NEGATIVE K MESON–NUCLEON INTERACTION AT LOW ENERGIES

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In a recent letter Matthews and Salam[1] observed that the emulsion data[2] for the total elastic scattering of K^- on protons may indicate a broad peaking in the cross section at ~25 Mev, and that this peak could be interpreted in terms of a $J=1/2$ resonance of the K^--p system. Such a resonance necessitates an attractive effective interaction between K^- and p, consistent with the rather indirect evidence of Alles et al.[3]

We wish to point out another, at present equally acceptable, explanation of the broad peaking at low energies, within the framework of the s-wave zero-range analysis.[4,5] If the K^--p interaction is assumed "repulsive,"[6] the destructive interference with the attractive Coulomb interaction will cause the integrated cross section to fall below the value in the absence of the Coulomb field. At energies above ~50 Mev this effect is negligible, but at low energies it is sufficient to cause the integral of the elastic differential cross section (suitably cut off at small angles) to behave as implied by experiment. For an "attractive" K^--p interaction the integrated cross section falls off monotonically with increasing energy even more steeply than the zero-range cross sections in the absence of the Coulomb field.

Recently we employed the R matrix formalism of Wigner and Eisenbud to include the effects of the $\bar{K}^0$-K^- mass difference in the zero-range analysis of the K^--nucleon interactions at low energies.[7] The formalism readily allows the inclusion of the long-range Coulomb interaction in the entrance channel (K^-p).

For K^- incident on protons, the elastic scattering, charge exchange, and reaction cross sections for $T=0$ and $T=1$ can be written in the following form:

$$\frac{d\sigma_{\mathrm{el}}}{d\Omega}=\left|\frac{\eta}{2k}\csc^2(\theta/2)\exp[+2i\eta\ln\sin(\theta/2)]+\frac{C^2(A_0+A_1-2ik'A_0A_1)}{2\Delta}\right|^2, \tag{1}$$

$$\frac{d\sigma_{\mathrm{ex}}}{d\Omega}=\frac{C^2k'}{k}\left|\frac{A_0-A_1}{2\Delta}\right|^2, \tag{2}$$

$$\frac{1}{2}\frac{d\sigma_{\mathrm{abs}}^{(0)}}{d\Omega}=\frac{C^2b_0}{2k}\left|\frac{1-ik'A_1}{\Delta}\right|^2, \tag{3}$$

$$\frac{1}{2}\frac{d\sigma_{\mathrm{abs}}^{(1)}}{d\Omega}=\frac{C^2b_1}{2k}\left|\frac{1-ik'A_0}{\Delta}\right|^2, \tag{4}$$

where $A_0=a_0+ib_0$, $A_1=a_1+ib_1$ are the complex scattering lengths in the absence of the Coulomb interaction,[4,7] k and k' are the wave numbers in the (K^-p) and ($\bar{K}^0n$) channels, $\eta=e^2/\hbar v$, $C^2=2\pi\eta\times(1-e^{-2\pi\eta})^{-1}$ is the s-wave Coulomb penetration factor, and Δ is defined by

$$\Delta=1-\tfrac{1}{2}i(A_0+A_1)[k'+C^2k(1-i\tan\alpha)]-A_0A_1k'C^2k(1-i\tan\alpha). \tag{5}$$

In Eqs. (1)-(5) it has been assumed that the range of the interaction (channel radius R) is small compared to $(\hbar^2/2me^2)=41.7\times10^{-13}$ cm and that $kR\ll1$. In that case

$$\tan\alpha=(G'/F')|_R\simeq-(2\eta/C^2)[\ln(2kR)+2\gamma+\mathrm{Re}\,\psi(i\eta)], \tag{6}$$

where $\gamma=0.5772...$, and ψ is the logarithmic derivative of the gamma function. In the calculations presented below, R was taken as the K meson Compton wavelength ($R=0.4\times10^{-13}$ cm), but the results are insensitive to this choice.

In Eqs. (1)-(5) the assumption of zero range (A_0 and A_1 independent of energy) implies the neglect of energy variation of the elements of the R matrix and of the momenta in the reaction channels. The earlier results[4,7] can be recovered by putting $\eta=0$ and $k'=k$.

