0053

SUPPLEMENT TO CURRENT SCIENCE

Vol. XIII] INDIAN SCIENCE CONGRESS, DELHI, 1944 [No. 1

Summaries of Addresses of the Congress President and Presidents of Sections

PRESIDENTIAL ADDRESS

Congress President: PROFESSOR S. N. BOSE

THE CLASSICAL DETERMINISM AND THE QUANTUM THEORY

I WOULD like to present before you certain aspects of modern physics and draw your attention to the profound changes in the principle of scientific explanation of natural phenomena brought about by the quantum theory. The last fifty years record remarkable discoveries. These discoveries have their repercussions in the realm of ideas. Fifty years ago the belief in causality and determination was absolute. To-day physicists have gained knowledge but lost their faith. To understand properly the significance of such a profound change it will be necessary to discuss briefly how it all came about. Classical physics had begun with the study of astronomy. Physicists had taken the equations of celestial mechanics as their model of a universal law. Since matter had resolved into a conglomeration of particles, the ideal scheme was to explain all phenomena in terms of their motions and interactions. It was only necessary to set up a proper set of equations, and to take account of all possible mutual interactions. If the mass, position, and velocity of all the particles were known at any instant, these equations would theoretically enable the physicist to predict the position and motion of every particle at any other subsequent moment.

The phenomena of light did not at first fit into this simple scheme. With the discovery of the electron as a universal constituent of matter, the electromagnetic theory of Maxwell was converted into an electronic theory by Lorentz. To the dynamical laws were added the electromagnetic equations and the two together apparently gave an exact and ideal formulation of the laws of causality. It was more or less a matter of faith to maintain that if it were possible for us to obtain all the necessary data by delicate observations, universal laws would enable us to follow each individual molecule in this intricate labyrinth and we should find in each case an exact fulfilment of the laws and agreement with observation. The above in brief forms an expression of faith of a classical physicist. We see that it involves as necessary consequences, belief in continuity, in the possibility of space-time description of all changes and in the existence of universal laws independent of observers which inexorably determine the course of future events and the fate of the material world for all times.

II

The development of the quantum theory has raised fundamental issues. Facts have been discovered which demonstrate the breakdown of the fundamental equations which justified our belief in determinism. A critical examination of the way in which physical measurements are made has shown the impossibility of measuring accurately all the quantities necessary for a space-time description of the motion of the corpuscles.

Experiments reveal either the corpuscular or the wave nature for the photon or the electron according to the circumstances of the case, and present us with an apparently impossible task of fusing two contradictory characters into one sensible image. The only solution suggested has been a renunciation of space-time representation of atomic phenomena and with it our belief in causality and determinism.

Let me briefly recapitulate the facts. In 1900 Planck discovered the quantum of action while studying the conditions of equilibrium between matter and the radiation field. Apparently interchange of energy took place in discrete units whose magnitude depended on h and the frequency of the radiation emitted or absorbed by matter. Photo-electric emission had similar disquieting features. Einstein, therefore, suggested a discrete structure of the radiation field in which energy existed in quanta instead of being continuously distributed in space as required by the wave-theory. This light-quantum, however, is not the old light-corpuscle of Newton. The rich experimental materials supporting the wave-theory preclude that possibility altogether. Moreover the fundamental relation, $E = h\nu$, and $p = hk$, connecting energy and momentum of the photon with the frequency ν and the vector wave number k, makes a direct reference to idealised plane wave so foreign to the old idea of a corpuscle. Soon afterwards Böhr postulated the existence of radiationless stationary states of atoms and showed how it led to a simple explanation of the atomic spectra. The extreme simplicity of the proposed structure and its striking success in correlating a multitude of experimental facts at once revealed the inadequacy of the ordinary laws of mechanics and electro-dynamics in explaining the remarkable stability of the atoms.

