CHAPTER 5

Science and Religion

Can science vouchsafe information on matters of religion? Can the results of scientific research be of any help in gaining a reasonable and satisfactory attitude towards those burning questions which assail everyone at times? Some of us, in particular healthy and happy youth, succeed in shoving them aside for long periods; others, in advanced age, have satisfied themselves that there is no answer and have resigned themselves to giving up looking for one, while others again are haunted throughout their lives by this incongruity of our intellect, haunted also by serious fears raised by time-honoured popular superstition. I mean mainly the questions concerned with the 'other world', with 'life after death', and all that is connected with them. Notice please that I shall not, of course, attempt to answer *these* questions, but only the much more modest one, whether science can give any information about them or aid our – to many of us unavoidable – thinking about them.

To begin with, in a very primitive way it certainly can, and has done so without much ado. I remember seeing old prints, geographical maps of the world, so I believe, including hell, purgatory and heaven, the former being placed deep underground, the latter high above in the skies. Such representations were not meant purely allegorically (as they might be in later periods, for example, in Dürer's famous *All-Saints* picture); they testify to a crude belief quite popular at the time. Today no church requests the faithful to interpret its dogmas in this materialistic fashion, nay it would seriously discourage such an attitude. This advancement has certainly been aided by our knowledge of the interior of our planet (scanty though it be), of the nature of volcanoes, of the composition of our atmosphere, of the probable history of the solar system and of the structure of the galaxy and the universe. No cultured person would expect to find these dogmatic figments in any region of that part of space which is accessible to our investigation, I daresay not even in a region continuing that space but inaccessible to research; he would give them, even if convinced of their reality, a spiritual standing. I will not say that with deeply religious persons such enlightenment had to await the aforesaid findings of science, but they have certainly helped in eradicating materialistic superstition in those matters.

However, this refers to a rather primitive state of mind. There are points of greater interest. The most important contributions from science to overcome the baffling questions 'Who are we really? Where have I come from and where am I going?' – or at least to set our minds at rest – I say, the most appreciable help science has offered us in this is, in my view, the gradual idealization of time. In thinking of this the names of three men obtrude themselves upon us, though many others, including non-scientists, have hit on the same groove, such as St Augustine of Hippo and Boethius; the three are Plato, Kant and Einstein.

The first two were not scientists, but their keen devotion to philosophic questions, their absorbing interest in the world, originated from science. In Plato's case it came from mathematics and geometry (the 'and' would be out of place today, but not, I think, in his time). What has endowed Plato's life-work with such unsurpassed distinction that it shines in undiminished splendour after more than two thousand years? For all we can tell, no special discovery about numbers or geometrical figures is to his credit. His insight into the material world of physics and life is occasionally fantastic and altogether inferior to that of others (the sages from Thales to Democritus) who lived, some of them more than a century, before his time; in knowledge of nature he was widely surpassed by his pupil Aristotle and by Theophrastus. To all but his ardent worshippers long passages in his dialogues give the impression of a gratuitous quibbling on words, with no desire to define the meaning of a word, rather in the belief that the word itself will display its content if you turn it round and round long enough. His social and political Utopia, which failed and put him into grave danger when he tried to promote it practically, finds few admirers in our days, that have sadly experienced the like. So what made his fame?

In my opinion it was this, that he was the first to envisage the idea of timeless existence and to emphasize it – against reason – as a reality, more real than our actual experience; this, he said, is but a shadow of the former, from which all experienced reality is borrowed. I am speaking of the theory of forms (or ideas). How did it originate? There is no doubt that it was aroused by his becoming acquainted with the teaching of Parmenides and the Eleatics. But it is equally obvious that this met in Plato with an alive congenial vein, an occurrence very much on the line of Plato's own beautiful simile that learning by reason has the nature of remembering knowledge, previously possessed but at the time latent, rather than that of discovering entirely new verities. However, Parmenides' everlasting, ubiquitous and changeless One has in Plato's mind turned into a much more powerful thought, the Realm of Ideas, which appeals to the imagination, though, of necessity, it remains a mystery. But this thought sprang, as I believe, from a very real experience, namely, that he was struck with admiration and awe by the revelations in the realm of numbers and geometrical figures – as many a man was after him and the Pythagoreans were before. He recognized and absorbed deeply into his mind the nature of these revelations, that they unfold themselves by pure logical reasoning, which makes us acquainted with true relations whose truth is not only unassailable, but is obviously there, forever; the relations held and will hold irrespective of our inquiry into them. A mathematical truth is timeless, it does not come into being when we discover it. Yet its discovery is a very real event, it may be an emotion like a great gift from a fairy.

The three heights of a triangle (ABC) meet at one point (O).

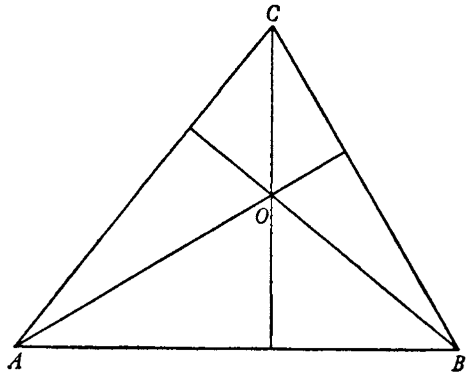

Fig. 1.