As an illustration of the effects of the Coulomb field we have calculated the elastic scattering cross section (1) with the scattering lengths determined by Dalitz[5] (his solutions $A_\pm$). A typical center-of-mass angular distribution at a laboratory momentum of 140 Mev/c is shown in Fig. 1, where attractive (repulsive) corresponds to a_0 and a_1 both positive (negative).[8]

The experimental data for total scattering cross section represent integrals over angles, excluding the immediate forward angles. For comparison with these data we integrated our angular

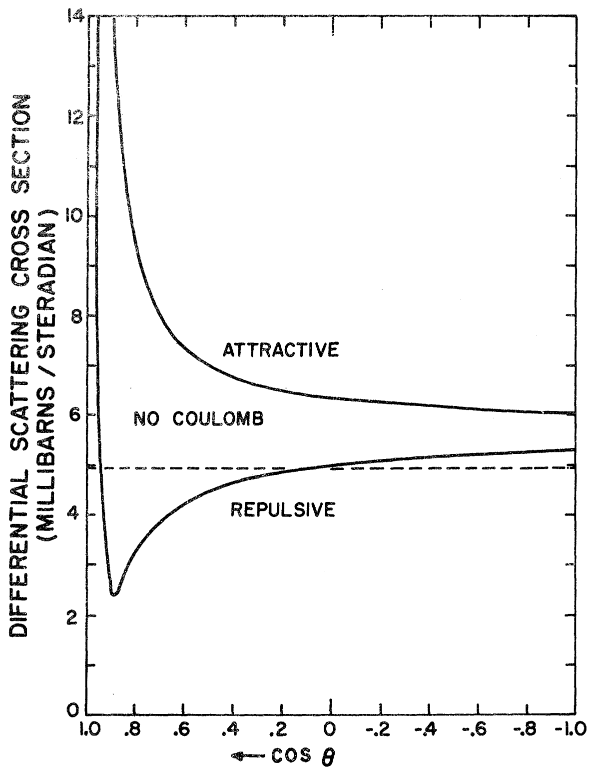

FIG. 1. Center-of-mass angular distribution for K^--p elastic scattering at 140 Mev/c laboratory momentum.

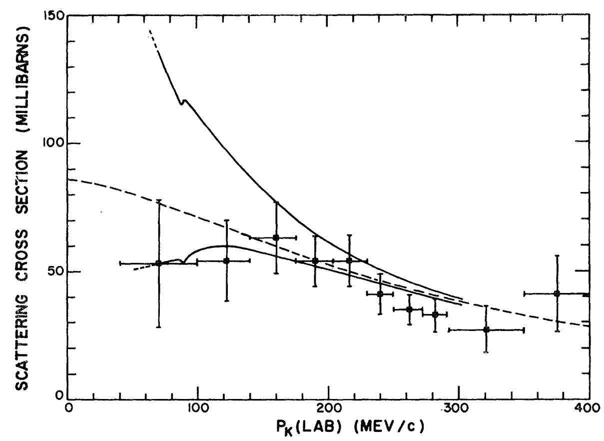

FIG. 2. Total scattering cross section as a function of laboratory momentum. The dotted curve is the zero-range result with no mass difference or Coulomb effects. The scattering lengths are $A_0 = \pm 0.28 + 0.54i$, $A_1 = \pm 1.19 + 0.22i$. The experimental points are emulsion data from reference 2.

distributions down to a forward angle determined at each energy by the criterion that the recoil proton have a laboratory momentum of at least 30 Mev/c (corresponding to a range of 5 or 6 microns in emulsions). The results for the total scattering cross section are compared with experiment[2] in Fig. 2. The effect of the destructive or constructive interference with the Coulomb amplitude is marked at low energies. At the threshold for the charge exchange reaction, small cusps appear in the theoretical curves for the elastic (and other reaction) cross sections.[7] The experimental data indicate that within the framework of the zero-range analysis the K^--p interaction is "repulsive."[9]

The comparison of theory and experiment shown in Fig. 2 can be criticized on several counts, none of which change the conclusion reached. First of all, different scattering lengths (apart from the change in sign of the real part) should be chosen to give the best over-all fit to the data for the two signs of the K^--p interaction. This would lower the "attractive" curve to give a better fit at high momenta, but its steep monotonic fall seems inconsistent with the data, independent of detailed fitting. Secondly, the variation of scattering lengths with energy due to final state interactions[10] can cause the cross sections in the absence of the Coulomb interaction to fall off less rapidly than in the zero-range approximation. While this will alter the detailed fitting, we argue that at the lowest energies such effects are not important, and the qualitative conclusion is unchanged.

Having concluded tentatively that the K^--p interaction is "repulsive" on the basis of the variation of the total elastic cross section with energy, we hasten to make the obvious remark that the differential cross section (see Fig. 1) provides a much cleaner and more direct means of determing the sign of the real part of the scattering amplitude, independent of the absolute magnitude of the cross section.

