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Protons of Double Charge and the Scattering of Mesons

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THE purpose of this note is to give a new formula for the scattering of mesons and to draw the attention of experimental physicists* to the consequences of a theory recently put forward by the present author[1] which predicts the existence of protons of charge $2e$ and $-e$ so that a proper search might be made for these particles.

On the old theory the cross section for the scattering of longitudinally polarized *charged* mesons by a proton or neutron caused by the charge of the heavy particles (g_1 interaction) was of the form

$$\text{constant } (g_1{}^2/\mu c^2)^2 p^4/\mu^2 E^2. \tag{1}$$

E denotes the energy, p the momentum and μ the rest mass of a meson. For high energies this cross section increases as E^2 and therefore completely robs the meson of its penetrating power. The corresponding cross section for the scattering of longitudinally polarized *neutral* mesons was calculated in a previous paper[2] (formula (43)) and correct to 1 percent it may be written in the simpler form

$$6\pi\frac{\mu^2c^4}{E^2}\left(1+\frac{1}{2}\frac{\mu^2c^4}{E^2}\right)\frac{1}{(3Mc^2/2g_1{}^2)^2+\{(E/\hbar c)^2\}}. \tag{2}$$

Even without the term in curly brackets which expresses the effects of radiation reaction, (2) would decrease as E^{-2} and is less than (1) by an order of magnitude caused by the appearance of M (the proton mass) instead of μ in the denominator. This difference between (1) and (2) is entirely caused by the fact that whereas on the accepted theory a positive meson can only be absorbed by a neutron and emitted by a proton, a neutral meson can be absorbed and emitted by both.[2] There are thus twice as many states leading to the scattering of neutral as of charged mesons and these largely cancel each other, reducing the cross section (1) to the magnitude (2). To avoid this difficulty I put forward the idea[1] that the heavy particles could exist in states of all integral charge positive and negative with different rest energies, of which only the two of lowest energy (rest mass), namely the proton and neutron, appear normally in nature. This idea was communicated to Dr. Heitler[3] and has been adopted by him to recalculate the scattering of charged mesons. It reduces the cross section (1) to a magnitude of the order (2). Further arguments in favor of this idea are given in my paper.[1]

A definite consequence of this assumption is that protons of charge $2e$ and $-e$ must also occur in nature. The processes leading to the production of these particles and the circumstances under which they might be expected to occur have been investigated in the above paper.[1] The most probable process for the production of these particles is the collision of two protons or two neutrons, thus

$$\begin{aligned} P+P&\rightarrow P_2+N \\ N+N&\rightarrow P_-+P \end{aligned} \tag{3}$$

where P_2 and P_{-1} denote the protons of charge $2e$ and $-e$, respectively. The process (3) only takes place if the kinetic energy of the colliding particles is at least twice the mass excess of a doubly charged proton over an ordinary proton, i.e., about 35 Mev. The cross section for the process (3) is of the order 10^{-25} cm^2, so that a very energetic proton would produce a proton of charge $2e$ after some 5 g/cm^2 of hydrogen. The doubly charged proton would not, however, emerge as frequently as an ordinary proton from heavy nuclei because at least 17 Mev goes to its

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* At my suggestion Professor H. J. Taylor made a search last May in photographic plates suitably treated to show the tracks of heavy particles and exposed on the Himalayas to cosmic radiation at a height of 18,000 feet. It is Professor Taylor's opinion that this method is not sensitive enough to distinguish between a proton, a proton of charge $2e$ and an α-particle. The search is therefore best made with a Wilson chamber.

[1] H. J. Bhabha, Proc. Ind. Acad. Sci. **A11**, 347–368, 468 (1940).

[2] H. J. Bhabha, Proc. Roy. Soc. **A172**, 384–409 (1939).