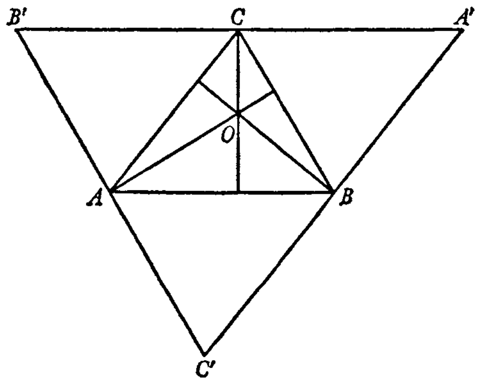

Fig. 2.

(Height is the perpendicular, dropped from a corner onto the side opposite to it, or onto its prolongation.) At first sight one does not see why they should; *any* three lines do not, they usually form a triangle. Now draw through every corner the parallel to the opposite side, to form the bigger triangle $A'B'C'$. It consists of four congruent triangles. The three heights of ABC are in the bigger triangle the perpendiculars erected in the middle of its sides, their 'symmetry lines'. Now the one erected at C must contain all the points that have the same distance from A' as from B'; the one erected at B contains all those points that have the same distance from A' as from C'. The point where these two perpendiculars meet has therefore the same distance from all three corners A', B', C', and must therefore lie also on the perpendicular erected at A because this one contains all points that have the same distance from B' as from C'. Q.E.D.

Every integer, except 1 and 2, is 'in the middle' of two prime numbers, or is their arithmetical mean; for instance

$$8 = \tfrac{1}{2}(5 + 11) = \tfrac{1}{2}(3 + 13)$$
$$17 = \tfrac{1}{2}(3 + 31) = \tfrac{1}{2}(29 + 5) = \tfrac{1}{2}(23 + 11)$$
$$20 = \tfrac{1}{2}(11 + 29) = \tfrac{1}{2}(3 + 37).$$

As you see, there is usually more than one solution. The theorem is called Goldbach's and is thought to be true, though it has not been proved.

By adding the consecutive odd numbers, thus first taking just 1, then $1 + 3 = 4$, then $1 + 3 + 5 = 9$, then $1 + 3 + 5 + 7 = 16$, you always get a square number, indeed you get in this way all square numbers, always the square of the number of odd numbers you have added. To grasp the generality of this relation one may replace in the sum the summands of every pair that is equidistant from the middle (thus: the first and the last, then the first but one and the last but one, etc.) by their arithmetic mean, which is obviously just equal to the number of summands; thus, in the last of the above examples:

$$4 + 4 + 4 + 4 = 4 \times 4.$$

Let us now turn to Kant. It has become a commonplace that he taught the ideality of space and time and that this was a fundamental, if not the most fundamental part of his teaching. Like most of it, it can be neither verified nor falsified, but it does not lose interest on this account (rather it gains; if it could be proved or disproved it would be trivial). The meaning is that, to be spread out in space and to happen in a well-defined temporal order of 'before and after' is not a quality of the world that we perceive, but pertains to the perceiving mind which, in its present situation anyhow, cannot help registering anything that is offered to it according to these two card-indexes, space and time. It does not mean that the mind comprehends these order-schemes irrespective of, and before, any experience, but that it cannot help developing them and applying them to experience when this comes along, and particularly that this fact does not prove or suggest space and time to be an order-scheme inherent in that 'thing-in-itself' which, as some believe, causes our experience.

It is not difficult to make a case that this is humbug. No single man can make a distinction between the realm of his perceptions and the realm of things that cause it since, however detailed the knowledge he may have acquired about the whole story, the story is occurring only once not twice. The duplication is an allegory, suggested mainly by communication with other human beings and even with animals; which shows that their perceptions in the same situation seem to be very similar to his own apart from insignificant differences in the point of view – in the literal meaning of 'point of projection'. But even supposing that this compels us to consider an objectively existing world the cause of our perceptions, as most people do, how on earth shall we decide that a common feature of all our experience is due to the constitution of our mind rather than a quality shared by all those objectively existing things? Admittedly our sense perceptions constitute our sole knowledge about things. This objective world remains a hypothesis, however natural. If we do adopt it, is it not by far the most natural thing to ascribe to that external world, and not to ourselves, all the characteristics that our sense perceptions find in it?

