests the qualities of the living only through the interactions it has with other species and their environment in the framework of ecosystems intertwined with each other. This is why the true autonomous and self-organised structure must be sought at a higher level than the species... and this research leads to the biosphere!"

- Is it really necessary to go so far?"

- Not if you give up autonomy as one of the fundamental characteristics of life and you just define it on a smaller plane."

- That of the individual for example?"

- Not even: I think that at this level the effort is doomed to failure: there are too many difficulties! Here is an example: you admit that an individual is either alive or dead; he cannot be alive and dead at once! This is why Schrödinger imagined his famous cat: precisely to demonstrate the absurdity of the Copenhagen interpretation! "

- The cat locked in a box with a cyanide bulb whose fate is linked to that of an unstable atom?"

- Yes!" Axel says: "Schrödinger made fun of Niels Bohr because if we accept with him that the attributes of the microcosm are not defined until we have observed them, we will end up with a cat that is at once dead and alive until you open the cage to see if the atom has disintegrated or not! "

- I remember. So what ?"

- So this example shows that an individual is either alive or dead, and that he cannot be in these two states simultaneously" continues Florian.

- Of course !"

- Well it's not so obvious! You think that he cannot be dead and alive at the same time essentially because he is remarkably well integrated: all his cells interact with such coordination that they create this illusion of an individual: for it is only an illusion !"

- You suppose we can find an undead cat? "

- But they are all to a certain extent, and you too! The individual is less integrated than we imagine! And it's been obvious since organ transplants or the freezing of cells or embryos have developed! We even had to think about and redefine death legally since the first heart transplant! "

- But a heart separated from its owner can only stay alive if it is integrated in someone else's body! "

- In the same way that an individual can only stay alive when he is integrated into an ecosystem! Thus the individual is less indivisible than one imagines, whereas the ecosystem and the biosphere are much more integrated than is generally perceived. "

- I understand that a species has to interact with its environment to live, but the opposite is not true! The biosphere can do without one species! "

- Of course ... up to a point! But integration is inscribed in its very nature and it is even that which drives its evolution. "

- What do you mean ?"

- Species continuously exchange matter and energy with their environment, they are, by nature, deeply dependent. But at the same time they modify their environment and thereby interact with other species and form a network of interdependence. And it is this network that evolves."

- I'm lost !"

- You need oxygen to breathe. If you were alone, you would end up depleting its concentration in the atmosphere and replace it with carbon dioxide ... and you would not stay alive long! But plants take advantage of your carbon dioxide and release oxygen and the whole biosphere was built on interactions that gradually became integrated until the emergence of an autonomous super-structure."

- And the engine of its evolution would be this progressive integration?"

- Yes, because each time a new species evolves by Darwinian selection, its fundamental interactions with its environment will have an impact on the ecosystem and lead to a co-

evolution of other species. We forget too often that the evolution of a species is actually a co-evolution in an ecosystem: again by interactions!

"On the other hand, the adaptive evolution of whole micro-ecosystems has recently begun to be experimentally explored and the first publications are exciting: it has been discovered that they can evolve in a measurable way according to the selection criteria defined by the experimentalist. This contradicts James Lovelock's opponents who were convinced that only individuals can evolve.

"But perhaps the best indication of the evolution of the biosphere is discovering how much time it takes to recover from planetary ecological disasters. She has known several: each time she has recovered faster than previously. She has acquired a capacity for resilience, a wealth that strengthens her in its potential for life, and this wealth is probably the result of the discovery and exploitation of new ecological niches in ecosystems. "

- What do you mean ?"

- Imagine two species competing for a particular way of life: they exploit similar resources in a similar way ... Darwinian selection will favour the descendants of these species who specialise laterally and thus avoid dangerous competition for each of them. It will favour mutants who are increasingly exploiting a new way of life that competes with no one. This evolution creates new opportunities for life, new ecological niches. The living tissue of the biosphere is becoming richer, more complex and more efficient. A very rich co-evolutionary ensemble emerges: it is no longer just the addition of juxtaposed species, so that after each disaster, the biosphere has more opportunities to restart from all discoveries than species may have done. She is based on material structures continuously recycled but her organisation is subject to the arrow of time: it is not recyclable! A disappeared species, an extinct culture ... are irreversible losses: lost information is forever. "

- I have the impression that for you, only the biosphere can be considered authentically alive! "

- That's right ! Especially since she is the only truly autonomous organism on this planet and autonomy seems to me to be an important quality of life! And that's why Lovelock's Gaia Hypothesis seduced me, even though he did not really want to say she was alive! "

## D.22 : BACK TO MONT-SION

I'm alone this time. The green dome is free of humans: to the vegetation are added only the mottles of white limestone that outcrop especially as I approach the summit. We would forget the humans if it were not the path, rocky, sandy in places, which divides the broad ridge of Mont-Sion on an East-West axis .

This world is very strange! Here is Physics that presents it to us under a hybrid, dualistic nature, which profoundly differentiates the microcosm of the macrocosm in an incomprehensible way for us. Here is Physics still which suggests the incredible: the universe would be infinitely multiple, or programmed to welcome us; its fundamental parameters would not be due to chance, but carefully chosen to bring forth life and intelligence! And if the mind rejects this perfectly unacceptable model for the scientific mind, it only remains for him to imagine the unimaginable: universes in infinite number ... And there, somewhere, one

of these worlds would be born by chance with the fundamental attributes all compatible to start a long story, to lead it to life and intelligence. There does not seem to be any other alternative! Whatever your choice, you will be dealing with a universe pregnant of life!

Then it is Biology that unseats the individual from his pedestal. Unable to define in a consensual way the fundamental object of its interest, it finds itself entangled in a web of relationships organised in hierarchical layers that add up to the emergence of the biosphere in its entirety. An autonomous biosphere capable of maintaining her structure in a dynamic of infinite richness, which recycles, detoxifies, renatures matter for billions of years; a biosphere greedy of energy that she transforms into living processes; a biosphere that creates spectacular interactive adaptations and, as a result, is enriched with new information throughout a very long history ... and even animal and human cultures ... The mind boggles!

And that's what I do, sitting in the grass, leaning against a block of limestone dotted with pads of alpine plants.

Here we are perhaps wanted, programmed: we would have a role, meaning!

Here we are perhaps organised by nature in a prodigious living structure and therefore, our personal history would be relativized while we acquire an ecological role, meaning again!

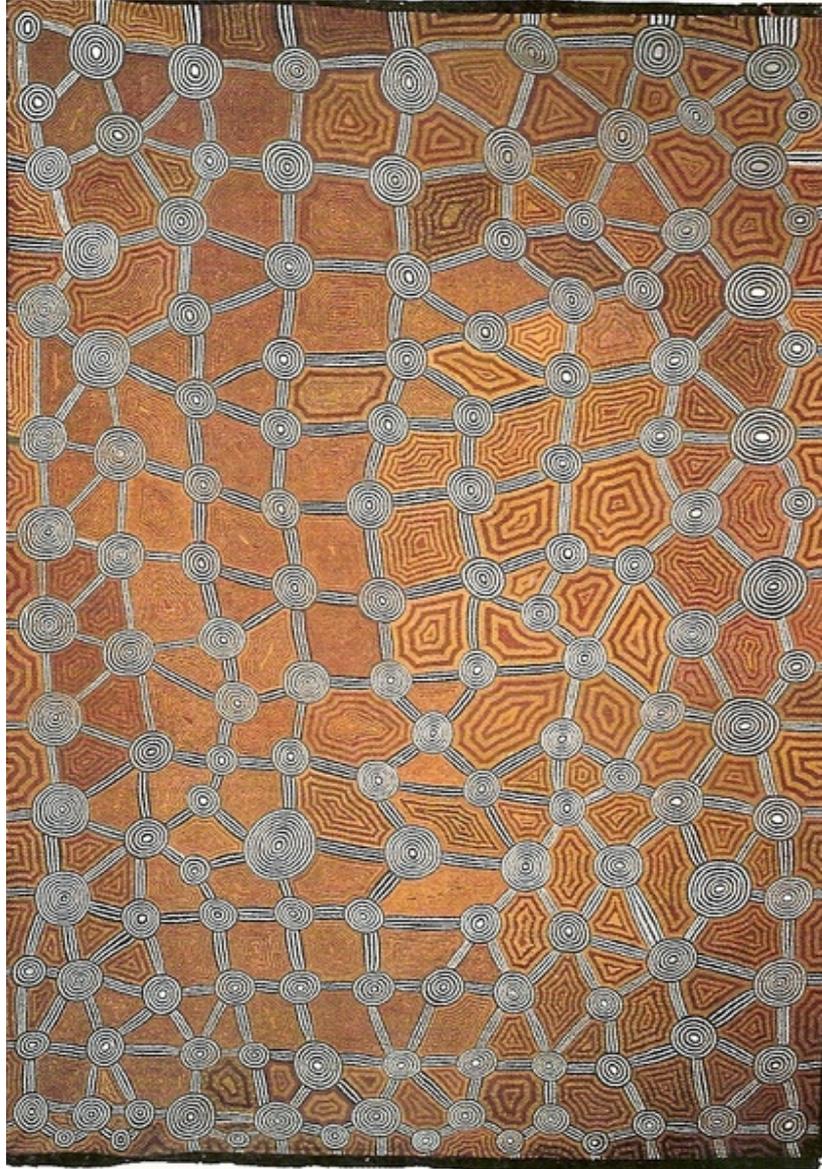
And here we are perhaps close to the moment when science would give back to philosophy what it owes it for three centuries; since philosophers have created the scientific method. It seems that no branch of the alternative offered by Physics can be tested, can be falsifiable: it does not fit within the framework of the scientific approach, but in that of philosophy! Thus science would have benefited from three centuries to begin to perceive its limits, to lift a corner of the veil so that the philosophers can take again the hand to explore in their turn the universe which is revealed.

And what is she, the true nature of this universe so strange? How to understand it? Our senses imprison us in the virtual world built by our mind which deceives us by persuading us of its reality: it is only an image ... but which seems to us so true!

But there may be a way, a particular state of mind that weakens a little this false image: it involves the emotion. It is a question of opening oneself to nature by means of several senses at the same time, without privileging one of them, and especially not the sight which predominates instinctively in our species. And this opening submerges the mind of so many simultaneous perceptions that it gives up for a short time its predisposition to analysis, succumbs to the wealth and immediacy of sensations and gives way to emotion ...

Eyes closed, one perceives better the quivering of the hair when the breeze caresses them. The skin heats up to the warmth of the sun, refreshes itself when air currents touch it. These light swirls circulate between the folds of the ears and stimulate the hearing, without however covering the fluted sounds of the birds ... do not try to recognise them, just hear them! The body and its position in space perceived by its weight and the information sent by the joints ... and, only now, open the eyes gently, restrict to look the panoramic view: see the left, right, up and down all at once. And for short moments we feel intuitively that we participate in the whole, members of a network of relationships that have been sustaining life for billions of years ...

About Life...



*Australian aborigines are mysterious. They are given all kinds of gifts: telepathy, clairvoyance, mystical communion with their land and the dreams of their Ancestors ... Maybe they seem so strange to us because they did not sacrifice their instincts on the altar of all-powerful reason. Perhaps they intrigue us because they still express certain fundamental aspects of the primitive human personality and have become foreign to us since Descartes. In a way that is quite natural for him, instinctively and intuitively, the artist-shaman felt the very essence of life: a network of creative interactions of emergences.*

Source: "Very Secret Dream" in "Aboriginal Words: Australia" Thomas Johnson; Ed. Albin Michel; (1998).

## BOOK FIVE: Revelation

*About Soul...*

## E.1 : THE VILLAGE OF PHYSICISTS

Fifty years ago, St-Genis was a tiny village of farmers, very far from Paris, nestling at the foot of the Jura, a generator of welcome rains to nourish the meagre limestones inherited from the geological period during which the entire region was submerged by a calm and shallow tropical sea whose fossils can be found on the ridges of the mountain, in the form of shells or coral skeletons. But today it is difficult to recognise the farms in this modern village, with flowery ways rich in street furniture; CERN, its powerful neighbour which straddles its border with Switzerland, has profoundly transformed it! A former farmer village, it became a village of physicists.

The meadows have disappeared under the housing estates of small, simple-to-live-in villas, mostly on one level, where CERN physicists and other engineers come to rest. Many of them have the vocation of Axel, so that their home is reminiscent of the cells of the convents where the monks revive in the middle of the bare necessities; the pomp and wealth being reserved for true values, that is to say, here, CERN and there, the church, the refectory or the ambulatory around the garden of meditation.

Florian leads us to a set of small identical villas spread regularly along a narrow one-way road that winds to serve them all. Each one differs from its neighbours only in the choice and the health of the plants that build their little garden.

We arrive at Axel's house: it's been three days now that he's invited us for tonight and it's been three days since we've struggled to contain our impatience because he has promised to finally reveal the reasons why he has triggered this adventure, a long time ago, when he had invited us to visit him on a Saturday morning in his office of the School of Physics.

Axel's companion loves gardening; the entrance to their house is beautifully decorated with hanging pots from which escapes a profusion of geranium-ivies in full health. A big pumpkin next to the door reminds us that November is nearby.

Axel brings us in. The interior of his home is as special as him! There are many works of art: paintings, sculptures and intermediate objects in between; it is about paintings from which emerge excrescences that appropriate the third dimension. Not really successful this attempt at synthesis between painting and sculpture! But Axel and his companion make charitable work more than aesthetic research. Who knows them well understands that these acquisitions represent acts of friendship towards their authors, which also explains the extreme heterogeneity of the styles. It gives a weird impression of bazaar but Axel and his companion do not care: the object of these purchases is not the interior decoration but a social relationship.

After a nice meal together, Axel finally invites us to come to his office to reveal what we have been waiting for so long!

## E.2 : PHYSICS AND MYSTICISM

Axel pours a swig of amber liqueur into three small cups without handle and then rest the carved crystal carafe on his desk on a tray with other small cups.

"Remember the 1970s. "We were finishing our studies and starting in our respective professions. In physics, a certain perplexity was taking precedence over enthusiasm ... " Florian takes his cup and notices while sitting down in his chair:

- There was reason for! Moreover, the bomb and the cold war have brought several perplexed physicists into the fold of the life sciences. And molecular biology has well benefited from this."

- That was not what I thought. It was in physics itself that questions grew. Einstein died without finding a theory capable of describing both the discoveries of Relativity and quantum mechanics. They remained incompatible despite the efforts of the best theorists. There were many published models, but generally only their authors were enthusiastic about them. And remember how weird they are! "

- That's an understatement! Before you presented them to us, I thought you were poor communicators and I attributed their strangeness to my misunderstanding of a complicated discipline. But no! Between a model that multiplies copies of each of us in parallel worlds, another that transcends space and time... and all that involve the entire universe in the least experience on the smallest particles...! I understand your perplexity; but where does it lead you? "

Axel does not answer: he seems to be looking for a strategy. Florian continues:

"But there must be some models that you favour!"

- Uh... not really. Their popularity is changing with new discoveries... We can say that the majority of physicists remain in expectation while waiting for better days. They apply the formulas and concepts that work very well while remaining incomprehensible when trying to bring them closer to the world we perceive every day. Look! If I asked you to choose the model that you think is the most appropriate, which one would you choose? You, Florian?"

- It's true that if you have to choose, they all seem impossible!"

- What about you, Matt?"

- Oh me, I have less difficulty than Florian to accept the incomprehensible! Let's say that I would rather go for decoherence because it allows the Moon to be in its place even if no one looks at it! Now, what happens in the quantum blur before one particle interacts with another... It affects me less and Bohr's position suits me when he decides that the question does not arise and that it is enough to be interested in what can be measured." Axel looks at me for a moment then answers:

"An informal survey has put Averett's Multiverse ahead of the list of physicists who responded!"

Florian opens his eyes wide: "It's not possible!"

- It is ! This is the result chosen by more than half of the physicists. But the investigation was not very elaborate since it only recorded the answers received and said nothing about those who did not take the trouble to express themselves."

- You reassure me: there are some who have kept their feet on Earth!"

- Perhaps, but they probably form the cohort of physicists who have decided to wait without asking philosophical questions and who are content to apply the formulas without a second thought."

- And you, what model do you choose?"

- Oh, I did not manage to wash my brain!"

- No kidding!" Florian smirked, but Axel did not notice.

- No, I'm trying to find a coherent concept, understandable links between the properties of the microcosm and our perception of the macroscopic world and I would like to tell you my journey... which led me to completely unexpected regions!"

- We are listening: we have been waiting for this moment for a long time!"

Axel is surprised and looks at Florian questioningly. Then he concentrates, drinks a sip and begins:

- To return to the 1970s, there was the model of David Bohm postulating an objective existence of all the particles of the universe, but at a price that few physicists accept: a mysterious quantum potential that instantly infuses the entire universe, transcending space and time to inform each object about the properties of all others. A kind of mysterious wave guiding the trajectory of the particles according to information coming from everywhere. I clung to Bell's theorem hoping that we could test it quickly despite the enormous technical difficulties."

- The photon experiment that you presented to us with the photos of Einstein and Bohr?"

- Exactly. Towards the end of the 1970s, some experimenters explored this path, which remained almost impossible to follow for technical reasons. But we were all convinced that we finally had the means to demonstrate that quantum mechanics was incomplete. We hoped that it would be theoretically possible to eliminate probabilities and replace them with certainties when calculating particle trajectories, as Einstein was convinced ...

"It was at the same time that, by chance, I was able to approach other philosophies than that of our scientific method, I had just been hired at CERN and I rubbed shoulders with a Viennese physicist very interested in philosophies. Heisenberg, Schrödinger, Bohm ... were clearly also intrigued by these other ways of apprehending the world, but not as much as Fritjof Capra."

- Ah, but I know him!" Florian continues: "He was interested in ecology and especially in networks. He applies the concepts to all kinds of domains ... <sup>2</sup> "

- Yes, later, in the 1990s I think. But in the 1970s he visited CERN and hosted seminars. He presented troubling analogies between our findings and Taoist or Buddhist teachings. Towards the end of the decade he also published his ideas in a book with the revealing title: "The Tao of Physics" <sup>3</sup>. Despite the success of his work, he had not satisfied me to the extent that - and I understand it - he was only emphasising analogies without drawing a concrete synthetic model."

- The analogies are not enough: they must be relevant! In biology we do not classify crocodiles with birds, although they all have claws, nor tomatoes with cherries, although they are red. A simple analogy can be misleading!"

- That's why I did not get any real satisfaction from his speech. But it was a path that many physicists were exploring; there was clearly a widening of points of view that was emerging."

I had read Capra in the 1980s but could not get much out of it; hence my curiosity to learn what had interested Axel: "You never told me about Capra, could you give one or two examples of his work and tell us why he interests you?"

- Of course ! He quoted texts which, when compared with some of our results, seemed to describe the same discoveries! Hold on!"

Axel gets up to extract a book he finds quickly in one of the three sections of library that circumscribe his office. He remains standing and leafing through:

"Here is an example: Capra describes the Feynman diagrams that can be interpreted as either the analysis of the trajectory of antiparticles that follow the normal course of time, or as that of normal particles that go back in time: travel back to the past<sup>4</sup>. Then, on page 189, he quotes a physicist who writes:

"In Space-Time, all that for each of us constitutes the past, the present and the future is given as a whole. Each observer, over time, discovers, so to speak, new slices of Space-Time, which appear to him as the successive aspects of the material world, although in fact all the events constituting the Space-Time exist prior to the knowledge that it has. "

Axel allows us to assimilate a small moment then continues: "Just after this passage, Capra quotes a Chinese mystic who suggested "to forget the course of time", then another Buddhist lama: "The temporal succession is transformed into a coexistence of phenomena, and it does not remain static but becomes a living continuum in which time and space are integrated." Then he quotes another Zen master: "Most people believe that time passes, in fact, it stays where it is. This idea of flow can be called time, but it is an incorrect idea, since we only see its passage, we cannot understand that it remains where it is."

Axel stops and lowers his head to look at me over his glasses, seeming to ask me if I am satisfied with his answer. But it is Florian who intervenes:

"It is the erudition of your friend that amazes me, but I remain very dubious about the substance of his ideas. I repeat: an analogy is not necessarily relevant unless it is used to discover a new and very real phenomenon."

- I agree with you but we cannot help being troubled, especially if we compare the resources invested to access this knowledge.

- But there is no comparison possible! On one side we have an objective and reproducible method; on the other, an esoteric mystique ...! "

Axel cuts the floor to Florian: "Do not forget that scientific objectivity is not what it was before quantum mechanics: we can no longer separate the observer from the observed, as we have always liked to do. Since the birth of the method, it is based on reproducibility by anyone who gives oneself the material and intellectual means. But if you look well, that's what happens with the mystics too! They give themselves the means, it seems, to transcend our current perception and discover phenomena that are all reproducible in lamas, Zen masters and other Taoist monks! "

- You will not train me on this path! I remain of the opinion that there is not much comparable between the results of science and those of the meditators! It is in the West that science is born, that it has created our culture and especially our technology. What are the results of the meditators you would like to compare with those of science? There is none: your comparison does not hold a single moment!"

- It's because you do not compare the same things! I'm talking about method and not objects studied. If we have achieved so much technological success, it is because we have applied the method to the objective universe by abandoning our inner universe. In the East, the opposite has happened. We are still in the infancy since the discovery of Freud when they explore this path since millennia. It is this way which seems to them the most important whereas since Descartes, we left it to religion and we have forgotten the "know thyself" of Socrates.

"But Capra's ideas have opened my mind to other ways of perceiving the world..."

- And did you become a Zen monk?"

- Maybe I should!" Axel smiles as he sits back in the chair.

"But you do not think I dragged you into this story on so low premises!"

- Then tell us everything!

### E.3 : CHINESE PHYSICS

Axel seems to be searching for his words, concentrating for a moment, both elbows tight on the armrests of his office chair and then explains. He seems to be talking to his cup held in his hands up to face: "I was well engaged in my research at CERN, more and more intrigued by the success of the quantum model, when I came across a book that the library had just acquired. The title was enigmatic but the author was well known to me, an American physicist of Chinese origin who had worked with another very famous Chinese physicist, Chen Nin Yang. The latter had dared to publish a revolutionary idea that was confirmed with the help of another Chinese physicist."

- Then it is not only in politics that they make the revolution, the Chinese! Axel smiles at Florian's remark and goes on: "It was a totally strange discovery... unexpected, so off the beaten path and rich in new perspectives that it earned a Nobel Prize for their authors."

- And the book exploited this discovery?

- Not at all ! It was a translation of a very old Chinese text, perhaps the oldest writing that has come to us since the dawn of time: the Yi-Jing."

Axel saw my sudden burst of interest: "Do you know it?"

- Of course! It is one of the five pillars of Chinese culture, much like the Old Testament for Jewish culture, though these works are very different in form and philosophy."

- I had never heard of it. But I was flabbergasted discovering the use made by Huang, the author of the book. He did not just translate it into English but he explained the ritual importance of the book for his Chinese culture. It is a kind of oracle that the Chinese consult during important events or as a help to difficult decisions."

- So what?" Florian looks very intrigued.

- That a physicist is interested in his culture to the point of writing a book naturally posed no problem. But he explained that he consulted the oracle itself, as his father did ritually and that he made a certain profit from it!

"Do you mean that your physicist has published a manual of clairvoyance?"

- You are tough: no! But he explained that this old text had been distorted by more than three millennia of comments more or less relevant and that he wanted to transmit a new translation as close as possible to the original text and with no frills.

- What for ?"

- Recover the poetic strength of the text. "

- But you said he used it as an oracle! "

- That's right !"

- Here we are! That's what I feared!" Florian is categorical: "Unable to understand the formulas you create, you drift dangerously towards obscurantism: an oracle!"

- I reacted like you when I read Huang's book. But he's exhibiting something very interesting: the Chinese vision of the world. It is an organic, holistic point of view that was totally foreign to me. Since Galileo we describe the universe with mathematical formulas, which the Chinese have never tried. Then following Newton we compare it to an immense mechanics whose work we are gradually discovering. But China has never ceased to consider it as an inseparable whole! A set organised, certainly, but they didn't have the idea to cut the universe into pieces to analyse before trying to rebuild it as we have done for three centuries! Or if they did, they did not pretend to understand it that way, but only to exploit one facet at a time, in a very pragmatic way."

- But our scientific method has had a certain success for three centuries!"

- That's true ... but seems to be running out of steam!"

I intervene because I would like Axel to express his point of view: "Florian, you will admit that scientific research isn't as popular as it was fifty years ago! The public is suspicious and sulky including GMOs you're so excited of!"

- I do not see any connection with the obscurantism that points..."

- There is one ! Science has lost touch with the public in the last century. He is baffled, seeks to understand, but he no longer recognises himself in the excessively mechanistic approach of science. He feels intuitively that you are wrong and do not trust you anymore. Progress is no longer expected as the royal solution, it is distrusted more and more. I am convinced that an organic approach would interest people! So let Axel present it to us!"

Florian does not answer but does not seem convinced! Axel continues: "My goal is not to expose you to Chinese philosophy... not now at least, but I would like to tell you about my journey by explaining it to you.

