Light and Matter, Two Sides of the Same Coin

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By

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INTRODUCTION

Science and technology continually give us surprises in the most disparate fields ranging from communications to transport, from medicine to cybernetics, and so on and so forth. Apart from the opinion of a number of die-hard protesters, these successes have spoiled us, making us believe that all knowledge is within reach and that all the secrets of nature will soon be revealed. It's just a matter of commitment and time. However, it is necessary to distinguish between the small steps forward in applications, acquired through the effort of a multitude of brilliant scientists, and the true understanding of the laws at the origin. We are still very late on this last point. And the situation does not seem to improve. On the contrary, various sectors, especially in the field of physics, seem to have slipped into narrow tunnels with ever fewer exit margins. Among the main reasons for this stagnation are the lack of interdisciplinarity (in order to have concrete results in a certain field one must inevitably be super specialized) and poor attitude to question everything even if that means going against the trend (too many efforts, and those who engage in this work of revision risk being isolated from a community that aims only at immediate achievements). It is understood that rowing upstream is not enough. First of all, the scientific method must be safeguarded and the conclusions must be based on and confirm the observations. You need to be informed about as many things as possible and be able to connect them in a new way, while keeping the principles safe. And even if the principles are narrow, you need to have the courage to modify them so that everything is still consistent. Despite these obvious considerations, any attempt to overturn the status quo is viewed with suspicion, also due to the lack of discussion and critical sense that should instead prevail above all in academic society.

Here we are! After this dutiful and moralistic preamble, the time has come to introduce myself. I am full professor of Numerical Analysis at the University of Modena and Reggio Emilia. I was educated in the best schools and made a rapid career. I won't bore you with my CV, which can be found on my website. From an early age, I always told myself that sooner or later I would try to make sense of the theory of quantum mechanics (my classmates preferred to go play football instead). Then the moment arrived, and I felt mature enough to broach the subject. I didn't know yet that I should have questioned everything that seemed to have been established in

the field of physics over the last hundred years, arriving at the conclusions that you will read in this booklet.

As for the purely technical aspects, I have written a couple of books (see references on the page ahead) and several peer-reviewed publications. The material presented here is instead addressed to the general public. I will therefore try to introduce the arguments in the way that seems to me the simplest possible, even if it is necessary that the reader is provided with a minimum of scientific bases (but above all a lively interest). I will try to give you my version of the facts, and therefore I suggest to the more suggestible reader not to be completely duped by my considerations, and to compare my statements with the official interpretations. I don't think I need to add anything else at the moment. Try reading the first chapter. I hope it's challenging enough to be able to face the next ones, even if the road will be slightly uphill. If, on the other hand, you believe that the subject matter and tone do not live up to your expectations, I do not take offense if you abandon reading. However, I suggest you follow the advice below.

WARNING

Some of the topics covered here are markedly (and deliberately) in contrast with the current theories of physics, therefore reading the following pages is definitely not recommended for:

- children under the age of five, even if they are precocious;
- easily impressionable minors (parental guidance);
- university professors of particle physics and quantum mechanics;
- the personnel of particle acceleration centres;
- who believes in the Big Bang;
- who believes that Santa Claus lives in Rovaniemi.

Some consequences due to an assimilation of the contents, not having the necessary suitability, can be:

- tingling in the extremities;
- the awareness that nothing is as before;
- altered states of perception;
- a powerful aversion to omelettes (this will be clear in the following);
- a marked drop in libido (in rare cases, however);
- a strong suspicion that Santa Claus does not exist (but perhaps someone already figured this out).

REFERENCES

Most citations will be provided in the text as footnotes. Here I only give the references concerning my two books, in which the reader can find the technical material that inspired the writing of the present volume:

Electromagnetism and the Structure of Matter. World Scientific, Singapore, 2008. ISBN: 9789812814517

From Photons to Atoms - The Electromagnetic Nature of Matter. World Scientific, Singapore, 2019. ISBN: 9789811204234

I would also like to mention some monographs, which may be of interest:

R. B. Laughlin, A Different Universe - Reinventing Physics From the Bottom Down. Basic Books, New York, 2005. ISBN: 9780465038298

J. Ziman, Reliable Knowledge - An Exploration of the Grounds for Belief in Science. Cambridge Univ. Press, 1978. ISBN: 9780521406703

CHAPTER ONE

WATER CRYSTALS

It took me some time to decide how to organize the material of this essay. On the one hand, I wouldn't have minded revealing the contents a little at a time, adding details to arrive at a definitive picture in the last few pages, so ending with a dramatic exit. The alternative, which is the one I opted for, consists of playing all (or almost all) the cards right away, enunciating the crucial points and then examining their meaning with due calm. In this latter context, the reader has the disadvantage of recognizing the murderer, motive and circumstances right from the start. On the other hand, he is given the opportunity to judge in a few pages whether or not he should continue reading, in order to avoid wasting his precious time.

