A Physicist's Journey between Science and Faith

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Friends or Foes?

By

Angelo Tartaglia

English translation by Daniele Tartaglia

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FOREWORD

For a long time now, in what is normally referred to as The West, which corresponds to Western Europe and its extensions such as America, there has been an ongoing debate, which has at times become a full blown clash, about the relationship between science and faith. The terms used have not always been these, in other times we would have talked about faith and reason, but the substance is the same. True, the debate or clash has generally been caused much more by historical than by cultural reasons, but at the same time it has always been enveloped in culture, therefore I think it is appropriate to analyse it on this level, in order to uncover any other reasons and, if there are any, discuss them without confusion and misunderstandings.

So, if we remain within the cultural remit, one of the most common positions, especially from the Enlightenment onwards and often cropping up today as well, maintains that science and faith are, and can only be, incompatible. Such an idea gives rise to very important practical consequences, which may lead, in totalitarian regimes, to the attempt to eradicate religion, maybe even by physically eliminating those who profess it. Or, in a tolerant and liberal environment, to “conceding” that one of the various quirks of humans may be a religious faith, just like collecting stamps or climbing glaciers, as long as those who believe do not try to go beyond the sphere of the private and give their faith a social dimension.

Since the attitude I am talking about is rooted in the human mind, and therefore has a life of its own, I must add that, if asserting this incompatibility leads to consequences for those who are on the ‘scientific’ side of the fence, it is present on the other side too. And there too it leads to consequences ranging from a sheer rejection of science and technology, which would not be worthy of any consideration, to their acknowledgment as long as they are subordinate to faith.

In short, there is a lot to consider, and if possible it should be done without behaving like spectators at a football match, who choose first and foremost whom they are going to support. Rivers of ink have been poured over this topic and perhaps every possible consideration on the matter has already been expressed at least once, but it is also true that no written thing, even assuming it has been read, is relevant unless it is generated again in our mind.[1] The discoveries or conclusions that matter most are the personal ones; the thoughts of other people can help us, but they cannot replace our own. So why not try to think, and do that using the tools we have available, without expecting to always be original, but also without hiding behind the alibi that we do not know all that has been thought before?

I am a physicist by profession, and besides my professional and institutional role I have been and still am involved and interested in all sorts of things. In my position, perhaps I am not particularly qualified to talk about science and faith. I could talk about faith as a Christian, and obviously a sinner, certainly not as a theologian; I could talk about science, confining myself to physics, seeing as I am a physicist; but talking about science and faith, i.e. analysing the relationship between them, is another matter entirely. In order to tackle this question, it is necessary to cover an extremely vast area of knowledge encompassing very different fields, ranging from psychology to physics, from philosophy to theology, from historiography to biology, from mathematics to economics, and so on. In this respect, I wish to state right from the beginning that my authority is limited to restricted areas; everything else I do possess a smattering of, but not much more than that.

Despite this, I can boast a certain inclination to putting together the elements at my disposal, in order to try and form a rational and as much as possible organic picture. Will this be enough to hold my own amongst the many who have written about science and faith in the past and who write about them at present? Amongst those who possess in-depth knowledge in only one of the specific areas listed above, whether theology or chemistry, biology or philosophy etc., as well as amongst those who seem to even claim to be truly competent in all significant fields, from linguistics to epistemology, from quantum mechanics to economics, from patristics to geometry? I don't know, but I will try.

[1] An aphorism ascribed to Goethe reads: "All truly wise thoughts have been thought already thousands of times; but to make them truly ours, we must think them over again honestly, till they take root in our personal experience."

CHAPTER I

SCIENCE AND FAITH

If we want to try and argue about science and about faith, it is first and foremost necessary to attempt to define the bounds of this comparison, so that we know what we are talking about.

Faith

I shall start with faith: what should we mean by faith? Or rather, what shall I mean by faith hereunder? We might say faith is a belief we think is worthy of our trust even if it is not backed up by completely factual or rational evidence; as long as it does not conflict with reason though, because otherwise we should talk of senselessness and pathology rather than of faith.

Of course it is more complicated than that. Everything is always more complicated, but we need to start from some minimal basis if we want to understand what we are talking about, and then we can leave it to the professionals to come up with more refined definitions. I will, however, try and make a further distinction myself. I shall put under the category of faith a belief, or a set of beliefs, which cannot be proven to be true or false, in the technical sense of the word *prove*; in other words that cannot be falsified, using an expression borrowed from Karl Popper.[2] Of course, a concept of faith such as the one I am describing includes a much wider scope than that of the religious faiths alone.

There are then also many convictions that are kept although they are not, currently, backed up by facts, but which could at least in theory be verified. These convictions are the expression of some type of trust, either in our intuition or in the authority of some witness.

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[2] Karl Popper was a great epistemologist of the 20th century. He suggested the concept of falsification as a criterion to prove the scientific character of a theory: a theory is scientific if it is possible to devise a crucial experiment the outcome of which can determine whether the theory in question is confirmed or rejected.

An extremely large part of our current knowledge lies within this type of trust beliefs, because the things we can directly prove are relatively few. Many people believe a certain fact happened in one specific way rather than another, or that it happened at all, "because they said so on the television" or "because it is written in the newspaper", or because the Prime Minister, a political leader, a star of showbiz or maybe the Pope said so. Sometimes these are short-lived convictions, but sometimes they are carved in stone and unflinching even when disproved by facts. I will obviously not talk about these things (social psychologists and sociologists deal with them) and they are not relevant with the topic I want to address anyway.

When people talk (or argue) about faith, perhaps needless to say, they almost always refer to religious faith, in other words to the faith in God. I will not dare go into theological or philosophical definitions; let's say that, very simply, believing in God is the conviction that the world exists thanks to a supreme, perfect and omnipotent being (these terms are typical of the western tradition and are not found, as such, in other cultures, but this does not change the substance of the definition).

