five times as effective as Be+D neutrons in the production of Fermi radioactivity.

A further check on the energy of the carbon neutrons was obtained by a cloud chamber comparison of the neutron recoils due to the carbon reaction and those due to the bombardment of deuterons by deuterons. A total of thirty-seven recoil protons due to the latter averaged 47.9 mm in reduced range, whereas forty-eight recoil protons due to the carbon neutrons averaged only 12.6 mm in reduced range. The energy of the neutrons from the deuteron reaction has been given as about 2 MEV by the Cambridge investigators. These cloud chamber measurements do not give a good determination of the energy of the carbon neutrons because of the probable inclusion of several unrecognized forks due to neutron-disintegrations. Although the observed energy of the carbon neutrons is somewhat higher than would be expected on the basis of the new mass values, it clearly contradicts the neutron energy of 4 to 5 MEV predicted by the old mass values, which required the 3 (4) MEV gamma-rays to accompany the 14- to 18-cm protons.

Measurements on the gamma-rays emitted by carbon under deuteron bombardment at 950 kv, using a cloud chamber in a magnetic field of 850 gauss, are shown in Fig. 2. Preliminary observations having indicated a preponderance of low-energy electrons, the first measurements were made with a 7/8-inch lead filter between the target and the chamber, giving the data of curve I. To insure against error, a few observations were made with 1 mg of radium approximately in the position of the target, yielding curve II. These observations indicated the maximum gamma-ray energy from carbon to be about 3.5 MEV (3.7 MEV if arbitrarily corrected for Compton recoil), and since this quantum-energy is near the minimum of the absorption coefficient curve, higher as well as lower energies are discriminated against and it consequently seemed desirable to make observations with less absorption. The data of curve III, taken with a 1/8-inch lead filter, indicate a maximum quantum energy of about 4 MEV (or even slightly more if corrected for Compton recoil), and this indication is sustained when the measurements are restricted to "forward" negative tracks, plotted as curve IV. No tracks were measured which had uniformly curved length of less than 10 cm, most of them being well above this length, and no attempt was made to measure the few doubtfully straight tracks above 7 MEV. Very few positrons were identifiable in the carbon observations, in contrast to the brief series of photographs made with protons bombarding lithium, data of curve V, which showed forward electrons of both signs up to very high energies. Using the new mass values, there is no possibility that such a high energy gamma-ray could arise in any reaction involving the formation of N^{13}, and consequently it must accompany a short range proton group as postulated by Professor Bethe. However, the indicated maximum energy of the gamma-ray equals or even exceeds the total energy observed in the known proton reaction (3.6 MEV, including recoil, at 0.95 MEV deuteron energy), and consequently the protons which accompany the gamma-rays must have an energy near zero. If this is the case, they should have great difficulty in penetrating the carbon barrier outward, and the gamma-ray process should be very infrequent compared to the 14- to 18-cm protons. This is not the case according to our measurements, the proton yield being about 3 per 10^6 at 950 kv, and by numerous experiments, including a direct cloud chamber comparison of the high energy electrons from 1 mg of radium with those from carbon, we find that the gamma-ray yield can hardly be under 1 per 10^6 incident deuterons. Thus until some way is found to account for the large intensity of these hard gamma-rays the carbon reactions cannot be considered to be in a satisfactory state, even with the new mass values. The old mass values seem to be completely excluded, however, even by these carbon observations alone, unless the proton and neutron reactions both lead to excited states.

We are grateful to Professor Bethe for taking an active interest in these measurements.

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[1] H. Bethe, Phys. Rev. **47**, 633 (1935).
[2] H. Schulze, Zeits. f. Physik **94**, 104 (1935).

Higher Order Derivatives in the Interaction "Ansatz" of the Fermi Theory[1]

Since there are theoretical arguments[2] for introducing higher order derivatives in the interaction of the heavy particle with the electron-neutrino field, we have investigated the effect of such a change on the form of the continuous electron or positron spectra. We shall consider only the light nuclei so that the influence of the nuclear charge Z may be neglected; furthermore we shall take the neutrino mass μ equal to zero.

