the expression of the hyperfine structure splitting, $|\psi(0)|^2$ being proportional to a^{-3}. It is customary to eliminate the Bohr radius by introducing the Rydberg constant for infinite mass, together with the reduced mass of the electron. It then turns out that the hyperfine structure splitting is given by the expression

$$\nu = C\frac{2I+1}{I}\mu_N\left(\frac{m_r}{m_0}\right)^3. \qquad (2)$$

Here C contains universal constants and numbers, while m_r stands for the reduced mass of H or D, respectively. m_0 denotes the electronic mass. The ratio ν_H/ν_D is then given by

$$\nu_H/\nu_D = (4/3)(\mu_H/\mu_D)(m_H/m_D)^3,$$

and the numerical value for ν_H/ν_D as observed, is 4.3416 compared with a computed value of 4.3393.

Equation (1) is derived by neglecting the small components of the Dirac equation and replacing the large components by Schroedinger functions.

The discrepancy observed which, if the accuracy of observation is sufficient, in the case of the ratio at least, cannot be ascribed to inaccurate values of the universal constants, makes it advisable to re-examine the derivation of (1).

We have obtained a value for ν by consistently using Dirac's equation, retaining all four components through the perturbation calculation and using the rigorous Dirac functions in the evaluation of the matrix element for the perturbed energy. The hyperfine structure splitting apart from numerical factors is now given by

$$\nu = C'\frac{e\mu_N}{(h/mc)^2}[1-(E/mc^2)^2]^{\frac{3}{2}} = C'\frac{e\mu_N}{(h/mc)^2}(2R/mc^2)^{\frac{3}{2}}. \qquad (3)$$

The second equation in (3) is obtained by the somewhat arbitrary insertion of the empirical Rydberg constant in place of R_∞ which would, of course, follow from the Dirac equation.

This calculation leads, within the accuracy aimed at, to the same value as given by (2), with the one difference that the ratio of reduced to electronic mass appears in the three-halves rather than in the third power. This correction diminishes the discrepancies between the observed and calculated values of ν_H and ν_D, as follows. For H, the discrepancy is reduced to one part in 600; for D, to one part in 500; both deviations are obviously still large if one believes in the presently accepted values of the universal constants.

The ratio ν_H/ν_D, on the other hand, now differs from its calculated value by only one part in 8000; this is much smaller than the accuracy claimed for the earlier determinations of μ_H/μ_D, which enters as a factor into (3) and is assumed to be known to about 1 part in 3000.

In interpreting this result, several points must be kept in mind: The accuracy of the experimental determination of μ_H/μ_D and the calculated value which contains it as its most uncertain element, are not yet sufficiently good to exclude a different dependence on the ratio of the reduced masses.

The theory here used is obviously not consistent; we have carried out all calculations with the one-body Dirac equation and taken into account the two-body nature of the problem by the empirical introduction of R_H and R_D. This point will need further theoretical study.

We have also investigated the question of how the electronic magnetic moment may be expected to depend on the nuclear mass and have found different results depending on the physical interpretation given to the coordinates which enter into the Dirac equation.

A detailed paper will follow shortly.

[1] J. E. Nafe, E. B. Nelson, and I. I. Rabi, Phys. Rev. 71, 914 (1947). I am greatly indebted to the authors for telling me about their results before publication.

Nuclear Capture of Mesons and the Meson Decay

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THE experiment of Conversi, Pancini, and Piccioni[1] indicates that the probability of capture of a meson by nuclei is much smaller than would be expected on the basis of the Yukawa theory.[2,3] Gamow[4] has suggested that the nuclear forces are due exclusively to the exchange of neutral mesons, the processes involving charged mesons and the β-processes having probabilities which are smaller by a factor of about 10^{12}.

We notice that the probability ($\sim 10^6$ sec.$^{-1}$) of capture of a bound negative meson is of the order of the probability of ordinary K-capture processes, when allowance is made for the difference in the disintegration energy and the difference in the volumes of the K-shell and of the meson orbit. We assume that this is significant and wish to discuss the possibility of a fundamental analogy between β-processes and processes of emission or absorption of charged mesons.

An immediate consequence of the experiments of the Rome group[1] is that the usual interpretation of the β-process as a "two-step" process ("probable" production of virtual meson and subsequent β-decay of the meson) completely loses its validity, since it would predict too long β-lifetimes: the meson is no longer the particle responsible for nuclear β-processes, which are to be described according to the original Fermi picture (without mesons). Consequently there is no need to assume that charged mesons have integral spin, as the Yukawa explanation of β-processes required. Once we believe that the ordinary β-process is not connected in any way with the meson, it is difficult to see strong reasons for the usual assumption that the meson decays with emission of a β-particle and a neutrino. We shall consider then the hypothesis that the meson has spin $\frac{1}{2}\hbar$ and that its instability is not a β-process, in the sense that it does not involve the emission of one neutrino. The meson decay must then be described in a different way: it might consist of the emission of an electron and a photon or of an electron and 2 neutrinos[5] or some other process.

In the hypothesis that the meson decay is not a β-process (meson of spin $\frac{1}{2}$) *the process of nuclear absorption or production of a single meson would be accompanied by the emission of a neutrino.* This analogy between β-particles and mesons suggests, in addition, that just as the production of single β-particles is extremely unlikely, while the production of electron pairs is a very likely phenomenon, so the production of a single charged meson would be very unlikely, while the production of pairs of mesons would be quite probable. The experimental evidence is, in fact,[6] that most, if not all, of the meson showers are created in connection with large Auger showers.

