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# THE MASS OF NEUTRAL MESONS

A. Sokolov and B. Kerimov
Sci-Res Inst of Phys
Moscow State U imeni Lomonosov
Submitted 20 Nov 1948 by Acad S. I. Vavilov

As is well known, the theory of scalar mesons leads to the following law of interaction between two nucleons, that is, between protons or neutrons:

$$U = -g^2 \cdot r^{-1} \cdot e^{-k_0 r}, \tag{1}$$

where g is the specific nuclear charge and $k_0$ is connected with the mass $\mu$ of the meson by the relation. $k_0 = 2\pi\mu c/h$.

Formula 1 cannot lead to the spin noncentral forces acting between the nucleons. Along with the scalar mesons, we can introduce also pseudoscalar, vector, and pseudoscalar mesons.

In the general case, by combining the various meson fields we obtain the following static law of interaction between two nucleons:

$$U = (g^2 + f^2(\vec{\sigma}_1\vec{\sigma}_2) + f_1^2(\vec{\sigma}_1\vec{\nabla})(\vec{\sigma}_2\vec{\nabla}))\cdot e^{-k_0 r}/r. \tag{2}$$

As a rule, the constants $g$, $f$, $f_1$, $k_0$ are so selected that one obtains the correct values for the energy of bond and for other quantities in the deuteron problem or in the problem of the scattering of one nucleon on another.

We shall show that we can arrive at a determination of these constants by investigating the equilibrium of a system consisting of many nucleons. (D. Ivanenko and V. Rodichev were the first to determine the mass of mesons from the condition governing the equilibrium of two nucleons -- the deuteron problem. See their article in Zhurnal Eksperimental'noy i Teoreticheskoy Fiziki, Vol 9, 1939, p 526.) For simplicity's sake, we shall limit ourselves merely to neutral mesons.

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Then, rejecting dipole terms proportional to $f_1^2$ which cannot give a stable state, we find by employing the Hartree-Fock method that the energy of the system of nucleons comprises the kinetic energy T of the nucleons, the potential energy $V^o$, and the exchange energy $V^a$: $E = V^o + V^a + T$.

Disregarding surface effects and also Coulomb repulsion, we obtain for the kinetic energy:

$$T = (3h^2/5MR^2)(3/4\pi)^{4/3} \cdot (\tfrac{1}{2}A)^{5/3} \cdot (2/n)^{2/3}, \qquad (3)$$

where M is the nucleon's mass, R is the radius of the system, A is the total number of nucleons, and n is the maximum number of particles which is able to be located in a given energy state (in our case we have n = 4; namely, two protons and two neutrons).

In a similar manner, the law of interaction (2) for small values of R leads to the following expression for the potential energy:

$$V^o = 3g^2A^2/2k_o^2R^3. \qquad (4)$$

Finally, for the exchange energy we have, when $R \ll (2/k_o)(9\pi A/2n)^{1/3}$, the following expression:

$$V^a = -\tfrac{1}{4}(g^2 + 3f^2)(9\pi A/2n)^{4/3} \cdot (n^2/3\pi^2 R) + \tfrac{1}{4}n(g^2 + 3f^2)k_oA. \qquad (5)$$

In the other extreme case, when $R \gg (2/k_o)(9\pi A/2n)^{1/3}$, we have:

$$V^a = -(0.75A^2)(g^2 + 3f^2)/k_o^2R^3. \qquad (5')$$

Introducing in the place of R the following dimensionless quantity x:

$$R = r_oA^{1/3} \cdot x,$$

we find for the total energy of the system of nucleons the value

$$E = A(a_o - a_1/x + a_2/x^2 + a_3/x^3), \qquad (6)$$

where

$$a_o = k_o(g^2 + 3f^2), \quad a_1 = (3/\pi)^{2/3} \cdot (3/4) \cdot (g^2 - 3f^2)/r_o \qquad (7)$$
$$a_2 = (3/\pi)^{4/3} \cdot 3h^2/160Mr_o^2, \quad a_3 = 3g^2/2k_o^2r_o^3.$$

Taking into consideration the conditions of equilibrium $\partial E(x)/\partial x\big|_{x=1} = 0$, and also the relation which must agree with empirical data on mass defect, one observes approximately at the position of equilibrium the relations:

$$a_o - a_1 + a_2 + a_3 \cong - a_2; \text{ and hence } a_o = 2a_3, \; a_2 = \tfrac{1}{2}(a_1 - 3a_3).$$

Hence, one can conclude that the mass of neutral mesons which leads to the equilibrium of a system of nucleons cannot exceed the value 130m, where m is the mass of the electron.

In this manner an investigation of a statistical model possessing well known boundaries permits one to indicate the upper limit for the value of the possible mass of a neutral meson.

Calculations of the noncentral forces proportional to $f_1^2$ and also calculations of surface effects or of the development of forces between protons and neutrons can hardly be sufficient to change basically the theoretical side



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of the picture, although the limiting value of the meson's mass can be somewhat different. That is, considerations of these forces, which were disregarded in the previous derivations, can hardly change the basic picture.

In this connection interest has been recently shown toward the spontaneous decay of heavy-charged $\pi$-mesons to charged $\mu$-mesons and neutral mesons whose mass cannot exceed 115 $\pm$ 30 m. This decay was discovered by Powell's group in thick photoemulsions. The decay of mesons was confirmed also in the well known experiments of A. Alikhanov and A. Alikhanyan and of others.) Recent photographs of Anderson and others also show the decay of mesons of cosmic rays with a mass of 200m to electrons and neutral mesons whose mass cannot exceed 130m. It is possible that it is exactly these neutral mesons that play an important role in nucleonic interactions.

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