I intend to collect a series of facts, apparently unrelated to each other, but whose connection will slowly come to form. The question concerns the description of our universe as the union of elementary massive particles together with a sort of fluid (let's call it generically "energy" for now) which blows around and between them, thus connecting the various parts and favouring possible bonds. Similarly, even if the comparison may seem far-fetched for the moment, one would tend to distinguish in a biological structure between the strict chemical envelope and a sort of vital force which supports and governs it. The advantage of the approach (of a pure deterministic type) is that of describing both said states with the same laws, which will become representative of both the material part, as commonly understood, and the dynamic of the substrate. But it will be possible to go further, assuming that matter and its background energy can, when circumstances permit, transform into each other. The model must therefore predict, unequivocally, when the ingredients of the universe, which will be specified later, can take the form of a compact particle or a shapeless floating immaterial fluid, not forgetting that there may also be other intermediate forms which cannot be exactly categorized as real matter, but which live in latent situations.

The program is therefore far from trivial, because it aims to give an answer to fundamental problems concerning reality in all its manifestations through a representation based on mathematical tools, gathering in a few

basic formulas the description of qualitatively different phenomena evolving at very different spatial and temporal scales.

Let's start sketching out some ideas. Without going to look for strange examples, the chemical element called *water* will be more than enough to convince us that there are very interesting aspects concerning it that await to be wisely investigated.

We all know water, like many other elements it has this extravagant habit: when it's cold enough, it freezes. It becomes solid, so compact that you can hardly scratch it with a hammer. Its molecules adhere to one another, with methodical and painstaking joints. An inspection of the freezer is enough to recall the vision, especially for those who, like me, defrost it if it's luxury once a year. However, the molecules cannot be seen. They are small. To discern them a magnifying glass is not enough, and neither is a good optical microscope. Too small! We'll see later how much.

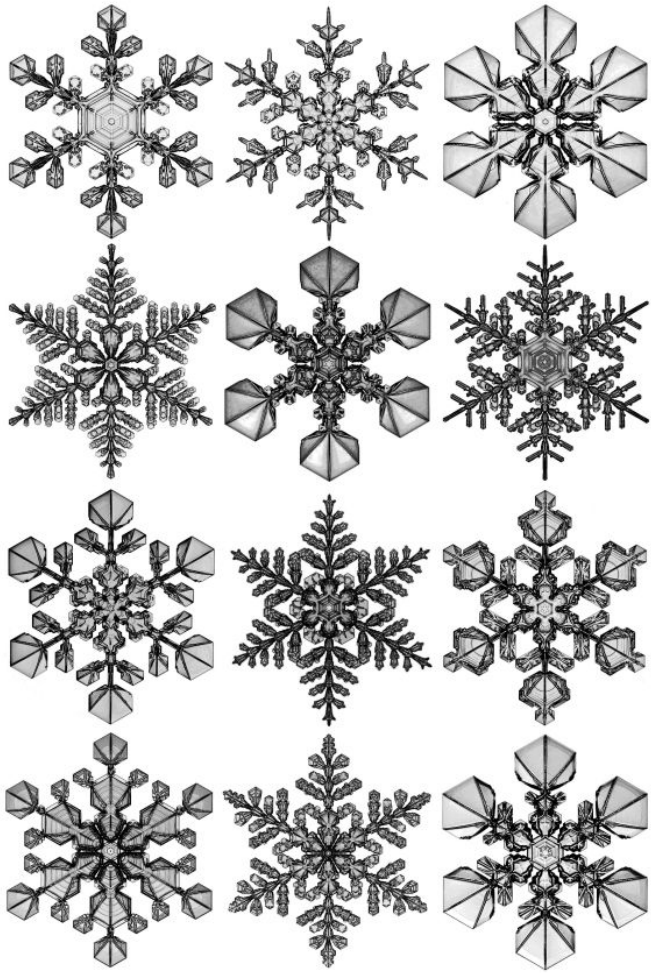
Solid-state water comes in much more poetic versions than those offered by the simple ice cubes that blunt inside a lemonade. In fact, everyone knows the crystalline ice called *snowflake*. Many, out of laziness or lack of interest, have never examined a snowflake closely. Surely someone will have noticed them instead in some magazine and appreciated their magnified photos. The latter, viewable even in the heat of Sahara's desert in summer, are easily found through a quick consultation of the *web*. The beauty of these images enhances the photographer's artistic skills. However, this should not obscure the fact that the real star of these chisel works is nature.

Water, devoid of a brain and a nervous system, as stupid as a handful of molecules can ever be, manages to organize itself in admirable hexagonal symmetry structures, which have been on various occasions sources of inspiration for designers and screenwriters.

There are an infinite number of stunning examples of inlay in which water (brainless as it is) engages. I have no comments to make on the aesthetic side. The photographic evidence already communicates too much. Instead, I have many observations regarding the mechanism that would allow such structures to self-generate.

