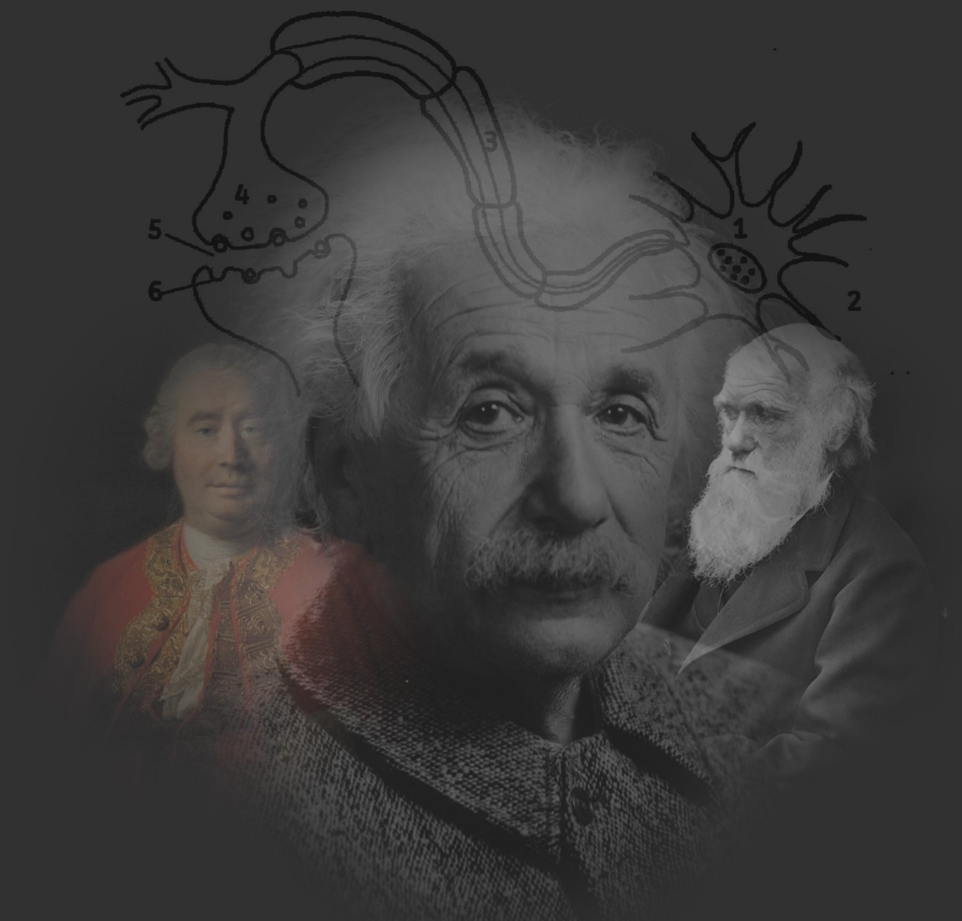
Einstein's Quantum Error

An Approach to Rationality



Simon Altmann

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By

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Cambridge Scholars Publishing

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PREFACE

This little book aims at introducing a difficult subject in the most user-friendly way possible, so that the reader will not be distracted by being offered more material than is essential. This is possible because all necessary bibliographical references as well as any additional material may be obtained from my more detailed book, *Is Nature Supernatural?*

I am sure I do not need to stress the importance of the subjects I treat here. Einstein's strong aversion to the probabilistic aspects of quantum mechanics obscured the understanding of this theory by scientists and the public. Even now, despite so much excellent work in the literature, its interpretation might appear confusing to the non-specialist.

The problem is that few books, if any, start from a discussion of the criteria by which basic principles are validated. And the crucial point made in this text is that principles that are used in the *macroworld* lose validity when dealing with elementary particles such as electrons and photons (the *microworld*). This explains why it is unavoidable that probability statements be used for such elementary particles, a question that so much exercised Einstein's mind.

The work discussed above will be conducted through a simple but careful analysis of Hume's ideas on causality, which fits in seamlessly with Darwin's theory of evolution. One important result of this analysis is that it provides a good example of what rational thinking entails.

It is a strange feature of our culture that despite the extraordinary successes of science, scepticism about it appears to be on the increase: belief in creationism and climate change denial are just two serious examples. What is even more worrying, however, is that some perfectly respectable academics, even scientists, with undoubtedly first-class intellects, appear prone to propagate ideas that undermine scientific thinking. I shall discuss a plausible reason for this unhealthy situation and if my defence of rationality here helps redress this confusion I will have done my job.

A novel feature of this book is that some chapters are accompanied by relevant poems (mostly transcribed from my collection "Not for Poets", available as an eBook). Not only do I hope that this will serve as a very necessary bridge towards the humanities, but it is also my experience that one page of poetry is worth many more of prose.

I am most grateful to my sons Daniel and Gerry, the first for reading a draft and making very useful suggestions and the second for very useful critical discussion. Paul Altmann, as always, provided invaluable help in keeping my computer within the bounds of sanity. Kate Altmann kindly produced for me a picture of a neuron, for which I am grateful. Errors and infelicities that remain, however, are my personal property.

SLA
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CHAPTER ONE

WHAT THIS BOOK IS ALL ABOUT

This chapter will present a broad bird's-eye view of the subjects that will be properly discussed later on in this book, so that no reader should worry if things are not sufficiently clear at this stage.

Given the title of this book I had better state now that it is not in any way intended to derogate Einstein's immense stature: no man, Darwin excepted, did more in the last millennium to allow mankind to grow up. Before them we were children: they made us into teen-agers; one day we shall be adults, I hope.

I expect that in going through this book some ideas will emerge about what we might call rational thinking, however tenuous this concept must be at the beginning. Just in case, I want to make it clear now that I do not consider rational physical thinking as the sum total of human mental acts: poetry, art, theology, politics and so much more are also necessarily amongst them. What is most important, however, is to respect the boundaries between the various forms of mental activity: there is nothing worse than a car driver who behaves as if he were in charge of a train. It happens sometimes, nevertheless, that distinguished scientists, like Einstein, engage in prophecy and, vice versa, that theologians try to sustain their otherwise respectable beliefs with the borrowed fig-leaves of scientific rationality.

Causality

One of the main props of rational thinking is the use of causality, which was empirically understood, however sketchily, ever since the dawn of civilization. Causality at that stage was little more than a recognition of some of the regularities of nature: the same event, *cause,* (e.g. fire) was regularly followed by the same *effect* (e.g. heat).

Causality came to have a fundamental role in physics when Newton discovered his laws of motion. His second law, in fact, means that the pair 'position and velocity' of a body is linked causally in time. This is so because the value of the position and velocity of a particle at a time *t* (*cause*) *determine* the value of the same pair at any later time *t'* (*effect*). It must be clearly understood that only the constant mass of the particle matters: whether it is made of ivory or wood is totally irrelevant. Also, you must realize that 'particle' may refer, with some adjustments, to any massive body such as a lorry, even.

Eventually, philosophers invented a *Causality Principle*, the validity of which was taken by many to be the result of everyday perception. Hume was the first major philosopher who took an empirical, naturalistic, approach to causality: he realized that, however counter-intuitive this appears to be, the causal *relation* when applied to the physical world is, despite appearances to the contrary, not perceivable, and neither is it the result of a logical necessity. Hume's ideas will play a major part in this book, since he was seriously misunderstood in the second half of the twentieth century, especially by the French-American philosopher Ducasse and his followers, and we shall have to discuss all this very carefully.

It was Darwin who changed the way in which humans understand their relation to nature. He taught us that we were not outright divine creations but the result of a process where randomness played a part. The important idea is now that humans, like the rest of the living world, must reflect the inputs that nature introduced in the evolutionary process (*philogenesis*) that created their species. As a result of this, allegedly universal principles that might be thought of as a reflection of a creator or of a world of eternal truths, cannot be uncritically used in rational thinking.

When we complete Hume's programme in the light of post-Darwinian natural science, it will follow that the principle of causality cannot be applied except to that part of nature (the *macroworld* of objects directly accessible to our senses) that created the inputs which guided the evolution of our rational system. This means that causality cannot be expected to apply necessarily to elementary particles like electrons or atoms, which were never experienced by humans in their evolutionary process. This totally undermines Einstein's attempt to preserve the use of causality in the *microworld*, the world of the elementary particles.

Causality as contextual: consequences

To summarize, the most important argument of this book is that causality is *contextual* and that it can only be applied in the context of the macroworld. I shall of course provide reasons for this statement later on in the book (Chapter 4) but I shall try to illustrate here the consequences of this fundamental principle as regards the behaviour of the electron, for example. In Figure 1 we measure the position of an electron by making it pass through a diaphragm. If this were a billiard ball, for instance, we could also know its velocity (given by the arrow in the figure) and the ball would hit the screen in the place shown. This is not so for the electron, because if we were able to know its velocity, then it would obey the *causal* Newton's equation, which is not permitted, since causality for an elementary particle is out of context. This is a crucial point which will be fully discussed in this book. As the electron leaves the diaphragm, therefore, its velocity will be in any random direction so that it will hit a random point on the screen. This is in fact what is experimentally observed.

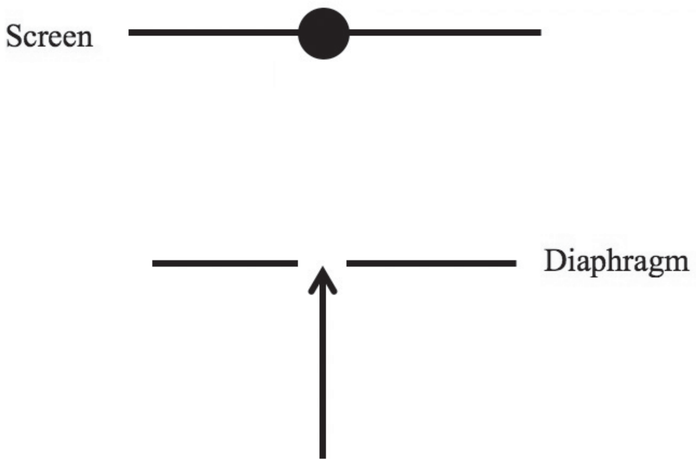

Fig. 1. Measuring the electron position

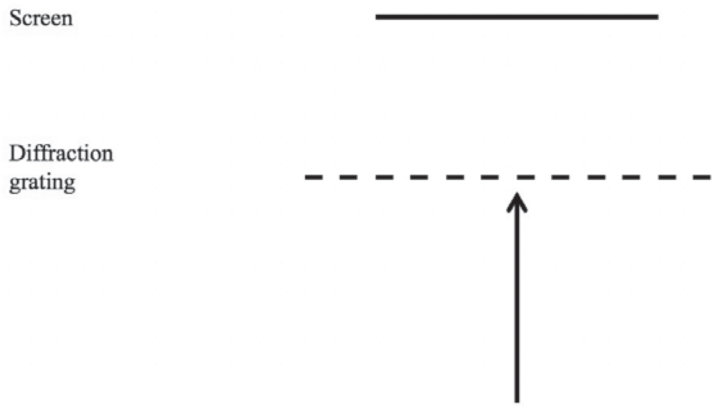

Fig. 2. Measuring the electron velocity

But we could perform an alternative observation in which we measure the momentum (mass times velocity) of the electron. This means that, if Newton's causality cannot be operative, the position of the particle cannot be determined. The particle will therefore be a delocalized object but with a precise velocity. This is exactly like a *wave*: a wave in the sea, for instance, moves with a given velocity but it can hit at precisely the same time two widely separated swimmers. It is known from elementary physics that to measure the velocity of a wave we need a diffraction grating, as shown in Figure 2. When the electron hits the diffraction grating it is delocalized, as waves are, but it will have a precise velocity which is measured by the diffraction pattern created in the screen. And this is precisely what is observed.

The fact that electrons could behave either as particles, when their precise position is measured, or as waves, when their precise velocity is determined, was well known experimentally since the early twentieth century and was the cause of much perplexity and confusion. This remarkable property, nevertheless, follows very simply from the principle that we enunciated, that causality is contextual and cannot be applied to the microworld, a point which of course, as I have said, we shall fully discuss. You can now appreciate, nevertheless, the extraordinary importance of understanding the contextuality of the causality principle. A little bit of good philosophy goes a very long way!

It is a pity that Einstein was very weak in this respect. As a teenager he had read Kant, and although later on he debunked this great philosopher for his wrong ideas on space and time, he seems never to have doubted

Kant's views of causality as a universal, absolute, principle. It is true that you cannot expect him to have known everything, but it would have been good if he had been aware of his own limitations, although the great reverence that he received did not help him in being more cautious.

Rational thinking

For centuries some philosophers, in trying to understand the world, put their money on the one thing that they thought they knew without intermediaries: their minds. Unfortunately, they are called *rationalist philosophers*, a name that has nothing to do with what I call *rationality*. Everyone knows Descartes' dictum: '*I think, therefore I am*,' but the preoccupation with the mental forced many philosophers into idealist positions that sometimes undermined the significance of the world of the senses.

All this could be understood in a far more naturalistic way after Darwin, especially after Santiago Ramón y Cajal discovered at the end of the nineteenth century the *neural network* in the brain and realized that it was a learning system, learning being closely connected to causal thinking. A new approach to rational thinking then opened up.

Randomness

The nineteenth century saw the introduction of *randomness* or *probability* as a natural phenomenon, in a way a negation of causality or determinism. Paradoxically, given his later denial of probability in nature, it was Einstein who was very significant in the acceptance of randomness with his study of Brownian motion in 1905. When quantum mechanics was introduced in the 1920's, it was found that randomness was a fundamental feature of the theory, a feature that Einstein abhorred: hence his famous dictum, '*God does not play with dice*.'

Einstein's position created a school of followers, like David Bohm and John Bell, who tried to bring back determinism into quantum mechanics, but such attempts have proved fruitless so far. (This is perhaps a good moment to note that causality and determinism are not identical concepts, but for the purposes of this book I shall not worry about the distinction and, as often in physics, I shall use these words as exchangeable.)

So, we shall have to tackle how randomness was introduced into natural science, how quantum mechanics shocked the world with its renunciation of determinism, which so much affected Einstein, and how the new principles can help us understand that the pursuit of determinism in the microworld is most probably misguided. It is also important to realize, as we shall see, that randomness in the microworld, as for instance in the movement of molecules in a gas, translates itself into deterministic laws in the macroworld.

Creation

One of the questions that has engaged humanity since civilization began is how the world was created, a problem that for centuries was the absolute province of religion. The new physics has given us a handle on it through the concept of the vacuum and the Big Bang. We shall have to discuss this and how the so-called *anthropic principle* was used in an attempt to underline the very remarkable feature of our universe being *self-referential*: through our mouths the universe speaks about itself.

'Humankind cannot bear very much reality,' so said the great poet T S Eliot, and duly enough people faced with the new rationality looked for various and even hidden ways to undermine it. The curious thing is that even some of the self-professed new rationalists held *Platonic* views, despite the fact that Plato had been the first major philosopher who turned away from the world of our senses towards an imagined and totally independent world of eternal ideas or *forms*, as he called them. It appears that it is not even sufficient to be a confirmed atheist to be immunized against this infirmity. So, we shall discuss some of the subtler attacks on rationality conducted in the last half-century or so.

The new rationality

The influence of Darwin on modern rational thought must be recognized well beyond his discovery of evolution. His was a new approach to scientific inquiry: his discovery that men evolved from primates was carefully grounded and most scientists would accept that this proposal, based as it was on experience, is a scientific result, although its validation or falsification cannot be the subject of direct experimentation. So, we shall have to look at this question.

I shall try to show in a final chapter that the new rationality is totally compatible with spirituality. Science is one exercise in the discovery of truth, and without knowing how to discriminate between the true and the false even the concept of morality suffers. But, of course, I shall not claim that science answers all the questions that humans pose: some of these will be discussed in the Epilogue to the book.

Chapter Two

How Causality Came to Be

Early attempts at understanding causality

We shall embark on a journey that for some readers will be unfamiliar if not totally academic. The problem is that we shall have to discuss some questions of philosophy, a discipline that people may suspect, given that some of the elucubrations of philosophy make sense only to philosophers. But I hope to show that some simple philosophical enquiry is not only relevant but indeed essential to our understanding of the physical world.

It is a pity that Einstein thought that he understood philosophy, of which he had only a superficial knowledge. But I promise that it will not take long following this road to understand that Einstein's views on quantum mechanics were rooted in prejudice, not on reason. You must agree that it is positively worth trying anything that protects you from an error that affected even a man like Einstein, one of the most remarkable men that ever existed.

Anyone who hears about the beautiful Greek myths may well believe that they are entirely irrational, that things happen in them without any reason. This is not so: the idea that an effect had to have a cause was already firmly there, even if the cause chosen makes no sense to our modern intellects.

I shall look at the story that attempts to explain the behaviour of the Gemini constellation, which comprises the star 'twins' Castor and Pollux. They are visible in the Northern Hemisphere only from November to April. What is the *cause* of this behaviour? Before we begin, you must understand that for the Greeks the celestial bodies were gods that resided on Mount Olympus and thus visible to humans. You will see that if we accept this as a premiss, however absurd it might appear to us, we can then explain known facts.

Here is the story. Leda was the beautiful Queen of Tyndareus, the King of Sparta. Zeus took a fancy to the lady and, cunningly adopting the shape of a swan, impregnated her: the result of this union were the twins

Pollux and Helen. The same day, however, Leda had intercourse with Tyndareus, which led to the birth at the same time of another pair of twins (from another egg), Castor and Clytemnestra.

The result is that Castor and Pollux are not really twins: Pollux, son of Zeus, is divine; he can therefore reside in Olympus and thus be seen in the sky all the time. But Castor, son of Tyndareus, is an ordinary mortal and thus cannot partake of Pollux's status.

The latter, however, intercedes with his father Zeus on behalf of his half-brother and a suitable compromise is reached: Castor is allowed to reside in Olympus and thus be visible on the night sky; but only for half the length of each year; the other half being spent in Hades, the Underworld, and thus invisible. Of course, Pollux generously agreed to the same constraints to help his half-brother.

All this 'explains', if you accept the starting premiss, the behaviour of the Gemini constellation. (Those of my readers familiar with W B Yeats' beautiful sonnet '*Leda and the Swan'* may notice that his reference to Clytemnestra's husband Agamemnon in relation to the rape of Leda is unjustified, since Clytemnestra was not an issue of such union.)

This example, which I present from the point of view of cause (rape of Leda) and effect (behaviour of the Gemini constellation) illustrates also a principle which the Greeks were adept at using, that is, that whatever happens must have a *reason.* It does not matter that their 'reasons' were totally nonsensical in the light of our present knowledge: no one these days believes, for instance, that celestial objects are animated in any way, let alone that they are deities. The important thing is that, given that premiss, conclusions could be drawn that 'explained' known facts.

More than two millennia later the great German philosopher and mathematician Gottfried Wilhelm von Leibniz (1646–1716) enunciated this method of explanation as the *Principle of Sufficient Reason*: nothing happens without a reason. It is pretty obvious that this must be strongly linked to the concept of causality, (the *cause* being the *reason* for the effect) but beware: saying that something is a 'principle' may seem very grand but I shall not accept any so-called principles as rational, however important the philosopher behind them, without *empirical reasons* for their acceptance. This is our first hint about how to think rationally.

The relation between cause and effect has given place to very many serious philosophical disquisitions and classifications, but not even the great Aristotle will be of serious interest to us. We shall take a few lines, however, to explore what people felt about that relation. One of the important problems is this. Paul, who is a very systematic Frenchman, switches off his lights at 9.30 p.m. in Paris to go to sleep. At precisely the same instant lazy Frank's alarm clock (set for 10.30 a.m. Hawai time) sounds in Honolulu to wake him up. And this routine is repeated day after day. Very few people (as long as they are not philosophers) would take any time in thinking that switching off the light in Paris might *cause* the alarm in Honolulu to sound. In other words, mere regularities are not sufficient evidentiaries of causality: *action at a distance,* as in this case, is ruled out and the cause and the effect are expected to be *contiguous,* although this is not necessarily so in quantum mechanics (but more about this later).

It is a common error to believe that civilizations less advanced than ours cannot manipulate causal relations. We have already seen how the Greeks managed, a great many pseudo-empirical premisses mixed with true facts. The Azande of North Central Africa believed that a witch was causally efficacious in acting on a given subject, even at a distance, because they regarded witchcraft as a substance stored in the witch's body, a substance that they claimed they perceived as light flashes travelling from the witch to the chosen victim. Just as Einstein later did, they rejected unmediated action at a distance, a question of major importance in quantum mechanics, as we shall see.

