The New Elementary Particles

By PROF. E. N. DA C. ANDRADE

ABOUT three years ago, the first period of investigation of the structure of the atomic nucleus may be considered to have closed. This period, of which the achievements include the artificial disintegration of the nuclei by alpha particles, the investigation of the energies of the protons ejected from these nuclei and the first investigation of nuclear levels by means of the beta ray spectra, was characterised by the general belief that all nuclei were, in the ultimate, to be considered as being built up of protons and electrons. The only other particle of an elementary kind which was considered as a nuclear constituent was the alpha particle, and this was generally accepted as being itself built up of 4 protons and 2 electrons.

It was stated as axiomatic that the unit of mass was always found in conjunction with the unit positive charge, and that the electron, the unit charge of negative electricity, had no positive counterpart—the unit positive charge could not exist apart from matter, in the ordinary sense, or the unit of matter apart from positive charge. Not only have both these beliefs proved to be untenable, with the result that, as will be discussed later, the electron is no longer considered to be one of the ultimate constituents of the nucleus, but also a particle of mass 2 and charge 1, which is, then, an isotope of hydrogen, of double the mass of the ordinary hydrogen atom, has been discovered. The new particles—the neutron, the positive electron or positron, and the isotope of hydrogen—have recently been the subject of a number of important researches, and their discovery has, as is usually the case, solved certain problems, and raised a host of new ones in their place.

The discovery of the neutron was the result of work in Germany, France and England, but the critical experiments found Cambridge ready to recognise their implication, since, many years ago, Lord Rutherford had contemplated the possible existence of such a particle, that is, a particle having mass, but no charge, in contradistinction to the electron which has charge but no material mass. He had even looked for it, but without success. The first step towards the new discovery was furnished by the experiments of Bothe and H. Becker, who in 1930 were working on the effect of bombarding various elements with the alpha rays from polonium, which have the advantage of being free from the accompaniment of beta and gamma rays. They were looking for long-range protons on the lines of the experiments of Rutherford, Chadwick, Pose and others. They found that certain light elements, notably lithium, boron and fluorine, gave rays which passed through 2 mm. of brass, while beryllium was particularly productive of such rays. The rays were more penetrating than was to be anticipated of any known corpuscular radiation, and the experimenters assumed without question that they were gamma rays.

The work was continued by Joliot and Irene Curie-Joliot, who used a much stronger source of polonium and showed that the radiation excited in the beryllium nucleus could penetrate several centimetres of lead: since then, it has been detected through 30 cm. of this metal. The French workers found that the beryllium radiation could expel protons from paraffin wax, protons which they detected in a Wilson cloud chamber. The range of these protons was, however, such as to offer great difficulties on the supposition that the radiation was of a wave nature, impelling the protons by the Compton effect. It was left for Chadwick, who, within a day or two of the French publication, was experimenting on the subject, to point out that all the difficulties could be met if the radiation was of a particle nature.

Both a wave-packet and a particle can transfer energy and momentum to a second particle. In both cases a particle of a certain energy, $h\nu$ for a wave-packet, and approximately $\frac{1}{2}mv^2$ for a particle, strikes the proton, say, considered to be at rest: the result of the collision is that the proton moves off in a certain direction with a part of the energy, while the impinging unit moves off in another direction with the remainder. In the case of an impinging particle, however, the momentum is obtained from the energy by multiplying by 2 and dividing by the velocity of the particle in question (supposing that relativity considerations can be neglected), while in the case of the wave-packet we divide by c. Since we have to consider both energy and momentum equations, the laws of collision are clearly different in the two cases, one where we deal with particles only, and the other where we deal with wave-packets and a particle. Suffice to say that the observed range of the struck proton can be easily reconciled with the particle law, but not with the Compton, or wave-packet, law. The deciding factor is not a qualitative observation, which furnishes no criterion, but a quantitative measurement.