However, the supreme importance of Kant's statement does not consist in justly distributing the roles of the mind and its object – the world – between them in the process of 'mind forming an idea of the world', because, as I just pointed out, it is hardly possible to discriminate the two. The great thing was to form the idea that this *one thing* – mind or world – may well be capable of other forms of appearance that we cannot grasp and that do not imply the notions of space and time. This means an imposing liberation from our inveterate prejudice. There probably are other orders of appearance than the space-time-like. It was, so I believe, Schopenhauer who first read this from Kant. This liberation opens the way to belief, in the religious sense, without running all the time against the clear results which experience about the world as we know it and plain thought unmistakably pronounce. For instance – to speak of the most momentous example – experience as we know it unmistakably obtrudes the conviction that it cannot survive the destruction of the body, with whose life, as we know life, it is inseparably bound up. So is there to be nothing after this life? No. Not in the way of experience as we know it necessarily to take place in space and time. But, in an order of appearance in which time plays no part, this notion of 'after' is meaningless. Pure thinking cannot, of course, procure us a guarantee that there *is* that sort of thing, But it can remove the apparent obstacles to conceiving it as possible. That is what Kant has done by his analysis, and that, to my mind, is his philosophical importance.

I now come to speak about Einstein in the same context. Kant's attitude towards science was incredibly naïve, as you will agree if you turn the leaves of his *Metaphysical Foundations of Science* (*Metaphysische Anfangsgründe der Naturwissenschaft*). He accepted physical science in the form it had reached during his lifetime (1724–1804) as something more or less final and he busied himself to account for its statements philosophically. This happening to a great genius ought to be a warning to philosophers ever after. He would show plainly that space was necessarily infinite and believed firmly that it was in the nature of the human mind to endow it with the geometrical properties summarized by Euclid. In this Euclidean space a mollusc of matter moved, that is, changed its configuration as time went on. To Kant, as to any physicist of his period, space and time were two entirely different conceptions, so he had no qualms in calling the former the form of our external intuition, and time the form of our internal intuition (*Anschauung*). The recognition that Euclid's infinite space is not a necessary way of looking at the world of our experience and that space and time are better looked upon as one continuum of four dimensions seemed to shatter Kant's foundation – but actually did no harm to the more valuable part of his philosophy.

This recognition was left to Einstein (and several others, H. A. Lorentz, Poincaré, Minkowski, for example). The mighty impact of their discoveries on philosophers, men-in-the-street, and ladies in the drawing-room is due to the fact that they brought it to the fore: even in the domain of our experience the spatio-temporal relations are much more intricate than Kant dreamed them to be, following in this all previous physicists, men-in-the-street and ladies in the drawing-room.

The new view has its strongest impact on the previous notion of time. Time is the notion of 'before and after'. The new attitude springs from the following two roots:

(i) The notion of 'before and after' resides on the 'cause and effect' relation. We know, or at least we have formed the idea, that one event *A* can cause, or at least modify, another event *B*, so that if *A* were not, then *B* were not, at least not in this modified form. For instance when a shell explodes, it kills a man who was sitting on it; moreover the explosion is heard at distant places. The killing may be simultaneous to the explosion, the hearing of the sound at a distant place will be later; but certainly none of the effects can be earlier. This is a basic notion, indeed it is the one by which also in everyday life the question is decided which of two events was later or at least not earlier. The distinction rests entirely on the idea that the effect cannot precede the cause. If we have reasons to think that *B* has been caused by *A*, or that it at least shows vestiges of *A*, or even if (from some circumstantial evidence) it is conceivable that it shows vestiges, then *B* is deemed to be certainly not earlier than *A*.

(2) Keep this in mind. The second root is the experimental and observational evidence that effects do not spread with arbitrarily high velocity. There is an upper limit, which incidentally is the velocity of light in empty space. In human measure it is very high, it would go round the equator about

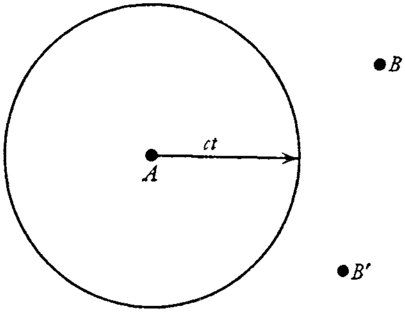

Fig. 3.

seven times in one second. Very high, but not infinite, call it c. Let this be agreed upon as a fundamental fact of nature. It then follows that the above-mentioned discrimination between 'before and after' or 'earlier and later' (based on the cause-and-effect relation) is not universally applicable, it breaks down in some cases. This is not as easily explained in non-mathematical language. Not that the mathematical scheme is so complicated. But everyday language is prejudicial in that it is so thoroughly imbued with the notion of time – you cannot use a verb (*verbum*, 'the' word, Germ. *Zeitwort*) without using it in one or the other tense.

The simplest but, as will turn out, not fully adequate consideration runs thus. Given an event A. Contemplate at any later time an event B outside the sphere of radius ct around A. Then B cannot exhibit any 'vestige' of A; nor, of course can A from B. Thus our criterion breaks down. By the language we used we have, of course, dubbed B to be the later. But are we right in this, since the criterion breaks down either way?

Contemplate at a time earlier (by t) an event B' outside that same sphere. In this case, just as before, no vestige of B' can have reached A (and, of course, none from A can be exhibited on B').

