HAVE WE ABANDONED THE PHYSICAL THEORY OF NATURE? *

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"Our business is with the causes of sensible effects."
NEWTON

The Greek philosophers showed that in the study of Nature there were three fundamentally different theories which could be put forward to account for the obvious and extensive characteristics of *stuff* and *change*: the physical, the mathematical, and the functional theories.

Thales noticed that Nature is composed of objects which have the quality of permanence, and Heraclitus emphasised that Nature contains change. The principle that Nature consists of permanent objects and change is the principle that the Universe is physical. Parmenides then proceeded to analyse change, and pointed out that it must be due to generation or motion. But generation is incompatible with this principle which involves eternal objects which do not change their properties. Change, therefore, must be due to motion. Parmenides went on to argue that motion was impossible if the Universe consisted only of 'stuff,' for motion requires that a body may move from where it is to where it is not, and there would be no where-it-is-not. In this, he, and those who followed him, were mistaken, for *cyclic* motion would be possible. However, all motion became possible when Leucippus and Democritus made the 'stuff' many and not one, and added the spatial characteristics of Nature, which they called the "void," thus laying the foundation of what later became the kinetic atomic theory, together with absolute space, in a form which has remained unchanged until recent times. This theory is the *physical theory* of Nature. The

* The substance of a lecture given to the Royal Institute of Philosophy, October 1955.

extensive fact of Nature—stuff—is accounted for by eternal atoms, and the extensive fact of change is accounted for by the movement of these atoms, and the movement is possible because they are in absolute space.

The *mathematical theory* owed its origin to Pythagoras and Eudoxus, and was greatly developed by Plato. Astronomical observation, and study of the musical harmonies of strings and pipes, appeared to reveal perfect geometrical forms and ideal mathematical proportions. These seemed to be the underlying reality, and so Nature was a system of logical and mathematical forms rather than a collection of moving physical atoms; and Plato was led to assert that certain and permanent knowledge is not derived from sensation but from *ideas* which are apprehended by the intuitive reason (*νοῦς*). There are several important consequences of this mathematical theory: firstly, the primary causal importance given to relations; secondly, the distinction between the apparent world of bodies and motion, and the underlying real world of mathematical form; and thirdly, since this underlying world of mathematical relations is not directly observed in Nature, it follows that reason and 'harmony' are better guides to knowledge than experiment and observation.

The third great Greek philosophy arose from the study of living things—the *functional theory*. It is associated with the names of Hippocrates of Cos, Empedocles and Aristotle. Hippocrates was the first to emphasise that a living organism is a mechanical system, and that form, or organisation, is one of its fundamental characteristics. Organisation in living things seems to require form as a cause as well as matter, and, if this is admitted, it means that neither the physical nor the mathematical theory of Nature is satisfactory, since the former only allows material causes, and the latter only formal causes. To solve this problem, Aristotle was driven to postulating a more fundamental and essentially different type of 'stuff,' of which matter and form were attributes. Since the formal aspect of Nature is always changing, it follows that this more fundamental substance must also change its properties. It was in this way that Aristotle was led to the functional theory and the principle of 'becoming,' *i.e.* the principle that what is real in Nature changes its properties. This, of course, is the opposite of the principle of 'being,' which asserts that what is real in Nature is fixed and unchangeable, and is involved in both the physical and mathematical theories. Mechanical causation cannot, for instance, appear in the functional theory, since what is real in Nature is continually changing its properties, and, in order to make forecasts, we should have to know final as well as present conditions and thus become entangled in teleology.*

In what follows, it will not be necessary to refer to the functional theory of Nature, although a modern form of it has been powerfully advocated by Whitehead. We shall be concerned with the competition between the physical and mathematical theories which has taken place since ancient Greek times. For, although Aristotle dominated later medieval thought, there was always an undercurrent of neo-Platonism, so that the mathematical theory of Nature was not quite eclipsed. Nicholas of Cusa (1401–64), for instance, held that the world was an infinite harmony, in which all things have mathematical proportions, maintaining that knowledge is always measurement, and "number is the first model of things in the mind of the Creator." Similar ideas can be found in Bruno's works. Kepler, too, thought of the underlying mathematical harmony, discoverable in astronomical observations, as the cause of them, the reason why they are as they are, but he differed from his predecessors in emphasising that this causal harmony must be verified accurately by observation. This was probably due to his association with that great observer, Tycho Brahe, as is also his opinion that laws of thought, which are a divine gift, cannot lead us to knowledge of themselves: there must be observable motions to supply the material for their exact exemplification.