In fact, the hypothetical conflict between faith and science is generally referred, in the West, to the Christian faith and, up to an extent, consequently to the Jewish and Islamic religions. Although the criticism, at least from some, is directed at any religion, it is focused towards the 'peoples of the book'[3] (according to a phrase of Islamic theology), namely the three great monotheistic revealed (according to the belief of those who profess them) religions.

This focusing on the three great faiths which developed in the Near East is due, as already mentioned, to precise historical reasons, which I will not go into in great detail. The fact of the matter is that the places where the confrontation is at its sharpest are in the (now globalised) "West". And they affect Christianity, the followers of which believe God himself intervened in history by becoming man (the Son of God), suffered the injustice and the violence of the world (and in a way also the formal strictness of religion) to the point that he was killed like a criminal, and then he rose from the dead, showing mankind the way to salvation. Or, in simpler terms, the meaning of everything that exists, including our life.

In light of the above considerations, in this book I will essentially refer to Christianity, although many reflections will apply to faith in general.

When we talk about a religion and the behaviour and beliefs of those who profess it we will find both faith, according to the definition I have

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[3] Ahl al-Kitāb.

given above (I may be tempted to use a capital letter, but I have grown a certain mistrust in everyday words that seek to acquire a nobler status with spelling), and that common trust, which I have also already mentioned, we have towards some authority or evidence or other. This latter ingredient permeates all our life and, as we shall see, is definitely present also in the world of science and it could not be otherwise. The reasoning I shall attempt will refer to the actual faith and, if I can manage it, I will try not to be sidetracked by all those big and small principles of authority we are faced with every day.

Science

What is science? There are experts who could write, and indeed have written, pages upon pages on the matter. Here too I will limit myself to very simple considerations, without any claim to being systematic or exhaustive. I will speak more as a person who works in the scientific environment than as a theorist of science.

I might be tempted to get away with it with a joke: paraphrasing Benedetto Croce,[4] I might write that "science is what everyone knows what it is", seeing as everyone talks about it. If we want to consider the question a bit more seriously we should begin by wondering whether it is correct to talk about *science* or if we should always write *sciences*. One of the implicit convictions in many debates and stances is that, effectively, there is something that unites all modern sciences, however different the subject of their study is; the common element is supposed to be the method, more specifically the experimental method. It is this common denominator that allows us to talk about science in the singular, science which is different from faith and, according to some, in conflict with it, or at least characterised by an obvious superiority to it.

The modern experimental method was devised from a philosophical point of view by Roger Bacon and from a practical point of view by Galileo. Ever since, scientific knowledge was considered to be derived not by reason alone, but by applying it to data acquired by the systematic observation of nature and actively acting in order to devise experiments that could verify the theories or interpretations of natural phenomena. Based on this, knowledge will grow and develop organising experimental data into interpretative paradigms which, though changeable, are such that, in general, any subsequent ones will incorporate the substance of the

[4] Benedetto Croce, Breviario di Estetica and *Aesthetica in nuce*, Adelphi, Milan 1990, incipit of the book. Croce was actually talking about art.

previous ones: scientific knowledge in this sense accumulates and does not decrease.

This is what we mean when we talk about scientific progress. And for the most part scientific progress is identified with sheer and pure “progress”, referred to the condition of mankind, although many of the events of the 20th century have shaken the belief in such identification; in any case the latter abandons the remit of science and is rather part of that of ideology.

Up to what extent it is true that the experimental method is the basis of science I’ll try and discuss later. I will include here, without any further analysis, this rooting of science in the objectiveness of facts in the very conventional definition of “science”.

Before we go any further, we need to specify one thing. The new science, beginning with Galileo, is expressed through the language of mathematics and the latter becomes more and more complex as the experimental sciences progress. Mathematics though, besides being a language for the other sciences, is a science in its own right, and in many respects older than the others as a form of rigorous knowledge. At the same time though, one of the basic traits of mathematics is that it is not experimental in the sense, for instance, of the so-called natural sciences, if we want to use this old category.

It is true that mathematics (both in terms of geometry and of science of numbers) was initially developed, somewhere in Mesopotamia or in the Nile Valley, out of practical needs. And it is also true that many developments, including modern-day ones, of mathematics have been and are driven by practical applications. Having said that, though, mathematics in its widest sense does not need the physical world to be validated: its scope of action and legitimisation is wholly comprised within the human mind.

A great surprise, or wonder, or mystery (or maybe a very trivial thing for some) is that the rules that appear to govern abstract thought can be applied so well to the representation of the outside world.[5]

What is important to stress here, also for the subsequent considerations on the faith/science topic, is the difference between mathematics and the natural sciences, however.

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[5] Albert Einstein said: ‘The most incomprehensible thing about the world is that it is at hall comprehensible’.

Another important difference concerns some disciplines that are nowadays considered sciences but which are not based, nor could they be, on reproducible experiments, but rather on systematic observation. I am mainly but not only talking about social and economic sciences, the theories of which are based on individual and collective human behaviour.

The scientific character of economics is essentially not very different from that of astrology (at least, astrology until the 17th century). This statement is not, and is not meant to be, disparaging: astrology was a complex and rigorous discipline, which developed for centuries on the basis of careful, methodical and difficult observation of the sky. Calculus and mathematics have been greatly stimulated by it; refined skills and instruments were devised in order to satisfy the needs of observation, as well as to gain benefits from its discoveries. Since ancient times, forecasting the eclipses in Mesopotamia, in the Nile or in the Huang Ho valleys, or observing the Venus cycle, which led to the complex calendar developed by the Maya, shows how important astrology was. Its importance is made even more evident by the technological developments it stimulated, as shown for instance by objects such as the Antikythera mechanism of the 2nd century BC,[6] or installations such as the "observatory" (assuming it was an observatory) of Chichén Itzá in the Yucatán (9th-10th century). Or still, the 15th century great Ulugh Beg observatory[7] in Samarkand, or Tycho Brahe's 16th century observatory on the isle of Uraniborg, complete with all its equipment of armillary spheres, astrolabes, sextants, etc.

