FUNDAMENTAL PARTICLES*

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IN the last fifteen years, the situation in fundamental physics has undergone a remarkable change. Previously only very few elementary particles were known; and optimistic observers, in fact, believed that it would be a comparatively simple task to elucidate the inter-relations of these particles and to account for the values of the few dimensionless constants (such as the fine-structure constant and the ratio of proton to electron mass) derivable from them. It was even said that the end of physics might be in sight.

Since then, however, discoveries of new elementary particles have followed each other at a rapid pace. No one would feel satisfied that a list which one could make up now was likely to be complete, and a great deal of further investigation is required to understand the relations between all these particles and to determine, let alone explain, the values of all constants arising from them.

The fundamental characteristics of elementary particles are as follows: mass (in units of proton mass), charge (in units of electron charge), spin (unit $\hbar = \frac{h}{2\pi}$), magnetic moment (in units of the Bohr magneton μ , or of the nuclear magneton $\mu_N = \frac{\mu}{1830}$), processes of generation and destruction, and their relation to other particles.

Elementary particles known before, say, 1930 were:

(1) *The electron*, with a mass of $\frac{1}{1830}$, a charge of $-e$, a spin of $\frac{1}{2}$ and a magnetic moment of -1 magneton.

(2) *The proton* (or hydrogen nucleus), of mass 1, charge $+e$, spin $\frac{1}{2}$. Its magnetic moment was later found to be about $+2.8$ nuclear magnetons. This somewhat surprising result indicates that the positions of the electron and proton are not quite analogous, since Dirac's wave equation in its simplest form would predict a magnetic moment inversely proportional to the mass. A possible explanation for this apparent discrepancy will be mentioned later.

(3) *The photon*. It may appear odd to classify the photon as a particle, but it does fall well within the list of fundamental units under discussion. It evidently has no rest mass or charge, and its spin is 1. The easiest way to justify attributing a spin of 1 unit to the photon is to remember that a photon in a given state of motion, say having given momentum and direction, is still not uniquely described unless its state of polarization is specified. There are two independent states of polarization, and one might for that reason expect the spin to be $\frac{1}{2}$, which would give rise to two orientations. More detailed analysis shows that the symmetry properties of light waves require the spin to be 1, so that the photon would have, in principle, three orientations (corresponding to the three components of the field vectors describing the wave) with one of these orientations being ruled out by the conditions that the waves are transverse.

Recent work has added the following particles to this list:

(4) *The positron* was predicted by Dirac to avoid the difficulties that would otherwise arise from the

solutions of his wave equation for negative energy. He imagined a state of affairs in which all conceivable states of negative energy were already filled, thus preventing, by Pauli's principle, any fresh electrons from acquiring negative energy; but occasionally one of these states might be empty, thus resulting in a lack of negative charge (hence the presence of a positive charge) and the lack of a quantity of negative energy (thus representing a particle of positive energy). The existence of this particle in cosmic rays was discovered by Anderson, and in laboratory processes by Blackett and Occhialini. It clearly must have a mass equal to the mass of the electron, a charge of $+e$, a spin of $\frac{1}{2}$ and a magnetic moment of $+1$ magneton. According to the theory of Dirac, the vacancy among the negative energy states, represented by a positron, can be filled if a negative electron is present which can jump into that vacant place. In other words, an electron and a positron together can be destroyed, with their kinetic energy and rest energy going into other forms of energy, such as radiation. Conservation of momentum requires for this two light quanta, unless the process takes place near a centre of force such as a nucleus. The inverse process is the generation of a pair of electrons (positive and negative) by the collision of two photons or by the passage of one photon through matter. Of these, only the second is of practical significance.

(5) *The neutron* was recognized by Chadwick in 1932 as a result of nuclear reactions. Its mass is approximately one unit, its charge, of course, is zero, its spin $\frac{1}{2}$ and its magnetic moment about -1.9 nuclear magnetons. It was realized at once that the neutron was the missing constituent of all nuclei, and that all known facts about nuclei suggest that they consist of neutrons and protons.

