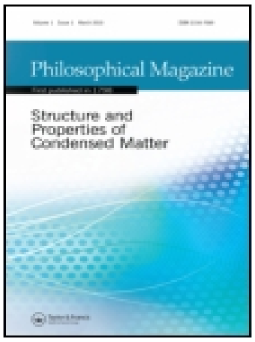

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The Interactions of π^--mesons with Complex Nuclei in the Energy Range (100–800) MeV

II. The Interaction Lengths and Elastic Scattering of 750 MeV π^--mesons in G5 Emulsion†

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Abstract

A total of 100·5 m of track has been scanned in a block of emulsion exposed to the 750 Mev π^--meson beam of the Brookhaven cosmotron. Allowing for the beam contamination of 7%, the interaction lengths for the production of inelastic events and for elastic scattering with projected angles of $2 \leqslant \phi < 10°$ are $(43{\cdot}6 \pm 2{\cdot}9)$ cm and $(66{\cdot}8 \pm 5{\cdot}6)$ cm respectively. The geometrical interaction length is 29·3 cm. A comparison with the optical model of the nucleus gives a value for the absorption coefficient $K = (1{\cdot}5 \pm 0{\cdot}2)\ 10^{12}\ \mathrm{cm}^{-1}$ and for the change in wave number $k_1 = (1{\cdot}84 \pm 0{\cdot}06)\ 10^{12}\ \mathrm{cm}^{-1}$. The absorption coefficient corresponds to a mean free path in nuclear matter $\lambda_n = (6{\cdot}7 \pm 0{\cdot}9)\ 10^{-13}$ cm, to an imaginary component of potential $V_I = (15 \pm 2)$ Mev and with the value of the change in wave number to a real potential $V_r = (36 \pm 1)$ Mev.

§ 1. Introduction

This paper is the second of a series concerned with an examination of the interaction characteristics of π^--mesons with G5 emulsion nuclei within the energy range (100–800) Mev. A previous publication (Allen *et al.* 1959) dealt with the elastic scattering of π^--mesons at an energy of 88 Mev and will be referred to hereafter as I.

§ 2. Interaction Lengths and Elastic Scattering of 750 Mev π^--mesons in G5 Emulsion

2.1. *Experimental*

The emulsion block consisted of pellicles each 2 in. × 3 in. × 400 μ and had been exposed to the 750 Mev beam of the Brookhaven cosmotron. The stack was received already processed.

A similar method of scanning was employed to that described in I. It was carried out on four Cooke M4000 microscopes under a magnification

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of $45 \times 1{\cdot}5 \times 15$. Tracks lying within $\pm 5°$ of the general beam direction were selected 1 cm from the edge of the emulsion. An eyepiece hairline was aligned on each track to be followed and a comparison of the track with this direction was made at intervals. Each track was followed to an interaction, out of the emulsion or for a maximum length of 2·5 cm. The beam energy of 750 MeV was not expected to vary appreciably over this length.

An initial classification of the interactions was made into elastic scatterings of type ($n_h = 0$, $n_s = 1$) and stars, the latter group including disappearances ($n_h = 0$, $n_s = 0$). A careful search was made over a region of 150 μ around each disappearance for secondary tracks or for a continuing primary. Star-sizes were estimated visually, particular attention being paid to those of type ($n_h = 1$, $n_s = 1$). Of 19 such events, three were identified on dynamical grounds as π^-–p collisions with a visible recoiling proton; they were classified therefore as elastic scatterings.

All detectable scatterings with horizontally projected angle $\phi \geqslant 1°$ were recorded and determined from the coordinates of four points on the track, two on either side of the point of scattering. Those events having $\phi < 2°$ were later discarded as being due chiefly to Rutherford scattering.