"So I come back to Huang's work. He explains, for example, that he and Chen Nin Yang spontaneously interrogated Yi-Jing right after the experimental discovery that confirmed Chen's revolutionary model. They asked the old book what their new discovery was going to bring physics..."

- Here are physicists who dare to question our work on evolution, because they would not be scientific enough, they say, and prefer to chat with an old grimoire...!"

- Florian, do not make amalgam! Huang and Chen have never questioned the work of biologists as far as I know. We must not forget that they are excellent scientists since their results prove it! So let me tell you their approach!"

- If you like..."

- Thank you! The Yi-Jing is a collection of formulas that can be interrogated in different ways. Essentially, it's about getting a number that refers to one of the many possible answers. It is deemed to describe an organic situation that illuminates the question posed, its current and future context."

- I guess the answers are sibylline, like those of the Pythia of Delphi, so that everyone finds his account ... afterwards!"

- I propose to judge for yourself! Huang briefly analyses the answer they obtained, which he said was entirely relevant insofar as it predicted that this discovery would lead to slow but steady progress over a long period of time."

- But these are typical answers! It is possible to interpret them in a multitude of ways: there will be one that will correspond to the circumstances! It's a bit like horoscopes, everyone can find one's situation in them, more or less!"

- No! If you flip through the Yi-Jing randomly, you will find that the answer they got seemed indeed appropriate to their question. But what amazed me was that Huang, an efficient physicist, said that this venerable oracle serves him as a tool, in a way!"

- And to measure what?"

- To evaluate a situation of which a human would be the centre. Huang circumscribes the field of physics very well: it is a discipline that begins by drawing clear boundaries between the areas it is able to study and the others. Then it idealises concrete situations to simplify them until they are able to describe them in the universal symbolic language of mathematics. For this, it models the reality by taking into account only the parameters that it considers important."

I'm not sure I understand anymore: "Can you illustrate your point?"

- Yes. If you study the movement of a car, for example, you will simplify the distribution of the masses within the machine and study only the movement of the centre of gravity of the whole. You will not consider the colour of the bodywork or the shape of the chairs..."

- Of course!"

- It's obvious for you who have bathed in our culture, but it is not necessarily so for everyone. And Huang makes the difference. He uses physics when it comes to an issue that he is able to study, but he refers to Yi-Jing when he feels incompetent to simplify a situation in a relevant way, or if he considers that it should not be simplified, or if he fails to choose the important parameters among the innumerable objects and their interactions that influence the situation studied. He uses Yi-Jing as a tool capable of describing the essence of an organic situation, an instrument that takes into account all the parameters and not just a few of them. He specifies that Yi-Jing covers the complex situations in which the emotions, the consciousness ... the whole person intervene. It synthesises the physical and the psychological!"

- What a goal! And does he make a profit?" Florian's tone is a little mocking.

- That's what he writes! Huang uses the old book as a counsellor, a guide, a sage who is consulted before making an important decision... And he ensures to benefit a lot."

- Well, let him have it! And you, have you found an application for your research?"

- I did not try to imitate Huang. But I was very intrigued by this return of an Eastern conception so different from ours. I found that physics surreptitiously extended well beyond the limits I imagined!"

- Physics or some physicists?"

- There were more and more physicists who were becoming orientalised and I could not remain indifferent to their approach since I was always looking for satisfactory explanations of our findings. I had to explore all the paths... reasonable, of course! By not forgetting how strange the worldview of modern physics, whether relativistic or quantum, is."

- And you think questioning a pile of paper is a reasonable practice?"

- I repeat to you that it is Huang who used the Yi-Jing, not me! I flipped through it and found the texts obscure, to say the least. But the old book had not finished to get me intrigued. I found it a little later through another physicist, Western this time!"

"But a physicist anyway," Florian says with a big smile on his face.

Axel does not react. He gets up to serve us a new swig and then stays near his desk facing us, buttocks resting on the table, legs crossed. He seems to be looking for memories to classify before describing them. I take advantage of the silence to suggest, "What if we interrogate the Yi-Jing, ourselves and now?"

Axel and Florian look at me in a bewildered way. "Because you know how to do it?"

- Of course ! No historian interested in Chinese culture can ignore the Yi-Jing! Let's go, we'll see if it works!"

- But what question to ask?" says Axel.

- I do not know... Why not ask it what to think about the usefulness of an oracle?"

- This is not a question that seeks to describe a situation!" remarks Axel.

- So let's ask it if the situation we are in tonight is conducive to questioning it!"

Axel hesitates. Florian looks too surprised to react. Axel finally decides and goes to look for a book on a shelf close to his desk chair: "I am an experimenter in the soul and your proposal challenges me. But whatever the answer we will reap, I would not analyse it right away to keep my lead.

- It's good for me. And you, Florian?"

- Oh, me... I feel that we are going to finish the evening all three, hands joined around a wooden table... So between discussing with a book or invoking an ectoplasm, I still prefer the book!"

Axel passes the book to me and looks at me questioningly and surprised at a time.

I choose three coins from my wallet, shake them between the palms of my two joined hands and throw them on the book, resting on my lap. And I repeat the operation six times. There are several ways to query the Oracle and the Chinese use this one most commonly.

- That's our answer. We have hexagram 18, which turns into 44 through lines 4 and 5.

Florian chuckles. "It's Chinese for me, what do all those numbers mean?"

- I want to talk about that later. I will just explain briefly the answer that the oracle gave us when I asked him if it was appropriate to question it tonight! It tells us about a difficult job because it involves extremes: especially the old and the new. It adds that it is necessary to comply with its true vocation, without concession and that we are in a corrupt situation against which we cannot do much alone but that we meet talented auxiliaries with whom we can provoke a profound reform and worthy of praise!"

Axel looks up at Florian questioningly, "I do not know what you think, but it speaks to me!" I turn a few pages and continue: "The evolution of the situation is not simple! The oracle describes a context in which extremes clash or complement each other. There is a danger naturally but also hope for a creative realisation of a new order."

Florian intervenes: "But you interpret God knows what text to adapt it to our context under cover of obscure text explanation, isn't it?"

- It is true that I simplified the reading, but it is wrong to believe that I cheated to adapt it to the context. I propose to let Axel continue and to return to the oracles later."

- No, it's too easy! Be honest and draw an oracle at random, without your mysterious manipulations. If I am right, it will seem to us neither more nor less relevant than the one you just read. Look! Give me your book and I'll do it myself!"

I hand the book to Florian, who opens it at random and points at a passage before reading: "Linked by strips of ox leather, he cannot even fight, release him."

Florian looks stunned and remains a moment without a voice. Axel smiles and asks him: "So what do you conclude?"

Florian does not answer. I quickly glance over his shoulder. His finger points to the text of the 2nd line of hexagram 33: "The little pig"! Decidedly the old book seems very subtle! In Chinese symbology the pig represents the animal that is fattened until the ceremonies. The piglet promises favourable future days. It is suspicious, resists approaches to domesticate it. It must be allowed time to free itself from its instincts, so that it gradually opens itself to domestic life.

The text that Florian drew "by chance" seems bright to me if one imagines that the Yi-Jing describes the state of mind of Florian: on his guard at the prospect of a profound change of his bearings! I hesitate ... If I propose my interpretation, I run the risk of offending him: I cannot see him accept the image of the piglet! On the other hand, he would triumph over Axel by showing him that it is possible to give meaning to oracles, whatever they are:

I decide to say nothing.

Axel questions Florian trying to hide his mocking tune: "Your interpretation?"

- None, it's gibberish ... not even sibylline!"

- You see! On the other hand, the text on which I fell just now was much clearer and, in my opinion, perfectly appropriate to the situation! But I would like to talk to you now about

another physicist, one of the fathers of quantum mechanics, also Nobel Prize winner for his fundamental discoveries. We'll talk about Yi-Jing later, if you will."

#### E.4 : THE PAULI EFFECT

Axel goes back behind his desk. Florian flips through the book and stops intermittently to read small passages. Axel looks at Florian and smiles: "Pauli was a dreaded physics teacher, he was having a terrible effect on young physicists who did not know him yet, and he was one of the most critical minds of his time and famous to ridicule the slightest inaccuracy in seminars, conferences ... He was quick-witted and his scathing remarks did not even spare his friends, but his criticism was constructive and did not sterilise him as sometimes happens: it is to him that one owes in particular the discovery of a kind of geometry of the behaviour of the particles which explains the bases of the structure of the atoms and the molecules and, consequently, the very existence of our universe and its inhabitants."

Florian seems to have found some familiar foundations: "You want to talk about the electrons that orbit in ordered layers around the nuclei?"

- Yes. It was Pauli who made it possible to understand the interactions between the electrons in an atom and between different atoms that interact. He created Quantum Chemistry in a way and his discoveries earned him the Nobel Prize in 1945."

- And he too was interested in Eastern philosophy?

- No, not that I know of. In any case he did not mention it as much as other founding fathers of quantum physics. But he seems to have very badly lived his hyper-rationalism and this malaise has opened doors to a very surprising world. I add that he was critical of the critics themselves!"

- That is to say ?"

- That he kept his mind very open to avoid falling into dogmatism. He even reproached Kant for having locked himself into a critique of pure reason exaggeratedly constructed on the rational idea of *a priori*. He preferred to leave the door open to other hypotheses than those constructed only from our pure reason and logic."

- You try to say that he privileged the experiment to pure reason, which did not prevent him to be very rational?"

- It's exactly that! But he was an execrable experimenter himself! Everything he touched broke! To the point that he had the reputation not only of missing the experiments he was trying himself, but of causing disasters in the laboratories of others! He confined himself to theoretical physics but several contemporaries say they have observed the "Pauli effect": disasters apparently related to his presence in the laboratories!"

- You insinuate that he was not only distracted and clumsy but that he distilled bad luck?"

- It's a bit like that he was perceived by the experimenters! He did not need to touch an instrument to disrupt it: his presence alone was enough, to the point that Otto Stern had formally forbidden him to enter his laboratory!"

- We swim in full magic again!" Florian finds himself faced with a situation he refuses.

- Do not exaggerate ! Nevertheless, Gamov has told a famous episode of the Pauli effect! This is the story of Professor Franck: he writes to Pauli to inform him that he had just experienced a catastrophe in his laboratory: a complicated apparatus had collapsed suddenly and for no apparent reason! He added that if Pauli had been present in his laboratory in Göttingen, he would surely have accused him of being responsible! He admitted that he could not be, because at the time of the catastrophe he was in Zurich, where Franck was sending his mail. In reality Pauli was not in Zürich but in Copenhagen, which Frank did not know. That's why Pauli received this letter much later, when he returned to Zurich. In his response to Franck, Pauli informs him that at the time of the disaster he was in Göttingen where his train had stopped! And that's how the Pauli effect had struck again!"

Florian worries: "How awful! You have the right to build a funny mythology, but you give me the impression of finally believing it yourself!"

- I do not know what to think about the Pauli effect: it may not be of great importance in the end. But the most interesting thing was that he attributed this effect and other problems he was dragging with him to the conflict between his very rational side and a part of himself that felt stifled."

This remark by Axel reminds me of some research in psychology: "Do you mean that Pauli unconsciously created a Poltergeist effect?"

- That is to say ?"

- Surprising effects attributed to very disturbed personalities, often related to difficult teenagers. Although very rare, it seems to me that serious testimonies exist and mention objects that break without reason in the presence of these people. <sup>3</sup> "

- I do not know these works of psychology but I rather tried to understand the approach of Pauli: you will see..."

Florian seems to be impatient: "I thought you'd talk about science and you're off to a psychology research worth two cents!"

- No. What really interests me and intrigued Pauli is the connection between physics and the psyche, between matter and mind, not psychology itself. But it was psychological problems that led him to consult a psychiatrist in the late 1920s. Pauli met Jung and the doctor quickly understood what he could do with the physicist for his own research.

Jung himself had a bad time: he had broken his privileged relationship with Freud, who had considered him his spiritual son, but Jung had not been able to share his personal convictions with his mentor. He was convinced that the unconscious was full of promise while for Freud it was a sort of dumping ground responsible for containing all kinds of impulses or feelings repressed by the conscious. Jung had observed positive facets in the subconscious of his patients: creative aspects of knowledge and positive feelings. In the back of Freud's garbage bin, he had caught a glimpse of a skylight that fascinated him. This interest was powerful enough to open his mind and lead him to explore areas difficult, obscure and often denied by rationalists."

- What are you thinking about more precisely?"

- Oh, the examples are not lacking! He himself had lived through singular episodes. In a painful discussion with Freud that he was trying to convince while respecting the father's

image, they had heard a loud creak in the wood of the library near them. Jung, suddenly inspired, told Freud that the crunch would be repeated! And he was right!"<sup>4</sup>

- What is singular about wood cracking in an old library?"

- The context! The fact that the noise was synchronised with a liberating psychological situation for him. He was not directly, materially responsible for the noise. But he was convinced that his mind had, if not provoked, at least foreseen without any kind of normal perception and that he had chosen this premonition to convince Freud of the reality of these phenomena."

- Maybe it was also a Poltergeist effect?" Florian looks at me surprised.

- Jung did not talk about it in this way. But he says he finally felt relieved, overwhelmed by an unknown force, while Freud was defeated and stunned. But Freud came to his senses to signify to Jung that he was wrong on seeing anything but chance in the coincidence between the crackling and the so-called premonition he had had. It was then that Jung chose to permanently break up and explore the new world he was glimpsing."

- And to come back to Pauli?"

- Yes, Jung had lost a frame of reference that was very limited but had the advantage of a solid, efficient structure. He had spent some very hard years researching and doubting, without finding a new structure for his research, until he received the translation of an old Chinese alchemical text. Richard Wilhelm, the sinologist translator and pastor, Jung's friend, had unintentionally offered him the structure he was looking for. Indeed, in this Chinese text Jung found alchemical symbols that he knew to have discovered in the texts of the European Middle Ages! Chinese and Europeans used the same symbols while they worked without contact, each at the other end of the world! They could not share them: they had inherited them! Jung had discovered a common source of symbolic images, regardless of our cultural heritage! Where could this source be, except in a collective unconscious that all humanity shares?"

- Hold on ! Do you postulate that we inherit these images at birth or that we discover them by a spooky psychological alchemy?" Asks Florian.

- Jung has almost always been clear on this point."

- Why "almost"?"

- Because he shares the rejection of simplifying clarity with other thinkers such as Bohr! Both favoured ambiguous formulations, which keep the mind alert, looking for new facets to enrich the concepts they explore. Bohr even said that the opposite of a righteous proposition is a false proposition, but that the opposite of a profound truth can be another profound truth!"

- Oh my gosh, we are not out of the wood! But you said that Jung was almost always clear on the collective unconscious. So what did he say?"

- That we inherit it genetically. It's an achievement of our history."

- That we inherit from our evolution rather!" says Florian.

- To my knowledge he did not exploit one of your theories of evolution to explain the collective unconscious. I do not know of any reference to Darwin in his works, but he imagines that the collective unconscious crystallised in our hereditary heritage through the experience of all humanity since its origin."

- Does he think that the experiences of our ancestors are in our genes?"

- I do not know ... But I know however that you refuse this idea since it implies a heredity acquired by our experience and that this option is incompatible with the Darwinian model of natural selection. But I repeat to you that Jung does not seem to have worried about the mechanisms of evolution about the unconscious. All his life he rejected the idea of magic to rest on science, but a science richer and more versatile than that of rationalists of all kinds. He bases his discoveries on scientific observation and experimentation, and not on the old grimoires he dissects in order to derive the substance of his work. It is a scientific work that he pursues and not psychology worth two cents!"

- It would be interesting to propose a model that explains the evolution of mental images common to all species!" suggests Florian. "There is a current of evolutionary psychology that could enlighten us.<sup>5</sup> But can you tell us what he means by alchemical symbol shared by different cultures?"

- He says for example that a teacher came to tell him a sudden vision that had disturbed him: he felt slipping into madness. But Jung reassured him by showing that the same symbol was in a collection that was 400 years old and represents the two poles that coexist in each of us: the feminine and the masculine. A more alchemical symbol that is found both at home and in China is the dragon. But in all cultures there are animals that oscillate between two worlds: beneficial or evil. Everywhere are also symbols of the mother, the feminine, the father, the close hero of the gods, the shepherd, the guardian of the borders, the old sage ... with associated signs that sometimes recall those engraved in prehistoric caves. Always related to alchemy, simple or complex geometric representations: circles, triangles and associated squares, oriental mandalas and western labyrinths. The circle represents the psyche, the square the matter, the triangle the couple..."

- I can not say that you enlighten me!" growls Florian. "But if Jung was OK with that...! And what does Pauli do in this alchemy?"

- He arrived at Jung's house just after he received the text from Wilhelm. From the first consultations the psychiatrist realised that the physicist's dreams were full of alchemical symbols quite unknown to the dreamer and he immediately acted as a good scientist. He led Pauli to one of his students rather than analysing him himself. He thus avoided any subjective interpretation of the dreamer's symbols as well as any unconscious influence on his part. And very quickly he was able to exploit hundreds of dreams very rich in symbols usable in his work ... and in that of Pauli too."

## E.5 : KEPLER'S SCIENCE BLOWS ALCHEMY

Axel returns to his desk and sits down in his chair: "Pauli's dreams were full of incomprehensible images for him, but his curiosity, his listening to the other, led him to study the interpretations his therapist gave him. In the long run, he discovered the interest of the concept of the collective unconscious to understand his own psyche, a dream filled him with an intense sense of harmony and his analysis convinced him of the existence of alchemical symbols that his unconscious used in his dreams while he himself had never learned their meaning: therefore these symbols must exist somewhere! Although they are used by the deepest part of our subjective they must exist somewhere, objectively! In a few months Pauli

accumulates hundreds of dreams that serve as material for his analysis but will later be widely used by Jung to materialise his ideas."

- But how could he dream so much? I can't!" says an amazed Florian.

Axel smiles as he listens to Florian: "Maybe it's because you do not need it, or if you remember them it would destabilise you so much that you carefully avoid this eventuality...!"

- It's true that what you teach disturbs me: but I think I'm sufficiently objective and authentically interested in the experimental results that you presented to me for having seriously tried!"

- That's one thing you cannot buy: the contents and memories of your dreams! It's a problem between you and your subconscious in which I do not want to interfere!"Axel says mischievously.

Florian does not answer. Axel continues: "But Pauli was a source of amazing symbolic images that Jung exploited to give body to his archetypes."

- What exactly did he mean by "archetypes"?

- This is a tricky question because Jung has written a lot, while evolving in his ideas. In particular, he has transformed his concept of archetype so that, sometimes, one discovers contradictions between his ideas when they are separated by time. But initially he defined the archetypes as a kind of psychic energy, a source of emotion that has definite and recognisable attributes whatever the culture in which one seeks them."

- For example ?"

- A kind of innate psychological module which, if activated, provokes an impulse, a kind of motivation or even a faculty of colouring perceived psychological events."

"It's still obscure!" complains Florian.

- Not if you illustrate Jung's thought as he does it himself. In his biography he describes his relationship with the archetype of the old sage: he even gave him a name - Philemon! It was a part of his unconscious that, when activated, urged him to interpret events from the perspective of an old sage. Philemon made him react or even explore new activities, as an experienced philosopher would have done. The fundamental values of Jung then became those of an old wise man: self-knowledge, of others and of the world, to guide his choices of life in a direction which allows to be realised.

- He was not a little schizophrenic your psychiatrist?" asks Florian mockingly.

- No! He was lucid enough and insightful to work in the most objective way with what is the least objective: his unconscious! And for this analysis to be done in the best conditions of objectivity, he splits into two personalities: one - Philemon - represented a part of his unconscious with which he wanted to establish a dialogue, and the other, was his everyday personality, conscious of herself. This work has opened to him a very rich world which is still far from having delivered all its marvels!"

As much as Florian, I am surprised by the lyricism of Axel: we take a quick look and let him continue.

"The old sage is only an archetype among a whole series that Jung has described: there is the image of the father, the mother, the woman, the guardian of the reserved territories, etc. All kinds of psychological modules more or less active at certain periods of life and most

often expressed in the form of symbols in dreams: symbols universally shared in all cultures through the collective unconscious."

- I think I see better what you mean," admits Florian: "It's a bit like the impregnation in birds. They are born with the instinct to recognise their mother in the first object they perceive in motion. Even if it is a human who holds this role, the chick will perceive it through his instinct and will behave with him as if it were his mother. Its perception will be coloured by its instinctive module."

- All things considered, we could compare certain archetypes to your impregnation, but it is up to the Jungians to specify it. I do not know them enough to answer you."

- And what did Pauli do that interest you so much?"

- He discovered the richness of his unconscious. He understood the origin of the conflict he had with his rationalist facet and this subconscious, subjective of course, which needed to express itself too. The images that his dreams made him share with the alchemists of the Middle Ages so intrigued him that he embarked on an exploration of their history. He discovered their power and their importance in the creation of scientific concepts, although they are still unknown today. He was interested in scientific creation and discovered that it was much less objective than one sometimes imagines: it is often based on implicit archetypes and thus loses its objectivity that it would like fundamental.

- Could you illustrate what Pauli meant by that?" worries Florian.

- He looked for what had happened at the very beginning of the history of science: at the moment when alchemy and philosophy shared the search for an understanding of the world. The first had a long history and was different from philosophy by its experimental side."

- Alchemy was less experimental than dogmatic!" says Florian.

- No Florian. I believe that what you associate with dogmas should rather be understood as a symbolic language shared by the alchemists of the time and which has become incomprehensible to us today. I think they were more intuitive and symbolic than dogmatic. But what interests us here is that by manipulating matter they created chemistry at the end of the Renaissance."

- "Aren't the philosophers creators of the experimental method who are at the origin of chemistry, as well of physics?"

- No! What interested Pauli is precisely that among the first scientists there were alchemists! And these are not obscure precursors of science, quickly forgotten because they are overwhelmed by real scientists. Van Helmont, one of the fathers of chemistry was an alchemist! Super-Newton himself seems to have spent more time in his alchemical laboratory than sitting at his desk to invent mathematics and physics! But his alchemical works have remained in the shadows: they are too far from the orthodox point of view of current science to arouse the interest of a Science historian!

"Kepler too was immersed in an alchemical vision of the world, Pauli tried to understand how the new scientific concepts were born by studying Kepler's work closely, and he showed how important archetypes are, even for today's science."

- But what is our interest in all this today? We have a method that has worked well for three centuries to transform the world like never before!"

- You forget that it does not allow us to understand quantum physics! Pauli wanted to understand, like Jung and I... and you, I'm sure!"

- You're right, I had forgotten the quantum mechanics and the absurd models of the world it offers us! So continue: what did Pauli find?"

- He studied the arguments that opposed the hard-line alchemists of the time, to Kepler who was progressively getting away from their model."

- "I do not understand what interested him in the alchemists."

- The alchemists have never separated matter from the mind. He did this study because quantum physics had forced him to re-enter the psyche into the study of matter: and this on several levels.

"Firstly because the choice made by the experimenter influences the result of the experiment, as I have shown you, without forgetting the impossibility of separating the observer from the observed: and the observer strolls a psychism with him, of course, a psychism which enables him, moreover, to conceive of the experience and then to interpret its results.

"But also because Pauli stands out from the empiricists of the late 19th century, Mach wanted to make believe that scientific models are based only on experimental results and in no way on the preconceived ideas of the observer."

- But fortunately they remain objective and without preconceived ideas! Otherwise science would become dogmatic!" says Florian.

- You have to see things further upstream. To be clearer, I'm going to tell you a discussion that the young Heisenberg had with Einstein and that marked him a lot. He had just given a lecture on quantum mechanics and his Principle of Uncertainty. Einstein had listened politely but had not concealed his aversion to the interpretation he gave to the experimental results: he had invited him to discuss with him after the conference. Heisenberg remembers reminding the teacher that he himself had made his discovery of Relativity by focusing experimental results on our perception of time and space. He did not understand why Einstein refused to do the same thing with the results of microphysics. But to his amazement, Einstein replied that he made a mistake of youth and that in reality it is not the experiments that make the theory but the theory that allows you to experience!"

- I still do not understand where you are heading to! "

- Einstein, like Pauli, meant that our experiences are only useful to the extent that our concepts allow us to conceive them and to understand their results. Pauli illustrated this idea by showing that Kepler had conceived the heliocentric system from ternary alchemical concepts in which the Sun represented God, the path of the Earth was the Son, and the link that held the two was the Spirit. Kepler was profoundly alchemist to the extent that his universe was animated: the Earth itself had a soul!"

- Ah, your fellow seems suddenly very friendly!" Florian rejoices.

- I'm very happy! But even as an alchemist, he has quantified by mathematical laws the relations between the Earth, the Sun and Space, and it is in this that he has distinguished himself from alchemy in favour of science. He caught the wrath of Fludd, a contemporary alchemist who tried to show Kepler that he was wrong. He reproached him for having lowered himself into the quantitative vile, whereas the true nature of the objects of the

universe can only be approached qualitatively, that is to say with symbols and not with numbers! The soul of objects is not quantifiable and the alchemist does not conceive that we can separate matter from the object without taking into account its soul! "

- "I still do not see why you tell us about Pauli's research on the origin of physics!"