Thus in both cases there is exactly the same relationship of mutial non-interference. There is no conceptual difference between the classes B and B' with regard to their cause-effect relation to A. So if we want to make this relation, and not a linguistic prejudice, the basis of the 'before and after', then the B and B' form one class of events that are neither earlier nor later than A. The region of space-time occupied by this class is called the region of 'potential simultaneity' (with respect to event A). This expression is used, because a space-time frame can always be adopted that makes A simultaneous with a selected particular B or a particular B'. This was Einstein's discovery (which goes under the name of The Theory of Special Relativity, 1905).

Now these things have become very concrete reality to us physicists, we use them in everyday work just as we use the multiplication table or Pythagoras' theorem on right-angled triangles. I have sometimes wondered why they made such a great stir both among the general public and among philosophers. I suppose it is this, that it meant the dethronement of time as a rigid tyrant imposed on us from outside, a liberation from the unbreakable rule of 'before and after'. For indeed time is our most severe master by ostensibly restricting the existence of each of us to narrow limits – seventy or eighty years, as the Pentateuch has it. To be allowed to play about with such a master's programme believed unassailable until then, to play about with it albeit in a small way, seems to be a great relief, it seems to encourage the thought that the whole 'timetable' is probably not quite as serious as it appears at first sight. And this thought is a religious thought, nay I should call it *the* religious thought.

Einstein has not – as you sometimes hear – given the lie to Kant's deep thoughts on the idealization of space and time; he has, on the contrary, made a large step towards its accomplishment.

I have spoken of the impact of Plato, Kant and Einstein on the philosophical and religious outlook. Now between Kant and Einstein, about a generation before the latter, physical science had witnessed a momentous event which might have seemed calculated to stir the thoughts of philosophers, men-in-the-street and ladies in the drawing-room at least as much as the theory of relativity, if not more so. That this was not the case is, I believe, due to the fact that this turn of thought is even more difficult to understand and was therefore grasped by very few among the three categories of persons, at the best by one or another philosopher. This event is attached to the names of the American Willard Gibbs and the Austrian Ludwig Boltzmann. I will now say something about it.

With very few exceptions (that really are exceptions) the course of events in nature is irreversible. If we try to imagine a time-sequence of phenomena exactly opposite to one that is actually observed – as in a cinema film projected in reversed order – such a reversed sequence, though it can easily be imagined, would nearly always be in gross contradiction to well-established laws of physical science.

The general 'directedness' of all happening was explained by the mechanical or statistical theory of heat, and this explanation was duly hailed as its most admirable achievement. I cannot enter here on the details of the physical theory, and this is not necessary for grasping the gist of the explanation. This would have been very poor, had irreversibility been stuck in as a fundamental property of the microscopic mechanism of atoms and molecules. This would not have been better than many a medieval purely verbal explanation such as: fire is hot on account of its fiery quality. No. According to Boltzmann we are faced with the natural tendency of any state of order to turn on its own into a less orderly state, but not the other way round. Take as a simile a set of playing cards that you have carefully arranged, beginning with 7, 8, 9, 10, knave, queen, king, ace of hearts, then the same in diamonds, etc. If this well-ordered set is shuffled once, twice or three times it will gradually turn into a random set. But this is not an intrinsic property of the process of shuffling. Given the resulting disorderly set, a process of shuffling is perfectly thinkable that would exactly cancel the effect of the first shuffling and restore the original order. Yet everybody will expect the first course to take place, nobody the second – indeed he might have to wait pretty long for it to happen by chance.

Now this is the gist of Boltzmann's explanation of the unidirectional character of everything that happens in nature (including, of course, the life-history of an organism from birth to death). Its very virtue is that the 'arrow of time' (as Eddington called it) is not worked into the mechanisms of interaction, represented in our simile by the mechanical act of shuffling. This act, this mechanism is as yet innocent of any notion of past and future, it is in itself completely reversible, the 'arrow' – the very notion of past and future – results from statistical considerations. In our simile with the cards the point is this, that there is only one, or a very few, well-ordered arrangements of the cards, but billions of billions of disorderly ones.

Yet the theory has been opposed, again and again, occasionally by very clever people. The opposition boils down to this: the theory is said to be unsound on logical grounds. For, so it is said, if the basic mechanisms do not distinguish between the two directions of time, but work perfectly symmetrically in this respect, how should there from their co-operation result a behaviour of the whole, an integrated behaviour, that is strongly biased in one direction? Whatever holds for this direction must hold equally well for the opposite one.

If this argument is sound, it seems to be fatal. For it is aimed at the very point which was regarded as the chief virtue of the theory: to derive irreversible events from reversible basic mechanisms.

The argument is perfectly sound, yet it is not fatal. The argument is sound in asserting that what holds for one direction also holds for the opposite direction of time, which from the outset is introduced as a perfectly symmetrical variable. But you must not jump to the conclusion that it holds quite in general for both directions. In the most cautious wording one has to say that in any particular case it holds for either the one or the other direction. To this one must add: in the particular case of the world as we know it, the 'running down' (to use a phrase that has been occasionally adopted) takes place in one direction and this we call the direction from past to future. In other words the statistical theory of heat must be allowed to decide by itself high-handedly, by its own definition, in which direction time flows. (This has a momentous consequence for the methodology of the physicist. He must never introduce anything that decides independently upon the arrow of time, else Boltzmann's beautiful building collapses.)