[3] W. Heitler, Nature **145**, 29 (1940).

creation and the double charge makes the penetration of the Coulomb barrier more difficult. The cross section for the creation of the new particles by fast mesons or γ-rays is of the order 10^{-29} cm^2. For mesons which have come to rest, the capture probability of a negative meson resulting in the conversion of a nuclear neutron into a negative proton is of the order 10^{11} per second, while for positive mesons it is negligible on account of the Coulomb repulsion.[4]

The new particles are unstable, the mean lifetime for spontaneous β-decay into an ordinary proton or neutron being $\frac{1}{6}$ sec., while the lifetime for annihilation of a negative proton by a reverse of the process (3) is $3\times10^{-5}/Z$ second in gases, Z being the atomic number of the gas.

The above assumption of new particles does not diminish the scattering of mesons caused by the *spin* of the heavy particles (g_2 interaction), which still remains of the order (1). I have now extended the classical theory of spinning particles moving in a Maxwell field[5] to cover a meson field. The resulting cross section for the scattering of *transversely polarized* mesons caused by the *spin* of the heavy particles on this theory can be written correctly to within 2 percent in the simple form

$$4\pi\frac{p^4}{(3\mu c^2/4g_2'^2)^2\mu^2E^2+p^6\hbar^{-2}} \tag{5}$$

The scattering is a large angle scattering, so that whenever it takes place, the meson is removed from the beam. The smooth curve in Fig. 1 shows the dependence of this cross section on energy, plotted for $g_2'^2/\hbar c=1/13.3$. For low energies the cross section is of the order (1) and agrees with the old quantum-mechanical cross section, as shown by the broken curve. It is a maximum at $E\sim3.5\mu c^2$, its value at the maximum being $\sim3\times10^{-26}$ cm^2 if we take $\mu c^2=85\times10^6$ ev. In spite of its largeness, the above cross section does not deprive the meson of its penetrating power since it decreases for high energies as p^{-2} due to the p^6 term in the denominator which expresses the effects of radiation reaction. The main scattering takes place for energies near $3\mu c^2$, and still further accentuates the cutting off of the energy spectrum of mesons for energies *below* $3\mu c^2$, as calculated by Euler and Heisenberg.[6] This agrees better with the observations of Blackett.[7]

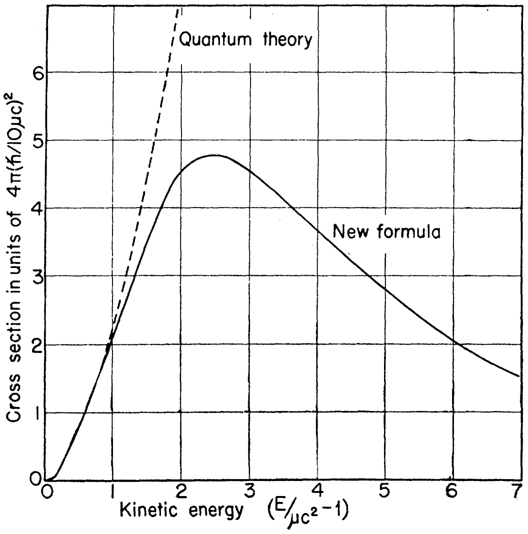

FIG. 1. The variation of cross section with energy.

Longitudinally polarized mesons are not scattered by the rotation of the spin and hence their scattering is of the order (2). This is less than (5) by a factor $(g_1^2/\hbar c)^2(\mu/M)^2<1/20{,}000$. *Thus longitudinally polarized mesons are very much more penetrating than transversely polarized mesons.*

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[4] Cf. S. Tomonaga and G. Araki, Phys. Rev. **58**, 90 (1940) for ordinary capture.

[5] H. J. Bhabha, Proc. Ind. Acad. Sci. **A11**, 247–267, 467 (1940); Nature **145**, 819 (1940).

[6] H. Euler and W. Heisenberg, Ergeb. d. exakt. Naturwiss. **17** (1938).

[7] P. M. S. Blackett, Proc. Roy. Soc. **A165**, 11–31 (1938).