- Then I'll try to summarise his interests."

"The idea came to him probably because the implicit concepts of classical physics are unable to explain the results of microphysics, so maybe we needed a conceptual evolution and it was interesting to study the gestation of the Copernican revolution, and it was Kepler who, one of the first, published quantitative results compatible with the heliocentric concept. Pauli also wanted to recall that it is the theory that directs the point of view and intuition, even if we do not consciously notice it."<sup>1</sup>

- I follow you. "

- Pauli was interested in Kepler because he was Platonist: he was convinced that to understand the world there was a correspondence between a perception and an archetype. Kepler even used the term "archetype"! For him it is an image created by God in our soul and which resonates when it is associated with a perception that stimulates it."

- I would prefer to associate a perception with a psychological module developed by our evolution to adapt to our environment rather than disturb God in this matter!" says Florian ironically."

- I do not mind. The important thing is to realise that to understand a phenomenon we must associate it with an image, a psychic concept. And Pauli is interested in discovering archetypes that would allow us to make sense of microphysics."

- I see."

- Finally, Kepler had an alchemical and scientific vision. The first regressed while the second affirmed. He was not dualistic like contemporary scientists but monistic like all alchemists. Each object had both matter and spirit. And this idea interested Pauli who wanted to find the monism that seemed to him more relevant and more logical than the Cartesian dualism."

- Why?"

- First because it is a simpler solution and eliminates an old problem: that of the influence that the mind has on the body whereas in the dualistic model they are not of the same nature and therefore cannot interfere. Pauli interpreted science as a "Christian deepening of the Platonic mysticism of light". Science seeks the common ground between matter and spirit. It ended up describing the soul of the world in the form of natural laws whose language is mathematical. And science makes the world intelligible to us because it evokes original images, the archetypes.

"Then because the monism of the alchemists led them to work on their own mind by working the material objects they manipulated, and with them, the mind."

- Could you say that differently?"

- If you like. Quantum mechanics reveals a world in which each object is more or less directly related to all the others. Remember the entanglement of correlated particles and the staggering results we get from them."

- Aspect's experiences?"

- Yes. Two correlated but far apart particles react simultaneously to interactions that one of them may have with its environment as if the two particles were one! This reciprocal influence, this link between what seems to us to be separate objects, interested the alchemists who thought to transform themselves by working the matter in their laboratory."

- I doubt that there can be any constructive link between the alchemical approach and the experimental results of science!"

- I understand. But Pauli sought to find a "physics of the background" in which matter and psyche are not yet separated: a little like in the world of alchemists. A kind of physics in which one could understand quantum mechanics and refute Bohr when he said that there was no access.

"And it was towards this goal that he was heading with Jung, throughout a relationship that lasted twenty years!"

- What interested Jung in physics?"

- The hope of finding a rational explanation for the many observations he made and, in particular, the ones that led him to discover synchronicity with Pauli."

## E.6 : THE ALCHEMY OF ART

Synchronicity! This is a known concept, but I am surprised that a physicist is interested in it! The portrait of Pauli presents us with a personality of rare richness and far from a sterilising dogmatism. For me, it is in the art that I discovered the synchronicity but I am not sure that it is the one that Axel will present to us.

It is in Provence, in St Cannat, at a market of potters, that I discovered how much the spirit can inhabit matter when the artist is inspired... but *a contrario!*

The whole central street was mobilised by craftsmen. The plane trees let small circles of sun, shining softly on the coloured faience. The displays, very heterogeneous, followed each other between the trunks of the big trees. A wide range of styles created by the many immigrants from all over northern Europe, seeking the sun and Provençal quality of life. And suddenly a shock: raku!

On the board, bowls of black earth, basalt, cracked. The sticky appearance of the exterior contrasts with an irregular enamel scattered on the inside. A sign explains that these are unique pieces of Japanese tradition, cooked at high temperature, moulded by hand, without turning. But... no emotion!

The real raku is actually a unique piece, but created by an artist rather than a craftsman. Some are sold a fortune but are worth the money and the Europeans do not understand that it can be commercialised at this price. But it's because we are blind to the art of raku.

A human has often worked a lifetime to become an artist, forming a channel connecting his mind and body to inspiration. It is a question of concretising a moment of total harmony between the raw material: earth, enamels, wood of cooking, architecture of the oven... the human: his knowledge, his skill, his intuitions, his state of mind, the spirit of the moment...

and that something mysterious that the Chinese call the Tao. Jung explored this path and discovered the synchronicity that perhaps modern physics is beginning to perceive as well by working on the world of particles.

The Japanese artist does not sign his work. Unlike the Western, he does not develop his ego through a style that would be personal: he knows he is not the only creator of his work. He blends harmoniously into a reality that far exceeds him, and his art is to disappear to be part of a new entity that encompasses the human, the material, the moment and the mystery that underlies the whole.

He does not think anymore; he lives his art. He enters a trance, helped by the ritual that his master bequeathed to him. He does not decide what he wants to do; rather, he's watching what's going on. The earth moulds with his hands and his mind. It becomes a unique object, a signature of a moment: creation is on the way...

Comes cooking. The oven and its load, the wood - solar energy stored - the air that feeds the flame, the fumes that caress the objects cooked... All this involved in the creation of the work. If everything happens at the right time, if the interactions are harmonious... then the first step is successful. The cooled object is observed with all the senses of the artist, the one who connects him to the Tao particularly in awakening. And he knows if he is on the right track.

It remains to choose the enamels... to melt them in the ground to cook all again, without forgetting the wood species whose smoke will react in the right way with the retained enamel.

Again waiting for the temperature rise of the oven. The intuition of the driving of the whole so that the heat is distributed inside as it is necessary. Then the decline of the flame regime and cooling. Finally the discovery of a success... if he managed to print a moment of synchronicity in the earth, its texture, its forms, its flamed colours, obscured in places by tongues of fire and smoke. The cracks that recall those that the Chinese oracles studied in the turtle shells exploded by embers. Signature of an underlying reality that allowed them to be in the universe and make a decision adapted to the moment.

If the raku is successful, then it is the crystallisation of a harmony, generally invisible to our physical senses alone and revealed through the feeling of serenity that invades the observer of the work. The fingers caress the texture and decipher the Tao as a blind reads Braille. The retina travels along the cracks and the eye runs through the rhythm of Tao. If it is successful, the work becomes a kind of religious object because it connects the human to a situation that transcends him. The work goes beyond the artist so far that it is normal for him not to sign it.

But few are the successes. Most of the time he does not feel the emotion expected when he observes his work at the exit of the oven. He does not perceive the shock that signs the synchronic event, the one that connected him to greater than him. The one he seeks to transmit to the recipient of the work. The bowl is most often destined for the tea ceremony, which is as close as possible to the original nature, in a place in the garden so carefully prepared that the hand of the gardener is no longer seen, but only that of nature. If the current does not pass, the artist simply breaks what has become a work of his, if not a work of art.

## E.7 : A STRANGE GOLDEN ROSE CHAFER

Axel amazes me: he seeks in depth a way to connect physics and psychology! Following him becomes exciting! He speaks a little with the tone of a storyteller:

"Jung was attracted to the mystery, it must be recognised. But he experienced inexplicable events from his childhood. And we must admit that he had always tried to find a framework for rational analysis. He balanced his interest in the unknown with objective empiricism, and this may be the reason why he hesitated for some 30 years before publishing his essay on synchronicity, encouraged by Pauli who contributed to the work by incorporating his study on Kepler."

- There is a link between Kepler and synchronicity?" asks Florian.

- Not directly to the extent that Kepler's discovery is not synchronicity. On the other hand, it is at the level of alchemy that we could bring them closer together. But it will become clearer when I introduce you to Jung's concept.

"His essay describes several synchronous events: one of the most astonishing happened during a consultation. His young patient irritated him more and more because she could not overcome an exacerbated rationality. Jung was trying to free her from her straitjacket to open her to other aspects of her personality that she did not want to admit. As his patient described her last dream in which a priest from ancient Egypt offered her a golden scarab, Jung heard a slight shock against the glass, just behind his back. He saw a big insect trying to get in. He got up to open the window and grabbed the insect that entered his study; it was a golden rose chafer ... "

- But that's what looks like a gold scarab in Europe!" exclaims Florian.

- And that's what interested Jung and allowed him to take an important step towards healing his patient. He offered her the golden rose chafer in a mirror gesture of the one she had just told. The shock was such that she got rid of her blockages and her treatment could evolve favourably."

I know this episode: "But it's a premonitory dream!"

- Perhaps. But Jung went much further, stunned by the behaviour of the golden rose chafer."

- It's amazing that it was looking for the shadow of Jung's cabinet," adds Florian. "Golden rose chafer normally appreciate sunny meadows."

- Jung was naturalist. Perhaps it was because he knew the biology of the beetle that he went further in his interpretation of the incident."

- Hold on ! Even if it was just a premonition, it would be amazing and would call into question the concept we have of time!"

- That's true, but Jung and Pauli have accumulated many such experiences and pointed to an even more radical interpretation. They imagined that there could be a real link between the description of the dream and the arrival of the beetle."

- The beetle wanted to hear the rest of the dream!" says Florian sarcastically.

Axel turns to him: "I repeat that this is only one example among many others that Jung and Pauli have lived for years! They decided to publish their interpretation knowing of course how difficult it would be for the reader to follow them!"

- So what did they conclude?" asks Florian seriously.

- That there may be links between events, but links that are not related to causality."

- A bit like in the theory of the signatures of the Middle Ages? asks Florian.

- What signatures are you talking about?"

- Paracelsus and many others were looking for signatures to find the right remedies. For example, the great scented liverwort is named after the appearance of its leaves, which is reminiscent of the lobes of the liver, which is why it was prescribed to treat hepatic diseases."

- And it would be God, in his extreme goodness, who would have disseminated signatures to help humanity to bear his suffering," laughs Axel.

- No. Because if it were true, there would be a causal link between the aspect of the leaves and the illness it is supposed to cure, and Jung and Pauli will invoke an a-causal connection..."

- That's not what I meant! The theory of signatures describes similarities between objects or situations that are not causally related but that share properties whose origin escapes us."

- Seen like that we could actually bring closer the signatures and synchronicity if they were not two important objections that Jung would do if he was here.

"He would say that a synchronicity brings together two events that have no causal link but that signify something important for the one who lives them. He would also say that the meaning that the subject derives from it is rooted in an archetype, a kind of deep emotion that participates in the acquisition of a particular significance of the event for the subject. A beetle that would ask for your hospitality would not have the same importance for you as it had for the patient of Jung.

"But the concept of synchronicity is rich and can be studied in different ways, and Jung and Pauli did not always agree on its definition, for example Jung wanted to include a-causality discovered in microphysics in his concept of synchronicity..."

- Wait, I'd like you to clarify what he meant by that. It seems to me that we cannot evoke an archetype in the case of microphysics," remarks Florian.

- This is exactly the argument raised by Pauli who blamed Jung for not being precise enough and structured."

- He too!" laughs Florian.

- But Pauli added something very interesting, especially when it comes from him! He said that his reason led him not to make a link between synchronicity and microphysics, but that his intuition suggested that he expand the definition of synchronicity to include microphysics!"

- I'm lost. I do not see how an archetype could intervene in microphysics!"

- You are right. But Pauli sought to transcend the difference of nature between matter and the psyche. He suggested that the probabilities were to matter, what the archetypes are to the

psyche. If true, it becomes possible to include particle behaviour in the study of synchronicity."

- You talk about your particles as if they were alive!" exclaims Florian.

- No! Though..."

I also intervene: "I still do not see how the probabilities could be compared to archetypes!"

- Hold on! I answer first to Florian.

"Physicists working on the quantum properties of a large set of particles sometimes have the impression that they are becoming staggeringly organised. A plasma or liquid hydrogen cooled to a temperature near the absolute zero, behave as an organised whole, in agreement with quantum mechanics. The behaviour of a particle can no longer be separated from that of the whole, just as all the cells of a living organism participate in the movement of the whole. It is very curious, but it's not life, of course."

- And for the probabilities?"

- Yes, remember our interference experiences. When we studied the behaviour of isolated photons we could not know if it passed through one or the other of the two slits that were on their path. We got interference patterns as if the photon was going through both slots at once."

- But it was a wave!"

- It is not that simple. It is rather a particle since it is found in the form of a well defined point on the screen against which it crashes. But everything happens as if its course was determined by a probability wave and not a classical wave. But I propose another example. One of the best described physical laws concerns the decay of the radioactivity of an unstable isotope over time. If you measure the number of atoms that burst in a kilo of uranium, you will find a result perfectly compatible with the one that gives you this law. But if you choose a particular atom of uranium, you have no way of knowing when it will explode: it can happen as well in the second that follows that in a million years. You can only calculate a probability and not a certainty."

- I still do not see how it brings me closer to an archetype."

- Probability and archetype both reveal a kind of order creation in nature. In quantum mechanics there is the creation of an order without really involving a causal link. Probability makes it possible to predict where the interference fringes of the photons passing through the slits will form, without there being a well-defined cause that assigns a particular place to each of the photons that you observe. Archetypes provide meaning for events that are not related by a cause. And finding meaning means that there is an underlying order that links the two events."

- I'm starting to see" I say, "but it's very strange!"

"Wait both of you!" Florian reacts, if I understood correctly, Axel wants us to believe that Jung's beetle came to hit the glass to obey an order that linked it to the psyche of his patient!"

- Jung has actually suggested a connection between the two events: but it is a-causal. So it's not about obeying anything at all. The beetle presented by Jung to his patient illuminates the archetype of rebirth since it is the symbol that the scarab represented in ancient Egypt. This experience allowed her to be reborn on her own, to blossom after getting rid of the concepts that prevented her from being realised."

- But what guided the beetle to the right place at the right time?"

- It is the great mystery of synchronicity that has fascinated two great minds of the twentieth century, each specialised in one facet of the phenomenon: physics and psyche! Although they have worked more than twenty years together, it seems to me that everything remains to be discovered. Unfortunately Pauli passed away too soon!"

- And you took over his torch?"

Axel looks at me surprised and does not answer.

## E.8 : PSYCHOPHYSICS: A MODERN ALCHEMY ?

- No, I did not take up the torch"... answers Axel. "It is still available today although Pauli died almost half a century ago. Very few... too few physicists are interested in his notes, most of which are still to be found in the CERN archives.

"But I was extremely surprised to find in a physicist as structured, clear, precise in his ideas, shining already when he was young, such a profound interest in a concept that goes far beyond the boundaries of his discipline.

"I will tell you the beginning of the eulogy that one of his colleagues has pronounced." Axel goes to his library, leans his head to the side to pick a book on a high placed shelf. He remains standing, leafing through, stops and reads: "The rigour of his criticism is famous and we all know it, as well as the pitiless irony with which he fought the misconceptions, the spiritual contempt he opposed to everything that seemed to him approximate and fictitious." Axel looks up at Florian: "There is no doubt that Pauli was a brilliant physicist and one of the most insightful of all. That's why I studied his ideas about the world revealed by quantum mechanics. He also refused to apply laws without understanding their deep origin.

"Two or three physicists have timidly started exploiting the archives he has left behind, including the publication of letters that Jung and Pauli addressed during the many years of their collaboration. What wasn't my surprise when I discovered a new reference to the old Chinese book: Yi-Jing!"

I can not believe it: "Pauli also used it?"

- Yes. He writes to Jung that Yi-Jing helps him a lot to interpret his dreams."<sup>1</sup>

- Gosh, here we are back in the magic " worries Florian.

- No," retorts Axel. "Jung has always clearly distinguished himself from any magical idea. He relied on empirical experimentation and Pauli did the same. Here, I'll give you some passages from his letters."

Axel lays Pauli's book on his desk, which he has kept in his hands, and goes back to picking another one, the sides of which are bristling with little stickers. He chooses one, opens the book: "I translate: "After a careful and critical evaluation of many experiences and their interpretation, I was led to accept the existence of deep spiritual strata that cannot be characterised in a meaningful way, adequate with the conventional concept that we have about time." Axel looks up at Florian: "How do you understand this sentence?"<sup>2</sup>

- I do not see any connection between a spiritual stratum and time! "

The quote seems clear to me though: "Look! It surely refers to premonitory dreams." Florian casts a skeptical glance. Axel does not answer. He draws on another mark, reads, then summarises: "In a letter of November 24, 1950, Pauli reminds Jung that they first admitted the possibility, the usefulness and finally the necessity of a new interpretative principle of nature, other than that of causality, this is of course synchronicity! <sup>3</sup> We cannot take lightly the opinion of one of the founders of modern physics and, what is more, whose whole life showed how he fought wrong and approximate ideas!"

- Those of others surely! But his?" ironises Florian.

- His publications have never been denied," says Axel.

- But these are opinions expressed in letters, not in scientific publications," remarks Florian.

- That's right. But I'm sure he just did not have the time to dig them up to the point of publication. He died too young. In the analysis of the work he started with Jung, we discover that he wanted to return to a context similar to that of Kepler to start back the exploration of the universe in a new and richer way. He hoped that we could realise the dream of alchemists: to find a language that encompasses matter and spirit."

- You mean a new mathematical area that would deal with psychology?"

- In "The Kepler Case" Pauli describes his interest in a mathematical language, of course, that would succeed where alchemists have failed. He attributes their failure to their substrate: they worked on the concrete matter, the one we see and feel every day. He thinks that the language that needs to be created should intervene on a much deeper level: a stratum that has become accessible to us from the moment we have been able to work with atomic particles. A new alchemy could emerge, a kind of monistic psychophysical philosophy, to use Pauli's language."

Florian seems stunned: "From physicist he has turned alchemist?"

- No. But perhaps it is for lack of time rather than lack of conviction. He thinks that the new language would make it possible to transcend the causality of classical physics and break through the barrier that Bohr discovered with his concept of complementarity. He is convinced that synchronicity should not be difficult to admit, she who creates a meaningful link between two events, since in microphysics we are constantly working with events that cannot be pursued along causal chains in time and space."

- Can you illustrate your point?

- What seems to be the trace of a particle trajectory in a bubble chamber cannot be interpreted in this way in quantum mechanics. We do not know where the particle actually is when we do not observe it, or even if it exists somewhere in a concrete way! It is only at the moment when the observer and the apparatus he has developed interfere with the particle that a given position appears among an infinity of others, that we can only discover through probabilities."

Florian looks disappointed: "Yes I remember, but it is not very clear though!"

- But no one really understands these discoveries. They are nonetheless established beyond all hesitation! We are looking for explanations, not for results!"

- And what did Pauli think?"

He thought that the causal chains described with immense success by the objective method of science no longer allow us alone to describe nature in its entirety."

- Did he admit that physics alone will never be able to explain everything?" asks Florian slyly.

- Yes" Axel answers with a smile... "But he also said that biologists had a very naive conception of chance that would be the source of adaptive variations of species! You should also admit that your theory of evolution does not explain everything!"

I'm afraid that our two scientists are moving away from the path opened by Axel and that interests me prodigiously: "Fight together later, if you wish, it's getting late and Axel still has some interesting things to reveal us!" Axel looks at me and resumes:

- Yes. Pauli has clearly admitted that physics is only one of the tools that would allow us to describe nature and that we must complete it with synchronicity which could be understood as a complementary principle of causality. He adds that this principle links physics to the psychic. He finally states that synchronicity is a principle that creates order by acting on the similarity of events that cannot be linked by a causal link."

- Florian sits in the back of the chair and smiles: "So here we are again alchemists... after three centuries of efforts to get rid of this conception of the world! But you only present theories to us! What results can you offer us to try to make us buy this enormity?"

- We are still at the beginning. Pauli did not dare to predict how psychophysical language could evolve. He acknowledged that all attempts he made were premature. He was all the same convinced of the necessity of such a language to overcome the oppositions between the rational way and that which privileges the mystical intuition. I quote from memory a sentence which he writes towards the end of his work on Kepler: "The only acceptable way nowadays is the approach that reconciles the two parts of reality, physics and the psychic, and which is able to understand them as a whole!"

- But to say something as overwhelming you need results in accordance!"

- It is true. But we must start by changing the frame of reference. Pauli naturally recognises the power of traditional forms of the explanation of nature, those expressed in our philosophical systems. But he adds that these systems belong to history, that they are outdated." Axel draws on a bookmark of his book: he adds: "It is appropriate today to lend a receptive ear to the formulation of new logical and empirical possibilities not foreseen by these systems."

"He realised that he needed experimental arguments, but he did not have the time to get them in. Do not forget that he was a theoretician, not an experimenter! But he admitted in a letter that he has come close to magic and its dangers, but he specifies that he would prefer this path to that which Einstein has chosen."

- Not less!"

- But Einstein's conception has been formally denied since the 1980s! He hoped to return quantum physics to a classic objective reality, remember. This is no longer possible!"

## E.9 : AXEL'S SECRET

- And you prefer to oppose Einstein's ideas and follow Pauli to regions that remind us of dark periods of history: obscurantism!" Florian looks incredulous.

- You'll understand right away why I did not have a choice, at least I hope so. But Pauli is very clear about this. A few years before his death, he shares his thoughts with a friend and explains that he still prefers the dangers of a primitive superstition, the renewal of a kind of obscurantism among those who do not really understand his approach, rather than doing like Einstein who turned his back on this new potential science.<sup>1</sup>

"Moreover Einstein and his point of view have been clearly disavowed since the 1980s and the results of Alain Aspect. I remind you that we must abandon either the objective realism or the principle of locality, if not both. The results we have accumulated for more than twenty years no longer allow us to believe that every object exists for itself, apart from any interaction it may have with other objects. They destroy the concept of concrete localisation of these same objects, somewhere in the universe, sheltered from instantaneous interactions with other distant objects."

- If you like! But these results apply to invisible particles. The concrete world in which we live does not present the properties of your enigmatic particles."

- I'm not so sure...!" Axel remains mysterious, he sits down in his chair and takes his favourite pose: "Do you remember the starting point of our experiences and our discussions?"

- Of course! The meeting at the university, at dawn!" answers Florian smiling.

- Yes: I invited you a little abruptly!"

- You even worried us. I understand your motives better now, but why this anxious, theatrical attitude?"

- Because I was sort of struck by the results of an experiment that I can now tell you."

- Finally! But I fear the worst!" Florian's smile tempers his words.

- That day I changed radically of conceptions... I had to modify deeply my vision of the world!"

- Gosh ...! After what experience?" exclaims Florian.

- One moment: lets summarise the steps! Very intrigued by the discovery of Pauli's ideas about the Yi-Jing, I decided to study what Jung had written about his personal work related to Chinese alchemy. We evoked the archetypes and the collective unconscious that are the results of his research fed by the texts translated by his friend Wilhelm, including the Yi-Jing<sup>2</sup>. Jung worked on this text from the 1920s with passion. This book has accompanied him throughout his life and seems to be the pivot of the development of his later work.

"He used it as a tool to explore the unconscious: his own and that of his patients. He expresses his amazement when he discovers the relevance of the answers to the questions he asks the oracle. He is convinced that there are not only coincidences, so sensible answers are the rule rather than the exception, it is these strange coincidences that put him on the road to synchronicity."

- He cites examples?"

- Of course! Here is one I remember. Jung says he interviewed the Yi-Jing for a patient who came to him for advice about a marriage he was considering. Until then, the young man had lived under the cup of his tyrannical mother and wanted to free himself. The response of the oracle was very clear: he textually advised not to marry such a girl because she was authoritarian! It's hard to imagine a more appropriate answer to this question!"

- You do not know anything about the girl's personality!"

- That's true, but the answer is well related to the question asked!"

- ... Florian does not answer but remains skeptical. I am delighted by Axel's confidences: his revelations promise to be exciting!

- And how does Jung explain his results?"

- By synchronicity. There would be an a-causal connection between Yi Jing's interrogation and its answer. Thus Jung explains the adequacy of the oracles to the situations experienced by the subject: the meaning of the text corresponds faithfully to the psyche of the experimenter. But here is another example: Jung relates in the preface to the English edition of the Yi-Jing that he wanted to do an experiment and ask the oracle how it would be received by Western readers. And, again, the answer was quite sensible."

- That is to say ?"

- Yi-Jing has defined itself as a tool for expressing the unconscious elements so that they can play their part in the life of each individual."

- This is obviously the translation that is expected of a psychiatrist even if the oracle is sibylline", intervenes Florian.

- It is up to the observer to feel if the answer is valid. And Jung recognises that he could not hope for a more sensible answer to the question he had asked! He adds that the great glory of the Yi-Jing is that a "productive reaction of meaning is born of a technique that apparently excludes all meaning from the beginning"!

"He has gone further but without giving a specific example, to my knowledge: he writes that when the observer is critical..."

"But how could it be otherwise?" cuts Florian.

- No, he meant "mocking" rather than "critical," since he himself had always tried to rationalise his empirical discoveries. But he knew how to be humble and admit what he could not explain."

- I see."

- Jung points out that if mockers ape the diviners, they receive answers that seem to coincide remarkably with the blind spot of their psyche."

- I do not see what he means by that," intervenes Florian.

