SCIENCE

VOL. 79 FRIDAY, MARCH 16, 1934 No. 2046

SCIENCE: A Weekly Journal devoted to the Advancement of Science, edited by J. MCKEEN CATTELL and published every Friday by

THE SCIENCE PRESS

New York City: Grand Central Terminal

Lancaster, Pa. Garrison, N. Y.

Annual Subscription, $6.00 Single Copies, 15 Cts.

SCIENCE is the official organ of the American Association for the Advancement of Science. Information regarding membership in the Association may be secured from the office of the permanent secretary, in the Smithsonian Institution Building, Washington, D. C.

THE PHYSICAL SCIENCES[1]

By Professor W. L. BRAGG, F.R.S.

LANGWORTHY PROFESSOR OF PHYSICS IN THE UNIVERSITY OF MANCHESTER, ENGLAND; NON-RESIDENT LECTURER IN CHEMISTRY AT CORNELL UNIVERSITY ON THE GEORGE FISHER BAKER FOUNDATION

MAY I first express my warm appreciation of the invitation you have extended to me to spend this semester at Cornell as your non-resident lecturer. It is an invitation of long standing, for on two occasions circumstances have made it necessary to postpone my visit, and I am warmly grateful to Professor Dennis and Professor Papish for their kindness in keeping the invitation open for so long. This is my third visit to your country, and my experience of your hospitality tells me what a very delightful stay this will be. I am glad of the occasion which this introductory lecture affords to express my gratitude.

When a scientist comes out into the open, away from the safe retreat of his own special line of work, he puts himself in a very dangerous position. In his own line he has some claim to expert knowledge. He can at all events save himself from falling into pitfalls of crudeness and naïveté, which will be ready for him if he wanders off the tract he knows. If I venture to talk about very general aspects of the physical sciences, I must try to disarm your criticism beforehand. I wish to show my appreciation of the invitation which you extend to your non-resident lecturers to talk to an audience with wide and varied interests. It would not be fair to ask you to take an interest in my own particular department of physics.

I want to talk about the development of the physical sciences, and review the general trend of the bewilderingly rapid advances of recent times. I must feel very diffident in proposing this as a subject, in view of the extent to which it has been treated by far more able exponents. On the other hand, it is of such interest and importance for us all that perhaps no ex-

[1] Introductory public lecture.

cuse is necessary for seizing an opportunity like this to discuss it.

I suppose it is a very common experience for those of us who study the physical sciences to be asked what "Physics" is. This not infrequently happens to me, for example, at dinner parties when the lady I sit next to, after angling a little to find out what sort of person I am, elicits the information that I am university professor of physics. My interlocutor generally has an idea that it is not something to do with medicine, though it sounds like it; I take refuge in murmuring something about "heat, light, sound, electricity and magnetism." It is an embarrassing, but very illuminating instance of the way in which one of the most significant factors for the future of our modern civilization, the increased power over nature due to the growth of the physical sciences, is quite incomprehensible to all but the few who make it their especial study.

I wish to class together all the physical sciences which seek to study nature as a mechanism, as distinct from pure mathematics and the biological sciences which deal with living matter. We seek to find out the way in which nature works as we may study the working of a machine. We try to do this as accurately as we can, to express everything as quantities; for this reason physical science is called the science of measurement.

There have been three well-marked stages in the attempt to explain nature in this way. In the first stage, some little bit of nature was selected, simplified, and isolated from the rest so that the sequence of cause and effect could be studied. We all start in this way when we learn physics at school. We work out the way in which a pendulum will swing, having been told its length and the pull of gravity, or the way in which a stone drops (the friction of the air being neglected). The interesting thing about physics of this kind is that we put ourselves in the glorious position of being (on paper) omniscient. We know all the facts to start with, and we can say exactly what is going to happen unless we make a howler in our calculations. The equally interesting consequence is that the events so described are eternal. As Eddington puts it, the arrow of time, distinguishing the future from the past, ceases to exist. The schoolboy, given the necessary data, could tell you what the pendulum was doing when William the Conqueror landed in 1066, and what it will be doing at any time in the future, for the definition of his problem includes no interference from outside. The ideal pendulum, or any other isolated natural phenomenon, has no history. It works equally well forwards or backwards. It can never surprise us by an unexpected turn; how can it when we are omniscient? Time has ceased to exist, except as a convenient label for the different parts of a completely known whole.