In that case, the existence of beta-transformations, in which electrons or positrons are emitted by nuclei, has to be accounted for by assuming that these electrons do not normally exist inside the nucleus (which would be difficult to reconcile with the laws of quantum mechanics), but that they are generated in the process of emission, just as pairs of such particles can be generated in the pair creation referred to above, or as photons are generated in the emission of light by an atom. Conservation of charge requires that, upon the emission of, say, a negative electron, a neutron inside the nucleus is converted into a proton. Hence the number of neutrons and protons in a physical system is not fixed; only the sum of the number of neutrons and protons is fixed.

The simplest case of such a transformation would be the decay of a bare neutron into a proton, with the emission of a negative beta-ray. Present evidence about the mass of the neutron indicates that it is greater than that of a hydrogen atom, so that the process is energetically possible. It has not so far been observed, but conditions for observing it are extremely difficult.

(6) *The neutrino*. While conservation of charge is evidently in order in the process of beta-transformations, there is difficulty with the conservation of spin, since an electron of spin $\frac{1}{2}$ is produced; this cannot be balanced by any change in the orbital angular momentum of the emitting system, which is capable only of changing by integer units. There are also difficulties with energy conservation, since the observed beta-particles show a continuous spectrum, while the remaining nucleus appears to be in a definite quantum state. Those difficulties can be overcome by adopting Pauli's hypothesis of the

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existence of a neutrino, that is, a particle of a mass at most of the order of the electron mass and probably less, of no charge, and spin $\frac{1}{2}$. This would rectify the difficulty with conservation of spin, and it could clearly take up the amount of energy which appears to be missing from the balance. Experiments designed to detect any action due to neutrinos have given a negative result, and it is estimated that neutrinos would have been detected in these tests if their magnetic moment were comparable to one nuclear magneton. It is, in fact, likely that the magnetic moment of the neutrino is zero.

The free neutrino must satisfy a wave equation like Dirac's equation for the electron and, in order to avoid trouble with negative energies, one has again to assume that its negative energy states are filled. Any vacancies in those negative energy states would again mean the existence of a particle which bears the same relation to the neutrino that a positron has to the electron. If the neutrino has no magnetic moment, this 'anti-neutrino' may, in fact, be identical with the neutrino itself; if there is a magnetic moment, the anti-neutrino must have a magnetic moment of opposite sign and would, therefore, be distinguishable.

The description of the processes involving the generation of an electron (or positron) and neutrino was formulated by Fermi. The inverse process of absorption of an electron by a nucleus with the emission of a neutrino should also be possible; but estimates based on the purely statistical argument of detailed balancing show that the cross-section for this process should be extremely small, of the order of 10^{-44} cm.², so that the detection of neutrinos by this means is practically impossible. The only direct support given to the neutrino hypothesis is the fact that the lack of energy balance appears to be coupled with a lack of momentum balance, detectable by the recoil of the nucleus. The neutrino theory makes a definite prediction about the amount of the extra momentum to be expected in each case, and recent experiments appear to confirm this prediction.

(7) *The meson.* The existence of a particle of a mass of the order of 200 electron masses was first predicted by Yukawa to account for the properties of nuclear forces. Neutrons and protons in the nucleus must be held together by forces which are strongly attractive at close approach but negligible at larger distances. Since there can be no direct action at a distance, these forces must be transmitted from one particle to another by some sort of field. The only types of field equations compatible with relativity are those governing also the wave function of a particle either with or without mass. Without rest mass one would obtain equations like those of the electromagnetic field, which give the inverse square law and hence are not compatible with the properties of nuclear forces. Introducing a rest mass, one obtains equations capable of giving the right kind of law, providing the mass is chosen to be about 200 electron masses. Charged particles with masses of that order were found in cosmic rays, and support was thereby given to Yukawa's theory, according to which a proton could change into a neutron with the emission of a positive meson, and the opposite change could take place giving a negative meson, provided sufficient energy was available to make up the rest energy of the meson. In cases where this excess energy is not available, the virtual possibility of this process leads to an interaction between proton and neutron of the required type.

