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Reactions between Nucleons and Mesons, and the Search for Negative Protons

SEVERAL authors[1] have suggested that negative protons (p^-) may be emitted from β^--radioactive nuclei which emit a delayed neutron (n_-^0). (In our notations for the particles, the upper index refers to the charge, the lower one to the magnetic moment.) Some unsuccessful attempts[2] at detection have been made. This suggestion has originated from the fact that the rest energies of the neutron and an electron ε^- are together greater than that of p^- by 1·826 MeV. It will be shown in this communication that the above suggestion is unfounded.

The argument starts from the observation that the reactions

$$p^+ + n_-^0 \rightleftharpoons \pi^+ \qquad (1)$$

$$n_-^0 + n_-^0 \rightleftharpoons \pi_+^0 \qquad (2)$$

are impossible, since their occurrence would not be compatible with the existence of atomic nuclei. This fact rules out just those 'classes' of reactions which are necessary for the spontaneous emission of negative protons from nuclei.

We have already used[3] the concept of 'classes' of reactions for discussing whether neutrinos should be described as Majorana or Dirac particles. When there is one reaction between s particles, this automatically implies the existence of other reactions, and the whole set of reactions is called a 'class'. The reaction may be virtual or real, though the latter may be possible only if the necessary energy is supplied (for example, pair creation : $\pi^+ \rightarrow p^+ + n_+^0$).

We defined a reaction between s particles by the $2s$ numbers M_r, L_r (index r running from 1 to s). M_r, L_r are defined as follows : M_r is $+1$ or -1, according as the rth particle is emitted or absorbed. L_r is either $+1$ or -1, and it indicates the sign of the electric charge of the rth particle or, in the case of a neutral particle with a magnetic moment, the sign of the magnetic moment. If the neutral particle has only one state of 'charge conjugation', its field can be described by a real wave function (for example, photon, Majorana particle[4]) ; L is then arbitrary, and such a particle will be called a 'strictly neutral' particle.

We define

$$K_r = M_r L_r \text{ and } \mathbf{K} = (K_1, K_2, \ldots K_s). \qquad (3)$$

The conservation of the electric charge requires

$$\Sigma^c M_r L_r = \Sigma^c K_r = 0, \qquad (4)$$

where Σ^c means the sum over the charged particles only.

The existence of a reaction, real or virtual, requires at least one constant of interaction, and this necessarily entails all other reactions with the same or opposite **K**. The set, or 'class', of all these reactions is therefore defined by $\pm$ **K**.

With the condition (4) we find that between: $p^{\pm}$, $p^{\pm}$, $\pi_{\pm}{}^{0}$ there can be only one class a_1; $p^{\pm}$, $n_{\pm}{}^{0}$, $\pi^{\pm}$ there can be only two classes, b_1, b_2; $n_{\pm}{}^{0}$, $n_{\pm}{}^{0}$, $\pi_{\pm}{}^{0}$ there can be only three classes c_1, c_2, c_3 of reactions. The impossibility of (1) and (2) excludes the existence of three classes. The other classes, a_1, b_1, c_1, have been used in several meson theories, and some of their reactions have been observed. (For describing all the different classes $\pm$ **K** it is necessary to use a Hamiltonian which contains the wave function ψ of the nucleons in expressions such as $\psi \mathrm{Op} \psi$, $\psi^* \mathrm{Op} \psi^*$ and $\psi^* \mathrm{Op} \psi$. It is possible to express the three classes, a_1, b_1, c_1, using only the last expression $\psi^* \mathrm{Op} \psi$, which can be interpreted as corresponding to transitions from negative to positive energies and vice versa, as opposed to the creation or annihilation of particles which requires the second quantization formalism.) These classes involve the creation or the annihilation of a pair of one nucleon (p^+ or $n_-{}^0$) and one antinucleon (p^- or $n_+{}^0$), and therefore they rule out the stable existence of antinucleons in nuclei. Furthermore, with these three classes of reactions we cannot obtain from a nucleus with A nucleons an assembly of n antinucleons and $\leqslant A-n$ nucleons, even with an arbitrary number of intermediate virtual reactions. Hence it is impossible to observe the spontaneous emission of p^- (or $n_+{}^0$) from an atomic nucleus. The above argument is also valid for every kind of interaction between nuclear particles involving one or several intermediate particles the sum of the rest-masses of which is smaller than $m_p + m_n$. This includes the case of β-radioactivity.

These considerations on the classes of reactions between mesons and nucleons can be applied to the study of the mesic charge. As is well known, this charge is either of the Majorana type (f'_1, g'_1, f_1, f_2) in the Møller and Rosenfeld[5] notation, or of the Dirac type ($\pm f'_2$, $\pm g_1$, $\pm g_2$, $\pm g'_2$); in the latter case there is charge conservation. It is easily seen from the above considerations that, in the charged meson theories, p^+ and $n_-{}^0$ always have the same mesic charge.

It is found that in all possible reactions of classes a_1 and c_1 the sign of $\mathrm{L}\pi^0$ is immaterial. Let φ be the wave function of $\pi_{\pm}{}^{0}$; it appears in the interaction terms only through the combination $(\varphi + \varphi^*)$. This is formally equivalent to the description of π^0 as a 'strictly neutral' particle $\pi_0{}^0$. The two possibilities $\pi_{\pm}{}^{0}$ and $\pi_0{}^0$ are completely equivalent for all purely nuclear phenomena. This seems strong evidence for assuming that the (vector or pseudovector) neutral meson has no magnetic moment.

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[1] For example, Kuan-Hun-Sun, *Phys. Rev.*, **76**, 1266 (1949).
[2] Feather, N., at Edinburgh Conference (Nov. 14, 1949).
[3] Michel, L , *Proc. Phys. Soc.*, **63**, 514 (1950).
[4] Majorana, E., *Il Nuovo Cimento*, **14**, 171 (1937).
[5] Møller, C., and Rosenfeld, L., *Det Kgl. Dansk.*, **17**, No. 8 (1940).

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