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TRENDS IN MODERN PHYSICS[1]

By Professor ALLAN FERGUSON

PRESIDENT OF SECTION A—MATHEMATICAL AND PHYSICAL SCIENCES

OUR section has suffered heavy losses in the twelve months that have passed since the Norwich meeting, and it is fitting that we should here pay due honor to the memories of McLennan, Glazebrook, Petavel and Pearson, who have, each in his own characteristic fashion, played so great a part in the advances made during this century.

The genius and vigor of Sir John McLennan were quick to seize on and to develop those ideas which were fermenting at Cambridge in the last years of the nineteenth century and to impress on them a character peculiarly his own. His energy and versatility are shown equally in his early studies of penetrating radiation, in his discovery of the single line spectrum of zinc and cadmium, in his later work on the spectrum of the aurora and the nature of the famous green line and in those studies of supraconductivity to which his last years in Toronto were given. His return to England found him unconquerably young in spirit and prepared to play his part in important investigations in radium beam therapy. He presided over the deliberations of this section at the Liverpool meeting of 1923, and those of us who were present at that meeting have vivid memories of an address which reviewed some of the major problems of atomic structure—an address which, the latest word on the matter in 1923, reads to-day as an ancient tale. The laboratory at Toronto which bears McLennan's name bears witness also to his genius as a leader of research and to his gifts as administrator and director.

Sir Richard Glazebrook belonged to the elder generation—he presided over Section A so long ago as 1893—and to the last occupied himself with certain aspects of those problems of macroscopic physics which dominated the science of his century. His early papers on the Fresnel wave-surface are admirable examples of accurate work accomplished with the aid of simple

[1] Concluding portion of an address given at the Blackpool meeting of the British Association for the Advancement of Science.

apparatus; and his experiments on the relation between the British Association unit of electrical resistance and the absolute unit marked the first step on a lifelong journey. *Felix opportunitate mortis,* illness was spared him, and death laid a kindly hand on his shoulder while he was still in the full tide of mental activity, still pursuing those studies which had been his companions for more than half a century. The National Physical Laboratory, which, opening in 1902 with two departments and a staff of twenty-six, had in ten years expanded to eight departments and a staff of 126, is Glazebrook's enduring monument.

The work of this great laboratory, stimulated by the conditions of the world war, was further developed by Sir Joseph Petavel; under his guidance the laboratory has steadily grown in prestige and in the range of its activities, which now demand the services of a staff of nearly seven hundred. In the counsels of our association, Sir Joseph Petavel ranked as an engineer—he presided in 1919 over the work of Section G—but we of this section are not unmindful of his contributions to physical science: of his studies of the emissivity of platinum at high temperatures, of the effect of pressure on arc spectra, of his interest in the problem of aeroplane stability.

Genius, both in its creative aspect and on that side which has been condensed by Edison into a whimsical phrase, marked all to which Karl Pearson put his hand. His ordered development of statistical theory, wherein new light is shed on the fundamental problems of frequency distribution, correlation and probable errors, formed a firm foundation number (k) which quantizes the angular momentum, and what is called the radial quantum number, the sum of the two being set equal to the total quantum number (N).

But the theory in this form was quite inadequate to cope with any system more complex than a single electron system. To deal with these more complex systems, quantum notions were extended on quasi-empirical lines and resulted in what may be called a vector model of the atom in which were visualized the possibility of electron and nuclear spins, with further possibilities in the way of quantization and quantum numbers. If these quantum numbers are shared between the satellite-electrons of an atom in such a way as to agree with an empirical exclusion principle which states that *no two electrons in an atom may have all their quantum numbers identical,* we may arrive at a distribution of the satellite-electrons as regards their energy-levels which gives a model capable of explaining many complex spectroscopic (and other) facts.