- I think he meant that an impartial observer would have recognised the adequacy of the answer but that the incredulous interrogator's psyche was unable to do so because he was not open or receptive enough to perceive the meaning of the answer. A bit like our eye is unable to perceive the part of the visual field that corresponds to the departure of the optic nerve and

compensates for this blindness by reconstructing an image from information extrapolated from the rest of the visual field."

Jung's observation reminds me of the reading I made just now for Florian! I found meaning but I am sure that Florian would not have agreed with me.

He is impatient: "And you, what was this famous experience that upset you?"

- I was coming there. I showed you why I became interested in Jung and Pauli's discoveries about synchronicity and then their application. A sentence pronounced by Jung at Wilhelm's eulogy struck me. He said something like: "Anyone who has experienced, like me, the joy of experiencing the divinatory power of Yi-Jing in spiritual communion with Wilhelm, can not fail to see in the long run that we are touching a point from which our attitude of Western spirit may be out of its hinges ".<sup>4</sup>"

- Axel stops, looks at us and continues: "He spoke of Yi-Jing as if it were a living being."

- But it's pure madness!" exclaims Florian.

- Jung knew that it would be the normal reaction of his readers if he published his ideas, and that is why Pauli had to insist and participate in the publication so that it appears... some thirty years after his first works! Jung also said that : "The function on which the practice of Yi-Jing is based is in total contradiction with the vision of the scientific world, incomprehensible to our scientific judgment". He was not crazy!"

- But we cannot do anything about it!"

- We can, provided we create a new concept, synchronicity precisely!"

- I see you coming... You have turned "Chinese alchemist" and you offer us oracles," sneers Florian.

- Before you make fun try to keep an open mind to hear more...

"In the morning of the day when I proposed our appointment, I decided to try an experiment similar to that which Jung tells, I stifled my disbelief, I bought a Yi-Jing in the edition that he had prefaced and, ashamed, I questioned it as if it were a person."

- And you have naturally found a satisfactory answer" laughs Florian.

- Actually... yes. But this is not the most amazing. Although Jung specifies that the validity of the answer cannot be verified experimentally since it depends on the overall situation, the moment, and that it is impossible to find exactly the same conditions to verify the correctness of the answer, I decided to ask a second time exactly the same question."

- Ah, you remember that you are an experimental scientist! But you're not going to tell me that you got exactly the same result? You did?"

- No... If that had been the case I would have been very surprised but I would have thought it could still be a coincidence and I would have started calculating what were the chances of falling back on the same answer by chance."

- So?"

Axel looks at Florian and then picks up his Yi-Jing, looks for a mark and replies: "I read you the answer I received the second time I asked my question: it is a hexagram called "The youthful madness" and here is the text: "The youthful madness has success. I do not look for the young crazy, it is the young fool who seeks me. On the first oracle I inform. If he

questions two or three times, it is impertunity: if he is unwelcome, I do not inform him." Axel stops and looks at us in silence then asks us: "So what do you think?"

Florian does not answer: he looks at Axel but does not give the impression to really see him. He looks lost. I recognised hexagram 4 and I gloated internally. I never imagined doing the experience Axel did but the result is amazing: "And you, what did you think?"

- Oh, me... I told you. I remained a moment immobile, the book in front of me, really overwhelmed! And every time I think about it, I feel overwhelmed with a sense of humility! I will not be able to see the world as I imagined before that day."

- And that's when you decided to call us..."

- No, it was later. I took a moment to recover my mind, to try to find a reassuring rationality. After a while, I decided to put a second question to the old book. I asked him how I could handle this amazing discovery... and here is the answer."

Axel flips through the book, stops and tells. "This time I came across a hexagram that invites you to do a serene search, the 54th. Here is what we find: "Man unites with his friends to confer and to practice... In the field of science, knowledge must be a refreshing and life-giving power, it can only be in a friendly trade with like-minded friends, with whom one confers and exercises one's self by applying vital truths. Then knowledge acquires a varied aspect while the science of the self-taught is always something unilateral and weighty."

I can not help but burst out laughing! "The old sage does not lack humour!"

- And that's where you decided to call us!

## E.10 : TOWARDS A RE-ENCHANTMENT OF THE WORLD ?

"You're both funny! Yes, do not look at me with that puzzled look, you're charming when you discover... what many already know!

"Do not take it wrong: you know how much I appreciate our research... we share a philosophical curiosity that I care about!" The results of Axel are disheveling! I am as astonished as you... but surely not for the same reason. I knew that the scientific method, as it is practiced nowadays, is not enough to explain everything and especially not to give meaning to the world: to give meaning to our relations with it."

- But that is not its role," cuts Florian!

- This is perhaps not its role today because you have distanced yourself from the motivations of its creators and the context in which they worked. They knew, well, that their method was only one among others, that its results would be to include in a more global approach which would benefit from the contributions of other disciplines...

"Pauli discovered the collective unconscious thanks to Jung: he even gave it a place in the objective world because he could personally exploit the information acquired through it, without the participation of his consciousness or his experience. This is a reality that does not appear to be affordable quantitatively, but only qualitatively, and this is probably what prompted him to look for when and how science has opted for pure quantity, abandoning quality.

"Let's go back to Kepler, who is one of the first creators of the scientific method: he built his work on a fundamental structure of a qualitative nature, closer to alchemy than mathematics, his concepts were binary: archetypes for foundations and mathematics for realisation. Today you keep only the external structure, forgetting, even denigrating, its metaphysical foundations."

- Of course! We do not need it at all. See the results of three centuries of discoveries! We have gone from a smug obscurantism, dangerous by the fanaticism it arouses... to democracies capable of making billions of people prosper in a quality of life that is out of all proportion to what it was before the creation of science!" Axel looks at Florian dubiously but does not react.

- You mean we're all happy thanks to science?"

- Those who are not, must turn against the economic, political or social systems in which they live, but not against science that has allowed us to control unknown sources of energy, to understand the origin of diseases, infectious or genetic, to devise ways to prevent and combat them..."

- It is true, but it is not enough to be in good health and provided with all sorts of mechanical slaves or energy-consuming computing to be happy! Still, we must have found meaning in all this!"

- What do you mean?"

- What drives us to be curious? It is not only the pursuit of physical well-being, but also the quest for meaning..."

- Not necessarily! Curiosity could have been selected by our evolutionary history: it would be enough for it to improve our adaptation. We are animals much more curious than magpies or chimpanzees! Perhaps it is this natural curiosity that has shaped us. A species that does not just rests when its basic needs are met but that explores its environment out of mere curiosity can make sometimes important discoveries. Some will surely have advantages for the species and curiosity will become a character selected by evolution, a behaviour inscribed in our genes.

"But it could also be the simple consequence of an anxiety that would have been selected by our evolution to allow us to escape the dangers..."

Axel is astonished: "Do you really think we have been doing science for so long only to forget our anxiety?"

- No, but I'm not convinced that our curiosity is really a search for meaning!"

- I am!" says Axel. "Put yourself in my shoes when I began my experiments with Yi-Jing: I could have imagined that I was hallucinating, forget all of this, and retreat into wise conservatism. I could not... I absolutely needed to make sense of these unexpected discoveries. That's why I asked you to help me. As Axel, I would have been devastated to discover myself fool... but as a physicist, I would have been relieved to put all that in false interpretations."

"Are you schizophrenic?" Florian asks.

- No, I meant that I am a physicist, that I do not just do physics!"

- Explain yourself!"

- An old farmer told me one day that her brother had to stop farming for health reasons and that he "plays" the postman. This expression succinctly sums up a whole philosophy of life. Her brother kept his personality. He was playing a social role by entering his mailman's uniform: he remained himself under his cap. I realised that we let ourselves go to the game by "becoming" a CEO, doctor, policeman or customs officer. We have lost this ancient wisdom: the recognition of the role we hold in society and which is not necessarily an extension of our personality.

"But to get back to physics, it is part of my personality: it is deeply involved in the construction of my philosophy of life. I am a physicist and that's why I'm concerned about the meaning of the results we get. But it is true that I have colleagues who "play" the physicist, who simply apply formulas. They operate within the restricted framework that has been defined to them and dispense them from being concerned about the meaning of phenomena.

"And if we worked together, it's because you, Florian, you're a biologist, and Matt is a teacher!"

- And also because you were a friend in need of help to find his mind", adds Florian smiling. "You'll see, we'll save you from the couch...!"

I do not know if Florian is serious but I find it unfortunate to leave so early the search for a link between the scientific method and the meaning of its discoveries: "I understand Axel's approach, he is brave because many scientists would think that if I do not content myself with the absurd universe that they propose to us, it is because of psychological fragility, an incapacity to support reality.

"But look where your quest leads: you have suppressed your primordial archetypal concepts and, proud of your unquestionable successes for three centuries, you have concluded that only them were real, that all the rest was only superstition! You build personalities like Steven Weinberg in physics or Jacques Monod in biology who want to share with us their disillusioned attitude to the absurdity and meaninglessness of the universe they describe... Obviously the universe that they study is meaningless: they got rid of everything that could give it meaning for three centuries!"

Florian is astonished: "What a rant, I do not remember hearing you attack science so far!"

- I do not attack it blindly: I relativize it by thinking of the other methods that can complete it.

"Science is probably one of the most important discoveries that our species has made since our birth, but I dispute its use when some people convince themselves that they are the only ones who hold the truth and insist on persuading everyone. I do not see how they are so different from the obscurantists that you fear! They worship the god "reason" and sacrifice much of our human nature: intuition in particular."

- Now I think you're going too far," intercedes Axel smiling. "Science does not deny intuition: it has allowed beautiful discoveries!"

- Cite me a scientist who explains in his introduction how the intuition put him on the trail of his discovery!"

- You know that nobody can go that far! A scientific publication is highly stereotyped, it follows a rigid model that has been proven for centuries and the subjective is banned! But in the informal talks, in the biographies, we often quote the importance of intuition and even

dreams like that of a snake biting its tail at the origin of Kékulé's discovery of the benzene ring "

- I know this kind of example, but it does not attribute to intuition its rightful place. The author implies that his rational mind creates knowledge by relying on thorough unconscious work before emerging to consciousness. Mathematicians, physicists, chemists... suggest this when they describe how a bright idea suddenly came to their minds after they were long obsessed with a problem. And it makes sense that we imagine this because we do not order our brain to do what we would like it to do... we are at a loss to do it! We need to remember this or that event and it is up to our brain, subconsciously, to manage to find the memory box concerned, to shape memories, associations with other events, relevant or not. We are soon led to accept that it works parallel to our consciousness to bring us the desired information, all shaped to be usable by our rational consciousness. But I imagine that there is another intuition, much more mysterious still and which would be closer to the phenomena related to synchronicity than to those of the rational mind.

"Here, Pauli is a real scientist who keeps an open mind on other perspectives and, in particular, those that give meaning to our interrogative approach."

- And what are they, according to you?" asks Florian.

- But precisely those which integrate intuition with logical reasoning and which seek significant associations between the results of the various disciplines."

Axel comes out of his silence: "I think I see what Matt means." He glances at me and continues: "You will tell me if I translate your feeling well.

"One may wonder why the scientific approach has not kept the interest of the alchemists in the sense of their approach. Since the Renaissance it has chosen to analyse the world from two fundamental concepts that may have made it gradually lose interest in a quest for meaning.

"The first concept is realism: the world is made up of objects that exist independently of me, whether I perceive them or not. They have their own properties that do not depend on me until I interact with them. Perceiving them is not an interaction that influences their intrinsic properties. If I just look at a leaf on its branch, I cannot change its position in space, its movements in the wind... it's not because I look at it that it's green, it stays green even if I close my eyes.

"The second concept is the objectification that forces me to separate the subject from the object being studied. If I analyse the objects that make up the world, I must do it in such a way that I, the subject, am no part of the object I study. The lessons that I draw from the perception of objects must be reproducible by subjects other than me to be admitted as real. If this were not the case, it would mean that the knowledge that comes from my perceptions are only useful to me and cannot be used to construct an image of the world that is compatible with that of my neighbours. To achieve this objectivity I must absolutely make myself insignificant and, in particular, refute any subjective attitude and privilege only pure logic.

"After three centuries of very concrete results, of unmistakable progress in our understanding of the world, I find myself completely separated from it, having lost the meaning, the importance that the alchemists gave me. I am useless, I have no meaning since the objects exist, whether I am there or not! And that is why the astrophysicist Steven Weinberg can write: "The more the universe appears to us understandable and the more it seems insignificant." Or what causes the biochemist Jacques Monod to write: "Man lives on

the border of a strange world, a world deaf to his music, indifferent to his sufferings or his crimes"!

"But the results of modern physics force us to have another look on these concepts since objectivity is not what it was and local realism is no longer compatible with our experimental discoveries! The confirmation of entanglement by Aspect's experiments in 1982 forces us to bring back the qualitative and the psychic in the description of the world, and leads us to wonder how an alchemist could have interpreted it. Perhaps his point of view would help ours to evolve. Schrödinger notes that the objectification of the scientific method has gently led us to a wrong paradigm. It is a paradigm because it is automatically, unconsciously, that we objectify the perceived world. And while doing this we exclude ourselves from it and regard it as a mere collection of objects. The emotion they can arouse in us is not objective, and therefore it is not "real" according to this worldview. And this is how the universe loses all meaning and all emotion. It becomes cold, impersonal. And we end up believing that we are too... cold, impersonal and insignificant objects!"

- That's what I wanted to suggest. But I also blame science for cutting itself into a multitude of disciplines more or less tight to each other: research has become very specialised, so targeted to find answers to questions more and more specific. But a quest for meaning seems to me to be the opposite of this evolution: on the contrary, it should seek what links rather than what describes objects more and more separated from their context."

- We have lost the humanist ideal, it's true. But we can understand it! Who today would be able to master enough what we have learned in all the important areas of knowledge and philosophy to claim to derive a meaning, a new humanistic ideal?"

"It is the work of philosophers and of any person truly interested in the meaning it gives to his life. But that would require discoveries to be accessible to them! It is perhaps at this level that lies the most important obstacle to the quest for meaning!"

- Perhaps... Your opinion makes me think of the expression of faith of a physicist convinced of the real existence of the Multiverse: it is by a quasi infinity of parallel universes that he explains the surprising results of quantum physics! David Deutsch has published an essay in which he proposes to study the kind of reality that emerges if one takes seriously the results of several disciplines.<sup>1</sup>" Axel gets up, chooses a book from his library and flips it while speaking: "He describes reality as it should be if we bring in physics, quantum and relativistic, evolutionary biology and cognitive psychology... and this is what he writes: "Taken individually, these four theories present "gaps in explanation" that can make them seem inhuman, limited and even pessimistic. I suggest that if taken as a whole, as a unified explanation of the fabric of reality, this unfortunate characteristic is transformed into its opposite. Far from denying free-will, far from placing human values in a context where they become trivial and insignificant, far from generating pessimism, these theories taken together constitute an optimistic worldview, where the human brain occupies a central place within the physical universe and where the explanation and the understanding are placed at the heart of the objectives which the humanity gives itself".

- Here is one who "is" a physicist and who does not just "plays" the physicist," exclaims Florian! "I agree. When we widen the perspective of reality that gives us genetic biology, evolution then ecology, we actually manage to perceive a world and a picture of the man full of sense and which has nothing to do with the one which belittles us to the level of simple reproductive machines ."

- Here is an evolution of science that can excite me! Axel described much better than I could have done the constraints of the method as it evolved today. It's not science itself that's a problem, it's what some people do with it! Besides, Pauli seems to have discovered how to create a new way since he used Yi-Jing."

- Yes, to interpret his dreams," Axel remarks. "But I do not think he used it to do science. However, it is likely that he would not have accepted the conclusions of Weinberg, Monod and others who are perhaps too specialised and rigid in their concepts. Moreover, he is very clear in his study of the "Kepler Case". He admits that physics has gradually been forced to give up its proud claim to be, in principle, able to understand the whole universe."

- Oh I like your fellow!" exclaims Florian with a big smile. "Finally an honest physicist and who puts his science where it belongs!"

- If you like! But I know pretentious biologists..." I intervene because it is prudent to bring back Axel's intervention to a more constructive way!: "But what did Pauli say about this new science capable of transcending physics to create a representation of the world adapted to recent discoveries?"

- He first observes that the unconscious psyche is largely a matter of objective reality."

- It's an extraordinarily important conclusion in the mouth of a physicist," I say.

- It is true. But he goes further: he finds that Jung's work: "suggests a unity underlying both psychic and physical processes" and considers that: "today the approach that recognises that we can reconcile the two parts of reality, the qualitative and the quantitative, the physical and the psychic, and which is able to understand them as a whole, is the only acceptable one."<sup>2</sup>

- He did not let himself be sterilised by the purely functional interpretations of physics, but he sought a deeper understanding of his discoveries: he did as you did, Axel. Moreover, he clearly wanted physics to recover the unity it has abandoned since its birth when he concludes that the only acceptable way of research to understand reality must combine physics and psychic, quantitative to qualitative!

"And you, Florian, you do not have much to do with this universe empty of meaning in which many molecular biologists evolve... In reality you are more ecologist than biochemist and by the globalising approach of the life you discover the importance of the links between species and their environment. When you describe the way of life of a species in its context, we cannot help but find meaning in this immense web of life that is the biosphere: each individual finds itself endowed with a role, a function... which participates in the life of the whole, and I bet you do not endorse the disillusioned conclusions of Monod."

- It is true. The more we learn, the more we discover that life is a global and interactive phenomenon. Each species, each individual itself, plays its role in order for the whole to function and perpetuate itself harmoniously. A biologist even suggested that: "life is an ecological phenomenon that only becomes individualised for fleeting moments!" But where do you fit, Matt?"

- Oh, it's been three decades that I discovered the Yi-Jing and that's the reason for my reaction lately! You were so sure to discover something perfectly unexpected: something that had required a lot of effort to deviate your view from your current beliefs, to ask yourself if there was something fundamental to discover elsewhere! I did not experience this difficulty. History makes me explore exotic cultures with an objective eye. And of course no historian can ignore the Yi-Jing, the fundamental basis of Chinese culture: the oldest that survives

today... Older than the Jewish culture! The Chinese may have created the most pragmatic culture ever! And if they continue to interrogate the Yi-Jing for more than 3000 years, it is surely because it is useful to them!"

- Perhaps because they are fragile, anxious and seek help to decide their fate?" suggests Florian.

- I never perceived the Chinese as fragile beings! The Romans questioned their haruspices: and I do not see them as fragile either! I have another interpretation: we have with China a civilisation that has not completely forgotten its Neolithic roots and Yi-Jing probably finds its source in the visions of the world of our ancestors to all, all cultures together."

- How can you say such a thing?"

- By practicing comparative history, supplemented by the discoveries of ethnologists. I will come back to this question later if it interests you. But as an historian I am trying to understand the evolution of civilisations. Their technologies interest me less than the meaning they give to their place in the world. And I am convinced that the Chinese have not cut the thread that connects them to their ancestors and links humanity to the entire cosmos. Look at the respect they still give to their ancestors today: this is a culture that does not really have gods, which obeys no pope ... but who venerates his ancestors statued on their small home altars. With the Yi-Jing they built a tool that allows them to blend into the movement, to decide without anxiety because in harmony with the times."

- And you do like them?"

- It's been more than thirty years since I benefited from their heritage with Yi-Jing. It has not stopped giving me answers perfectly suited to my questions, beyond any possible coincidence. Jung is not alone when he discovers the relevance of the old book's answers! What Axel discovered and stunned him, has not surprised me for ages. Or rather, I am still very impressed by the phenomenon but I am used to receiving appropriate answers to my questions. Who would not be, when we discover that we can dialogue with our soul!"

## E.11 : SOUL OR SPIRIT?

Florian looks at me with an air of dismay: "The soul?"

Axel agrees: "Yes, why do you involve the soul here?"

- When the Yi-Jing returns you a sensible answer, with whom do you think you're talking? Not with a pile of paper, of course. Not with any condescending god who would manipulate the muscles of your hands to draw the features that answer your question! It seems to me that the simplest model involves your soul in the process."

- But what is it for you? What are the evidences or clues that make you think you have one?"

- I see! It is true that there is a lot of confusion about terms and concepts. I did not find it useful to do an exhaustive study of the points of view of the various and varied cultures and of all the philosophies that have examined the subject. But I had to find a model that could explain how such an oracle could work!

"The first step is to remember how the phenomena that seem to us today perfectly understandable and controllable with the formulas of the physicist, may have seemed magical to our ancestors. Florian! Imagine that you are a brave Neolithic savage remained safe from our western culture... for example before 1950... "

- Is it a composition role?" Florian worries about the meaning of my request!

- Of course! Look! You are hunting in your favourite wooded Savannah, and all of a sudden, an entirely unknown roar comes from the sky. You lift your head and discover an immense object that looks perfectly solid and that you had never seen before. It flies without any noticeable effort. Only this great noise signals its presence. It shines in the sun and eventually disappears, and the noise with it."

- A plane then?"

- You have no way of understanding how it can fly! Don't you think you'll be tempted to give it some kind of supernatural power that keeps it in the air?"

- Probably."

- While a physicist can perfectly demonstrate to you why the air flowing on both sides of the profile of the wing creates a lift which supports the weight of the craft. By analogy, we could hypothesise that we still have phenomena to discover that are so far removed from our current concepts that they may seem supernatural, magical today."

- Let's admit... but I point out to you that you can buy any argument with this kind of hypothesis..."

- Okay. But it has the merit of relativising our certainties and keeping our minds open!"

- Ok, so what?"

- The second step is to ask ourselves how do we perceive the world, where exactly does the information come to us? Reflecting on it, I was tempted to classify the sources of our perceptions in two families. The first brings together our five senses and nourishes our spirit."

- How do you define it?"

- This is a confusing concept, perhaps as a result of Anglo-Saxon influences? Spirit... spiritualism! It comes from the United States through Great Britain and very clearly involves immaterial ectoplasms. In English "spirit" seems to me to describe a supernatural entity whereas "soul" rather evokes the intimate essence of a living human. I take as a clue the famous S.O.S which means "Save our souls" and that implores a help to stay alive!

"I suggest to define the mind as the result of the functioning of our physical brain, of our mind if you prefer."

- You reassure me... and the soul?"

- A moment! We agree that our mind is material: it receives the perceptions of our physical senses, sorts them, analyses them, associates them, compares them to what is memorised, uses neural networks that can be built on genetic bases or from our own personal history. This spirit is subject to the natural laws of biochemistry: it is disrupted by alcohol or drugs, decreased by cerebral accidents or subject to age, senility. The brain secretes the mind as the liver secretes bile!"

- I follow you!"

- Well. But the liver does not just secrete bile... and I'm sure our brain can access transpersonal information through unconscious processes that we do not control by nature!"

- And what evidence can you give?"

- I believe that it is reasoned conviction rather than objective proof since it relies mainly on personal experiences and the meaning they have had for me. But I find the equivalent in others, through their own testimonies and that's why I'm tempted to generalise my feeling."

- How do you want to be followed if you remain evasive and personal?"

- It is difficult to share feelings when one is deeply persuaded to have perceived information through mysterious channels. But refer to the anecdotes told by Jung and Pauli. They clearly had access to perceptions from their subconscious, personal or collective! Jung even narrates premonitory or visionary dreams that he was able to confirm, <sup>1</sup> a bit like Swedenborg saw the Stockholm fire while he was in Göteborg, hundreds of miles away, or that Dunne perceived in his premonitory dream the fire of a factory... I'm not alone in this kind of experience!"

Axel intervenes: "I see where you are heading to ... Do you think that the collective unconscious discovered by Jung and experienced by Pauli, is rather what you would call our "soul" rather than our "spirit"?"

- It certainly is not so simple! I am convinced that at least a good deal of what is unconscious is part of the mind. No! I postulate that our soul is the part of ourselves that has access to perceptions that do not involve our five senses. In particular, it has access, through routes that remain mysterious today, to information that transcends our concepts of space and time. Swedenborg perceived two realities at once, the one in Stockholm that was burning and the one in Göteborg where he was at the same time. And all the premonitory experiences force us to admit that time is not limited to the concept that we have it most often."

- And how would we access perceptions that do not pass through our physical senses? From what I understood from the collective unconscious, we would inherit some of them with our genetic inheritance, from hereditary neuronal modules that would colour our physical perceptions in the same way for all humans..."

- Yes, but that is obviously not enough to explain everything one can perceive! Both Jung, Pauli and others have concluded that we have the means to transcend time and space, and this cannot come through the mind as it was defined just now."

Axel has been entrenched in meditative behaviour for a while. Everything has frozen in him: his features have subsided but he has kept his tic: from time to time one of his eyebrows contracts suddenly and disappears under the frames of his glasses... But here he comes suddenly out of his hypnagogic state: "It's interesting what you are talking about. It should be considered more seriously to see if there is a way to exploit your suggestion and especially to demonstrate it experimentally. Besides, it is not very different from that of Heisenberg! He was convinced of the reality of a central order, and he thought that our soul represented the part of this central order that everyone bears: the concretisation of the central order in a given individual. And he had felt reality through his scientific research but also by a kind of mystical intuition that he experienced when he was young.<sup>2</sup> Your suggestion does not seem totally ludicrous to me... "

- Thank you !"

