the calculated values (equal to 0.6 to 0.8 of the geometric cross sections) obtained by Sternheimer[2] and by Osipenkov and Filippov[3] on the basis of the optical model, with an interaction potential in the form of a rectangular well of radius R. In these calculations, the parameters of the well (depth of well and coefficient of absorption of the pions in nuclear matter) were determined from the cross sections for the scattering of pions by free nucleons.

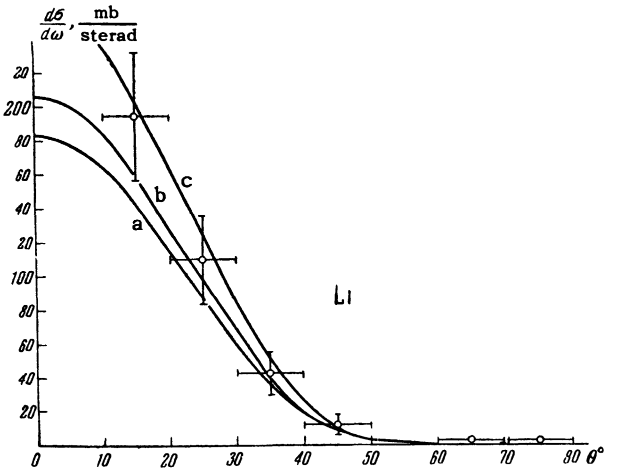

FIG. 2

The experimentally-obtained angular distribution of elastic scattering by carbon and lithium are illustrated in Figs. 1 and 2. The solid curves represent the angular distributions computed in the quasi-classical approximation from the optical-model equations* (for the range from 0° to the angle corresponding to the position of the first diffraction minimum) for the following values of the parameters: nuclear radius $R = 1.4 A^{1/3} \times 10^{-13}$ cm, coefficient of meson absorption in nuclear matter $K = 0.83 \times 10^{13}\ \text{cm}^{-1}$ the real part of the potential V is equal to zero for curve A and 30 Mev for curve B; $K = \infty$ and $V = 0$ for curve C. As can be seen from the diagram, the measured distributions agree with the computed ones, but within the limits of experimental error no definite conclusions can be made regarding the magnitude or sign of the real part of the potential. It is obvious that the description of the measured angular distributions with the aid of a rectangular-well potential is inadequate, since these distributions (as shown in references 5 and 6) do not exhibit the clearly-pronounced minima and maxima which characterize such a potential. For example, it was found in references 5 and 7 that to obtain correspondence between the experimental and computed data over the entire range of distribution angles it is necessary to forego, in the computations with the optical model, the homogeneous distribution of the nucleons of the nucleus and to add to the interaction potential a term proportional to the gradient of the nuclear density. No right-left asymmetry of elastic scattering of positive pions was observed in the experiment for either nucleus.

*The computation formula is taken from the book of Akhiezer and Pomeranchuk.[4]

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ELECTROMAGNETIC MASS OF THE K MESON

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IN the recent experiments by Rosenfeld et al.[1] and Crawford et al.[2] it was established that the mass of the neutral K meson exceeds that of the charged K^+ meson by ~4.8 Mev. On the face of it the sign of this mass difference appears to contradict the concept that the K^+ and K^0 mesons are spinless particles belonging to the same charge doublet. Indeed, if the K^0 meson has no electromagnetic interactions and the mass difference is of electromagnetic origin then the electromagnetic self-mass of the charged K meson should make it heavier than the neutral one (see, e.g., reference 3). On this basis the above-mentioned authors are inclined to interpret their results as an argument in favor of the Pais hypothesis,[4] according to which the K^+ and K^0 meson do not form a charge doublet and may have different intrinsic parities.

It is shown below that there is not as yet sufficient basis for this conclusion since the mass difference can be explained, within the framework of the Gell-Mann–Nishijima multiplet scheme, by the electromagnetic interactions of the K^0 meson. Indeed, as noted in an interesting paper by G. Feinberg,[5] a spinless neutral particle which is different from its antiparticle, e.g., K^0, can interact with the electromagnetic field. This interaction results from a virtual dissociation of the K^0 meson into strongly interacting particles, for example a nucleon and an antihyperon. As a consequence the K^0 meson will have an electromagnetic structure.