By observing the sky, it was possible to identify, with a great level of accuracy, the regularity and typologies of phenomena happening in it, although without understanding their causes. Of course the reason for investigating was practical, in a way, because of the conviction that there was a strict correlation between celestial phenomena and the everyday life of human beings, and this belief was based on correspondences that people thought they observed, even without any direct proof for or against them. The priest-astronomers of ancient times looked at the sky to find predictions and signs for the future, but Galileo and Kepler too used to cast horoscopes, if nothing else to supplement their income.

Economics nowadays in some respect does not match the level of the astrology of the past, also because it deals with human behaviour *sub*

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[6] It is an object found in the wreck of a Grecian ship, recovered in 1900 from the sea off the coast of the island of Antikythera; it has been interpreted to be an "astronomic calculator".

[7] Ulugh Beg, of Mongolian descent and the grandson of Tamerlane, inherited a large part of the empire conquered by his grandfather, but also became famous as a mathematician and astronomer.

specie œconomica. Economics too is based on the accurate observation of behaviour, and it makes use of sophisticated analysis tools, mainly statistical, some of which were devised specifically for this. But its theories are far from having a validity comparable with that of physical theories, and it is common knowledge that a very important part of the decisions made on the stock markets (especially the Asian ones, but not only those) is inspired by... fortune-tellers.

We might say that, just like astrologists in the past, economists nowadays cast horoscopes too and, just like the best astrologists-psychologists of yesteryear, if their method is rigorous and rational their predictions may show a certain correspondence with the actual economic trends, though without ever being able to identify their mechanisms in a completely certain way.

In short, a big part of the skills that play such an important role in today's world could be considered empiric more than scientific. They are, ultimately, much closer to the type of practical knowledge which has always directed the actions of craftsmen than to that which was accumulated with the rise of modern science, from Galileo onwards. They may be very sophisticated skills, as a great gothic cathedral or the perfection of an ancient jewel show, but we do not ascribe a scientific character to them. On the other hand, an enormous part of everyday practical skills in our technological society (which are, not by coincidence, called *know how*) are of empiric-phenomenological type. Almost none of the people who use a smartphone have the faintest idea about how and why it works, and it is quite easy to verify that, even among people possessing a certain technological knowledge, some Aristotelian notions on nature that Galileo and Newton have long wiped out and that years of education, from primary school to university, should have eliminated are still deeply rooted.

Common behaviours and convictions, even among experts, are often derived more from prejudice than from scientific knowledge, which is not at all widespread even in the scientific circles, outside the specific technical sector in question.

So, to sum it up, in the course of this discussion I will essentially focus on the so-called exact and natural sciences, and I will use the term *science* for these as a whole.

CHAPTER II

BUT WHAT IS TRUTH?

Pilate's question[8] was probably meant in the educated context of the time and not referred to the Judaic religion. Many philosophers in Greece,[9] like most of the Eastern religious thought, stated (and state) that the sensible world is an illusion, or at least an imperfect offshoot of the real world, attainable only through reason (in Greek philosophy)[10] or meditation, in its different forms, typical of the followers of Buddha, of the yogas, of Christian and Muslim mystics. Pilate expresses the position of pragmatic-sceptical thought, which is certainly present around us nowadays too.

As far as we are concerned, I shall say that the truth of faith concerns the meaning of existence and the destiny of humans; it cannot be attained through reason alone, it is revealed: it is Truth itself that makes the first move. By its very nature the truth of faith can neither be "proved" nor subjected to a general examination; if that were the case, faith itself would no longer be necessary, in fact it would become counterproductive and dangerous instead. This consideration did not prevent humans from looking, for centuries, for proofs of the existence of God, and maybe, occasionally as well as naively, some people still look for them today.[11] If such proof was possible to find, theology would ipso facto turn into a branch of mathematics, and instead of believers and non-believers we would have to talk about educated and uneducated people. At the same

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[8] John 18:38: 'What is truth?'

[9] Parmenides of Elea for instance, Περὶ φύσεως (*On Nature*), 5th century BC.

[10] Plato will do as an example, for instance in book VII of *The Republic*.

[11] In the first half of the 19th century Neapolitan mathematician Vincenzo Flauti published the *Teoria dei miracoli*, in which he provided a mathematical demonstration of the existence of God. In 1854 George Boole, the father of formal logic, in chapter XIII of his work *The Laws of Thought*, related a set of formulas that demonstrated the existence of God, which had been proposed more than a century before by theologian Samuel Clarke. In the 20th century, even Kurt Gödel, whom we shall talk about later on, formulated a "mathematical proof of the existence of God".

time, just like it is not possible to find "proofs" of God's existence, it is not possible to prove his non-existence either, therefore the faculties of "scientific atheism" that existed in the last century are just tragic caricatures of the faculties of theology and expressions of a "faith", also "revealed" (under the control of the regime) and entirely dogmatic.[12]

Having thus placed the contents of (Christian) faith in the context of revelation, and therefore beyond what is humanly accessible, though still within the domain of what is understandable and acceptable (by choice) by each of us, let's now see what can be said about scientific truths.

Mathematic truths

Sometimes, in the debate on the subject of science and faith, we may come across stances that only assume as true, whether explicitly or implicitly, what can be proved. This type of approach is seemingly typical of mathematics; mathematics is generally considered to be the realm of "2 plus 2 equals 4": cold but undeniable. Is that so?