The new ideas found application in different branches of physics. Discontinuous quantum processes furnished solutions to many puzzles. Suitably modified, the theory furnished a reasonable explanation of the periodic classification of elements and thermal behaviour of substances at low temperature. There was, however, one striking feature. It was apparently impossible to characterise the details of the actual transition processes from one stationary state to another, that is, to visualise it as a continuous sequence of changes determined by any law as yet undiscovered. It became clear that the dynamical laws as well as the laws of electromagnetism failed to account for atomic processes. New laws had to be sought out compatible with the quantum theory capable at the same time of explaining the rich experimental materials of classical physics. Böhr and his pupils utilised for a time a correspondence principle, guessing correct laws for atomic processes from analogy with the results of the classical theory. In every case these appeared as statistical laws concerned with the probabilities of transition between the various atomic states. Einstein tackled the problem of the equilibrium of matter and radiation on the basis of certain hypotheses regarding the probabilities of transition between the various states by absorption and emission. A derivation of the Planck Law was obtained by Bose by a suitable modification of the methods of classical statistics. Heisenberg finally arrived at a satisfactory solution and discovered his matrix-mechanics and a general method for all atomic problems. Dirac and Schrödinger also published simultaneously their independent solutions. Though clothed in apparently dissimilar mathematical symbols, the three theories gave identical results and have now come to be looked upon as different formalisms expressing the same statistical laws.

I have mentioned that the photon gave a simple explanation of many of the properties of radiation and thereby presented its corpuscular aspect while the well-known properties of interference and superposibility brought out its wave character. That the same dual nature may exist in all material corpuscles was first imagined by De Broglie. His phase-waves found quick experimental verification, and raised a similar problem of the real nature of the corpuscle. The formulation of wave-mechanics by Schrödinger, once raised a hope that by a radical modification of our usual ideas about the corpuscle it might be possible to re-establish the law of causality and classical determinism. Subsequent developments have shown such hopes to be illusory. His waves are mathematical fictions utilising the multidimensional representation of a phase-space and are just as incapable of explaining the individuality of the electron, as the photon is incapable of explaining the superposibility of the field. The true meaning of his equations appears in their statistical interpretation.

III

The adherents of the quantum theory interpret the equations in a peculiar way. They maintain that these equations make statements about the behaviour of a simple atom and nothing more than a calculation of the probabilities of transition between its different states is ever possible. There is nothing incomprehensible about such a statistical law even if it relates to the behaviour of a single particle. But a follower of determinism will interpret such statements as betraying imperfect knowledge, either of the attendant circumstances or of the elementary laws. We may record the throws when a certain die is cast a large number of times and arrive at a statistical law which will tell us how many times out of a thousand it will fall on a certain side. But if we can take into account the exact location of its centre of gravity, all the circumstances of the throw, the initial velocity, the resistance of the table and the air and every other peculiarity that may affect it, there can be no question of chance, because each time we can reckon where the die will stop and know in what position it will rest. It is the assertion of the impossibility of even conceiving such elementary determining laws for the atomic system that is disconcerting to the classical physicist.

Von Neumann has analysed the statistical interpretation of the quantum mechanical laws and claims to have demonstrated that the results of the quantum theory cannot be regarded as obtainable from exact causal laws by a process of averaging. He asserts definitely that a causal explanation of quantum mechanics is not possible without an essential modification or sacrifice of some parts of the existing theory.

Böhr has recently analysed the situation and asserted that we cannot hope any future development of the theory will ever allow a return to a description of the atomic phenomena more conformable to the ideal of causality. He points out the importance of the searching analysis of the theory of observation made by Heisenberg, whereby he has arrived at his famous principle of indeterminacy. According to it, it is never possible for us to determine the simultaneous values of momentum, and positional co-ordinates of any system with an accuracy greater than what is compatible with the inequality

$$\Delta p \, \Delta q > \frac{h}{4\pi}.$$

This natural limitation does not affect the physics of bodies of finite size but makes space-time descriptions of corpuscles and photons impossible. When we proceed to study the behaviour of the elementary particles, our instruments of measurement have an essential influence on the final results. We have also to concede that the contributions of the instrument and the object, are not separately computable from the results as they are interpreted in a classical way with the usual ideas of co-ordinate and momentum accepting thereby a lack of control of all action and reaction of object and instrument due to quantum effects.

