STATEMENTS IN PHYSICS[1]

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STATEMENTS in physics are statements in physics. They are not statements connecting physical data with non-physical conclusions.

Statements in physics are usually either true or false. Statements connecting physical entities with non-physical ones are usually neither true nor false but senseless.

Simple examples of such arguments can be taken from a field more limited and less involved than physics: elementary arithmetic.

Here, the statement $2 + 1 = 3$ is true; the statement $2 + 1 = 4$ is false; the statements $2 + 1$ are green, or virtuous, or a solid body, are senseless.

This distinction is sometimes less obvious if the statement is given in the form of a conclusion. For example: if $1 + 2 = 3$, then $2 + 4 = 6$ is a true statement; if $1 + 2 = 3$, then $2 + 4 = 7$ is a false statement; if $1 + 2 = 3$, then space has three dimensions, is a senseless statement, and it is senseless quite independent of the question whether space really has three dimensions or not.

Senseless statements of this type have been made regularly during the last half-century with reference to physical entities; and it is just these statements which have usually made the greatest impression on non-scientists, and even on occasions on scientists themselves. Thirty or forty years ago, when the phenomena of radioactivity were first investigated, it was found that it was not possible to predict whether a single defined particle of a radioactive material would decay within a given period, and that only statistical judgments could be made with precision. At that time, and for years thereafter, and even quite recently, one could hear the argument: as it is, in principle, impossible to predict how an individual particle of a substance will behave at a given moment, therefore the law of causality is not valid—a typical statement of the kind which is neither true nor false but senseless, and this quite apart from its inherent paradox.

Similar arguments were heard nearly every time that a new

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[1] A paper read before the Aquinas Society, Cambridge, on 8th February 1956.

scientific discovery concerning elementary particles was made. A great many of them were based on the fact that for a number of problems only statistical methods are applicable; and an hypothesis like the principle of indeterminacy which says that either the position or the velocity, but not both, of an elementary particle can be determined at the same time, led to pronouncements about causality, apperception, free will, and even theology, all at least formally senseless.

Statements of this type have not been limited to nuclear physics. Only a few years ago an eminent Cambridge astrophysicist gave a series of broadcast lectures on astronomy, and in particular on current theories concerning distant galaxies. One of his arguments which later received great publicity, ran approximately as follows:

'Matter of the distant nebulae is continuously disappearing from the observable part of astronomical space. Our theories and equations require a constant amount of matter within this space.' Both of these statements may be true or false, but the conclusion drawn from them was: 'Therefore matter is created continually'; and this again is a statement which is neither true nor false.

It will now be asked: what are statements in physics? I propose to define: 'Statements in physics are quantitative descriptions of material events.'

Quantitative descriptions; not moral descriptions, not artistic descriptions, and generally not qualitative descriptions.

The physicist may do work on electromagnetic oscillations, and he may one day investigate such an oscillation with a wavelength of 5200 Angstrom units. He may know that this wavelength is the wavelength of green light, but he should be aware that any statement whatsoever which he may make about this oscillation will not teach him anything about the specific quality of the colour green; and an electromagnetic oscillation with a wavelength of 6500 Angstrom units will not teach him anything about the quality of the colour red, although he may have found that this wavelength corresponds to just that colour.

In a slightly different sense: he may even investigate the electromagnetic oscillation with the wavelength of 1500 metres, find that this is the wavelength of the B.B.C. Light Programme, and still not be able to pass any judgment on the quality of that programme.

In general, the confusion between a quantitative description and a qualitative judgment can sometimes have rather grave consequences. I think one of the most extreme examples came from that branch of physics concerned with the quantitative description of the functions of the human body, usually called physiology. Many will have heard the statement—pronounced not only by physiologists—'Thinking is a movement of the brain cells', which is quite analogous to the statement 'Green is the electromagnetic oscillation of wavelength 5200 Angstrom units.'

The definition, 'Quantitative descriptions of material events', refers of course only to physics (obviously including chemistry and astronomy) as it has been understood during the last few hundred years. There are certainly other types of science imaginable which admit qualitative description, and it is a fact that a science of this type has been in existence for far longer than our modern physics, for many hundreds if not thousands of years; it was and is known by the name of alchemy.

In alchemy qualitative data and descriptions are essential and significant. In that science a White Lily means something fundamentally different from a Black Lily, and one must not confuse under any circumstances a Red Lion with a Green Man. The alchemist has, in contrast to the modern scientist, the perfect right to make statements connecting his alchemical processes with colour or thought, or even creation. His data and arguments may be false, may even appear absurd, but they are not logically senseless, they are not what some modern scientists may be tempted to call 'utter nonsense'.