Causality and philosophers

It is most important to understand that many of the problems that concern philosophers are of no importance in science. In Newtonian mechanics just about all that we need is the fundamental relation that *forces* cause *accelerations* (changes of velocity): Newton's equation determines the acceleration produced by any given force. End of story. On the other hand, some philosophers, like Rom Harré have a (to a scientist) injudicious interest in *powers,* which are supposed to permit the causes to produce the corresponding effects. But this can lead to ridiculous results, as the following example shows.

Imagine a factory of 'unbreakable' plate glass. Obviously 'unbreakable' must be defined in terms of a standard test, in which the glass plate is subjected to a specified stress without breaking. A scientist is employed to carry out this test, in which he drops a steel ball of a specified weight on the plates from a given height. He is instructed to report on the causes of failure, whenever the test fails. He examines one hundred plates of glass and reports that three had failed the test, and that the cause of the break was the weight that he had dropped on them: he says this because he knows that this was the only source of *power* in the experiment. End of story and end of employment for the hapless man: his employers were not interested in powers, but rather in any microstructures in the glass that entailed a disposition to induce a break.

Likewise, if you think that the push that John gave to Jack was the cause of the latter's death, because as he fell on the floor he cracked his skull, John's defence lawyer would plead that such push could not be the cause of death, since if John and Jack had been on a space station an identical push would have had no consequences. The cause of death, he would argue, is the force of gravity, as the only cause with the *power* to produce the fall.

So, *powers,* which are in the nature of metaphysical constructs, are of no serious interest to scientists, however much some philosophers might love them. In general, the concept of power is replaced by a causal chain. 'Fuel powers the car' is replaced by: 'combustion of fuel in the engine's cylinder causes gas expansion', 'the gas expansion causes piston movement', 'piston movement causes rotation of an axis', and so on.

There is another very important question about which practising scientists clash with philosophers. Take the following statement: 'Short circuits cause fires in houses.' Philosophers argue that the cause *A* (short circuits) is not *necessary* to produce the effect *B* (fires), since many fires are caused by arson, not by short circuits. Even more, they argue that it is not *sufficient,* since a house entirely made of non-flammable materials, like stone, will not catch fire even when short circuits occur.

Scientists, instead, are only interested in causes that are both *necessary and sufficient*, for which they arrange the experimental conditions in such a way as to rule out any deviations from strict causality. That is, if they were to study fires in houses they would make sure that the houses are all of the same type and that extraneous events like arson and lightning are ruled out. In other words, they will say that *A* is the *necessary and sufficient* cause of *B*, '*all other conditions being equal*' which the philosophers refer to with the Latin expression '*ceteris paribus*'. For scientists to ensure that their experimental studies satisfy the *ceteris paribus* condition is perhaps the most essential part of their experimental expertise.

Nature's regularities

A question that scientists take for granted, but which is a thorn in the flesh of many philosophers, is that of the *regularity of nature*, which for scientists is just an empirical fact: this, after all, is for them (but not necessarily so for philosophers) their professional commitment. (A discovery by a scientist, for instance, is not accepted until it is *repeated* by other scientists.)

Philosophers have in fact a deep-seated need for logical necessities, an exemplar of which is: 'one side of a sheet of paper examined under daylight cannot be both red and blue all over at a given instant.' This may be good enough for a philosopher, but scientists would ask: what do you mean by an 'instant'? If you say a millisecond, they would then say that no property of daylight is logically necessary and that it could, in principle, be red for half a millisecond and blue for the other half, and that the same argument would be valid for any definition of 'instant'.

The principle of the regularity of nature is an undeniable empirical fact *at the present time* (but beware: philosophers have a trick to deny this, which goes under the name of *conventionalism*, of which more later). Of course, the fact that the sun has risen in the sky every morning for billions of dawns does not mean that it is logically necessary that it will rise tomorrow. This is the great problem of *induction*, about which no scientist has ever been known to lose sleep: I can safely say that the sun will rise tomorrow *ceteris paribus*, that is, disregarding extraneous events like a collision with another galaxy or the like. Any scientist who does not subscribe to an empirical principle of the regularity of nature is an ex-scientist, if not a mad one. And any scientist that does not know how to look after the *ceteris paribus* condition is a bad scientist.

It is worthwhile considering briefly another 'solution' to the problem of induction. Sir Karl Popper (1902–1994) observed that what characterizes scientific statements is that they can be *falsified.* A very useful remark which he, unfortunately, elevated to the status of a dogma. He then proposed that while the theory that 'the sun rises every morning' is not falsified, it may be used, thus 'solving' the great problem of induction. But, as Bertrand Russell (1872–1970) had observed, the theory that 'there is a small teapot orbiting around the sun' has never been falsified, but it would be foolish to use.

In any case, to accept the proposition 'the sun rises every morning' on the grounds that it has not so far been falsified is the same as accepting the regularity of nature, although the fact that this has obtained until today does not entail that it will be valid tomorrow. Therefore, we find ourselves with exactly the same problem that the proposition about the sunrise entails: nothing has been advanced by Popper's 'solution' of the problem of induction.

Scientific statements, on the other hand, acquire their empirical validity because they interconnect a large number of well-established facts. They are never taken in isolation, but they must fit into a *mesh* of facts and theories. In the sunrise example, for instance, scientists know that it results from the rotation of the earth, which in itself is one datum in an immense database of astronomical facts. It is this sort of internal consistency that validates the sunrise statement, but as always in science, the *ceteris paribus* condition must be stated, since a great cosmological catastrophe can never be dismissed as impossible.

This clearly shows the advantage of the scientific approach over Popper's falsification dogma: whereas he would do nothing to trust that the sun rises tomorrow, except to depend only on past events, scientists would verify the *ceteris paribus* condition: if they were to observe the dangerous approach of another galaxy, they would raise the alarm (not, alas, with very useful results, except perhaps to allow those so inclined to commend their souls to the god they worship).

This, however should be a cautionary tale for armchair philosophers. To paraphrase Dr Johnson, a man is never as safely occupied as when doing something useful. No scientist loses sleep about falsifiability: they will not waste their time with hypotheses that are not falsifiable, although from time to time people will introduce theories that, at the time of their enunciation, are not so, hoping that when experimental technics advance this situation will change. This was the case with the introduction of atomic theory, or of quarks, or of the Higgs boson. This temporary disregard of falsifiability (or experimental evidence) is always justified on the basis that entities introduced that cannot *at the time* be subject to experiment (as atoms were when they were first postulated) nevertheless help explain a large and until then obscure part of the science mesh of consistent facts and theories. And because of this, the unobservable entities postulated are used until they become eventually observed or, if experimentally falsified, discarded.

In opposition to falsifiability, the question of *ceteris paribus* is constantly, if perhaps only implicitly, in front of the scientists' minds, and will always be so, as an essential tool for scientific research: it is set in stone in every laboratory; it leads to useful protocols rather than the theoretical claims of falsifiability.

Time and causality

Time is one of the most difficult concepts in science and I shall not attempt a full discussion. There is no question, however, that early humans recognized regularities of nature that permitted them to use a necessarily rough time-scale, such as implied by the ideas of *days* or *seasons*. I shall happily jump millennia to reach Galileo (1564–1642). He suspected that the time an object takes to fall from a given height depends only on that height and not on the body's weight. But to verify that statement he had to measure the time, whereas sufficiently accurate clocks (at least portable ones) were not easily available at that time. So, he very probably used a method later found most useful in physics, of *successive approximations.* He might have started by measuring the time interval with his own pulse, which could have shown to him that he was roughly on the right track to verify his hypothesis.

He then used a *water clock,* in which the weight of the water that falls out of a spout or hole is taken as a measure of the time. He was a good experimentalist though, and like all such, he had to make sure that the *ceteris paribus* condition was satisfied. He realized, in fact, that he could not make the above assumption about time measurement with a water clock unless the height of the water column in it was constant. To achieve this within a reasonable approximation he made his water containers very wide, so as to ensure that the level change was minimal during a short interval. And this way he verified his law within a reasonable approximation.

What Galileo was saying was that there is a causal relation between the height from which an object is dropped and the time it takes to hit the ground. But for such a law to make sense, it must obey a very important principle: the starting time must not matter; in other words, the law of falling bodies must be independent of the time or, in scientists' language, *invariant in the time.*

This is one of the most important principles in physics and much more general than so far enunciated: *all physical laws are time-invariant,* which means that the time at which they are applied is irrelevant: time must not be part of the causes. (Of course a presumptive law of nature that is not time-invariant is of little use.) You must realize that in order to establish the time-invariance of laws a long and painstaking successive-approximations process had to be undertaken to obtain better and better clocks, leading to the modern atomic clocks, that is, to better and better time-scales. And if the invariance principle were broken our present understanding of nature would totally collapse.

The construction of a time-scale that leads to time-invariance of all physical laws is an empirical, not a logical, fact. It says something about the nature of our universe during the present epoch that we are able to construct a *causal time-scale* (first proposed by Georges Lechalas in 1896) with respect to which all laws of physics are time-invariant.

Some philosophers find it difficult to substitute empirical facts for logical necessities and have claimed that rather than the time-scale being empirical, it is *conventional,* and conventionally chosen so as to fit conventional causal laws. The mathematician-philosopher Henri Poincaré (1854–1912) introduced the theory of *Conventionalism* and he was followed by Rudolf Carnap (1891–1970), and Hans Reichenbach (1891–1953), among others.

Basically, their argument is that the causal time-scale makes the laws of physics not only time-invariant, but also simpler. Using any other time-scale would merely lead to more cumbersome laws; but this, they claim, is only a matter of convenience. Although such an argument would not be totally unreasonable in dealing with just one set of empirical facts, it does not explain why it is empirically possible to choose a time-scale that deals *simultaneously* with *all* physical laws.

CHAPTER THREE

MORE ABOUT CAUSALITY: HUME

Hume as a natural scientist

I shall explain the programme that the great Scottish philosopher David Hume (1711–1776) had in mind, which has not always been properly understood. This is so because it was necessarily truncated, owing to lack of knowledge of the theory of evolution (of course, not yet discovered). Another problem is that he has sometimes been read by modern philosophers as if he were one of them, whereas in Hume's time the current distinction between a philosopher and a natural scientist did not exist. It is easier to understand Hume, in fact, if he is regarded as a natural scientist, at least in his treatment of causality. As we shall see, in order to understand Hume, one has to add empirical facts to his philosophical ideas, an approach that repels many philosophers who hold that they must remain entirely within philosophical discourse without any factual accretions.

One of the major problems in the study of nature is to validate the principles that one uses. The crucial one is the *principle of causality*. (Remember that it is the possibility of a causal time-scale that allows the laws of physics to be what they are.) Hume started with two very important ideas. One is easy to accept: that fire burns (that is, that fire *causes* burns) is *not a logical necessity.* That fires are not cold is, in fact, merely an empirical fact.

Hume's second important idea is, I'm afraid, rather counterintuitive. He claimed that when we say that this fire has caused this burn, all that we observe is that the event *A* (fire) is followed by the event *B* (burn). The causal relation, thus, is something that *happens in our minds*, it is not anything that we *observe*. And if we accept this, we must recognize that Hume was probably the first thinker who tried to produce an empirical theory of mind.

Because the non-observability of a causal relation is a difficult (but vital) concept, let me elaborate a little on it. First of all, we must erase from our thoughts the concept of *power,* which I have already criticized. Of course, it is legitimate to ask: why does a fire *cause* burns? But you must avoid doing two jobs in one go: before you can ask that question you *must* have established the causal relation, and this, as any experimentalist will know, can only be done by *repetition* (keeping of course *ceteris paribus*).

If we want to pursue the 'why' question, what will happen in fact is that a *chain* of subsidiary causal relations must be established. In the case of fire, it might be found that the fire *causes* the air molecules to move fast, and then that the collision of fast moving molecules with the molecules of the epidermis *causes* blistering of the latter, and so on.

Another example: when we hit a stationary billiard ball with a cue (force) the ball moves, that is, it experiences an *acceleration.* All that we *observe* is that the force is followed by the acceleration. If we then say that the force *causes* the acceleration it is no more than introducing a new language, which like always in the use of language, must be properly licensed. It remains, however, as a 'mind act', a concept that we use to attach to some 'fact'. And all scientists would agree that the word 'cause' is licensed if, by repetition, the same effect follows.

Finally, to help you understand Hume's important point that the causal relation is a 'mind act', not an observed fact, it is useful to remember that what connects a cause with its effect is a *relation*, and relations cannot be established just from a single instance. Consider this simple example. You see Tom kissing Jane. Can you then say that they are in a *relationship*, that they form *'an item'*? Certainly not: they could be actors on the stage or rehearsing, or models preparing a commercial. Even more, the fortunate Tom might have won a tombola, the prize of which is a kiss from a pretty girl, Jane, and this is clearly an unrepeatable event. It is only after repeated instances of an event that you can draw conclusions, which are of course 'mind acts'. *Repetition,* as Hume had surmised, is essential to establish a relation.

Hume's 'custom or habit'

Having discovered that the causal relation is neither logically necessary nor observable (remember that in the relation '*A* causes *B',* all that we observe is fact *A* followed by fact *B*), Hume went on to investigate the *psychological problem* of why we use causal relations at all. He concluded that our minds have a *predisposition* to use causal relations, which is generated by *repeated* instances of the sequence '*A* is followed by *B'*. Because in his time, repetition of events was known to create *customs or habits*, he used these names for the predisposition just described. This, unfortunately, caused a great deal of confusion amongst some commentators on Hume's ideas. A fairly usual misunderstanding is to equate Hume's 'custom' with such habits as playing golf on Saturdays. Hume had something far more significant in mind, as we shall see a little later.

It is important to remember that Hume insisted that the causal 'custom' was created in the mind after repetition of the same sequence from *A* to *B*. And anyone with the slightest concern with teaching will recognize that repetition is the basis of all learning. If a fire were hot one day and cold the other, a child would never learn how to avoid being burned. Likewise, a teacher who says one day that two plus two equals four and another day that it equals five, will achieve nothing except driving his pupils crazy. I insist on this point because we shall soon see that apparently perfectly sensible philosophers denied the significance of repetition.

Philosophers versus Hume

The above heading is not entirely fair to the great German philosopher Immanuel Kant (1774–1824) who, in fact, handsomely acknowledged his debt to Hume, insofar as he accepted Hume's conclusions that the causal relation is neither logically necessary nor observable. But as a difference from Hume, he was a believer, and thus prone to introduce absolutes in his arguments. Kant's position, though, is plausible, because he thought of causality as a principle of universal value, which as a norm for the laws of thought, could not be questioned. His idea of the mind was thus very different from that of Hume: he accepted innate ideas for which the skeptic Scot had no use. The distinction between these two approaches, we shall see, is crucial for the understanding of the world of physics.

The strongest attack on Hume came nearer our time from the American philosopher (born in France) Curt John Ducasse (1881–1969), who alleged that the causal relation does not require repetitive inputs and may be apprehended in a single event. When I throw a brick at a window, Ducasse would claim, the brick must be the cause of the glass breaking, because there is nothing else that happens in its vicinity.

This is extremely naïve, if not careless, on two grounds: first, it obviously entails an implicit acceptance of Leibniz's *Principle of Sufficient Reason* (nothing may occur without a reason) which has then to be grounded: but why should an event have to have a reason? And this is no rhetorical question, since in the study of the microworld it has been found without any possible doubt that events may arise randomly so that no reason for them can be found. In fact, if this were so, actions could be taken to produce the desired event, for instance the spontaneous splitting of one particular radioactive atom, a result that is empirically impossible.

But what is indeed most surprising is, secondly, that neither Ducasse nor his followers appear to realize that the question of a single event had been clearly discussed – and dismissed – by Hume. For it was his purpose to try and construct a theory of the mind: for him, it was a fact that we have a predisposition to use causal statements, which was not, as Kant posited, innate, but had been acquired by experiencing innumerable repetitions of causal-type of relations since birth, a suggestion that we shall soon see is totally corroborated by modern neuroscience.

Thus, Ducasse's single event in which a causal relation is 'perceived' would have to be experienced, Hume asserted, by a totally virgin mind, like that of a new-born baby, to be suitable evidence for that (Ducasse's) theory. (I shall show a little later how Hume stated this condition.) It is difficult to understand why, despite these two serious failings of Ducasse's theory, it had been enthusiastically and uncritically embraced by experienced philosophers like Rom Harré and Nancy Cartwright. It must be conceded, nevertheless, that although these authors were using the word 'cause', they meant something different from the same word as used by Hume, as we shall later see. In my view it is the dangerous concept of *powers* that led them down this road. But let us consider in some more detail Ducasse's claim that repetition is irrelevant in establishing a 'cause'.

We shall go back for this purpose to the plate-glass factory discussed in Chapter 2. We shall now assume that this is situated in a prudent country where the use of breakable glass is forbidden. Even more, all glass installed is required to resist impact with a brick in specified conditions. Now comes Professor Ducasse who walks along a street, throws a brick to a window (which happens to be defective) and breaks it. Because he does not need repetition to warrant a causal statement he says 'the brick was the *cause* of the glass breaking.' He can mean either of two things by this: (1) that the brick hit the glass and the glass broke, or (2) that there is a causal relation between the brick hitting the glass and the latter breaking. If Ducasse means (1) the use of the word *cause* does not add anything whatsoever to his observation that the glass broke.

It is only if he could claim the meaning in (2) that the use of the word *cause* licenses him to project the statement to the future, that is, use the process of induction to claim that 'all panes of glass break when bricks are thrown at them.' But this projection is totally wrong in that prudent country. There is no way of getting rid of the need of repetition to warrant meaningful causal statements, contrary to Ducasse and his followers. And we can see that any powers that the brick might have are irrelevant.

The problem with Ducasse's approach is that he and his followers use the word 'cause' but, as I have averred, they do not mean what Hume means: Ducasse's 'cause' is very much what Aristotle understood as *efficient cause*, that is, one that has a *power* to create a given effect. Although such a concept may have provided suitable entertainment for the medieval schoolmen, it has, as we have seen, no place in modern practice.

Hume's programme

I have already said that Hume must be read as a natural scientist. For what Hume was trying to understand was not just the 'philosophy' of the causal relation but *why* it is that humans have a predisposition to use causal relations at all. He embarked for this purpose on an ambitious programme that gave him intuitions of crucial ideas so much ahead of his time that he did not have the empirical basis needed to sustain them.

I shall now provide a précis of this programme, for which we shall have to look at some quotations from his writings that show-case the depth and originality of his mind. And please do not think that doing this is mere pedantry. On the contrary, reading Hume in his own words will lead us to some of the most important results and ideas in Western intellectual history.

We need for this purpose some references from Hume's *Enquiries*. Hume had previously produced another book, the *Treatise,* often favoured by philosophers as more rigorous, but in his second work he had tried to convey his main ideas with greater force so as to make them accessible to a wider public. (Full references to these books may be found in the List at the end of the present one.)

We have seen that the fact that Hume claimed the causal relation as a 'custom or habit' caused concern because these traits could be related to low-level activities of little significance, like reading the morning paper after breakfast. Hume, however, gave a much deeper meaning to 'custom or habit' than these words imply:

> 'Custom, then, *is the great guide of human life*. It is that principle alone which renders our experience useful to us, and makes us expect, for the future, a similar train of events with those which have appeared in the past.' (*Enquiries,* Part I, 36, p. 44, my emphasis.)

You can see here that Hume is now wearing his hat of natural scientist, if not of a psychologist. Even more, as I shall now show, Hume, in an extraordinary Darwinian insight, not only appeals to the significance of the principle of causality in the struggle for life, but searches, like Darwin would later, for a harmony between nature and the way in which we react to it:

> 'Here, then, is a kind of pre-established harmony between the course of nature and the succession of our ideas […] Custom is that principle, by which this correspondence has been effected; *so necessary to the subsistence of our species*'. (*Enquiries,* Part II, 44, pp. 54–55, my emphasis.)

It is clear from these two quotations that Hume's 'custom' has nothing to do with what we now mean by this word. A guide to human life, necessary for the subsistence of the species: what human trait could be more important?

Finally, Ducasse and his followers, by denying the need for repetition in establishing a causal relation, ignored the principle of regularity of nature without which science could not survive, whereas Hume intuited that the human mind is pre-wired to acquire the ability to process such regularities:

> As nature has taught us the use of our limbs, without giving us the knowledge of the muscles and nerves, by which they are actuated; so has she implanted in us an instinct, *which carries forward the thought in a correspondent course to that which she has established among external objects*… (*Enquiries,* Part II, 45, p. 55, my emphasis.)