The polar four-vector which is needed to make up the interaction energy may be formed with the help of the gradient vector $\partial/\partial x_i$ and the quantities γ_i, M_{ij} and k_{ijk}.[3] The possibilities with the gradient alone, for example, are:

$$(m+1,\, m)_i = \frac{\partial}{\partial x_i}\cdot\frac{\partial^m \psi\dagger}{\partial x_\alpha \cdots \partial x_\beta}\cdot\frac{\partial^m \varphi}{\partial x_\alpha \cdots \partial x_\beta}, \quad (1)$$

$$(m,\, m+1)_i = \frac{\partial^m \psi\dagger}{\partial x_\alpha \cdots \partial x_\beta}\cdot\frac{\partial}{\partial x_i}\cdot\frac{\partial^m \varphi}{\partial x_\alpha \cdots \partial x_\beta}. \quad (2)$$

The order of the derivatives of $\psi\dagger$ and φ must differ by unity only, because otherwise factors like $\partial^2\psi\dagger/\partial x_\alpha \partial x_\alpha$ or $\partial^2\varphi/\partial x_\alpha\partial x_\alpha$ would occur. From the second order Dirac wave equations for the electron and neutrino, which, with $Z=0$ and $\mu=0$ are

$$\partial^2\psi\dagger/\partial x_\alpha\partial x_\alpha + \psi\dagger = 0, \quad \partial^2\varphi/\partial x_\alpha \partial x_\alpha = 0,$$

such factors would cause the vector to vanish or to reduce to one of the forms (1) or (2). Making use also of the first order Dirac equations

$$(\partial\psi\dagger/\partial x_\alpha)\cdot\gamma_\alpha + \psi\dagger = 0, \quad \gamma_\alpha(\partial\varphi/\partial x_\alpha) = 0,$$

one can reduce all the other four-vectors, involving γ_i, M_{ij} and k_{ijk}, to three types and their linear combinations.[4] These three types are (1), (2) and

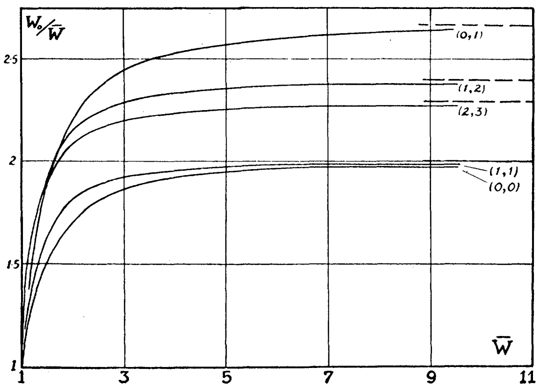

FIG. 1.

$$(m,\, m)_i = \frac{\partial^m \psi^\dagger}{\partial x_\alpha \cdots \partial x_\beta} \cdot \gamma_i \cdot \frac{\partial^m \varphi}{\partial x_\alpha \cdots \partial x_\beta}. \qquad (3)$$

Four-vectors of the type (1) can be immediately excluded. Since the order of the derivative of the electron wave function is higher than that of the neutrino wave function, these vectors would lead to energy distributions which give greater weight to high electron energies than the original Fermi theory. This, as we have seen in I, §2, is in conflict with the experimental facts. The energy distribution resulting from the four-vectors (2) and (3) for different values of m are:

(0,0): $P \sim W(W^2-1)^{1/2}(W_0-W)^2$,
(0,1): $P \sim W(W^2-1)^{1/2}(W_0-W)^4$,
(1,1): $P \sim W(W^2-1)^{1/2}(4W^2-1)(W_0-W)^4$,
(1,2): $P \sim W(W^2-1)^{1/2}(4W^2-1)(W_0-W)^6$,
(2,2): $P \sim W(W^2-1)^{1/2}[(4W^2-1)^2-4W^2](W_c-W)^6$,
(2,3): $P \sim W(W^2-1)^{1/2}[(4W^2-1)^2-4W^2](W_0-W)^8$.