2.2. *The Interaction Lengths*

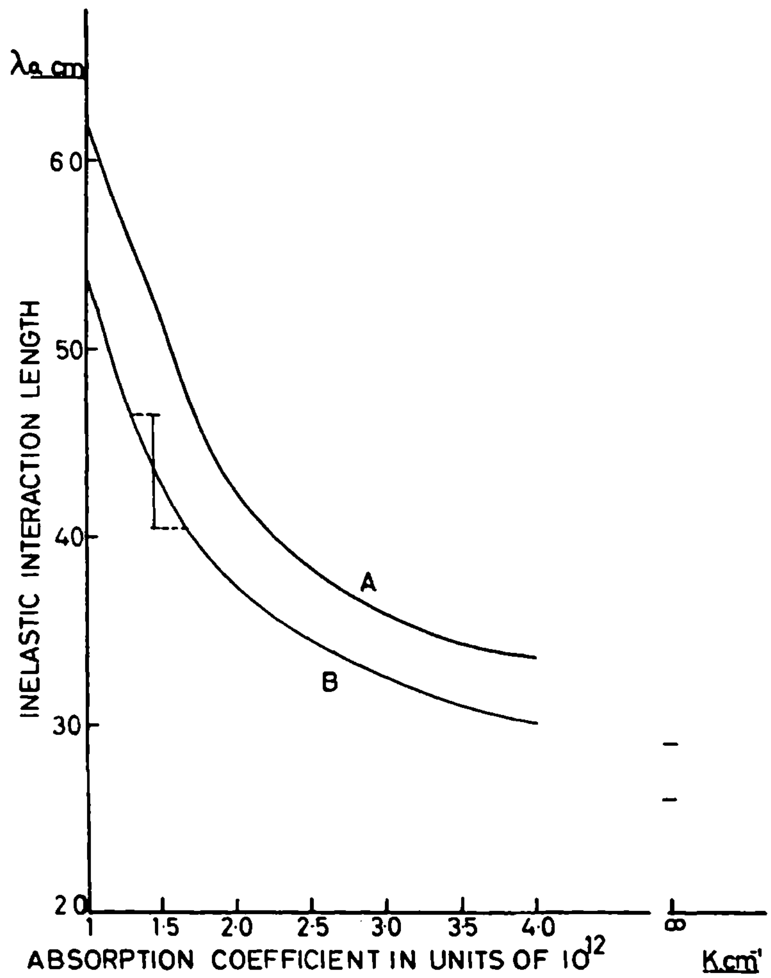
There were found in a total track length of 100·5 m, 282 events initially classified as elastic scatterings, 3 π^-p elastic scatterings and 233 stars including 19 disappearances. Of the elastic scatterings, 130 were through projected angles $\phi < 2°$ and were due chiefly to Rutherford scattering, and 12 were through angles $\phi \geqslant 10°$ for which the probability of diffraction scattering is very small. Allowing for the contamination of the beam which has been given as 7% (Blau and Oliver 1956, Lindenbaum and Yuan 1955), the interaction length for the formation of inelastic events in G5 emulsion at 750 MeV is $(43{\cdot}6 \pm 2{\cdot}9)$ cm and the interaction length for elastic scattering through projected angles $2 \leqslant \phi < 10°$ is $(66{\cdot}8 \pm 5{\cdot}9)$ cm.

The mean free path for inelastic interaction is consistent with that which can be computed from Blau and Oliver (1956) of $(42{\cdot}6 \pm 2{\cdot}4)$ cm at 750 MeV and by Barbaro *et al.* (1958) of $(42{\cdot}4 \pm 2{\cdot}4)$ cm at 570 MeV. Moreover the three elastic scatterings on hydrogen which were identified in the events of type $(1+1)\pi$ are consistent with the five events expected from the cross sections of Crittenden *et al.* (1959). From this it is concluded that scanning losses are small.

2.3. *Comparison with the Optical Model*

A summary of the essential features of the optical model of nuclear interactions and its application to emulsion nuclei has been given in I. The cross section for inelastic interaction is determined by the radii of emulsion nuclei and the absorption coefficient, K, of nuclear matter for meson waves. The total and differential cross sections for elastic scatterings are both further determined by the change in the wave number, k_1, of the meson wave on penetrating nuclear matter. From the expressions for the inelastic cross section given in I, the variation (with the absorption coefficient) of the interaction length for inelastic interactions, λ_a, has