It is in this imperative necessity of describing all our knowledge with the usual classical ideas, that Böhr seeks an explanation of the apparently irreconcilable behaviour of corpuscles and radiation in different experiments. For example, if we set our experiments in such a fashion as to determine accurately the space-time co-ordinates, the same arrangement cannot be simultaneously used to calculate the energy momentum relations accurately; when our arrangements have pushed the accuracy of determining the positional co-ordinates to its utmost limit, the results evidently will be capable only of a corpuscular representation. If, on the other hand, our aim is to determine momentum and energy with the utmost accuracy, the necessary apparatus will not allow us any determination of positional co-ordinates and the results we obtain can be understood only in terms of the imagery of wave-motion. The apparently contradictory nature of our conclusions is to be explained by the fact, that every measurement has an individual character of its own. The quantum theory does not allow us to separate rigorously the contribution of the object and the instrument and as such the sum total of our knowledge gained in individual cases cannot be synthesised to give a consistent picture of the object of our study which enables us to predict with certainty its behaviour in any particular situation. We are thus doomed to have only statistical laws for these elementary particles and any further development is not likely to affect these general conclusions.

It is clear that a complete acceptance of all the above conclusions would mean a complete break with the ancient accepted principles of scientific explanation. Causality and the universal laws are to be thrown simultaneously overboard. These assertions are so revolutionary that, no wonder, they have forced physicists to opposing camps. There are some who look upon causality as an indispensable postulate for all scientific activities. The inability to apply it consistently because of the limitations of the present state of human knowledge would not justify a total denial of its existence. Granted that physics has outgrown the stage of a mechanistic formulation of the principle, they assert that it is now the task of the scientists to seek for a better formulation. Others of the opposing camp look upon old determinism as an inhuman conception, not only because it sets up an impossible ideal, but also as it forces man to a fatalistic attitude which regards humanity as inanimate automata in the hands on an iron law of causation. For them the new theory has humanised physics. The quantum statistical conception of determinism nestles closer to reality and substitutes a graspable truth for an inaccessible ideal. The theory has brought hope and inspired activity. It constitutes a tremendous step towards the understanding of nature. The features of the present theory may not all be familiar but use will remove the initial prejudice. We are not to impose our reason and philosophy on nature. Our philosophy and our logic evolve and adjust themselves more and more to reality.

In spite of the striking success of the new theory, its provisional character is often frankly admitted. The field theory is as yet in an unsatisfactory state. In spite of strong optimism, difficulties do not gradually dissolve and disappear. They are relegated to a lumber room, whence the menace of an ultimate divergence of all solutions neutralises much of the convincing force of imposing mathematical symbols. Nor is the problem of matter and radiation solved by the theory of complementary characters. Also we hear already of the limitations of the new theory encountered in its application to nuclear problems.

The quantum theory is frankly utilitarian in its outlook; but is the ideal of a universal theory completely overthrown by the penetrating criticism of the nature of physical measurements?

Böhr has stressed the unique character of all physical measurements. We try to synthesise their results and we get probabilities to reckon with instead of certainties. But how does the formalism $\frac{h}{2\pi i}\frac{\partial\psi}{\partial t} = H\psi'$ emerge as a certain law? The wider the generalisation, the less becomes the content. A universal law would be totally devoid of it. It may nevertheless unfold unsuspected harmonies in the realm of concept. More than ever now, physics does need such a generalisation to bring order in its domain of ideas. M. A. G.

CHEMISTRY

President: Dr. R. C. Ray, D.Sc., F.I.C.

SOME ASPECTS OF MODERN INORGANIC CHEMISTRY

THERE are many who think that there is no future for inorganic chemistry, except in its application to industry. It is generally assumed that inorganic chemistry has progressed as far as it could with the tools at hand. The discovery of the inert gases of the atmosphere by Ramsay and his co-workers and practically all the missing elements seems to have added the last chapter to inorganic chemistry; and one may really wonder what is there left to be done. The accumulated treasures, no doubt, seem marvellous, but as each year rolls by we find ourselves, like Balboa, looking down from the mountain top, beholding an infinite and beautiful expanse, yet unfathomed. The vista continues to widen, and new problems, new theories, new view-points loom large before us.