The so-called "experts" are quick to point out that those immortalized and exhibited are the best examples; that not all donuts come with a hole, and that most snowflakes are shapeless chunks of ice not worthy of any consideration. It may be that the formation of the structure begins in an excellent way, but due to accidents along the path, the flakes do not reach a maturation worthy of being named "crystals". What remains are small masses of solid water that no one would waste time classifying. Squeezed by a finger, they melt, becoming stupid liquid water again. However, suc-

cessful examples are not as rare as one might think. This is enough to get the curiosity going and ask serious questions about water, which despite its sublime lack of intelligence sometimes manages to organize itself so well that it doesn't seem foolish at all.



These water crystals are astonishing. They are some of the wonders that Prof. K. J. Libbrecht at Caltech, is capable to reproduce in the laboratory in order to classifying them and understanding how they originate (see also his book: Snow Crystals - A Case Study in Spontaneous Structure Formation, Princeton Univ. Press, 2022).

Now the expert intervenes and tells us: it is a matter of probability. A sort of hexagonal imprinting is partially contained in the atomic structure of the water molecule. When the various little pieces come into contact, they are not free to combine entirely as they please. They adapt to imperceptible joints, while maintaining a certain freedom of action, as in that famous Danish construction game. The different combinations are the result of the variation of the climatic conditions, mainly linked to temperature. The branches develop from a central nucleus and everything seems to have already been decided by the structure of the joints and some environmental parameters. Here is the basic explanation. As simple as drinking a glass of water!

But I have some doubts. There are many molecules in a flake. How many will be said later. If we really want to bring chance into play, we could dwell on the classic example of a cruet containing an equal number of black and white grains of sand (equal to each other in size and density). Mix everything randomly leaving extra space, close and then shake the container. Shake. Shake. Shake. Until the two families of grains of sand are again completely separated; all whites on one side and blacks on the other (vertically, horizontally, obliquely … as you prefer). Ideally, each jolt could be matched by nature's attempt to produce a snowflake, which is to be considered "acceptable" only if the degree of separation between grains is worthy of attention. I don't know what you think about, but it seems implausible to me that in reasonable periods of time (even when measured on the scale of *aeons*) one could obtain configurations approaching a tenuous separation of whites from blacks. Yet, in theory, something of interest should sooner or later be observed. It should also be noted that there are far fewer grains of sand in a cruet than the number of water molecules in a snowflake. Much less.

Similarly, there would be the example of the monkey who randomly punches the keys of a typewriter, until he hits the exact sequence of sentences that make up the entire Pickwick Papers, from "*The first ray of light which illumines the gloom …*", up to "*… which nothing but death will terminate*" (typewriters are now only found in antique shops, but I stick to the traditional version). Even if we passed some complete phrases under the table to the illiterate animal, I fear that over the centuries it will be difficult for him to come up with something that, albeit with some venial grammatical errors, has the semblance of a single paragraph.

Someone can observe that in a snowfall, flakes descend galore. However, under favourable conditions, there are many acceptable crystals, and among them, almost perfect ones are far from rare. No! The reasons related only to probability do not convince me. In fact, I don't think even the

experts are convinced, who play the next card, i.e. that of energy minimization.

Nature, for some codified principle, tends to do things “saving”. Saving what? At this point, having the time and an interested audience, I should properly formalize and quantify the ideas. For simplicity, instead I prefer to remain vague, limiting myself to saying that a cost is assigned to each combination of water molecules, a sort of price to pay. The solutions that tend to minimize this cost come first of all. The fundamental hypothesis is based on the fact that the splendid crystals with hexagonal symmetry, thanks also to the properties of the individual water molecules, create configurations of minimal price. This is how it happens that during aggregation, both due to constraints dictated by the atomic structure and to a tendency towards global optimization of resources, an enormous population of molecules finds its magical way towards geometric perfection. If you really want it, a pinch of randomness can season everything, like an icing on the cake (this is the first of the culinary references that will enrich the pages of this text).

Unfortunately, there are still problems. The energy expended for molecular bonds is usually estimated at a very local level. It is based on electrical and magnetic considerations. Atoms are made up of positively charged nuclei and negatively charged electrons. Roughly speaking, the reader knows that charges of different nature interact in some way, mutually influencing their spatial distribution. So, each molecule “talks” to its neighbours. Despite having this gift, a molecule is somewhat “discreet”, therefore, tends not to poke his nose too far. According to the classical canons, it does not even have the opportunity to take a look at what happens in other branches of the snowflake. Furthermore, it is also true that the gossip that arises in each farmyard tends to spread to neighbouring farms by chain reaction. Unfortunately, it usually happens that the message is conveyed in a distorted way and a phrase like “don’t bother with that switch” ends up being transformed into: “your mother is a witch” (typical epithet in many family situations).

