OPTICAL MODEL POTENTIAL FOR K^- MESONS*

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(Received January 26, 1960)

The K^--meson optical model potential has long been suspected to be attractive. The strongest argument is that due to Ceccarelli et al.[1] who have considered the inelastic collisions of K^- mesons in flight with heavy nuclei. Experimental results[1-3] indicate that such collisions are very rare, K^- mesons re-emerging from the nucleus in only about 1% of the cases at 50 Mev. Ceccarelli explained this phenomenon by postulating the existence of an attractive potential. Monte Carlo calculations using the known K^--meson elastic and annihilation cross sections with nucleons confirmed that an attractive potential of some 30 Mev was sufficient to explain the rarity of such events.[4] A more direct method of determining the sign of the potential is through an optical model analysis of elastic scattering. This method was not immediately successful because of the very strong absorption of K^- mesons in nuclear matter. Essentially nuclei absorb nearly all K^- mesons which enter, the K^- mesons annihilating to form hyperons and pions. This means that the elastic scattering is rather insensitive to the central depth of any real nuclear potential. A number of early square-well optical model calculations in WKB approximation[5] were made before it was realized that the imaginary potential was large, and indications were obtained of an attractive real potential. Further exact calculations[6] using the correct imaginary potentials indicated late in 1958 that the available experimental data were not sufficient to make a decision on the sign of the nuclear potential. Recently data of much greater statistical weight in more narrowly defined energy intervals have been obtained and Jones,[7] for instance, has concluded from an analysis of events found in following 73 meters of track-length in nuclear emulsion between the energies of 105 and 140 Mev that the potential is probably attractive. The purpose of this Letter is to present a rather more detailed analysis of some new experimental results from 93 meters of track-length between the energies of 95 and 125 Mev.[8]

The experimental results were obtained by scanning along the tracks of K^- mesons in nuclear emulsion for all deflections $\geqslant 2°$ in the emulsion plane. The stack of emulsions was exposed to the separated K^--meson beam of the Berkeley Bevatron. The scanning was started at a residual range of 7.2 cm and ceased at a residual range of 4.5 cm, these ranges corresponding to 125 and 95 Mev, respectively. Space angles were measured for all events whose projected angle in the emulsion plane was $\geqslant 3°$. Geometrical corrections were applied to each individual event to allow for events excluded from measurement by this criterion. Solid angle factors to convert the number of events found per meter of track length to a cross section in barns per steradian were also applied individually to each event. Finally the events were grouped into various angular intervals and the average cross section computed in each interval. The values obtained are shown plotted in Fig. 1. It should be pointed out that the possibility of

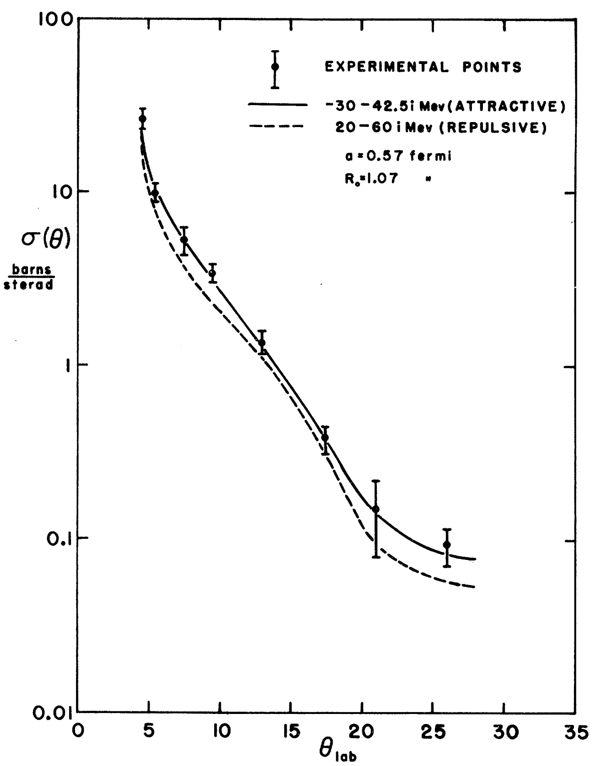

FIG. 1. Experimental angular distribution. The two curves are the theoretical curves for the potentials corresponding to the minimum and maximum values of $\sum \chi^2$ for the shape parameters given. They were obtained by plotting the theoretical averages. They do not represent a continuous differential cross section but rather the midpoints of the theoretical histograms.

direct excitation followed by the re-emission of the K^- meson has been neglected; such events would be included in the elastic category. For low momentum transfers, however, the effect is likely to be very small.