In the general case the gauge-invariant electromagnetic interaction Lagrangian can be written as

$$L = -j_\mu(x) A_\mu(x) \tag{1}$$

where $j_\mu(x)$ is the operator for the total current of all interacting particles. In the β-formalism of Duffin and Kemmer the matrix element of the current taken between single K-meson states will have the form*

$$\langle p' | j_\mu(x) | p\rangle_K = -ie(2\pi)^{-3} e^{-iqx} \bar{v}(p') \beta_\mu [F_{1K}(q^2) + \tau_3 F_{2K}(q^2)] v(p),$$

$$q = p' - p, \quad \bar{v}(p') = v^+(p')(2\beta_4^2 - 1), \tag{2}$$

where p' and p are the K-meson four-momenta in the final and initial states, $v(p')$ and $v(p)$ are the corresponding wave functions in the β-formalism, and $F(q^2)$ is the form factor satisfying

$$F_{K^+}(q^2) = F_{1K}(q^2) + F_{2K}(q^2), \qquad F_{K^+}(0) = 1,$$
$$F_{K^0}(q^2) = F_{1K}(q^2) - F_{2K}(q^2), \qquad F_{K^0}(0) = 0, \tag{3}$$

since the charge of the particle is $eF(0)$.

Due to interaction (1) and by taking into account (2) we find for the self-mass of the K meson†

$$\Delta m = \frac{ie}{(2\pi)^4} \frac{\bar{v}(p)}{\bar{v}v} \beta_\nu \int d^4 q \times \frac{i(\hat{p} - \hat{q}) + (\hat{p} - \hat{q})^2/2m - [(p-q)^2 + m^2]/m}{[(p-q)^2 + m^2]\, q^2} \beta_\nu [F_K(q^2)]^2 v(p),$$

$$\hat{q} = \beta_\mu q_\mu \tag{4}$$

or

$$\Delta m = \frac{ie^2}{2(2\pi)^4 m} \int d^4 q \, \frac{[F_K(q^2)]^2}{q^2} \left\{ \frac{(2p - q)^2}{(p-q)^2 + m} - 4 \right\}. \tag{5}$$

The $F_K(q^2)$ as a function of q^2 can be determined only from an as yet nonexistent exact theory or a full analysis of future experiments. For our purposes it is sufficient to take, for example,

$$F_{K^+}(q^2) = 16m^4/(q^2 + 4m^2)^2,$$
$$F_{K^0}(q^2) = -4\lambda q^2 m^2/(q^2 + 4m^2)^2 \tag{6}$$

then from (5) and (6) we obtain for the mass difference

$$m_{K^0} - m_{K^+} = (m/8\pi^2) e^2 (^7/_3 \lambda^2 - 1)$$
$$= (m/2\pi)\alpha (^7/_3 \lambda^2 - 1). \tag{7}$$

Comparing with the experimental value of 4.8 Mev we deduce that $\lambda \approx 2$.

We note that it will be difficult to observe experimentally other effects due to the interaction under consideration.‡

Consequently it is not necessary to give up the idea that K^+ and K^0 form a charge doublet in order to explain the observed[1,2] mass difference. Both the sign and the magnitude of the difference $m_{K^0} - m_{K^+}$ could be a consequence of electromagnetic interactions.

*As remarked by Feinberg in the case of the π^0 meson, which is a truly neutral particle, such a matrix element would vanish as a consequence of invariance under charge conjugation.

†Expression (5) for the self-mass may also be derived from the usual theory in which the K mesons are described by second order wave equations and the electromagnetic interaction is introduced in a gauge-invariant manner by the substitution: $\partial/\partial x_\mu \to \partial/\partial x_\mu - ieF(-\Box^2) A_\mu(x)$.

‡The absence of bremsstrahlung and the difficulties involved in separating the electromagnetic and nuclear scattering for K^0 were discussed by Feinberg.[5] The most characteristic experiment would involve observation of fast δ electrons from K^0 mesons. However the K^0–e scattering cross section is very small at low energies. Consequently the effect will be vanishingly small since even a 1-Bev K meson in the laboratory system will have an energy of the order of only a few Mev in the K^0–e center-of-mass system.

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