This passage demonstrates that Hume, having discovered a predisposition in the human mind to rely on causal relations, tried to understand its origin (*not* as a philosophical but as a natural-science problem), and he intuited that this predisposition arose from a process of adaptation to nature. Of course, Hume could not go any further because he was already anticipating by more than a century the fundamental work that radically changed the human understanding of humans: the colossal discoveries of Charles Darwin (1809–1882).

Let me say a few words about this extraordinary man. For a short time, he read medicine at Edinburgh, but he soon moved to Cambridge. Science as such was not yet taught there, so he formally was studying to become a parson, although he immediately concentrated on natural science studies, like geology and palaeontology. But what changed his life was his five-year travel around the world on board of *HMS Beagle*, during which he made an enormous number of observations.

Darwin, as we shall see, opened the way to the understanding of how species, including the human one, had arisen, but an approach to the understanding of the human mind had to wait a few more decades until the structure of the brain cortex became understood. This was the work of an amazingly gifted Spanish histologist, Santiago Ramón y Cajal (1852–1934). It was him who at the end of the nineteenth century discovered the neural network in the brain's cortex, which totally justified Hume's intuited *predisposition*. And which, at the same time, amply showed that Ducasse's dogmatic rejection of repetition as a major element in the causal relation is totally injudicious.

Hume, in fact, had clearly stated in the *Treatise* (Book I, Part III, §VIII) that even if we see a single instance of an effect, the mind had already been trained by millions of instances to accept that similar causes produce similar effects. This is why, as mentioned before, it would have been necessary for a new-born baby to apprehend a single instance of a causal relation as evidence for Ducasse's views. There is no doubt that this philosopher and his followers were stuck with this idea because of their belief that *powers* where the key to the causal relation.

We shall now be able to finalize Hume's programme by jumping more than a century in order to understand how the ideas of these two giants, Darwin and Ramón y Cajal, tied up seamlessly with those of the Scottish philosopher to complete his understanding of causality.

CHAPTER FOUR

DARWIN AND A NEW VIEW OF CAUSALITY

Evolution

To understand the way in which his 'custom or habit' became a part of human nature Hume, as we have seen, had intuited that this was so because it helped preserve the human species. This intellectual leap, however, required an understanding of ideas that came from Darwin more than a century later. We don't need delving too deeply into the *Theory of Evolution,* which, supplemented by the modern knowledge of genetics, may be summarized for our purpose as follows.

Genes are sections of DNA that carry the information by which traits of an individual are passed on to its descendants. But genes can *mutate,* that is, they can be altered, whereby entirely new traits may appear in members of the species. Because mutations happen at *random* over long periods of time, individuals with the new traits also appear at random. If a given trait confers advantages to the individual in the *struggle for life* over other competitors, individuals carrying this trait will reproduce more easily, thus ensuring that the new trait is preserved in the species. This way, over millions of years, species have come into being, a process which is called *philogenesis.*

A most important part of the philogenesis of the human species was the evolution of the brain structure: the development of cognition was of course fundamental in allowing the human species to succeed in the struggle for life. It is obvious that the ability to *learn* was most significant for *'the subsistence of our species'* as Hume so wisely intuited. And learning and causality are indissolubly linked. Despite Ducasse, Harré, and Cartwright's denial of repetition, no teacher in his (or her) right mind would say that learning without repetition is possible: no wonder than in France a teaching instructor is called a *répétiteur.* And remember that for Hume repetition was essential for humans to acquire the 'custom' to use causal statements. In order to understand how this happened we need the knowledge of the brain structure that emerged towards the end of the nineteenth century and which triumphantly proved Hume's intuition right.

The brain's neural network

Modern knowledge of the brain structure started around 1873 when a provincial doctor from Italy, Camillo Golgi (1843–1926), discovered accidentally how to stain brain cells, thus rendering their structure visible under a microscope. He used for this purpose silver chromate produced *in situ* from silver nitrate and potassium bichromate. This allowed him to identify what he thought was a continuous network of nerves in the brain, a result, however, which was wrong.

The real, amazingly important discovery, was done by the prodigiously gifted Spanish histologist, Santiago Ramón y Cajal (1852–1934), who became acquainted with Golgi's work in Madrid in 1887. Ramón y Cajal used Golgi's technique, but his extraordinary attention to detail allowed him to discover that instead of the continuous network of nerves that Golgi had postulated, the cerebral cortex was made up of *cells,* which were later called *neurons*, and he was able to study their structure in complete detail. Moreover, and most importantly, he opened the way to understanding the mechanism by which neurons communicate between themselves.

I rank this discovery as at least as important as that of the structure of DNA more than half a century later. And I say at least, because whereas Crick and Watson (with the unacknowledged help of Rosalind Franklin) provided an entry to the understanding of life, Ramón y Cajal opened the door to the study of the *mind*, and it is the latter that makes us humans such a distinctive species. Already in 1888, when Ramón y Cajal showed his results at a conference in Germany his work was hailed as extraordinary.

Its importance will be clear when we consider Ramón y Cajal's discovery of the structure of the brain cells, later called *neurons*, which I show in Fig. 3. The cell body is covered with a very large number of ramified filaments projected from it, called *dendrites.* But a large and thick tail comes out also from the cell body. This is called an *axon* and actually carries out stimuli *away* from the cell).

The most important feature is that neurons *do not directly contact each other*: they do not even touch. What happens instead is that the tip of an axon approximates a dendrite end of *another neuron*, leaving a small gap, which was later called a *synapse*. It is most probable that the secret of learning and of the mind lies there, as Ramón y Cajal already intuited.

Ramón y Cajal realized that as the neuron 'fires' on receiving a signal from the perceptive system, the impulse is carried along the axon away from the neuron's body, and is indirectly transmitted*,* through the synapse to the dendrite of another neuron, thus creating a neural path. At the time it was not clear whether the transmission was electrical or chemical.

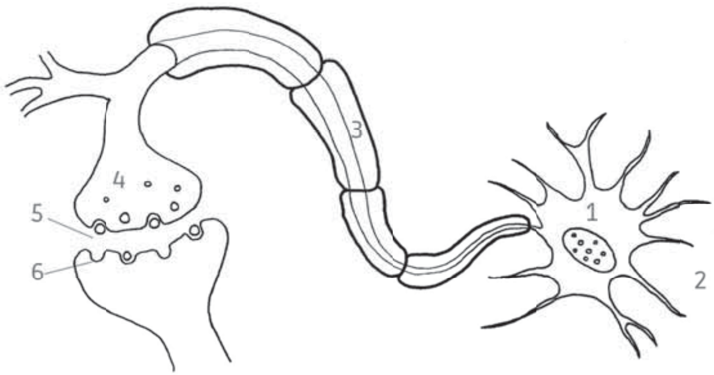

Fig. 3. A neuron. 1. Body of neuron. 2. Dendrites. 3. Axon. 4. Axon end. 5. Synapse. 6. Dendrite end of a neighbouring neuron.

It was Otto Loewi who in 1921 made an experiment that showed that the transmission through the synapse is produced by means of a chemical called a *neurotransmitter,* such as acetylcholine or adrenaline. Repeated stimuli (bravo Hume!) reinforce the synapses (increase the concentration of the neurotransmitter), so that the neural paths are strengthened. Thus the neural network 'learns', that is, it acquires a predisposition (Hume's custom or habit) to use causal statements.

The discovery of the neurons was celebrated with the Nobel prize in 1906, shared by Ramón y Cajal with Golgi, as the discoverer of the staining technique. Even in his Nobel lecture, however, the latter insisted in the continuity of the neural structure, very much to the stupefaction of the audience. Nevertheless, Ramón y Cajal's intuition of the firing of the neurons and the role of the synapses was later confirmed by the American neuroscientist Eric Kandel (1929–), who received the Nobel prize for this work in 2000. He was a reductionist, that is, experimented with an animal with very few but very large neurons, so that he could study single neural paths.

Modern studies of the human brain[1] show that the same stimulus causes many neural paths to fire together at random, but as we shall see in Chapter 5 this is another instance where causality in the macroworld is induced by random probabilistic events in the microworld. For the time

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[1] I am indebted for this information to Professor Gerry Altmann, Head of the University of Connecticut Institute of Brain Studies and Cognition.

being, however, I shall keep within the reductionist approach of Kandel and consider single neural paths.

The neural network and causality

We can now move forward to an understanding of the neural network and of its role in explaining how Hume's 'custom or habit' came to be part of the human mind. A very important point for this purpose is to understand the *ontogenesis* of the human brain, that is, its development in the individual from its birth. When a child is born its brain already contains almost 100 billion cells. (Unfortunately, it is doubtful that this number increases later, but it is rather steadily reduced in adult life.)

Each neuron in the adult is connected on average to some 1000 other neurons so that the number of synapses is around 100 trillion. When an infant is born the number of synapses is minimal, but it immediately increases at a prodigious rate (almost two million per second until the age of 2): the infant receives stimuli, synapses are created, and repeated stimuli reinforce them (increase the density of the neurotransmitter) and thus favour establishing a causal relation between the stimulus (such as heat) and its effect (feeling of burn). This process is exactly as Hume had intuited, and fully confirms his prescient insistence on repetition. For a Ducasse type of 'causal' experiment to prove that a single instance of the causal relation is apprehended, the virgin mind of an infant would have to be used, as already averred. Not only is this impossible, but with empty synapses it is most unlikely that a single event would establish a working synaptic link.

Even Ramón y Cajal himself had realized that nature had created a learning apparatus in forming the brain's neural network. In fact, when a baby begins to receive stimuli, the synapses that are formed are largely 'empty', that is the chemical neurotransmitter's concentration is very low, thus allowing for learning through the gradual increase of the concentration of the transmitter.

Hume, augmented by a Darwinian-Cajalian argument, allows us, as detectives studying nature with often insufficient clues, to organize our rational thinking. When doing so, we can use the causality principle because we have not pulled it out of an arbitrary repository of *a priori* logical principles à la Kant. Instead, we have a very important *nomological* (procedural) rule: *the use of the principle of causality is acceptable in rational discourse because we can argue that it is implanted in our minds by a process of adaptation to nature, which it must therefore map in some way.*

I shall claim that the rational use of nomological rules must be grounded in a similar way, by showing that they appeared in our cognitive system by a process of adaptation to nature.

But adaptation to which nature? Because we know that underlying the macroscopic world of classical particles (billiard balls, moons and so on) there is a microscopic world of elementary particles, like electrons and neutrons. This world, however, has never provided us with stimuli to contribute to the development of our neural network. Thus, causality should not be used in rational thinking about the microscopic world, at least not without very serious justification. This means that the principle of causality is *contextual*, and that it can only be used in the context of the macroworld.

Unless you are Einstein, who had a gut feeling that any theory grounded on probabilities rather than causal certainties must be incomplete (see Chapter 6). What makes his position even more extraordinary is that it had been thanks to him that the concept of randomness was accepted in physics, as we shall discuss in the next chapter. A colossus as he undoubtedly was, it is almost reassuring to realize how widely off the mark his reasoning about causality could be. His weakness, of course, was his imperfect understanding of philosophy, despite his feeling that he was good at it. We shall later see that had he had some knowledge of theology, of which he knew nothing, he would have known an example that contradicted his existential (or *ontological*) prejudices.

Before we go any further, please notice that the at first rather nebulous concept of *rational thinking* has now been provided with some very important conditions. These rule out the use of arbitrarily formulated nomological (procedural) rules, however persuasive philosophers might be in formulating them.

In order to understand Einstein's worries about quantum mechanics we shall have to learn about the introduction of randomness in the study of physics, which we shall do in the next chapter.

The most important idea since Genesis

Galileo, Newton, Einstein, hallowed names
of giants who in their times fought and tamed
nature. Yet, the Mother could not explain herself:
she needed a cause and she needed a purpose.

It was the acute insight of the man of Downe
that it is in the nature of nature that it contains
its own explanation. All that happens in it
happens because nature of its own accord evolves
always favouring structures that best fit
the totality of facts at any one time.
It is only in this way we may understand life.

Darwins's idea. So simple, so vast, so neat.
Yet he had to amass a huge network
of facts to show he had a good case to plead.
Even the cleverest of Darwin's contemporaries
thought that God had created the laws
that created species, each to His own design.
The laws that gave humankind its special status,
evident to all of us by our unique afflatus.

This big modest gentle man,
vanity forgotten at birth,
did not much bother about status,
nor with mysteries: there were facts,
thousands of facts to understand and to explain.
Thousands of facts from across the world,
facts with which he filled museums over and over again.

No design without a designer, thought his friends.
How can you get perfection by chance?
Darwin taught us to forget about perfection:
what there is there is, the rest is our invention.
Chance and the vastness of time
do the job. Randomness and the struggle for life
rule the living world. Nothing is textured
perfect except that it works within nature.

Some in his day thought of evolution.
Most thought the idea depraved,
transmutation of species a perverse scenario.
Darwin understood the infinite patience of nature,
the unimaginable passage of time
that could turn a patch of skin into an eye.

That the sleep of man was adapted
to the day's duration others thought absurd:
The length of the day had been
planned to meet man's needs for rest.
All this Darwin put to his strictest test.

He knew that you cannot collect facts
as the philatelist collects stamps.
He needed problems, he needed hypotheses,
to find facts worth examining.
The simplest of facts that no one
had even thought of finding out.

He had to understand how continents arose.
Not from the withdrawing of the Flood waters
as in the scriptures, but he found good evidence
that some lands were raised and others were sunk.

So islands did emerge from the sea isolated
and not all formed from one great continent:
But a plant in Chile also grows in Tasmania.
If the seeds had to move across the sea,
are they capable of survival in salt water?
How could they move through improbable distances?
That was one of many questions that required
Darwin's indefatigable lengthy inquire.

He, an expected future parson, became a geologist
to understand the formation of continents and islands,
a palaentologist to read the bones of unknown fossils,
a botanist to fiddle with the germination of seeds,
a zoologist, barnacles and pigeons for friends,
an embryologist to discover that foetal mammal
contrary to expectation resembles foetal fish.

An ornithologist to understand the origin of bird species.
And for eight years he studied the sexual mores
of barnacles to understand how sex arose.

Was all this easy for him? Chronically sea-sick,
he rounded the world for five years,
and chronically sick most of his life
hardly spent a thoughtless day and found the time
to be a loving father to ten children. (Not all survived.)
How cruel it was of life, Darwin's admired teacher,
to take away from him his beloved Annie aged nine.

He freed science from the shackles of theology.
But he also freed theology from the pretence
that much of science lies within its province.
In the end, all strife consumed, appropriately,
this wise agnostic lies in Westminster Abbey.

CHAPTER FIVE

HOW RANDOMNESS ENTERED PHYSICS

Early work

The concept of random or probabilistic motions is indissolubly related to the atomic theory of matter. This was first proposed by Democritus (ca 460–370 BCE), but we had to wait until Daniel Bernoulli (1700–1782) used it to produce a model of gases. The picture of what was called an *ideal gas* emerged in which the 'atoms' (which in modern terminology are often molecules) occupy a very small proportion of the gas volume, which, like the gas pressure, is sustained by the rapid motion of those particles. This model of an ideal gas, still in use, entails that, because the space in the gas is largely empty, the particles are well separated so that their interactions may be neglected.

It was Rudolf Clausius (1822–1888) who realized that on heating a gas the observed expansion is due to an increase in the average velocity of the 'atoms' (or molecules). Clausius also went much further, laying out the foundations of the science of *thermodynamics* in which, for example, relations are obtained for the energy required by a gas to reach a given temperature (the latter being a measure of the average velocity of the gas particles).

The main thrust for the *kinetic theory of gases*, was provided by James Clark Maxwell (1831–1879), who was the first to introduce the concept of probability in physics. In this theory such observable properties as temperatures and volumes are discussed by means of a mechanical model of the motion of the gas particles. Of course, if this motion is random, as it is assumed in the kinetic theory of gases, we cannot predict what will be the velocity (kinetic energy) of each particle of the gas at a given temperature. Its particles, in fact, will be moving at different velocities around an average that increases with the temperature. But Maxwell provided an equation that gave the distribution of *probabilities* for each velocity as a function of the temperature.

We can now understand the way in which probabilities in the microworld may entail causal effects in the macroworld. When we heat a gas with a Bunsen burner we know that its temperature will increase. This does not mean that the kinetic energy of each molecule in the gas will increase: some of the molecules might even have their velocities reduced, but the average kinetic energy of all the molecules will be *higher*.

Later on, when radioactivity was discovered, it was found that, although one could predict how long it would take for half the atoms in a radium sample to decay, it was not possible to predict when one given atom would spontaneously split. Even more, there was no way in which the decay of a single atom would be induced: such a process was truly random: causality was in no way involved.

The neural network again

The way the neural network works is somewhat more complex than so far discussed and a few words here are necessary. Although Kanton's reductionist approach was most important in order to understand the role of the synapses and of the neurotransmitters by studying a single neuron, the human brain is more sophisticated, entailing redundancy of the paths that are created by a single causal relation, like 'heat causes burns.' Thus, when a cause is input into the system, (a nerve signalling 'heat'), not one but many synapses fire *at random* thus signalling the effect (burn). Notice that as a difference with radioactive decay, the effect is a response to a proper cause, but is induced by a combination of many random microevents. It is thus similar to the heating of a gas, where it is the *average* kinetic energy of its particles that is increased, although the microevents created are random, some molecules actually losing kinetic energy.

We may now go back to thermodynamics.

Phenomenalists vs atomists

It is at this stage of modern physics that philosophy entered the battlefield, but its banner was carried not by philosophers but by a group of scientists, led by Ernst Mach (1838–1916). They were called *positivists* or, sometimes, *phenomenalists.* For them, the science of thermodynamics should only deal with *observable* phenomena, such as energies, volumes, and temperatures. They strongly objected, therefore, to the introduction of, at the time, unobservable entities, such as atoms, to explain the observed experimental results. Of course, the refusal of Mach and his followers, of whom Friedrich Wilhelm Ostwald (1853–1932) was the most notorious, to consider the mechanical motion of the then unobservable atoms, was virtuous but sterile. Such study, in fact, permitted the derivation of many observable facts, which was an indication that it provided the basis of a good programme of further work.

Boltzmann

If the name of just one man must be given to associate with that programme – which ultimately led to the acceptance of atoms and of the probabilistic kinetic theory of gases – it is that of Ludwig Boltzmann (1844–1906). His fight against the phenomenalists was long, hard, and sometimes aggressively conducted by the latter, who were not averse to attack the personality and even the sanity of poor Boltzmann.

He had, nevertheless, been able to achieve considerable success in explaining and calculating the *specific heat* of gases, which is the quantity of energy required to raise the temperature of a unit mass of a gas by one degree. Boltzmann obtained this quantity by assuming that the energy received by the gas (provided, for instance, by heat) is distributed at random between all the possible modes of motion of the gas particles. (If they are monoatomic, these are only the three translational motions, but if they are diatomic molecules, vibrations and rotations must also be included.) This approach was totally dismissed by Mach as pure metaphysics: virtue may sometimes become excessive. Nothing that Boltzmann did was sufficient to persuade the sceptics, although many experimentalists were convinced by the force of Boltzmann's arguments and results.

Brownian motion and Einstein

To solve this impasse science needed some new facts that were at last provided by Albert Einstein (1879–1955) in his *annus mirabilis* of 1905.

In that year young Einstein studied the work of a botanist, Robert Brown (1773–1858), who had observed that the particles of pollen suspended in water move around in a random fashion, which was thought to be related to their vital nature. It was Einstein's achievement to realize that their motion matched that of the particles in the atomistic model of an ideal gas and, on using the hypotheses of the kinetic theory of gases, was able to reproduce experimental facts. He was also able to propose a method to calculate the number of particles in a given volume of an ideal gas (called the *Avogadro number*), which was later found to agree with the results from kinetic theory.

On seeing these new facts Ostwald withdrew his objections to the atomic kinetic theory, too late for Boltzmann, who had hanged himself while on holiday in 1906. As for the stubborn Mach, he died ten years later in the odour of sanctity, still refusing to believe in the atomic theory and the new ideas of probabilities and randomness.

This story has a happy ending with the work of Jean-Baptiste Perrin (1870–1942), who showed that a number of totally different experimental methods all led to exactly the same value of the Avogadro number. From then on no one dared object to the existence of atoms and of their random, probabilistic, motions in gases. Perrin even got the Nobel prize for this work in 1926. Yet Einstein, the man most responsible for the acceptance of random motions of gas particles, would later deny randomness when quantum mechanics negated the possibility of deterministic motions for elementary particles such as electrons and photons, as we shall now discuss.