Well, not even for mathematics only what can be proved is true. In the 1930s Kurt Gödel, an Austrian mathematician who then became naturalised American, demonstrated two important theorems. Those, aside from the technical details, state that in any axiomatic system[13] which includes the elementary theory of natural numbers there necessarily are some propositions that are true but cannot be proved to be true, or that are false but cannot be proved to be false.[14]

Gödel was an extremely intelligent man, but since his youth he had always been psychologically fragile; he died in 1978, practically of starvation because he was convinced that somebody wanted to poison him.

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[12] Just like, in recent years, the advertising campaigns promoted by the Union of Rationalist Atheists and Agnostics (Unione degli Atei e Agnostici Razionalisti-UAAR) on city buses of several cities, in Italy like in Spain or in the United Kingdom, are perfectly suitable for a *de propaganda fide* organisation.

[13] That is a set of statements that can be logically deduced from a set of axioms. An axiom is a proposition that is assumed to be true, without demonstration, and that serves as a starting point to build the system consistently.

[14] There are numerous examples of undecidable propositions within specific logic systems. Generally, a number of technical terms need to be explained in order to appreciate them. I will only mention a couple of cases already identified by Gödel and by Paul Cohen within the scope of traditional axiomatization of the set theory: the so-called axiom of choice and the continuum hypothesis.

Perhaps it took a person like him to *prove* that there are logic truths… that cannot be proved.

One might think that the question only applies to the abstruse world of mathematical logic, but that is not the case. We must not forget that formal mathematics and logic constitute the language physics, and in general the natural sciences, use, and that by this language they describe the world. Basically, no mathematically-formalised scientific knowledge can prove all the implications of its assumptions, however verifiable they are on a case by case basis.

The truths of physics

So, if in mathematics too there are indemonstrable truths, what can be said about physics? Having dealt with the issue of demonstrability, we now have to address verifiability.

For a physicist it is true what can be subjected to experimental test. It will never be, in principle, a final truth, because a new fact may always come up and alter the pattern set out to account for all previous facts, but it will always be a progressive and adaptive truth, which grows and expands with experience and methodical investigation. At least, this is the idealised way in which physics is portrayed. In order to understand if and to what extent things are really like this we need to look a bit deeper at how this science has developed over the last two centuries.

During the whole of 19^{th} and the first part of the 20^{th} century, physics, which is in fact so vast and diverse that could be considered more as a set of sciences than as a single science, made exceptional progress in understanding the physical world, based on the solid foundations of experimentation. Physicists of the 19^{th} century, and of most of the 20^{th}, were convinced they did not need "metaphysical" criteria to ascertain the truth, because "truth" was out there, in the world, objective and verifiable.

How can I get to know whether light is made of corpuscles or not? I will devise a set of consistent experiments and analyse their results; I will not go and read the thoughts of philosophers of the past on the matter, nor will I consult some "prophet" or go by the current opinion of the scientific community.

This relevance, in fact dominance, of the experimental approach led to an enormous growth of practical knowledge and technology, and with them to the extraordinary development of industry. A very popular image of the "scientist", present throughout the 20^{th} century also in comic books, is that of a man in a white coat, in a laboratory filled with weird machinery. On the other hand, as late as in the 1930s, Enrico Fermi and the other members of the famous Via Panisperna group[15] were able to substantially advance the knowledge on radioactivity and on the atomic nucleus by carrying out tests with a tin tablets tube they bought at the chemist's and the water from the goldfish fountain in the courtyard of the Institute of Physics in Rome. Today the situation is very different: actual experiments are no longer carried out with makeshift tools and a lot of ingenuity, technological apparatuses are extremely complex, processing the raw data needed to get to what is believed to be the result is much more important than the experiment in itself, and the method employed often already contains most of the theory that needs to be verified. Separating fact from interpretation is not always easy, and, at the most advanced frontier of research, experiments are often impractical and sometimes altogether impossible.

The very progress of knowledge of physics has in a certain way consolidated the "middle ground" of learning, pushing the limits of the unknown or of the not understood towards the two opposite directions of the extremely small and the extremely large. Down in the innermost depths of the structure of matter we have now got to much below the size of the atomic nucleus; going further down (which means getting nearer and nearer to the heart of those entities we keep calling "particles") requires more and more energy, so much that it sets practical limits that are insurmountable on the surface of the earth.

At the opposite extreme, the possibility of observation has reached immense distances which, if we measure them in terms of the time light needs to cover them, far exceed 99% of the age attributed to the whole universe (about 14 billion years). At such scale experiments are, by definition, impossible and observation can only provide what is given and accessible to our instruments, i.e. a minimal part of what we would need to validate many of our theories.

Fundamental physics, in such conditions, is experiencing more and more what I would call a "metaphysical" drift (in its literal meaning: μετὰ τὰ φυσικά, beyond physics).[16] To unsolved problems physicists tend to suggest solutions which, based on known facts (sometimes very few), are logically deduced from a group of axioms or basic assumptions, consistent with each other but not proved. This approach is very similar to the one of mathematics, even though it does not fall in its remit because it is applied to the world, which is in principle testable, if not yet very much tested.

[15] The Institute of Physics of the University of Rome at the time was in Via Panisperna.

[16] In the series of Aristotelian books this was the name of those that followed the discussion of the physical world.

The great paradigms of physics

The unsolved problems in the interpretation of the physical world fit into two mutually incompatible scientific paradigms, both developed in the 20th century: general relativity and quantum mechanics. There is an ongoing effort aimed at reconciling these two setups (actually, more than anything trying to bring the former into the latter). So far this effort has not yielded any real results.

The root of the incompatibility between the two paradigms (please note, both successful in their own domain) lies in an old friend of philosophers': time. '*Quid est tempus*?' asked himself Augustine, and answered that he knew very well as long as nobody asked him, but he no longer knew when someone asked him the question.[17]

Relativity

Einstein solved the problem of the nature of time (as far as physics is concerned) by converting it into a fourth dimension of space-time (a specific space that, besides height, width and depth, also includes duration), substantially equivalent to the three traditional ones. In this setup, the description of the physical world is reduced to a question of geometry. In particular, gravitational attraction is described as a geometrical property of space and time, joined in space-time.