However, for us as modern physicists or contemporaries of modern physicists, the definition 'quantitative descriptions' provides another set of useful limitations. As every schoolboy knows, the infinitely small and the infinitely great cannot be treated according to the normal rules of arithmetic, they are not quantities within their meaning. Quantitative descriptions have therefore to be applied with great care when referring to very great and very small objects, and become contradictory when applied to infinite entities, for instance areas of space extended beyond measure. What may happen, and will, if one is not aware of this rule, could be seen a few months ago when an article by a former Astronomer Royal, dealing with observations on distant nebulae, was published in a London evening paper, and the headline, probably added by a sub-editor, pronounced in letters two inches high spread over the whole page: 'The universe is getting bigger'.

Statements in physics are quantitative descriptions of material events. What do we understand by material events? I do not intend here to go into the philosophy of *materia prima* and forms; but it is at least necessary to be aware that matter can appear under various forms, and that of course form does not only mean shape.

Probably the simplest and most obvious definition, not of matter perhaps, but of the adjective 'material', is to say, 'material is everything which we perceive by our senses'. So formulated, the feeling of heat or of an electric shock is as material as the feeling of a solid body. It would be wrong, I fear, to deduce from this fact that the equivalence of mass and energy must have been obvious to the philosopher before the physicist discovered it. There is however no reason why the philosopher should be surprised about the fact as such once he is told of it by the physicist. It must certainly be understood that I am not considering solid, liquid or gaseous bodies only if I speak of 'material'.

In order to get some understanding of the different forms under which matter may appear to the physicist, it is useful to compare matter as we normally see it with those forms of matter investigated by the nuclear physicist; let us call them super-atomic and sub-atomic matter. A great number of apparent paradoxes well known in either field may be solved by clear definitions.

The first apparent paradox refers to the atom as used in classical physics, and I suppose that nearly everybody, at least of the older generation, has worried about it for some time. We know that the atom gets its name from being considered as the indivisible particle, the elementary brick from which matter is built; but we also know that everything extended in space can by definition be further divided, and that the atom has extension in space.

The solution can be found by an analysis of that often heard half-benevolent and half-ironical utterance of contemporary physicists—and not physicists only—speaking about nineteenth-century scientists: 'They treated atoms as if they were billiard balls'.

Now, what is the function of a billiard ball? Obviously to serve for a game of billiards. Billiards can be played with many different numbers of balls. Snooker generally starts with twenty-one, and the number diminishes during play. Continental billiards is played with three balls, and this number remains constant. There is no reason why billiards should not be played with more than twenty-one balls, if the table is large enough; and one can still play it with one ball only, as frequently happens at the end of a game of snooker. But what is the position if I divide the billiard ball into several parts, or, in modern idiom, split it? No doubt, there is still something material present, but I definitely cannot play billiards with it any longer. I may put the parts of the ball to different uses, may even turn smaller spheres out of them, but whatever I do, they remain of no use for a game of billiards. The billiard ball is, in effect, the atom for a game of billiards. It has extension, is divisible, and is still an atom.

This argument gives an analogy to what happens if we pass from super-atomic to sub-atomic particles. Of whatever form the sub-atomic particles are, we cannot expect to use them for a super-atomic game. In this way, our analogy offers an immediate reply to some of the paradoxes which beset a physicist engaged in nuclear research. For example, he may be working with the mental picture of an atom model where electrons move in fixed orbits round a nucleus. His theory requires that under certain conditions one electron may pass from one orbit into another but explicitly does not admit the question how this happens.

Obviously the whole paradox is only an apparent one and arises because the physicist suddenly treats the sub-atomic particles as if they were super-atomic ones. Remembering our analogy, we feel he is most unreasonably surprised that he cannot play billiards with the parts of a billiard ball.

A similar apparent contradiction is found in the modern theory dealing with radiation, according to which radiation appears under one aspect as a wave, under another as a corpuscle. That there is a strict difference between these two concepts in macroscopic physics does not necessarily mean that their equivalence in sub-atomic physics is a paradox. As in the case of mass and energy the discovery of the quantitative relationship has to be established by the physicist, but their equivalence does not represent any difficulty to analytical thought. That sub-atomic particles behave quite differently from macroscopic super-atomic, terrestrial, or celestial bodies is not necessarily paradoxical.[2]

We ask next: first, what quantities are used in physics, and secondly, what is described by means of them? A simple quantitative description is: 'Two apples and three apples are five apples', and this is a genuine physical statement. It may even be expressed as an 'event' by saying: 'If I have two apples and somebody comes and adds three apples, then I shall have five apples'.