It might be feared that in different physical systems the statistical definition of time might not always result in the same time-direction. Boltzmann boldly faced this eventuality; he maintained that if the universe is sufficiently extended and/or exists for a sufficiently long period, time might actually run in the opposite direction in distant parts of the world. The point has been argued, but it is hardly worth while arguing any longer. Boltzmann did not know what to us is at least extremely likely, namely that the universe, as we know it, is neither large enough nor old enough to give rise to such reversions on a large scale. I beg to be allowed to add without detailed explanations that on a very small scale, both in space and in time, such reversions have been observed (Brownian movement, Smoluchowski).

To my view the 'statistical theory of time' has an even stronger bearing on the philosophy of time than the theory of relativity. The latter, however revolutionary, leaves untouched the undirectional flow of time, which it presupposes, while the statistical theory constructs it from the order of the events. This means a liberation from the tyranny of old Chronos. What we in our minds construct ourselves cannot, so I feel, have dictatorial power over our mind, neither the power of bringing it to the fore nor the power of annihilating it. But some of you, I am sure, will call this mysticism. So with all due acknowledgment to the fact that physical theory is at all times relative, in that it depends on certain basic assumptions, we may, or so I believe, assert that physical theory in its present stage strongly suggests the indestructibility of Mind by Time.

CHAPTER 6

The Mystery of the Sensual Qualities

In this last chapter I wish to demonstrate in a little more detail the very strange state of affairs already noticed in a famous fragment of Democritus of Abdera – the strange fact that on the one hand all our knowledge about the world around us, both that gained in everyday life and that revealed by the most carefully planned and painstaking laboratory experiments, rests entirely on immediate sense perception, while on the other hand this knowledge fails to reveal the relations of the sense perceptions to the outside world, so that in the picture or model we form of the outside world, guided by our scientific discoveries, all sensual qualities are absent. While the first part of this statement is, so I believe, easily granted by everybody, the second half is perhaps not so frequently realized, simply because the non-scientist has, as a rule, a great reverence for science and credits us scientists with being able, by our 'fabulously refined methods', to make out what, by its very nature, no human can possibly make out and never will be able to make out.

If you ask a physicist what is his idea of yellow light, he will tell you that it is transversal electro-magnetic waves of wave-length in the neighbourhood of 590 millimicrons. If you ask him: But where does yellow come in? he will say: In my picture not at all, but these kinds of vibrations, when they hit the retina of a healthy eye, give the person whose eye it is the sensation of yellow. On further inquiry you may hear that different wave-lengths produce different colour-sensations, but not all do so, only those between about 800 and 400 $\mu\mu$. To the physicist the infra-red (more than 800 $\mu\mu$) and the ultra-violet (less than 400 μμ) waves are much the same kind of phenomena as those in the region between 800 and 400 μμ, to which the eye is sensitive. How does this peculiar selection come about? It is obviously an adaptation to the sun's radiation, which is strongest in this region of wave-lengths but falls off at either end. Moreover, the intrinsically brightest colour-sensation, the yellow, is encountered at that place (within the said region) where the sun's radiation exhibits its maximum, a true peak.

We may further ask: Is radiation in the neighbourhood of wave-length 590 μμ the only one to produce the sensation of yellow? The answer is: Not at all. If waves of 760 μμ, which by themselves produce the sensation of red, are mixed in a definite proportion with waves of 535 μμ, which by themselves produce the sensation of green, this mixture produces a yellow that is indistinguishable from the one produced by 590 μμ. Two adjacent fields illuminated, one by the mixture, the other by the single spectral light, look exactly alike, you cannot tell which is which. Could this be foretold from the wave-lengths – is there a numerical connection with these physical, objective characteristics of the waves? No. Of course, the chart of all mixtures of this kind has been plotted empirically; it is called the colour triangle. But it is not simply connected with the wave-lengths. There is no general rule that a mixture of two spectral lights matches one between them; for example a mixture of 'red' and 'blue' from the extremities of the spectrum gives 'purple', which is not produced by any single spectral light. Moreover, the said chart, the colour triangle, varies slightly from one person to the other, and differs considerably for some persons, called anomalous trichromates (who are *not* colour-blind).

The sensation of colour cannot be accounted for by the physicist's objective picture of light-waves. Could the physiologist account for it, if he had fuller knowledge than he has of the processes in the retina and the nervous processes set up by them in the optical nerve bundles and in the brain? I do not think so. We could at best attain to an objective knowledge of what nerve fibres are excited and in what proportion, perhaps even to know exactly the processes they produce in certain brain cells – whenever your mind registers the sensation of yellow in a particular direction or domain of our field of vision. But even such intimate knowledge would not tell us anything about the sensation of colour, more particularly of yellow in this direction – the same physiological processes might conceivably result in a sensation of sweet taste, or anything else. I mean to say simply this, that we may be sure there is no nervous process whose objective description includes the characteristic 'yellow colour' or 'sweet taste', just as little as the objective description of an electro-magnetic wave includes either of these characteristics.

