Trends in Modern Physics*

By Prof. Allan Ferguson

THE world-picture of the older generation was, as we look back on it to-day, extraordinarily simple. It is, or has been, the fashion to describe nineteenth-century science as materialistic. There certainly was Buchner, and there was Tyndall's Belfast address. But *Dr. Stoffkraft* had neither a long reign nor an influential following, and we shall be nearer to the truth if we look upon Victorian science as showing a simple realism—the realism of the man in the street—not wholly unrelated to that simple realism of to-day which sees in an alpha-ray track evidence for the existence of an atom, of the same order as that furnished by a diffraction photograph (or, for that matter, by our own eyes) for the existence of a star.

What we have learned to call the classic outlook was based on those notions of velocity, acceleration, momentum and force which were first formed into an ordered scheme by the genius of Newton—a scheme which sufficed to describe, succinctly and clearly, the series of perceptions involved in such phenomena as the motion of a pendulum, a billiard ball, a railway carriage, and (with certain reservations concerning fine points) the complex motions of the bodies of the solar system. The physical science of the eighteenth and nineteenth centuries was occupied in extending and clarifying these concepts, although eighteenth-century science in England was hampered by an excessive devotion to the memory of Newton, which committed the English mathematicians to the fluxional notation. It required the formation of a society at Cambridge "to inculcate the principles of pure *d*-ism, and to rescue the University from its *dot*-age", before the British physi al school could rival the advances of their Continental brethren.

As we have said, the attitude of the physicist to the fundamentals of his science was, in general, naïvely realistic. Mass was quantity of matter, and matter itself was defined as "that which can be acted upon by, or can exert force", or alternatively "that which may have energy communicated to it from other matter". *Obscurum per obscurius*, with a vengeance!

Quantitatively, mass was defined, following Newton, as the product of volume and density; and even Thomson and Tait are roused to a hint (without attempting to resolve the difficulty) that such a process results in a circular argument, inasmuch as we have no other way of defining density than as the ratio of mass to volume.

Early in the nineteenth century, discoveries, mainly in the realm of chemistry, gave fresh interest to atomic doctrines, and the simple concept of the billiard-ball atom proved to be brilliantly successful in explaining old happenings and in predicting new ones. It is not immediately obvious that an extrapolation of those laws which describe the motions of bodies of the dimensions of a locomotive or a planet down to bodies of the indescribably minute dimensions given to an atom or molecule is likely to be successful in subsuming certain perceptual events; the extraordinary thing is, not that such an extrapolation should break down somewhere, but that it should have any validity at all; and the triumphs to be put to the credit of the hypothesis are sufficiently remarkable, as any treatise on the kinetic theory of gases will testify.

No survey of the physical science of the last generation would be complete did it contain no reference to radiation and to the nineteenth-century concept of the mechanism by which radiation is conveyed. Despite the difficulty of framing a theory of the ether which should satisfy dynamical laws—"Why should it?" we might remark incidentally to-day—the concept of an ether of space was so brilliantly successful in correlating and predicting so many and so diverse phenomena—we need but instance that bending of light round corners which we call diffraction, that alternate heaping up and destruction of light which we term interference, and that remarkable refraction of a ray of light by certain crystals as a cone of rays—as to draw from Lord Kelvin the downright statement, "This thing we call the luminiferous ether . . . is the only substance we are confident of in dynamics. One thing we are sure of, and that is the reality and substantiality of the luminiferous ether". Strange reading, to-day; and reading which might well introduce a note of hesitation into some of the confident declarations of present-day realities.

Molar mechanics, the billiard-ball atom, the ether: the nineteenth century had built on these apparently stable foundations an immense structure of ordered knowledge. The closing years of the century were fated to show cracks in the superstructure and weaknesses in the foundations.

* From the presidential address to Section A (Mathematical and Physical Sciences) of the British Association, delivered at Blackpool on September 11.