The cup of tea

He thinks of a cup of tea
he remembers it
he remembers the remembrance
of a madeleine cake
dunked in the friendly brew.
He thus transmutes object into spirit,
dwelling on the thread of memory,
the cotton-thread of life.

As I remember his remembrance
of the warm vessel I remember
Boltzmann's paradigmatic cup,
the cup that after however much stirring
stubbornly refuses to separate
into candid milk
and a brown warm drink of *echt* tea.

I remember Proust's cup of tea
and Boltzmann's
and rejoice that the thread of life
is not a thread but a braid,
each strand joining into
the plurality of the human mind.

In a famous passage of *À la recherche du temps perdu* Proust used his recollection of tea with madeleine cake as an entry into his world of memories. That Boltzmann gave the cup of tea as an example of irreversibility might be apocryphal, but it is part of the oral tradition in physics.

A random sestina for Ludwig Boltzmann

Not many in his time believed in atoms,
and most did blindly trust pre-determination:
Nothing that happens could be random.
Hot was hot and cold was cold.
But Boltzmann the bold thought that the transition
from cold to hot was an orderly increase of disorder.

The Viennese was famous for his determination
and he proved that his decrement of disorder
gave you the energy going from hot to cold.
Well-ordered nature rests on a raft of random
events. It is the motion and vibration of the atoms
that explains and calibrates the heat transition.

To prove why heat does not go from cold
to hot the clever man showed that this transition
was infinitely improbable from the laws of random-
ness. Rubbish, his critics said. If you film the motion of atoms
and you run the film backwards, the determination
of the process, physics proves, is valid, and yet disorder

waxes in one film and wanes in the other going cold.
Hard problem that even nowadays creates disorder
in people's minds. But Boltzmann's determination
in getting so much explained by his transition
convinced many that this could not just be random
chance. Even then others said: all this is nonsense, atoms

do not exist: Boltzmann suffers from mental disorder.
And without atoms, randomness goes and pre-determination
remains. And on and on they blew hot and cold
upon poor Boltzmann's head. Then an experimental transition
came to verify that nature's nature is random
and that this randomness truly rules the atoms.

Too late, alas, for poor Boltzmann, who had hanged cold
in his seaside Gasthof, never to know that disorder
had been shown at last to be behind the random
movement of micro specks, kicked by the atoms

of a liquid. Einstein it was who did this determination
thus proving the reality of Boltzmann's fabled transition.

That science progresses in a mist of disorder
is no cause of wonder. Humankind's determination,
from initial thraldom, if well checked, is never random.

A sestina is a poem composed of six stanzas of six lines each plus a final one of three. The last words of each line are only six, permuted in a very specific way. I have instead, randomized these permutations in honour of the great Boltzmann.

CHAPTER SIX

QUANTUM MECHANICS, PROBABILITY, AND EINSTEIN

Everybody knows these days that electrons, for instance, can behave sometimes as particles, sometimes as waves (a dangerous phrase that we shall soon sharpen considerably). Should we be surprised by this fact? Do we have to accept this as a 'paradox' from the mystery merchants? Of course not. But in order to understand this curious behavior of quantum particles, we must first discuss classical particles.

Classical trajectories

What makes a macroscopic, that is, a classical particle, a *particle*, is that it has a *trajectory*: it is, in fact, its unique trajectory that labels it. And the trajectory of a classical particle is unique because, given its initial position and momentum (mass times velocity), Newton's equation will *determine* its position and momentum at any later time.

Several assumptions must be made here: the force acting on the particle must be known at each point in space (*force field*) and the interactions with other particles must be sufficiently weak to be disregarded. But we must also accept a principle of *continuity,* since the solution of Newton's equation can be any point along the curve that forms the trajectory.

It is most important to realize that the notion of a classical trajectory is deterministic, because the Newton equation is *causal*, position and momentum (mass times velocity) at a time *t* being the cause of the position and momentum at any later time *t'* (effect), if the force field is known.

Classical trajectories and existence

The concept of a classical trajectory offers a pragmatic solution to an existential problem: when I do not observe the moon, I can accept that it is there because it has a trajectory, which means that, if I know where it was at a certain time, I shall know where it will be at any later time. George Berkeley (1685–1753) had claimed that objects do not exist as such but only our *ideas* of them. It therefore follows that when I do not observe an object I cannot claim that it exists, but Berkeley filled the existential hole that he thus created by claiming that unobserved objects exist because they are observed by God. He thus made God necessary to endow objects with existence. (He never disclosed a conflict of interests: he happened to be a bishop.)

A famous example he produced is an unobserved tree in your garden, which of course could not exist without God's help while you sleep and are not able to observe. But the tree is a classical 'particle', it has a trajectory: observation shows that this trajectory is stationary. Therefore, when I go to bed in the evening I can predict by means of Newton's equation that the tree will be there in the morning (*ceteris paribus*). This is precisely what we mean when we say, 'there is a tree in my garden.' I do not have to keep observing it for it to be 'there'.

Quantum particles: observing the electron

The concept of a classical particle depends on that of trajectory, and the latter depends crucially on causality. But I have already argued that, post-Hume/Darwin, principles such as causality are not carved in stone: they are licensed to be used because they have both directed the evolution of our cognitive system and have emerged from this evolution. Our cognitive system, however, has never interacted with the microworld: thus, we cannot assume causality for electrons, and therefore we cannot expect to have trajectories for them. Therefore, we cannot treat them as particles, that is, as classical particles.

This means that if we want to observe an electron we cannot expect to operate in the same way as when observing a classical particle, such as a billiard ball. To start with, we cannot measure simultaneously its position and its momentum (mass times velocity) because, if we were able to do so, we could apply Newton's equations, which are valid for any particle (classical) whatever its substance, and are *causal,* whereas we know that causality cannot be assumed for the microworld. (Gentle reader: notice that here we have painlessly stated the crux of Heisenberg's Uncertainty Principle, which we shall discuss later. Also, our argument explains the behavior of the elementary particles as anticipated in Chapter 1.)

So, the most we can do at a given time is to measure either the position or the momentum (mass times velocity) of the electron. To measure the position of the electron, (Fig. 1, p. 3) the simplest thing is to let it pass through a single narrow slit. In fact, if we place a screen on the exit side of the slit the electron will strike it very near the centre of the slit. But we cannot expect this result to be causal, because we have no right to expect causality in the microworld. Sure enough, if we send successive electrons one at a time through the slit they will not hit the same point on the screen but they will be distributed around the centre of the slit in a distribution that turns out to follow the laws of probability.

The second way to observe the electron is one in which we know nothing about its position, but we want to measure its momentum. In order to guess what we have to do we must think back about what we know of physical objects. And the archetypal object that is delocalized but has a precise momentum (and thus kinetic energy) is a *wave.* (In the sea the same wave will hit with the same energy two bathers separated metres apart: the wave is delocalized.)

It is well known from elementary physics that the momentum (mass times velocity) of a wave is very simply related to its wavelength, which is easily measured with a diffraction grating. This is in effect a collection of parallel slits which is hit by the delocalized wave, thus producing on a screen parallel to the grating what is called a *diffraction pattern*. This is a periodic pattern from which period you can deduce the wavelength and thus the momentum of the wave. This is precisely what was observed with electrons, except that because they have much greater momentum and thus shorter wave length than optical waves, the diffraction grating used had to exploit the periodicity of a crystal. (See Fig. 2, p. 4.)

In the early days of these experiments people wrongly talked about the *dual nature* of the electron which, unfortunately, many do even now. This is a nonsense: the electron has one and only one nature, but because this nature must be manifested by macroscopic means (we have no others!) it must be revealed either by measurements of position or of momentum. This was perfectly well understood by Sir Arthur S. Eddington (1882–1944) who in 1928 coined the portmanteau noun *wavicle* to make it quite clear that the electron is not a particle with a dual nature but it is rather an object, a wavicle, the nature of which can be revealed macroscopically by particle-like (localized in space) or wave-like experiments.

Unfortunately, this name has never been systematically used with, to the best of my knowledge, a single exception, a book called *Is Nature Supernatural?* Because this approach has not been universally followed, a great deal of confusion has been created in the literature to this very day.

It must be understood that in the same way that the position of the electron at a given time permits finding a probabilistic distribution at a later time, the same happens for the momenta. Although I have to say that prediction of the evolution in time of these properties requires rather delicate concepts of quantum mechanics.

Einstein: a first reaction

As we have seen, Einstein had been most influential, through his study of Brownian motion, in getting the scientific community to accept the concept of atoms and molecules, so abhorrent to Mach and his school. Now, Brownian motion, which Einstein realized was a manifestation of the molecular structure of a liquid, is one of the best natural examples we have of random motion, but if randomness was there, it could be blamed on the complexity of a system with a huge number of particles. Einstein, on the other hand was repelled by the idea of randomness for the motion of a *single* particle, as attested by his already mentioned dictum: *God does not play with dice*. This was not a one-off jest, as shown by his continuous fight for some fifteen years, which we shall discuss later, with Niels Bohr, the apostle of quantum mechanics.

Randomness in Quantum Mechanics

Quantum mechanics, however, soon showed that there were inherently random, that is, non-causal, processes in nature. We have already seen that when an electron goes through a single slit, its later position is given by a probability distribution. Another very clear example of quantum random processes is radioactive decay. A radioactive atom in a piece of radium metal, say, will decay into an atom of another element and in the process emit an alpha particle (helium nucleus). It is an incontrovertible experimental fact that given a lump of radium the time it takes for half its atoms to split is fixed. But, as we have seen, if you consider an isolated single atom, not only it is impossible to determine when it will spontaneously split, but there is no way whatsoever to alter the time at which it will do so: that time is entirely random.

Despite such clear experimental evidence, Einstein mistrusted this feature of quantum mechanics almost obsessively, and he was sure that it appeared to exist only because the theory was incomplete. His misgivings infected the minds of some of the cleverest theorists of the twentieth century, John Bell (1928–1990) and David Bohm (1917–1992). Their work was important and useful, but they also supported a feeling that quantum mechanics could not be a complete description of nature, because it depended too much on those damned random phenomena. Experiments after experiments were triumphantly proposed in the expectation that the nonsense behind quantum mechanics would be exposed but, when they were eventually performed, quantum mechanics consistently came up trumps.

Bohr's misguided attempt at epistemology

An unfortunate consequence of the barrage of complaints about quantum mechanics raised, mainly by Einstein and his followers, in the first few decades following the introduction of the new theory is that, because of the intensity of the criticisms, it elicited the wrong responses from the theory's own guardians. The high priest of such a group was Niels Bohr (1885–1962) a great physicist but a bad philosopher, who tried to resort to an *epistemological* fig leaf to avoid ontological attacks.

I shall explain this: Bohr's defensive epistemological position was to assert that quantum mechanics deals only with *our knowledge* of wavicles, like electrons, photons and so on, without any commitment as to their nature or even their existence. (This is, of course, the essence of *epistemology.*) On the other hand, he intuited that elementary particles were no longer 'particles', because they lacked physically meaningful trajectories. Thus, when unobserved, they could not be assumed to have precise positions and velocities. In the same way that we cannot say anything about a classical particle unless we know its trajectory, to discuss a wavicle, as we have seen, we must manifest it by means of macroscopic observations, which means that we must determine either its position or its momentum at any given time.

Bohr claimed, however, that these measurements provided purely epistemological information, thus avoiding Einstein's ontological preoccupations. This was entirely unnecessary: wavicles are possessed of as robust an ontology as billiard balls: their 'existence' is entirely independent of the observer. The fact that the observer can choose how to make them manifest, by measuring either momenta or positions, is not fundamentally different from the choice an astronomer has as to where to point out his telescope. The possibility of a single ontology (a single substance) manifested in two different ways has been known well before quantum mechanics, indeed since 325 CE, as we shall discuss in Chapter 9, which will show again the philosophical weakness of Bohr's position

Of course, the Dane's misguided pretence that all that quantum mechanics did was no more than epistemological, created instant discomfort, eagerly exploited by the enemies of the theory. The strange 'wave-particle' had no ontological status at all, it was claimed, following on Bohr's steps. But David Bohm went further: for him the only objects that can have a proper ontology are ‘particles’ that, like the classical particles, can be described by means of proper and decent trajectories.

I do not wish to claim that these scientists were utterly wrong, because ontological claims have various levels of credibility. In physics, however, one takes the pragmatic view that when a theory saves the facts correctly, then the ‘objects’ of the theory, such as quarks, electrons, and so on, ‘exist’, that is, are ontologically licensed (as in fact the American philosopher Wilfred Sellars, 1912–1989, held). This means, of course, that they are credible objects that may be incorporated in further theories. So, orthodox quantum mechanics is as ontological as any other physical theory, the ‘wave-particles’ or Eddington’s ‘wavicles’ having the same ontological credentials as classical particles have within classical theory. This statement would have been much clearer, in fact, if the scientific community had stuck to Eddington’s terminology.

Einstein’s views of quantum mechanics

Faced with the elusive nature of the electron in quantum mechanics, whose very existence appeared to depend on that of an observer who chooses how to manifest it, Einstein famously demanded that, as he knows (despite Berkeley) that the apple tree in the garden is there when not observed, so it must be with the electron. But we have seen that we know that the tree is there when not observed because it is a classical particle. Newton’s equation determines the position and velocity of the particle at any later time from their initial values. Thus, even when we do not observe the apple tree in our garden, we know it is still there, his causal Newtonian trajectory (*ceteris paribus*) being stationary. From the arguments discussed in Chapter 4, however, we are not licensed to use causality in the microworld, so that wavicles cannot have classical trajectories. Of course, Einstein could claim, as I have said, that an unobserved electron could perfectly well follow causal laws. I have argued, however, that *such an assumption is not rationally tenable and is based on a misunderstanding of the use of the Principle of Causality. This is so because this principle is not of universal application but can only be used when it can be shown to be firmly entrenched within the evolutionary process. And this, as we have seen, is only the case for the macroworld.* In other words, the Principle of Causality is *contextual*, its context being the macroworld, wherefrom came the stimuli that created it. Substantial evidence would have to be provided to make a causal point of view à la Einstein in quantum mechanics to be more than just an act of faith: he was behaving not as a scientist but as a prophet. And, in fact, all his objections to the theory from the point of view of physics were successfully rebutted by Bohr.

The reader must understand, however, that prophets are not necessarily wrong: it is a result of logics that a false premiss might yield a true consequent, for instance: ‘In 2015 all European Prime Ministers were Eton’s alumni, therefore the British Prime Minister was an Eton’s alumnus.’ (An unfortunately correct conclusion in the UK.) At the moment, however, there is no reason whatsoever to support Einstein’s rejection of the probabilistic interpretation of quantum mechanics.

Uncertainty principle

It is useful to understand the well-known historical disagreement between Bohr and his graduate student Werner Heisenberg (1901–1976) when the latter discovered the *Uncertainty Principle*. This principle states, as we have already done, that you cannot determine precisely and simultaneously both the position and the momentum of a wavicle. Armed with the knowledge of causality we now have, we do not need Heisenberg to tell us this: if we were able to measure the position and momentum of an electron at the same time, then we could use Newton’s law for it, which we know is not permitted since this law is causal and causality cannot be applied in the microworld. If Heisenberg and Bohr had understood this, a great deal of confusion and strife would have been avoided.

But this was not the case: Heisenberg had used a thought experiment (*gamma microscope*) in which, in order to measure the position of the electron (which he regarded as a particle) it had to be illuminated by a beam of photons. Heisenberg argued that the collision with the latter would necessarily change the electron’s momentum (mass times velocity). This would make it impossible to measure precisely at the same time the position and momentum of an electron. As a result, an electron with precise momentum could not be assigned precise positions but only its probability of being found at given positions in space.

Bohr profoundly disliked this picture, and he tried to persuade his young colleague that before the position of the electron is measured, you do not have a particle at all, (or a wave, until the momentum is measured). In other words: what you have is a *wavicle*, which must be manifested macroscopically (the only way in which *anything* may be manifested!) either by measuring its position or its velocity.

Unfortunately, so obscure were the arguments used by Bohr at that time that Heisenberg did not understand what he meant. Almost a century later we still suffer from the wooliness thus created, which was not made easy to overcome, given Einstein's well deserved intellectual prestige and the obscurity of Bohr's arguments. Even now, many textbooks claim that on measuring the position of the electron its momentum is perturbed. This is wrong, because the position and momentum of an unobserved electron have no physical meaning and thus cannot be perturbed. (This is not the case for a classical particle that has a well determined momentum and position at each point of its trajectory.)

Likewise, the role of the observer in 'perturbing' the wavicle, is exaggerated: all the observer does is choose a way in which the wavicle may be manifested.

We shall now consider an application of the principles of quantum mechanics that, again, and with good reason, baffled Einstein.

Entanglement

It is a well-known fact that the electron is possessed of an extra variable called *spin,* which can be visualized as some sort of rotation, except that it can have only two states, corresponding to the electron 'rotating' clock or counterclockwise. The remarkable experimental fact is that pairs of electrons can be created simultaneously so that one of the pair is counterclockwise and the other the opposite. Such pairs are said to be *entangled.* Notice that therefore the total spin of the pair is zero, and it is a result of quantum mechanics that the total spin, zero in this case, must be conserved. Now comes the amazing result: you create a pair of entangled electrons, say *A* and *B*, and separate them by a distance *d.* If you change the direction of the spin of electron *A*, (e.g. from clockwise to counterclockwise) since quantum mechanics *requires* the null value of the total spin to be preserved, the spin of *B* must also be reversed: this means that you have acted on electron *B* at a distance *d.* In a famous paper Einstein, Podolsky and Rosen proposed that this possible experiment would reveal a paradox of quantum mechanics, since such *action at a distance* they regarded as *impossible.* (In his colourful language Einstein called it *spooky*.)

Everybody knows the famous dictum of Sherlock Holmes: 'When you have eliminated the impossible, whatever remains, however improbable, must be the truth.' This appears to be perfectly rational because for a detective a good alibi determines an impossibility: but we must be weary of using it ourselves because there is no way of knowing what for nature is *impossible*. In fact, the experiment suggested above was carried out many times for distances *d* reaching kilometers and quantum mechanics always triumphed, so that the hated action at a distance is an undeniable fact.

Undeniable, but so counterintuitive that I suggested in *Is Nature Supernatural?* that entanglement might require a change in the concept of distance so that entangled particles are constantly contiguous. We are tied up with the idea of space as a bucket of sand, ultimately resulting in the mathematical points between which distances are determined. But space could instead be like a bucket of spaghetti, distances determined by two *different* strands. *Strings*, as used in String Theory, could not do this job, because they are minute, but recently Juan Maldacena and Len Susskind (google 'EPR=ER') postulated that entangled particles are linked by what in relativity theory are called *wormholes* (invented by none other than Einstein and Rosen). These are remarkable features of spacetime: a wormhole could start in α - Centauri and end in Miami but, since distance inside the wormhole loses meaning, those two 'points' become now contiguous. In the same way entangled particles are constantly contiguous: the impossible becomes obvious: good old Nature!

Although this might not be the end of this story, it has the virtue of being compatible with string theory, as proved by the authors mentioned. But, most importantly, it shows again that prophecy is not an acceptable substitute for rational thinking.

Superposition principle and the Schrödinger cat

I shall not attempt to discuss how you define a quantum state: I hope that the reader can accept that this can be done and that these states do not form a continuum but are *quantized, that is, that they form a discrete set*. These discrete states are called *eigenstates.* This is in fact the remarkable feature of quantum mechanics. Imagine a hydrogen atom, which has a nucleus of one proton (positive) and one electron outside it, with the same charge as the proton but negative. If you heat the atom the electron will gain energy. In classical theory it would have a continuous set of energy values that it can assume as you excite the atom. It is well known that this is not so: as stated above the electron states are *quantized*. If the lowest energy level the electron can take is, say, ψ_0 the higher eigenstates will all be separated forming a discrete set, ψ_1, ψ_2, ψ_3, ψ_4, and so on. The electron may acquire energy only through *quantum jumps*, jumping for instance from ψ_0 to ψ_3.