But space presses and we must return, in this rapid survey, to a consideration of that dualism of outlook which appeared so early in the story of twentieth-century physics. The discovery of the Compton effect further emphasized this corpuscular aspect of radiation.[2]

Suppose we carry this dualism into concepts that are fundamentally corpuscular and assert that matter may have a wave aspect? This is the notion put forward by Louis de Broglie, who postulated that, associated with a particle having momentum mv, there is a wave of wave-length λ given by $\lambda = h/mv$. As radiation which shows the fundamental wave-property diffraction also exhibits corpuscular properties, so electrons which are conceived primarily as corpuscular may be expected to exhibit wave-properties; and they do so. If a beam of electrons be passed through thin foil, diffraction phenomena are observed which are perfectly consistent with the wave-length postulated by de Broglie. If, moreover, leaving the sub-atomic world, we deal with *molecular rays* of hydrogen or helium, we may allow them to be reflected from a crystal surface and may observe diffraction phenomena consistent with a de Broglie wave-length of the right magnitude; *and we may collect the reflected waves as an ordinary gas.*

But all this merely emphasizes the dualism of the wave and corpuscular aspects of matter—a dualism which is now disappearing under the analysis of the last few years. The analysis, which is essentially mathematical, has introduced the notion of probability into our estimates, say, of position. We describe the wave which accompanies a corpuscle by means of an equation which will contain an expression for the amplitude of the wave; and the amplitude at any point gives us a measure of the probability of finding the corpuscle at that point; if the amplitude vanishes anywhere the probability of finding the corpuscle at that point vanishes also. The concept of an electron as a definite entity at a definite point in space is replaced by a probability pattern which, very dense in a certain locality, rapidly thins as we move away from that locality. In fact, if we fix our attention on the densest part of a given pattern, the probability of finding an electron at a distance of 10^{-13} cm therefrom becomes vanishingly small, and most of us may be content to use the concept of an electron almost in our accustomed manner, realizing that it has become a little fuzzy at the edges.

Despite the impending disappearance of this dualism, the story of the discovery of sub-atomic particles

[2] When x-rays are scattered by impact with the more lightly bound electrons in an atom, the radiation scattered at an acute angle has a smaller frequency than the frequency of the incident radiation, a simple explanation of the change being at once forthcoming if the problem is treated in the manner of the treatment of the impact of elastic spheres. Thus a light quantum hn communicates kinetic energy to an electron by impact. The scattered quantum hn' will have less energy, and hence n' will be less than n.

is most easily told in particle fashion. The discovery of the electron is now more than a generation old, as is the discovery of the α-, β- and γ-rays of radium, and the α-rays or particles—fast-moving helium nuclei—provided an atomic projectile which in the hands of Rutherford became a most potent weapon for exploring the intricacies of atomic structure.

Electrons, α-particles and protons are electrical in origin; they may therefore be deflected by electrostatic fields. They move and so constitute an electric current; they may, therefore, be influenced by magnetic fields. Information concerning their charges and masses may therefore be deduced from their behavior when subjected to such fields. Further, special means have recently been devised for the generation of controlled fields of high potential which may be used to accelerate charged particles subjected to their influence. In this manner it has been found possible to produce swift protons which may be used to bombard various elements. We can in fact now load, aim and discharge our atomic rifle almost at will, and with very remarkable results. For example, the bombardment of lithium with high velocity protons results in the formation of α-particles, a process which may be described by saying that the lithium nucleus whose atomic mass-number is 7 when bombarded by a proton whose mass-number is 1, gives rise to two α-particles, each of mass-number 4.

With this advance in technique has come a corresponding advance in discovery. Thus the bombardment of a light element such as beryllium by α-particles results in the production of γ-rays together with a radiation which does not ionize the air through which it passes, but may be recognized by its effect on the nuclei which it itself bombards, producing, as it does, ionization tracks due to the protons expelled from these nuclei. We have to deal, then, with a massive uncharged particle, whose mass may be deduced from a study of the tracks made by the nuclei with which it collides. The mass of the particle is very nearly equal to that of the proton, and it has been called the *neutron*.

For long it has been known that radiation of high penetrating power exists in the atmosphere, a radiation which increases in intensity, that is, in its power to discharge an electroscope, with increasing height. This is the so-called cosmic radiation, which may be assumed to have its origin in interstellar space. Investigations on cosmic radiation, using the Wilson cloud chamber placed in a strong magnetic field, disclosed the fact that when cosmic radiation passed into such a chamber tracks were produced, some curved in one direction, some in the opposite sense. This opposite curvature might be produced by a reversal of the sign of the charge or it might be due to the fact that the particle was moving in a direction opposite to that of its fellows of opposite curvature. It was not difficult to rule out this latter possibility, and we are thus provided with another sub-atomic entity of mass equal to that of the electron, and with a positive charge equal to the electronic charge.