The theoretical values of the cross section were calculated from the phase shifts which were obtained by solving numerically a simplified form of the Klein-Gordon equation. The potenital adopted was of the Saxon type,[9] V, W, a, and R_0 constituting the four parameters of the diffuse-surface optical model. The computations were carried out on the IBM 709 of the Western Data Processing Center at U.C.L.A.

For given values of V, a, and R_0, the value of W is determined by the total reaction cross section. An analysis of the published data on the mean free path of K^- mesons in emulsion indicates that the best value for the reaction cross section per "average" emulsion nucleus at a mean energy of 110 Mev is 770 ± 30 mb. The statistical weight of the experimental results is insufficient to determine a or R_0, in addition to the real potential; reasonable values therefore have to be assumed for these parameters. We have chosen to carry out the analysis at two values of R_0, 1.07 and 1.20 fermis; and over a range of a values from 0.4 to 0.72 fermi. The value of the Coulomb radius was fixed at 1.07 fermis.

Because the experimental data are spread in energy from 95 to 125 Mev, for each set of optical model parameters, three calculations were made: at 100, 110, and 120 Mev; these were then averaged in the appropriate fashion. These calculations were done for two representative nuclei in the emulsion: $A = 14$, $Z = 7$ and $A = 94$, $Z = 41$, and combined in the ratio 57.4:42.6. The final result is thus an average of six individual curves—a so-called 6-run group. This result was compared with that from a 2-run group in which only one energy, 110 Mev, was considered. The differences were at all angles less than 1% and the latter half of the analysis was therefore performed using 2-run groups only. The theoretical curves were approximately integrated[10] over each angular interval and an average value thus obtained. This was then compared directly with the experimental data and values of $\sum\chi^2$ computed. Plots of $\sum\chi^2$ versus V are shown in Figs. 2 and 3 for radius parameters of 1.07 and 1.20 fermis, respectively. In all cases the value of W was chosen to exactly reproduce the reaction cross section of 770 mb. Figure 2 shows a substantial minimum in $\sum\chi^2$ in the attractive region for all a values except the lowest, 0.40 fermi. Unfortunately this is only significant for a values of 0.54 fermi and above; below this, all potentials considered give a good fit with the experimental data, Pearson probabilities being in excess of 10%. At $a = 0.57$, 10% Pearson probability limits would set the potential at a value

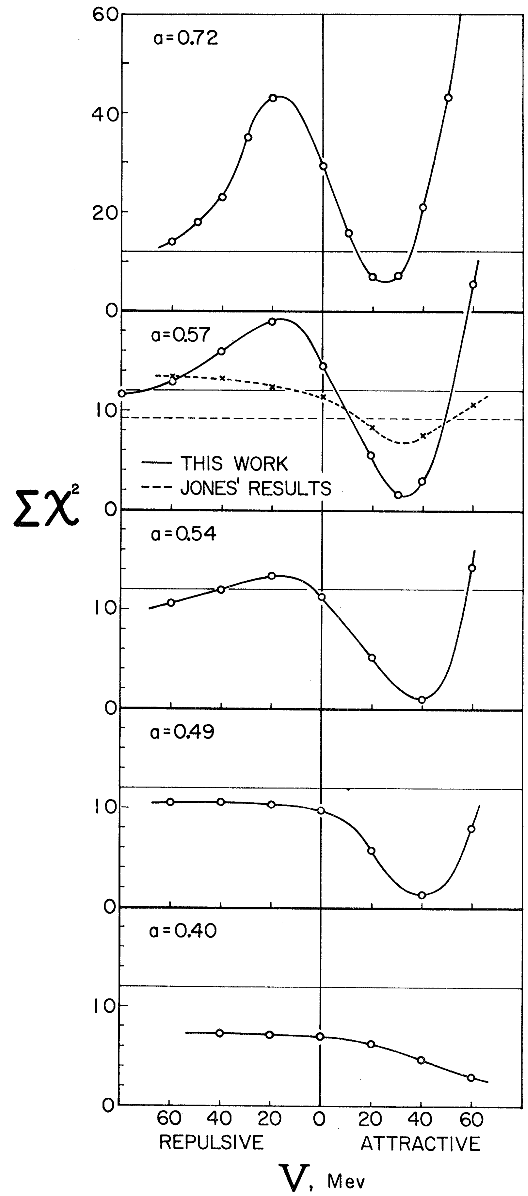

FIG. 2. Values of $\sum\chi^2$ plotted against V, the real potential, for different values of a at a constant radius of 1.07 fermis. The thin line shown at a $\sum\chi^2$ value of 12.2 is the 10% significance level.. The dashed horizontal line at $a = 0.57$ is the 10% significance level for Jones' analysis.