It is therefore difficult to think of a close-knit organization which, through neighbouring interactions, but without a central direction, is able to materialize in spectacular games of symmetry. Instead, it would be plausible to expect that each of the six arms, however regular, would follow different evolutionary patterns. There are certainly many flakes malformed in this non-symmetrical way, and yet it is surprising that, albeit with less frequency, there are several others that have succeeded almost perfectly. Excellently forged. Too much!

To be honest, it should be added that snowflakes, good or bad, are not always obtained, but only when external circumstances allow it. Temperature and humidity play a significant role here. Indeed, the effect of the environment should not be overlooked. Mark this note. We will need to remember this often in the sequel. However, external factors go beyond what can be adjusted through the knob of a thermostat. The real mechanism is going to be far more complex. In fact, we need to specify better what is meant by "environment".

To better reiterate the concepts expressed above, we ask the reader to compare some photos of enlarged snowflakes. At the top of each branch you can see small details (fringes, darts, bolts ...). They are splendid friezes reproduced almost identical six times. Similar protuberances also appear within the central hexagon. Are you still of the opinion that these six events are expressions of chance, after an exaggerated number of unsuccessful attempts? (Resume the cruet full of sand and start shaking). Or, do you think that some principle of energy minimization applies where, however, the branches have no opportunity to keep an eye on each other?

On the question of reciprocal distances, let us try to get a more realistic idea of the dimensions involved. This will help us better understand the difficulties inherent in the self-building of a snowflake. The diameter of a molecule is on the order of a few *Ångstroms*. This unit of measure is obtained by dividing the length of one centimetre by one hundred million. Something that is hard to imagine. Let me write it for you:

1 Å = 1 Ångstrom = 1/100,000,000 centimetre
= 1/10,000,000,000 metre = 1/10,000,000 millimetre.

You did not understand. I repeat. Take the span of one millimetre. OK? Divide it a thousand times and divide each fraction a thousand times again. It's not over yet. Divide by ten again.

To give a concrete example, an iron wire can be considered having the diameter of a hair. We are around a few hundredths of a millimetre. The object is still clearly visible (farsighted are exempt from this exercise). Well, the diameter of the section would then contain about one hundred thousand molecules aligned. The diameter alone! The entire section, one molecule thick, would contain a number proportional to one hundred thousand molecules squared, that is, 10,000,000,000 elements. And then it is necessary to mention the length of the filament (a hair can also be tens of centimetres long). Unpronounceable numbers come. Fill a sports hall with tiny polystyrene balls and you will begin to get an idea of the quantities involved. Although nature works very fast at the atomic size level, the

magnitudes are such as to make the factor of randomness decidedly unrealistic.

Let's go back to the snowflake. With exceptions, its diameter is generally just under a millimetre, which translated into Ångstroms makes it ten million. In other words, the distance between two "spires", following the edge, could involve millions of water molecules. To give you an idea, ten million might be roughly the number of steps it takes to walk coast-to-coast from New York to Los Angeles. We have said that molecules relate according to close kinship ties. Therefore, there does not seem to be a way for a molecule placed on one of the six "masts" to have direct information on the behaviour of the other five homologues. On the basis of what we have available for now, it is difficult for the six ramifications to proceed in unison.

The following objection could be raised. Once a few hundred molecules in the centre combine in an appropriate manner, the subsequent evolution is somehow decided. It is enough just to respect the constraints of the joints. In other words, the conformation of the initial central nucleus (usually a hexagonal prism) is the germ that influences the structure of the whole system in a peculiar way. The reasoning could hold up if the pieces that are added from time to time did so with impeccable precision. Unfortunately, this does not appear to be true. From an examination of the photos, gross errors of asymmetry emerge here and there, which however do not seem to influence the final shape that much. Sometimes there is a missing bolt, a badly made dart, an imprecise spire. There are also cases where it is the central part that is slightly misshapen. The process of formation can in principle follow an outrageously huge number of combinations, so an imperfection occurring in one branch can result in a total destruction of symmetry. Yet a sort of widespread communication organizes the growth of the crystals in such a way that what happens along a single branch is cloned almost perfectly along the remaining five. Parts of the design can be slightly different and this is probably the most striking feature. These differences could have led to an alternative evolution of a single *dendrite*; instead all the crystal ends up with incredible regularity. In short, despite a number of sinful shortcomings, the construction process turns out to be *stable*. In other words, secondary disturbances have no tangible effect on the global project, which is generally respected. But what project am I talking about? Water is stupid, it doesn't think and much less has plans.

We add that a snowflake floats in the air, i.e. a disorganized ensemble of other well-known molecules such as oxygen and nitrogen. These blur the "vision" and confuse the signals. So, you see that the problem is less

trivial than it might appear at the beginning. Many scientists are well aware of this and the literature is full of ideas and explanations. There are already a number of mathematical models that attempt to replicate snowflake growth. The inherent complexity of the problem has led to a gap between the theoretical principles and the practical phenomenology. The algorithms that model the evolution through the reproduction of hexagonal type stencils, and the theories that allow the simulation of the individual dendritic components, are well founded and quite effective. However, there is a fuzzy area when trying to understand the simultaneous and autonomous growth of six independent branches of a real snowflake. I believe that the deeper aspects of the problem have not yet been analysed. That is instead what I am going to do in these notes.