Nothing really happens in this way, though some bits of nature, like the rotation of the earth, approach very closely to it. We are almost omniscient as regards the rising of the sun to-morrow morning. The increasingly ambitious physicist tried to tackle problems where he could not say he knew all the initial conditions, and was able to do it with success. This success ought not to surprise us, for we can draw many parallels. A life assurance company does not know everything about the people on its books, yet it can calculate its premiums to a nicety and be confident of a profit on the year's working. It does not know when Smith or Robinson will die, but a study of vital statistics has led to a knowledge of what the average expectation of life of a large number of Smiths and Robinsons will be. We treat a body like a gas in the same way. It consists of vast numbers of molecules flying about in all directions. We do not know what they are all doing, yet we can discover laws which the gas as a whole will obey very accurately indeed. An engineer can calculate the power his steam engine will develop, although the individual molecules in the steam are pursuing their lively careers in a way of which he is completely ignorant.

Although we have ceased to be omniscient, we may still picture some one, more clever than ourselves, who is omniscient. An ideal physicist with all the possible resources of apparatus at his command and infinite patience might size up the flight of every molecule, and by using mechanical laws might predict what they were all going to do at any future time. The theoretically possible existence of such an ideal physicist would be sufficient to determine our attitude to this world around us. It implies that the gas, or the universe, is as timeless and as determined by physical law as the ideal pendulum; it is only more complicated. It has equally no history and no development; its whole past and future are sufficiently described by an accurate description of its present state. This is the logical reasoning which leads to a purely deterministic attitude. The events of to-morrow may surprise us because we are not clever enough to know all about the purely physical to-day; but if we knew all about to-day we would know the end of the story. We feel the difficulty of escape from this deterministic attitude, sensing that somehow it is wrong but unable to see how to avoid it.

There is an important qualitative difference between the simple pendulum and the complex world, however. In such complex events as the above, Eddington's arrow of time comes in. Things do not work as well backwards as forwards. A hot body is placed in contact with a cold one, and by the jostling of their atoms they take up the same temperature. We do not see the reverse process of two bodies initially at the same temperature growing hot and cold, respectively. Eddington cites the more complex case of a cup falling off the table and smashing to pieces. If at a given instant the velocities of every fragment were reversed, the pieces would fly together, form a whole cup and leap on to the table. This would surprise us, and we accept more readily the time sequence of a whole cup becoming fragments than the reverse sequence. It must be realized, however, that a time sequence only comes in here because we suppose an initial something which from the point of view of physics is miraculous. A whole cup is a miracle, not of course in the sense that it is against the laws of physics, but in the sense that no unaided physical causes will produce it. In a less obvious sense, we must start with some original miraculous state of affairs in order to have two bodies at different temperatures. Physical processes may destroy the miraculous but can not create it. We may say again that history (meaning by history a sequence of events for which only one time-order is natural) only exists as a record of miracles, or rather of the consequences of an initial miracle whose origin transcends the merely physical. Apart from the miraculous, history and time have no meaning except as a system of labels. The running down of the world, so often quoted as one of the results of physical laws, is evidence of something quite apart from physics. It is the changing aspect of an initial state whose creation is not contemplated by physical laws.

The last stage is more difficult to describe. It is more recent, and there has not been time to realize its implications fully. In picturing the ideal physicist examining every detail of the gas, we have tacitly assumed that his delicate apparatus feels all round every molecule with tentacles so sensitive that they do not disturb it in any way. This is not possible, however. Given the most delicate apparatus in the world, the collection of information about the gas in some headquarters means that each molecule has sent a message, necessarily an ether wave because that is the only way in which a message can travel from one point to another. Forcing it to send such a wave by throwing light on it is again of necessity a brutal cataclysmic process. The molecule has a nasty shock, and is not the molecule it was before. Further, we can not say exactly how the shock has affected it, except by making it send another message at a future time. This gives it another shock and though we have succeeded in discovering what it has been doing in the past we are as badly off as before as regards predicting its future. It is important to realize that the shock is received because the molecule, having had light directed upon it, sends a message betraying its whereabouts; the shock has nothing whatever to do with the apparatus receiving the message, which we may make as delicate as we like.

We may compare it, rather inaccurately, to a grown-up watching children at play. He wishes to remain unobserved himself; otherwise the little beings will become self-conscious and their antics will not be those they would have indulged in had they been left alone. It is impossible to remain unobserved, however, because he can only discover what they are doing by making them describe it to him. We can not as physicists be non-interfering observers of any object in front of us; we must interfere with it, and the consequences of the interference can not be exactly predicted. Or we may go back to our insurance company. If it wished to calculate its profits for the coming year to the last penny, it might send an army of doctors to visit all its policy holders, make a report on their state of health and home life, and predict precisely when the company would have to pay up for each of them. We must suppose, however, in comparing the company with the physicist examining matter, that the examination itself put the patient in such a nervous twitter as to make him an altered man. A subsequent examination would show how he had been altered by the last, but would again introduce a new incalculable element.