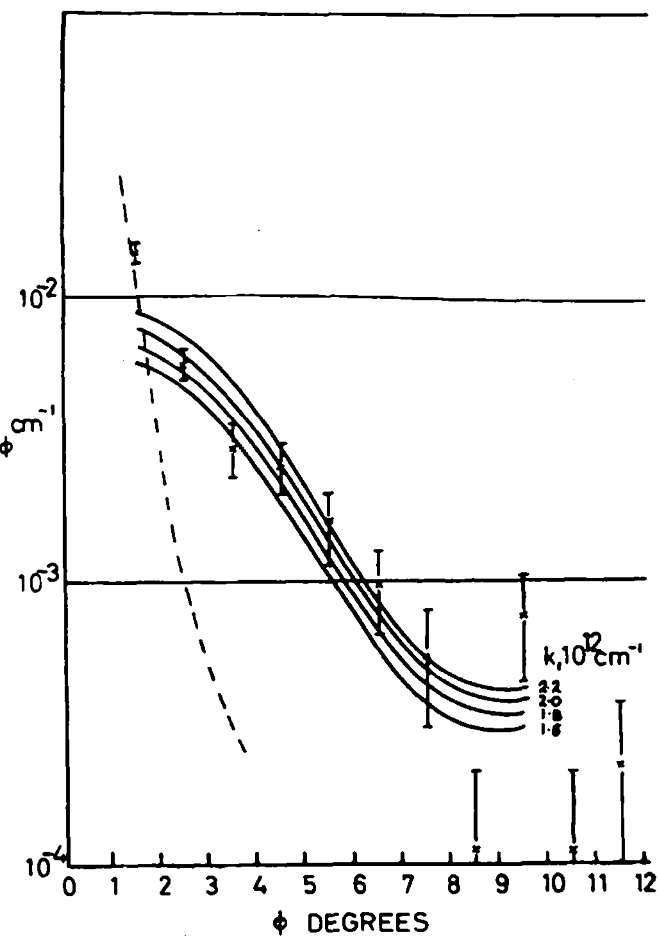
Fig. 1



The variation of the inelastic interaction length with absorption coefficient. Curve A is computed from the optical model and in curve B allowance has been made for the de Broglie wavelength.

been calculated. This is shown as curve A of fig. 1; the nuclear radii have been taken as $r_0A^{1/3}$ with r_0 as $1{\cdot}35 \times 10^{-13}$ cm. The increase in cross section due to Coulomb attraction was calculated to be of the order of 2% and is considered negligible. In curve B allowance has been made for the de Broglie wavelength of the meson. Using this curve the experimental value of the interaction length yields a value of $(1{\cdot}5 \pm 0{\cdot}2)10^{12}$ m^{-1} for the absorption coefficient.

Fig. 2



The observed distribution of horizontally projected angles of elastic scattering per 1° interval. The full curves have been calculated from the optical model for various assumed values of nuclear potential. The broken line represents Rutherford scattering.

With this value of absorption coefficient, the horizontally projected angular distribution of the scattered mesons was calculated for various assumed values of the change in wave number between 1·6 and $2{\cdot}2 \times 10^{12}$ cm^{-1} which correspond to various values of the real component of nuclear potential. In fig. 2 are shown the calculated distributions and the experimental results, together with the distribution for Rutherford scattering. It is seen that the contribution of the latter to the angular distribution is small above 2°. To obtain a precise value of k_1 a numerical integration of the distributions was carried out to give the interaction length for scattering through projected angles between 2° and 10° as a function of k_1. The observed value of the interaction length corresponds to $k_1 = (1{\cdot}84 \pm 0{\cdot}06)10^{12}\ \mathrm{cm}^{-1}$.

The attenuation mean free path of the meson wave in nuclear matter, λ_n, is given by $1/K$ and is found to be $(6{\cdot}7 \pm 0{\cdot}9)10^{-13}$ cm; it corresponds to an imaginary component of nuclear potential $V_i = (15 \pm 2)$ MEV. The value of k_1 corresponds to a real component of potential $V_r = (36 \pm 1)$ MEV.

2.4. *Discussion*

The absorption coefficient may be calculated if the detailed processes of the inelastic interaction are known. Evidence of these may be obtained from the meson star-size at 750 MEV which is found to be $(4{\cdot}1 + 0{\cdot}5)\pi$. The secondary particles with ionization near the minimum value will be chiefly charged mesons. If allowance is made for uncharged mesons then the scattering of mesons must be the predominant process of inelastic interaction. In the case of the inelastic scattering arising from several scatterings of the meson on individual nucleons within the nucleus, the absorption coefficient may be calculated from the cross sections σ_{π^-p}, σ_{π^+p} of charged mesons in hydrogen. These are reduced within the nucleus by the restriction on low-energy transfers imposed by the Pauli exclusion principle. There are insufficient data at energies near 750 MEV to support a detailed calculation of this effect. An approximate calculation has been made assuming that the momenta of the nucleons are given by a Fermi distribution. The reduction in the cross section for elastic and charge exchange scattering in hydrogen is calculated approximately by the method of Cronin *et al.* (1957) and is about 13%. The reduction in the cross section for production of mesons in hydrogen has been computed from the momentum distribution of the recoiling nucleon (Puppi 1958), and is 32%. The total cross section for interaction of 750 MEV π^--mesons is thereby reduced by about 25% and it is assumed that there will be a similar reduction in the cross section for interaction of π^+-mesons.

Recent determinations of σ_{π^-p} and σ_{π^+p} have been made by Burrowes *et al.* (1959) and Brisson *et al.* (1959) who found the cross sections to be (38 ± 2) mb and (17 ± 1) mb respectively. Assuming charge independence and allowing for the exclusion principle, the absorption coefficient is calculated to be $(2{\cdot}0 \pm 0{\cdot}1)10^{12}\ \mathrm{cm}^{-1}$ for the average emulsion nucleus. The estimate of error arises from the experimental uncertainties on σ_{π^-p} and σ_{π^+p} and includes no estimate of the inaccuracies involved in the very approximate calculation of the Pauli effect. In view of this it is felt that significance should not be attached to the difference between this value of K and the value deduced earlier from the experimental results.

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