The possibility of compound formation by the inert gas was first suggested by Villiard, who found that crystalline hydrates were formed when the inert gases admixed with water, were cooled under pressure. The structure of these hexahydrates would seem to be similar to that of the co-ordination compounds of the cobaltamine type. The recent work of Nikitin in U.S.S.R., have established the formation of $Rn.2C_6H_5OH$ and $Xe.2C_6H_5OH$ corresponding to $H_2S.2C_6H_5OH$ or $HCl.2C_6H_5OH$. Booth and Wilson have also obtained and studied the formation of $A.6BF_3$. The formation of these co-ordination compounds of inert gases opens up an interesting field of research, and a considerable amount of work still remains to be done in this direction. The formation of such compounds by the higher atomic weight inert gases is permitted also by theoretical considerations, which indicate besides that the other lighter inert gases may also form compounds after excitation. Thus while Helium does not form co-ordination compounds of the type mentioned, it is apparently capable of combining with mercury in presence of electric glow discharge at low pressures. The formation of several other helides such as WHe_2, etc., by the reaction of excited He atoms, has also been reported.

During the last thirty years, considerable progress has been made in the chemistry of Boron and its compounds, but a large amount of work still remains to be done, before adequate answers could be found for many questions which remain unanswered. The study of hydroborons and borohydrates has raised new

Scientific Notes of the Indian Meteorological Department—Vol. V, No. 50:

"Inversions of Lapse Rate of Temperature over Karachi" by A. S. Hariharan.

Scientific Notes of the Indian Meteorological Department—Vol. V, No. 51:

"A Preliminary Study of Rainfall at Quetta" by A. K. Roy and R. C. Bhattacharya.

Annual Report of the Imperial Institute of Veterinary Research.

Memoirs of the Indian Meteorological Department "On Evaporation" by S. K. Banerji.

Reviews.

THEORY OF ELECTRICITY AND MAGNETISM. By Prof. Max Planck. Translated by Henry L. Brose, M.A., D.Phil. (Oxon.), D.Sc., Macmillan & Co., Ltd., London, 1932.

This is an English translation of the third of a series of five volumes on theoretical Physics by one of the acknowledged leaders of thought in Modern Physics. The book aims at giving a unitary exposition of the Field Theory of Electricity and Magnetism and as such its arrangement and treatment of the subject are different from what are usually found in English treatises on the same subject.

English writers usually follow Maxwell as regards arrangement and method. Electrostatics, magnetism, current electricity and electrodynamics are generally treated as separate and independent branches of science with their own special laws. They usually begin with the Coulombian Laws of force based on the hypothesis of action at a distance and though the Field Theory finds a place in every book it occupies usually a very subordinate position. Emphasis is, on the other hand, mostly laid on the experimental aspects of the subject and the wealth of details given is apt to be a bit confusing to students of theoretical Physics. It is usually towards the end of the book that the classical equations of the Field Theory are deduced through which the final synthesis and fusion of the separate domains into one homogeneous whole can be achieved. This important task is, however, very often overlooked or is usually treated in a modest and neglected corner.

The author of the book under review prefers a different mode of exposition. Being one of a series of five works on theoretical Physics the book treats the subject of Electricity and Magnetism more or less in the same way as Mechanics of deformable bodies and of continuous material media are treated in the earlier volumes.

The ultimate aim of the theoretical physicist is to bring the divergent domains with their special laws under the sway of a minimum set of general principles from which all special laws would be deduced as particular cases. Such a survey of the whole field of physics from a single unitary standpoint is as yet unrealizable, but the author here has tried to bring about the rapprochement between the distinct subjects of Electrodynamics and Mechanics, by giving the principle of the conservation of energy and the principle of contiguous action a prominent position as in the other volumes.

A plausible deduction of the Laws of Maxwell is first attempted with the help of certain assumptions about the nature of electric and magnetic energies and with the idea of the flux of energy. Once the general laws of the Field Theory are established the author deduces the special laws of Electrostatics, Magnetism, Current Electricity and of quasi stationary electrodynamical phenomena, as special consequences of the same general equations which get more or less simplified owing to the special conditions which the electric and magnetic vectors satisfy in the different cases.