The identification of heat and energy—a commonplace to-day—was not established without difficulty. The twentieth century has seen a possibly more remarkable identification—that of mass and energy—an identification which was made, to within a factor of $\frac{3}{4}$, by Hasenöhrl and was put forward in its present form in 1905 by Einstein. In this form the energy (E) possessed by a mass (m) is given by $E = mc^2$, where c is the velocity of light. Increase of mass of a system means increase of energy and conversely. And if mass be destroyed a corresponding amount of energy appears as radiation, if conservation laws hold. These conservation laws have been arrived at from a study of large-scale phenomena, and there is no *à priori* reason why they should be expected to hold when applied to atomic happenings far outside the perceptual scheme of things. Indeed, one is tempted to ask, Why should the concept of energy have any meaning, let alone any validity, when applied to such systems? The necessary and sufficient answer is the pragmatic one.

The possible invalidity of this law of conservation is no new concept. Twelve years ago Bohr and his colleagues put forward a theory in which an atom in an excited state emits radiation continuously, radiation which, falling on another atom, may make more probable its transition to a higher energy-state. It may be shown that such a theory involves a contradiction of the conservation law in single atomic processes, and experiments carried out to test the theory were best explained on the assumption of conservation.

Recently the supposition of conservation which, as we have seen in the Compton effect, was invoked to explain the changes of frequency involved in the impact of a light quantum and an electron, has again been called into question as a result of experiments made, using modern counting apparatus, on the scattering of γ-rays.

If we apply the conservation laws to nuclear transformations involving protons and neutrons we find that energy is conserved quantitatively, the kinetic energy liberated in a reaction being accurately accounted for by the disappearance of mass which occurs. It is different when we consider atomic processes which involve high speed particles—electrons, say, moving with velocities comparable with that of light. Such processes are not in agreement with the conservation principle, and to pull them into line a new particle, the neutrino, has been introduced, possessing no charge and, if Fermi be right, a negligible mass. Such a particle is not likely to be detected by direct experiment; its principal function is to "explain" continuous β-ray spectra.

Obviously we have a considerable range of choice in our atomic building materials, and the supposition that the nucleus is composed of protons and electrons in suitable numbers may need modification. The α-particle, long described as made up of four protons and two electrons, may also be considered as composed of two protons and two neutrons, and there are good reasons for this supposition. But whether the neutron is an elementary particle and the proton may be written as neutron + positron, or whether we have more justification for considering the neutron as proton + electron are matters which can not be discussed in detail here.

One of the most remarkable of the discoveries of recent years has been that of artificial radioactivity. Rutherford's fundamental discovery of 1919 was that transmutations may result from bombardment by α-particles. Thus, for example, the bombardment of nitrogen by α-particles results in the transmutation described by the nuclear equation

$$N_7{}^{14} + He_2{}^4 \rightarrow O_8{}^{17} + H_1{}^1$$

[Read: The nitrogen nucleus of atomic mass-number 14 and atomic number 7 when disintegrated by an α-particle yields the isotope of oxygen of atomic mass-number 17 and atomic number 8 together with a proton.]

Radioactive bodies, on the other hand, are bodies that break down spontaneously. We have various particles at hand with which to effect transformations by bombardment of nuclei, and for the most part the products resulting from such transmutations are stable. It might, however, happen that a product is produced which spontaneously disintegrates, and we then have the phenomena of artificial radioactivity. The bombardment (*e.g.*) of aluminium with α-particles resulted in the emission of neutrons (the neutron $n_0{}^1$ being a particle whose mass-number is unity and nuclear charge zero).