The assumption that the emission or absorption of one meson is accompanied by the emission of a neutrino would explain in a natural way a somewhat puzzling experimental result. Among the few pictures of a meson stopping in the gas of a cloud chamber, no "star" has been observed at the end of the meson track.[7] The absence of a star must be due to a process leaving the capturing nucleus in a not too excited state: the mechanism proposed here would explain that the capture of a negative meson from a nucleus Z results in a nucleus $Z-1$ close to its ground level, since the excess energy could be carried away by the neutrino. Actually, in such a process we should expect that the emission of a neutrino of high energy with consequent production of the nucleus $Z-1$ in a state of low excitation would be more likely than the emission of a neutrino of low energy with the production of the nucleus $Z-1$ in a state of high excitation (cf. K-capture process).

The hypothesis that the meson decay is not a β-process, while the meson absorption is a β-process, does not require that hypothetical particles such as neutral mesons are invoked to account for nuclear forces. In fact, a heavy electron *pair* theory of nuclear forces was successfully developed by Marshak.[8] Moreover, a pair theory is capable of accounting, at least in principle, for the existence of processes in which several pairs of mesons are produced in a single act, as suggested by Heisenberg in connection with a different problem.[9]

Returning to the actual decay of the meson, an experiment suggests itself which might answer the following question: Is the electron emitted by the meson with a mean life of about 2.2 microseconds accompanied by a photon of about 50 Mev? This experiment is being attempted at the present time, since it is felt that the available analysis[10] of the soft component in equilibrium with its primary meson component is probably insufficient to decide definitely whether the meson decays into either an electron plus neutral particle(s) or electron plus photon.

[1] M. Conversi, E. Pancini, and O. Piccioni, Phys. Rev. **71**, 209 (1947). See also T. Sigurgeirson and A. Yamakawa, Phys. Rev. **71**, 319 (1947).
[2] E. Fermi, E. Teller, and V. Weisskopf, Phys. Rev. **71**, 314 (1947).
[3] J. A. Wheeler, Phys. Rev. **71**, 320 (1947).
[4] G. Gamow, Phys. Rev. **71**, 550 (1947). See also G. Gamow and E. Teller, Phys. Rev. **51**, 289 (1937).
[5] W. Nordheim, Phys. Rev. **59**, 544 (1941).
[6] G. Cocconi, A. Loveredo, and V. Tongiorgi, Phys. Rev. **70**, 852 (1946).
[7] See for a critical survey: T. H. Johnson and R. P. Shutt, Phys. Rev. **61**, 380 (1942).
[8] R. E. Marshak, Phys. Rev. **57**, 1101 (1940).
[9] References can be found in *Cosmic Radiation*, edited by W. Heisenberg (Dover Publications, New York, 1946), p. 127.
[10] See reference 9, pp. 84–97.

An On-Orbit Injector for Betatrons and Synchrotrons

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ONE of the primary limitations on the yield from present electron accelerators of the betatron and synchrotron type lies in the injection process. The injector must lie off the orbit in which the acceleration is supposed to occur in order not to interfere with the acceleration process, and this necessarily implies radial oscillations of the injected electrons of an amplitude at least equal to the distance between the stable orbit and the injector. The frequency of these radial oscillations is approximately $\nu_0(1-n)^{\frac{1}{2}}$, where ν_0 is the rotation frequency of the electrons, and n is the exponent in the expression $H=H_0(r/r_0)^{-n}$ law of decrease of the magnetic field with radius. If n has a nominal value of 0.5, it is seen that the oscillation frequency is 0.71 of the electron frequency and that as a consequence we cannot expect any appreciable damping of this oscillation by increasing magnetic field in a time comparable to several cycles of this oscillation. Moreover, the beneficial effect of such damping is further reduced if, as is the practice, the injection is performed at high voltage, since in a given time interval the relative change of field is less with a large field than a small one for a field increasing approximately linearly with the time. The net result of these conditions is that although injected electrons may clear the injector on the first transit because of the difference between ν_0 and $\nu_0(1-n)^{\frac{1}{2}}$, nevertheless a great many of them will strike it on subsequent transits and thus be lost.

In order to circumvent this difficulty, it is proposed to employ an injector which surrounds the stable orbit so that electrons rotating in the stable orbit may pass through the injector structure without interference. Thus in substance the injector (see Fig. 1) consists of an annular

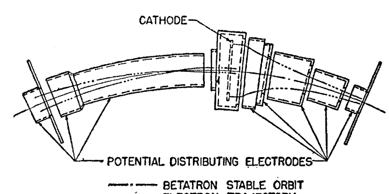

FIG. 1. Schematic drawing of on-orbit injector. The magnetic field is normal to the paper.

cathode and a series of electron lenses which narrow and collimate the electron beam, so that as it emerges from the injector it appears ideally as a cylindrical tube the axis of which is the stable orbit. One can design the lens system to make the diameter of this tube of such a size that oscillation within the beam is of no importance. The part of the injector behind the cathode can be designed so that electrons, passing through the injector on subsequent transits and having been defocused because of space charge or for some other reason, can be refocused as they pass through the low potential region near the center of the