The same holds for other sensations. It is quite interesting to compare the perception of colour, which we have just surveyed, with that of sound. It is normally conveyed to us by elastic waves of compression and dilatation, propagated in the air. Their wave-length – or to be more accurate their frequency – determines the pitch of the sound heard. (N.B. The physiological relevance pertains to the frequency, not to the wave-length, also in the case of light, where, however, the two are virtually exact reciprocals of each other, since the velocities of propagation in empty space and in air do not differ perceptibly.) I need not tell you that the range of frequencies of 'audible sound' is very different from that of 'visible light', it ranges from about 12 or 16 per second to 20,000 or 30,000 per second, while those for light are of the order of several hundred (English) billions. The relative range, however, is much wider for sound, it embraces about 10 octaves (against hardly one for 'visible light'); moreover, it changes with the individual, especially with age: the upper limit is regularly and considerably reduced as age advances. But the most striking fact about sound is that a mixture of several distinct frequencies never combines to produce just one intermediate pitch such as could be produced by one intermediate frequency. To a large extent the superposed pitches are perceived separately – though simultaneously – especially by highly musical persons. The admixture of many higher notes ('overtones') of various qualities and intensities results in what is called the timbre (German: *Klangfarbe*), by which we learn to distinguish a violin, a bugle, a church bell, piano . . . even from a single note that is sounded. But even noises have their timbre, from which we may infer what is going on; and even my dog is familiar with the peculiar noise of the opening of a certain tin box, out of which he occasionally receives a biscuit. In all this the ratios of the co-operating frequencies are all-important. If they are all changed in the same ratio, as on playing a gramophone record too slow or too fast, you still recognize what is going on. Yet some relevant distinctions depend on the absolute frequencies of certain components. If a gramophone record containing a human voice is played too fast, the vowels change perceptibly, in particular the 'a' as in 'car' changes into that in 'care'. A continuous range of frequencies is always disagreeable, whether offered as a sequence, as by a siren or a howling cat, or simultaneously, which is difficult to implement, except perhaps by a host of sirens or a regiment of howling cats. This is again entirely different from the case of light perception. All the colours which we normally perceive are produced by continuous mixtures; and a continuous gradation of tints, in a painting or in nature, is sometimes of great beauty.

The chief characteristics of sound perception are well understood in the mechanism of the ear, of which we have better and safer knowledge than of the chemistry of the retina. The principal organ is the *cochlea*, a coiled bony tube which resembles the shell of a certain type of sea-snail: a tiny winding staircase that gets narrower and narrower as it 'ascends'. In place of the steps (to continue our simile), across the winding staircase elastic fibres are stretched, forming a membrane, the width of the membrane (or the length of the individual fibre) diminishing from the 'bottom' to the 'top'. Thus, like the strings of a harp or a piano, the fibres of different length respond mechanically to oscillations of different frequency. To a definite frequency a definite small area of the membrane – not just one fibre – responds, to a higher frequency another area, where the fibres are shorter. A mechanical vibration of definite frequency must set up, in each of that group of nerve fibres, the well-known nerve impulses that are propagated to certain regions of the cerebral cortex. We have the general knowledge that the process of conduction is very much the same in all nerves and changes only with the intensity of excitation; the latter affects the frequency of the pulses, which, of course, must not be confused with the frequency of sound in our case (the two have nothing to do with each other).

The picture is not as simple as we might wish it to be. Had a physicist constructed the ear, with a view to procuring for its owner the incredibly fine discrimination of pitch and timbre that he actually possesses, the physicist would have constructed it differently. But perhaps he would have come back to it. It would be simpler and nicer if we could say that every single 'string' across the cochlea answers only to one sharply defined frequency of the incoming vibration. This is not so. But why is it not so? Because the vibrations of these 'strings' are strongly damped. This, of necessity, broadens their range of resonance. Our physicist might have constructed them with as little damping as he could manage. But this would have the terrible consequence that the perception of a sound would not cease almost immediately when the producing wave ceases; it would last for some time, until the poorly damped resonator in the cochlea died down. The discrimination of pitch would be obtained by sacrificing the discrimination in time between subsequent sounds. It is puzzling how the actual mechanism manages to reconcile both in a most consummate fashion.

I have gone into some detail here, in order to make you feel that neither the physicist's description, nor that of the physiologist, contains any trait of the sensation of sound. Any description of this kind is bound to end with a sentence like: those nerve impulses are conducted to a certain portion of the brain, where they are registered as a sequence of sounds. We can follow the pressure changes in the air as they produce vibrations of the ear-drum, we can see how its motion is transferred by a chain of tiny bones to another membrane and eventually to parts of the membrane inside the cochlea, composed of fibres of varying length, described above. We may reach an understanding of how such a vibrating fibre sets up an electrical and chemical process of conduction in the nervous fibre with which it is in touch. We may follow this conduction to the cerebral cortex and we may even obtain some objective knowledge of some of the things that happen there. But nowhere shall we hit on this 'registering as sound', which simply is not contained in our scientific picture, but is only in the mind of the person whose ear and brain we are speaking of.