All this is well known but now we can start a little bit of work to understand one of the most remarkable features of quantum mechanics, the *superposition principle.* I shall do this by using as an example the ammonia molecule, NH_3. It is very easy to visualize its structure: The three hydrogen atoms are in a plane, of course (three points determine a plane uniquely), on the vertices of an equilateral triangle. If you take the centre of this triangle, the nitrogen atom is at a certain height exactly above that point. Let me call ψ_1 the state of the ammonia molecule that I have just described. The interesting thing is that there is another state which must have exactly the same energy and which I shall now describe. To do this imagine the first structure I defined as an umbrella with three ribs attached to the N atom. If there is wind often an umbrella inverts: this is equivalent to the N atom moving from above the plane of the H atoms to the opposite side, at exactly the same distance. Now we have two structures, the first one ψ_1 and the second one ψ_2 which have two important properties: one, that they must have exactly the same energy because the relative distance between all atoms is the same in both cases. The other one, that they are independent, that is that they cannot be transformed one into the other by a rotation. (A wind-inverted umbrella cannot be righted by just rotating it, or, what is the same, the right hand cannot be made into a left hand by any form of a rotation.)

The *superposition principle* says that we must write the state ψ of ammonia as a superposition of the two states ψ_1 and ψ_2:

$$\psi = c_1\psi_1 + c_2\psi_2. \qquad (1)$$

The coefficients here have a very simple physical meaning: $(c_1)^2$ is the *probability* (sorry, Professor Einstein) of finding the molecule in the state ψ_1 and similarly for $(c_2)^2$. Because the two states are energetically identical, you would expect these squared coefficients to be both equal to ½. It is most important to realize that the probabilities that appear in (1) are totally different from classical probabilities. Classically, you would expect a gas of ammonia molecules to be a *mixture*, 50 % of the molecules in one state and 50% in the other. This is most emphatically not the case in quantum mechanics. All the molecules are in the *same state* described by (1). That is, this equation describes the state of a *single* molecule. It is only when you interact with a molecule that the state function ψ *collapses* into one or the other of the eigenstates ψ_1 or ψ_2. (More precisely, it is said that the state function *decoheres* randomly into one of the eigenstates.)

Of course, this was an almost intolerable situation for Einstein. Not only probabilities appeared in the definition of the state of a single particle, but this state, unless measured, had a strange existence, being a sort of hybrid between two different eigenstates. I have to emphasize that the quantum mechanical description of a state that I have given is not a bit of metaphysics excogitated from an armchair. Its validity and its importance are validated by experimental results. For instance, if you want to calculate the length of the NH bond, and you work it out using only the geometry corresponding to ψ_1 (N up) you do not get the correct experimental value, until you consider also ψ_2 (N down) and the proper combination of these two states. If you want more experimental evidence: the two states I had mentioned will react differently with an electrical field, because the charges in the N atom will be either in the direction of the field for N up or against it for N down. This is the basis for generating microwaves in the first laser-type device ever designed, called an *ammonia maser.*

All this, however, was of no avail for Einstein. As you probably know, he was very keen (and very good) at designing *gedanke* (thought) *experiments* and in 1935 he had some correspondence with Erwin Schrödinger as a result of which the latter produced the most famous *gedanke experiment* of the century. This was so, because Schrödinger designed the experiment in such a way as to excite as much as possible the public's imagination, which he did by introducing a cat in the experimental set up, a brilliant piece of PR. I shall be more restrained, by doing first the same experiment in a more humane way without a cat, which I will only introduce in a second stage.

So, we have a very simple set up: a box with a lid, inside a small lump of radioactive material, so small that it might take several hours for a single atom to decay emitting an alpha particle. Also inside the box, a Geiger counter, a digital one with a dial with only two digits, 1 when no alpha particle has been detected and 2 when it has. We put everything in the box, close the lid and wait, say 2 hours. Meanwhile, we set up a quantum-mechanical state function for the Geiger counter. (Gentle reader, if you think that this is foolish, it is not my fault.) The counter has only two possible states, which we label as ψ_1 and ψ_2 (no decay or decay, respectively. So, the state function of the counter will be by the principle of superposition,

$$\psi = c_1 \psi_1 + c_2 \psi_2. \qquad (2)$$

This means that while we wait with the lid on we cannot think of the counter as reading either 1 or 2 but rather being in a composite state, neither decayed or not decayed. It is only when we lift the lid and peer into the box that the Geiger counter is read as in 1 or 2. All this is very clever because it does two things. It discredits the principle of superposition which forces us to imagine the counter in a very strange way. Also, it brings the observer to the fore: it is only when the observer lifts the lid that this nonsense stops.

It is pretty easy to discover in which sleeve the magician had hidden the joker card. In (2) we have applied quantum mechanics to a macroscopic body. Admittedly, it would be very desirable if this were possible, but should this ever be the case it could not be in this crude way. You would start with a microworld object, set up the state function, and make the object gradually bigger. At some stage the state function will decohere into a single state, as it should be the case for macroscopic, classical, objects. For a heavy object as a Geiger counter this would happen almost instantly. So, before we lift the lid we know that it will be either in state 1 or state 2. No paradox.

What about the cat? Schrödinger modified our experiment. He coupled the Geiger counter to a phial that would emit poison gas in case 2, when a radioactive atom decays. He callously ads a cat to the box and shuts the lid. During the waiting period the counter is in 1 (no radiation, cat alive) or the counter is in 2 (radiation, cat dead). If before it was abhorrent to think of the counter in a superposition of states ψ_1 and ψ_2, now it is worse because we must think of the cat as neither alive nor dead but in a superposition of the two. But we know that the explanation is that the cat putative quantum state would have decohered instantly into one of the two possible vital states of the poor animal. Amazingly good idea this of the cat to attract immense attention: dozens of books have been the result.

All in all: quantum mechanics may appear a bit strange, because unfamiliar, but it is still a rational branch of knowledge.

Coda

Archaeologists have a difficult task: very often they only have small shards and some coins, which they have to use as a testimony to a culture that they try to understand. What for the archaelogists is a culture to which they have to extrapolate their data, for us it is Nature. To learn how to describe it, our cue, which replaces the shards and coins of the archaelogists, is the structure of our neural network. It is this structure that suggests a principle for organizing our thoughts, the Principle of Causality.

The important idea is that this cannot be an absolute, it has to be *contextual*, that is, used in relation to the link we have established between inputs from nature and our neural system. Because all those inputs are macroscopic (since our cognitive system cannot ‘read’ inputs from the microworld) causality cannot be applied except to classical, macroscopic, particles. This means that electrons, for instance, cannot be treated as classical particles, for which causality is determined by their positions and momenta. At any one time only one of these variables may be measured exactly for microscopic particles (*wavicles*), the other generating a probability distribution. This simple argument shows that Einstein's profound rejection of probability in quantum mechanics was not rational. But irrational thinking in our description of nature is to be found in a variety of cases, especially when it relates to matters that traditionally arise strong emotions: one of them is the problem of creation which will be discussed in the next chapter.

Heisenberg cried

Winter came and Master went
in search of snowy slopes.
Boy alone at last,
respite from incessant talk.

Boy dreams, boy understands.
Photon on electron:
wave no wave.
No photon: particle no particle.

Boy understands:
His dream explains facts.

Master returns and they talk and talk.
Master says, your picture is wrong,
you do not have a particle or a wave
before you hit it with a photon.
You know nothing then.

They talk and talk, eight days.
Master says, do not believe in your eyes.
Boy, who does not understand why, cries.

In the end, compromise,
the world is told,
and a new world
and a new century arise.

This event is documented in a letter from Heisenberg to his friend Wolfgang Pauli.

Particle no particle

"Reasonable" is not quite the word that leaps spontaneously to mind when we are told that the same nuclear particle can pass through two different apertures at the same time.
—Terry Eagleton, *Reason, Faith, and Revolution,* Yale, 2009, p. 113.

A Poet told me, you physicists
believe unreasonable things.
That is not possible, I retorted,
science demands that nothing
we accept be bereft of reason.

That's a tall story, my friend answered,
you claim that a nuclear particle
may disport itself in two places at once,
which would have driven Thomas Aquinas
nuts, had he heard of quantum mechanics.

Dear Poet, I said, you poets
are Masters of Words
so you well know that they
are like comets which in their travels
collect all sorts of debris in their tails.

Some of this gives words delicious flavours
but sometimes the tail robustly
changes the signified. Would you dear Poet
roast a decoy duck?
                                        Of course not,
a decoy duck is no duck.
Good, I said, in the same manner
a nuclear particle is no particle.

Because we cannot experiment
except at our own large-scale level
we can only observe it either as a particle
or as a wave, in which case,
as waves are wont, they can act
in two places at the same time,
like a sea roller that knocks down
two bathers many yards away.

Democritus, dear Poet, was wrong:
if you break a stone into ever smaller pieces,
the moment comes when the essence
of the object necessarily changes.
This is the way the world is.
Would you not say that the wise life
is the recognition of reality?

Entanglement

Like Castor and Pollux
they were born together;
unlike them, of identical substance.
And unlike them, separated at birth,
they move always in opposite directions
on a long dark stage.

If you ask me what they really are
I shall not say,
but I shall call them Jean and Jane.
I do not know much about them:
I think of them as dancers.

I also know this:
Jean moves always to the left
while Jane progresses to the right.
They are not *prime ballerine*.
All they can do besides
their constant translation is gyrate,
gyrate to right, gyrate to left.

In the dark, I do not know what they do,
and I do not care.
But I have an interactive torch on stage left:
When I shine it on Jean, who is there,
I can choose to make her gyrate in one way
or gyrate in the other.
On stage right a passive torch
helps me reveal Jane's work.

We now come to an amazing fact:
I shine my interactive torch
and induce Jean to gyrate *left*.
Then I can bet you that
if I repeat this a thousand times,
each time I shall find Jane spinning *right.*
If instead I force Jean to gyrate right
then I shall find Jane spinning left.

What Nature is telling us, and she
is always right, is that the left torch,
narrowly focused as it is on Jean,
acts instantly on Jane as well though this twin
could be miles away (our stage is so long).

Great as Einstein was, he rejected this
even before experiments were made:
Nature, he thought, would abhor
action at a distance, spooky as voodoo.

Clever men (who thought him right)
invented and constructed a machine:
But Nature refused to accept
the results of Einstein's doctrine.

Whether you like it or not
entanglement exists, no doubt,
and with it action at a distance.
We had better think again
what distance means to Jean and Jane.

I can now tell you what they both are:
a graceful pair of photons, such
as Castor and Pollux beam to us
any night from the dark sky.

CHAPTER SEVEN

CREATION

Creation is the fountain-head of all religions and a concept that appeared to be beyond any possible rational scientific explanation. Quantum mechanics has changed all that, as I shall show in this chapter.

Miracles

Before getting into this I have to say a few words about 'miracles' and in so doing I must apologize to theologians because I shall strip such events of their theologically most important feature (e.g. Luke 7:19-22): their intension or significance, since such qualities are beyond the province of rational discourse. (Miracles are theologically like birthday cakes: they do not mean anything at the baker's until they are made to signify, and it is only then that they become a Birthday Cake.) It is for this reason that I give the word in quotes.

So, for our purposes a 'miracle' is just an event of exceedingly small probability. If you were to throw a perfectly unbiased coin ten times and you obtain a sequence of ten heads, this will count for my purposes as a minor 'miracle'. Such an event was shown in a television programme in the UK some years ago by the illusionist Darren Brown. At the end of the evening he disclosed his trick: they had spent the whole day throwing a coin but had only kept in the film the short sequence of the ten heads.

This is precisely what probability theory tells us: if you observe an event with a very low probability it must be part of a very large sequence of such events. The smaller the probability the larger the number of events required to materialize the 'miracle'. With a lot of patience, say taking a few billion years, you could even walk on water, since the random movement of the water molecules must include a distribution of their positions that produces a firm layer. So: if anything happens with a very small probability, it would be entirely wrong to postulate that it is the result of supernatural intelligent design: what you must do is to look for the possibility of the event being part of a much larger sequence of such events. You have been warned. Now we can start the work of the chapter.

The vacuum and the Big Bang

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The 'miracle' of creation is one that has exercised the minds of people for millennia and for a very long time it was inconceivable that some explanation of it could be provided that was not the province of theology. Quantum mechanics was the first physical theory that gave us a plausible and rational insight into the phenomenon of creation, which I shall sketch very roughly since the details are still not fully determined.

The problem, of course, is that creation must be creation from nothing (otherwise, the existence of a pre-existing non-nothing must be explained) and for centuries everyone believed in the dictum: *ex nihili nihil* – from nothing, nothing may be created. We now know better, because quantum mechanics has given us a totally different picture of 'nothing', that is the absence of matter, the vacuum.

The modern vacuum is a highly dynamical object. In it wavicles are constantly created and annihilated in such balanced quantities that the result is: nothing. But quantum mechanics is always subject to randomness, and random fluctuations can happen in the vacuum, as a result of which wavicles that are created might exceed those that are annihilated. If this happens very suddenly and in a very concentrated region a Big Bang ensues and a universe is created.

Anthropic principle

If we accept this very sketchy picture of the Big Bang, a serious problem follows. Clearly, the first instants of the universe created by a big bang will determine the laws of physics which, in turn, will determine the nature of the wavicles and atoms that are created. And here is the rub, because if for instance carbon atoms had not been possible as a result of a big bang, then life as we know it would not have evolved. The question then arises: why is it that these beneficial but highly unlikely physical laws – given an almost infinite number of alternatives – have appeared?

The answer is provided by the Anthropic Principle, of which there are several formulations but basically the one that interests us is the following: things are as they are because otherwise we would not have been here to witness them. As you can see this is hardly any explanation at all, but rather a description of the state of affairs, a conversation stopper.

Having said this, we now remark that ‘our’ Big Bang, some 14 billion years ago, is very special, because it has created a self-referential universe: the universe speaks about itself through our mouths. Those who like to believe in the supernatural then claim this feature of the Anthropic Principle as making the Big Bang so very improbable that rather than been a ‘miracle’ in our terminology, it is a Miracle, the result of some purposeful intelligence.

If you are tempted by this argument please remember that if you witness an event with infinitesimal probability, a ‘miracle’, then it must be part of a very much larger sequence of events. This is in fact what contemporary cosmology is moving to at present: it is possible that a quasi-infinite number of big bangs have created a quasi-infinite number of universes, may be in parallel, of which ours is one (and if it had not been self-referential you would not have been here reading this book). Another possibility, of course, is a quasi-infinite succession of big bangs, the created universes having been annihilated in time, except ours. Either way, there is no need to postulate a supernatural entity with an intelligent purpose: one more step towards rational discourse. But make no mistake: the irrational is very dear to the human mind, at least until the present moment, and numerous ways have proliferated to undermine rationality, as we shall now see.

The devil's arse

Le miroir est le vray cul du diable.
—Medieval saying

When he was young
and nothing but his loins mattered
he wrote some lines
about the demiurge he decried:

"Tired of not being,
with your hands you made
in the void a hole
and you became."
As time went on
He mulled over the void:
he first discovered
the orphan void, the void
that once had been
lively of matter now gone;

the pregnant void, void as void is,
but with the potential
to become. The cutest of these is
the void physicists posit,
a perfect balance of particles
created and dying
in such numbers and at such
speed that the result is:

nothingness.

A slight defect in such
equilibrium might have
created the BIG BANG.

After this he was assailed
by grammatical doubts.
Could he only speak of The Void,
or is it possible that in this realm
of non-existences there is more than
one void, and thus 'voids' in plural.

But surely if there are two,
such voids could not be side
by side. Because in the void
there is no right no left,
no up and no down. And please
do not say that there, in between
two voids, that’s where the devil’s arse lies.
Or some clever god lurks.

Shakespeare's brain

There are many who still believe
the improbable to be impossible,
that no network of diligent monkeys
however many, however long the time,
could type the works of the great poet.

Nature knows better: in millions upon millions
of years, by means of millions and millions
of competing mutations, she perfected
a network not of monkeys but of billions
upon billions of brain cells.

This huge number allows them
to operate in years rather than aeons.
So one day by the quiet Avon river,
Nature started training her network
and in just a few years the nearly impossible
happened: Shakespeare's works got written,
heirs of some primeval lump of mud.

So improbable this seems that there are those
who still claim that he could not have authored
such a quasi-miracle.

Conspiracy theories and Creationism

As all the world has known
no man ever landed on the moon.
It was a trick that NASA did.

JFK was never shot:
a double died instead,
and Jack promptly escaped
to the balmy island of Tonga
with lovely Marilyn Monroe
and learned to dance the conga.

(The story of Marilyn's suicide
was CIA's shrewd fabrication.)

Nine Eleven was a clever
ruse, a TV show easy
to fake. To these days the towers
are intact. It was Uri Geller
with some ingenious mirrors
who created the perfect illusion.
The towers are day and night
full of perverse Jews
working to manipulate the news.

No more strange conspiracy
than Princess Diana's murder.
She was trying to run away
to marry her driver Paul,
carrying Dodi's decoy.
It was jealous Dodi Fayed
riding his red moped
who caused the car to veer
and the princess to disappear.
He then secretly flew away
to a friendly Cayman Island
to keep well away from the taxman.

Say what you will, the creator
is by far the greatest conspirator:
he begot the earth and the stars
eight thousand years ago,
but made mountains and fossils
look millions of years old.
And he constantly continues
to delay the light from the stars
to make them look very far.

Fakers of antiques know the word:
distress – make the new look old.
Why the creator does this
has only now become known.
Some of our parallel universes
are populated by simpleton trillionaires
who desire to purchase antique worlds.
At this very moment, how perverse,
bids are made for our distressed universe.

CHAPTER EIGHT

THE NEW ENEMIES OF RATIONALITY

There was a time when we had no trouble in finding where the enemies of rationality lurked. And because they normally operated outside the domains most concerned with rational thought, such conflicts as existed were easy to keep within clear boundaries. In the last thirty or forty years, instead, some of those who profess to be the defenders of rational thought, philosophers, mathematicians, and scientists, have effected concerted attacks against its fabric. As a result, the general public has been much mystified. Even worse, the siren songs have been eagerly tuned to by social scientists, and since they are by the nature of their profession those most able to communicate with the public, such truth as thus percolated to the media became tainted with wide misconceptions.

We are witnessing a new *trahison des clercs* which, in an era of instant global communications, is more serious than anything experienced before. Curiously, one of the institutions that was traditionally seen as an enemy of rationality is now amongst those that support the position of science as a legitimate and independent seeker of truth. To think that, while the Vatican has moved in this direction, distinguished academic thinkers of famous universities have moved in entirely the opposite one, is indeed awesome.

The consequences of this neglect of rationality cannot be over-emphasized: it affects some of the most urgent problems of our times, such as climate change and the multiple vaccination of children. The basic problem is that a significant number of people, led by the tabloids and populist politicians, are affected by a profound distrust of science. Two important aspects of the scientific endeavor are totally misunderstood. First, that nothing in science means anything in isolation: it must make sense within the vast amount of facts and theories that constitute the mesh of scientific knowledge. And, secondly, that nothing has scientific value unless it complies with the *protocols* that guarantee the validity of any scientific work. Unfortunately, it is not that scientists have failed to communicate properly with the public: it is that many within the scientific community have subscribed to ideas that imperil the proper understanding of the scientific endeavour, as we shall now see.

The anti-rationalists

There are four strands to this academic attack on rationality. First, philosophers like Ducasse and followers have led the move, by debunking the most rational of British philosophers, David Hume. Secondly, some mathematicians have flown to a Platonic empyrean, followed by philosophers eagerly engaged in dissociating mental processes from any possible resemblance to computers. Thirdly, some theoretical physicists have created a distrust of quantum mechanics, producing ‘paradoxes’ and ‘mysteries’ that have consumed whole forests of trees in popular expositions designed to encourage some sort of mysticism. What is even worse, a unique position for the human mind was claimed in quantum mechanics, implying in some way that perfectly natural processes cannot exist independently of an observing mind: Bishop Berkeley would have chuckled with delight.

The fourth strand is by far the most dangerous one, because it has been the most effective: *cultural relativism*, the equation by Thomas Kuhn of science with one more myth, intellectually no better grounded than Aristotelian physics. And Thomas Kuhn has been the dominant influence in the history and philosophy of science in the last generation.

Detractors of Hume

We can be very brief here because the subject has been fully discussed in earlier chapters. It is enough to remind the reader that Ducasse’s claim that the causal relation is a percept is totally unwarranted and does not even satisfy the conditions set up by Hume for such claim to be valid.

Moreover, Hume had claimed that the causal relation is both necessary and sufficient, which, *ceteris paribus*, is the way science uses such relations. If this is denied then you must look for criteria to distinguish accidental from causal connections. As mentioned in Chapter 3, Rom Harré, the Oxford philosopher, does this by means of ‘powers’, whereas Nancy Cartwright, of the London School of Economics, put her money on ‘capacities’. Thus, a force has the power or the capacity to produce an acceleration. Very pretty, except that forces have a very precarious physical status. If your car stops suddenly and you do not wear a seat belt, you hit your head against the windscreen: the ‘inertial force’ entailed, however, is a fictional construction, required, as well known in mathematics, by the unfortunate use of vectors, which change meaning in different coordinate systems.

