luminous ring or corona was regarded at that time as a structureless aureole appertaining to the moon and not, as we know it now, the upper regions of the solar atmosphere, only visible during total eclipses.

Those who have observed total eclipses are familiar with the feelings of weirdness of the occasion, the chilly and damp nature of the air, and the behaviour of animal life, and many who will observe their first total eclipse this year will also be able to corroborate the following account of the 1715 eclipse given by Halley:

"I forbear to mention the *Chill* and *Damp* with which the Darkness of the Eclipse was attended, of which most *Spectators* were sensible and equally *Judges*: or the Concern that appear'd in all Sorts of *Animals, Birds, Beasts,* and *Fishes* upon the Extinction of the Sun, since ourselves could not behold it without some sense of Horror."

The eclipse of 1715 was followed by that of 1724, which took place in the month of May, and was the last to be observed as total in Great Britain. The track of totality passed over the southern portion of Ireland and the south-west portion of England, London being situated just outside the northern boundary. This eclipse was well observed, and Halley again played an important part in connexion with it.

After June 29, 1927, the next total eclipse that will be of special interest to observers in the British Isles is that which will occur in 1999 on August 11 (see Fig. 2). The central portion of the track just skirts the extreme southern coast of Cornwall, so that totality will only be visible to those stationed in the extreme south-west of England. At that remote epoch it is difficult to forecast what the work of the astronomer will be. It is safe to say, however, that the problems now studied during total solar eclipses will all be solved, but it is almost as certain that new problems will have arisen which will necessitate possibly still greater attention being paid to the study of the sun under eclipse conditions. Even if there were no scientific reasons for observing total solar eclipses, they must still attract close attention by reason of the remarkable solar phenomena which then become visible and the weird and awe-inspiring feelings which are aroused by the spectacle.

Spinning Electrons.

By R. H. FOWLER, F.R.S.

THE past fourteen or fifteen months have seen some striking advances and simplifications in theoretical physics. The trench warfare of the preceding three years, which consolidated the ground and marked out slowly the key positions for the new attack, is past. That attack has been launched with almost complete success. The first fury of the advance is perhaps now over. At least it is now possible to survey our older difficulties afresh, to find in many cases that they are no longer formidable. It therefore seems the right moment, and perhaps of general interest, to try to indicate the parts played in this advance by the more striking of the ideas associated with it—in this article the spinning electron. In a later article it may be possible to discuss similarly the other primary conception—the new mechanics, and particularly Schrödinger's equation. Without any assertion of finality in the description of electronic interactions by its means, the importance of the spinning model of the electron can scarcely be over-estimated. Yet the spinning electron has been so lost in the far wider ideas embodied in the new mechanics that it is as yet scarcely appreciated at its full value. It is convenient therefore to devote this article to it alone.

Without prejudice to the difficult prior questions of internal structure, we may regard the electron merely as a singularity in space—the source of the external field by which it is known to us. Until recently this singularity has always been assumed to be the simplest possible, with the external field of an electrostatic point charge acting radially and symmetrically in all directions. The first serious suggestion that the electron should be treated as a more complicated singularity appears to have been made by A. Compton (*Jour. Franklin Inst.*, **192**, 145, 1921). In connexion with a survey of gyromagnetic, diamagnetic and ferromagnetic phenomena he suggested that the singularity might be such as to give rise to the magnetic field of a magnetic doublet besides the usual electrostatic field. Structurally, such an electron must have an axis of symmetry—the doublet axis—and it is natural to think of its magnetism as arising from a spin of its charge about this axis, which will therefore also be its axis of mechanical angular momentum. The fields above mentioned are of course the fields of the electron relative to a set of axes in which its centre is at rest. Relative to other axes they must be derived by the transformation of Lorentz.

We will now show in turn how the use of this more complicated model of the electron resolves the remarkable set of paradoxes in which atomic theory had involved itself by the spring of 1925, owing, as we now see, to the use of an inadequate mechanical model. The most clear-cut of these depends on the statistical conception of weight, so that its appeal is perhaps not so direct as that of some of the others. We know, by a purely enumerative study of atomic spectra and their structure in magnetic fields, the total number of states which must be associated with any one spectral term of an atom or ion. This total is the statistical weight of the term. We know further that spectral terms can be grouped into sets, each characterised by a maximum multiplicity R. If R is one, all the terms are single. If R is two (for example, for sodium), the S terms of the set are single and the rest double, and so on. The weight, as counted above, for an S term of a spectrum of maximum multiplicity R is always R. Now the normal state of any once ionised atom is the core of the atom during the various stages of capture of the next electron. The weight of the core is therefore R, indicating that it can split under perturbation into just R different states. The new electron then comes in, and describes its possible orbits about the core in an approximately central field of force. If the electron is a point charge there seems no escape whatever from the conclusion that the total number of states of total quantum number n must be asymptotically equal to n^2 for large n, and the total number of states of core and orbital electron Rn^2. The actual number found is $2Rn^2$ for all n in all cases. No form of the quantum theory yet propounded offers a rational escape from this paradox, *unless the electron has a structure*. The difficulty of avoiding the enumerative difficulty in any other way is exceedingly grave, though it lies rather deep and is not readily appreciated. Its gravity comes from the fact that it depends solely on the number of degrees of freedom and an asymptotic approximation at great distances to the law of the inverse square for the force between the electron and the ion, which can scarcely be called in question. If, however, the electron spins and can set its axis at just two inclinations relative to the plane of its orbit, the paradox disappears.