Before finishing this first chapter, I would like to dwell on a couple of small questions, which in the end will not be so negligible. First of all, the classic dendritic-shaped snowflakes are quite flat. With the endless geometric opportunities that can be realized in the three-dimensional world, unintelligent water, when it's not forming unstructured clumps in the freezer, materializes into beautiful doodles. To tell the truth, bizarre and variegated hexagonal columns also appear in the general catalogue. But if we remain on the so-called *stellar* geometries, arms pointing obliquely upwards do not seem to appear. If this rarely happens, it is because there has been a sort of mistake in some instant of the construction process, an anomaly which however is commonly censored in the classifying process. Therefore, the crystals (I always speak of the successful ones) do their utmost in infinite and unrepeatable manifestations. However, not everything is granted to them. Who or what has the power to limit their freedom of expression?

The second and even more profound peculiarity on which I would like to dwell concerns the size of the snowflakes, almost all relatively small but visible to the naked eye. We are talking about diameters around the millimetre, a little less, a little more. Other massive and articulated structures are mainly obtained from compositions of planar flakes. The average crystal size is a standardization which should not necessarily be required a priori. What is it imposed by? Consider that the rough hail (formless and less noble) can take on dimensions ranging from those of a blueberry to those of a voluminous and heavy baseball. However, there is no record of individual snowflakes ten centimetres in diameter crashing on the hood of a motor vehicle. If this ever happened, surely the insurance company would have found good pretexts to avoid compensation.

But, if it is not chance, or the most elementary physical principles, to coordinate the success of a water crystal, what else are we forgetting?

Continuing to believe that molecules are singularities without intellect, perhaps we could work on the fact that, once put together in groups, they go to create new entities. The latter must exhibit properties in addition to those exhibited by the individual parts. Properties that act globally and disappear once the complex is decomposed.

I would not like the reader to start thinking at this point in the discussion that I am appealing to some explanation of "spiritual" origin. I will maintain as much as possible a rational attitude, although the subject may lend itself to ambiguity. Will I be able to give scientific basis to my project? I am convinced yes. But not right away. We need to work on it a bit. I will begin to throw the description of the atomic world into turmoil as early as the next chapter.

CHAPTER TWO

LET'S TURN THE OMELETTE

Hey! Are you a scientist? A physicist? Maybe a somewhat conservative academic. Those for which some "certainties", obtained with difficulty in the past by brilliant minds, should never be called into question again, even if they are in open conflict with "common sense". Common sense is a vague concept, yet useful in putting a stop to abstraction, which arose to sort out our heads and translate into words what we perceive from the events of nature. An abstraction at the service of us humans to study what may be rational in reality. An abstraction that, in certain sectors, from a certain moment, has replaced reality itself, and in cahoots with reasoning wants us to understand things that, alas, due to common sense, we find it hard to make our own.

Hey! Are you still there? You know, it's because I'd like to clarify the matter right away. It is not my intention to throw away centuries of "hard" science in search of popular consensus on the cheap. There are many people around who, appealing to scientific bases, spread lies. I promise to be good. Nonetheless, considering that today's physics has strayed a little too far from its clarifying mission, I will unashamedly launch a number of vehement attacks. Since I would like to spare you some excess of anger, which is not good for the heart, I advise you to proceed cautiously with the reading. Instead, those possessed by a revolutionary soul (and boasting an excellent electrocardiogram) are invited to continue at full speed.

Let's talk about the atom. How it's made, or rather how it's thought to be made, because we don't have eyes to get to see something the size of a few Ångstroms. By now we know how atoms tend to behave, we know how they react to natural perturbations or to laboratory experiments. We know pretty well how they combine chemically. In short, after more than a century of relentless experimentation, many facts are quite certain. If we believe that a rational description of nature must exist (note that this is not the case for everyone), the final picture can only result from the symbiosis of the severe scientific method with dutiful common sense.

Let's see what the ingredients of the omelette are. In the atom there is what is called the *nucleus*, a sort of very small concretion, with a diameter

one hundred thousand times smaller than that of the entire atom that hosts it. No, you still don't get it: one hundred thousand times smaller! This implies that, if the diameter of the nucleus were one centimetre, we would have to walk in some direction for at least a kilometre before finding another one. We infer that in a molecular lattice these nuclei are quite scattered.