The insistence in powers and the like is a way back almost to Aristotle's *efficient causes*: like them, they have no place in modern scientific thought, except perhaps as a help in creating physical models.

We have also seen that Hume's programme, completed by Darwin and Ramón y Cajal allows us to understand the status of the principle of causality as a non-metaphysical principle. Indeed, it is for us an example of a rationally established principle, reflecting its genesis through the evolutionary interaction of our cognitive system with nature, and through the ontogenesis of the neural network in our brains.

Reading Hume not having got rid of Aristotelian cobwebs has serious consequences for the interpretation of science. Nancy Cartwright has claimed that *'the laws of physics lie'* (the title of one of her books, which has thus added some fuel to the pyre on which modern science has been consumed). The laws of nature cannot lie because they do not exist. We only have laws of *models* of nature. Newton's laws, for instance, are applied to *mathematical points*: these do not exist in nature but are only a map of it, and everybody knows that to confuse the map with the object is nothing short of lunacy.

The art of science is to map nature onto, say, nature(2), the model nature, and then produce laws for the latter. These laws allow us to predict model 'effects', starting from their model 'causes'. Once you apply a law that way, you must map back from the model 'effect' to its natural counterpart. Science thus entails an excursion from nature to nature(2) and back. If this excursion is interrupted, you are left with a model object that need not have a counterpart in nature, and any attempt to map it back may lead to nonsense. This situation is common in mathematical physics, especially when using a procedure called *perturbation theory*, in which the intermediate steps used in the models have no physical meaning. It is only the first ('cause') and the last ('effect') points on the excursion into model nature, nature(2), that must have counterparts in nature.

You have been warned.

Mathematical Platonism

I shall now discuss the question of mathematical Platonism. There are, like in most religions, different orthodoxies of Platonism, but most mathematicians that embrace the doctrine claim, first, that mathematical objects form a world of their own, entirely independent of nature and of the human mind. Secondly, that mathematicians have a direct perception of such objects (*afflatus*), just as real as my perception of the table on which I am writing. I can justify my belief in my writing table because I can establish a causal chain from it to my perceptive system, photons, retina, nerves, synapses, and so on. But not even the most devout Platonist can attempt any such thing for the perception of mathematical objects. I have asked Roger Penrose (1931–) during a seminar how he justifies this perception, and his answer was: it is a 'mystery'. We all know that mysteries are wonderful because of their interest by the media, but that they indicate a total abdication of rationality.

The arch-Platonist of the twentieth century was Kurt Gödel (1906–1978), who revolutionized mathematics when he discovered deep limitations to the properties of completeness or consistency of mathematical-logical systems. If you take completeness, for instance, a physicist who claimed that physical theory could in itself be complete – which entails that physical 'proof' be independent of nature (that is, of experiment) – would have his or her sanity instantly questioned. In fact, what Gödel proved was that, just as you cannot give a complete *closed* account of why natural language is used the way it is used, so there cannot be a completely closed account of why mathematical propositions are accepted as true (something outside the system is required). In other words: he showed that we can't walk without feet, whereupon he, like his followers, chose to levitate.

One of the most extravagant consequences of mathematical Platonism is the way in which it has affected the perception of the human mind. Everybody knows that when a mathematician has a creative moment, as when discovering a new theorem or, even better, a new mathematical concept, he or she achieves this, not by a routine, repetitive, (algorithmic) process but by what is appropriately called a leap of imagination, such as is shared with most creative people. This, however, is of no interest to the Platonists, because at that moment, for them, the mathematician is neither inventing nor creating: he or she is *discovering,* reading the Platonic world by such mysterious means as Penrose claims.

On the other hand, such non-algorithmic thinking, they believe, is what separates men from machines, as the Oxford philosopher John Lucas (1929–) claimed. Here the Gödel theorem comes handy, because his demonstration that no mathematical system is complete means that there are true statements that cannot be proved within the system, but which can be known to be true by mathematicians (by non-algorithmic methods, because they are outside the system): herein Lucas expected to dig the chasm between men and machines and Penrose has very much exploited and extended Lucas's idea.

If you put this against the fact that we all know, in any case, that such non-algorithmic thinking is there as part of the creative process, the appeal to Gödel appears to complicate unnecessarily the discussion of intelligence. Wittgenstein (1881–1951) had claimed that you cannot expect philosophy (or for that matter mathematics) to solve problems of natural science. But this wise precept is constantly forgotten by those who appear to yearn for a return to a-prioristic forms of thought.

The reader might believe that the mathematical Platonist must have some form of mystical mind. The power of mathematics is so extraordinary, however, that it links as Platonists people of entirely opposite religious beliefs. Gödel himself had gone so far as to have once produced a logical proof of the existence of God, but the Cambridge mathematician G. H. Hardy (1877–1947), who was a staunch Platonist, held God to be his enemy.

Quantum mechanics and the human mind

The third strand that has propelled human thinking outside the safe paths of rationality is quantum mechanics. Bohr's philosophical misconception, discussed in Chapter 6, that quantum mechanics is a purely epistemological theory, had the most confusing consequences when discussing the role of the observer in the theory. If an electron is purely epistemological, that is, if it is only what we know about it, all we have is the act of observation, which is classical. But the act of observation requires an observer. Thus, the quantum world, it is claimed, is firmly tied up to the human mind, because until the mind observes, the observed has no more than an ontologically disadvantaged existence.

Of course, measurement and observation are crucial in quantum mechanics, but the end result of a measurement is macroscopic, the position of a pointer, say. You need as much the mind of the observer there as we need our mind to observe the moon and thus give it existence à la Berkeley. Yet, the despondent voices continue to this day, trying to fit the square peg of microscopic nature to the round hole of the macroworld. Naturally, this is a recipe to display contradiction and paradox; and thus more 'mysteries' are thrown onto the public. How people can believe that the scientific process is a rational one is difficult to understand when such a weave of contradictions is presented to them. But nature is never contradictory: it is us that abuse her by trying to array her in the wrong clothes.

Cultural relativism

I now come to the strongest attack that science *ever* experienced, and I write this with care: even Galileo's inquisitor, Cardinal Roberto Bellarmino, held it possible, as he wrote in a memorandum to the Vatican, that the day might come when Galileo might be proved right. (Galileo himself admitted that he had no full proof of Copernican theory. Incidentally Bellarmino is almost always misspelt as *Bellarmine*: he was in fact Italian, born at Montepulciano in Tuscany and buried at the St Ignazio Church in Rome.) That is, Bellarmino appeared to believe that science can, in successive steps, approximate to the truth.

No such optimistic view of science-based knowledge was held by the most influential science historian of our generation, Thomas S. Kuhn (1922–1996). To paraphrase him, if Aristotelian dynamics or phlogiston chemistry are to be called myths, then myths are also produced and held by present scientific knowledge and will *always* be so produced. This extraordinary idea is the gist of what he says on the second page of the most influential book in the subject for a generation, *The Structure of Scientific Revolutions,* published in 1962.

Before I go any further I must clear up one important point. To start with, Kuhn is not the clearest of writers. The word 'paradigm' that he introduced in his book and which is now indispensable to many writers had very nearly twenty different presentations in his book. Moreover, Kuhn not only changed his mind along the years but he even disowned some of the ideas that people assigned to him. The great theoretical physicist Fryman Dyson actually reported Kuhn telling him 'I am not a Kuhnian.'

In this short exposition I cannot get involved in an accurate exegesis of Kuhn's ideas. Neither am I interested in doing so: my problem is not what Kuhn himself thought, but rather what the media and intelligent writers took to be his ideas, or what they themselves absorbed from the ideas that through Kuhn came to be discussed at large. And if his followers misrepresented him, it is not a responsibility he could have shed: a science or philosophy writer should be sufficiently clear and consistent to avoid misinterpretation.

As just one example of what I mean, consider the following quotation from Professor Terry Eagleton, in his book *Reason, Faith, and Revolution,* 2009, Yale, p. 125. I have no idea whether Eagleton has ever read Kuhn, but it is in my view fair to say that had Kuhn never existed it is unlikely that such a clever and well-informed man as Eagleton (1943–), regarded by some as the most influential literary critic of his generation, would have written the following:

> [H]ow many major scientific hypotheses confidently cobbled together by our ancestors have crumbled to dust, and how probable it is that the same fate will befall many of the cherished scientific doctrines of the present.

If this statement were true, the whole magnificent edifice of modern science would be no more than a house of cards: but it is emphatically wrong.

Kuhnian philosophy of science is based on two strong assumptions. The first is that science at any one time depends on a body of principles and beliefs that are largely arbitrary (result of 'human idiosyncrasy') and disposable; and he called this body a *paradigm.* Secondly, paradigms change abruptly from time to time, through *scientific revolutions,* like the Copernican or Einsteinian revolutions.

Paradigms

If Kuhn had said that the so-called paradigms are contingent, then he would have been nearer the mark with respect to the structure of science; but then everything in this sublunar world is contingent, and such a claim would have been banal. Let me give an example that might go some way towards supporting his notion of 'paradigm', in the sense that science could at any one time have proceeded through alternative modes of description, as evolution itself could have proceeded through alternative mutations.

Newton's dynamics was based on two independent variables, space and time. Velocity, instead, is a dependent variable given by space divided by time. But Newton could have used a Doppler gauge, which reads instantaneous velocities and thus classical mechanics could have been based on two different independent variables, space and velocity. Time would then have been given as space divided by velocity: no need for clocks! Why we never went through such a 'paradigm'? The answer is quite simple: concepts in science *evolve,* and in evolutionary systems each step depends on the *whole of their previous history*. Thus, it would not have been possible to design Doppler gauges not having had previous access to Newtonian physics.

Science has to start from approximate observations and theories and build on them *progressively*. Kuhn's paradigm is just as idiosyncratic as the human eye is idiosyncratic: it is what it is because of its previous evolutionary history. Of course, it is contingent, but to say that the human eye could have been entirely different, say infrared-sensitive, is useless. In an evolutionary process, although the evolutionary histories are contingent, every intermediate step entails an element of necessity, insofar as the original step from which any evolutionary process arises (which itself depends on the whole of the previous evolutionary history) is a fixed datum that can as much be changed as we could change the date of the battle of Hastings.

Science, in fact, creates no arbitrary paradigms, but a mesh of facts and theories that must all fit together at any one time. This fitting, following Nelson Goodman (1906–1998), I have called *entrenchment.* Some elements of the mesh may be precariously entrenched. Others will be very well entrenched because they fit a very wide range of elements of the mesh. Such is the case, for instance, for the Second Principle of Thermodynamics, from whose validity a huge amount of the science mesh depends. It is because of this need of consistency throughout the mesh that scientific statements can never be judged in isolation but rather in relation to as many well-known facts and theories as possible that inform the science mesh.

Scientific revolutions

Contrary to Kuhn, the mesh is not rendered asunder by *revolutions.* Just as the human eye did not evolve in a single revolutionary step from a piece of skin, so the science mesh evolves, never shedding entirely well-entrenched theories, but defining every time more precisely the domains of the mesh upon which they may be applied. Thus, relativity theory did not destroy Newtonian mechanics. It did not even replace it: it merely stated the errors that the use of Newtonian theory would entail as a function of the velocities. In fact, it showed that such errors are negligible for most of the velocities we are likely to encounter on earth with macroscopic objects.

Einstein himself rejected the view that he was a revolutionary. The whole purpose of his first paper on special relativity was to *save* Maxwell's electromagnetic theory. To put it in a nutshell: this theory contained only one parameter that could be identified with the velocity of light. Hence, the velocity of light had to be constant, independent of the state of motion of the emitter and of the direction of propagation (because, otherwise, more parameters would have had to appear in Maxwell's equations). From this observation, the whole of special-relativistic mechanics arose.

Yes, of course: there was a relativistic revolution, but this was *philosophical* and not scientific. From Einstein onwards, Kant's-style of armchair study of space and time was finished. A whole chunk of human thought was taken away from philosophy and became physics.

Surely, we all speak of the Copernican revolution. But this was *theological*, not physical. If you think about it, whether the earth is or is not the centre of the solar system is of course a very important *fact*, but from the point of view of physical theory not more conceptually significant than the principle of inertia. It was this principle that, allowing for motion without an Aristotelian first cause, permitted dynamics to be divorced from animistic preconceptions.

What Copernican theory did, was to remove a whole chunk of physical knowledge from the hands of the theologians: *Genesis* was no longer authority on astronomical studies, as Galileo's inquisitor, Bellarmino, had recognized it might happen. As we have seen, he even suggested that the time might come when changes in the reading of *Genesis* might have to be accepted. And the whole thing clearly ended when Vatican Council II permitted the reading of the scriptures metaphorically.

As for Newton removing the need of a first cause for the movement of the celestial bodies, that this had serious implications on theology is evident from Leibniz's 1715 letter to Caroline, Princess of Wales, when he expressed his concern that Newton's views (not those of Copernicus) would destroy belief.

A favourite whipping-boy to stress the fragility of scientific theories is phlogiston theory, once widely accepted and now dead as a dodo. But this theory was based on wrong or incomplete facts, and when all the facts became well established not a single one of them could be explained by the theory. Phlogiston was not what we would now call a scientific theory. Whereas there is still a substantial part of the science mesh that is properly treated by Newtonian mechanics, there is not even the smallest segment of it that any scientist would treat by the phlogiston theory.

Coda

The damage that Kuhn's views on science have done is unprecedented, as coming from a distinguish academic. Of course, scientists have gone their own way, but Kuhn's ideas have been eagerly taken up by many social scientists, thus creating forms of cultural relativism that have done nothing else than confuse rational thought.

I must stress that cultural relativism properly understood is both legitimate and important. The voodoo paradigm may be totally valid as a form of expression of a certain society, but to claim that it has the same standing as the scientific paradigm, to follow Kuhn's terminology, is entirely wrong. What may be valid and important for one form of activity may be absurd in another. Van Gogh was an outstanding painter, but, were he alive, would you fly in an airplane piloted by him? There are cultures and there are activities. Of course, across different cultures, some activities, like medicine, might somewhat change. But there are certain activities that must transcend cultures: rational thinking is one of them. I am fully aware that this is still only a hope: I wish it were a programme. And for this to be so, academics should shoulder this enormous responsibility, instead of obscuring matters with dubious philosophies.

And if you think that my view of Kuhn is idiosyncratic, the Nobel Laureate physicist Stephen Weinberg published a very important attack on Kuhn in Number 15 of *The New York Review of Books,* November 1998 (available on the web). Even more, in an unprecedented event, the British Institute of Physics had a leader on this article in its own journal.

The Princess of Wales received a letter

Aristotle, Time Lord,
ordained: no motion
without a mover. Wrong:
He did not grasp friction.

Had he thrown a bowl
on a marble floor
he would have known
that it goes so much further
than on a lawn.

Not too much to ask
for the cleverest
human ever
to have performed this task.
But it was not for the great man
to dirty his hand
with an experiment.

Galileo started the change
more than a millennium later,
but it was the great Newton
who went all the way and said
no mover but motion, Yes!

You who hear this, may
think nothing of the thought,
but for those who had been brought
under the rule of Aristotle
their despondency was total.

The stars, they move
and who moves them but God.
This, Newton says, is not
the fact: they move
of their own accord.

The Freiherr von Leibniz
was worried. He wrote
to the Princess of Wales
that this baseness
must be suppressed
lest men lose their faith.

So, the Princess of Wales received
a letter, well conceived.
Yet Sir Isaac won,
and freed from Aristotle
medieval man got lost
modern man was born.

Good laws never die

Ptolemaic view of the world
has gone.
Ingenious Phlogiston theory
is dead.

Ergo, people say,
doubt every scientific
theory now on show.
As the blooms
of the summer wither
and die,
most science theories will go.

I do not think so.
Has Einstein's theory
killed Newton's laws?

Ask any car designer
to use relativity theory:
she will call you a simpleton
and stick to dear old Newton.

And Einstein did not enter
the temple of science to destroy:
he carefully preserved
the beautiful laws
that Maxwell early gave.

Was statistical mechanics lost
when anomalies were found?
Not at all. The time came
when the anomalies were explained
and the theory not only did not die
but became better and richer.

Of course, untested hypotheses
come and go, but once
a set of facts is known
that a theory has explained,
the theory may be changed
but where the facts worked
the old theory remains.

Science, my friends,
is not a perfect tool.
But show me a better way
to fly an aeroplane
or to amputate a leg without pain.

Einstein and the philosophers

I am convinced that the philosophers have had a harmful effect upon the progress of scientific thinking...
—Einstein 1950.

Most people accept
that they cannot see their nape
with their unaided eyes.

Of course, because they
are natural elements
that must obey natural ways.

Our minds, whatever their arts,
are natural parts,
but philosophers venture
via the unaided mind
to comprehend total nature.
What a wondrous eye!

(Some thought it more consistent
to deny nature's existence
and thus commodiously reside
solely in their capacious minds.)

It was in this way
that the Königsberg sage
thought that he could explain
time and space.
Space was a kind of stage
constructed by the mind
to place objects therein.
And time was a sort
of great universal clock
to order events.

Young Einstein, not a philosopher he,
started by looking at nature.
He realized that, whereas if you
move up an escalator
your two velocities add up tight,

this appeared (on all good evidence)
not to be so for light.

As a result, he intuited
that time cannot be universal.
A pilot flying round the world
and his stationary mate,
separated and then reunited,
measure different durations
on their clocks. (A verification
that was later made.)

Likewise, Einstein discovered
that space is not a stage
passively to hold the actors:
the more of them that come,
the more it deforms
and bends. These factors
show that space
is not a mental framework
but more like a substance
that can stretch and curve.

Wonderful new ideas that opened
the century to more and more good facts.
Did philosophers think
they had egg on their faces?
Did it stop them going places?
People these days look askance
at intellectual arrogance:
but make no mistake,
it is as difficult to contest
as it is rare to shed.

The Königsberg sage: Immanuel Kant.

The Inquisitor

He had no blood on his hands
this good Doctor of the Church,
only the dust of Bruno's ashes.
Yet he is a Blessed and a Saint.
Certainly not a brute.
Certainly a cut above the rest.

He offered Galileo a clever pact:
Do not insist that the Earth
is not the Centre of the World.
Do not insist that the Sun's
in that place. Pretend that
what you say is but a trick
the better to compute.
What Ptolemy said
you must not refute.

Galileo, after all, had no final proof,
yet he did not bite.
He knew he did not have all the facts
but Copernicus had to be right.

That the surface of the moon
was polished as glass, as the Church
believed (the Greek had left us in a swoon),
his telescope had shown him to be untrue.

The Inquisitor had no way out,
but he wrote to his Church:
be prepared to teach our flock
that the Scriptures are but a metaphor
should time
prove Galileo right.

A couple of centuries later
the Inquisitor's advice
proved itself of greater
value than former blind cant.
Not perhaps a great performance

to carry on so long in ignorance,
but the irrational is dear to man.

The Greek: Aristotle

From Plato to Gödel

You and I hold this to be true,
that human knowledge of the world,
however perfectible is for ever imperfect.
Plato exploited this to invent a ruse
that made a hostage of our intellect.

There is, he claims, a far superior world
where truths are all universally true
and eternal to boot.
It is because our world is but a grey
substitute of that heavenly sphere
that our knowledge and perception fail.

Take heart, he says, the mind is able
to read the mysteries of the superworld.
If you want to know what mud really is
do not use a microscope, Plato implies –
had he known such a device –
think hard and every eternal truth
will be revealed to your fruitful mind.

Clever Euclid tried to apply
this to geometry. Afflatus of Platonic
oracles gave him some eternal
geometric super truths, the axioms,
and a little more of the same furnished
eternal operating rules to use them.
In this ingenious manner all truths
of geometry were deduced, all present
and correct, none missing, none false.

For a couple of hundred years, though,
all mathematicians have known
that this approach is wrong.
Humankind, bear this in mind,
longs for absolutes of whatever kind,
and Hilbert, the mathematical pope
of the century newly gone, did hope
that an arithmetical system could

be constructed from clever axioms and rules;
and then, if the system was really good,
that is, if it would never ever prove
that zero plus one makes two,
then all true arithmetical theorems
would follow without a single exception
from steady and repeated application
of the same axioms and the same rules.

Then young Gödel arrived,
untried, unmarried, unknown,
armed with a guided missile:
Hilbert's dream, he proved,
was just that, a dream,
and like most dreams untrue.