We could discuss in similar manner the sensations of touch, of hot and cold, of smell and of taste. The latter two, the chemical senses as they are sometimes called (smell affording an examination of gaseous stuffs, taste that of fluids), have this in common with the visual sensation, that to an infinite number of possible stimuli they respond with a restricted manifold of sensate qualities, in the case of taste: bitter, sweet, sour and salty and their peculiar mixtures. Smell is, I believe, more various than taste, and particularly in certain animals it is much more refined than in man. What objective features of a physical or chemical stimulus modify the sensation noticeably seems to vary greatly in the animal kingdom. Bees, for instance, have a colour vision reaching well into the ultra-violet; they are true trichromates (not dichromates, as they seemed in earlier experiments which paid no attention to the ultra-violet). It is of very particular interest that bees, as von Frisch in Munich found out not long ago, are peculiarly sensitive to traces of polarization of light; this aids their orientation with respect to the sun in a puzzlingly elaborate way. To a human being even completely polarized light is indistinguishable from ordinary, non-polarized light. Bats have been discovered to be sensible to extremely high frequency vibrations ('ultra-sound') far beyond the upper limit of human audition; they produce it themselves, using it as a sort of 'radar', to avoid obstacles. The human sense of hot or cold exhibits the queer feature of 'les extrêmes se touchent': if we inadvertently touch a very cold object, we may for a moment believe that it is hot and has burnt our fingers.

Some twenty or thirty years ago chemists in the U.S.A.

discovered a curious compound, of which I have forgotten the chemical name, a white powder, that is tasteless to some persons, but intensely bitter to others. This fact has aroused keen interest and has been widely investigated since. The quality of being a 'taster' (for this particular substance) is inherent in the individual, irrespective of any other conditions. Moreover, it is inherited according to the Mendel laws in a way familiar from the inheritance of blood group characteristics. Just as with the latter, there appears to be no conceivable advantage or disadvantage implied by your being a 'taster' or a 'non-taster'. One of the two 'alleles' is dominant in heterozygotes, I believe it is that of the taster. It seems to me very improbable that this substance, discovered haphazardly, should be unique. Very probably 'tastes differ' in quite a general way, and in a very real sense!

Let us now return to the case of light and probe a little deeper into the way it is produced and into the fashion in which the physicist makes out its objective characteristics. I suppose that by now it is common knowledge that light is usually produced by electrons, in particular by those in an atom where they 'do something' around the nucleus. An electron is neither red nor blue nor any other colour; the same holds for the proton, the nucleus of the hydrogen atom. But the union of the two in the atom of hydrogen, according to the physicist, produces electro-magnetic radiation of a certain discrete array of wave-lengths. The homogeneous constituents of this radiation, when separated by a prism or an optical grating, stimulate in an observer the sensations of red, green, blue, violet by the intermediary of certain physiological processes, whose general character is sufficiently well known to assert that they are not red or green or blue, in fact that the nervous elements in question display no colour in virtue of their being stimulated; the white or grey the nerve cells exhibit whether stimulated or not is certainly insignificant in respect of the colour sensation which, in the individual whose nerves they are, accompanies their excitation.

Yet our knowledge of the radiation of the hydrogen atom and of the objective, physical properties of this radiation originated from someone's observing those coloured spectral lines in certain positions within the spectrum obtained from glowing hydrogen vapour. This procured the first knowledge, but by no means the complete knowledge. To achieve it, the elimination of the sensates has to set in at once, and is worth pursuing in this characteristic example. The colour in itself tells you nothing about the wave-length; in fact we have seen before that, for example, a yellow spectral line might conceivably be not 'monochromatic' in the physicist's sense, but composed of many different wave-lengths, if we did not know that the construction of our spectroscope excludes this. It gathers light of a definite wave-length at a definite position in the spectrum. The light appearing there has always exactly the same colour from whatever source it stems. Even so the quality of the colour sensation gives no direct clue whatsoever to infer the physical property, the wave-length, and that quite apart from the comparative poorness of our discrimination of hues, which would not satisfy the physicist. *A priori* the sensation of blue might conceivably be stimulated by long waves and that of red by short waves, instead of the other way round, as it is.

To complete our knowledge of the physical properties of the light coming from any source a special kind of spectroscope has to be used; the decomposition is achieved by a diffraction grating. A prism would not do, because you do not know beforehand the angles under which it refracts the different wave-lengths. They are different for prisms of different material. In fact, *a priori*, with a prism you could not even tell that the more strongly deviated radiation is of shorter wave-length, as is actually the case.

