Einstein's Quantum Error

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An Approach to Rationality

By

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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.

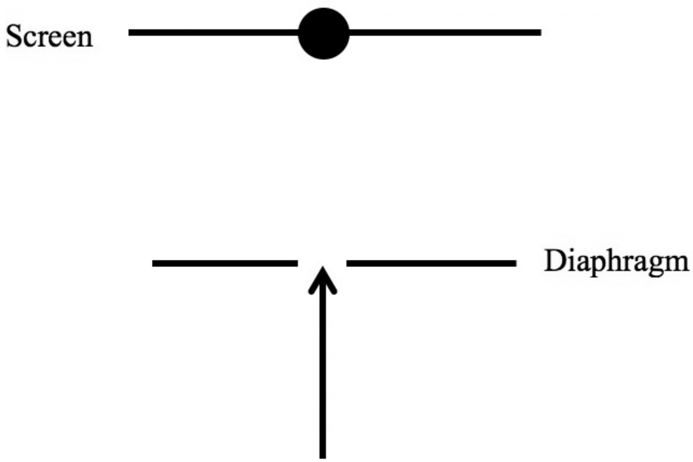

Fig. 1. Measuring the electron position

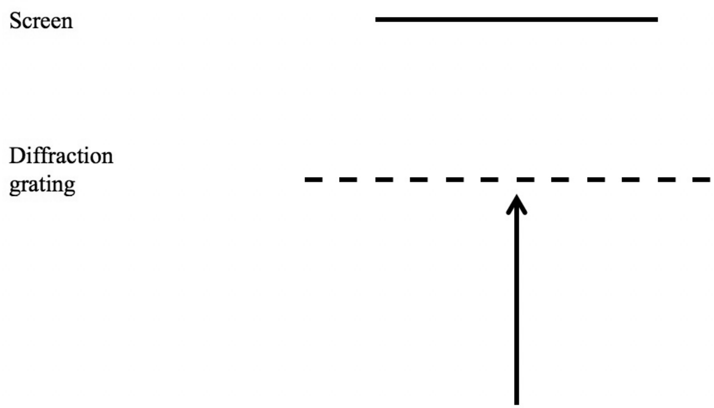

Fig. 2. Measuring the electron velocity

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-