Galileo, also, was intoxicated by mathematics, and called it the queen of the sciences; he regarded confirmation by experiment as only "necessary for conclusions into whose necessary and rational basis we can have no immediate intuition" (*Opere* IV, 189). His success in introducing number and geometry into the motion of earthly bodies (the heavenly bodies had been assumed to have constant speeds since the cause (God) is "constant and unremitting," and hence the effect must be uniform) caused him to think that the primary qualities of bodies were only those which could be completely expressed mathematically, *e.g.* number, figure magnitude, position and motion. All other qualities, and these are often more prominent to the senses, are secondary effects of the primary.

Adopting the atomic theory, Galileo was led to the physical theory of Nature, namely that the world consisted of eternal atoms moving in space and time according to mathematically expressible laws.

* For a fuller account of these three theories, *see* F. S. C. Northrop, *Science and First Principles*, C.U.P. (1931), and for a summary with examples taken from the work of Eddington and others, *see* "Modern Physics and the First Principles of Science," Science Progress, **27**, 256 (1932).

These ideas caused Hobbes to try to reduce everything, thought included, to bodies and motions, and he was the first to restate clearly that the motion of bodies was the cause of all change.

It is interesting to note how *space* has increased its stature since Greek times. The Greek merely called it the "void"—nothing; but it became more and more prominent as the background of the motions of bodies that were the causes of everything, and Descartes' emphasis on extension as the fundamental character of a body also enhanced its importance, until we find More, in his *Enchiridion*, listing 20 different attributes of space that were shared with God (immobile, eternal, perfect, necessary, immense, incomprehensible, etc.).

With the appearance of Newton, the physical theory of Nature finally became dominant and was placed on a firm foundation, the position of mathematics being solely that of a method for the solution of problems which arise from sensible experience of the natural world.

The *Principia* preface gives us clearly Newton's view of scientific procedure: "all the difficulty of philosophy seems to consist in this—from the phenomena of motions to investigate the forces of Nature, and then from these forces to demonstrate the other phenomena." The word demonstrate here means mathematical demonstration, and this passage shows clearly that Newton regarded mathematics as a useful tool in science. He did not in the least share the beliefs of Kepler, Galileo and Descartes that the world was essentially mathematical, and in his *Universal Arithmetic* he even suggests that there may be problems that cannot be dealt with mathematically. As Prof. E. A. Burtt says in his admirable *Metaphysical Foundations of Modern Science*, this would have been "a hideous heresy to Galileo and Descartes . . ." (Newton) "was little interested in mathematical reasonings which were not destined for application to physical problems: they were essentially a helpful tool in the reduction of physical phenomena."

Newton's view of the ultimate goal of science was expressed in the often quoted passage:

"I wish we could derive the rest of the phenomena of Nature by the same kind of reasoning from mechanical principles, for I am induced by many reasons to suspect that they may all depend upon certain forces by which the particles of bodies, by some causes hitherto unknown, are either mutually impelled towards one another, or are repelled and recede from one another. These forces being unknown, philosophers have hitherto attempted the search of Nature in vain; but I hope the principles here laid down will afford some light either to this or some truer method of philosophy."

Here we find expressed a belief in a mechanical explanation of Nature, that is to say, an explanation in terms of unchangeable material particles whose structures and motions could be described in the language of geometry, together with the forces, or interactions, between them. All changes in Nature are to be regarded as separations, associations, and motions of permanent atoms, to whose properties of extension, hardness, impenetrability and mobility, Newton added inertia and, possibly, gravity.