(0,0) is the original Fermi distribution for $Z=0$, which is just the statistical factor; (0,1) is the distribution proposed in I, §4. In these equations W is the *total* energy of the electron measured in units.

Although, in order to make a definite decision, a direct comparison of the above formulae with the experimental distributions should be made, an indication can be obtained by considering the relation between the average energy $\overline{W}$ and the maximum energy W_0. In Fig. 1 we have plotted $W_0/\overline{W}$ as a function of $\overline{W}$ for the different formulae. $\overline{W}$ is chosen as abscissa since it can be determined experimentally much more accurately than W_0. The curves corresponding to interactions of the type (3) all approach an asymptote at $W_0/\overline{W}=2$. The type (2) curves also have horizontal asymptotes but these vary with m and are given by $W_0/\overline{W}=(4m+8)/(2m+3)$.

From the empirical material now available it seems that one can already exclude interactions of the type (3). They lead to distributions which have about the same degree of asymmetry as the simple statistical factor (0,0) and are therefore just as unsatisfactory (see I, §2). The recent results of Crane, Delsasso, Fowler and Lauritsen[5] on the high energy β-ray spectra of B^{12}, Li^8 and F^{20} may allow a decision on the value of m in the interactions of type (2). The average energies of these spectra are respectively $\overline{W}=9.0$, 8.6, 4.8 in our units; the upper energies are about $W_0=23$, 22, 11.5. If the average energies can be regarded as correct within a few percent then, by finding a lower limit to W_0, one can set a lower limit to $W_0/\overline{W}$. All the interactions whose asymptotes are below this value can then be eliminated. For example, in the case of Li, if $W_0 \geqq 20$, $\overline{W}=8.6\pm0.1$, then $W_0/\overline{W} \geqq 2.3$ so that already the (2,3) interaction is excluded. The distribution curve given by (2,3) is also quite unlike the empirical energy distribution.

Of course, theoretically, also linear combinations of interactions of the different types or of different orders are possible. Since, however, interactions of type (3) and of type (2) for larger m give comparatively symmetrical distributions, already the study of the asymmetry of the high energy β-ray spectra will make it possible to restrict the amount with which the higher order derivatives can be present in the interaction function.

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[1] This is an extension of our paper (hereafter cited as I) in the Phys. Rev. **48**, 7 (1935) to which reference is made for further details. We continue to use the same notation, units, etc.
[2] W. Heisenberg, Zeeman Jubilee Papers, Nijhoff, The Hague, 1935, p. 108.
[3] See Pauli, *Handbuch der Physik*, Vol. 24, 1, p. 220.
[4] For an example of such a reduction see I, §4.
[5] Crane, Delsasso, Fowler and Lauritsen, Phys. Rev. **47**, 887, 971 (1935).

Concerning the Possibility of a Unified Interpretation of Electrons and Protons

The purpose of this note is to show: (a), that it is formally possible to construct irreducible equations of the Dirac type which are invariant under the extended Lorentz group and contain more than four components and, (b), that these equations suggest the examination of the feasibility of interpreting the fundamental physical particles in terms of particles of a single kind. Such an interpretation would possess certain attractive features, but in view of several difficulties (the one concerning the magnetic moment of the proton being perhaps the most important) it is at present doubtful that the procedure indicated below can be made successful. The equations in question contain one or more four-vectors, denoted below by B's, whose physical meaning, if they have any, is at present obscure. For the sake of brevity we shall not consider the general case,* but shall let an example illustrate the trend of the argument.

The Dirac equation for the electron can be written in the form

$$\{\alpha_K P_K + \beta c\}\psi = 0, \qquad (1)$$

where $\alpha_0=1$, where α_1, α_2 and α_3 are square roots of unity which anticommute with each other and with β, and where

$$\beta^2 = m^2, \qquad (2)$$

and

$$P_K = p_K + e/c \cdot A_K. \qquad (3)$$