The particle concerned clearly cannot have any charge, or its interaction with matter would stop it within a small fraction, of the order of a hundredth, of the distance which it actually traverses in a metal. Since Chadwick's announcement early in 1932, neutrons have been produced from other light elements, for example, boron, and by other means than the impact of alpha particles, notably that of protons accelerated in an electric field. The equations for the transfer of momentum which established the particle nature of the neutron, also showed that its mass is approximately that of the proton. The exact mass of the neutron can be obtained by considering the masses of the particles concerned in its production ; for example, in the case of an alpha particle striking the nucleus of the 11 isotope of boron

$${}_5B^{11} + {}_2He^4 = {}_7N^{14} + n,$$

the neutron being denoted by n. The masses being accurately known from Aston's measurements, and allowance being made for the mass equivalent of the kinetic energy, a value of 1·0066 was obtained by Chadwick, which has been confirmed by the consideration of collisions with other atoms*. Other methods give slightly different results, however, and while it can be stated that the mass of the neutron lies very close to that of the proton, there is some doubt as to whether it is slightly greater, slightly less, or equal to that mass.

The history of the positive electron starts with the experiments of C. D. Anderson, of Pasadena, who was using a Wilson chamber, operating in a magnetic field of some 15,000 gauss, to detect particles released by cosmic rays. The curvature of the tracks of the particles gives their energies, but the sign of the charge cannot be decided unless we know the direction in which the particle is travelling. Anderson found not only that a particle, which from the appearance of the track (density of ions) was an electron, could pass through a plate of lead 6 mm. in thickness placed across the chamber, but also that the curvature was markedly different on the two sides of the plate. Supposing, as is only natural, that the greater curvature is on the emergent side of the plate, we can at once deduce the direction of travel, which, in the case of one of Anderson's early photographs, implies a positive charge on the particle. The mass of the particle can be deduced from the fact that the velocity of a particle making a track of given curvature in a given field depends upon its mass, while the ionisation depends upon the velocity and the charge, but not on the mass. Ordinarily, the ionisation produced by a proton of given curvature of path will be much greater than that produced by an electron of the same curvature in the same field. Anderson concluded that he had a record of a particle of positive charge and of mass much less than that of a proton.

About the same time, Blackett and Occhialini were experimenting on the same lines with a chamber in a magnetic field, with the great advantage that, with the help of a coincidence method employing Geiger-Muller counters, they had devised an automatic release, the effect of which was that the expansion only took place on the passage of a cosmic particle, when they had something to record. They obtained records of groups of particles, often round about twenty in number, the tracks of which all radiated from a point. This furnishes a new type of evidence of direction of travel, since it is very difficult to imagine any mechanism which can lead to many independent particles all rushing to the same point. The groups, or 'showers' as the experimenters called them, are evidently produced by one cosmic ray particle of high energy interacting with an atom of matter in the neighbourhood of the chamber. By a consideration of the tracks in showers and of tracks passing through a plate of metal, of the ionisation, the field and the curvature of the tracks, Blackett and Occhialini were led to the conclusion that the particles had a positive charge of magnitude equal to that of the electron charge and had the mass of the electron. To such particles, the name positive electron or positron has been given. The same conclusion has been furnished by further experiments of Anderson. It is noteworthy that Dirac's theory had already, in a sense, predicted the existence of such particles, and also given a reason why they should only be observed under exceptional conditions, since their free life must be very short.

The discovery of the isotope of hydrogen, of mass 2, has been so recently discussed in NATURE (March 31, p. 481) that there is no need to trace its history. Let us call the nucleus of mass 2 and charge 1 a diplon, and write it ${}_1H^2$, while a hydrogen gas made up of molecules of this kind, ${}_1H^2{}_2$, we will call diplogen. The use of the new atoms as projectiles has led to very interesting results in the field of artificial disintegration. In the experiments of Lawrence, Lewis and Livingstone, of Rutherford and Oliphant, and of Cockcroft and Walton, bare diplons produced in a discharge tube are accelerated in a field of some hundreds of thousands of volts, and the stream is directed on to light elements. Nuclear reactions of the type

$${}_5B^{10} + {}_1H^2 = 3\ {}_2He^4$$

have been produced, to be added to what is fast becoming a special chemistry of the nucleus. Oliphant, Harteck and Rutherford have been led by this type of experiment to the belief that the helium isotope ${}_2He^3$ can exist.