This is the physical theory of Nature, and, after Dalton had re-established the atomic theory and firmly founded chemistry upon it, it became the dominant theory.

Is this physical theory the dominant theory today, or is it not? In order to estimate the present position, we must first consider briefly the re-emergence of the mathematical theory of Nature in its new form, and we can then go on to discuss the important question as to whether it is likely to advance or destroy Western science.

Newton's authority, and his refusal to enquire into the mechanism of gravitational attraction, probably prevented speculation in this subject, but, in the case of electromagnetism and optics, the question of a medium which would transmit effects from one body to another attracted more and more attention. The many similarities between the behaviour of waves of sound and the hypothetical waves of light made the consideration of an ether inevitable. It soon became evident, however, that the ether must be assumed to have properties very unlike those of known material substances, and thus arose the temptation to treat it in a very general way without attempting to describe its exact mechanical action. This was possible because of the invention of the term *energy*, which was, of course, quite unknown to Newton. The mathematical function *potential*, which later became potential energy, was invented by Lagrange solely to make calculations from Newton's law of gravitation easier. Later the function *kinetic energy* was added,* and also *action*. With the help of these functions, mechanical problems can be dealt with in a very general way, without a precise consideration of forces, positions and motions at every instant. Green, in 1838, makes his excuse as follows: † "... we are so perfectly ignorant of the mode of action of the elements of the luminiferous ether on each other, that it would seem a safer method to take some general

* Sir Edmund Whittaker says *kinetic energy* first appeared in an article by W. Thomson and P. G. Tait in *Good Words*, edited by Charles Dickens, October 1862.

† *Mathematical Papers*, p. 245, Paris (1903). Quoted from Mary B. Hesse, "Models in Physics," *Brit. J. Phil. Sci.*, IV, 206 (1953).

physical principle as the basis of our reasoning, rather than assume certain modes of action, which, after all, may be widely different from the mechanism employed by nature; more especially if this principle . . . lead to a much more simple process of calculation."

MacCullogh, the Irish mathematical physicist, was very frank about the mathematical function he invented to deal with the optical properties of the ether: "If we are asked," he wrote, "what reasons can be assigned for the hypotheses on which the preceding theory is founded, we are far from being able to give a satisfactory answer. We are obliged to confess that, with the exception of the law of *vis viva*, the hypotheses are nothing more than fortunate conjectures. These conjectures are very probably right, since they have led to elegant laws which are fully borne out by experiments; but this is all we can assert respecting them. We cannot attempt to deduce them from first principles; because, in the theory of light, such principles are still to be sought for. It is certain, indeed, that light is produced by undulations, propagated, with transversal vibrations, through a highly elastic æther; but the constitution of this æther, and the laws of its connection (if it has any connection) with the particles of bodies, are utterly unknown." *

Here we may notice the suggestion that conjectures are probably right if they lead to elegant laws which are fully borne out by experiments, and also the dogmatic tone, so common among those mathematically minded, of the assertion that light is certainly produced by undulations in a highly elastic ether. The cautious attitude of Newton is already being abandoned.

Airy went a step further † in referring to his mathematical equations as not "giving a mechanical explanation of the phænomena, but as showing that the phænomena may be explained by equations, which equations appear to be such as might possibly be deduced from some plausible mechanical assumption, although no such assumption has yet been made."

In this passage we have the statement that physical phenomena can be *explained* by equations (mathematical relations). This is far removed from Newton's insistence that phenomena depend upon *forces* exerted by *bodies*, and it is to this period in the history of science that we may look, perhaps, as the time when the mathematical theory of Nature—that mathematical relations are causes—re-emerged and proceeded to grow.

* Quoted from Whittaker, *A History of the Theories of Æther and Electricity*, **1**, 138.

† Airy, *Phil. Mag.*, **28**, 469 (1846).