What inference is to be drawn from all this? The statement, "If I know the precise present physical state of an object in front of me, I can predict its future," is seen to be meaningless. The object can not reveal its present state without altering its future. Omniscience as an ideal and a precise connection between cause and effect are seen to be illusions as regards the physical world. This does not mean that the incalculable element which upsets our precise physical predictions is necessarily an element of blind chance. To think this is as revolting as is the previous deterministic attitude. A more attractive way of accepting the new view-point is to consider that those qualities of any object in front of us which can be measured by any purely physical means do not sum up the whole of the truth about it. The physical nature of a body is merely its projection upon one plane (like the plan of a building without the elevation). The body has an extension in other directions, other qualities which are not expressed in physical measurements. This does not imply that the laws of physics do not hold universally. The plan upon the physical plane is self-consistent and governed by universal law to which we find no irrational exceptions. It is nothing but the truth, but not the whole truth.

When a physicist talks like this, he is often told by friends with a philosophic turn of mind that physicists have found nothing new. I can not accept this. I am sure that when the first circumnavigators of the world returned from their voyage they were told by friends that some Greek philosopher, who lived in ? B. C. had held that the world was round and that they might have spared their trouble. The world is either round or flat, and endless discussion might have been carried on for ages between opposing schools who held the one view or the other. The real contribution to settling the problem was made by the circumnavigators. The achievement in physics which I have tried to outline is like a circumnavigation of the physical world. There will be no end to further exploration, but we realize for the first time certain bounds within which it must take place, just as we now know that geographical exploration must take place over the surface of a globe and not upon an infinite plane.

To summarize, let me try to explain by an analogy the position in which we find ourselves as students of the mechanism of nature. You know those large glass-paned floors which often form the pavement of an upper room or of the street, which are such that any one in a lower room can look upwards and see the footsteps of people passing above. Let us suppose a physicist placed in such a lower room, and that his sole means of observing what was going on above was by observation of the feet of the passers by, and of anything else in contact with this glass floor. He could learn a great deal and would be able to formulate laws. He would observe that footsteps did not suddenly disappear into space—the indestructibility of matter. He would observe that the footsteps always passed around objects and not through them—the impenetrability of matter. Starting in one direction they on the average pursue the same direction, though fluctuations from the average are evident. Sometimes a foot slips; such a phenomenon is generally followed by violent movements of the feet and their disappearance altogether, followed by the appearance in their place of an object of roundish outline—a kind of radio-active transformation. The laws governing a crowd of footsteps all moving in one direction would be more exact than those applying to a single individual. Yet he could never predict exactly what they would do.

We may make our analogy a closer one by supposing that we can only tell where the footsteps are, not by looking at them, but by reaching up and tweaking their toes. A light tweak has little effect on their movements, but leaves us uncertain of their exact position. A heavy pinch tells us exactly where they are, but causes them to swerve from their course in an erratic way which we can not predict. To see where they have got to, we must pinch again, and this introduces a new element of uncertainty into the future, though it tells us what has happened in the past. The physicist might be tempted to say that an element of blind chance enters into the behavior of all he observes, upsetting his precise calculations. We know that he would be wrong. The objects above exist in a third dimension of which he is unaware.

Is not this precisely our position as regards the physical world? The same element of uncertainty enters into all our physical calculations, and does so not because our instruments are imperfect, but because of the very nature of physical laws. We must think of the physical world around us as the footprints of something which exists in other dimensions as well, which has other qualities which are not physical and which no physical apparatus, however delicate, can measure.

It seems to me that this is the contribution which recent developments of the physical sciences makes to human knowledge. Nothing can exceed our instinctive horror of the finite, our revulsion at the idea of being entrapped in a mechanical web. Science now suggests the way of escape from a dilemma, for which its own logical pursuit has been largely responsible.

THE SUPREME INTELLECTUAL OBLIGATION[1]

By Professor JOHN DEWEY

THE scientific worker faces a dilemma. The nature of his calling necessitates a very considerable remoteness from immediate social activities and interests. His vocation is absorbing in its demands upon time, energy and thought. As men were told to enter their closets to pray, so the scientific man has to enter the seclusion of the laboratory, museum and study. He has, as it is, more than enough distractions to contend with, especially if, as so often happens, he is also a teacher and has administrative and committee duties. Moreover, the field of knowledge can not be attacked *en masse*. It must be broken up into problems, and, as a rule, detailed aspects and phases of these problems must be discriminated into still lesser elements. A certain degree of specialization is a necessity of

[1] The undersigned served as a committee to make the plans for a dinner held in the honor of Dr. J. McKeen Cattell, at the University Club, Boston, Wednesday evening, December 27, 1933. At that time an address was given by Dr. John Dewey. The committee has requested SCIENCE to publish Dr. Dewey's address.

OTIS W. CALDWELL
BURTON E. LIVINGSTON
HENRY B. WARD