The facts of radioactivity and the discovery of the electron showed that the concept of the atom must increase in complexity were it to remain competent to subsume the additional perceptual facts; and the experimental study of the radiation from a hot body revealed a state of affairs inexplicable on the lines of classical theory, as did the investigation of the phenomenon known as the photo-electric effect.

It is unnecessary to tell in detail the story of the introduction into physical science of the revolutionary notion of quantization; of the concept of the nuclear atom; of the rationalization of the facts of spectroscopy by the application of quantum ideas to the nuclear atom; of the breakdown of this latter concept when applied to atoms more complex than a single electron system; of the building up on quasi-empirical lines of a vector model of the atom which should be capable of providing an explanation for the complex facts of spectroscopy; of the further emphasis placed on that dualism of outlook which appeared so early in twentieth-century physics by the discovery of the Compton effect and by the investigation of electron-diffraction and of molecular-ray diffraction; and of the impending disappearance of that dualism under the impact of the analysis of the last decade.

Atomum expellas furca—and there is something appropriate in giving such a designation to a Ψ-function—*tamen usque recurret.* If two of the high lights of twentieth century physics are provided by the introduction of quantum ideas and by the identification of mass and energy, a third is provided by that remarkable rain of sub-atomic particles which has increased incredibly in intensity since the discovery of the electron more than a generation ago, and has provided opportunities for nucleus-building of which theorists have not been slow to make use.

By nothing has the world-picture of to-day been so transformed from that of a generation—nay of a decade—ago than by the introduction of the uncertainty principle and by its effect on our notions of causality.

It can be shown that of two conjugate quantities —time and energy, or position (x) and momentum (p)—the product of their uncertainties of determination can never be less than the quantum h. Thus an increase in the accuracy of the determination of one quantity necessitates a corresponding decrease in the accuracy of the conjugate quantity, and in particular the exact determination of one quantity leaves the other completely undetermined. An attempt to determine the position of a particle involves its illumination by light of suitable wave-length, and decrease of the wave-length in order to improve the definition of its position involves an increase in the magnitude of the recoil due to the Compton scattering process.

Following a suggestion of Dr. H. T. Flint, let us fix our attention on the quantities position and momentum, and consider a co-ordinate system in which momentum (p) is plotted along one axis and position (x) along the other. The co-ordinate space gives us the possible simultaneous values of x and p. Suppose this space divided into rectangles each of area h. Then the uncertainty principle, which asserts that the product ($\delta x \delta p$) of the uncertainties of the determination of position and momentum can never be less than h, may be illustrated by resuscitating Maxwell's demon and permitting him to push a point about at will within any one of the rectangles. The movement of the point, that is, the corresponding changes of position and momentum, will not be detected, for they do not correspond to any detectable change in the world of sense.

Unfortunately the word 'indeterminism', which has other connotations, has become associated with the statement of the principle. Many will recollect Clerk Maxwell's immortal account of the proceedings of Section A at the Belfast meeting of the British Association sixty-two years ago, when Mr. Herbert Spencer regretted "that so many members of the Section were in the habit of employing the word Force in a sense too limited and definite to be of any use in a complete theory of evolution. He had himself always been careful to preserve that largeness of meaning which was too often lost sight of in elementary works. This was best done by using the word sometimes in one sense and sometimes in another, and in this way he trusted he had made the word occupy a sufficiently large field of thought".

Is it heresy to suggest that some of us who have sung canticles in praise of indeterminism and the disappearance of causality have given a similar generousness of meaning to these words?

Similar considerations apply to the term *observable*, which has suffered a sea-change in transference from its ordinary usage in the realms of perception. There is quite as much complicated physical theory lying between the perceptually observable marks on a photographic plate and the inferred frequencies, as there is between similar perceptual observables and the non-observable electron orbit or state which was inferred in order to subsume the perceptual facts. A similar generosity of treatment is accorded to the term *observe* when it is applied to the conceptual experiment for the determination of the position of a particle such as an electron.