Finally we note that the sign of the K^--p amplitude at low energies has a bearing on the parity of the K meson.[11] Although there are questions regarding the handling of the unphysical regions in the dispersion relations,[12] it seems that a "repulsive" K^--p interaction leads to a rather definite conclusion. If one (a) accepts the zero-range analysis and the inference from Fig. 2 that the K^--p interaction is "repulsive," (b) assumes that the Λ and Σ have the same parity, and (c) believes in the validity of the heavy meson-nucleon dispersion relations, then the K meson is scalar, i.e., has the same parity as the Λ and Σ. If the Λ and Σ have opposite parities, no conclusion can be drawn about the parity of the K.

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[1]P. T. Matthews and A. Salam, Phys. Rev. Lett. 2, 226 (1959).

[2]Summarized by M. F. Kaplon in the 1958 Annual International Conference on High-Energy Physics at CERN, edited by B. Ferretti (CERN, Geneva, 1958), p. 171.

[3]Alles, Biswas, Ceccarelli, and Crussard, Nuovo cimento 6, 571 (1957).

[4]Jackson, Ravenhall, and Wyld, Nuovo cimento 9, 834 (1958).

[5]R. H. Dalitz, 1958 Annual International Conference on High-Energy Physics at CERN, edited by B. Ferretti (CERN, Geneva, 1958), p. 187.

[6]We use the terms "attractive" ("repulsive") in the usual field theoretical sense of the sign of the real part of the tangent of the phase shift at low energies being positive (negative). For a "repulsive" interaction, the question of whether the phase shift is dropping down from π (corresponding to a strong attraction) or going negative from zero (corresponding to a repulsion) can only be decided by the higher energy behavior (e.g., the sign of the effective range).

[7]J. D. Jackson and H. W. Wyld, Nuovo cimento (to be published).

[8]Dalitz showed that a_0 and a_1 must have the same sign.

[9]See reference 6. We note that a strong attraction is automatically consistent with the tentative conclusion of reference 3. It is not clear whether the experimental data of reference 3 are inconsistent with the other possibility of a repulsive, but strongly absorbing, interaction.

[10]R. H. Dalitz (private communication), and M. Ross and G. Shaw (private communication).

[11]P. T. Matthews and A. Salam, Phys. Rev. 110, 569 (1958); C. Goebel, Phys. Rev. 110, 572 (1958); K. Igi, Progr. Theoret. Phys. (Kyoto) 19, 238 (1958).

[12]S. F. Tuan, Phys. Rev. (to be published); also University of California Radiation Laboratory Report UCRL-8461 (unpublished).

UPPER LIMIT FOR THE DECAY MODE $\mu \to e+\gamma$

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In theories of the Fermi interaction, it has been suggested that the weak interactions all arise from the coupling of a vector current with a heavy charged boson.[1] One of the consequences of the existence of such an intermediate boson is the decay mode[2] $\mu \to e+\gamma$ which would be expected to occur with a branching ratio

$$R(\mu \to e+\gamma)/R(\mu \to e+\nu+\bar{\nu}) \sim 10^{-4}.$$

Experimentally an upper limit for this branching ratio has already been found[3-5] to be $\sim 10^{-5}$. Although the calculation based on the idea of the intermediate boson is ruled out by these measurements, the status of the theory of weak interactions demands a close examination of the possible decay modes of the muon. We have therefore continued the experiment previously reported[4] and improved upon the result.

The search for the $\mu \to e+\gamma$ decay mode was made by observing coincidences between a gamma detector and an electron detector placed on either side of a source of decaying positive muons. These were obtained by stopping the 60-Mev π^+ beam of the Nevis cyclotron in a lithium target. There, the π^+ mesons decayed into muons whose range was too short for them to escape from the target. The decay products were then counted in the two telescopes. The experimental arrangement is shown in Fig. 1. An event was defined by a fast coincidence between counts in the electron and gamma-ray telescopes with the requirement that none of the anticoincidence counters triggered at the same time. All counts were gated so they were recorded only if they occurred during a cyclotron beam burst.

In addition to the electronic selection of the events, an event was checked by photographing pulses displayed on two oscilloscopes. On one, a sweep speed of 20 millimicroseconds per centimeter permitted a rough check on the timing of one counter pulse from the electron telescope relative to two from the gamma-ray telescope. Displayed on a second oscilloscope, with a relatively slow sweep speed, were pulses from the remaining coincidence counters as well as 2′ and 3′ anticoincidence signals before they were pulse shaped. The signature of an event is shown in Fig. 2.

The efficiency of the electron telescope to detect 53-Mev electrons was estimated to be 0.75.