- No, that's not what I meant!" says Axel smiling. "You give me the opportunity to make interesting associations that I would like to deepen. Here's one: remember the Multiverse. This interpretation of the results of quantum physics postulates a multitude of parallel universes to avoid the concept of collapse of the wave function at the time of measurement. One imagines that whenever a choice is possible, the universe splits into so many parallel universes that there are probabilities of finding a given result."

- I really do not understand how you can take this model seriously," protests Florian.

- It is because it is the interpretation of quantum physics that is the most economical in new concepts. And that's why a majority of physicists prefer it to others, in keeping with Occam's razor principle."

"Who is this bearded guy?" I say.

"It was a theologian," laughs Axel. "But he lived in the Middle Ages and I do not know if he was a bearded man! The virtual razor of Guillaume d'Occam served to decide in favour of the hypothesis which, while being the simplest, was able to explain the most observations at once. And the Multiverse model satisfies this criterion. For example, rather than imagining that a photon is both a wave and a particle according to the means of investigation that we choose to analyse it, the Multiverse makes it possible to interpret the interferences as amplitudes of existence, that is, a measure of the number of different parallel universes in which the clones of the particle we measure are."

- I do not follow you anymore!"

- Remember the Young Slots experience we did at the School of Physics. If you pass a ray of light through a slot you get a single bright spot, but if you open a second slot within 0.2 mm next to the first, then you discover a series of bright spots interspersed with dark spots."

- I remember. We concluded that adding light creates shade and we interpreted this as evidence that light was a wave. We cannot easily imagine how two grains of light that add up can produce shade while it is easy to observe waves that destroy each other when they are in phase opposition." Florian seems to recite his lesson!

- Right! Well, the Multiverse does not involve waves but only photons in their particle form. But it explains the interferences by imagining that when we open a second slot, we allow ghost photons, coming from parallel universes, to prevent the photons of our universe from reaching the target at the places where we observe shadow. David Deutsch even calculates something like  $10^{12}$  ghost photons unobservable in our universe but that can interfere with each tangible photon and prevent it from reaching certain parts of the target."<sup>13</sup>

- And for you ghost photons are easier to accept than wave photons?"

- Yes, because it is a model that saves new postulates and makes it possible to interpret the experimental results in the most direct way."

Florian does not seem persuaded but does not answer. Axel continues: "If parallel universes can interfere with ours, we should be able to somehow get information from them! This is what drove Feynman and Deutsch on the path of quantum computers."

- How do they function?"

- Oh, they are only in their infancy. But the experiments are encouraging and it even seems that their theoretical realisation can be considered as established. Moreover, if they work as expected, this would be a great argument for the reality of parallel universes!"

- Why?"

- Because they would allow us to carry out calculations in parallel in a multitude of universes and to recover the results almost instantaneously in ours! But that's not my interest tonight in these experiments. What interests me is an analogy that we could make to try to understand the functioning of the mind and its extension to what Matt calls the soul!"

- Explain yourself !"

- Assume that you exist in a multitude of parallel universes. You are here with your mind, of course. Suppose your mind can do like photons, interfere from one universe to another! We would thus have a kind of quantum computer in the brain, able to obtain information from parallel universes, that is to say, which transcend common space and time... And this is the postulate of Matt. In a way the soul would be to mind what the quantum computer is to the conventional computer!"

- Hold on, where are we going?" complains Florian. "Come to your senses! We started from tangible results and you train me in a metaphysics that is more magic than science!"

- We're not training you anywhere," Axel stops. "Obviously, Matt and I have been exploring areas that are still foreign to you but belong to you. Only you can decide to explore them since the trip involves the meaning you would find in the adventure. Whether it is a premonition, a perception that transcends space or time, whether synchronicity... you alone can feel the merits or not of your experiences. Keep your mind critical, but use it as Pauli used it... Be a scientist and beware of "playing" the scientist!"

Florian does not answer: he looks embarrassed. He ends up turning to me: "Well, I want to try to think about it calmly. Your arguments are interesting, but it is also true that they lead to perspectives that make you dizzy!

"In the meantime ... If you told us how a historian came to question an old Chinese oracle, I knew physicists were fool, but I imagined so far that historians were more lucid! What led you towards these experiences? "

## E.12 : FROM LASCAUX TO YI-JING

- Physicists seek to put the universe into formulas, biologists wish to describe life from the most intimate processes, molecular, to its ultimate expression, the biosphere... More modestly, I try to understand mankind, our nature that leads us to create societies and then to lead them throughout a history."

- You're kidding!" answers Florian "Man is probably the most complex thing to understand in the universe!"

- It is true. But I do not have your ambition: I just come up with parallels, common denominators between different cultures and their development in the form of visions of the world, social structures... imagining that these analogies tell me about some facets of our nature."

- And this method led you to connect the Yi Jing to the Neolithic?

- Yes. I have no solid proof since we are in prehistory. But there are significant analogies between cultures far apart from one another and which I interpret as the signatures of a common heritage."

- Do you have examples?"

- Of course! The shamanic vision of the world is one. Mircea Eliade proposed as early as 1960 that it was universal, that its fundamental concepts were found everywhere, in all primitive cultures, so that it certainly constituted an inheritance bequeathed by our ancestors to all."<sup>1</sup>

Axel interrupts me: "Do you think the alchemists would be the heirs of the shamans?"

- As for the Western alchemists who interested Pauli, I do not know. This is an interesting hypothesis. On the other hand, Taoist alchemists are clearly related to shamanism. It is really in China that we discover best this long chain that binds us to our ancestors: it is the only culture that has not cut this link, while maintaining a written archive that is among the oldest."

- But what do you mean by shamanic vision of the world?" asks Florian.

- I prefer not to develop this concept now: it would take us too far. Suffice it to say that all primitive cultures are animist. They differentiate the natural from the supernatural but they give a soul to all living species, plant or animal and even to inert objects. One can imagine that for the neolithic, the aurochs, the deer or the horse had souls that the shaman could perceive, with whom he could communicate to negotiate the result of a hunt or the healing of a sick person. But the mountains, the streams... also had souls. A prehistoric as an alchemist would have had no difficulty to imagine a kind of psychophysical language that would allow him to enter into relationship with the material and the soul of objects.

- Hold on! Am I hallucinating? You're giving a soul to the chair in which you're sitting?" Exclaims Florian ironically.

- It's not about me but about the worldview that prehistoric men probably shared with current shamanic cultures. To tell the truth they would rather use the word "spirit" than "soul". But for the reasons I described earlier, I prefer to keep the term "mind" to describe the result of mental processes and to retain the word "soul" to mean a hypothetical property that would connect all objects of the universe so that they can share information without going through the perceptive channels we know today. My chair clearly has no mind: it has no soul either because it is unable to perceive anything!"

"But you said just now that a mountain or stream could have a soul!"

- The animists believe it... Perhaps they mean that these important objects in their environment crystallise a perception they share between themselves and these inert objects?"

Axel comes to my aid with a smile: "I think we are quite unable to decide whether or not your chair can have a soul so long as no one can provide a consensual definition of a soul!" But I remind you that in the microcosm particles participate through quantum entanglement to information sharing that is still waiting for an understandable explanation!"

Florian looks exacerbated: "Decidedly no, I cannot follow you on this ground, let's go back to the hypothetical Neolithic cosmogony. It is on the basis of the geographical distribution of shamanism that you build it?"

- This is important because it links cultures that have been separated for a very long time. Shamanism exists, for example, among Amerindians, Bushmen of South Africa and

Aborigines of Australia. These are three cultures that have not been in contact for 40 to 60,000 years and yet share the same vision of the world. But that's not the only argument. These cultures also share similar customs and can even enlighten us on the vision of the world that had the artists of Lascaux! In recent years a shamanic interpretation of European prehistoric sanctuaries has been constructed from a comparative analysis of the paintings and symbols found in caves with those of San culture in South Africa."<sup>2</sup>

- So what?"

- These discoveries pushed me to look for complementary analogies and I found them in the divinatory rituals precisely."

- But an analogy is not a sufficient argument," Axel reminds us! "All peoples probably use some sort of astrology but that does not prove that they have a common origin: the spectacle of the celestial vault just explain this parallel!"

- I agree with that. But your argument cannot explain why Arab geomancers or bushmen use symbols common to those of Yi Jing!"

- What symbols?"

- The Chinese oracle is based on six traits each of which can take one of four possible forms. Two are female, two male and in each group, one is youthful and stable, the other adult and changing. The divination ritual of all ethnic groups in South Africa uses four plates decorated with symbols and notches that vary according to their origin. But they all symbolise equivalent images: either a girl, a mature woman, a young man or a senior! We find the same bases from which the Yi Jing readings are calculated! There are sixteen possible configurations and each has a name, like each of sixty-four hexagrams.<sup>3</sup>

"In Arab culture there is also a divinatory ritual based on even or odd numbers, similar to Chinese yin and yang, which consists of drawing sixteen lines of traces on the sand and then counting them to determine the parity of each of them, then we must study their hierarchy in a manner reminiscent of the six traits of Chinese hexagrams! There is a very kinship that binds these oracular techniques, kinship which seems to go back to a kind of forgotten numerology but of which archaeological evidence has been found in China."

- Hold on! How are you sure that what you take for an original and significant kinship is not simply the result of transfer of techniques accompanying migrations or commercial contacts between these cultures?"

- I thought about it. But then it would be necessary for these techniques to spread everywhere from China, because that is where we find the oldest evidence of these oracular techniques. And even if it were the case, it would be necessary to accept that they are particularly effective since used for so long! In either case it becomes interesting to try to understand how they work and to test them. That's what I did !"

- What tracks are you talking about?"

- Bone... mountains of oracular bones discovered in China a little more than a century ago."

## E.13 : TURTLES AND IDEOGRAMS

Florian frowns: "Oracular bones?"

- Yes, gathered in archives almost 3500 years ago. They have only recently been discovered despite their age: archeology is a very young science in China! Before Mao, the Chinese did not find any use in archaeological excavations because they respected and lived their traditions since always and did not need to find them while trying to reconstruct the past. They had not lost the image of the world that links them to the ancestors and their philosophy; they still worship them on their small domestic altars, possibly supplemented by some famous figure of the Chinese past. Fortunately, a large flood of the Yellow River has cleared a whole cliff that covered a prehistoric site of prime importance: a sort of bronze age library of oracles carved on turtle shells, a good hundred thousand of shells!"

- Gosh, but they have exterminated the species!" exclaims Florian.

- It seems so, and maybe that's what forced them to find another support, and the Yi-Jing was born!"

- But why have chosen shells of unfortunate turtles?" wonders Axel.

- Oh, there are several possible reasons! First it is an animal that can be offered as a sacrifice without much effort to catch it and which is not expensive; but it is not only that! In China the turtle symbolises the whole universe: the carapace is the celestial vault which overhangs the Earth represented by the square ventral breastplate. The latter lends itself very well to ancestral oracular techniques whose traces are found everywhere, even in Greece."

- The Greeks also sacrificed turtles?"

- I do not think so. But we found calcined flat bones, goat shoulder blades in Delphi for example, which was a high place of divination already before the construction of the temple and then for many centuries."

- What is the link with turtles?"

- The calcination! The ancients must have noticed that an offering propelled to the sky by fire seemed to respond to the gift by signs left on the calcined bones. And the intuitive reading of these traces made it possible to know if the sacrifice had been accepted, if the future would be favourable. The Chinese are very practical and to simplify the reading of the oracle, they learned to prepare the turtle breastplates, clean them, polish... probably to restrict the types of cracks possible. They even invented a kind of standardised protocol that consists of applying a white-hot punch on a specific spot, always the same, to compare the slots on different shells and start to build a kind of reference dictionary to translate the qualities of the moment.<sup>1</sup> "

- A sort of generalised weather forecast?" asks Axel smiling.

- If you like! They tested the environment by sacrificing a cheap turtle to ask the gods if the conditions were favourable enough that it would be worth sacrificing the most beautiful beast of the flock..."

- But it's a terrible blasphemy!" exclaims Florian, laughing. "These are men wondering if their gods deserve a sacrifice or not! I would never have dared to do that if I had been religious!"

- It's a bit like that, except that it was probably no longer gods but local spirits, themselves quickly replaced by the reading of a kind of global climate, the result of myriad interactions at the origin of cycles that can be deciphered through the signs they leave. The notion of "creative God" is foreign to the Chinese mentality. Creation arises from interactions between objects, events and minds.

"I remind you that we are still in the Neolithic era: we are dealing with hunter-gatherers whose existence is based on their ability to read the tracks, translate any clue that would lead the hunt to a favourable outcome. Their shamans were probably in a trance to discover the game and negotiate the result of the hunt with their tutelary spirits; they are probably the ones who learned to read the spirit of the time through the cracks of calcined bones, and their pragmatism allowed them to invent the oracular technique that would evolve in the Yi-Jing."

- How so?" asks Axel.

- By engraving on the turtle shell the question asked, the date, the name of the supplicant and the interpretation of the answer in return. Then by archiving the carapaces to control a posteriori the relevance of the interpretation and perhaps benefit from it to modify the grid of reading of the cracks and to refine the following readings..."

- But you describe a real experimental protocol!" wonders Florian. "If that were true, then why did not the Chinese invent the science long before us?"

- It's a big mystery, all the more enigmatic that their technology has been much more evolved than ours! An American biochemist has spent his whole life trying to answer this question... which remains open!<sup>2</sup>

"It seems that a set of factors has failed them, starting with the creation of mathematical and geometric techniques that we have benefited from Greek civilisation. Science is not only experimental, of course. In the beginning it is the daughter of the mathematisation of the world. The scientific method is born from the cult of reason associated with the creative genius of individuals born by chance in the West and who have explored the mathematics of the world and reductionism. But the Chinese have never really been reductionist: they are rather globalising, synthetic, even in their writing system. They tend to favour global intuition rather than reductive analysis. This intuition cannot be of the same rationality as linear analytical vision such as the one that predominates here.

"Moreover, mathematics and the experimental method have benefited from a religion that favours the idea of natural law since it is itself based on divine laws."

- How do you explain their technological prowess?" asks Axel.

- Perhaps by their holistic approach precisely! They had no trouble inventing the compass although the magnetic field is invisible, everywhere present and we do not perceive a cause that can move the needle! Action at a distance does not pose a conceptual problem for them because they live in an organic world, where everything is linked to everything according to a hierarchy and cyclical interactions that one has to learn to read!"

"Okay with the compass," Axel replies. "Besides, Newton was very annoyed by his discovery of gravitation, precisely because he could not explain how distant objects could interact. But for the other technological discoveries, how did they do?"

- Their pragmatism has certainly allowed many explorations freed from any *a priori* theory. The Chinese Taoists - the local alchemists - were wary of theorists and seem to have

favoured measurement and experimentation. This is probably how they invented the powder, through observation and alchemical experience... The Greeks favoured rational analysis instead. It is of course very effective when it is based on quality observations. But it can mislead to false conclusions if the premises are of poor quality."

- All that does not seem convincing to me," remarks Florian. "But back to our carapaces: how did they give birth to Yi-Jing?"

- Surely through a series of successive steps from a period before the carapaces, a time during which the divination probably used a forgotten numerology but whose traces remain on the carapaces and in the Yi-Jing, as well as in the African cultures of which I have already spoken to you. In China it is four figures: the 6, 7, 8 and 9. They symbolically represented specific ideas: they are found engraved on the carapaces, next to the cracks they seem to translate into oracles. Today they are still used to calculate the features of the Yi-Jing hexagrams. The even numbers - the 6th and the 8th - have a rather feminine connotation - yin - and the odd numbers - the 7th and the 9th - are yang. The 6 and the 9 represent active, evolutive situations, as opposed to 7 and 8 which symbolise more stable atmospheres. The Chinese diviners have probably applied their numerology to translate typical cracks, then the numbers allowed to classify them, to archive them to find easily and compare the results to the forecasts. The oracular interpretation was to arise from the juxtaposition of these figures as it relies today on the juxtaposition of the features that form the hexagram."

- And how to turn encrypted cracks into hexagram?" asks Axel.

- If we study the legends, we can imagine that, turtles becoming rare, shamans have found a way to classify the carapaces used for divinations so that they can find the one whose cracks corresponded to the answer that they would have found if they had sacrificed a new beast. They had to discover or postulate that all situations could be satisfactorily described by a finite number of oracular combinations. It only remained for them to devise a technique which indicated to them the place occupied by the appropriate carapace in their archives: that which answered the question asked. And the method chosen may have been inspired by ancestral numerological techniques that used yarrow sticks to determine oracular numbers. The hexagram that we know today goes back to this time: it combines six traits, each of which can take the appearance of one of the four figures chosen by neolithic shamans, which gives sixty-four possible combinations."

"You mean that there are only sixty-four possible situations to describe everything that can happen on Earth!" Florian smiles, "not much more than the signs of the zodiac that are supposed to represent all the humans characters!"

- No, it's more complicated than that," intervenes Axel. "But it is true that they have found a way to describe a finite number of situations that is of the order of a few thousand, to describe what we think to be an infinite collection of potential situations!"

- It's ridiculous!" Florian replies, "How do you describe the richness of the world with so little information?"

- And yet the Chinese are happy for millennia!" remarks Axel.

I intervene in my turn because the moment has come to recall the origin of all this discussion: "And we saw that they were not the only ones since Jung, Pauli and so many others were very impressed by the old oracle!"

- And what brought you to explore the Yi-Jing" asks Florian after a moment of silence.

- It's a long story, which begins with the discovery of the charm of ideograms. The oldest of them are precisely engraved on the turtle shells. By discovering them, we are witnessing the birth of an entire writing from signs and symbols that connect us to our Neolithic roots!

"There are many older writings: Sumerian cuneiforms, for example, but only Chinese writing evokes images and ideas, directly from the drawing of ideograms: it is not abstract as all the other alphabets are; it does not only speak to reason but it also involves the image."

- But this is the case of Egyptian hieroglyphs!" Axel remarks.

- In part only because a hieroglyph represents a sound whereas an ideogram is a whole word or even a concept, an idea. The ideogram evokes an emotion while conveying a meaning. This is sometimes the case of hieroglyphs, when they are chosen to represent the image as well as the sound that is appropriate. But that's not the rule.

"An ideogram can represent a gesture, a movement, an object... The symbol of the arrow planted in the middle of its target is the image of what is perfect... the right gesture. The silhouette of a man who is walking, the drawing of a hole in which he is stuck... awaken emotions as much as they transmit information. The ideograms still reflect today the feelings that their creators wanted to express by signs. They are much richer than abstract alphabets that evoke nothing *a priori* and that stimulate only rational analysis; the possible emotions depend on the meaning of words and sentences, their juxtaposition, their meaning learned and not felt, instinctively. It is very moving to find the evidence of the origin of a writing, and these testimonies are oracular shells, that's why I was interested in turtle carapaces."

"But that does not teach me why you've been using it as an oracle for so long!" asks Florian .

- If you plunge into the text of the Yi-Jing, you are naturally led to discover it in the manner of the ancient! It can be read as a normal book but it is not made for that and you discover it quickly. You are led to question it to actually enter the book. And if you are not restricted in your freedom of mind by preconceived concepts, if you keep an authenticity and an open attitude to the experience, then there is every chance that it will captivate you as it has interested many other researchers! Because it really answers your questions!

"Florian you should try yourself, since you are the only one of us who has no experience with it!"

- What I will try to do is to find my mind! It is terribly late and I wonder if we are not all in a dream! I would like to resume all that with a clear head if you agree!"

- I understand," Axel adds, "I too would like to think about what I'm discovering today."

I stand up just after Florian: "So let's conclude here for the moment, the time that Florian buys a Yi-Jing and make some readings," I say with a smile as a deeply perplexed Florian reacts with a great gesture of the hand that seems to describe a wait-and-see attitude!

Axel accompanies us to the steps: "My evening was more interesting than expected! I thought I was revealing important events and now I discover myself others, quite interesting! I wish you a good night and... very interesting readings!" he adds, smiling.

## E.14 : , DEAR READER

« *Doubting is fruitful, provided you know how to doubt your doubt.* »

Didier Norton.

Here you are again before a moment of truth: an invitation to interrupt your reading to discover for yourself a tool that made Jung say: "*Whoever has experienced like me the happiness of experiencing the divinatory power of the Yi-Jing [...] cannot fail to see in the long run that we touch there a point of Archimedes from which our attitude of Western mind can be taken out of its hinges*"<sup>1</sup>. And Jung's terms are not exaggerated! Discovering the Yi-Jing is a real shock, followed by a feeling of intense happiness; perhaps the sign of the restoration of a subtle and mysterious link that binds us to the world, through a part of ourselves, too long ignored.

It is very easy to question the Yi-Jing: on the other hand, the interpretation is enriched with experience. A single requirement... a profound intellectual honesty to look over the glasses coloured by the paradigms of the day; which allows us to think for ourselves, freed from the tutelages tied by a culture, a philosophy, a religion lived superficially rather than deeply understood and accepted. An honesty capable of supplanting our prejudices to approach the Yi-Jing with the humility it arouses when our freedom of mind reveals to us the immense universe that remains to be discovered; our knowledge of the nature of time and space being so rudimentary!

It is then that we can experience the immense happiness of blending with our Self or our soul which becomes a meaningful interlocutor, in search of integrative harmony, another source of deep satisfaction. The Yi-Jing opens channels of communication between the conscious and an entire unconscious world. It becomes a kind of bridge on which the self walks towards the discovery of the Self and the soul. It becomes a kind of tool to refocus our centre of gravity towards balance by moving it away from the self to bring it closer to the Self.

But this requires personal commitment and a lot of courage to overcome the formidable barriers created by several centuries of total worship of reason, of contemptuous rejection of a whole part of ourselves, of repression of all our thoughts, ideas, feelings that would not immediately be understandable by reason alone. This castration obliterates a good part of our humanity, perhaps the most lovable, to exploit only reason. Of course it is specific and precious to us! But it separates us from the rest of the world and can be very dangerous and dry our hearts.

Reason: object of our pride, itself our strength and our weakness at the same time! Our strength when it convinces us that the whole universe is understandable to us, that we only need to satisfy our curiosity by exploring it to be able to exploit it. But our weakness also when, out of habit, we forget an important source of our creativity because we cannot explain it in a rational way! This is the case with intuition and dreams that some interpret as mere waste of the work of the mind since for them, what we do not rationally understand is most often uninteresting by nature!

Remembering dreams is a matter of genuine will. The approach to the extraordinary tool of communication with our soul that Chinese civilisation has developed over thousands of years

is similar: the old oracle only becomes comprehensible through the eyes of innocence, which allows our deep intuition to be expressed, which should not be confused with a type of faith that is widespread within the framework of religion.

Indeed the approach here is not blind, but experimental! It is not a question of being "believer" and proud to extinguish to the last suspicion of personal interpretation, of blending totally into the thought, at best, revealed, at worst, dictated by a charismatic and unscrupulous guru. This type of believer sacrifices his critical mind and his faculties of personal analysis to let himself be carried away by an all-powerful faith that manages everything in his place. For him, man's wealth is this faith blind to any distraction that would take his attention away, even for a moment, from the object of his enlightenment and the forgetting of himself. For the humanist scientist, it's the opposite! He is proud to analyse, to understand, to control his emotional impulses in order to channel them between the dikes of reason. He analyses what he perceives of the physical world and the psyche to become as responsible as possible for his actions and ideas. For him, it is rational thought that makes man.

Can we imagine a synthesis of these two such contradictory attitudes? Perhaps, taking Saint Thomas as a model! By not accepting anything that is not perceived as the object of a deep conviction, by remaining critical and vigilant about the criteria of personal conviction. It goes without saying that everything that is rational can easily raise the deep conviction of its reality and can be classified, according to the importance it is given, in the organisation of knowledge to enable people to forge their own image of the world. But you have to be careful of your classification criteria!

This does not mean that we should reject what is intuitive. It is enough to apply to it the safeguards that the scientific method has built so well: personal experimentation that leads to a reasoned conviction of the reality of the phenomenon studied and that allows it to be part of the image of the world that we create for ourselves. We must be careful not to fall into the trap that has opened up with the rapid evolution of science and technology, which consists in believing without experimenting, since specialisation increases with the evolution of the complexity of knowledge and makes the strict application of the scientific method illusory. It may come as a surprise to learn that in Algeria, the hardest fundamentalist fanatics are recruited from the faculties of science! But, on reflection, we understand why students of literature are more hesitant to adopt a behaviour that is as radical as it is irrational, as they are used to the critical analysis of texts and ideas, whereas in science it sometimes happens to learn formulas by heart without really understanding how others explain a phenomenon and draw a natural law from it that is often considered inappropriate to question! Paradoxically, it is modern science, misunderstood, that seems to create the most dogmatic individuals!

We would have to go back to the origins of the scientific method; to the moment when everyone could reasonably convince himself of the validity of a knowledge by making the appropriate personal observations or experiences, or by carefully analysing those described by someone else, in the light of a powerful critical and analytical mind.

How can we solve the problem of complexity that leads to specialisation and then to the danger of blind faith in what the specialist says? Part of the answer is of course to mobilise all the communication resources we can, but additional help may be needed to build sufficient personal conviction. And this help could come from a means of acquiring irrational knowledge today but which will perhaps join tomorrow the catalogue of methods whose functioning is well understood: synchronicity.