Until then, most people had assumed
that mathematics was self-contained:
all its truths could for ever be deduced
by means of mathematical good work
and nothing else. This popular view
Gödel at a stroke slew.

Such a fate shouldn't worry you.
If you invent a wonderful theory,
say why an electron should have weight,
no amount of magnificent thinking
will ever persuade you that it is true:
you will have to consult mother nature
and experiment till you gain a clue.

Gödel having discovered
that our knowledge of mathematics
is also necessarily incomplete,
it would be the normal expectation
that a modicum of consultation
of the book of nature
would not come amiss.

Not for Gödel this:
what mathematics could not prove,

mathematicians knew to be true
through their unique perception
of the Platonic superglue.

Gödel's demonstration is the Mona Lisa
of maths. But though it was such a teaser
and Gödel such a genius, you must
not conclude that he was also clever
in his non-mathematical Platonic revels.

Poor Gödel, he had to wear a thick overcoat
even in the hot Princeton summers,
and fear of poison finished him by hunger.

No wonder that he was not very fond
of such nature as we all mostly enjoy,
and that he hankered for a Platonic heaven.
Never forget, however, this truism:
super-intelligence and brilliance do not
necessarily entail super-wisdom.

Theology and the electron

In the fretful night I had a dream –
the massive figure of Thomas
Aquinas crept from the silent dark.

He wasted no time – *since you come*
from the twentieth century could you,
he said*, explain to me how can*
electrons be sometimes particles
but other times they appear as waves?

No trouble I said, Father, going
as far back as Nicaea and Chalcedon
you believe that Jesus' substance is one
and only one, and yet that he is
wholly divine and wholly human.

His disciples knew him fully as a man
and, as you believe, he also
died as a man. Yet at least once,
it is said, he appeared to some of them
as fully divine in the epiphanic Transfiguration,
so aptly depicted in Raphael's last work.

The disciples were not able to apprehend
the godhead's substance with which Jesus
was hypostatically united, as you theologians say.
They had to know him either as a man, or as divine.

The electron likewise has an unusual ontology.
Its substance is one and only one, but whatever
we experience must belong to our sensible world.
So, we cannot directly cognize atomic events,
and electrons must be revealed sometimes
as waves, and other times as particles:
by their manifestations you shall know them.

Young man, Aquinas said*, you must accept*
that we theologians intuited modes of being
that you scientists discovered centuries later.
And turning his broad back he faded into the shadows.

Chapter Nine

Philosophy of Science after Darwin

One of the major strands of philosophical thought from Plato until our time has been concerned with our cognition of the external world. Dreams may appear to be so real, it was felt, that one should be worried that our knowledge of reality might not be more solid than our knowledge of dreams. Plato was thus the first important philosopher to start a flight from reality, which led philosophers into taking refuge in our minds as a source of non-mediated knowledge: surely we know what we are thinking.

It was Hume who first intuited that our cognitive system could be relied upon to construct a faithful map of nature, as we have seen (p. 20):

> so has she [nature] implanted in us an instinct, which carries forward the thought in a correspondent course to that which she has established among external objects…

We have to take a moment to reflect about the role of philosophy in understanding the external world. It happens sometimes that when science advances big chunks of speculative philosophy become obsolete, as was the case with the work that Kant had done on space and time after Einstein discovered Relativity. It is wonderful, on the other hand, to find philosophical ideas that tie up smoothly with later scientific facts, and perhaps the most remarkable case is the way that Hume speculations, as quoted above, joined smoothly with later scientific facts, as we have shown above (Chapter 4) was the case between Hume and Darwin.

To what extent our cognition of the macroworld really parallels, as Hume expected, what it is 'out there'? An apparently very powerful argument to contradict this expectation comes from the question of colour perception. Because we know that colour is not a feature of the objects that we observe but only of our perceptive system. If our eyes were like those of cats, able only to see black and white, the world would be (look?) different. Daffodils would not be yellow!

But we know that the eye is a very special case: during evolution eyes were at first able to recognize only black and white in the light reflected by the objects perceived. It was only because colour perception was a great help in discriminating objects that mutations that produced it were successful. So, a daffodil is not really yellow, but it is not a rose: in fact, its colour helps us to discriminate the object. But to go from there to expect that what we see as a lion is not really a lion is nonsense, since such erroneous perception would not have had any evolutionary advantage at all, on the contrary, it would have been positively deleterious.

When Dr Johnson, to deride Bishop Berkeley's view that all that existed was his *idea* of a stone in his mind, kicked it and exclaimed: 'I prove it [its existence] thus' he was, by the knowledge of the time, acting irrationally, since all that he proved was the existence of a pain sensation experienced in his brain. Years later Darwin's theory provided a justification for the good doctor's attempt.

Let me compare Darwin with a detective. If the law were to require for successful prosecutions that detectives had to have witnessed the crime, then hardly any criminal would ever be found guilty. What a detective must do is to find as many clues as possible and assemble a case in which all the known facts and hypotheses form a consistent network. No one would accuse a detective of being ontologically naïve when he claims that a crime has been committed and that the defendant is guilty of it, although he himself had witnessed nothing.

This is precisely the new rationality practiced by Darwin. He collected an immense amount of data on as disparate subjects as he could, and he showed that he had obtained a network of consistent results. Even though nothing was known at the time about genes or DNA his approach was entirely rational because he had acquired enough evidence to be satisfied that he had a theory that was consistent with all the known facts.

Darwin of course, never witnessed a primate evolving into some sort of humanoid but, like a detective, he did not have to justify himself for that omission, which was inherent to the problem he had tried to solve. Instead, he patiently collected evidence to show the chain by which every part, every bone of the human body, had evolved from the primate's ancestors.

We can now go back to Dr Johnson. Of course, he could never prove the existence of the stone in a way that would satisfy the superhuman ontological requirements of Berkeley: the ontology of the latter was ingeniously arranged so that the only being that could answer for it was God. So: are we for ever alienated from any form of existence more 'real' than our brain states, for which, at least, we can claim immediate knowledge?

The Principle of Evolution gives us a handle to treat this problem, because we are nothing more than a part of the extraordinary mesh of consistent facts that goes with evolution. We know, for instance, that if there were no light there would not have been light-sensitive patches on the skin of animals, patches that eventually evolved into the eye. So, light ‘exists’, that is, it belongs to the mesh of facts that makes us a part of the universe. Of course, this does not mean that the colours that we perceive have necessarily an objective meaning, because our perceptive system is a receptor designed by evolution so as to be just sufficient for our vital purposes: the receptor, for instance, is not sensitive to infrared light because its perception is not within our evolutionary history.

What about Dr Johnson’s ‘perception’ of the stone? In reality what he has immediate knowledge of is some reaction in his brain’s neural system. But this neural system has evolved modelled by the inputs from nature that have created such an amazing learning system. If stones had never existed to act on humans, then humans would not have evolved a neural system capable of recognizing them, just as they have not evolved eyes that perceive infrared light.

So please do not think that Dr Johnson was just a naïve philosophically illiterate person. He merely anticipated Darwin.

If you believe that a detective cannot say that a crime has been committed unless he had seen the criminal with a smoking gun over the dead body, then you may as well believe that the ontology of Nature is for ever beyond our grasp. But if you believe that the only rational apparatus that humans can use is a vast consistent mesh of theories and ‘facts’, so defined that they are internally consistent, then those ‘facts’ lead to a *scientific ontology* within which stones, electrons, photons, quarks, and mental states ‘exist’. If you want more, try to communicate à la Plato (as some *soi-disant* ‘rational’ mathematicians claim they do with the Platonic world of forms) or commune with the best mystic you know, preferably with a beard.

It is interesting to remark that ontological problems do not just arise in the study of the nature, for instance, of the electron, but that theology faces a similar conundrum, solved of course in a different way. The nature of God the Father is ineffable within the Judeo-Christian tradition, but the Incarnation has given humanity a wholly human Jesus.

After Constantine made Christianity in 312 the state religion of the Roman Empire, great doubts remained about the nature of Jesus. To resolve them Constantine summoned in 325 the First Church Council in Nicea (in modern Turkey). What the bishops decided was that Jesus and God the Father had one and only one substance, a dogma that was referred to with the Greek word *homoousion.* It was also said that what appeared to be two separate entities, God the Father and Jesus, where in fact *hypostatically* united in a single one. So, within this creed it would be totally wrong to say that Jesus had a dual nature. But, like the electron, Jesus' ontology could be manifested in two different ways: the disciples saw him as totally human on the Cross but as totally divine on the Transfiguration.

It is nevertheless the sub-lunar ontology of Jesus the Man that is the kingpin of Christianity. Jesus the Man, for his disciples, was not a mere mental state, just like Dr Johnson's stone was not a mere figment of his imagination. The Crucifixion was for them a 'real' event, not just mental (although the Docetists believed it to be an illusion, and were of course promptly persecuted by the Church). So, the bishops of the Council of Nicea had anticipated in the year 325 CE an ontology parallel to that of the wavicles.

It is useful to recognize here the weakness of Niels Bohr's 'epistemological' approach to quantum mechanics: to avoid criticism he threw away the important ontology of elementary particles, very much like the Docetists had done for the deity. The Council of Nicea was perfectly clear in accepting an apparently dual entity with a single ontology. Bohr's heresy, in avoiding that question, was however respected by many and caused endless trouble: the bishops of Nicea had done better than the Danish prophet. If he had understood a bit of Theology…

Chapter Ten

Science, Spirituality, Religion

The natural world comprises for humankind not only external objects but also the whole of our recorded history (including oral transmission). The material sphere thus sustains a 'spiritual sphere' but, of course, not all entities of the latter may be treated by the rational methods of science. Science, however, is paramount as a search for objective truth and in that sense it overlaps with one of the essential features of morality.

What about the great questions such as the meaning of life, the meaning and purpose of the universe and so on? The first remark we may rationally make here is that such questions, which necessarily entail *relations,* have no meaning at all unless one posits beforehand something external to life and to the universe with which they can be related, because a relation requires two objects to sustain it. If there was nothing in the universe except one chair, to ask for its meaning and purpose would be meaningless. It is only if, say, a human also exists that the chair could have a purpose or a meaning.

This means that such relational questions as meaning and purpose of life and of the universe are meaningless, unless one already subscribes to a theistic point of view in which an entity external to life and to the universe (god?) is postulated. Discussion of these questions, therefore, does not in any way add solidity to a theistic view, despite their strong emotional content.

This criticism undermines many arguments loosely used by some theologians to try and support their beliefs with something apparently more substantial that a mere act of faith. When these spurious accretions to belief are got rid of, what remains is a purer form of it, which, although alien to the rational mind, can have its own legitimate credentials. But remember, here it is the question that matters, not the answer.

But religion is not the only component of what I have called the spiritual sphere. An important constituent of it is language, without which the recording of human history would have been impossible. Although the use of language, however, can be reasonably simple in science and mathematics, humankind needs forms of expression well beyond those confined to such subjects. Emotions must be expressed, judgments must be delivered, and so on, and for this purpose metaphors, images, allegories, similes, are all necessary. And then we have the language of art and poetry. What is most important is to recognize that rationality and science are not antagonistic to these languages, and that the harmonious conjunction of all these tools is what makes humanity wonderful.

It must be remembered, however, that we inherit a serious distrust of science strongly expressed in the nineteenth century, the dawn of modern science, by the romantic poets. John Keats took the view that the scientific analysis of natural objects, like rainbows, destroyed their human significance. Although we have now experienced how new technologies have revealed, rather than obscured, the marvels of nature, this attitude is still imbued in the minds of many people.

One last word: we have seen that there is more than one language that we use, the language of science and, amongst others, the language of poetry. Rational thinkers must guard against the injudicious mixture of different languages in the same discourse, which serves no other purpose than that of creating mental confusion. I hope that this little book might help in avoiding such an infirmity.

Lamia redux

Philosophy will clip an Angel's wings,
Conquer all mysteries by rule and line,
Empty the haunted air and gnomèd mine –
Unweave a rainbow, as it erewhile made
The tender-personed Lamia melt into a shade.
—Keats, *Lamia,* II, 234–38.

Lamia, returning from the shade,
needed help to struggle back to life.
She wisely wanted more than to be made
into a human, once again. The fight
had to be meaningful, she maintained,

and she and the world must return to charm.
An artist promised that he would capture beauty,
painted a rainbow dipping into a tarn,
and declared to the much belovéd lady
that total eternal charm was within his art.

Lamia, who in her deadly sojourn had ascertained
that art and beauty are not needfully conjoined,
ordered her artist lover to go away, for ever estranged.
A philosopher arrived, a real one, who coined
prudent perspicuous principles and proclaimed:

What you need Lamia dear is to understand
how to recognize the true from the false.
This I can teach you at your command.
You will then know everything that calls
for a proof and will no longer walk on shifting sands.

True knowledge will quickly guide you
to discover and to possess total charm.
Do not accept the sophistry, plainly untrue,
of my fellow scientist who, to my great alarm
replaces the world by abstract symbols, without rue

eliminating beauty, value, meaning from it.
Lamia summoned then a scientist of renown.
You, he said, know how a poet must omit
so many of the words he first puts down:
nothing inessential must he then admit.

This is the way I also work: I simplify,
I reduce the vast confusion of the world
to a meaningful picture: not to satisfy
like the philosopher, some intellectual quirk
but to approximate world events ever nigh.

It is only when you know nature
without mediating myths
that you can truly venture
to understand what a human is,
and it is then and only then you are

able to love fully without harm.
That I understand the rainbow
does not reduce its beauty or its charm.
Would you take my love for you in tow
without me knowing who you are?

Lamia dried a tear from her pearly eyes –
her scientist friend had moved her fickle mind.
Fraudulent love had to be for ever exorcized
and she had to value world and humankind
from well-grounded reason, not from senseless wiles.

Notice that Keats uses the word 'philosophy' meaning roughly what we now mean by science. Keats wrote his poem in 1820 and the word 'scientist' in the modern sense was first coined by William Whewell in 1833.

EPILOGUE

We have seen that the Principle of Evolution is essential in order to understand how nature and our mind works. But an important part of nature is the spiritual sphere formed by the creations of the human mind of which science, art, and religion are major components. We have already discussed science a good deal and also to some extent religion, but in this Epilogue we shall show how all three subjects have developed under a Principle of Evolution, which we shall discuss. Also, this Epilogue, because it overlaps a little with material treated in the rest of book, will serve as a revision of some of the ideas developed in it.

Science, Art, and Religion

If you do not want to talk nonsense about these vital subjects it is essential to avoid at all costs the misuse of language: these three words have been in circulation for more than 2000 years and their meaning has changed over time. 'Science' in the King James Bible means *Gnosis,* a particular form of heresy. Worse is to come. In the 14th Century the good masons of Milan were building its cathedral and they found that they had made the columns so high that they did not know how to cover the church. They called in a very experienced master mason from France, Jean Mignot, who taught them how to proceed and, to justify his approach to the work, pronounced a dictum that is famous to this day: *Ars sine Scientia nihil est*.

Even today this phrase is often mistranslated as *Art without science is nothing*. This is totally wrong: art meant something completely different at that time, *craftsmanship, skill* being perhaps the nearest things. (When T S Eliot appropriated for his *Ash Wednesday* Shakespeare's line from Sonnet 29: '*desiring this man's art, that man's scope',* he substituted *gift* for *art,* not to mislead his readers. What a good poet does with words is not always, alas, done by some historians.) As for 'science' as we normally mean now, of which more later, as the occupation of *scientists*, it is a modern concept, the very word *scientist* having been coined by W. Whewell in 1834. So Mignot's dictum should be translated as *Skill without knowledge is nothing*, an entirely different meaning from the spurious proposition *Art without science is nothing.*

You have been warned: if you do not want to talk nonsense you must make sure what your words mean. So, beware of false prophets that talk of ancient science as if it were, perhaps in a reduced form, the same activity as that, for instance, carried out today at CERN.

You may think that Science, Art, and Religion have nothing in common, but they are fundamental human activities and as such they have all been affected by the two most important ideas in the history of human thought: Platonism and the Theory of Evolution. Plato was the love of my youth: his writings are so wonderfully persuasive that it is impossible for a sixteen-years old not to be seduced. But when I came to my senses in my twenties I realized that he had been responsible for the worst error in human history: the flight from nature. Enough to quote for the time being: *soma sema,* ‘the body is the grave of the soul,’ uttered by Socrates when nearing his death as a welcome for shedding his earthly body. But you will hear a great deal more about the horrendous influence of Plato, especially on art and religion, although science itself is not immune from the disease.

Darwin instead, with his Theory of Evolution, has given nature back to us. It will take generations for the impact of Darwin on human life to be fully effective but the day will come, because not only he gave us an understanding of nature (which includes of course the human species) but he taught us how to achieve it: whereas the Platonists thought in a vacuum, Darwin showed us that true knowledge comes only when you think with your hands. And an important feature of the Principle of Evolution is that it works not only for the natural world for which it was created but also for the spiritual world of the creations of the human mind. And although I shall deal with western culture I hope that the problems I shall discuss will still have sufficient relevance for eastern life.

Now we are ready to start.

Science without metaphysics

Do not worry, I shall simplify things to the bone. The great master of metaphysics was Immanuel Kant: if you like armchair thinking he is your man. He asserted that rational thinking required some principles that were not derivable from observation of nature, not very easy to do from an armchair, but that rather were eternal truths. That is why they are called *metaphysical:* they are not derived from experience but, as we have already seen, they were considered as pre-conceived norms required to study experience. One such was the Principle of Causality.

Simplifying things somewhat, when we say that the *sun heats the stone* it means that whenever the cause (the sun) appears, the effect (stone heated) follows. Whereas classical (macroscopic) physics is causal, when Quantum Mechanics was discovered in dealing with elementary particles, like electrons, protons, and so on, it turned out that causality is not obeyed. This means that the Principle of Causality is not universally valid, like Kant's metaphysical principles were supposed to be: armchairs are not very good for thinking. If you want to engage with nature you have to get your hands dirty. Einstein, who had read Kant at 16 and who later demonstrated the sage to be wrong on space and time, believed nevertheless with Kant that causality was universal and that Quantum Mechanics, denying this, was incomplete. Experiment after experiment proved him wrong but the damage was done: as politicians know only too well, when you throw mud around it sticks for a very long time.

Poor Science: Einstein's was not the only idea that percolated to the general public and planted the seeds of doubts in the minds even of well-informed people. The other one was the concept of *cultural relativism* whose prophet was the American philosopher of science T. S. Kuhn. Seldom if not never an idea so badly excogitated has had such a profound effect on the public. We know that in C18 chemists believed in a stupendously wrong theory, the phlogiston theory. But to say that all that happened when Lavoisier discovered the truth is a change from one set of accepted scientific beliefs, or *paradigm,* to another set no more valid, just a new paradigm, is nonsense.

Before Lavoisier science as we now conceive it did not exist, just as before Jesus Christianity did not exist, because science is what it is, not because of *accepted beliefs,* but because of *accepted protocols* for the *admission* of *facts as scientific facts, and these protocols do not go back much further than the nineteenth century.* Nothing can be a scientific fact unless it can be checked by more than one scientist. Alchemists, astrologers and all practitioners that do not accept the scientific protocols are not scientists in the correct use of this word. When the Higgs Particle was discovered at CERN the discovery was accepted as scientific fact because it was corroborated by two independent groups of scientists that were using two independent detectors at CERN.

Another problem where cultural relativism misrepresents the facts is the historical development of science. This is not punctuated by catastrophic scientific revolutions, as postulated by the cultural relativists, but it is led, like almost any other change in nature, by a principle of evolution à la Darwin. The state of the total scientific knowledge at any one time is dependent on all previous such states and *evolves* into a new state better adapted to the existing conditions of knowledge, technology, economics and so on. The change, from Lavoisier onwards, is never as total and as dramatic as a revolution (in which Lavoisier himself lost his head, literally, not metaphorically). In a revolution, like the French or Russian ones, everything political is changed, but science experiences changes that are more like mutations that keep the pre-existing essentials but adapt the system to new conditions. Relativity theory is one example: it was not a revolution, it kept the whole of classical theory intact for the speeds normally used on earth.

I shall give another example of one of the most dramatic advances in science in the last 70 years or so. When in 1953 I used the first commercially produced computer in Europe, the Ferranti Mk 1 computer at Manchester, the basic principles of it were just two: first, it only worked with binary numbers, that is, numbers expressed not like in the decimal system with ten digits but only with two, 0 and 1. Secondly, the instructions and the numerical data were indistinguishable. As for the hardware, you had an immediate access memory, very small by modern standards, constructed from cathode-ray tubes, and a larger back-up memory, a magnetic drum about 3 ft high and almost 1 ft wide. The whole system was run by arrays of thermionic tubes occupying several rooms.