It must be noted that even this simple statement is only possible by an act of abstraction, by understanding what is meant generally by 'apple' as distinct from a single given apple. By increasing abstraction it is even admissible to say 'Two apples and three pears are five pieces of fruit'. Generalization, or, if the expression is preferred, the use of universals, takes place at a very early stage of physical science.

Of course, the usual statements with which the physicist has to deal are much more complicated than simple arithmetical operations, and rather complex concepts are introduced in order to make physics possible. While many of these entities were originally connected with direct human experience, the general trend has been to free physics more and more from anthropomorphical concepts.

By the end of the last century it was discussed for the first time whether one should use the physical concept of 'force' at all. As even non-physicists may remember, one of the fundamental formulae of mechanics is expressed as 'force = mass × acceleration'; and originally this 'force' was identified with the force we as human beings apply to move a heavy object.The Germany physicist Heinrich Hertz wrote before the end of the last century a

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[2] We have defined 'material' as everything perceptible by the senses, and this means that the events to be described quantitatively occur in time and space. We might therefore just as well have said from the beginning: 'Statements in physics concern movement'. Our task would then have been to show what is meant by description of movement, arriving in the end at the original formula. Both definitions can be considered as equivalent.

complete textbook of mechanics just to demonstrate that it is not necessary to use this concept of force at all, and it appears that during this century physicists have more and more turned away from anthropomorphical concepts and analogies.

There are exceptions to this rule, particularly in textbooks for students, where even today preferences for anthropomorphisms may be found. It may be that the authors see pedagogical advantages in this method.

Within a short paper it is not possible to come to a really satisfactory analysis of the principal physical concepts such as mass, energy, power, momentum, etc. I can only point to the fact that their consideration as quantities requires a considerable widening of the concept of quantity. This process is analogous to that which takes place in mathematics when one passes from pure geometry to calculus, from a static to a dynamic consideration of configurations. The same progression has happened in physics; in the terminology of the Neo-Kantians we have passed from substances to functions, and even sometimes to functions of functions.

If within a system of this type we speak of force or mass or energy, we are well aware that each of these quantities gets its definition and sense from a functional relation. The greatest distance from anthropomorphic pictures is reached if the theoretical physicist is mainly interested to know what functions of his functions are invariant from any change of systems of co-ordinates, whatever their respective movements may be. This happens in the higher reaches of the theory of relativity, which should nowadays rather be called the theory of invariance.

Our second question was: what do we describe by means of quantities of this type, and what is the purpose of this description? The answer is that we want to describe relations with the purpose of predicting future events. How is this done?

In a limited sense even such a simple physical statement as 'Two apples and three apples are five apples' is a prediction of a future event, as at every time and at any place that three apples are added to two apples the result will always be five apples. For most physical statements, however, a more complicated relationship is required. The scientist not only wants to be able to predict what will happen because he knows that an identical fact has previously happened. He also wants to predict what will happen by combining a number of causes not previously combined. Inversely, if he discovers some new facts he wants to know why they have happened, i.e., find the causes. Thereafter, he expects that the same thing will happen again under the same circumstances.

The method of achieving this result consists in forming in our mind a model picture of the event, making mental experiments within this picture, and expecting then that the results will correspond to the facts later verified by experiments. In the words of Henri Poincaré, our pictures of events are then correct if the consequence of the pictures is a picture of the consequences.

These pictures are working hypotheses and nothing can be said about their absolute truth. Model pictures which have done excellent service in the past are now not considered admissible and have been discarded. Maxwell developed his electro-magnetic theory by means of the assumption of an ether filling empty space, and his equations are still valid today, although we no longer assume the existence of the ether. In nuclear physics important discoveries have been made by means of the assumption that a mechanical model of an atom is possible; but we may now be allowed to think that an atom cannot be represented mechanically.

It is understandable under these circumstances that physicists prefer to speak of 'right' assumptions rather than of 'true' ones; but once relations are established it may be said that they are true or at least a better approximation to the truth than others formerly held. Maxwell's equations may be called true although the concept of an ether is not accepted any longer, and even his equations may be only an approximation to be corrected at a later date.

The concept of truth within physics is therefore a purely pragmatic and relative one. Within physics logical positivism reigns—not very surprisingly if it is remembered that logical positivism has its roots in science.

But is it really necessary to consider two sets of relations or functions as equivalent, if each gives a satisfactory answer why certain causes have certain effects and permits the precise prediction of what will happen if a number of these causes are combined? Or must one distinguish what relations, which theory, is to be accepted if there are two different ones, each of which gives the same satisfactory results?

This is not an empty question; on the contrary, one theory being preferred to another and superseding it is just what happens in physics continually on a small scale and from time to time on a large scale. It happened on the largest scale when the modern physical picture of the world superseded the ancient one.