The effect of the theory of relativity, especially as advocated by Eddington, in supporting the mathematical theory of Nature is well known, and need not be treated in any detail. Instead of drawing physical conclusions from the null-result of the Michelson-Morley experiment, such as contraction of material bodies with motion, or inferring that the ether did not exist so that we have action-at-a-distance, Einstein wrote down the condition that the velocity of light should always be *measured* to be the same by differently moving observers, and this he treated as a postulate. The equations obtained (the Lorentz transformations) showed how the observers' measurements must be supposed to be related for this to be the case. But no mention was made of any forces which would cause the instruments to read differently, the clocks to go slow, and so on, and we were left once more with nothing but mathematical relations together with pseudo-epistemology, involving a lot of hypothetical observers attached to anything from an electron to a galaxy. But the physical universe is the supposed external cause of the sensations, and is there even if no observers are alive to enjoy the sensations or make any measurements. The relations between measurements made by observers are derived as *conclusions* from a genuine physical theory, they cannot be *postulates*, for physics is concerned with what the observers *observe* and the measurements *measure*. The emphasis on metrical observations caused Eddington to say that all a physicist needs is one colour-blind eye —just to read the pointers of instruments with. Then, going one step further, he maintained that our exact knowledge of the physical universe is only metrical knowledge, and this forced him to redefine the physical universe as "the world which physical knowledge is formulated to describe" * which is, as he said, an epistemological definition, and finally he made the truly astounding claim "that the fundamental laws and constants of physics are wholly subjective, being the mark of the observer's sensory and intellectual equipment on the knowledge obtained through such equipment: for we could not have this kind of *a priori* knowledge of laws governing an objective universe." † Thus, by restricting the sensations to those of a colour-blind eye reading a *number* on a dial, Eddington gave powerful reinforcement to the mathematical theory of Nature.

Sir James Jeans even asserted that the Great Architect of the Universe was a mathematician: "If we want the ultimate truth about the universe or its constituents, we must go to the mathematician," he said. If we ask what is the ratio of the masses of the

* Eddington, *The Philosophy of Physical Science*, p. 159 (1939).
† *Ibid.*, p. 104.

proton and the electron, we can take Eddington's word for it, since : "the methods of the mathematician can give us a full and final answer, while those of the experimentalist only give a partial answer. . . . In brief, we live in a mathematical universe." * Thus mathematics became once more enthroned as the queen of the sciences, and physicists were directed, not to say pushed, into a back seat.

In microscopic physics—that dealing with the atom and the nucleus—the method of being guided by mathematical conceptions without any physical meaning, which, as we have seen, can be traced back to the early part of the last century, has been greatly extended. Present-day mathematical physicists have abandoned any attempt at causal explanation : they are satisfied if, by analogy and mathematical artifice, they can produce a formula which gives a correct relation between experimental measurements ; and which, when suitably interpreted in physical terms, may be said to predict the existence of some particle or interaction in the physical world. Needless to say, considerable latitude exists in the process of interpretation, and many of the conclusions are manifestly absurd or involve infinities. Consequently such few predictions as may be said to have been verified do not carry conviction.

Some mathematicians, it is true, have been partly aware of the dangers of the mathematical theory of Nature : Poincaré, for instance, said : "The mathematical method, by its apparent rigour and inflexible course, often inspires in us a confidence nothing warrants and prevents our looking about us." † Eddington, too, felt bound to admit : "In one sense deductive theory is the enemy of experimental physics." ‡ Physicists have, for the most part, remained silent, but Rutherford was characteristically outspoken ; of Planck's work he said : "I was rather struck in Brussels by the fact that Continental people do not seem to be in the least interested to form a physical idea as a basis of Planck's theory. They are quite content to explain everything on a certain assumption and do not worry their heads about the real cause of a thing. I must, I think, say that the English point of view is much more physical and much to be preferred." §

* Jeans, Essay in *Scientific Progress*, Allen & Unwin (1936).

† H. Poincaré, *The Foundations of Science*, The Science Press, New York (1929). Quoted from *Scientists are Human* by D. L. Watson, Watts, London (1938).

‡ A. S. Eddington, *Mathematical Theory of Relativity*, 2nd edition, p. 238, C.U.P. (1924).

§ Quoted from P. M. S. Blackett's Rutherford Memorial Lecture to the Physical Society, 1954 (*Year Book of the Physical Society*, 1955).

