DIFFRACTION SCATTERING OF HIGH-ENERGY PIONS

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The scattering of particles by nuclei has an intrinsic interest, mainly in terms of nuclear size and nuclear structure theory, but it can also lead to results, not otherwise readily available, concerning the elementary interactions. For example, the attractive nature of the average pion-nucleon interaction [1] was established from Coulomb interference effects in the scattering of pions by carbon. More recently, Drell [2] has analyzed the difference between the known radius of the nucleus and the radius of the optical-model potential for nucleon scattering in terms of nuclear force effects; he shows that one studies in this way only the relatively long-range ($\gtrsim \frac{1}{2}\hbar/\mu c$) behaviour of the direct part of the central nucleon-nucleon potential. His work emphasizes the usefulness of the accurate knowledge which has become available in the past year or so concerning the size and density distribution of nuclei. An analysis [3] of the high-energy experiments [4] which provide the most clear-cut nuclear evidence on nuclear size indicates that the matter density distribution coincides with the charge density [5] to within a few per cent.

In the present note we apply the high-energy optical model, using an accurate nuclear density distribution, to the nuclear-emulsion results of Walker and Crussard * [6] on 1.5 Bev negative pions. They studied 2700 interactions found in 934 meters of along-the-track scanning; their principal interest was in pion-proton collisions, but they also report the following data on nuclear interactions: interaction mean free path $\lambda = 35$ cm.**; mean free path for elastic scattering in the range 1°-10°, three times greater. Interpreting this as diffraction scattering, and correcting for the omitted small-angle scatterings with a square-well model, they find $\sigma_{\text{diffraction}}/\sigma_{\text{interaction}} \approx 1/2.5$, and point out that both the small absolute value of $\sigma_{\text{interaction}}$ (conventional "geometric" mean free path is 27 cm.) and the small ratio indicate appreciable transparency. We cannot safely use the standard square-well transparency analysis, however, because the results are rather sensitive to the actual shape of the nuclear density distribution.

The "tapered model" form for the nuclear density is described in [3] it has a "radius" (to the 50 percent-density surface) of $R_{50} = 1.1\ A^{1/3} \times 10^{-13}$ cm. and a 10 per cent-90 per cent surface thickness of $\sim 2.6 \times 10^{-13}$cm. (for Pb); it is nearly identical, for heavy elements, with the form given by Hofstadter [5], and also agrees with the high-energy interaction cross-section experiments [4]. It should therefore fit the pion interaction cross section using $\bar{\sigma} = 34$ mb [7] as the elementary cross section, in the expression for the absorption coefficient, $K(r) = \bar{\sigma}\,\rho(r)$. With one adjustable parameter—the increment in wave number, $k_1(r)$, assumed proportional to the nuclear density—it should also yield the diffraction cross section. We have calculated, using the familiar optical model method [4], the average integrated diffraction cross-section for Ilford Nuclear Emulsion.

The results of [3] for the interaction cross section lead to a mean free path of $\lambda = 38.6$ cm, compared with the observed value of 35 cm. The diffraction cross section calculation, with $k_1 = 0$, leads to $\sigma_{\text{diffraction}}/\sigma_{\text{interaction}} = 1/1.8$. (A value of k_1 different from zero would only increase this ratio, which is already larger than the observed 1/2.5.)

Agreement is somewhat better than we would have obtained with the square-well model. The calculated smallest value of the diffraction scattering is still greater than the observed, however. There are two effects which would bring closer agreement, though they are both small: 1. the extrapolation down to 0° which was made by Walker and Crussard to cover the region of low scanning efficiency was calculated on the basis of a square-well model, whereas the tapered model would require a larger small-angle contribution; 2. about 20 per cent of the weighted-average cross section arises from the light nuclei C, N, and O, which are represented, in the model we have used, as being less diffuse than they really are. A better treatment of these nuclei would increase $\sigma_{\text{interaction}}$ and decrease $\sigma_{\text{diffraction}}$.

In any case one can scarcely escape the conclusion that the dispersive part of the scattering of 1.5 Bev pions is small compared with the absorptive part, i.e., that k_1/K is small and the elastic scattering is minimal. This contrasts with the scattering of 1.4 Bev neutrons by nuclei [4],

* The application of their results to the problem at hand was suggested by W.D.Walker.

** It is interesting to note that a somewhat similar along-the-track study, at energies perhaps 100 times greater, (U. Haber-Schaim a private communication) gave a significantly larger cross-section ($\lambda = 23 \pm 5$ cm.), suggested that the pion-nucleon cross-section rises at extremely high energies. A similar claim has been made concerning the nucleon-nucleon cross-section [3].

for which one finds the diffraction scattering about 30 percent greater than minimal, and $k_1/K > 0.3$ (the complete analysis has not been carried out for the tapered model). In terms of elementary interactions, we infer that the forward scattering amplitude for the pion-nucleon interaction at 1.5 Bev is largely imaginary. This is consistent with the finding of Walker and Crussard that more than two-thirds of the π^--p cross section is inelastic.

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