The modern path of physics, which has been linked to that of philosophy for almost a century, opens up new perspectives that Pauli's untimely death may not have allowed us to explore sufficiently, perspectives that could have an impact on questions of theoretical science, on psychology, or on interactions with the physical or social world...

Pauli, with the lights acquired in Jung's work, had experienced for himself the reality of archetypes and the interest of the concept of the collective unconscious. He even drew from it the subject of an important study for the philosophy of science concerning Kepler's working method in the seventeenth century. Kepler, who had resolutely turned away from alchemists and their symbols, to focus only on concrete physical matter as a source of well-mastered knowledge. Kepler, one of the founding fathers of the method so effective that today it shades others.

The time has come to do as Pauli did, to abandon the blinders of preconceived ideas and get a Yi-Jing! There are many translations and adaptations: the easiest for a discovery is perhaps Wilhelm's <sup>2</sup> who impressed Jung and Pauli.

Then comes the time for the first reading! It may be wise to prepare it by reading Jung's preface to the English edition of Wilhelm's work, especially to discover that chance is perhaps something much different from what we imagine, to discover the Chinese vision of the world, more likely than ours to accept synchronicities when they emerge, to realise with Jung that *"modern physics is succeeding in the enterprise where Kant failed with his "Critique of Pure Reason". The axioms of causality are shaken to their foundations. "You will remember with him that: "The microphysical event includes the observer just as the reality underlying the Yi-Jing includes the subjective, that is, psychological, conditions in the entire situation of the moment". And you will ask yourself like him: "Why not try a dialogue with an old book that declares itself animated? There can be no harm in this, and the reader can thus observe a psychological procedure that has been used from age to age throughout the millennia of Chinese civilisation, representing for a Confucius and a Lao Tzu both a supreme expression of spiritual authority and a philosophical enigma."* And perhaps you will have the happiness of discovering like Jung that: *"This strange fact, that a meaningful productive reaction arises from a technique that apparently excludes all meaning from the beginning is the great glory title of the Yi-Jing", that: "The prediction obtained[...] is so reasonable and so full of common sense that it would be hard to imagine a more accurate answer".* <sup>3</sup>

In preparing his preface to the English edition, Jung asked the Yi-Jing how to present it to the Western reader. The response shocked the psychiatrist: the old oracle defined itself as a tool for expressing unconscious elements so that they could play their role in the life of each individual. It is therefore the path of individuation, of self-accomplishment par excellence! And if that were true, the effort to discover it would be an invaluable investment!

At this stage you must choose the reading ritual that suits you best. For different reasons, Axel and I first experimented with the classical technique using chopsticks. It allowed Axel to control the reticence of his reason because it wraps the intervention of chance in a long and complicated ritual that predisposes, like any ritual, to establish a link between the known and the unknown, the natural and what is less known... or not yet. You will find in note 4 a brief introduction to this ritual because Wilhelm described it in a very obscure way, as if he was still very reluctant to involve chance in such a serious matter!

Once the channels of communication between the conscious and the unconscious have been opened, the transmission of information adjusts itself to the change in language; it

becomes possible to explore tools other than the Yi-Jing, perhaps more appropriate to our culture.

Without reading the ideograms it is impossible to draw on the richness of the old book as much as a Chinese person who has access not to abstract symbols but to images that transmit concepts as well as precise information and that can arouse emotions directly, by the very aspect of the image, whereas to arouse an emotion in the reader of English, it is necessary to make him pass into an imaginary world in which he visualises what the author wanted to transmit and that he cannot see directly in the book. The Yi-Jing is a kind of comic strip for the Chinese, which transmits both information and emotions, while in translation we lose the part that allows it to be in direct contact with the emotions of the reader, the part of his mind that is perhaps the closest to his soul; a great loss! <sup>5</sup>

But Western culture is not to be outdone on Chinese civilisation! It also has its channels of communication between the conscious and unconscious: for example, the Tarot cards loaded with symbols capable of stimulating archetypes. Perhaps, as our civilisation has given too much priority to abstract and restrictive communication through the precision sought, the Tarot pushes the pendulum a little too far in the opposite direction by not proposing any text to accompany the images! The arcana have only their name in their texts and some even sacrifice this last frontier between accuracy and personal interpretation: the XIII arcane of the Tarot de Marseille is thus the "nameless arcane"!

Nothing prevents the explorer of the soul from using the language appropriate to his own personality as well as to circumstances and questions. Sometimes the images of the Tarot, sometimes the text of the Yi-Jing and, why not, sometimes the complementarity of the two: the abstract and exotic dryness of one, compensated and completed by the illustrated and emotionally charged richness of the other. But to be productive, this method is necessarily based on the translator's work of the conscious reader and especially not on stereotypical interpretations of some magic guru! There is no dictionary that can translate the language of the soul other than yours: the one that your experience has dictated to you! Even the symbols of the collective unconscious - the archetypes - should be translated by everyone, in the light of their personality and their own history. It is at this price, which is essentially based on the authenticity of the approach, that the researcher will find the communication channels and will be able to make the most of them. Of course, the work of others is valuable! Freud demonstrated the existence and importance of an entire unconscious part of our personality. Jung and others have clarified certain aspects of it, have worked on the anatomy and physiology of the unconscious. But we must admit that much remains to be done if we compare our interest in intuition with that of cultures that have exploited it for thousands of years. It is true that their work is not at all of the same nature as ours, since it is based solely on personal intuition and does not benefit from the universality typical of the results acquired by reason and the scientific method, which is itself a source of rapid progress induced by the pooling and objective exploitation of each other's results. But this success is at the cost of limitations in the field in which the scientific method is able to produce results.

Zen monks use koan <sup>6</sup> to force the disciple to abandon rational analysis and replace it with intuition alone. But analysis should contribute to the discovery of the world in collaboration with intuition! Why not put in place a strategy that uses the qualities of all our abilities? Why reject rational analysis in the East and intuition in the West? Is it not better to allow intuition to create a situation rich in promises of new understanding, outside the beaten track,

conventions, dogmas, habits... dust covering the eyes, then to analyse it in the light of reason? Placing analysis just behind imagination would benefit our creativity.

Jung has seen the danger of sacrificing our culture by believing that the use of oriental techniques alone would allow us to catch up. He shows that it is up to us to create our own method, which takes into account and benefits from our history, our discoveries and our originality: a method that perhaps brings together reason, intuition and emotion, "*work that will remain our lot*" according to Jung who proposes not to disown the intellect to imitate the East lamentably, but rather to raise other psychological functions to its level !

Once the process of communicating with your soul is well underway, you may see evidence of the potential for acquiring information far beyond what our senses allow us to acquire. As we descend to the deepest part of ourselves in search of our soul, through the communication channel of the unconscious, we paradoxically discover that our individual personality expands, a little as if we were travelling through an inverted funnel, to encompass an increasingly vast universe as we plunge into the unconscious! The boundaries dissolve gently until the individual gradually melts into the universe with the help of his soul!

The testimonies of "journeys out of the body" could be of any other nature than a transfer of an animated part of ourselves through space and time! These could be perceptions of parts of our soul that are so far removed from the individuality circumscribed by our senses that we do not consciously perceive it. The path of dreams to the unconscious is a royal path for our culture which needs to momentarily extinguish our rational mind to access the unconscious and then the soul. The oracle is a more direct path towards the same objective: it leads the researcher to experience and live his entire personality, the one that goes so far beyond the borders that we most often give it, especially in Western civilisations.

## E.15 : ABOUT INTUITION

The austere architecture of the School of Physics is softened by the ochre-orange light of this late afternoon. It's autumn. On the stairs leading to Axel's office, I am suddenly overwhelmed by the feeling of an end of cycle. The adventure began here a long time ago, on a Saturday morning in May. But intuitively I feel that the loop is not really closed; rather, I feel like I have travelled along a spiral that comes back over a known region but discovers it from a new, more global perspective while offering a promise of evolution.

I see Axel who has left his door open; his head barely protrudes from his traditional bouquet of fresh flowers, at the edge of his desk. Today it is large white orchids with purple hearts that bring a touch of poetry to this rather functional room.

"Thank you for moving," he says to me looking over his glasses. "I have too much work right now to leave the School but I wanted to see you soon. Here, sit down while I make you some coffee!"

"I'm interested in what you said the other night at my house and I'd like to explore your ideas about intuition with you."

- About the Yi-Jing?"

- No. Or rather yes, too! But it's mostly about the intuition itself that I'd like your opinion."

- I see. Moreover, consulting the Yi-Jing or any other method of clairvoyance involves intuition first; rational analysis only occurs after the fact... when it occurs!"

- I retained that you defined at least two types of intuitions: the simplest to describe would be the result of a work of the mind in a level lower than consciousness but based on information perceived classically by our nervous system and with working methods that we could qualify as rational if we had access to it through consciousness."

- I imagine that it is indeed the most economical and direct solution to explain the flashes of creative genius that history offers us. We have probably all personally checked how much a night's sleep or a few days' holiday can help us solve a recalcitrant problem. The classic image of lightning is a good illustration of this phenomenon. It is not a step-by-step analysis but the result of a process that seems to us to be synthetic, global."

- Yes. We have many examples in science. I mentioned Kékulé's dream, but there are many others. Fred Hoyle, for example. This astrophysicist was one of the first to understand how a star works. He told how the solution to a problem that had been bothering him for a long time suddenly appeared to him while he was stepping on a bus! He was struck, not only by the dazzling nature of the idea, but also by this kind of global vision, of instantaneous understanding so deep that he had no need to take notes so as not to forget it. He was able to go quietly to the congress, give his lecture and then write a whole analytical demonstration at home in the evening.

"Einstein also seems to have suddenly understood the essence of Relativity. He woke up one night with a finished painting in mind: intuition also seems to have taken advantage of his sleep to paint it.

- There are also many examples among artists! Coleridge dreamt a long poem before writing it, as if it had been dictated to him!"

- It seems that inspiration - that's what we're talking about - inspiration is fostered by relaxation, by letting go of our ability to analyse rationally. In science, Heisenberg tells how his thoughts came to life suddenly while he was on holiday so that he was able to build new concepts of quantum mechanics in the process. It was on holiday in a mountain chalet that Schrödinger, accompanied by a beautiful girlfriend, created one of the most famous equations in physics..."

- Wasn't intellectual relaxation enough for him?"

- I guess not," Axel says with a smile. "You see there are very pleasant ways to do physics! But let's get back to the inspiration. We cannot exclude that the sequential analysis is indeed at the origin of the solution but that it remained unconscious until the mind found the result."

- Of course: we will probably never be able to prove it because the process is involuntary and deeply buried below conscious analysis."

- But you were also referring to another kind of intuition that would involve information obtained through channels other than our senses."

- Yes. But I am not aware of any work that could assure us of their origin. Jung thought that the archetypes were embedded in us, genetically in a way, to develop in our unconscious without going through our senses."

- What is the connection between an archetype and intuition?"

- The archetype triggers a sudden and global understanding of a situation: these are the characteristics of an intuition."

- I see."

- Do these archetypes have a genetic basis? There are certainly no genes for archetypes, of course. But we can make an analogy with instinct. However, we know that instinctive behaviours have a genetic basis and, in the same way that a signal from the environment triggers automatic behaviour in an animal, we can imagine that a given situation awakens in our mind an instinctive mechanism that would lead us to understand it with an insight inherited from our history, through our genes."

- You're too vague!"

- Then let's start again! It is well established that instincts have a genetic basis."

- In our species?"

- It is not possible to prove it in our species but everything leads us to believe it: laughter, tears... seem to be good candidates... But in animals that are suitable for experimentation, it has been discovered that hybrids of subspecies recognisable by different behaviours have inherited intermediate reactions when compared to their parents: instinct does have a genetic basis.

"In our species the subject is very controversial, but it seems that some types of personalities share a genetic component and are not only shaped by the individual's history. This is the case for risk taste, for example <sup>1</sup>. It is not impossible to have inherited with our chromosomes certain genes that trigger emotions typical of a given situation. An emotion would arise somewhere, instinctively, in our deep brain, far from our consciousness. This emotion will influence the way we perceive our environment, a bit like a stained glass window colours and gives shape to the light that passes through it: this is a situation that reminds us of the Jungian archetypes!"

- And why should they be part of our heritage, these genes that trigger emotions?"

- Perhaps because our ancestors who expressed them were at an advantage over others. They were probably better adapted to the situations they were experiencing, so evolution selected them."

- I have a hard time seeing why an archetype would be an adaptive advantage!"

- Everything remains to be discovered! But imagine that an archetype allows you to understand a complex situation in a global and fast way without having to analyse it laboriously with your logic-deductive device.... This would be a kind of instinctive intelligence of the world, an intelligence that benefits the individual because it allows him to react more quickly and appropriately to a characteristic situation.

"Imagine, for example, that a young Cro-Magnon starts to make mistakes out of inexperience. If he receives advice from an adult and a Cro-Magnon's teenage crisis is of the same nature as ours, he may not listen to him and put his life, and his descendants, in danger. But if his genes trigger in him the archetype of the father or the old wise man and lead him to respect the advice of the adult, perhaps he will take the opportunity to enrich his experience, improve his life expectancy, that of his descendants and his genes, at the same time."

- You sound like Florian!"

- He taught me evolution! It's his hobby!"
- And you explored the evolution of archetypes?"
- No, but we talked about human evolution... and in a rather original way... on the edge of the scabrous!"
- No kidding?" Axel asks smiling, "Tell me!"
- Ask him to explain how our species diverged from chimpanzees and you'll see!"
- I will not fail to do so. For now your point of view on the adaptive evolution of archetypes seems very vague to me, but let's admit... Intuition could thus be the result of an unconscious work of the mind based on information delivered by our senses and emotions triggered by these perceptions. And these emotions would be, at least in part, the result of the expression of our genome in characteristic situations."
- I'd see something like that quite clearly."
- But it seems to me that you were also suggesting the existence of an even more mysterious intuition, which involved what you called the soul, and not just the mind. I had derived a hypothesis based on the Multivers model..."
- Of course! How could you understand the relevance of the Yi-Jing's answers without access to information through channels other than our senses?"
- I don't know! I explained to you how disturbing this experience of the Yi-Jing has been to me, precisely because it challenges some of my deepest convictions!"
- I had a longer experience with this text than you did: it tamed me in a way! At first, like you, I was amazed by the feeling that you could talk to a book! Over time, a more natural relationship has developed: it has led me to explore a little bit the new perspectives that are needed when we have finished questioning our own faculties of discernment to fully recognise the reality of the lived experience."
- I know what you mean."
- Only your lived experience will allow you to know what kind of relationship you can have with your intuition, through the Yi-Jing."
- That's exactly the question I'm asking you. How do you connect intuition to Yi-Jing? What do the Chinese say about that?"
- I don't know if they're talking about intuition. Rather, they invoke a kind of discernment that allows them to feel the air of the times in a way, through the reading of the Yi-Jing, and to draw lessons from it to adapt as harmoniously as possible."
- I don't see any creative intuition there, only the possible discovery of a given situation!"
- You forget the random manipulations that allow you to draw the right hexagram: there is indeed creation of information without you being able to invoke your will or your reason. Your muscles have done what it takes to pull the appropriate hexagram, so that you have access to the text of a hexagram that, although it is perfectly unknown to you, answers your question so well that you have difficulty believing it!"
- You're assuming a causal link that would link my muscle movements to the result of the reading? "

- It can't be that simple! Moreover, Jung analyses it clearly as synchronicity and, consequently, the link between the question and the drawn hexagram is not causal but passes through the meaning that its reading awakens in you."

- So this brings us back to the problem of chance: synchronicity, quantum mechanics, genetic mutations and evolution... always this mysterious chance!"

- Unless, in the case of the Yi-Jing at least, it would not really be a matter of chance but of synchronicity and that it depends on a new type of logic that remains to be defined. I have no idea what is behind this phenomenon, of course. But if we have to find a link that creates meaning from events that seem random and perfectly independent to us, such as randomly drawing a hexagram, the question asked and the answer provided, I can only admit the approach described by Jung and Pauli who construct the concept of synchronicity to give a defined framework to the phenomenon, a necessary prerequisite for studying it. But half a century later, we are still there. We are trying to find a conceptual framework in which we could study synchronicity in a productive way, but have not yet succeeded!"

- This brings us back to our discussion the other night, when you introduced us to your conception of the soul."

- Yes, we must admit that our mind is not enough to explain how we can draw an unknown hexagram that perfectly answers the problem we are concerned about. I am led to evoke a source of knowledge that clearly exceeds me and which seems to me to deserve this name, insofar as it connects me in a mysterious way to a universe much broader than my own individuality and which, although incomprehensible, remains concrete for me thanks to the experience I have lived."

- You are talking with your soul in a way, through Yi-Jing interposed; and this discussion involves what you call your intuition. Is that some kind of common language between you and your soul?"

- That's it!"

- I see... Or rather, to be honest, I understand better what you mean, but I don't see how I can connect these hypotheses in any concrete way to the physics and biology that we know today, except perhaps by seriously exploring the links that might exist between consciousness and the Multiverse. Everything still has to be done, as you often say," Axel adds mockingly.

- But you will admit that these hypotheses are not much crazier than the ones you presented to us to explain modern relativistic and quantum physics!"

- I agree with that. We have been sensing for a few years a new world described by physics and so different from what our senses teach us that it is beyond our imagination! I will not say that everything becomes possible, but it is certain that we will have to seek a new model of the world with a much more open mind than we imagined earlier! We will have to question very deep convictions in order to one day arrive at a model of reality that would allow us to explain our past observations, the behaviour of matter at the microscopic level and above all to understand it and not only to describe it as we do today."

- You have taken an important and courageous step by deciding to question fundamental questions about interpreting quantum mechanics experiments in the light of your personal history. I think this is the only possible approach for anyone who is curious about the world. Some forge keys that open doors for us. But no one but ourselves can really cross them for us: only the experience we have lived can satisfy us in this area."

- In which everything remains to be discovered... I know! I propose to think about the means available with Florian as a safeguard," Axel adds with a smile. "He excels in this role! But what would you think if we continued this discussion by walking along the Arve? I've been sitting here all day and I'd like to move a little."

- It's perfect for me. But to get back to Florian, you deeply disturbed him, no matter what he says to make fun of you," I say as I get up.

- It reminds me of colleagues who use theories when they work and leave them in the closet on the way home," Axel adds as he walks past me towards the office door.

- Oh no! That's not his style at all! Your impression probably comes from the fact that he has not found a way to build a global and coherent world view. But I'm sure he's working on it."

- In secret then?"

- Maybe! Until the day his pride allows him to admit that he cannot understand - and he does not yet want to accept this - or until the day he finds a revolutionary concept that solves our problems!"

- Florian and pride...," Axel sighs with a friendly smile and then closes the door behind us!

## E.16 : THE THREE PILLARS OF WISDOM

Happy symbiosis between nature and artifice, the trail runs along the right bank of the river and offers the walker a bit of savagery, interspersed here and there by scraps of landscaped gardens: pocket gardens. Some toddlers play their role as juveniles very seriously by exploring wooden horses or other slides and climbing nets arranged for them on a small square with rubbery ground. To see them suspend with delight it becomes difficult to doubt still our relationship with primates! Two dogs sniffle while at the other end of the leash their owners seem to take advantage to get to know each other. On the dirt trail, at the extreme edge of the water, is the dark silhouette of a fisherman who seems to join his home, his paraphernalia and shoulder bag loaded.

Axel breaks the silence: "Again about intuition: what do you think about its usefulness for research in general? You reproached us for not mentioning it officially in the scientific publications among the premises of the researches described, like a trigger and guide of the work presented. However, its importance is unofficially acknowledged, and it seems that one of Einstein's main qualities was a kind of faith in his intuition!"

- Warning! You're venturing on a minefield talking about faith," I say mockingly!

- Do not make me more royalist than the king! Einstein has never hidden a kind of intuitive faith in a principle of order and harmony, of beauty... Principles on which he has always relied to build his theories. He really believed in the elegance of the world, in the subtlety of its creator, the "Old Man" as he sometimes called him!

"But this faith is a sort of profound spirituality and not at all an extrovert religion, which seeks rather to weld a community around its identity culture rather than to promote the personal fulfilment of each of its members: their "individuation"! And no one was more

independent of spirit than Einstein! Religion is extroverted to amalgamate individuals in rituals that dissolve their personality. In the worst case it goes so far as to prohibit heterodox individual reflection, in favour of the power of a few, the only ones able to interpret texts and situations in all orthodoxy! And Einstein hated that one thinks for him!"

"As you do, don't you?" I say, smiling.

- We can say that!" Axel responds in a quieter tone.

- The independence of mind that you describe makes me think of another genius, but in the field of arts! Leonardo da Vinci could not stand that one thinks for him and he was an immense creator, like Einstein, actually!"

- Would they have common qualities that would be at the origin of their creative genius? Would independence of spirit be part of it?"

- Perhaps! You mentioned the intuition that Einstein used in symbiosis with his science: I could tell you about the science of Leonardo that underpinned his artistic work!"

- And their genius would be based on this alliance between rational mind and intuition? It's interesting!"

- I think there is a third indispensable factor: emotion."

- What do you mean ?"

- The engine, the energy that is the basis of their prodigious power of work and creation... the deep drive that protects their concentration, which brings them back on the road for a lifetime! An eternal youthful curiosity that leads them to ask questions that an adult would tend to describe as stupid because contrary to common sense, and yet rich in creative explorations on ways still virgin. And this great independence of spirit which is the signature of a personality well realised, autonomous. A curious association between juvenile and adult qualities. I would tend to associate reason, intuition and emotion in the pursuit of wisdom: three pillars on which a method of understanding the world should be built."

- Einstein has always recognised the importance of intuition in his research: he even regretted that our society does not recognise it as a mysterious but primordial gift, to retain only the work of reason!"

"The West has promoted reason to the forefront of the faculties necessary to understand the world. It got rid of the intuition it rejected in the dustbin of history. But reason is not enough and exerts a despotism that made Jung say that it became the new god to whom everything is sacrificed! He thought that *"our true religion is a monotheism of the conscience"*, that *"we have no more god because we adore only the conscience!"*<sup>1</sup>. He added that, by profession, he was regularly confronted with the damage caused by a rational civilisation pushed to the extreme to the detriment of certain facets of our humanity, such as instinct, intuition and sometimes even feeling."

- And the geniuses creators would be able precisely to avoid the extremes, to marry harmoniously reason, intuition and emotion...

"The portrait seems convincing to Einstein, the archetype of rational genius, the symbol of irreproachable mathematical intelligence, but he has always used his reason to verify, to elaborate, what his intuition offered him, without ever to deny it, on the contrary! And this attitude has even earned him a sort of rejection of the community of physicists toward the end of his life. *"God does not play dice"*: his intuition prevented him from accepting that chance

was irremediably embedded in the formulas of quantum mechanics, it was absolutely necessary to give up all hope of eliminating probabilities in order to one day understand the behaviour of matter, which he refused until his last breath, guided by his intuition!

"Too bad Aspect's experiments could not have been made during Einstein's lifetime: I wonder if he could have continued to follow his intuition to refuse Bohr's interpretation."

- I would think he would not have abandoned his point of view: he would have found a way to broaden his perspective to encompass the new results."

- Maybe you're right !"

- We discover somewhat the same form of character in Leonardo, but inverted, a bit like a mirror since his official profession is artistic intuition and emotion while his formidable rational work, scientific, comes before, in preparation of the ground where will express, then, emotion and intuition. He goes so far as to dissect corpses secretly to discover the finest details of our anatomy! His notebooks have nothing to envy to the records of modern observations, on the contrary: we find the art and more! The smallest bone of the smallest phalanx is carefully reproduced, with remarkable dexterity and art!

"His research led him to synthesise art and science, to build prodigious automatons for the time, musical instruments with new sounds... He was consulted for hydraulic projects, studies of fortifications and much more ... And this prodigious effervescence is always powered with vitality, humanity: never dry but always alive because it relies as well on intuition, emotion as on reason."

"Was he as independent of spirit as Einstein?"

- Oh yes! And it was even counterproductive, sometimes, in that he created new techniques better adapted to his way of working, but without the necessary hindsight to ensure long-term results. He sometimes painted under inspiration only a few brushstrokes, before abandoning the painting in anticipation of a new inspired period. His sponsors had to wait years before he wanted to decide that the work was finished! It has happened to him never to succeed to finish a work! You think that in these conditions, the fresco technique could not suit him because it is necessary to finish painting before the plaster has finished solidifying! He invented a personal method that allowed him to return to the work, long after the coating. But it was a disaster: the paint began to flake already before he could finish it! In this case at least, his independence of mind and his intuition did not allow him to succeed."

- But this is a technical problem related to his method of work, not really the result of independence of mind," comments Axel.

- It is true. But he quickly showed a great originality while the painting was subject to the canons of the time. It was religious, hieratic, rigid... The hairstyles were to be ordered, the attitudes, conventional... Leonardo advocates to paint man as he is and not as we think he should be! He places his model in the breeze to free his hair. He studies movement to transmit its sketch, the spirit, more than inevitably immobilised action in the static work. He dissects the anatomy, the emotions, to paint the fugitive expressions rich of humanity, the smiles thought rather than expressed. The expression of the Virgin who looks at her son is human, affectionate, moved: she is not sad and severe in the control of her emotions as it was recommended to paint her... From his apprenticeship Léonardo distanced himself from the conventions, to the point that one recognises his claw in the paintings of workshop painted by his master and the apprentices, classmates of Leonardo."