The second paradox was the better-known anomalous Zeeman effect. By Larmor's theorem the action of a magnetic field on any stationary state of any atom should split the state into a number of states equidistantly spaced, and this spacing should be the same whatever the original state. As a result every spectral line should split into a certain triplet called the normal Lorentz triplet. In fact, such triplets are rare, being found only for lines of singlet systems. The general more complicated splitting structures found can be formally described by assigning to each state a splitting factor g depending on the type of the state. Larmor's theorem asserts that $g=1$ always. It has been known for some time that the anomaly could be formally explained if the magnetic moment of the atom arose from two sources, of which one was the orbital angular momentum contemplated by Larmor's theorem. The other source must then be such that its ratio (magnetic moment)/(mechanical moment) is twice the ratio of the magnetic and mechanical moments arising from orbital motion. The spin of the electron provides just this source of supply, and exact examination shows that it provides a complete explanation.

The third paradox was the so-called relativity-doublet formula, for the separations found between pairs of X-ray or pairs of optical terms. Familiar cases are the separations of the $K\alpha_1$, $K\alpha_2$ X-ray doublet and the D-lines of sodium. The separations which obey the theoretical formula vary in absolute magnitude by a factor of 10^7, which is accounted for by its salient feature, a factor approximately Z^4, where Z is the atomic number. It was thought most unlikely that any other type of perturbation could supply just this vital factor, but it is impossible rationally to accept this origin. For if we do, the sodium doublet, for example, must be interpreted as due to the difference of energy, owing to the variation of mass with velocity, of orbits of azimuthal quantum numbers one and two and the same total quantum number in an inverse square field. At the same time the much greater difference between the *pair* of P orbits and the S orbit, for example, must be interpreted as a difference of energy due to differences of penetration into a non-inverse-square field again by orbits with different azimuthal quantum numbers one and two. The pair of P orbits must for one purpose have the same and for another different azimuthal quantum numbers! If, however, the electron has a magnetic moment, there will be a secular perturbation of its axis by the magnetic field which arises from the linear velocity of the electron in the field of the nucleus, and a corresponding secular perturbation of the plane of the orbit. We can at once show from this that the energy of a single orbit in a central field of force splits up into a set of energies the differences of which vary as Z^4 as required. Finally, if the ratio (magnetic moment/mechanical momentum) required for the Zeeman effect is assigned to the electron, and the calculation of the perturbation exactly carried through, we obtain the proper quantitative formula for the doublet separation. This now enters as the difference of energy between orbits, otherwise the same, for which the momentum of the electron $h/2\pi$ has its two different orientations with respect to the plane of its orbit.

It was of course this success which finally established the value of the spinning electron. The idea and its development in this connexion we owe to Goudsmit and Uhlenbeck. Bichowsky and Urey obtained independently most of the same results. The finally correct numerical form of the separation formula is due to Thomas.

Two further paradoxes may be mentioned. One was that it appeared from a study of the behaviour of spectra in strong magnetic fields (Paschen-Back effect) that four quantum numbers must be used to specify the orbit of an electron. If the electron is a structureless point, with therefore three degrees of freedom, three quantum numbers are the maximum allowed by any form of quantum theory yet proposed. But if the electron has a rigid structure, it has in all six degrees of freedom. If further, as is assumed, its axes of spin and angular momentum always coincide, its orbits can be fully described by five quantum numbers, of which one, defining the magnitude of the spin, is invariable and may be ignored.

The last paradox to be mentioned is the following. In spite of numerous attempts to produce a coplanar model of the helium atom, most physicists have remained convinced that the normal state of helium must correspond to orbits filling three-dimensional space round the nucleus. But there was then the grave difficulty that a diamagnetic atom could not result. Two equal moment-vectors cannot have a zero resultant unless they are oppositely directed and the orbits coplanar. But when the moments of the electrons are added, there are four vectors to combine and the difficulty disappears.

We see then how the spinning electron has brought order out of chaos in the broad outlines of atomic theory. Its necessity and its successes are qualitatively independent of the new mechanics. Without in any way underrating the importance of the new mechanics, it is fair to say that its first effect on the determination of atomic weights and energy values is confined to small adjustments, such as replacing an integer n by $n+\frac{1}{2}$, or n^2 by $n^2-\frac{1}{4}$. (It is not until we come to the extremely important resonance theory of Heisenberg that the new mechanics brings in primary effects on the energy values.) These refinements are of course necessary for the correct theory. But the broader difficulties we have been discussing depend solely on the spinning electron for their solution, and order reigns once again.