The general theory of relativity, which includes the above, apart from being particularly elegant (even though the concept of "elegance" for a theory is not scientific at all), has been successful in explaining, and more importantly foreseeing, several phenomena that were then actually observed. The first result Einstein achieved was explaining a small anomaly, which had already long been detected by astronomers, in the behaviour of the perihelion of Mercury's orbit around the sun. Alternative explanations would have also been possible, but they would have been much more *ad hoc*. Another success came when general relativity made it possible to predict that the gravitational field of the Sun causes a bending of the rays of light streaming near the star in a way that was first confirmed in 1919 by Eddington,[18] during a solar eclipse. With the benefit of hindsight, we can see that that confirmation, because of the experimental uncertainties, was much more problematic than it was admitted at the time,

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[17] '*Quid est tempus? Si nemo a me quaerat, scio; si quaerenti explicare velim, nescio*' (What is time? If nobody asks me I know; if I wanted to explain it to those who ask me I don't!) St Augustine, *Confessions*, XI, 14.

[18] Early 20th century British astrophysicist Sir Arthur Eddington.

but in any case it was precisely from 1919 that Einstein's theory gained the universal popularity, including with the media, it still enjoys today. And anyway several other confirmations, much more accurate than Eddington's, followed.

Amongst the forecasts obtained from studying and solving the general relativity equations there was also one that Einstein did not like at all, so much that he tried for a while to skirt around the problem by modifying his own equations; it was the expansion of the universe.[19] However, whether Einstein liked it or not, in 1929 the forecast of the expansion of the universe was also confirmed:[20] apparently galaxies, which are scattered across the cosmos, tend to move away from each other at a speed that increases as they get further away from us.[21]

The reason why Einstein did not like this prediction of his theory was that, if we extrapolate the universal expansion backwards we get not so much, as it is often erroneously written at popularising level, towards a single geometric point, but towards a state of infinite density. Or in any case towards something that is very similar to a *beginning*, with all its extra-scientific implications. Einstein, as well as many other physicists up to him (and some even after him),[22] was convinced that the universe had to be in a sort of stationary state: always more or less the same to what it always was, since eternity and for eternity. The real world took it upon itself to prove Einstein right even when he did not think he was, and this is probably one of the characteristics that we can count as positive of the scientific method.

Having said that, it is not necessary for us to go any deeper in discussing the problems of cosmology as seen through the eyes of science or through those of faith, nor to go into the technical-mathematical aspects of the theory of relativity. The significant element is the one I began with above: for relativity, time is a dimension just like the spatial ones (apart

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[19] Russian mathematician and cosmologist Aleksandr Friedman and Belgian priest, physicist and astronomer Georges Lemaître in the 1920s discovered, independently of one another, that Einstein's equations, when applied to cosmology, implied an expansion of the universe in time.

[20] It was confirmed by the observations of American astronomer and astrophysicist Edwin Hubble.

[21] The latest news on the expansion of the universe, discovered towards the end of 1998, is that the expansion appears to take place at a speed that increases in time: basically, at least in the stage of life of the cosmos which includes us, it is an accelerated expansion.

[22] The most famous is probably British astrophysicist Fred Hoyle, who coined the *Big Bang* expression (which was meant to be ironic), universally used to refer to the initial singularity.

from a few technicalities) and serves the purpose of identifying “points”, which are actually called *events*, within a particular space-time, exactly in the same way as, in our everyday experience, the distance from the floor and from two vertical walls can be used to locate the corner of a table.

Essentially it is as if the universe was, so to speak, “drawn” on a four-dimension sheet (which therefore we are not able to imagine, but which we can perfectly deal with from a mathematical point of view). If that is the case, past and future are just figures of speech: everything is simultaneously present on the “sheet” anyway. It is funny how this view reminds of the traditional one of the great book of fate, where everything is already written.

From this point of view relativity (both special and general) was in some respect the last great physics theory of the 19th century, although it was formulated at the beginning of the 20th century. The world is described in strictly mechanistic terms, more or less like Descartes used to do. Obviously within this paradigm nobody knows what happens to freedom and conscience, since nothing is open or changeable. Is our perception of the things of the world just an illusion? And on the other hand, even the word illusion does not mean anything if referred to some sort of mechanical robot.

Bear in mind though, we are not talking about a philosophical conjecture, but about a physical theory confirmed by plenty of experimental evidence. As regards the evanescence of the “present”, for instance, we have the concept of relativity of simultaneity, which caused quite a stir when restricted relativity was formulated (and to this day is one of the aspects of the theory that most mystifies novices). If we consider two observers who are in the same place at the same time, but that move in relation to each other, two events that appear to be simultaneous to one of them happen, instead, in succession for the other, and vice versa. This astonishing statement is confirmed, although indirectly, in several cases found in physical phenomenology. However, things can go the way I described only if the two observed events coexist also when one happens to be in the future of the other.

What in our everyday experience appears as a small, practically punctiform, object, corresponds in space-time to a “story”, represented by a line; we may identify a future and a past in relation to a specific point of the line, but the whole line is already there. The mystery regarding what we are, with our vicissitudes, deepens.

Although there are countless suggestions as regards extending or modifying general relativity, almost a century on from its formulation the theory remains strong and its mathematical system is consistent.

Quantum mechanics

The other great paradigm of modern physics is quantum mechanics. The situation here is just as astonishing, indeed unsettling, as for relativity. I will try and avoid any detail and stick to the aspects that are in some way paradoxical.