Which brings us round to the starting-point of this discourse. Many of us who desire to proceed with our measurements untrammelled by these philosophic doubts have asked if there is not some canon by which the plain man could test his everyday beliefs. I suggest that a starting-point at least to this end is provided by a study of Karl Pearson's work, and that, with certain reservations and additions to the method discussed in the "Grammar of Science", we may develop a canon which will serve as a guide through the jungle of additional perceptual facts which the physical science of the twentieth century has added to that of its predecessors.

Those who discuss the doctrine of causality do so with little reference to the attitude taken by the philosophers, and it may not be without interest—it certainly has some bearing on present-day thought—to consider the development of the notion of cause since the time of Newton. The views of Locke, Newton's elder contemporary, are clear and simple. He remarks: "Thus, finding that in that substance which we call *wax*, fluidity, which is a simple idea that was not in it before, is constantly produced by the application of a certain degree of heat, we call the simple idea of heat in relation to fluidity in wax the *cause* of it, and *fluidity* the effect. . . . So that whatever is considered by us to conduce or operate to the producing any particular simple idea, whether substance or mode, which did not before exist, hath thereby in our minds the relation of a cause and so is denominated by us".

Newton, dominated as he was by the principle of causality and ever searching for a clear physical picture of the results of his investigations, was capable of a philosophic breadth of view which needs surprisingly little modification to-day. He makes, for example, a physical picture of matter as formed in "solid, massy, hard, impenetrable, moveable particles", and assumes that they have not only a *Vis Inertiæ*, but are moved by certain active principles, such as gravity. These principles are to be considered "not as occult qualities . . . but as general Laws of Nature . . . their Truth appearing to us by Phænomena. . . . To tell us that every Species of Things is endowed with an occult specifick Quality by which it acts and produces manifest effects, is to tell us nothing; but to derive two or three Principles of Motion from Phænomena and afterwards to tell us how the Properties and Actions of all corporeal Things follow from these manifest Principles would be a very great step in Philosophy, though the Causes of those Principles were not yet discovered; and therefore I scruple not to propose the Principles of Motion above mentioned, they being of very general extent, and leave their Causes to be found out". Evidently Newton takes the view that we have made an important step forward when we have subsumed a number of perceptual facts under a general formula.

It is to Hume, though he may owe something to Glanvil and other predecessors, that we are indebted for a clearly ordered statement of the experientialist doctrine of causation. The generalization, for example, that the earth attracts a stone is explained as a generalization from thousands of observations. "Adam . . . could not have inferred from the fluidity and transparency of water that it would suffocate him, or from the light and warmth of fire that it would consume him. No object ever discovers by the qualities which appear to the senses, either the causes which produced it or the effects which will arise from it; nor can our reason, unassisted by experience, ever draw any inference concerning real existence and matter of fact".

Mill further developed the experientialist doctrine in the statement that the law of causation "is but the familiar truth that invariability of succession is found by observation to obtain between every fact in nature and some other fact which has preceded it, independently of all considerations respecting the ultimate mode of production of phenomena, and of every other question regarding the nature of things in themselves". To the doctrine of succession in this simple form the objection has been urged that day may be regarded as the cause of night and conversely. Mill meets this objection by pointing out that invariable sequence does not necessarily involve causation. To involve causation the sequence must not only be invariable but also *unconditional*. The day-night sequence is conditioned by the sun and so does not conform to this test. "We may define, therefore, the cause of a phenomenon to be the antecedent, or the concurrence of antecedents, on which it is invariably and unconditionally consequent".

It is difficult to sum up Pearson's attitude to the problem of causality and to the general problem in a few sentences. Perhaps Kirchhoff's dictum concerning mechanics: "Die Mechanik ist die Wissenschaft von der Bewegung; als ihre Aufgabe bezeichnen wir: die in der Natur vor sich gehenden Bewegung *vollständig* und *auf die einfachste Weise* zu beschrieben", touches very nearly the root of the matter.