Turning now, last of all, to cosmology, we have a field in which the temptation to grandiose speculation is almost irresistible, and certainly in recent times it has run riot. Milne constructed a model of the universe built on metrical assumptions which he assumed the actual universe *must* resemble. Why was this ? Because, he claimed, he had built up his model without using any physical hypotheses and had shown it to be unique ! Since this was the only universe that could be conceived by reason it *must* be the actual one. Illusions of this kind, one would have thought, had died with Descartes, but apparently not. According to Professor McCrea, in a very illuminating summary of the present state of cosmology *— " all our physical and mathematical training leads us to seek for *invariants* ; we instinctively consider that the universe must have invariant properties, and that the universe as a whole must certainly be invariant." But, actually, this is only a fashion of the present day, and physicists will probably retort that in the past our theological training led us to seek for *perfection* in celestial matters. And, strangely enough, perfection has reappeared as a principle in cosmological speculations, although the modern authors are probably innocent of theology. Moreover, in order to sustain these ideas of perfection and invariance, some modern astrophysicists do not hesitate to postulate the creation of matter from nothing, a hypothesis for which, it is hardly necessary to add, there is no evidence whatsoever.

This account of the tendencies in the methodology of physics in the last hundred years or so is sufficient to show that the mathematical theory of Nature is being revived. The universe is mathematical, and theories of its behaviour can only be successfully carried out by mathematicians whose status has risen from that of mathematical physicist who calculated conclusions from physical theories (as, for example, Laplace did from Newton's conception of universal gravitation) to that of theoretical physicist who tells the physicist what to find in his experiments. It would be misleading, however, to allow the impression to arise that everything in the mathematical garden is perfect—there are many weeds whose vigorous growth tends to obscure the flowers (Eddington called them " lumber "). Professor André Mercier, in " Fifty Years of the Theory of Relativity " † concludes that the relativistic quantum field-theories are almost certainly not capable of tackling the real problems of nuclear physics and the behaviour of the so-called

* McCrea, " Cosmology," *Phys. Soc. Reports on Progress in Physics*, XVI, 339 (1953).

† Mercier, *Nature*, **175**, 919 (1955).

fundamental particles. Difficulties remain (*e.g.* infinite self-energies) and are inherent in the theory as a whole. Furthermore, the relativistic treatment of systems of material bodies or particles is "more or less Utopian. So one gets the impression that there is some incongruity and some insufficiency in relativistic quantum theory." As regards the unification of our knowledge of electromagnetism and gravitation, Mercier admits that "no unitary theory yet proposed has been definitely recognised as the right one," and then goes on to make a most extraordinary statement for one who has given such a dismal picture of present-day 'theoretical' research, and such an unappetising account of the fruits of 'relativity': "I should like to stress the importance which *reason* has had in the acceptance of the theory of relativity. Here again, excessive positivism has been destroyed. The dignity of pure theoretical speculation has been rehabilitated: not in the form of an arbitrary speculation, but based on a process of the mind with its own justification which I should like to call the 'experience' of the theory."

"Despite these remarks, it is not to be concluded that general relativity has no experimental background whatever. It is not merely an empirical science, though it is not pure mathematics; it is the prototype of that theoretical endeavour which is one of the characteristic features of our scientific century. For this reason, Einstein is largely responsible for the moulding of contemporary thought." He goes on to say that relativity "has saved science from narrow experimentalism, it has emphasised the part which beauty and simplicity must play in the formulation of theories of the nature of the physical world, and it has reinforced the conception of Heinrich Hertz that physics gives only models of that physical reality. But at the same time it has considerably modified the conception, because the models are no longer plainly mechanical: mathematics is the store where models are to be found, so mathematical abstraction is a necessary source even of positive knowledge."

We could hardly have a better picture of the dignified theoretician guided by reason, by beauty, by simplicity, and by experience of the processes of his own mind which are their own justification! The whole history of science condemns this philosophy as fallacious, and yet here are the descendants of the logicians of the Middle Ages proclaiming it again in 1955. Logic itself is still too discredited to be mentioned, but mathematics, another form of logic, is now the "necessary source" of knowledge.