Beginning in 1900 with Max Planck, continuing with Einstein in 1905 and with a long series of great physicists, such as Niels Bohr, Erwin Schrödinger, Werner Karl Heisenberg, Paul Dirac and many others, it was discovered that a number of phenomena that could be detected experimentally at the atomic and subatomic scale could not be explained if the particles constituting matter kept being considered like small solid objects (almost punctiform balls). On the other hand, things were fine when considering them to be like waves. To be precise it was noted that, depending on the conditions of the problem and of the physical quantities that were to be calculated, the same object, for instance an electron, had to be treated as a particle or as a wave. This dualism had to be applied also to light, which at least since the very first years of the 19th century, with Thomas Young, had been usually thought of as a wave, discarding the old corpuscular theory upheld by Newton himself. The paradox, though, was (and still is) that the equations allowing to describe the behaviour of an electron (to continue with the same example) are wave equations, but when, guided by the forecasts achieved through those equations, we devise an experiment aimed at detecting the presence of an electron, the latter will appear as a particle. It was Niels Bohr who condensed this twofold nature in the concept of *complementarity*: the nature of the constituents of matter (as well as of electromagnetic radiation) is simultaneously both of particles and of waves; however, when they are detected, only one or the other of these two natures will manifest itself. The macroscopic objects of our everyday life do not show any similar behaviour, but it is also true that any extended body, including our own, is formed by an enormous number of those particles to which the principle of complementarity applies.

As far as we are concerned, the most significant aspect is yet another, although it is not entirely separate from the complementarity I mentioned. The equations describing the behaviour of the constituents of matter are *wave equations*, but they are perfectly defined and, in some simple but essential cases, can also be solved exactly.

Despite that, the behaviour of a quantum system, i.e. a material system at an atomic or subatomic scale, is never exactly predictable. One solution of the equation(s) describing one electron in a given context is a specific wave function[23] which has values in an entire space region, if not everywhere. But nobody can detect or measure a wave function *per se*: ultimately, what a measuring apparatus will be able to detect is the presence of a particle in a position and not in another, with certain characteristics and not others.

What is the link between the wave function and the particle detected? From the wave function it is possible to calculate the probability that the outcome of an experiment will be one rather than another: no more and no less. In other words, although the elementary laws that are applied are deterministic and the equations are complete, and although all the values of all the parameters and the initial conditions are known, it is not possible, not even in principle, to predict the result of a single quantum experiment. It is only possible to calculate the distribution of probability of a number of results, all equally possible. In other words still, if we repeat the same[24] experiment 100, 1000, 100,000 or even more times, in principle we will get a different result every time, but results will tend to gather around the most probable values.

A given quantum system does not have a single future for itself, but a number of futures, all possible although with a different degree of probability. This property of the equations and of their solutions has implications worthy of a science-fiction novel (and effectively there is a large number of fantasy literary works on the matter),[25] which can be legitimately be formulated as complete scientific theories though, like the theory of many-worlds, brought forward by Hugh Everett in 1957.[26]

The debate over the interpretation of quantum mechanics has been ongoing for at least 90 years, and to this day we could say without any straining that, as Nobel Prize Richard Feynmann stated, nobody can claim to have truly understood quantum mechanics.

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[23] Those of you who are familiar with this subject matter are aware of the subtlety and conceptual complexities of quantum mechanics; I hope they will forgive the hyper-simplifications I am making and will try and focus on the essence of the concepts rather than on the formal rigour.

[24] Each time with the same conditions and the same initial values.

[25] Proper science-fiction aside, there are also works that are halfway between popularisation and fairy tale, like the series of short stories written by Ukrainian (and naturalised American) physicist George Gamow from the 1930s onwards, under the titles: *Mr Tompkins in Wonderland, Mr Tompkins explores the atom, Mr Tompkins inside himself: Adventures in the new biology, Mr Tompkins learns the facts of life.*

[26] Hugh Everett III, *'Relative State' Formulation of Quantum Mechanics*, 'Reviews of Modern Physics', vol. 29, no. 3, July 1957, pages 454-462.

Quantum mechanics, though, is an extremely successful theory. It has achieved exceptional results in the field of molecular, atomic and nuclear physics and is the basis of an enormous number of applications also affecting our everyday life.[27]

At the same time though, it is also evident that the basis of quantum mechanics is incompatible with the theory of relativity,[28] according to which future is already happening and everything in space-time is perfectly determined.

A specific point of conflict between quantum mechanics and relativity is that of action at a distance. Modern physics, and specifically relativity, has discarded any possibility of "action at a distance". Every event must have local immediate causes: if something happens here, it means that the causes of what has happened are present here. This implies that no cause can produce instant effects in different places from the one in which it acts: it takes time for any physical "messenger" to travel between the source of interaction and the system in which it will manifest itself. Moreover: any interaction must propagate at a finite speed, maybe extremely high, such as the speed of light, but finite. Immediate action at a distance is, in short, confined to the realm of witchcraft and not of physics.

Now though, the nature of the equations of quantum mechanics and the fact that global (i.e. valid everywhere) solutions depend on local conditions, lead to something very similar to action at a distance and propagation at infinite speed. Einstein insisted a lot on this point, especially in the 1930s, and he kept maintaining that quantum mechanics was in some way incomplete. Yet, quantum mechanics does not seem to be "incomplete", as Einstein claimed, and despite this it seems to imply exactly some sort of action at a distance.[29] Here too, there is total discrepancy between quantum mechanics and relativity.

So, we have seen that according to quantum mechanics the world is essentially unpredictable, even when we know the mechanisms regulating it. But there is no need for the extreme abstraction of quantum mechanics

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[27] In the healthcare field we can mention nuclear magnetic resonance imaging and Positron Emission Tomography (PET); as regards the study of materials I will mention the electron microscope; laser is found in a vast number of diverse applications; nanotechnologies, which allow the manipulation of single atoms, are based on quantum mechanics; most of microelectronics would be unthinkable without quantum mechanics, and so on and so forth.

[28] To be precise, quantum mechanics is compatible with special relativity, but not with general relativity.