According to G. N. Lewis and his collaborators at Berkeley, a diplon has been recently disintegrated into two protons by proton bombardment, the energy of the impinging particles corresponding to 1·5 or 3 × 10^6 volts, so that in any case there is no need to consider it as a fundamental constituent of atomic nuclei. Lawrence

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* See also NATURE, August 18, p. 237. Ed.

and his collaborators, and Cockcroft and Walton, have likewise found that the diplon is unstable in a strong nuclear field. As for the alpha particle, while it is convenient, especially for radio-active considerations, to regard it as a separate entity, there is little doubt that it is a particularly stable structure built of the fundamental entities of nuclear structure.

We are left then with the neutron and the positron as fundamental new particles to be added to the proton and the negative electron. Clearly, on paper, two or more kinds of these particles can be used to build up nuclei of any given mass and charge. Before the new discoveries, the proton and the electron were taken as basic particles: there is now a measure of agreement that the proton and the neutron are to be taken as the fundamental constituents of all nuclei, the electron as such having no existence in the nucleus.

The reasons that have led to this conclusion can only be very briefly indicated. One is that difficulties concerning the measured spin of certain nuclei, which arise if the electron be considered as a nuclear component, can be explained on the proton-neutron basis. Again, the number of particles in the nucleus gives a wrong type of statistics for the nuclear particles, as evidenced by the alternating intensities in band spectra, if the electron is admitted as a nuclear particle. For nitrogen, for example, the total number of nuclear particles should be even, as it is on the basis of 7 protons + 7 neutrons, while it is odd on the basis of 14 protons + 7 electrons. Another argument against the nuclear electron is furnished by Dirac's electro-dynamics, which leads to grave difficulties if we try to confine an electron in the limited nuclear space. A rough analogy, which must not be pressed, is offered by the classical treatment of the light quantum, which must travel and cannot be confined to one spot. Fermi suggests that the electron is ejected from the nucleus by a quantum switch somewhat analogous to that which ejects the photon, or light quant, from the atom. When a neutron switches over to a proton a negative electron is liberated; when a proton switches over to a neutron a positive electron is yielded. We can, then, think of neutron and proton as two different internal quantum states of one and the same fundamental particle.

Finally, a word may be said about the hypothetical 'neutrino', a particle which not only has not been detected, but may even be impossible to detect. The trouble is that the experimental facts of the beta ray spectrum are against the conservation of energy and momentum, both linear and angular: on the other hand, the conception of conservation is a valuable and familiar tool, the use of which is involved in all our usual atomic calculations, and the desire to preserve it justifies strange assumptions. Now the conservations can be retained even for the beta ray spectrum if we introduce a new particle with certain *ad hoc* properties. The mass must be much less than that of the electron, probably zero, like that of the light quant. The spin quantum number must be ½, as with the proton and electron. The ionisation produced must be extremely minute, say one ion in a path of 150 km. in air at N.T.P., which is one reason why detection is so unlikely: further, any reaction with nuclei must be extremely small. A particle with these properties and lack of properties has been called a neutrino. An entity which it is practically impossible to detect is not a very attractive hypothesis, but in the present stage of development it is, to say the least, a convenient way of expressing our difficulties about conservation—of packing them all in one bag, as it were. The neutrino may be likened to one of the face-saving formulæ so popular with our statesmen: it may not solve any problem, but with a new word it stops troublesome questions for the time being.

Recent Gliding Performances and their Meteorological Conditions

By SIR GILBERT WALKER, C.S.I., F.R.S.

THE impelling force in the life of one at least of the ablest designers of sailplanes and aeroplanes is the desire to quicken and cheapen transport, with the object of facilitating acquaintance with other countries and promoting international good feeling. Whether the need of national defence is admitted or not, airmindedness is warmly to be welcomed, and far more people can cultivate it by sailplanes than by power-driven machines. But in Great Britain, habits change slowly, and comparatively few have realised the chances offered by gliding of indulging their love of adventure, or of developing the team spirit.

Even in Germany, where the movement secured a firm hold owing to treaty restrictions on power-flight, the removal of the restrictions ten years ago led to a critical period when the survival of gliding was in doubt: the situation was then saved by the formation of the Rhon-Rossitten Association, with a material subsidy from Government, a central institution for research, and the consequent growth of technical ability. In England, growth has naturally been dependent on local enthusiasm: of the clubs that were started, many lasted long enough to train their members to glide downhill for short periods: but it is