According to this view, a proton will spend a

fraction of its time tending to become transformed into a neutron and a meson. The energy needed for accomplishing this is not available, and therefore this transformation will not actually take place; but since, when accomplished, it would lead to the existence of a particle rather lighter than the proton, with a correspondingly higher magnetic moment, the brief instant when a meson tends to appear has a substantial influence on the total magnetic moment of the system. This is likely to explain the fact referred to above, that the magnetic moment is greater than one nuclear magneton. The reverse process applied to the neutron similarly accounts for the existence of a negative magnetic moment of the neutron. The same view predicts that some fraction of the charge of the proton is spread out over the meson field surrounding it, and this should lead to observable effects in processes, such as the emission and observation of gamma-rays by nuclei of light elements, which depend on the charge and current distribution. The experimental evidence on this point is not yet, however, very clear.

If this theory is adopted, the meson must have an integer spin. Theories have been advanced in which this spin is either 0 or 1, and certain difficulties connected with the magnitude of the forces at extremely close approach can be avoided if it is assumed that the forces are due to mesons with both these values of the spin. Evidence from cosmic rays seems to indicate that mesons observed at sea-level cannot have spin 1, and if mesons of spin 1 exist they cannot survive the passage through the atmosphere.

The ordinary mesons (presumably of spin 0) are known to be beta-radioactive, and this has given rise to the suggestion that the ordinary beta-transformation, as observed in the nucleus, might be the result of a double transition in which, say, a neutron tends to transform into a proton plus a negative meson, the latter not being able to form in free space because the energy for its rest mass is not available and, therefore, transforming in turn into an electron plus a neutrino.

A quantitative study of this double transition shows, however, that the observed radioactivity of the meson is insufficient to account for the observed beta-decay constants by this double process. The suggestion has, therefore, been made that the latter is mostly due to the mesons of spin 1; there would then have to be ascribed to them a shorter life for beta-decay, which would satisfactorily account for their absence from cosmic ray observation.

There are, therefore, arguments for the existence of at least two kinds of mesons. In addition, the evidence from nuclei of light elements indicates strongly that the forces between like particles (two neutrons or two protons) is as strong as that between unlike particles, and this is hard to understand unless there exist neutral mesons as well as charged ones. Again, in all likelihood both values of spin, 0 and 1, would have to occur for each kind.

It is not settled whether the masses of mesons of spin 0 and 1 should be the same or different. Theories of the nuclear forces can be formulated with either hypothesis. There seems to be evidence from cosmic rays that not all observed mesons have the same mass. Whether it is possible to relate this difference of mass to the two spin values, or whether one has to assume independently two or more different masses for each spin and for both charged and uncharged mesons, is not as yet clear. In any event, one should not regard the meson as one fundamental particle but as a rather bewildering variety of them.

(8) *The negative proton.* For the same reasons for which Dirac's theory of the electron requires the existence of a positron, it is likely that there exists a counterpart of the proton with negative charge. This would annihilate any positive proton it collides with, and thus would not live long in the presence of ordinary matter. It cannot now be produced in the laboratory since this requires too much energy. There are reasons to think that it is contained in cosmic rays.

Lastly, it has been pointed out that, just as the wave equations of the electromagnetic field give rise to photons, and those of the nuclear force field to mesons, the gravitational field should be similarly quantized. Since gravitational forces are extremely weak if expressed in units appropriate to elementary particles, the quanta constituting the gravitational field would have only an extremely weak interaction with other particles. It is tempting to relate this to neutrinos, which are indeed extremely elusive particles; but the idea is somewhat less attractive when it is remembered that the symmetry properties of the gravitational field are such as would correspond to particles of spin 2, and that therefore the only way of introducing neutrinos would be in terms of an elementary process consisting of the simultaneous emission or absorption of four neutrinos. It is likely that this problem will remain in the realm of speculation for a considerable time.