The two fundamental theories which come first to mind if the difference between ancient natural science and modern physics is discussed are: the law of inertia in mechanics and the substitution of the heliocentric for the geocentric system in astronomy.

Both theorems are supposed to give solutions of ancient problems by modern methods. How is this done?

The law of inertia says that a solid body free from external forces will move with uniform velocity in a straight line. Has any person ever seen a body moving in this way? No laboratory experiment showing a body behaving even approximately as required for such a demonstration could possibly be performed. On the other hand, free rotational movement can be shown in good approximation without the slightest difficulty. One simply puts a wheel with good bearings on an axis, pushes the wheel slightly, and the rotational movement may go on for minutes, hours, or days. Why is it that, in spite of this experience, uniform movement in a straight line is considered a simple fundamental law of mechanics, and rotational movement a result of complex conditions?

Furthermore, rotation as a natural phenomenon is discovered by observation of the fixed stars and other celestial bodies, while no movement of the earth is felt by the senses; why, then, was the geocentric system in astrophysics superseded by the heliocentric one?

The answer to this second question cannot simply be that with the heliocentric system the movements of planets, the phases of the moon and eclipses may be predicted and the correct date for Easter calculated. These could be and have been predicted with great precision by the assumption of the independently rotating spheres of the Aristotelian cosmology. If one presumes 60 to 70 spheres each rotating with a constant angular velocity, all the stellar movements known until a few centuries ago can be explained; and in order to provide for the additional ones which were discovered at a later date, one would simply have to introduce a few more spheres.

Why then is it said nowadays that this picture, this model of the universe, is unacceptable, and that the one initiated by Copernicus when he put the sun into the centre, quantitatively described by Kepler and finally unified by Newton with his law of gravitational attraction, is to be preferred? Is one picture really 'truer' than the other?

The first, the geocentric theory, requires a great number of independent assumptions; the second, the heliocentric theory, reduces everything to one central hypothesis, the law of gravitational attraction. The difference between the structure of the two theories is that between multiplicity and unity, between the use of uncoordinated hypotheses and the achievement of unification. This same distinction also explains why the by no means evident or easily demonstrated law of inertia is to be adopted as the fundamental theorem of mechanics. With this theorem of uniform rectilinear movement a unification of mechanics is achieved such as would not be possible by taking the rotational movement so easily observable in the sky and so easily reproduced in the laboratory as the fundamental principle. The power of the law of inertia is not that it solves some problems such as the ancient question why an arrow continues moving through the air after being shot by the bow; it might just have been invented for an *ad hoc* explanation of the arrow's flight. It is accepted because of its power of unification.

Why are unity and simplicity taken as criteria of physical truth? Various reasons may be given. Reference may be made to Ockham's razor, that often quoted and slightly worn formula about the economy of hypotheses, known to St Thomas a hundred years before him, as Fr Gilby recently pointed out. A belief in harmony, pre-established or otherwise, Kant's synthetic unity of apperception, or even pantheism might be given as further reasons.

There are a sufficient number of arguments why the unified picture is preferred to the multiple one. But all these reasons have one thing in common: they are not statements in physics, they are all statements beyond the field of physics, they are all metaphysical.

Furthermore, one can even think of two different theories, or sets of pictures, of fundamental physical phenomena, both achieving further unity in physics, both equally satisfactory, and both mutually exclusive; and this is not a vain speculation, but may happen at any time, is possibly happening just now.

Today it appears quite possible that the quantum theory and the field theory, one treating physical matter as discrete particles, the other conceiving it as a mathematical continuum, will have to be considered as just such a pair of equivalent suppositions. Again, to decide for either concept would not be possible within the boundaries of pure quantitative science. It would be necessary to go beyond physics, to metaphysics.

Thus it may be seen that precisely by accepting—possibly modified—logical positivism within physics, the concept of physical truth receives its sense only in metaphysics.

While it must be insisted that conclusions about metaphysical entities derived from physical data are senseless, recourse must be made to metaphysics in order to give sense to the concept of truth in physical statements.

Does this mean that physics cannot teach us anything about metaphysics? Certainly not. By applying metaphysical criteria to the problems of natural science our definitions and propositions may have to be reconsidered, our conclusions made more precise, and, all the time, our connection with earthly matters maintained.

One last question: Is it possible, could it happen, that one day, when a choice between two sets of equivalent physical propositions had to be made, an analogous ambiguity in metaphysics might be revealed? And if this happened what means would there be to decide the matter?

Here I have come to the end of this present paper, and with good reason. Because, whatever the replies to these last questions might be, one thing is certain: they would not be 'Statements in Physics'.