A great change came in the seventies, the transistors, much smaller, which replaced the thermionic tubes. But we still worked on binaries, and the instructions were still indistinguishable from numbers. Then came the solid-state circuits that allowed miniaturizing the necessary parts, but the same principles were still used. And the cumbersome magnetic drum was replaced by gradually smaller magnetic disks and eventually by solid-state memories. The whole process resembles in a much shorter time-scale the way in which the eye was created by biological evolution. Of course, in biological evolution there are catastrophes like the extinction of the dinosaurs that affected the whole of the natural world. Such events are very rare or perhaps inexistent in scientific history, because even the deepest conceptual changes that new discoveries might entail cannot affect the whole mass of facts that are constantly tested and that are correct at the level of approximation at which they are used every day.

We can now turn our attention to art, a very controversial concept.

Art without beauty

In the year 1819 the English romantic poet John Keats wrote a famous poem, '*Ode to a Grecian urn*' which in its last stanza attempted a whole theory of aesthetics: '*beauty is truth, truth beauty*'. This, alas, is an intellectual disaster, and one that must be expunged from our minds if we want to understand the art of the twentieth century. Putting the matter very simply, we do not know what is meant by the word *beauty.* And as for the word *truth* that great American philosopher, Donald Trump, has exposed it as totally meaningless.

The trouble with John Keats I would lay on the head of Plato, whose ideas suited admirably the romantic poets. I have already mentioned Plato's dangerous flight from reality: for him the world as known to our senses, which is necessarily transient, is a pale reflection of another eternal world that contains eternal truths, which he called *forms.* One such was Beauty, the real thing. We humans cannot read fully the Platonic world, but we may experience a remembrance of its Platonic forms. So, when we perceive an object, or a poem, or a woman or man as *beautiful* we can do that because we have a partial recollection of the real thing, neatly filed in the Platonic world. And pigs will fly.

Before I discuss this porcine propensity at hovering in the sky I should mention that mathematics is so perfect that most mathematicians are Platonists, firmly convinced that they never *invent* new theorems but rather *discover* them by an amazing feat of reading the Platonic heaven, which miraculously contains not only all the known mathematics but also all which will ever be known.

Our flying pigs are indeed getting obese but still ascensional. So, let us debunk the idea of eternal beauty: it takes only two minutes to show that it is not only culturally dependent but also transient. First, sitters that were beautiful for Rubens or Renoir would not have a chance in a beauty-parade competition now. As for me, I have watched again one or two films from the sixties with dancers that then stirred my heart, but who now would only be able to gain useful employment as models for oversize underwear. So, *beauty* is a word that may only be used in very limited circumstances where there is some commonality of points of view. And we shall soon see that beauty has nothing to do with art, unless you are still living in the nineteenth century. But we must first of all come to an agreement as to what art really is. For which purpose it will be easier to start with the concept of *art object*.

In 1972 the Trustees of the Tate Gallery in London purchased a sculpture by Carl Andre called *Equivalent VIII.* I had seen a retrospective of this man in New York a couple of years before and realized that he was a serious and significant artist. To no avail, people who had never had any interest whatsoever in art, and probably never stepped inside a museum, were enraged and raised a hue and cry not much milder than the one now (2018) obtaining over Brexit. (And I suspect that the same people that then complained would now if still extant be ardent Brexiteers.) How could an art museum spend money on 120 firebricks, disposed in two layers of 60 each, each layer with 10 rows of six bricks each, laid long side up? You see, you already have the prescription, go to a brickyard and you can construct a valuable work of art in no time and for next to no money.

The philistines were incandescent; the admirable BBC sent a TV camera with one of their men to the museum. He was very lucky because he soon ran into one of the sagest philosophers in London. Is this a work of art? asked the journalist. Of course it is, answered the philosopher, *everything in the museum is a work of art*; and calmly went on sweeping the floor with his broom. I doubt that this excellent man had ever heard of Wittgenstein, but who needs Wittgenstein when you have a good broom?

We do need Wittgenstein, however, because he had thought a good deal about defining activities such as being a mathematician or a builder: for him a builder is a person that makes buildings and a mathematician a person that makes mathematics. This is what philosophers call definition by *ostention,* the nearest thing to pointing out with your finger (we have already praised the use of the hands for thinking!). So, our first idea is that a work of art is anything that is in an art museum. But then, what about beauty, what have we done with it? We have done nothing because beauty has nothing to do with art in our century.

Before you get cross and complain, please wait, I shall give evidence for this statement. In the year 1907 Pablo Ruiz Picasso painted in Paris a picture which he called *Les demoiselles d'Avignon,* the ladies being five prostitutes conducting their merciful trade in the Carrer (Street) d'Avignon in Barcelona. You may see this wonderful picture, undoubtedly the most important one of the twentieth century, on the fifth floor of MOMA in New York. The artist, however, thought it so ugly that he rolled it up and did not show it until 1916 in Paris, to universal disgust, even from his friends. But he had not only changed twentieth century art: he had for ever decoupled art from beauty. (If you are lucky enough to see the picture please do not believe the learned critics that describe a *curtain* through which the ladies pass. It is not a curtain: it is the main tool of their profession, a *crumpled bed-sheet*, its colour, that should have been black, favoured by prostitutes to flatter their complexions – as in Velázquez's *Rokeby Venus* at the National Gallery, London – reduced to greyish for obvious pictorial reasons.)

If you still want to rescue beauty as a necessary element of a work of art, nothing can be more effective to disabuse you of the idea than the admirable *Fountain* shown in 1917 in New York by Marcel Duchamp: it was a run-of-the-mill urinal, bought at a plumber's merchant, and signed R. Mutt. The artist's purpose might have been 'to piss on a work of art' but, as Borges would have said, the work of art is in the reader, and everyone would now say that the urinal is a work of art because it gives us a new idea, that beauty has no place in modern art.

But we still have to define a work of art. And we must do it not because of what it is, as Plato would have wanted, but because of its *function*. The urinal in a gentlemen's toilet is identical with Marcel Duchamp's urinal, but its function is totally different. Marcel Duchamp's piece poses a challenge, it says: look at me and react, love me or hate me, but react; and notice that it opens your eyes to an idea that you never had before, you never thought that a urinal could be in a museum and be a work of art.

The same can be said of a poem, at its best it may be a bridge between two elements of reality that you never thought related. Or it might express known ideas in a new way. Of course, this is my personal view, and many poets would never come even near it. But once, when I wrote the poem called '*Theology and the* electron' (p. 86) I thought that even if it was not poetically very great, it had a decent reason to exist.

But what I am saying entails that an object changes its nature by the mere fact that it is in a museum, thus creating an *aesthetic activity*. In order to justify this assertion I must understand how an *activity* works. And this is not obvious: even the man who probably thought he was the best philosopher in the world, Sir Karl Popper, was not very successful on this question. An activity whose existence he denied was *observing*, and in his modest way he demonstrated it during lectures by telling his audience '*please observe*': after half a minute he would triumphantly notice that no one had observed anything. But he could just as well have told his audience '*please swim'* with identical results. Because any activity requires a *predisposition,* an *expectation*: the chemist will go to a lab to observe, the astronomer to his telescope, the swimmer to his health club.

So, a work of art, requires an *aesthetic activity,* such as one accomplishes by going to an art museum or in discussing with an art expert. You go to the toilet to use an urinal, but when you go to a museum you are intellectually prepared to interact with Duchamp's urinal in a different way, because in the museum you have an *expectation,* and in a way you create the work of art by reacting to whatever is there, just as the astronomer reacts to what he sees in the telescope, although his reaction of course will not be an aesthetic one.

All this may be very nice, but I prefer to support my ideas with facts: my armchairs are not so comfortable. I will suggest an experiment. You send observers to a museum, they first go to the lavatory and you take a brain MRI scan and observe that some parts of their brain fire. Now they enter the museum and look at, say, Duchamp's piece, and while they do that again you take a scan and see a completely new signal in a particular part of the brain. This shows without a shadow of doubt that it is the predisposition that creates the *aesthetic experience*: even if this is totally negative, it still is an aesthetic experience.

Of course, this is an excellent experiment but one that it is impossible to carry out: how could you do a brain scan in a museum? Fortunately, Martin Kemp, now retired as Professor of the History of Art at Oxford University, designed an alternative experiment, which was possible to conduct, and which proves that it is the expectation that creates the aesthetic experience. You show a genuine Rembrandt engraving to a subject and tell him it is a genuine picture and you find a new reaction in the cerebral cortex, but if you tell the subject that it is a copy, no such reaction is observed. (You can see the details in Menfei Huang et al, *Frontiers in Human Neuroscience*. 2011, vol 5, no 134, pp. 1-8.)

This view of the aesthetic activity solves a problem that much exercised Nelson Goodman in his book *Languages of Art:* what is the difference between a painting and an absolutely perfect copy of it? The difference is not in the objects, which can be identical atom by atom: the difference is in the observer, if he or she is told which is the original and which the copy, the corresponding degrees of expectation change by that knowledge. This may be the reason why the curators of the Albertina in Vienna indulge in a piece of *suppressio veri* and never reveal that almost all the exhibits in it are copies, thus kindly allowing the unsuspecting visitors to achieve for a modest fee adequate aesthetic experiences.

Let me summarize: a work of art is the subject of an aesthetic experience, which is stimulated by a predisposition or expectation of the observer (created by visiting a museum, or receiving a statement from experts, such as art dealers). The aesthetic experience in interaction with the work of art will create an enhanced reaction. In a sense, the work of art is created in the observer by that interaction. This is very much like the claim by Jorge Luis Borges that a poem is created by its reader.

Some poets, like the English poet David Constantine, believe that poetry must bring *pleasure* to the reader. I do not accept this, although of course sometimes, like in an *epythalamium* (a poem to celebrate a wedding) they must do so. Pleasure is a word that must be used, if at all, with extreme caution: I refuse to share it with paedophiles and rapists, and I would be ashamed if I just felt pleasure in front of Picasso's *Guernica,* perhaps the strongest indictment of the horrors of war for a generation. And a poet who has never written a poem to cause despair is not a poet, because he or she must be indifferent to the colossal inequities of life.

So, we have sent two words, *beauty* and *pleasure* to the doghouse. A third word must also be put in quarantine: *taste*, implicit in the much-quoted sayings, *'beauty is in the eye of the beholder*,' or '*chacun à son goût*.' Taste is of course much affected by culturilization, but this is precisely the problem: the work of art, be it a painting or a poem, must be approached with an open mind; culturilization might harbour prejudice, whereas modern art thrives in freedom. It is perfectly possible to say: ' my favourite period in architecture is Romanesque, but I find the Baroque work of Francesco Borromini (or even Guarini) challenging and stimulating.'

Finally, I have moved the discussion of art from the object to its reader: our centre piece is the aesthetic experience, elicited by the anticipation or predisposition created by, for instance, going to a museum. You must not believe that there is a magic way by which such a process happens. Any activity requires training, it is no good for me to go to a telescope or into a chemistry lab because I will experience nothing. So, if you are interested in art, spend as much time as you can visiting museums; keep your mind and your eyes open. After some time, things will happen.

Before I leave art, and because I believe that evolution is at the basis of all life, let me remind you briefly how it affected art, which I shall take for this example to be western art. The dark years during the fall of the Roman Empire had a profound effect on art. Probably because of lack of economic surpluses the craftsmanship necessary to produce art works was greatly reduced until it began to grow again into the Byzantine art. For much of this period human figures were represented in the easiest way, frontal, mainly on mosaics, until experience was regained. Most of the art produced in Europe until almost the fourteenth century was religious and portraits were rare and used only for great people. In architecture many centuries produced Romanesque cathedrals and monasteries, eventually replaced by Gothic monuments.

Art evolved just to serve the purposes of the few people, mainly clerics, who could commission it. The Renaissance happened because, especially in towns like Florence, lay people appeared, bankers, silk merchants, and so on, that commanded vast economic surpluses. For the first time, pictures and portraits were produced for the pleasure (sorry, it was long ago) of the rich, including clerics and the Pope. In fact, not all art was really innocent: mythological themes were much favoured by rich patrons often because they created opportunities to depict nudes, the soft pornography of its time.

Titian produced five *Danaes*, she being the girl locked up by her father to prevent her being impregnated, a purpose which Jupiter circumvented by reaching the naked girl as a cloud of gold. Mythology was not the purpose of the exercise: the best *Danae* by Titian, the one at the Museo di Capodimonte, Naples, was commissioned by the Duke Ottavio Farnese for the benefit of his brother Cardinal Alessandro Farnese, whose mistress the model was; I imagine that the other four were similarly created.

A great impulse to non-religious art appeared in the low countries, where the distribution of economic surpluses was more even, which created a market for bourgeois portraits. I shall jump several centuries to the development of photography and oil-paint tubes in the nineteenth century. The first made representational art less attractive and the second allowed the impressionists to paint outdoors: art evolved to adapt itself to new conditions. And notice that the very definition of art had to evolve in the twentieth century in order to respond to the challenges of artists such as Picasso and Duchamp.

Religion without absolutes

This is my most difficult subject, because I am a total agnostic and I would hate to upset believers with my rational approach. But even Galileo's inquisitor, Cardinal Roberto Bellarmino, suggested to the Vatican in the seventeenth century that, should Galileo ever have a total proof of Copernican theory, the brethren would have to be instructed to read Genesis in a metaphorical way, which much later was agreed upon by the Second Vatican Council in the 1960's. And Pope Francesco wrote an article in 2013 entitled '*La verità non è mai assoluta*.' (Truth is never absolute.)

To make my views crystal clear: I believe that attacking irrationality unreservedly is itself irrational. Because everything in life exists only if it serves an evolutionary purpose or if it is a relict of once useful features. In the seventeenth century pregnancy was the bane of women. Nothing existed to make deliveries safe, medics themselves being a primary source of infection and death.

Thus, Isabel de Borbón, the first wife of King Phillip IV of Spain, was so desperate that she caused a famous religious relic (the Virgin's Holy Girdle) to be transported to Madrid from many miles away in Tortosa, which required episcopal permission, to be placed on her abdomen before delivery. This was her only possible source of comfort although it did not work, of course (she died at 29 leaving after seven deliveries only one daughter alive and a soon-to-die boy). But to deny her the only placebo available at the time would have been cruel. Likewise, I think that the persecution of the Church in Russia by the communist leaders (one of which was my mother's uncle) was probably one of the worst political mistakes of the century.

What I want to show is that religion (for which I have generally taken Christianity as an example), like everything else in life, was created not in a big bang but by a gradual process of evolution. This process, by which a religion adopts practices of another one is called *syncretism*, and appears strongly in Christianity. An early example is baptism, which was part of the rituals of the Mithraic religion, fairly popular in the days of the Roman empire. Likewise, much of Christianity derives from Judaism, although circumcision, a religious Jewish practice that may have been derived from their sojourn in Egypt, was soon abandoned. Monotheism, which is the basis of the three Abrahamic religions, might have also come from Egypt. Akhenaton, Pharaoh of Egypt around 1350 BCE, changed the traditional Egyptian religion to worship a single Sun god. Although this change did not last long, being reversed by his son Tutankamun, it might have inspired Moses, (as suggested by Sigmund Freud), who was part of the Hebrew tribe that were forced into Egypt around 1450 BCE.

A very complex problem is the invention of the soul and thus of resurrection, a concept so vital for Christianity. If you think that it is crystal clear from the Gospels, please think again: there is one and only one verse in the four gospels that suggests that the soul survives immediately after death. This is Luke 23:43. When Jesus was on the Cross, with the Good Thief on his right, he turned to him and said: 'Verily I say unto thee, Today shalt thou be with me in paradise.' I am not a theologian and I might be wrong in reading this in plain English, but it appears to me to be at least unclear on two counts. If 'today' means today, it cannot be right because Jesus did not go up to Heaven straight after his burial: he spent three days in the Harrowing of Hell. The second problem is that the idea that a Jew (as both the Thief and Jesus were) could instantly have his soul resurrected into Heaven was neither orthodox, nor one that Jesus apparently countenanced.

The whole question of resurrection within Judaism at the time of Jesus was very confusing because this religion was more than anything else concerned with the here and now. The guardians of the Temple, the *Saducees,* did not believe in resurrection, whereas the mass of the people followed the *Pharisees*, who did, (Acts*,* 23:3). That Jesus followed the latter is evident from his colloquium with the elders of the Temple (Mark 12:24), where He defends the concept of resurrection. The whole question was very obscure for the first two or three centuries after Christ, until in the third century Plotinus, a philosopher that had lived in Alexandria, resurrected Plato's idea of the soul, later adopted by St Augustine.

An even more interesting case of syncretism is how the Virgin Mary acquired her present status in the Christian Church. After the Battle of Ponte Milvio in 312 CE, that made him the Roman Emperor, Constantine adopted the Christian religion as that of the Empire. As we have seen in Chapter 9, the status of Jesus being the cause of quarrels between the Bishops, Constantine summoned the first Church Council in 325 at Nicea (in Turkey), hoping for a settlement. The result of the Council was that Jesus was declared to be one with God: the logical conclusion was that the Virgin now became the Mother of God.

It is almost certain that some of the Bishops saw this as an opportunity to make Christianity more attractive to the masses by bringing in a female element to it. The Oriental and the Greek and Roman religions had long enjoyed such a presence. Not only Isis was a major deity in Egypt, but her symbol, the *tyet*, had a cross as a part of it. (Also, she shared with Mary an asexual conception, since the body of her husband Osiris, murdered and mutilated by his brother Seth, which she recovered from the Nile and reconstructed, lacked the sexual organs, which had been eaten by a fish. Isis, nevertheless managed to have intercourse with her husband: the god Horus was her son.) The Greeks, of course, held the sister and wife of Jupiter, Hera, to be the queen of the goddesses, and she was later adopted as Juno in the same role by the Romans.

It did not take long after Nicea to try to bring in spirit these goddesses by means of a raised status for the Virgin Mary. In 358, the legend goes, the Patrician Giovanni had a dream that told him to give his money to the Church for the glorification of Mary and he went to see Pope Liberius to tell him of this. The Pope prayed to the Virgin to give him a sign and, although it was Summer, a miraculous snowfall took place on 5 August 358 on the Mount Esquilino in Rome covering the ground with exactly the shape of a church, which is now Santa Maria Maggiore, the main Marian basilica in Rome. The snowfall may have been miraculous but I doubt very much that the choice of the Esquilino was accidental: it was the site of a then ruined temple to Juno. This is how syncretism works. At the next Church Council in Ephesus, 431CE, the Virgin Mary was officially given the title of Mother of God and Christianity never had to look back.

In the fifth century, in fact, a temple to Isis in Soissons was converted to the worship of Mary, and much later, around the twelfth century, the Church of Santa María a Momentana in Monterchi (near Arezzo) was built on Juno's Hill, long a site of pagan rites.

We have now been able to show that the Principle of Evolution treats the whole of nature, including the spiritual sphere that humans have created, as a river in constant movement, changing sometimes but always adapting itself to the natural constraints, which include also those created by us. And if you are worried about the present state of the world, remember please that we are a very young species. If ants behave in a more rational way than us it is because they are millions of years older as a species. And anyhow: who wants to be an ant?

Luke 23:43

On the barren hill
on Adam's stock.
Man, arms outstretched.

Man and man
hands almost touch
but feet do not reach the ground.

Do not get it wrong:
They do not levitate.
They mutely talk.

They will meet that day.
Not there, not on the town.
In a better place.

Did they meet?
Did they meet that day?
The Italian sage

said not. Man saw man
elsewhere, carrying timber
over his curved back.

Did they meet?
Did they levitate?
On the answer read your fate.

The Italian sage: Jacopo da Varagine (*The Golden Legend*), who stated that Jesus saw the good thief in limbo (*sheol*) carrying a cross. Notice that one man is always in capitals.

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Is Nature Supernatural? 'Whether you agree with much of what it says this is a must-read book. L. W. Colter in *Philosophy in Review.*

About the Author

Simon Altmann is a mathematical physicist who taught and researched for over forty years at the University of Oxford as a Fellow of Brasenose College. He has published some 80 research papers, five mathematical books, two on the history and philosophy of science, and a large book, *Is Nature Supernatural?* on which the present one is based. He is a published poet and his collection *Not for Poets* is available as an eBook. He has also published '*A Tale of Three Countries*', and four papers on the history of art, one on Velázquez's *Las Meninas*, and three on the problem of right and left in the Annunciation, on which he is currently working. He is a total agnostic but believes in building bridges between all forms of human thought.

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