The theory of the diffraction grating is much simpler than that of a prism. From the basic physical assumption about light – merely that it is a wave phenomenon – you can, if you have measured the number of the equidistant furrows of the grating per inch (usually of the order of many thousands), tell the exact angle of deviation for a given wave-length, and therefore, inversely, you can infer the wave-length from the 'grating constant' and the angle of deviation. In some cases (notably in the Zeeman and Stark effects) some of the spectral lines are polarized. To complete the physical description in this respect, in which the human eye is entirely insensitive, you put a polarizer (a Nicol prism) in the path of the beam, before decomposing it; on slowly rotating the Nicol around its axis certain lines are extinguished or reduced to minimal brightness for certain orientations of the Nicol, which indicate the direction (orthogonal to the beam) of their total or partial polarization.

Once this whole technique is developed, it can be extended far beyond the visible region. The spectral lines of glowing vapours are by no means restricted to the visible region, which is not distinguished physically. The lines form long, theoretically infinite series. The wave-lengths of each series are connected by a relatively simple mathematical law, peculiar to it, that holds uniformly throughout the series with no distinction of that part of the series that happens to lie in the visible region. These serial laws were first found empirically, but are now understood theoretically. Naturally, outside the visible region a photographic plate has to replace the eye. The wave-lengths are inferred from pure measurements of lengths: first, once and for all, of the grating constant, that is the distance between neighbouring furrows (the reciprocal of the number of furrows per unit length), then by measuring the positions of the lines on the photographic plate, from which, together with the known dimensions of the apparatus, the angles of deviation can be computed.

These are well-known things, but I wish to stress two points of general importance, which apply to well-nigh every physical measurement.

The state of affairs on which I have enlarged here at some length is often described by saying that, as the technique of measuring is refined, the observer is gradually replaced by more and more elaborate apparatus. Now this is, certainly in the present case, not true; he is not gradually replaced, but is so from the outset. I tried to explain that the observer's colourful impression of the phenomenon vouchsafes not the slightest clue to its physical nature. The device of ruling a grating and measuring certain lengths and angles has to be introduced, before even the roughest qualitative knowledge of what we call the objective physical nature of the light and of its physical components can be obtained. And this is the relevant step. That the device is later on gradually refined, while remaining essentially always the same, is epistemologically unimportant, however great the improvement achieved.

The second point is that the observer is never entirely replaced by instruments; for if he were, he could obviously obtain no knowledge whatsoever. He must have constructed the instrument and, either while constructing it or after, he must have made careful measurements of its dimensions and checks on its moving parts (say a supporting arm turning around a conical pin and sliding along a circular scale of angles) in order to ascertain that the movement is exactly the intended one. True, for some of these measurements and check-ups the physicist will depend on the factory that has produced and delivered the instrument; still all this information goes back ultimately to the sense perceptions of some living person or persons, however many ingenious devices may have been used to facilitate the labour. *Finally* the observer must, in using the instrument for his investigation, take readings on it, be they direct readings of angles or of distances, measured under the microscope, or between spectral lines recorded on a photographic plate. Many helpful devices can facilitate this work, for instance photometric recording across the plate of its transparency, which yields a magnified diagram on which the positions of the lines can be easily read. But they must be read! The observer's senses have to step in eventually. The most careful record, when not inspected, tells us nothing.

So we come back to this strange state of affairs. While the direct sensual perception of the phenomenon tells us nothing as to its objective physical nature (or what we usually call so) and has to be discarded from the outset as a source of information, yet the theoretical picture we obtain eventually rests entirely on a complicated array of various informations, all obtained by direct sensual perception. It resides upon them, it is pieced together from them, yet it cannot really be said to contain them. In using the picture we usually forget about them, except in the quite general way that we know our idea of a light-wave is not a haphazard invention of a crank but is based on experiment.

I was surprised when I discovered for myself that this state of affairs was clearly understood by the great Democritus in the fifth century B.C., who had no knowledge of any physical measuring devices remotely comparable to those I have been telling you about (which are of the simplest used in our time).

Galenus has preserved us a fragment (Diels, fr. 125), in which Democritus introduces the intellect (διάνοια) having an argument with the senses (αἰσθήσεις) about what is 'real'. The former says: 'Ostensibly there is colour, ostensibly sweetness, ostensibly bitterness, actually only atoms and the void', to which the senses retort: 'Poor intellect, do you hope to defeat us while from us you borrow your evidence? Your victory is your defeat.'

In this chapter I have tried by simple examples, taken from the humblest of sciences, namely physics, to contrast the two general facts (*a*) that all scientific knowledge is based on sense perception, and (*b*) that none the less the scientific views of natural processes formed in this way lack all sensual qualities and therefore cannot account for the latter. Let me conclude with a general remark.

Scientific theories serve to facilitate the survey of our observations and experimental findings. Every scientist knows how difficult it is to remember a moderately extended group of facts, before at least some primitive theoretical picture about them has been shaped. It is therefore small wonder, and by no means to be blamed on the authors of original papers or of text-books, that after a reasonably coherent theory has been formed, they do not describe the bare facts they have found or wish to convey to the reader, but clothe them in the terminology of that theory or theories. This procedure, while very useful for our remembering the facts in a well-ordered pattern, tends to obliterate the distinction between the actual observations and the theory arisen from them. And since the former always are of some sensual quality, theories are easily thought to account for sensual qualities; which, of course, they never do.