The nucleus is given an integer positive electric charge and a mass equal to almost the entire mass of the host atom. For strange reasons which we are not going to investigate now (but which may be made clearer later), electric charge at the atomic level always comes out in integer multiples of a certain base unit. Then there seems to be not much else inside an atom except a sprinkle of electrons, each of which has relatively negligible mass, negative unitary charge and insignificant size. That's all? Is this the famous recipe? Not a very fancy menu. Our universe is quite tasty. There must be some other seasoning. How are the ingredients cooked?

In a neutral atom, the number of electrons equals the charge of the nucleus. In the previous chapter we considered water. I assume my reader knows that it is composed of hydrogen and oxygen. The hydrogen atom has a nucleus of charge equal to one unit and it is equipped with the corresponding electron. The oxygen atom has a nucleus of charge equal to eight units with eight annexes electrons. One could certainly be more precise in this description, but I don't think there is much need to go into the details of this discussion. Questions immediately arise. Why is an atom so big (so to speak), if in the end it must only contain a finite number of tiny fragments? Is there an edge, a frontier? How do you figure out who's in and who's out? But the crucial question is: what the hell is in between? We know there's "energy" down there, but we'd like to know how it is organized, because this is the important question, the most important of all. With due calm I will try to answer … in my own way.

Going forward, considerations can be made on how the atom presents itself to us. I'll try to roughly describe the general picture, letting the curious delve into the details autonomously, being able to count on an immense collection of published material and the versatility of *internet*. As an example, let's take the generic oxygen atom. Left in total rest, it doesn't like to be noticed. If teased, it emits distinctive signals, so distinctive that you are almost certain that it was exactly the owner. It is able to swallow energy and expel it, but it is quite picky, especially with regard to doses. It is here that we begin to talk about *quantization*. An atom treats energy only in "packets". If the quantity is insufficient it is rejected, if it is in excess the atom takes only the useful part. And so it behaves in restitution, not before having shredded the merchandise in his own way.

After the "lunch" of an atom, the so-called photons, very small electromagnetic radiations, are usually expelled in digestion. The question of what exactly photons are will be discussed later. It is sufficient for now to say that all modern physics of the last hundred years has been, and still is, kept in check by a superficial and incomplete description of these entities. I specify this to make it clear that here we are moving on swampy terrain. From a qualitative point of view, photons are projectiles traveling at the speed of light, carrying an electric and magnetic signal. They are "light" in all respects. If you don't disturb them, they travel straight ahead and don't dissipate. Atoms of the same element, always oxygen for example, in specific environmental situations, when tickled, emit photons each time belonging to the same range of energies. These messages are different from those you would get from other types of atoms, such as nitrogen, carbon or phosphorus. Each element has its own distinctive imprint called *spectrum*, and the same happens for molecules, which are the result of the aggregation of several atoms. In short, each material speaks to us of itself, showing off with fireworks of various colours that uniquely characterize its presence.

You don't need a large laboratory to do some simple photon experimentation. There is actually no need for anything. Your eyes are enough. They are sensitive to photons which carry with them energy doses whose variability belongs to a vast range (which however does not cover all the situations that may actually arise, so that our sight captures only part of this phenomenon). The brain is subsequently able to differentiate the various photonic packets according to the message they transmit, translating each individual energy dose into what we call "colours".

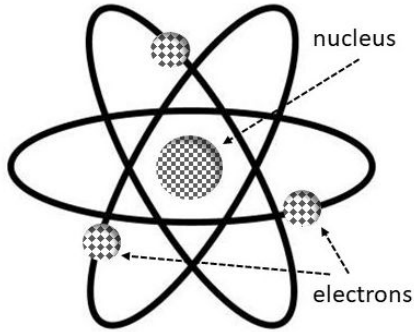
We light a room and the molecules of the objects that make up its interior methodically grind the energy administered. Many of them return it almost immediately, but not before stamping their mark on it. Coloured photons shoot in all directions. Hey, look! They say. I am the molecule of the upholstery of the chair you are sitting on, and I am sending you this beautiful crimson colour. I come from the glass of lemonade you're drinking, and I am sending you this dull yellow. I am the cap of the pen, I don't send you anything, I keep everything to myself. You'll notice me anyway: I'm the black one. Many other photons are not perceptible to our eyes. However, we can count on a vast and elaborate technical instrumentation. Now comes the wise little thought at the end of the paragraph. If each atom or molecule is a machine capable of doing everything that has just been described, perhaps we understand why it needs much larger space than the very small one occupied by the nucleus and the electrons.

Well! We have a new updated set of ingredients for the omelette: nucleus, electrons, photons. Now we have to cook it. Let's take a few recipes from specialized manuals. About a century ago the procedure was as follows. The nucleus has a positive charge, the electrons are negative, so they attract each other. In the great-grandmother's recipe, to avoid collapse, the electrons are whirled around the nucleus like planets around a star. The forces of electric attraction are compensated by the centrifugal ones and the system is brought into equilibrium. This would explain why the atom is bulkier than the particles that compose it. The electrons spin rapidly at a relatively small distance in orbits around the nucleus. From some approximate computations and notions of elementary physics, things can also be justified from a quantitative point of view, respecting the actual dimensions.