"They are very similar, Einstein and Leonardo. But is it reasonable today to give free rein to emotions and intuitions? Is it not to avoid fanaticism and obscurantism that Western civilisation has promoted reason to the place of honour?"

- It is true. But did not we throw the pendulum too far? The renewal of obscurantism and fanaticism are they not symptoms? The adoration of reason has blinded us! Does not it make us less human by denigrating much of what makes exactly our humanity: creative intuition, life-giving emotion?"

- But the emotion is dangerous: often a whole life is not enough to learn to control it... Intuition can lead to maladjustment to realities, if not madness, in the worst case! "

- Then we would have to master it but without stifling it! Three centuries of critical thinking should be enough as a safety net!

## E.17 : ABOUT THE SCIENTIFIC METHOD

Our walk led us under the Junction Bridge. It is very dark: the water reflects a little of its light in flickering reflections on the pillars and the stone vault. The noise of cars on the bridge deck makes us deaf, while we open on the other side of the structure. From here on, the city gradually dilutes itself into nature. On both banks of the river, the forest-gallery emancipates itself and conquers the entire hill of La Bâtie. The blue-grey water of the Arve, inherited from the icy water that gave birth to it in the nearby Alps, will soon melt into the deep emerald green of the Rhône, a few hundred metres from here; and nature powerfully emancipates itself as soon as man releases a little bit the hold that ties it up.

Seagulls have joined the ducks on the river and accentuate the feeling of freedom that increases as we leave the city. The path narrows; no more traces of landscaped gardens. The natural balance is gradually being rebuilt.

After a moment of silence I answer Axel's question: "You are right to be concerned, of course. But I wonder if we have not finally reached a period in our history that would allow us to fulfil ourselves entirely without sacrificing one part of our nature for the benefit of another. We could imagine ways to preserve the advantages of each of the three pillars of wisdom, without suffering the disadvantages."

- It would take a very improbable amount of wisdom to assign to each of the three pillars the place they should have in establishing and applying hierarchies, to avoid emotion overwhelming reason, for example!"

- Of course! But three centuries of training in the scientific method, the discovery of its extraordinary performances, the recognition of its limits too, could ensure that reason has the place it deserves best, just after creative intuition, in Einstein's way."

- So you reject Leonardo's method?"

- You're right, I am wrong to prioritise the contribution of reason and intuition: we should work with all our characteristics at once, even if it means favouring one or the other at certain times.

"Leonardo first left emotion and reason to clear the path... this is how he prepared the ground in which his creative intuition would allow him to accomplish himself entirely. There are probably more benefits to intuition when it inherits rich, diversified, well assimilated, elaborated knowledge. This is evident when intuition is the result of cascading associations unconsciously made from memorised facts and events. In this case, intuition would intervene to propose the relevance of one association among others, an association that could not be made without the objects that support it, of course!"

- And emotion would be the driving force, the energy that would lead to reflection... But how can we avoid overflows, loss of control, sort of religious wars? "

- Again, the relationship to our history should help us to set safeguards. One of them would be a better knowledge of ourselves, our nature and our evolution. We could then build an environment that would be better suited to us.

"It is not a question of promoting naive neo-Rousseauism, of seeking to recover our nice deep nature! But it becomes obvious that violence is developing all the more so as anxiety and frustration overwhelm the Cro-Magnon that we have remained and are confronted with ultra-technological and overcrowded megacities for which he is absolutely maladjusted!"

- Aren't we a particularly dangerous species for others and for ourselves: a kind of killer monkey?"

- Our intelligence makes us more dangerous than other species, but Florian has convinced me that our violence is sometimes the result of an environment for which we are not at all adapted because it does not correspond to our primordial nature."

- Maybe, but it's utopian to believe that we could return to our original caves!"

- But it's not what he imagines, on the contrary! Florian does not see us regressing but rather progressing towards a more evolved way of life that takes into account our discoveries in animal and human ethology. And now I understand it completely!

"He begins by recognising that aggression is a perfectly natural phenomenon, even indispensable: delimiting a territory, appropriating a spouse, maintaining a hierarchy... Each species has developed essential aggressive behaviours, but most often ritualised, to keep only the benefits without the dangers."

- Aggressiveness would be natural: but violence then?"

- Violence would be a perversion of aggressiveness, a dangerous behaviour for individuals and species, but that evolution could not have sanctioned because the conditions that triggered the diversion of natural aggressiveness did not occur often enough or because we are no longer as subject to natural selection as species without culture."

- Yet the story is full of violence and I doubt very much that Cro-Magnon was a tender one!"

- He must not have been very bloody since he survived thousands of years in the company of Neanderthal without us having the slightest hint of violence between the two races. They probably lived in good harmony, each according to their own way of life, without violence but with ritualised behaviours."

- But Neanderthal has disappeared!"

- Not without leaving some hybrids with Cro-Magnon; again an indication of good understanding rather than violence! They had to express natural behaviour and defend their territory without endangering their lives. A bit like two male doves that would measure themselves by cooing without violence, until they were locked in an artificial environment, a cage. And then the symbol of peace turns into a horror of violence! Unable to express the behaviours of submission, appeasement, flight, the defeated will be scarred to death!"

- And what would be the characteristics of the environment in which we would become lambs again?

- I'll leave it to the ethologists to answer you! But I am convinced that if we admit the interest of a better knowledge of our deep nature, we could evolve towards a greater tolerance towards ourselves and others."

- I don't see the connection you make between an environment and tolerance."

- Analyse the causes of racism, for example. It could be born from a behaviour that is important for a deeply social species that has perverted itself! "

- What do you mean, isn't it the other way around? Why would a fundamentally social species have racist tendencies?"

- Evolution has surely endowed us with a whole set of behaviours to promote the life of small hunter-gatherer tribes. Our ancestors probably nomadised over a vast territory to ensure the subsistence of a few dozen individuals, a few hundred at most. And this territory had to be defended against the neighbouring tribes. It was a case of life and death! It was vital to immediately recognise a member of one's own tribe and to differentiate them from foreigners. And since the general appearance of our species is very similar, our ancestors had to cling to every visible detail to differentiate groups, whether physical or cultural."

- You mean we'd be racist by instinct?"

- That's quite possible! And again, this behaviour made sense when it was necessary to defend a territory against foreign tribes with the help of other members of one's own tribe, whom one had to recognise without error. It was well adapted for Cro-Magnon but it is no longer adapted at all today since agriculture and technology allow us to live in huge communities in which it is impossible to know everyone anyway! We had to invent flags and patriotic anthems to recognise us!"

- So what to do!"

- We should recognise that our genes are still Cro-Magnon genes and that they have a responsibility to adapt us to an environment that is no longer his. We would have to accept our deep nature to adapt it to our new way of life. Reason and an emotion, empathy, should be used to fight against racist instinct, which could be intuitive. We must not hide our faces and refuse to acknowledge any racist feelings, but understand that they could be part of our instincts to eliminate them through our reason! And it will be all the easier if we know and accept our deep similarity, regardless of our geographical origin! It is in this sense that I plead for a better knowledge of ourselves and our history, which is essential to lead us towards greater tolerance.

"Racism is not really based on genetic races! Racists focus on the expression of a few genes whose result is easily perceived, while 99.9% of genes are identical even if we analyse the genome of populations separated from an entire hemisphere! And when there is no way to

find a physical difference - which is the most common case - then racism becomes cultural. The best proof of this is anti-Semitism, which includes physical types as different as Ashkenazi and Sephardic! A long history in two different environments, obvious occult hybridisations, has led to a strong divergence in physical appearance between the two groups: one is as blond as the other is tanned and yet racists associate them in their rejection!"

- I see! You should add a fourth pillar to your stool of wisdom: tolerance," Axel adds with a smile!

- An immense tolerance to ensure a future for our species!"

- I'm not as optimistic as you are. Tolerance is insufficient... too passive. It would also require unfailing respect and genuine curiosity for other cultures: the conviction that they can all enrich us in one way or another... to avoid the disappearance of this heritage. It's a difficult task!"

## E.18 : WHERE ARE WE ?

It has not escaped you that these chronicles plead for a freedom of mind, the rejection of guardianship that all kinds of powers would seek to impose. Is it not one of the human specificities that the construction of an autonomous personality, from a reasoned assimilation of ideas and discoveries of others, throughout a long history? Is it not one of the human specificities that the use of reason and its corollary, the critical spirit, to forge an image of the world and, eventually, to implement it to create an environment and a community in harmony?

Are we witnessing the last incarceration of a civilisation that is coming to the end of its adolescent crisis after experiencing episodes of personal power of individuals, communities or cultures with its share of submissions to guardianship of all kinds? Perhaps we will soon have to turn a page in our cultural history. On the back of the last page we would find the infallibility of an individual or the unrestricted admiration of specialists' opinions even when they venture beyond their skills or the full and uncritical acceptance of opinions. famous or charismatic personalities.

The new chapter would deal with regional cultures confronting globalisation, at a time when no religion, of course, can rally all cultures. It would deal with tolerance, to avoid violence related to the refusal of the right of the other to his own point of view. It would safeguard our respective cultural riches. Perhaps it will describe the emergence of a globalised culture that gives pride to philosophy, from the soil accumulated over the centuries by the discoveries and specificities of each. On the new page of our story, perhaps everyone will be able to write their own image of the world without blindly following those who would like, for one reason or another, to force us to share theirs. Perhaps it will describe how we have been part of the world, body and soul, since its creation; how everything connects us to it, although we have very quickly developed our specific characteristics.

The two million years that separate us from Australopithecus have been sufficient to create an ecological niche so original that we attribute qualitatively different characteristics to those of other species. Conversely, it would appear that we can not be entirely human alone, without the help of other humans: even bipedalism would not seem to be acquired without the learning

that binds us closely to others. Likewise, the essential substrate for cultures - speech - is inherently derived from interactions with others. And the culture itself is a sharing, a set of interactions that build the personalities of each one from its own qualities and those of the group.

Perhaps he will describe the discovery of keys that would allow us to build a new image of the world and our interactions with it; an image that would allow everyone to draw their personal framework and to create an energy of individuation; an image that would be built rather than inherited as it is, without personal analysis.

Today I understand Axel's attitude the night he phoned Florian and me. He was shocked by an impressive discovery: he had found the link between the natural - a book - and the supernatural - his soul - through a synchronicity, that is to say a step that gives meaning to events!

The path that Axel took us to Florian and I revealed to us a world quite strange, perhaps even unknowable! The one that Florian described to Axel and I is also extremely rich and surprises us by the perspectives it opens on our relationship with the world. All three of us are stunned by the accumulation of recent fundamental discoveries.

Indeed, we are all convinced, *a priori*, to understand the nature of Time, at least empirically if not intellectually! No thinker has been fully satisfied with the result of his reflections after seriously considering this research. One feels that it flows inexorably, always in the same direction, at the same speed, and that it drives the universe in its movement without origin or end. And yet Einstein had the genius to shake this conventional certainty from common sense: Time is elastic and is not universal! It seems consistent when we look at our history and relationships to the world. But it is not the same for everyone. It is so little that even realism does not come out unscathed: what is simultaneous for one is not necessarily for the other...!

The door opened by Einstein reveals amazing perspectives but they require an abandonment of preconceived ideas. And if Time was an illusion due to our inability to perceive it from a higher perspective, an illusion linked to our limited perception unable to represent it in its true nature? Einstein has shown that Time is inseparable from Space and that they both constitute a continuum in a fourth dimension that physics allows us to apprehend, to verify their existence, but that our senses do not allow us to perceive from a perspective that would reveal it to us in its true nature. We are a bit like an intelligent ant who, while walking on the surface of a large sphere, is able by its experiences to know that its girlfriend is somewhere beyond its horizon, behind the curvature of its world, and that it could possibly be seen both at the same time provided to propel a camera above the sphere and high enough to neglect the curvature of the horizon. Perhaps the equivalent of this camera exists for us and the organiser of our dreams sometimes uses it to choose mental images from the future as well as the past to illustrate his dreamlike creations. None of us knows how or why he is able to do it, but even today Florian is intimately convinced of having experienced it himself. He admits that Time is not what it seems at first sight. What is more exciting than exploring the new perspectives suggested by these discoveries? Perhaps those that derive from the true nature of Space!

Like Time, Space seems to us immutable, universal. It separates objects and allows them to exist independently of each other. As Time, it seems to us untouchable, unalterable, primordial ... But as Time, it is relative! And, just as it is possible to imagine transcending the perspective that sticks to Time, quantum physics shows us that it is possible to transcend

Space. Each object of the universe can be in contact with any other, whatever the distance that separates them, if they were once in interaction. Physicists have demonstrated it for more than two decades with correlated particles. But it seems that all the particles of the universe have been correlated at least once, at the time of the Big Bang! What is more surprising than exploring the possible consequences of such discoveries? Maybe exploring the nature of reality?

Our senses reveal real objects that exist outside of us and our consciousness. But quantum physics - again - tells us that if we exist, it is apparently because the particles that build us are in continual interaction with the rest of the universe. Decoherence stabilises the potentialities that alone seem to constitute the intimate framework of the world ... and ours at the same time! And decoherence is the result of interactions between the ultimate constituents of matter-energy: the object that seems concrete, real, is only because it interacts with other objects that, themselves... while not really separated from each other!

Astonishing perspective, which requires serious experimentation to be accepted. And it was this experience that Axel had the courage to undertake when he interviewed the Yi-Jing. He has placed himself in a perspective that transcends Time and Space that illusively separates the objects we perceive... in a perspective that even goes beyond the boundary between physics and the psyche! And his questions gave rise to coherent, meaningful answers... without it being possible to really analyse the ways in which these answers were born. Great humility and a strong critical mind are required to undertake this exploration.

A great humility to counter the pride of believing that the image of the world inherited from Descartes three centuries ago and now obvious... is the only one possible: perhaps it has become insufficient. Confining physics and psychics in two separate and sealed worlds may no longer be always relevant.

A strong spirit of critical analysis to avoid the trap of uncontrolled intuition. The ability to doubt the doubt itself without restricting creativity.

But what could be more exciting than to go in search of oneself, of one's intimate essence, of one's soul?

After his first experience with the Yi-Jing, Axel had intuitively understood that he was holding a tool in his hands to communicate with his unconscious. And physicists being what they are, I wouldn't be otherwise surprised if he would soon end up considering the natural history of the soul as a new chapter in physics!

## E.19 :THE ADVENTURE CONTINUES

We are back in front of the School of Physics; it is all dark now. Only the nearby Arve provides a little natural light, street lamps take over from the city side.

The adventure began here one spring morning. Does it end here on an autumn evening? I don't think so. It gave us keys: it is up to us to use them to try to open as many doors as possible. It is up to us to try to cross them in order to find out what they lead to. Winter is conducive to assimilation: perhaps next spring will be the right time to exploit these keys?

Florian is looking for a synthesis that would involve both the individual and the functioning and evolution of ecosystems to try to understand the living phenomenon from a new perspective. He is intrigued by the applications of the quantum model to the theory of evolution. He would like to explore the possible consequences of the mechanisms and laws of the microcosm on the living phenomenon. Perhaps entanglements, interactions, decoherence... also affect the underlying mechanisms of life and evolution in a way that would allow us to better understand them. Perhaps the mystery of emergence is partly based on these behaviours that are typical of the microcosm and so strange to the perceived world that we have great difficulty applying them in our research. Perhaps models based on an Implicate Order or a Multiverse could fertilise our research on the mechanisms of living organisms. Perhaps a-locality and a-temporality would provide useful hypotheses for understanding mechanisms related to evolution or ecology...

Axel would like to find a theoretical model that integrates the discoveries of quantum physics into an understandable image. He would also like to explore the paths opened by Jung and Pauli concerning the unification of the physical and psychological worlds. He takes up the work of David Bohm and Schrödinger who were also interested in this subject towards the end of their lives.

And I am interested in the new approach to the Yi-Jing that Axel's experiences have suggested to me. I had studied the old text as a historian and now physics invites me to explore it from a new perspective. I would also like to compare it to essentially rational Western philosophies when it is based on a rather intuitive approach. Is a synthesis possible?

The experiments that Axel presented to us and the interest of some physicists in studying the links between physics and the psyche open up new perspectives on synchronicity and individuation that Jung described. The Yi-Jing and other tools available to question our intuition are fabulous guides on the path of individuation in the sense of Jung.

Is the impulse towards individuation of a religious nature? The answer might be positive if it involved the collective unconscious and if it connected us to a world that significantly transcends that of ordinary consciousness.

To be religious would be to seek to connect with a current that links the natural to the supernatural, the concrete objective reality to another that transcends it and creates the world perceived by the senses. However, the psychoid archetypes described by Jung and which interested Pauli create the physical world on the one hand and our psychological emotions on the other hand; thus they participate in the transcendental reality that interests the religious. It is of course the mystical religion that dissolves the individual in this intuitively perceived transcendental reality. It is not about the recovery of this impulse by institutions or individuals interested in a gathering around a given culture. It is the individual's step towards the fulfilment of a deep need and not a commitment to a structure that decides for us what rituals are necessary to establish the relationship with the supernatural or, worse, who decides for us what is right and what is wrong. For the mystic, the good consists in following this impulse that melts him into the Whole, that guides his actions towards harmony with those of other individuals and the events of the perceptible world.

To experience synchronicity gives a very deep feeling: would it be religious? Perhaps because synchronicity plunges us into both the objective and subjective worlds and signifies our belonging to a Whole that connects them and creates meaning; synchronicity then becomes a reference point on the path of individuation.

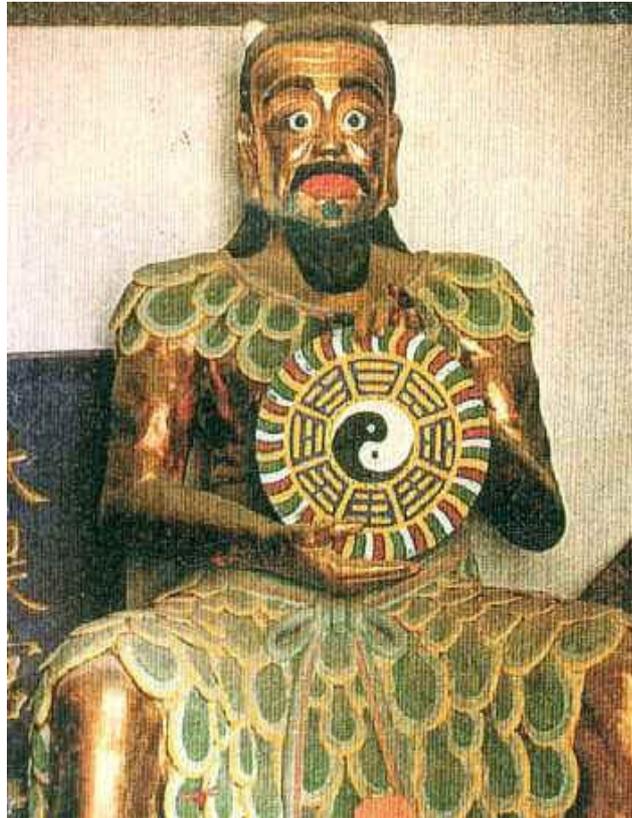
What about ecology and the feeling of belonging to the whole living world; is it a kind of mystical feeling? Perhaps it is because the individual represents himself in a more global context that generates meaning by actively participating in the maintenance of life and the balance of the entire ecological system.

The three lived experiences: the mystical link with the rest of the world through the Self, which encompasses the personal and collective conscious and unconscious, the synchronistic link between the objective world, the subjective reality and the mysterious psychoid reality that is at the origin of both, and finally, the ecological feeling of belonging to the living world, are all deeply satisfying. The discovery of our real dimension, much more important than its objective part alone, fills us with serenity.

A faded leaf twirls towards the ground. But the tree will regain its strength for next spring and the leaf will feed the life of the litter before its constituents find their way back to the roots of the tree that gave birth to it last spring.

Going in search of man by using all his potentialities, reason, intuition, emotions, will perhaps make it possible to go beyond the dichotomy that separates science from religion.

About Soul...



*Statue of Fu Xi, the mythical creator of hexagrams: temple of Tien Sui in the province of Gan Su.*

*For the Chinese, his garment covered with leaves symbolises the time of his life: the Neolithic. He presents his discovery: the eight founding trigrams of the Yi-Jing that allow our rational facet to rely on the mysterious creativity of our intuitive component.*

*Our ancestors were as intelligent as we are. Only their culture separates us: ours having had much more time than theirs to amplify and become more complex.*

*Perhaps we have been overwhelmed by its rational component, to the point of forgetting its intuitive roots, the sources of its creativity. Have we not reached a stage in our evolution that would allow us to synthesise the different components that build our specificity?*

Source : [http://www.regenerating-universe.org/Yin-Yang,\\_I-Ching\\_and\\_cosmology.htm](http://www.regenerating-universe.org/Yin-Yang,_I-Ching_and_cosmology.htm)

## NOTES AND REFERENCES

Some notes refer to the collaborative website ([www.olive-verte.ch](http://www.olive-verte.ch)) that was linked to this book. These are links to other sites that offer virtual experiments... or illustrated presentations, discussions... considered interesting.

This website has been replaced by a WordPress one which hosts the second volume: "SIMULISM. Are we Living in a Virtual Universe?"

<https://simulismblog.wordpress.com/simulism/>

## A: ABOUT TIME...

### A.10 :

**Note 1:** I was unable to get my hands on the original edition of Robertson's novel. But I found a painting comparing the Titan and the Titanic in a recent book by Erik Pigani: "Psy"; Ed. J'ai lu (2001). And I can't avoid sharing Axel's feeling! I'll leave you to judge!

	TITAN	TITANIC
Weight	70 000 tonnes	66 000 tonnes
Lenght	800 feet	882,5 feet
Propellers	3	3
Maximum speed	24-25 knots	24-25 knots
Capacity	3000 passengers	3000 passengers
Passengers on board	2000	2230
Lifeboats	24	20
Watertight partitions	19	15
Speed during the collision	25 knots	23 knots
Damage	To starboard	To starboard
Passagers disparus	About 1500	1491

**Note 2:** Dunne's book seems to have been very successful in its time. It was reprinted by C. Tart; "An Experiment with Time "Hampton Roads Pub. (2001).

**Note 3 :** There are a multitude of books - some written by Einstein himself - on the conceptual revolution introduced by the theory of Relativity. Here is a small selection:

- By Banesh Hoffmann ; « The strange story of the quantum »; Ed. Dover (1959); Éd. Belin (1985) or « Albert Einstein: Creator and Rebel »; Ed. Viking Adult (1972)

- By Thibault Damour ;« Si Einstein m'était conté » ; Ed. Le Cherche Midi (2005).

## **A.12 :**

**Note 1 :** It is the first book of Robert Monroe : « Journeys Out of the Body » ; Ed. Dolphin Book(1971)

Lucid dreams were studied in a laboratory at Stanford University by Stephen LaBerge ; « Lucid Dreams » ; Ed. Ballantine (1986).

**Note 2 :** There are also a multitude of books available. It is Patricia Garfield's ; « Creative Dreaming » Éd. Fareside (1974) ; who proposes the method described here.

## **B : ABOUT SPACE...**

### **B.1 :**

**Note 1 :**  $I = F^3 / (\exp(hT/T) - 1)$  with I = intensity of the emitted light, F its frequency, T the temperature of the emitting body and h = a constant. This equation gives results that reproduce the experimental measurements very well.

**Note 2 :**  $E = hF$  with E = light's energy, h a constant and F the frequency of light.

### **B.3 :**

**Note 1 :** It is possible to simulate this experience and discover the results as virtual photons accumulate on the screen. These simulations are available on the Internet.

### **B.7 :**

**Note 1 :** Published in « Albert Einstein ; Philosopher-Scientist » ; Ed. P.A. Schilpp ; The Library of Living Philosophers, Evanston (1949).

### **B.11 :**

**Note 1 :** The society's name is ID Quantique : it has an Internet site ([www.idquantique.com/](http://www.idquantique.com/) )

## **C : ABOUT MIND...**

### **C.1 :**

**Note 1 :** « Physics and Beyond: Encounters and Conversations. » Ed. Harper & Row. (1971) .

**Note 2 :** There are of course many physicists who, like Axel, are concerned about disseminating the discoveries of their discipline. Here is a list of documents that have been useful to me in following Axel as well as possible.

#### **Reference books on physics with a philosophical and humanistic connotation:**

Of course all the books for the general public by Hubert Reeves who knows how to combine science with art and philosophy.

« Nature loves to hide » by Shimon Malin ; Ed. Oxford University Press (2001). Explains quantum physics and attempts an interpretation that draws on Whitehead's philosophy. Clear.

« On Physics and Philosophy » ; Bernard d'Espagnat ; Ed. Princeton University Press (2006). It is much more about philosophy than physics, but it is written by one of the most creative physicists in quantum physics. « In Search of Reality » by the same scientist; Ed. Springer (1983). Clearer than the first.