Before considering whether the physical theory of Nature really needs to be abandoned in such a curt fashion, let us look at some present-day examples of the dangers of re-adopting the mathematical theory. First of all, to be fair to the early thinkers who held that mathematical relations were causes, it must bs remembered that they believed in a deity who was the source of everything, and who caused bodies to behave in such a way as to exhibit perfect mathematical relations. Newton, with his physical theory of forces, absolved the deity from the necessity of continually looking after the universe, and only called on him to do the original creation, after which, and after doing a few miracles just to show his power and to keep people on their toes, he had gone into semi-retirement, leaving natural forces to cause the movements of the universe to continue. But if the mathematical theory is to be revived today without a deity, then all hope of causal explanation vanishes, since mathematical relations (equations) do not exert force and cannot cause even a speck of dust to change its motion. As Newton so clearly stated: "Our business is with the causes of sensible effects," and these causes were the forces which particles exerted on one another, and which, in some cases, we can ourselves experience, for we have a special set of deep-seated nerves which allows us to detect force directly. There is no justification for ignoring the information given by this set of nerves and restricting ourselves to that given by one colour-blind eye!

Great emphasis nowadays is placed on a formula's power of *prediction* (when suitably interpreted in physical terms). A mathematical theory should yield an equation which not only produces correct numerical results when properly applied, but which allows, perhaps, the presence of a new particle to be inferred. Prediction, however, is only a heuristic property of a genuine physical theory, whose main business is with causes. We can well imagine that a mathematician might produce a formula that would yield the heights and times of high tide at a given place when suitably interpreted, and which could be used to predict future tides, or which gave the relation between measurements by observers in different places. But it would not *explain* the tides in any causal sense. This, of course, requires a *physical* theory of forces between physical objects. Physics is more than just formula-finding.

Mathematical physicists of today seem to feel this lack of any causal explanation, and many try to overcome it by using causal language when talking of fictions, such as "virtual mesons"—which sound like physical objects but are not. Space-time, again, a purely mathematical conception, is spoken of by many writers as the cause of planetary motions being what they are. Another pitfall for the mathematically minded, who do not keep close to Nature and her ways, is the occurrence of *constants* in physical laws: they are so used to adding constants in their mathematical work that they do not pay enough attention to them. An important example is the gravitational constant G, the occurrence of which in the inverse-square law of gravitation is due to the fact that the inertial mass of a body is about four thousand times greater than its attractive mass. But books by relativists * tell us that the inertial and attractive masses of a body are identical, and that it was Einstein's genius to see this! This is due to overlooking the physical meaning of the constant G.

Another very grave danger consequent upon adopting the mathematical theory of Nature is the subsidiary importance attached to experiment and observation, so that Newton's mistrust of deductive reasoning unless confirmed by experiment, and his continual request for "more experiments" is now called, as we have seen, "narrow experimentalism." Observations are made in order to test theories already conceived rather than to learn Nature's ways. So much is this the case that a recent philosopher of science has declared "In physics, it is no use even beginning to look at things until you know exactly what you are looking for: observation has to be strictly controlled by reference to some particular theoretical problem." † The result of this attitude is a great temptation to find what you are looking for. If the result is not quite what you expect, you think of possible corrections that have been overlooked, and you make these corrections until the result agrees with expectations within the 'probable error.' After that the zeal for correction ceases. But worse than this is the tendency to ignore contrary instances. Extraordinary examples of finding what was expected are the early attempts to prove the formula for the "bending of light" by the Sun. When the eclipse photographs were examined, some of the star images had moved *towards* the Sun, the exact opposite of what was predicted, and others had moved sideways. Hardly any star image had moved radially, but only the radial components were considered; the tangential components, although of similar magnitude, were regarded as accidental errors and ignored. The mean deflections measured changed markedly during the passage of the Moon's shadow, as did the mean directions as well. Moreover, Einstein's formula for the variation of the deflection with distance from the Sun was *assumed* in determining the "scale contents" of the photographic plates, from which the deflections