The principal consequences of the laws are then worked out for each of the separate branches of the subject, and the peculiarities of conception which the Field Theory involves are discussed lucidly and in a masterly manner. This survey of the whole field from a unitary standpoint proceeds systematically through domains of increasing complexity, and ends finally with the Electro-dynamics of moving bodies where already the weakness of the Maxwellian theory begins to show, and its failures and limitations are pointed out in the last chapter where references are also given to the greater generalizations achieved in this respect in recent times.

The perusal of the book will benefit immensely the reader who has got leanings towards the theoretical side of Physics: one should, however, remain conscious of the limitations of the method and of the one-sided character of such an account.

One of the advantages of the Field Theory according to the author is that the hypothesis of this theory are of more special nature than the rival theories based on the principle of action-at-a-distance. It is pointed out that whereas there have been different theories of action-at-a-distance in Electrodynamics there has been only one, that of Maxwell, based on the principle of contiguous action. A fewer number of undetermined constants occur in the theory than in any other. This very special nature makes the Field Theory capable of making comparatively unambiguous predictions about future events; it thus achieves more as a theory, than any other rival theories in the same field.

The method of deduction of the Field Equations which the author pursues, however, does not at all make it clear or plausible that only one unique formulation is possible of the Field Theory. Even when one accepts the principle of conservation of energy, the existence of the vector of flux and the principle of contiguous action, a large margin of possible alternative solutions still remains. The unambiguous nature of the answer expected from the Field Theory is thus not self-evident. For example, even if one accepts that the flow-vector is completely determined at every point by the electro-magnetic state it is not at all clear why this particular vector should depend on 'E' and 'H' alone and not also upon their space and time differential coefficients. There is no *a priori* objection against such a hypothesis (on the Field Theory). Exactly the same criticism might be made against the method of deduction of the fundamental equations. Maxwell's equations are not the only solution which suggest themselves of the equation (52*a*) of p. 21. It is easy to conceive of other solutions equally simple which, however, differ from Maxwell's equations in having additional terms in the right hand side of 27 (*a*) and 27 (*b*). Even the additional assumptions that in the statical case the general equations should break up into two independent sets which 'E' and 'H' will separately satisfy, will not remove the ambiguity. In fact the uniqueness of the Maxwellian theory does not follow from the general principles from which the author starts.

It is well known that various attempts have been made from time to time to deduce the Field Equations from some general Mechanical Principle like the principle of least action, and every such attempt has failed. The justification of the Field Equations in the special Maxwellian form is as yet to be furnished only by the crucial experiments. The equations thus remain up to this time a convenient empirical hypothesis which furnishes the best fit to the observed facts.

The empirical nature of the Field Theory is apt to be a little overlooked in an exposition such as the author has given in the book under review. A more satisfactory and, to our mind, a more logical procedure would have been to take the Field equations as tested hypotheses and then to show as is usually done in some books that these equations are compatible with the mechanical principles of conservation of energy and momentum if certain quantities are taken as representing energies, momentum and flux vector in the electro-magnetic field.

One misses also in this book, a discussion of the Lorentz equations which preserve the advantages of the Field Theory so admirably and meets at the same time the demand for a hypothesis involving a discrete structure of electricity as revealed by experiments. Not only do the simple equations of Maxwell and Hertz prove inadequate for moving bodies as the author himself points at the end of the book, but its unsatisfactory nature is apparent as soon as a rational theory of the dielectric or conducting media is attempted. An additional chapter on this question would have been welcome.

However much we would have liked our author to have gone further in the exposition of his subject in certain directions, the book in its present form, presenting as it does an admirably simple and masterly exposition of the Field Theory of Maxwell and Hertz will prove certainly of immense benefit to all students of theoretical Physics. The translator of the book deserves our grateful thanks for thus making once more accessible to the students of Indian Universities a really good book bearing the impress of a master-mind.

S. N. BOSE.

* * *

MODERN PHYSICS. *Lehrbuch der Theoretischen Physik*, Von. Joos. Akademische Verlaggesellschaft m. b. H., Leipzig 1932. Price 14 Marks.

The bold and rapid advances which, since the beginning of the present century, have revolutionised Physics, have also brought with them new problems for the teacher. The wealth of material which requires to be examined at least cursorily by every serious