[29] From a technical point of view, the argument involves the inequalities proposed by Irish physicist John Bell in 1964 and the subsequent experimental tests.

to state the impossibility, for science, to foresee the future, if not in general terms and as possible evolutions. In fact, classical physics is more than enough, although this was not noticed until about 1963,[30] when an article written by American meteorologist Edward Lorenz gave rise to a branch of research that led to the definition of what was later called, with an apparent contradiction in terms, "deterministic chaos".

What is it then? The behaviour of complex material systems (made up by many parts interacting with each other) is described in physics by mathematical equations and, in most cases, these equations are not linear. In simpler terms, in these systems effects, contrary to what our intuition would normally lead us to think, are not simply proportional to the causes.

When this is the case, an even imperceptible change of the initial conditions of the problem may lead to completely different evolutions; in properly chaotic systems even an *arbitrarily* small change of the initial conditions produces entirely different developments.[31] All this, I wish to stress once more, in the presence of known and deterministic laws.

A typical example is meteorology. Nowadays, as everybody knows, the weather forecast has reached levels of reliability that were simply unimaginable a few decades ago; yet, beyond four of five days predictability decreases dramatically: the behaviour of the atmosphere is intrinsically chaotic, just like some aspects of biological systems are chaotic, such as fluids or more generally thermodynamic systems.

In short, even with 19th century physics and even knowing the initial conditions, the future may result essentially unpredictable.

A coherent picture?

In light of the previous paragraphs, we see that nowadays physics does not offer a unified view of the physical world; in fact, it proposes, with

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[30] The problem had actually emerged several times before, for instance with Jules Henry Poincaré, but it had never been properly addressed.

[31] Astonishingly, this concept was effectively expressed in a literary work in 1842 by none other than Edgar Allan Poe, as can be seen from the following quotation taken from *The Mystery of Marie Roget*: 'For, in respect to the latter branch of the supposition, it should be considered that the most trifling variation in the facts of the two cases might give rise to the most important miscalculations, by diverting thoroughly the two courses of events; very much as, in arithmetic, an error which, in its own individuality, may be inappreciable, produces, at length, by dint of multiplication at all points of the process, a result enormously at variance with truth.' (*Tales of Mistery and Imagination*, CRW Publishing, London 2008, page 278).

equal success, two mutually incompatible basic frameworks. On the one hand relativity, strictly deterministic, on the other quantum mechanics, intrinsically probabilistic. On the one hand a future that already exists, on the other a range of futures, each of which is possible although with different probability. In any case, an essentially unpredictable future even when a deterministic model is adopted.

Of course, at first sight quantum mechanics would seem more appropriate for a world destined to house beings who can in some way hope to *build* their own future. And, as we might expect, there have been those who have interpreted it in this sense,[32] both in the Christian world and in contexts centred on other types of spirituality (see for instance the views expressed by Fritjof Capra in *The Tao of Physics*). We must be extremely cautious, however, when using in the philosophical field categories and theories developed in a physical-mathematical environment.

Attempts are currently being made, and have been for some time, at eliminating the conflict between general relativity and quantum mechanics, but none of them has produced convincing results. Generally speaking, perhaps because of its being more "human", like I mentioned above, and despite its formal abstruseness, these attempts try to trace general relativity back to quantum mechanics, or, as they say, to "quantise" gravity. The main branches along which theoretical physicists interested in this are moving are essentially two, not entirely compatible with each other: the "string" theory, called that because it hypothesises that the fundamental constituents of matter are extremely small one-dimensional objects, like small strings or lanyards; and Loop Quantum Gravity, based on a discretisation of space. Both approaches, though, seem to need to clearly separate space from time and, at least in the case of the strings, require the existence of additional, non-perceptible, dimensions to the prescribed four.

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[32] See for instance Julian Barbour, in *The End of Time*. In some respect Richard Feynman, 1965 Nobel Prize for physics, saw it that way too.

CHAPTER III

PHYSICS, METAPHYSICS AND IDEOLOGY

In the previous paragraphs we saw that those who consider the truths of physics as something that is built in a progressive and univocal way according to a certain and incontrovertible process are very much mistaken. If we move away from the scope and the dimension of phenomena on a human scale, that is those ranging from the microscopic (in its literal meaning) to the celestial (meaning what we see in the sky) there is even more.

I have already mentioned that the utmost frontiers of research in physics concern the universe and its history on the one hand, and the nature, structure and properties of the essential constituents of matter (assuming this expression makes even sense) on the other. Well, if somebody took the trouble to read through the extremely vast scientific literature on these topics (granting, for the sake of argument, that they can overcome the technical-linguistic barrier preventing the forays of non-experts in the field), they would easily notice how highly conjectural the theories which are developed are. In such situation, research is also characterised by an unavoidable ideological element, in that those who carry out the investigations try to see what they want or would like to see. Ultimately, for many authors and for most work, it is a case of elaborating the consequences of particular conditions without them having been in some way validated, if not verified. '*Entia non sunt multiplicanda praeter necessitatem*',[33] William of Ockham wrote in the 14th century, but in fundamental physics many unsolved problems are "solved" by introducing new "fields", new dimensions, new components to the universal mix.

I shall now go back to a point I have mentioned before: the problem of action at a distance. The need for causes and effects to be contextual in time and space undoubtedly creates problems when we consider universal gravitation, or even just the action of a magnet on a nail located a few centimetres away. To paraphrase Aristotle, we could say that there is

[33] 'Entities should not be multiplied beyond what is necessary'.

nothing between the "motor" and the "mobile": how is it possible for the action to be transmitted?