Hence we have

$$Al_{13}{}^{27} + \alpha_2{}^4 \rightarrow P_{15}{}^{30} + n_0{}^1,$$

the resulting product being an isotope of phosphorus. But if the bombardment ceases we find that positrons are emitted, the positron (p) being a particle of negligible mass and unit positive charge. The isotope of phosphorus produced is in fact radioactive and the nuclear equation gives

$$P_{15}{}^{30} \rightarrow Si_{14}{}^{30} + p,$$

the final product being an isotope of silicon. Bombardment by protons, neutrons or deuterons may produce disintegration products which are unstable; the unstable products resulting from bombardments by α-particles or deuterons pass over into stable species, sometimes with the emission of positrons, sometimes with the emission of electrons; this latter species of decay—the β-active species—is often accompanied by γ-radiation, so that artificially produced radioactive substances behave in the manner characteristic of natural β-active substances. Neutron bombardment, when it produces radio-elements, produces elements which are β-active.

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. Flint, let us fix our attention on the quantities position and momentum and consider a coordinate system in which momentum (p) is plotted along one axis and position (x) along the other. The coordinate 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 of us remember Clerk Maxwell's immortal account of the proceedings of our section at the Belfast meeting 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.[3]

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.

[3] In what follows I have drawn on the material of an article which I wrote some four years ago (*Nature,* vol. 45, 1932, p. 130). See also Broad, "Perception, Physics and Reality."

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 inertiae,* 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 *unconditional.* The day-night sequence is conditional 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 *ouf 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 esthetics 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 correction, but not that the two 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.[4]

Taking the definition as it stands, we find that in the realm of quantitative physical events we can not, purely as a matter of measurement, predict *accurately* in advance any one physical event—this, without introducing quantum considerations. Professor 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

[4] This definition should be carefully examined in the light of the argument of Hume ("Enquiry concerning Human Understanding," Section VII) and of Mill ("Logic," Book III, Chap. V).

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.

It must not be assumed that the discussion of uncertainty has passed beyond the region of fundamental criticism. In two recent papers in the *Philosophical Magazine*, Dr. Japolsky has developed a theory of elementary particles—electrons, protons, positrons, and so forth—which are considered as systems of Maxwellian electromagnetic waves. On this basis, using classical electrodynamics, he develops the usual quantum and relativity relations, including the de Broglie equation. The interaction of the particles follows the inverse square law (breaking down at small distances), and demands a mass-ratio between proton and electron which happens to be that deduced from experiment.

It is impossible to conclude a sketch of the trend of modern physics without touching upon the remarkable advances made in large-scale and applied physics; equally impossible is it to do more than mention a selection from such topics. The flotation process for the separation of minerals may be instanced as one, now of large-scale importance, which depends on a knowledge of physical quantities of very academic interest. In the practice of this process the powdered ore is churned in water which contains some substance capable of producing a stable froth. The mineral which it is desired to concentrate must cling to the surface and so remain in the froth, the gangue sinking to the bottom, and a reagent must be added whose action will ensure this. Obviously some very nice physical and physico-chemical problems are involved. In particular, a knowledge of contact-angles—a rather neglected subject—is of great importance, and during the last year or two much attention has been given to the measurement of contact-angles and to the application of the results of flotation processes. Indeed, a knowledge of surface-constants has many applications to industrial and to purely scientific problems, and it may not be out of place to draw attention to the curious shape of the curves showing the march of surface tension with temperature for certain crystalline liquids.

A most interesting application of classical atomic physics has recently been made in certain extensions of the theory of the Brownian movement. Measurements have been made of the Brownian movement of delicately suspended balances, movements due, of course, not to mass-motion of air or draughts but to irregular molecular bombardment, and a remarkably good value of Avogadro's number results from a determination of the amplitudes of such movements. Obviously if instruments become so delicate that their Brownian motion is appreciable, it becomes possible that Brownian motion may set a limit to the use of the instrument; this question has recently received consideration.

Electron diffraction has been applied with success to problems in technical physics. The very small penetration of even the swiftest electrons employed makes them peculiarly suitable for the study of surface structure, and the method has been used to attack such problems as the poisoning of oxide-coated filaments, and the study of lubrication.

Of the remarkable progress made in low-temperature research, we shall hear during the meeting of the section. One other matter may be mentioned in passing—the development of precision methods in calorimetry which may make it possible to study accurately the temperature-variation of the specific heats of liquids (deuterium oxide, for example) available only in small quantities.

Of recent years our 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 Professor 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.

Our association is peculiarly fitted to develop and discuss such knowledge; in our own section 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.