We live, in fact, amid a mass of perceptions; and it is the business of physical science to correlate, in as simple a fashion as may be, a certain section of these facts. To this end the physicist devises a *conceptual* world of atoms and molecules, from which he builds up a system—a world-picture—of molar masses whose motions correspond to the routine of our sense impressions. Given a frame of reference, we can formulate laws of motion for two isolated particles in a conceptual world which may be summed up in the statement that whatever be the positions and velocities of the particles the ratio of their accelerations is always constant; this ratio is defined as the inverse mass-ratio of the particles; and in virtue of this we have the relation that—

$$\text{Mass of } A \times \text{acceleration of } A = \text{mass of B} \times \text{acceleration of } B.$$

We give the name *force* to this product, and hence obtain the law that action and reaction are equal and opposite. On the basis of such definitions we can build up a structure of bodies in the conceptual world the motions of which, predictable under the descriptive laws formulated, will agree with the routine of our world of sense perceptions. We have, in fact, *explained* certain phenomena.

There is, of course, no logical reason why, in this description, we should stop short at the second derivative—acceleration—or go forward to it for that matter. We are concerned to find the simplest and most consistent explanation, and this procedure provides it. Indeed something of æsthetics may also influence our choice.

The atom, whatever its complexity, whether the concept remains sharp as that of a billiard ball or a miniature solar system, or whether its outlines disappear in a probability-smear, remains a *concept* outside the realm of perceptual happenings which it is the business of the concept to correlate. It may or may not emerge into the perceptual world; unless and until it does, discussion of its reality is beside the mark.

Planck, defining the causal condition in the statement that an event is causally conditioned if it can be predicted with certainty, goes on to remark that the possibility of making a correct prediction has not to be interpreted as anything more than a criterion for a causal connexion, but that the two do not mean one and the same thing. Day is not the cause of night, although we may be able to predict the advent of night in the day-time. Day is, therefore, a causally conditioned event.

Taking the definition as it stands, we find that in the realm of quantitative physical events we cannot, purely as a matter of measurement, predict *accurately* in advance any one physical event—this, without introducing quantum considerations. Prof. Planck escapes from the indeterminist position by transferring the definition to a conceptual world in which exact measurements may be made and events correctly predicted. He assumes, in fact, in its broad outlines, the thesis of the "Grammar of Science". He thus retains the principle of causality, as defined above, in the happenings of the conceptual world, remarking that the relation between events in the perceptual and conceptual worlds is subject to a slight inaccuracy.

The introduction of Heisenberg's uncertainty principle necessitates a corresponding process in dealing with perceptual problems from the point of view of quantum physics. A conceptual world of quantum physics is framed in which a strict determinism reigns. True, the world has not so many points of resemblance to the perceptual world as had the older schemes—billiard-ball and solar-system atoms have disappeared, and the wave-function, which does not refer to ordinary space, is not so easily interpreted in terms of the world of sense. But the philosophical problem of the transfer is the same.

Whatever the form of the picture, the hard-pressed physicist of to-day remains on firm ground if he refuses to confuse the concept—the world-picture—with the percept; if, making this distinction, he studies the question of the reality underlying phenomena as philosopher rather than as physicist; if he is as ready to discard outworn models as ever Maxwell was.

There is no finality in these matters, and solutions of these difficulties are solutions for a day; but it is interesting and heartening to know that Planck, the initiator of the movement which has revolutionized physical thought, has, a generation later, pointed a way to a resolution of the fundamental doubts and difficulties which his genius has raised.

Of recent years the British Association has concerned itself more and more with a study of the repercussions of the advancement of science on the fabric of our society. Never in the history of mankind have more powerful weapons for good and for evil been placed in the hands of the community as a direct result of the growth of scientific knowledge; and never has it been more necessary for the scientist to develop some awareness of the effects of his activities on the well-being of that community of which he himself is a responsible member.