* *E.g.*, Born: *Einstein's Theory of Relativity.*

† Toulmin: *The Philosophy of Science*, p. 54, Hutchinson (1953).

were derived which were supposed to prove it. With the help of this procedure, and brushing aside other serious difficulties, results were obtained which were held to be "in exact accord with the requirements of Einstein's theory." * Thus what was sought was found. Nowadays it is fairly generally admitted that this prediction has not been proved; and the same is true of the second relativity prediction, the redshift in the spectrum of atoms near bodies of great mass; this has not been proved satisfactorily. That only leaves the third prediction—the movement of the perihelion of the planets. But this was already known and might be accounted for in other ways.† It is not surprising, therefore, that some physicists hold that the general theory of relativity has no real support in observation. But those who think more of the beauty of their mathematics and the processes of their own minds than the beauty and processes of Nature will no doubt continue to keep the theory alive.

The tendency to divide physicists into theoretical physicists and experimental physicists also has serious consequences. The suggestion that observations and experiments should be made by one set of people, and then the results handed on to another set for interpretation and explanation, is one that Bacon made 400 years ago, and is generally regarded as an error in his system. The reason is that when you actually make an experiment and observe what happens carefully, you nearly always find more data presented to you than you had expected from your theory. If you are the theory-maker as well as the observer, you can sometimes see at once that the extra unexpected data invalidate your theory straight away, or would require it to be modified. In any case, you are able to estimate whether the additional data are relevant. But if the experimenter is not the theory-maker, it is difficult for him to say whether the additional data can be safely ignored or not, and the temptation to overlook them, and even not record them, may be quite strong. Theoreticians, too, suffer through their lack of contact with observation and experiment, for they are not able to judge at second hand whether the results prove what they are claimed to show. A simple example is photography. How can a

* *Lick Observatory Bulletin*, No. 346. *Cf.* C. L. Poor, "The Deflection of Light as observed at Total Solar Eclipses," *J. Opt. Soc. Amer.*, **20**, 173 (1930), and for a summary of recent results, *see* M. W. Ovenden, SCIENCE PROGRESS, **40**, 647 (1952). These results, by improved methods, are held to indicate a displacement of the stellar images greater than the predicted value.

† *See* Whittaker, *loc. cit.*, **2**, 148.

man who knows nothing of all the many processes that can occur in photography judge whether a photograph of fairies on a leaf, or stars near the Sun, proves anything or not?

Over-confidence in mathematical treatments may even affect adversely the application of science to human needs. A claim has recently been made that the production of high-speed planes in this country was retarded by scientific authorities who were impressed by the difficulties of "penetrating the sound barrier"—as they put it. But when the experiment was tried, the pilots did not know whether they had exceeded the velocity of sound or not, so little evidence was there, physically, of any "barrier."

Misuse of language is another feature of present-day physics and is common in the textbooks. Let us take the case of the word *energy*. As we have seen, this mathematical function, originally employed to simplify mathematical treatment, can be used to avoid consideration of details of physical processes. Now energy in physics is what it is defined to be, and that is a product of some numbers obtained by measurement—a metrical feature of a physical process—just as the product *man-hours* is a metrical feature of the process of, let us say, producing the *Queen Mary*. It is certainly useful to know that the building of such a ship requires, let us suppose, ten million man-hours; for, with a given labour force, we can then *predict* how long the production of the ship will take. But we would not say that the *cause* of the appearance of the *Queen Mary* was that man-hours had flowed into the shipyard. Yet the statement that we are warmed by energy flowing to us from the Sun is quite common, and is just as absurd physically. To take another example: saying that an atom cannot emit an electron until it has absorbed a certain quantity of energy sounds like a causal explanation, but it is just as absurd as saying that shipyards cannot emit ships until they have absorbed a certain quantity of man-hours. Energy is not a thing, or an interaction between things, but is what it is defined to be, a metrical feature of a physical process or state. Energy, therefore, can never be a causal agent in science; it can never take the place of force, and its increasing use as a causal agent only goes to justify Spengler's description of it as the great myth of Western science. Linguistic confusion in physics is increasing: another very bad example is the way in which writers who ought to know better, after mentioning the equivalence of energy and mass, go on to equate energy with *matter*.*