It would not be right in a description of the recent work on the spinning electron to pass over in silence a remarkable essay by L. V. King.[1] This embodies an attempt to break right away from the recent trend of atomic physics, to find in h a characteristic constant of a spinning electron, and to develop thereby an almost classical theory of matter and radiation which hopes to avoid all the old classical difficulties without appeal to external postulates such as those of the quantum theory. The exposition given hitherto is, it must be confessed, difficult to follow, and it is difficult to believe that the author has really proved all that he states. A fuller exposition would clear up such points. There is much to admire in gallant excursions such as this; whether they turn out right or wrong it is by such excursions that physics lives.

[1] "Gyromagnetic Electrons and a Classical Theory of Atomic Structure and Radiation." (Montreal: Louis Carrier; Cambridge: Heffer.) 5s.

Obituary.

MR. T. S. P. STRANGEWAYS.

THOMAS STRANGEWAYS PIGG STRANGEWAYS, who died prematurely after a month's illness at Cambridge on Dec. 23, was a retiring man of strong character who had done remarkable work in pathology and tissue culture. Born on Dec. 28, 1866, his original name was Pigg, which he changed to Strangeways on his marriage. Educated medically at St. Bartholomew's Hospital, where he obtained the Matthews Duncan gold medal (1895) and took the qualification of the Conjoint Examining Board (M.R.C.S., L.R.C.P.) in 1896, he was assistant curator of the Museum and came under the inspiring influence of the late A. A. Kanthack, with whom he early collaborated in the *Journal of Pathology and Bacteriology* and in the *Transactions of the Pathological Society of London*. He accompanied that distinguished pathologist when in 1897 he left St. Bartholomew's to become professor of pathology at Cambridge.

Strangeways was appointed demonstrator of pathology in 1897, and held this office under Sir German Sims Woodhead until after the War, so that many generations of Cambridge medical students hold his teaching in grateful remembrance. His handbook on "Clinical Pathology and Practical Morbid Histology" passed into a seventh edition in 1912. He was made an honorary M.A. of the University in 1900, and in 1905 became the first Huddersfield lecturer on special pathology, this endowment being provided by a fund collected by Sims Woodhead from friends residing in or connected with Huddersfield.

Up to this time, Strangeways' life and work had been those of an ordinary university demonstrator, but he now struck out a new line in the intensive study of special diseases of a chronic nature and, under the ægis of a strong committee, energetically and successfully organised a special hospital for the investigation of selected cases. This research hospital, at first in a small private house, was in 1912 properly accommodated in a specially built hospital which was opened on May 24 by the late Sir Robert Brown of Preston, a generous benefactor to the institution. Already four thousand cases of rheumatoid arthritis had been exhaustively investigated pathologically, clinically, and therapeutically; researches had been made into gout, purin metabolism, and the opsonic index by Strangeways and the keen collaborators he gathered together; the results of these researches were collected in the five well-illustrated volumes of the "Bulletin of the Committee for the Study of Special Diseases." The museum of the research hospital contained 2000 arthritic joints dissected and mounted by him.

For the first three years of the War the work was suspended, as the hospital was given over to wounded officers, but continuation of the work showed that at least seven pathological forms of rheumatoid arthritis can be recognised clinically. In 1923 the wards of the hospital were again closed for a time in order to concentrate on tissue culture *in vivo* and *in vitro*, with the object of studying cancer patients in the hospital. The extremely valuable results thus obtained appear in Strangeways' papers in the *Proceedings of the Royal Society*, and his books, "Tissue Culture in Relation to Growth and Differentiation" (1924) and "The Technique of Tissue Culture *in Vitro*" (1924). His observations on the effect of X-rays and radium on tissue cells growing *in vitro* deserve special attention. Thus beginning as a pathologist, he became a biologist, as was eloquently shown in "G. P. B.'s" tribute in the *Times* of Dec. 30.

Strangeways had the power of communicating his enthusiasm to others, and was a lovable collaborator. He bore his infirmity of deafness with admirable patience, and has left a memory behind him which his friends will ever regret. Unfortunately his family are left with very scanty means, and five of his seven children are boys whose education is not completed, the youngest being eight and the eldest twenty-one years of age.

H. R.

PROF. R. W. PHILLIPS.

THE late Prof. Reginald W. Phillips, who had been head of the Department of Botany at the University College, Bangor, for nearly forty years, was born at Talgarth, Breconshire, on Oct. 15, 1854. He took the two years' course of training at the Bangor Normal College, where he was certificated as elementary school teacher in the December of 1874. During 1875 he was headmaster of a school in Ferndale, but soon left to become lecturer at his old college, where he remained until 1881. He then became a scholar of St. John's, Cambridge, at the same time studying for the London B.Sc. In 1884 he was appointed head of the Department of Biology at the newly established Bangor College, and a little later he became professor of botany. As the University of Wales had not then come into existence, the college confined itself to the preparation of students for London degrees; and as there was no efficient system of secondary education the devoted band of teachers at the college had, for years, to hold matriculation classes, in addition to the ordinary degree courses.

Prof. Phillips was a keen observer, and an excellent field naturalist. He became an enthusiastic student