What about photons? Now the explanation becomes very ambiguous. Here it is. The electrons are charges in motion and, for principles of electrodynamics (of which some readers are probably aware), when accelerated produce electromagnetic radiations. Different orbits correspond to different energies. A rotating electron subjected to stress changes its orbit, and, if for some other reason, it is forced back into its original path, it bridges the energy difference by emitting radiation in the form of one or more photons. These manoeuvres occur very frequently, with electrons swirling at speeds approaching the speed of light.

The principle just stated is crude, badly formalized, difficult to digest. It's not my fault (or a willingness to be hasty) that I haven't been able to tell it in more detail, because details don't exist. At this point, I feel compelled to raise some reproaches (I will do so at other times later) regarding the approach considered by many to be "scientific". It is true! Flows of charges produce electromagnetic fields. The examples and applications are endless. However, the electron is a particle that is considered point-like. On the basis of known mathematical models, the calculations are rather difficult in this case and, unfortunately, the tendency prevails to assume certain answers based on experience, promising to get back to the problem as soon as possible. But time inexorably passes, and those answers given in an insecure manner slowly become the truth. No one then finds more time and reasons to re-discuss them. Something electromagnetic happens around a moving electron, but it is certainly not the emission of a photon, an entity of which, at the modelling level, little or nothing is known. Let's leave the matter hanging here. We will discuss photons in the next chapter. For the moment we return to the description of the atom, as it was proposed by Ernest Rutherford and successively revised by Niels Bohr.

The idea is beautiful. Poetic. A micro solar system in every atom. All in all, however, things are not going so well. We may say that they are reasonable in the case of the hydrogen atom (a star and a planet) and for simple related cases. In the water molecule there are 13 interpreters: the oxygen nucleus, two hydrogen nuclei and 10 electrons. I don't think that mathematically it is possible to combine their motion so that the system maintains a perfect balance. Even if the theoretical path yielded results, the practical implementation would be difficult, if not impossible. These dynamic configurations are "unstable" and a blow is enough to make everything collapse. On the contrary, knock a table with your knuckles to realize its solidity: no flaking. In more complex molecules, made up of more sophisticated atoms (just think that uranium is composed of a nucleus and 92 electrons) there is no way out. The solar atomic model has difficulty supporting itself. What a pity! It looked so brilliant.



This image is creepy. Although widely used, it represents an example of how a draft of an idea, subsequently reworked several times, has become the emblem of a certainty, when instead the concept of atomic structure has not yet found a satisfactory formulation. At school we are fed the idea that a group of electrons circles around the nucleus. The continuous repetition of certain (not yet fully founded) concepts makes them become absolute truths, and this does not help scientific progress.

There is also the problem of quantization. Each atom grinds the photons according to the rules dictated by its own *spectrum*, which, as noted, characterizes a specific atom and all its cousins in a univocal way. This means that not all orbits are admissible, but only those which allow the passage of an electron from one energy state to another, the difference of which is compatible with the energy of the acquired or emitted photon. And who dictated these constraints? They do not appear in classical me-

chanics. In short, without naming a series of other problems that were anything but trivial, it was soon realized that the idea of the micro solar system could not succeed. Despite the harsh truth, through the use of symbols, the atom is always depicted through the trajectories of a cloud of balls that spin merrily around a central point. For the reasons that I will give shortly, I find this representation not only erroneous, but largely harmful, as it suggests a behaviour that cannot in fact reflect the real world.

The fact is that the ingredients were the same and the omelette had to be cooked anyway. Therefore, a new team of *chefs* came up with ingenious ideas. Here the discussion becomes long and technical, but in the end the substance is what I'm going to describe. If classical mechanics is not suitable for treating an atom respecting all its peculiarities, it is enough to invent a new physics, that is *quantum mechanics*, where everything that could not be done before can now be done instead. It is enough to put the right stakes and give it a semblance of officiality. This is where common sense begins to wane. At the beginning, the hypotheses can also be digested, but as the reasoning continues, one slips into a tunnel that becomes increasingly tortuous. So much so that the theory becomes nonsense. More precisely, the theory, as a mathematical and philosophical exercise, has its right to exist. It is its link with the real world that no longer has roots. To make the situation more dramatic, some companies of chefs have even suggested inserting among the "Commandments" that regulate the dynamics of the atom the one that establishes that our mind will never be able to understand its functioning. Therefore, certain situations must be accepted as dogma. No one has decreed that any rebellious attitudes would be severely sanctioned, but I suspect that some extremist scientists have seriously considered proposing it.