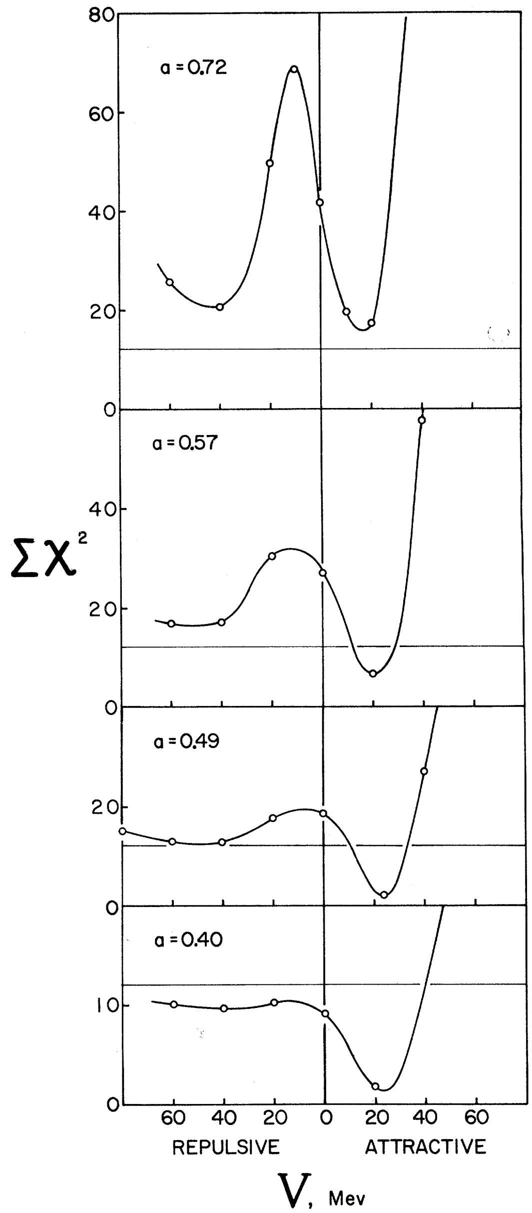

FIG. 3. Values of $\sum\chi^2$ plotted against V, the real potential, for different values of a at a constant radius R_0 of 1.20 fermis. The thin line shown at a $\sum\chi^2$ value of 12.2 is the 10% significance level.

between -5 and -50 Mev with a maximum probability of 95% at -30 Mev. This result is in agreement with the work of Jones whose $\sum\chi^2$ curve at $a = 0.57$ is also shown plotted in Fig. 2. For $a = 0.72$ fermi, the region of good fit is more restricted with the best value at -25 Mev. The situation at $R_0 = 1.20$ fermis is very similar. An attractive potential is first significantly favored at $a = 0.49$, for $a = 0.57$ the region of best fit being from -12 to -28 Mev with a best value at -20 Mev. There is no longer any potential at $a = 0.72$ which can be considered a good fit.

As the correct values of a and R_0 are not known, it is a little difficult to give a best value of V, although if a is more than 0.50 it is very likely to be attractive and most likely to be about 25 Mev. Such a potential would agree with the $(a+)$ and $(b+)$ s-state scattering length solutions of Dalitz and Tuan[11] and would also agree with the constructive interference found by Alvarez et al.[12] in K^--meson–proton scattering.

The authors would like to thank Professor H. K. Ticho, Dr. J. H. Mulvey, and Dr. I. E. McCarthy for discussions. They are greatly indebted to the Western Data Processing Center for the use of the IMB 709 and to Mrs. Lisa Greenstadt for help with the programming. We thank Dr. E. J. Lofgren and the Bevatron crew for making the emulsion exposure possible.

*Partially supported by the U. S. Atomic Energy Commission and by programs of the National Science Foundation and the Office of Naval Research.

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