The answer to this question was found by introducing a concept that any physicist will now take for granted, but which is anything but trivial: the concept of *field*. A field is something real that permeates space (in principle the whole of space, apart from the limits set by specific conditions on some of the boundaries) and that lasts in time. Fields are responsible for the propagation of some sort of interaction between a physical source and a receptor, also physical. Audience and actors in a theatre are immersed in the same sound field: the audience hears the voice of the actor not "at a distance", but because locally their eardrums are stimulated by the fluctuations of the air that have just been originated by the mouth of the actor. This situation, which in the case of sound waves seems to be easily understandable, is not so simple to accept (and indeed it has caused problems) in the case of gravity and electromagnetism.

Ultimately, what is the difference between a field of force and the Aristotelian idea of "proper places" towards which elements naturally tend? The difference lies in the fact that the field is described by specific mathematical equations and therefore its behaviour and properties can, in principle, be perfectly known and foreseen: there is nothing mysterious and unfathomable. However, the idea of field should be harder to accept for a rational spirit than it is for those who are prone to emotional-irrational explanations, so much so that Galileo rejected the idea, commonly widespread since ancient times, that tides were caused by the action of the Moon. It was unthinkable that the Moon, which is in the sky, could cause an effect on what is on Earth, and he preferred to formulate his own (wrong) explanation, based on dynamic considerations on the movement of the Earth.[34] One of the objections to Newton's theory of universal gravitation, and not a trivial one, was similar to what Galileo brought up (a few decades before Newton was born) about the tides: how can bodies that are so far away from each other exert any action on one another, and moreover do so, as the theory of universal gravitation claims, instantly?

Einstein refuted the idea of action at a distance altogether in his general relativity, considering exactly that any interaction can only be local, both in space and in time: anything happening here and now cannot be due to anything but causes that are present here and now. Generally speaking, this approach implies that the explicit observation of remote sources of local facts can only be explained through the presence of "something" which, located between the source and the local system, is able to transmit

[34] The theory is expounded in the fourth day of the *Dialogo dei massimi sistemi*.

the interaction: this, once it was defined formally and in mathematical terms, is the field. A direct consequence of this is that there cannot be instant actions at a distance: no interaction, including the gravitational one, can propagate instantly, that is at infinite speed.[35]

Apart from the modern formalisation, what we nowadays call "field" had been long considered, in the philosophical-scientific thought, with the name of *ether*. Descartes too, more or less at the same time as Galileo, thought that heavenly bodies interacted with each other through an ether-vortex.[36] The whole of the 19^{th} century (and the very first years of the 20^{th} century), in physics, was characterised by the (theoretical and experimental) search for the luminiferous ether, namely the means responsible for the transmission of light and, more generally, of electromagnetic interactions through space, which was otherwise empty.

It is a known fact (and it is commonly believed that this was the end of it) that the need to hypothesise an ether was eliminated once and for all by Einstein in 1905. Actually it was no longer talked about in physics, but on closer inspection we see that ether has simply changed name: nowadays, in quantum mechanics, the old ether is known as "vacuum" and in general relativity as "space-time".

The most intriguing situation is that of quantum mechanics, where, effectively, a field, i.e. something that in principle permeates the whole universe (and the whole of time), is associated to each of those that are traditionally called "particles".

I will now finally get to the point about which I have been digressing so much. Let's say that theoretical physicists have got a bit carried away with fields, and discovered that, as long as some more or less intricate mathematical rules are respected, the multiplying of fields can be a convenient way of explaining facts that would otherwise be unexplained. In fact, a field can only be revealed through the interactions it causes; therefore, if we are faced with some phenomenon that does not fall within the patterns accepted up to that point, why not suggest the existence of a new field responsible for it?

While exploring the sky we discover a radiation corresponding more or less to the same temperature in every direction, even though the regions it

[35] In fact, the idea of instant propagation is linked to the concept of rigid body: if a bar of perfectly rigid (i.e. non-deformable) material were to be placed between two points, a push on one end would instantly be felt at the other end. Rigid bodies, though, are abstractions and any action needs a finite time in order to propagate, even within matter.

[36] René Descartes, *Principia Philosophiae*, Elzevir, Amsterdam 1644.

seems to be coming from are extremely far from each other, so much that they are in no causal contact with each other? Things will fall back into place by supposing the existence of a suitable field,[37] which would have determined, for a short time, an extremely fast expansion of the universe (known as "inflation"), to the point of "freezing" the situation of the instant in which the inflation started and instantly transfer it to a much bigger scale. We discover that, seemingly, from a certain point onwards the expansion of the universe is accelerating? Everything is back to normal if we imagine that the universe itself is permeated by a suitable "dark energy"[38] which produces the acceleration. This dark energy can be imagined in many forms, and the more astonishing its properties are, the least they are verifiable. However much the universe is expanding, for example, this energy never dilutes.[39] Or we can assume that it behaves differently and consequently give it different names, maybe borrowing them from the history of philosophy, such as "quintessence",[40] or using fantastic definitions such as "phantom energy".

We realise that the speed at which stars revolve inside spiral galaxies, or at which galaxies move in clusters is higher than what Newton's (or even Einstein's) gravitation would imply? We can assume the existence of some invisible matter (namely, dark matter) that makes sure everything tallies up.

In animist societies, seemingly incomprehensible natural phenomena are generally "explained" by ascribing them to a multitude of specialist spirits: those of the springs, those of the trees, those of the clouds etc. Could it be that the difference only lies in the use of mathematical language?

The main point, though, is that on the basis of a limited number of observed or tested facts it is possible, as long as we make sure the internal logic is consistent, to build several separate conceptual frameworks, without concretely being able to differentiate between them.

The progress of sciences, including the "exact" ones as long as experimental, is not linear at all. It often moves in leaps and bounds and, besides reason, is based on intuition and also on the faculties of the princes

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[37] The inflaton.

[38] Dark because it does not manifest itself in any way other than through the effect it is supposed to explain.

[39] This is the version of the "cosmological constant".

[40] A "fifth essence" is mentioned by Aristotle as an additional element to the four already known: air, water, earth and fire.