It is correct to make a very brief summary of this sad story. I will not deny that this will be a bit biased (very biased; otherwise why would I have started writing this booklet characterized by a rebellious approach?). The first proposal was to assign a wave to each moving entity, based on its mass and speed. Yes! Precisely. A wave. Something that oscillates in time, like marine, acoustic, electromagnetic waves; but not corresponding to any typology among those mentioned. A wave and that's it. With its good frequency (number of oscillations in the unit of time). The starting point comes from a series of experiments that find a convenient explanation when matter is attributed "wave-like" properties, whatever meaning this adjective may have.

The idea fits just right in the case of electrons revolving around the nucleus. The quantization of their orbits would be broadly explained in the

following way. An electron is assigned two frequencies. One is that of rotation, high when the electron orbits close to the nucleus, low when it is kept at a distance, as happens in astronomy by comparing the motions of Mercury and Neptune. The other frequency, which occurs spontaneously in automatic correlation with the effective speed of the electron, is the one associated with the artificial and mysterious wave discussed earlier. The preferential orbits are those for which the two frequencies coincide (or the second is an integer multiple of the first). This makes a very good selection. The mechanism is well thought out because, by evaluating the energy of an electron in the various admissible orbits, a sequence of numbers is obtained. By calculating the two-by-two differences between these numbers, we obtain quantities that actually correspond to the energies of the photons emitted (or absorbed) in the possible transitions from one orbit to another. In simple cases there is perfect correspondence between the values calculated theoretically and the results of the experiments. A bitter taste remains in the mouth for the question of the wave of unknown nature, invented ad hoc to solve the contingent problem. So far, the panorama could still be acceptable.

Then the disaster happens. The question of good or bad orbits further complicates the problem of identifying the motion of electrons in a slightly complex molecule. This question was already difficult before; with the additional constraints it becomes unaffordable. See what they come up with at this point. Again, to justify some experiments (I will return on this in chapter 7), the explanation of which does not seem to fall within the rules of traditional mechanics, it is decided that the atomic world is dominated by chance. With a flick of the magic wand the orbits are made to disappear. The electrons keep moving, but we don't know which way they go. It is only allowed to know the probability of finding them somewhere near the nucleus. We speak of an "electron cloud". Where this is dense, the easier it will be to find electrons. Where this is rarefied, they will rarely be seen. An appropriate set of equations was proposed to successfully address the problem of establishing electron density on a case-by-case basis. The role of the equations is therefore very clear. However, it remains unclear what kind of reality they describe.

A dogma called the *principle of indeterminacy* was also coined, which in a nutshell places limits on freedom of expression. According to it, any attempt to describe the atom using classical laws of Newtonian type (such as force equals mass times acceleration) is forbidden. I would add that, although the uncertainty principle finds confirmation in very numerous experiments, it often happens that, when it is not appropriate, one is allowed to "get around" it. Or, in order to safeguard it, one is willing to give

up the laws of conservation of mass and energy, as long as these are violated in very small time-intervals. In short, quantum mechanics imposes a lifestyle which, as circumstances vary, seems to be decided on the basis of convenience. What are the limits of applicability of these doctrines is not clear. In fact, where is the dividing line between the everyday world and the randomness that reigns in the atomic one?

The construction described above might not seem outrageous after all. I dismiss the suspicion that I am against the hypothesis of adopting methods of statistical investigation in the study of the problems posed by science. These methods are necessary in countless contexts, above all where one wishes to deduce general properties from a large number of individual observations. However, the quantum representation of the atomic world is based on much more extreme axioms, which undermine the foundations on which our usual intuition of reality is based. Consider that the level of randomness allows a single precise electron to occupy distinct areas of space at the same instant. It is one thing to analyse a large number of samples whose dynamics are supported by precise deterministic rules, it is another thing to attribute a meaning of randomness to each sample, not so much because this is useful for some mathematical manipulations, but because is part of intrinsic and indivisible properties of the object itself.

Let me explain the above statement better. Given a box containing 10 white and 10 black marbles, we want to draw a marble at random. We all know that the probability of hitting a white ball is 50%. The same box, seen in the context of quantum physics, contains 20 “grey” marbles, thus meaning that each one can show the black or white colour as it pleased with equal probability. The moment you pick up a marble and “observe” it, this takes on a specific colour. From the abstract mixture that it was before, the marble becomes “real” in our eyes. The probability that white comes out is therefore equal to 50%. The final result is therefore the same, but you can clearly see that the assumptions are very different, so as to arrive at the paradox of being able to carry out statistical investigations on a “population” exclusively composed of a single element. As a provocation, one of the supporters of the theory brought the (theoretical) example of a cat which, due to the uncertainty of a certain process at the atomic scale, through an amplification mechanism turned out to be both alive and dead at the same time (fifty & fifty). I hope that by virtue of this expedient, no feline has been made the object of violent actions. If these hurried statements of mine should still be smoky to the reader, we’ll meet again in chapter 7 for more information, as already announced.

The frying pan sizzles from the kitchen, and an unpleasant smell of roasted onions fills the air. As much as I like the onion omelette (with a