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SIXTH INTERNATIONAL CONGRESS FOR APPLIED MECHANICS

AT the Fifth International Congress for Applied Mechanics held in Cambridge, Mass., in 1938, an invitation to hold the Sixth Congress in Paris in 1942 was accepted. Though it was not possible to adhere to the original date, Prof. Henri Villat and his colleagues started to organise the Sixth Congress as soon as the war in Europe finished. Despite great economic and other difficulties, their courageous labours were completely successful, and the Congress was held in Paris at the Sorbonne during September 22-29. About 450 members attended, including scientific people from nearly all the Allied countries as well as from Switzerland, Italy, Denmark, Sweden, Turkey and Spain. The British group was large, and included many young scientific workers who have been attracted to applied mechanics in the course of their war activities.

The programme was a very heavy one, since it included the delivery of about two hundred and fifty scientific papers. These were divided among four sections, namely: (1) structures, elasticity and plasticity; (2) hydro- and aerodynamics and hydraulics; (3) dynamics of solid bodies, vibrations and sound, friction and lubrication; (4) thermodynamics, heat transfer and combustion.

So far as possible, the papers were grouped in symposia. In Section 1 there were symposia on plasticity, methods of calculation and impulsive loading; in Section 2 on turbulence, ship resistance, hydraulics, supersonic flow, aeroplane wing theory and instruments; in Section 3 on friction and lubrication; in Section 4 on jet propulsion and turbines.

Meetings of the four sections were held simultaneously, so that members who had interests in more than one section were not able to hear all they would have liked. A period of twenty minutes was allotted to each paper, including discussion on it. In this way,

every author was able to get a hearing. In many cases, however, the time allowed for discussion was insufficient, and animated debates were carried on after the official closing time of the session.

The papers presented fell roughly into two groups, one comprising such normal developments of pre-war lines of thought as it has been possible to carry out during the war period. The other group consisted of papers stimulated by war activities, in some cases merely as a by-product of those activities. In the former group, the work of H. L. Dryden was specially noteworthy. At the time of the 1938 Congress, the way in which the boundary layer of retarded fluid close to the surface of a body changes its character from being in steady motion to being turbulent was the subject of much discussion and uncertainty. Dryden has now shown that if the air stream in a wind tunnel is sufficiently free from turbulence, an instability of the boundary layer which had been predicted mathematically does, in fact, appear at the calculated wind-speeds, and that it has the calculated frequency and wave-length. These unstable waves are masked by larger effects in wind tunnels not specially designed to be free of turbulence.

The second group contained a number of papers which had recently been released from war-time restrictions on publication. Some of these were devoted to the theory of high subsonic and supersonic airflow, subjects which have made great progress since the Congress of 1938. Others dealt with the analysis of stress waves in plastic materials, a subject which has now been brought forward for the first time.

The Congress was entertained at receptions in the Hôtel de Ville and the Inter-Allied Club. A large proportion of the members had the privilege of staying in the Cité Universitaire, a group of splendid hostels in which live many of the foreign students of Paris.

The science of applied mechanics owes a debt to Prof. Henri Villat and his colleagues for the initiative they took in organising so successfully such an important international scientific meeting so soon after the liberation of their country.

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EDUCATION IN THE BRITISH ARMY

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I: Problems Involved

WHEN thinking of the Army Education Scheme it is not unnatural that the civilian mind tends to approach the problem by comparison with some civilian education organisation, for this is the only kind of yardstick ready to his hand. The soldier, on the other hand, will feel that he is a better judge; yet in the majority of present cases he will be able to bring to bear on the problem little more than the experience of some particular form of military organisation with which a few years' war service has made him familiar.

The Army Education Scheme was devised not as the best education scheme possible, but as the best education scheme possible in the particular circumstances in which the Army would find itself at the