« Physics and Beyond: Encounters and Conversations. » ; Werner Heisenberg ; Ed. Harper & Row. (1971). By one of the creators of the School of Copenhagen. « Physics and Philosophy » by the same author ; Éd. Penguin Books (1958).

« Entretiens sur la multitude du monde » ; Thibault Damour and Jean-Claude Carrière ; Éd. Odile Jacob (2002). With a presentation of the concept of Time and a model of the Multiverse.

#### **Books on the popularisation of physics:**

« Traité de physique à l'usage des profanes » ; Bernard Diu ; Éd. Odile Jacob (2000). Textbook that presents physics with the mathematical tool clarified enough for the layman to appreciate.

« The Elegant Universe » and « The Fabric of the Cosmos » by Brian Green ; Ed. Penguin Books ( 2008 et 2005). The emphasis is on cosmology, but the concepts of time and space are very clearly outlined.

« Six Easy Pieces » by Richard Feynmann ; Ed. Kindle;(2011). A particularly brilliant mind exposes physics with amazing images.

« Cosmic Blueprint » de Paul Davies ; (2004). Several other books by the same author cover more specific questions such as the nature of time... (" About time " Ed. Penguin Books (1996.)

#### **Books presenting quantum physics:**

« In search of Schrödinger's cat : Quantum physics and reality » by John Gribbin ; Ed. Corgi (1984).

« Where does the Weirdness go? » by David Lindley ; Ed. Vintage (1997). A journey through the new physics in search of an interpretation that holds up.

« The Strange Story of the Quantum » by Banesh Hoffmann ; Ed. Dover (1959).

« QED: The Strange Theory of Light and Matter » by Richard Feynmann ; Ed. Princeton Science Library (2014). Amazing and original lectures with a new and disconcerting interpretation of the results of quantum physics.

« Initiation à la physique quantique » by Valério Scarani ; Ed. Vuibert (2003). A series of lectures given as part of a philosophy course for high school students. Written by one of the members of the applied physics team at the Geneva School of Physics.

« The New Quantum Universe » by Tony Hey and Patrick Walters ; Ed. Cambridge University Press (2003). The authors are physicists who know CERN well; a walk through the history of the fundamental discoveries of quantum physics. Very well illustrated.

« Schrödinger's Rabbits: The Many Worlds of Quantum » by Colin Bruce ; (2004). A presentation of the Multivers and the results that support this interpretation.

#### **Books presenting Relativity:**

« La Relativité animée : comprendre Einstein en animant soi-même l'espace-temps » de Stephane Durand ; Éd. Belin Pour la Science ; (2003). Very original presentation of the theory with material that allows to approach the fourth dimension in an imaginative way.

« Si Einstein m'était conté » (op. cit.).

Biographical books with a presentation of physical theories:

« Albert Einstein: Creator and Rebel » ; Banesh Hoffmann ; Ed. Vicking(1972).

« Niels Bohr et la physique quantique » ; François Lurçat ; Éd. Seuil (2001).

« Ne dites pas à Dieu ce qu'il doit faire » ; François de Closet s; Éd. Seuil (2004).

#### **C2 :**

**Note 1 :** See for example : « Frames of Mind: The Theory of Multiple Intelligences » ; Howard Gardner ; (2011).

#### **C.7 :**

**Note 1 : In** « Law without Law » ; texts collected and published by par « University of Texas Center for Theoretical Physics » (1983).

#### **C.8 :**

**Note 1 :** Long after this conversation took place, Alain Aspect's team published the results of an experiment to verify Wheeler's predictions: it is: « Experimental Realization of Wheeler's Delayed-Choice Gedanken Experiment » ; Vincent Jacques et al. ; Science Vol. 315. n° 5814, pp. 966-968 (2007).

**Note 2 :** See for example : « Origin of Quantum-Mechanical Complementarity Probed by a "Which-Way" Experiment in an Atom Interferometer » ; Dürr, S., Nonn, T., Rempe G. ; Nature Vol 395, pp 33-37 (1998).

**Note 3 :** See for example : « A Delayed-Choice Quantum Eraser » ; Yoon-Ho Kim et al. ; Phys.Rev. Lett. 84, pp 1-5 (2000). It is an experiment proposed in 1982 by Scully and Drühl that consists in choosing whether or not we want to know where a particle has passed through! If we erase the data that would allow us to know where it went, we find the interference fringes that are lost if we keep the data! Reality is well worth calling "indistinguishable"!

## **C.9 :**

**Note 1 :** David Lindley ; (op.cit.).

**Note 2 :** David Bohm imagines a sort of ' « active information ». See for example « Science, Order and Creativity » ; David Bohm et F. D. Peat ; Ed. Bantam (1987).

## **C.12 :**

**Note 1 :** Several authors have tried to illustrate the strange properties of universes different from ours. To explore those of our 4D universe from which we only perceive 3D but by raising you up instead of a god living in the 5th dimension, you must read Rudy Rucker's book soberly entitled "The 4th dimension" but which is in reality a journey from which you will return different ! Rucker is a mathematician who has published a brilliant and humorous work: he offers the reader many exercises that enable him to imagine the world as it is, with at least one additional dimension to the three we perceive.

« The Fourth Dimension » ; Rudy Rucker ; (2014).

**Note 2 :** Stéphane Durand's book, quoted in C.1: note 2, makes it possible to realise for oneself in a simple and very effective way the strange properties of space-time.

## **D : ABOUT LIFE...**

### **D.2 :**

**Note 1 :** Jacob von Uexküll was one of the first to realize that each species lives in its own world. He has built ingenious experiments to discover a little bit of the images of the world

constructed by organizations different from us. His work is published by University of Minnesota Press ; « A Foray into the Worlds of Animals and Humans » (2010). Since then, ethology has been born and abounds in surprising discoveries! An introduction to this new discipline of biology can be found in « L'éthologie : Histoire naturelle du comportement » de Jean-Luc Renck et Véronique Servais ; Ed. Seuil (collection Sciences) (2002).

#### **D.6 :**

**Note 1 :** Philip D. Gingerich works at the Museum of Paleontology at the University of Michigan.

**Note 2 :** The SWISS-PROT' website is a database containing all known protein formulas available to researchers. Its address: <http://www.expasy.org/>

#### **D.9 :**

**Note 1 :** Erwin Schrödinger : « What is Life » : Cambridge University Press ; (2001).

#### **D.13 :**

**Note 1 :** Richard Dawkins ; « The Blind Watchmaker » Ed. Norton ; (2015).

**Note 2 :** Work of Jean-Jacques Kupiec's team. See for example : « L'expression aléatoire des gènes » Pour la Science N° 342 pp.78-83 ; (avril 2006) or « Un ordre humain, trop humain » Dossier Sciences et Avenir ; pp. 30-42 (juillet-août 2005)

#### **D.15 :**

**Note 1 :** James Lovelock has published several books that evoke and describe « The Gaia Hypothesis ». See for example : « Gaia: A New Look at Life on Earth » ; Ed. Oxford University Press (2016). « The Ages of Gaïa: A Biography of our Living Earth » Ed. Norton; (1995).

**Note 2 :** There are even congresses devoted to the Gaïa concept alone! For example: « Scientists debate Gaïa » Ed. MIT Press (1991).

**Note 3 :** There are websites that offer DaisyWorld simulations.

#### **D16 :**

**Note 1 :** Lynn Margulis was a microbiologist: she was very involved in the discovery of the microbial origin of intracellular organelles as well as in the discovery and formulation of the Gaïa hypothesis with James Lovelock. In particular, she has published

« Microcosmos » ; Lynn Margulis et Dorion Sagan ; Ed. University of California Press (1997),

« What is Life » ; Lynn Margulis and Dorion Sagan ; Éd. Simon and Schuster (1995),

« The Symbiotic Planet : a New Look at Evolution » Lynn Margulis ; Ed. Phoenix (1998) which are exciting introductions to the foundations of the living phenomenon.

The book by Patrick Forterre « Microbes de l'enfer » Ed. Belin : Pour la Science (2007) is a walk to discover the microbes that now live in the environments and conditions similar to those that gave birth to life 4 billion years ago.

#### **D.18 :**

**Note 1 :** Unfortunately, it is possible to find a multitude of examples illustrating the role of species in their ecosystem through the disasters we have caused by our ignorance. Thus Australia has been affected for more than a century by a very invasive population of rabbits, which are the descendants of 21 animals introduced at the end of the 19th century by a hunter! We collect blunders by voluntarily or involuntarily introducing species from foreign ecosystems into super-organisms where they do not belong. At best, they disappear, but more and more often they become invasive because they do not participate in the local economy. They have no predators or parasites that regulate their demographics while local species are actively regulated.

Similarly, decreasing the population size of some species indirectly causes the population explosion of another species. There appears to be a proliferation of jellyfish in the Atlantic today as a result of the depletion of fish populations due to overfishing.

**Note 2 :** It was only in 1997 that some economists began to seriously try to calculate the price of the services of certain ecosystems. Robert Costanza's team published a well-documented study « The Value of the World's Ecosystem Services and Natural Capital » in Nature ; Vol. 387 N° 6230 pp. 253-260 (1997).

Subsequently, in June 2001, then UN Secretary-General Kofi Annan appointed a large committee of international experts to assess the state of ecosystems and the services they provide to us. The documents are available under the title "Millennium Assessment of Ecosystems" at UN presses.

**Note 3 :** There are some symbiotic parks such as Kalundborg in Denmark, Devens in Massachusetts (USA)... The theory of this approach can be found in Suren Erkman « Vers une écologie industrielle : Comment mettre en pratique le développement durable dans une société hyperindustrialisée » ; Éd. Charles Léopold Mayer ; Paris (2004). Or « Perspectives on Industrial Ecology » by the same author; Ed. Routledge (2003).

#### **D. 19 :**

**Note 1 :** Molecular biology has made the advances that we know thanks to the very thorough study of a few well-chosen organisms, such as the *Escherichia coli* bacterium or the *Drosophila* fly... But the vast majority of bacterial species do not grow under the laboratory conditions that would allow them to be studied! Only 1 to 5% of species are able to do so without the services of other species to live in an artificial environment!

See for exemple : « Isolating “Uncultivable” Microorganisms in Pure Culture in a Simulated Natural Environment » ; T. Karberlein et al. *Science* Vol. 296 N° 5570 ; pp. 1127-1129 (10 May 2002).

## **D.20 :**

**Note 1 :** « L'homme devant l'incertain » ; Ilya Prigogine and Werner Arber ; Ed. Odile Jacob ;(2001).

**Note 2 :** For an introduction to the debate on the profound nature of emergence, see for example: « A Different Universe : Reinventing Physics from the Bottom Down » by Robert Laughlin ; Ed. Basic Books ( 2005).

« Emergence : the Connected Lives of Ants, Brains, Cities and Software » by Steven Johnson ; Ed. Penguin Books (2001). This work is based on recent discoveries related to computer models designed to imitate the intelligent behaviour of anthills, for example, which seems to be emerging without any hierarchy or intelligence really distributed among individuals.

« L'énigme de l'émergence » ; Dossier “Sciences et Avenir” Hors-série (Juillet-août 2005).

**Note 2 :** See for exemple : « The Anthropic Cosmological Principle » ; John D. Barrow, Frank J. Tipler ; Ed. Oxford Paperbacks (1988).

**Note 3 :** There is an old controversy over group evolution among evolutionary biologists. However, it seems that these are only misunderstandings, sometimes based on definitions that are too restrictive.

We have observed group behaviours that have surely been selected during the evolution even in the most primitive beings there are: bacteria! See for example:

« Le comportement de groupe des bactéries » ; James Shapiro ; *Pour la Science* N° 130 ; pp. 30-37 (août 1988).

« Microbial Co-operation in Evolution » ; Eugene Russo ; *The Scientist* Inc. (2003). Many examples of associations of individuals and even cooperative species.

« Bacterial Programmed Cell Death and Multicellular Behaviour in Bacteria » Hanna Engaltery-Kulka et al. ; *PLOS genetica* Vol. 2 N° 10 (october 2006). Bacteria "kill themselves" in favour of the group!

« How Bacterial Communities Expand Functional Repertoires » ; James Versalovic, David Relman ; *PLOS Computational Biology* Vol. 4 N° 12 (12 december 2006). Different species cooperate and create what looks very much like a new organism!

« Plantes et champignons : l'alliance vitale » ; Marc-André Selosse et al. ; La Recherche N° 411 ; pp58-61 (septembre 2007). Very different species have obviously evolved together.

#### **D.21 :**

**Note 1 :** See for exemple « Heritability at the Ecosystem Level » Charles J. Goodnight ; PNAS Vol. 97 N° 17 ; pp. 9365-9366 (August 15, 2000). The authors find that it is possible to select entire ecosystems rather than isolated individuals based on entirely Darwinian criteria.

### **E : ABOUT SOUL...**

#### **E.2 :**

**Note 1 :** Investigation cited in Colin Bruce's book referenced under note 2 chapter C.1

**Note 2 :** « The Web of Life » ; Fritjof Capra ; Ed. Flamingo (1997).

**Note 3 :** « The Tao of Physics » ; Fritjof Capra ; Ed. Shambala (2010).

**Note 4 :** Feynmann was famous for his originality, great independence of mind and intelligence. Among his discoveries, he proposed to consider the path of an anti-particle in the normal flow of time as the mirror image of the path of a normal particle that would travel back in time to the past! A Nobel Prize was awarded to him for the discovery of a mathematical technique for reformulating quantum mechanics that eliminates certain inconsistencies. The basic concept is to admit that a particle explores absolutely all the possible paths and that the interferences built from these paths explain the observed results.

Feynman was also an outstanding teacher. The reader interested in the concepts of physics could read in particular:

« QED: The Strange Story of Light and Matter » ; (op.cit).

« Six Easy Pieces » ; (op.cit).

#### **E.3 :**

**Note 1 :** « I-Ching » ; Kerson et Rosemary Huang ; Ed. Workman (1987).

#### **E.4 :**

**Note 1 :** Quoted by H. Atmanspacher and H. Primas in « The hidden side of Wolfgang Pauli » ; Journal of Consciousness Studies, 3, N° 2 ; (1996). pp : 112-26. This is a reference

from M. Fierz (1979) in a commentary on the joint book by Jung and Pauli « The Interpretation of Nature and the Psyche ».

**Note 2 :** « Trente années qui ébranlèrent la physique : histoire de la théorie quantique » ; Gamov ; Ed. Dunod (1968).

**Note 3 :** See the works by Hans Bender professor at the university of Freiburg ; founder of the journal « Zeitschrift für Parapsychologie und Grenzgebiete der Parapsychologie ».

**Note 4 :** « Memories, dreams, reflections » ; by Carl G. Jung and Aniela Jaffé ; Ed. Vintage ; (1989).

**Note 5 :** See for exemple : « From Evolution to Behaviour : Evolutionary Psychology as the Missing Link » de L. Cosmides et J. Tooby ; dans « The Latest on the Best : Essays on Evolution and Optimality » ; Ed. MIT Press (1987).

### **E.5 :**

**Note 1 :** « The Interpretation of Nature and the Psyche. Jung: Synchronicity, an Acausal Connecting Principle. Pauli: The Influence of Archetypal Ideas on the Scientific Theories of Kepler. » ; Wolfgang Pauli ; Ed. Pantheon Books (1955).

### **E.8 :**

**Note 1 :** The correspondence between Jung and Pauli is published under the title « Atom and Archetype : The Pauli-Jung Letters 1932-1958 » ; Ed. Princeton University Press (2001). The reference to the Yi-Jing quoted in the text is on page 42 and concerns a letter dated 4 June 1950.

**Note 2 :** Letter from Pauli dated 15/10/1938 ; p.20 in « Atom and Archetypes ».

**Note 3 :** Letter from Pauli dated 24/11/1953 ; p. 53 in « Atom and Archetypes ».

### **E.9 :**

**Note 1 :** This is a letter to his friend Mr. Fierz dated August 10, 1954. Quoted by H. Atmanspacher and H. Primas in« The Hidden Side of Wolfgang Pauli » p. 124 (op. cit).

**Note 2 :** It is the book « The I Ching, or, Book of Changes » by Richard Wilhelm ; translation by Cary F. Baynes ; Ed. Princeton University Press (1967). References to the I Ching text are taken from this translation. There are many others: Cyrille Javary's will be mentioned below.

**Note 4 :** This eulogy is published in « The Secret of the Golden Flower: A Chinese Book of Life » Ed. Harcourt Brace Jovanovitch; (1962).

### **E.10 :**

**Note 1 :** « The Fabric of Reality » ; David Deutsch ; Ed. Penguin (1998).

**Note 2 :** « The Interpretation of Nature and the Psyche. Jung: Synchronicity, an Acausal Connecting Principle. Pauli: The Influence of Archetypal Ideas on the Scientific Theories of Kepler. » ; Wolfgang Pauli ; p. 105 (op. cit).

#### **E.11 :**

**Note 1 :** « Memories, dreams, reflections » Carl G. Jung ; (op. cit).

**Note 2 :** « Physics and Beyond: Encounters and Conversations » ; Werner Heisenberg ; (op. cit).

**Note 3 :** « The Fabric of Reality » ; David Deutsch ; (op. cit).

#### **E.12 :**

**Note 1 :** « Shamanism: Archaic Techniques of Ecstasy » ; Mircea Eliade ; Ed. Princeton University Press ; (2004).

**Note 2 :** « The Shamans of Prehistory » : Jean Clottes and David Lewis-Williams ; Ed. Harry N. Abrams (1998).

**Note 3 :** « Board-games and divination in global cultural history : a theoretical, comparative and historical perspective on mankala and geomancy in Africa and Asia » ; Wim van Binsbergen ; (1995). The text can be found on:

[http://www.shikanda.net/ancient\\_models/gen3/mankala/mankala1.htm](http://www.shikanda.net/ancient_models/gen3/mankala/mankala1.htm)

#### **E.13 :**

**Note 1 :** A major study of the history of Yi-Jing was recently published under the title « Le discours de la tortue : découvrir la pensée chinoise au fil du Yi-Jing » ; by Cyrille Javary ; Ed. Albin Michel ; (2003). This book analyses the archaic Chinese culture and its development to the contemporary era as well as the introduction of Yi-Jing into Western culture. A second volume is a commented translation of the Book of Changes, also published by Albin Michel (2003).

**Note 2 :** Joseph Needham has published extensively. A brief introduction to his findings can be found in: « La Science chinoise et l'Occident » ; Ed. Seuil ; (1973).

#### **E.14 :**

**Note 1 :** Mortuary speech in memory of Richard Wilhelm in « Commentaires sur le mystère de la fleur d'or » ; (op. cit).

**Note 2 :** Translation of the Yi-Jing par Richard Wilhelm (op.cit).

**Note 3 :** Jung's preface to Richard Wilhelm's English edition of Yi-Jing.

**Note 4 :** Cyrille Javary does not have Richard Wilhelm's reservations: he explains very clearly the techniques of drawing a hexagram. But if you have Wilhelm's translation, the following may help you.

For those who begin and feel overwhelmed by reason, perhaps it is better to start with the reading with yarrow rods (or any chopsticks) because the ritual is long and perhaps a little less revolting for the rational mind.

The first step is the most important: to get in shape (open-mindedness and humility) and ask a question appropriate to the philosophy of the old oracle.

### **Reading with chopsticks.**

You need to have 50 practical chopsticks to handle. One is spread out and the remaining 49 are taken in the palm of the hand and then divided into two piles by the thumb. The two piles are placed in front of you. A stick is removed from one of the piles and placed between the little finger and the ring finger of the left hand if you are right-handed. The remaining chopsticks are removed from the pile in groups of four until there are only four or less left. The remaining rods are placed between the ring finger and middle finger of the left hand. We repeat this operation with the second pile. We find ourselves with three batches of chopsticks between our fingers. We add them up and put them aside. The number obtained is 5 or 9.

All the chopsticks that have previously been counted in groups of four are grouped together and placed in the palm of the hand to separate them again into two piles. The operations described for the first separation into two piles are repeated and a second number is obtained, which is either 4 or 8, the chopsticks are placed with the first ones, while the chopsticks previously counted in groups of four are recovered and subjected for a third and last time to the same process of separation into two piles followed by the counting of chopsticks as before. At the end there are 4 or 8 chopsticks left again.

Finally, the three remaining chopsticks are added together to obtain one of the four possible numbers: 13, 17, 21 or 25.

The 21 is a solid line (young yang). The 17 is a double line (young yin). The 13 is a solid line in mutation (old yang) while the 25 is a double line in mutation (old yin).

The whole process is repeated six times to build a hexagram starting from the bottom line.

The mutant lines form a second hexagram when replaced by their final stage (i.e. 25 is transformed into 21 and 13 into 17).

If we have acquired the reasoned conviction that synchronicity is real, we can try reading with coins. It is much faster and so close to the "random" draw that it revolts the rational mind! But synchronicity seems to care nothing about it!

### **Reading with coins.**

You need three coins. The front side is 3 and the back side is 2. Each time the three coins are read together to add up the results. Three backs will make 6 which is a double line in the process of mutation. A 9 (three front) will be a solid line in the process of mutation. A 7 will be a solid line (young yang) and an 8, a double line (young yin). The hexagram is also built starting from the bottom and 6 coins rolls.

**Note 5 :** Cyrille Javary's work (op. cit.) introduces the reader to the reading of hexagrams through their ideograms.

**Note 6 :** The koans are proposals that the master asks the disciple to meditate until he finds an answer, but it is impossible to use rational analysis to succeed. A koan consists, for example, in finding the face you had before you were born. Another proposes to discover the sound of an applause made by one hand....

### **E.15 :**

**Note 1 :** Behavioural genetics is a very young and still controversial discipline. One of the pioneers was Dean Hamer who published with Peter Copeland « Living With our Genes : Why they Matter more than you Think » ; Ed. MacMillan (1998).

### **E.16 :**

**Note 1 :** In « The Secret of the Golden Flower: A Chinese Book of Life » (op. cit).

### **E.19 :**

**Note 1 :** Several physicists have been interested in the links between physics and the psyche: either directly as W. Pauli or indirectly through the study of various philosophies. See for example:

« Synchronicity, Science and Soul-Making » ; Victor Mansfield ; Ed . Open Court (1999).

« Head and Heart » ; Victor Mansfield ; Ed. Quest Books (2002).

« Synchronicity : The Marriage of Matter and Psyche » ; F. David Peat ; Ed. Pari (2014).

I warmly thank Reverend Father Pascal who shared his vision of Gaïa, Reverend Father Baechler who shared his keys, Reverend Fathers Savoy and Wider who shared their enthusiasm and pedagogy and Albert Einstein who popularised his image of the world and science.

## BACK COVER

*You don't understand the Theory of Relativity? And even less so  
Quantum Physics?*

*Does the Biological Revolution challenge you?*

*Then this book is for you!*

*As a bonus, you could learn to dialogue with your Soul!*

A physicist frustrated at being unable to build a bridge between the world as we perceive it and the one discovered by modern physics, decides to take the revolutionary discoveries of the 20th century seriously. His approach leads him to attempt a bizarre experience in the Cartesian paradigm. But he is struck by the result: against all odds he has the impression of having lifted a corner of the veil that separates matter from spirit!

He calls on two long-time friends who are separated by everything but a frank friendship and their quest for concrete and well-documented knowledge. Under the guidance of the physicist, the three friends follow the path of modern physics to dissect in the clearest possible way the fundamental experiments that revolutionized our conceptions of the world when the Theory of Relativity and Quantum Mechanics were created.

With the physicist's friends, a biologist and a historian, the reader discovers the foundations of modern physics that challenge the image of the world we inherited from the Renaissance. With them, he relives the thought experiments proposed by Einstein to understand his Theory. He participates in the debate that opposed him to Niels Bohr and which culminates in the EPR paradox. He rethinks the reasoning that led John Bell to publish his famous Theorem and then seeks to verify it with Alain Aspect. He imagines new cosmogonic experiences with Wheeler to feel the profound strangeness of the Physical Microcosm.

In turn, the biologist explains the foundations of the Biological Revolution he experienced and its consequences on our image of the living world. With him the reader analyses the Theory of Evolution, the nature of the Gene and the history of the Individual. An unusual connection between the results of modern physics and those of biology leads the reader to reconsider our conception of the environment and our place in the biosphere.

The historian refers to the work of C. G. Jung and recent archaeological discoveries to shed light on the results of physics and biology. The three protagonists use their pedagogical experience to explain very clearly the fundamental concepts of their discipline. In this way, the reader discovers keys based on clearly stated knowledge and exercises or experiences designed to provide him with the materials for building a personal and reasoned conviction about the nature of the world and our relations with it, without forgetting the main one: human specificity: an astonishing combination of rational cognitive faculties and creative intuitions; the first inviting us to understand what others reveal to us.

## THE AUTHOR

Alain Rifat obtained a degree in biology and then specialised in biochemistry and biophysics. He experienced the great moments of the genetic revolution of the 1970s and 1980s in molecular biology laboratories: his doctoral thesis was on microbial molecular genetics. His personal interests have familiarised him with physics, ecology, history and psychophysics. He teaches biology at the high school.