We are most of us ready enough to discuss the "Impact of Science on Society", so long as we restrict ourselves to an enumeration of the benefits which science has bestowed upon mankind; and on occasion we may make a rather snobbish distinction between cultural and vocational values. But we have to remember actively that there are dysgenic applications of scientific knowledge, and if the scientist claims, as he rightly does, that place in the counsels of the nation which the importance of his work warrants, he must cease his worship of what Prof. L. Hogben calls the "Idol of Purity", must be prepared to discuss all the social implications of his work and to educate himself, as well as his less fortunate brethren trained in the humanity schools, in a knowledge of these implications.

The British Association is peculiarly fitted to develop and discuss such knowledge ; in Section A we have made a beginning, but we have as yet touched on but few of these interactions. Our steps are naturally at first a little halting, but with increasing knowledge there will come, I trust, an increased power in elucidating those complex and difficult social problems which the astonishing developments of the last generation have forced on the civilized world.

Science and the Poultry Industry

THE claim of the poultry industry to rank as the third largest branch of British agriculture, when judged by the value of its output, will scarcely be questioned by the visitor to Blackpool for the recent meetings of the British Association. Over the greater part of the County Palatine through which he travelled, the fortunes of farming are based largely upon cows, poultry and pigs, mainly in the order given, whilst the more immediate hinterland of Blackpool is thickly studded with specialist poultry farms. On arrival he would not have been surprised, therefore, to find from his programme that two sections of the Association had thought it worth while to devote a whole afternoon to a joint session for the discussion of problems of the poultry industry, and that further, provision had been made for an external lecture at a rural centre, Poulton-le-Fylde, on the same subject.

For this latter purpose no choice could have been happier than that of Mr. Percy A. Francis, the Poultry Commissioner of the Ministry of Agriculture, who combines unique opportunities of observing the progress of the application of the various sciences to the practice of poultry husbandry with a flair for the exposition in simple terms of his observations that is widely appreciated throughout the industry.

Mr. Francis' survey of the applications of science to the poultry industry necessarily covered a wide field, since in no branch of livestock husbandry are the needs of scientific guidance so varied as in the poultry industry of to-day, with its systems ranging between the two extremes of the open pasture and the intensive 'battery'. At every stage—mating, incubation, rearing, laying, fattening—and in every phase of management—feeding, housing, hygiene, disease control—the keys to success have scientific wards, and the ultimate result is largely affected by the degree to which fundamental scientific postulates have been respected or ignored.

In view of the popular conception of the farmer as being too slowly responsive to the aid of science, it will come as a surprise to many to learn that Mr. Francis is inclined to suggest that some part of the present troubles of the industry on its production side may be traceable to over-haste and ill-informed zeal on the part of the poultry farmer in the incorporation of scientific discoveries into his practice. That there is substance in this suggestion can scarcely be doubted. In the application of new ideas to the development and management of the animal, an immediate improvement can only be accepted as desirable if it is not offset by an ultimate disadvantage of more serious import. Where the animal is used as a breeder, this disadvantage may not be evident until the third or fourth generation or even later. With an animal that grows and multiplies slowly, like the bovine or the human being, the deterioration may indeed cover so long a period of years as to escape detection unless the most careful and prolonged records are kept ; but with a species that grows and multiplies so rapidly as the fowl, the penalty is likely to fall more swiftly, and moreover to be far more widespread in its incidence.

For any errors committed by the poultryman in this respect, the scientific investigator must accept a share of blame, in that all too often he has not made sufficiently clear to the layman that his new discovery, though the latest, is almost certainly not the last word on the subject, and therefore does not justify the poultryman in dissolving completely the partnership with Nature, which hitherto has helped to make good the defects of the combined knowledge of farmer and scientific adviser.

Nowhere has the great advance in our knowledge of animal nutrition furnished by the discovery of vitamins and the study of mineral requirements been more strikingly exemplified than on the poultry farm ; nowhere has the incompleteness of our extended knowledge been more clearly demonstrated.

The major problem with which the industry on its production side is now faced is that of the rising rate of mortality amongst adult stock. There can