In conclusion, is there any real justification for abandoning the

* *E.g.*, Einstein and Infeld, *The Evolution of Physics*, p. 208, C.U.P. (1938).

physical theory of Nature? Many physicists feel that this is far from being the case, and would agree with Blackett that: "Even in the highly complex subject such as nuclear structure today, there is always the chance that new and simple concepts will be discovered." * The present writer has investigated the possibility of extending the physical theory of Nature by adding to the basic idea of atoms in motion which act on one another by 'contact' the hypothesis of forces which act at a distance, though not simultaneously, *i.e.* they act at a distance after a time interval given by dividing the distance by a constant of Nature (usually called the "velocity of light").† The necessity for an ether, therefore, disappears, and the Michelson-Morley and Kennedy-Thorndike experiments are at once accounted for. This action varies with relative motion as well as distance, and the unification of electromagnetism and gravitation is achieved by extending the idea of the universality of gravitational force to include all macroscopic forces, with the assumption that they vary in the same way with relative distance and motion.

The metrical expression of this macroscopic physical theory is the formula for the force between two particles. Everything else should follow from superposition using the parallelogram of forces. The procedure used for finding the formula follows ordinary Newtonian method; that is to say, the physical theory having been made first, the force formula is found from observation and experiment. Newton, Cavendish, and Coulomb found the first term—the well-known inverse-square expression. In like manner, from electrodynamic experiments we can find the velocity terms, and from radio experiments we can find the acceleration terms. The formula yields the correct results for electromagnetic induction and also appears capable of dealing with high-speed particles, the phenomena observed being due to the variation of electric force with velocity, and not due to any change in the coefficients e and m, which remain constants. This avoids the anomaly in relativity theory where m changes with velocity while e does not. 'Magnetism,' change of magnetic flux, fields of force, displacement currents in the ether, retarded potentials, electromagnetic waves, absolute space, space-time—all disappear. The eleven sets of equations of Lorentz are replaced by the one cardinal force-formula giving the force between two particles. If dynamical units of mass are used, the force-formula applies to gravitation by merely substituting the symbols m_1, m_2 for the symbols e_1, e_2. The force of inertia is accounted for by

* P. M. S. Blackett, *loc. cit.*

† "A Theory of Action-at-a-distance," *Proc. Phys. Soc.*, 68, 672 (1955).

relative acceleration with respect to the total matter of the universe, and it agrees quantitatively with that calculated from the amount and distribution of the known matter. A perihelion motion of the planets occurs, and this can be made to agree with observation by adjustment of a constant. No prediction of any gravitational 'bending of light' near the Sun is involved, since on this physical theory all 'bending' is due to phase differences caused by superposition; but an increase in inertia near bodies of large mass should occur. The possibility of inertial forces varying with the distribution of matter, and in particular the possibility of electrical inertia (both accelerative and retardive) might throw some light on curious and unexplained formations in the nebulæ and on the origin of high-speed particles.

While it is too early yet to say whether this theory will survive criticism in its present form, it does indicate the possibility of tackling modern problems without abandoning the physical theory of Nature and adopting the mathematical theory, with all the difficulties and dangers which have been illustrated in this article. As regards microscopic physics, it seems doubtful whether much progress will occur until we abandon the concept of waves (which turn out to be waves of nothing or—worse still—waves of probability or even waves of knowledge), and concentrate on the other feature of periodic events, the frequency: it might be possible, for instance, to account for quantum phenomena and the 'diffraction' of matter by assuming that all forces are really intermittent, with a very high frequency.

Spengler maintained in *The Decline of the West* that Western science would decline in the same way as Western art and music, and other expressions of a developed culture. If the belief that mathematics is the "necessary source of positive knowledge" triumphs —a view that, as Whitehead said, reintroduces the errors of the logicians of the Middle Ages—then Spengler may prove justified in his prediction.