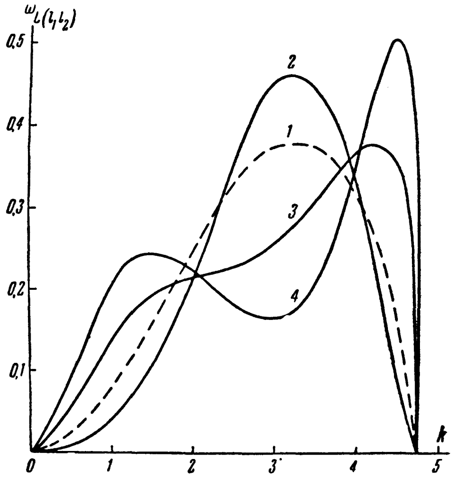
for $l_1' + l_2' \geq l_1 + l_2 + 2$, and if the matrix does not have singularities, then

$$T^{1/_2;2}_{J,lL(l_1l_2)}(k_1, k_2; k_0) \approx N k_1^{l_1} k_2^{l_2} \tau^{1/_2;2}_{J,lL(l_1,l_2)}(k_0), \tag{2}$$

where N is a normalizing factor and $\tau(k_0)$ is a function very weakly dependent on k_1, k_2. For energies ~ 1.3 Bev, π mesons with $l \leq 5$ take part in π-N scattering (see the survey article of Gell-Mann and Watson,[6] Fig. 1). This gives 4 and 6 for the maximum $L = l \pm 1$. Taking into account the expenditure of energy on the production of the additional π meson, we thus assume (underestimating somewhat) that the states with $l_1' + l_2' \geq 4$ do not essentially contribute to the matrix element. Then, for energies ~ 1.3 Bev, approximation (2) can be used for the cases in which $l_1 + l_2 \geq 2$. In the figure are shown the momentum spectra for



Curve 1 – Statistical theory; Curve 2 – $L(l_1l_2) = 2(11)$; Curve 3 – $L(l_1l_2) = 2(20), 2(02)$; Curve 4 – $L(l_1l_2) = 3(30), 3(03)$.

some partial states and for $E_\pi = 1.37$ Bev, calculated from approximation (2). The normalization makes the area of each curve equal to unity. The spectra corresponding to states with $l_1 = l_2$ have single maxima, and the greater the angular momentum, the sharper the peak. For $l_1 \neq l_2$ the shape of the spectrum changes with increasing $\Delta l = |l_1 - l_2|$, and acquires the character of a double-humped curve.* The total momentum spectrum is formed by the superposition of the partial spectra (with the interference of the partial states taken into account) with weights determined by the specific character of the interaction; the spectrum can take on all intermediate shapes, from a curve with one sharp maximum to a curve with two characteristic maxima. If it is assumed that the weight of the orbital angular momentum is due to one of the mesons, then the total momentum spectrum of the π^+ mesons, for sufficiently large energies, will be represented by a double-humped curve. A similar result can be expected for the total momentum spectra of the π mesons in other reactions mentioned above.

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*This result may be explained by an extreme simplification of the problem. If the mesons are assumed to be ultra-relativistic and the nucleon is assumed to be at rest, then the law of conservation of energy gives $k_1 + k_2 = \epsilon$, where ϵ is the total energy minus the mass of the nucleon. In this case $w_{L(ll)}(k) \sim k^{2l}(\epsilon - k)^{2l}\rho(k)$, $w_{L(l0)+L(0l)}(k) \sim [k^{2l} + (\epsilon - k)^{2l}]\rho(k)$, where $\rho(k)$ is the state density function; $\rho(0) = \rho(\epsilon) = 0$, and $\rho(\epsilon/2) = \rho_{max}$. For sufficiently large l, the second probability has two maxima.

[1] Eisberg, Fowler, Lea, Shephard, Shutt, Thorndike, and Whittemore, Phys. Rev. **97**, 797 (1955).

[2] R. M. Sternheimer and S. J. Lindenbaum, Phys. Rev. **109**, 1723 (1958).

[3] R. C. Whitten and M. M. Block, Phys. Rev. **111**, 1676 (1958).

[4] B. d'Espagnat, Kgl. Danske Videnskab Selskab., Mat-fys Medd. **28**, 11 (1954).

[5] V. A. Astaf'ev, JETP **36**, 98 (1959), Soviet Phys. JETP **9**, 70 (1959).

[6] M. Gell-Mann and K. M. Watson, Annual Review of Nuclear Science **4**, 219 (1954) [Russ. Transl., Usp. Fiz. Nauk **59**, 399 (1956)].

Translated by E. Marquit
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THEORETICAL INTERPRETATION OF ELASTIC π^--p SCATTERING EXPERIMENTS ON THE PROTON SYNCHROTON OF THE JOINT INSTITUTE FOR NUCLEAR RESEARCH

I. PATERA and Ch. D. PALEV

Moscow State University

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EXPERIMENTS on π^--p scattering at high energies are of great interest for the study of nucleon structure. In particular, it is possible from the analysis of such experiments to obtain data on the distribution of nuclear matter in the proton and also the value of the mean square of its radius.[1]

Using the experimental data obtained in Dubna[3] at an energy of 7 Bev, we computed the phase shifts of the elastic scattering by a method described in reference 1. From these we then obtained the absorption coefficient of pions in a proton as a function of the distance from its center, and also the mean square of the "pion" radius of the nucleon. In references 1 and 2 such computations were carried out for energies of 1.3 and 5 Bev.

In the region of small angles we approximated the differential elastic scattering cross section in accordance with the optical law $4\pi\lambda\!\!\!^{-}\,\mathrm{Im}\,F(0) = \sigma_t$ (assuming that Re F = 0). The value of the total interaction cross section σ_t was assumed to be (30 ± 5) mb (reference 3). As a result of our computations we obtained

$$\sigma_{in} = \sum_{l=0}^{12} \sigma_{in}(l) = (24.3 \pm 4.2)\ \text{mb},$$

$$\sigma_d = \sum_{l=0}^{12} \sigma_d(l) = (6.6 \pm 1.1)\ \text{mb},$$

which is in good agreement with the experimental data. We have neglected the partial cross sections with $l > 12$. As can be seen in Fig. 1, their relative contributions are sufficiently small.

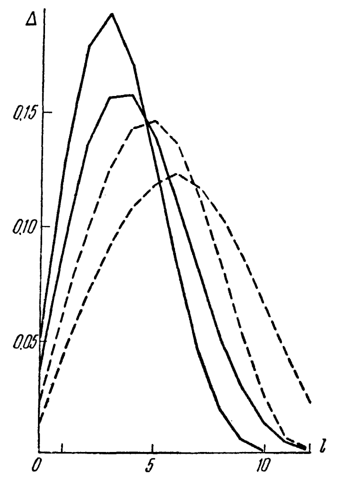

FIG. 1. Relative value of the partial elastic (solid curves) and inelastic (dashed curves) cross sections:

$$\Delta_{in} = \sigma_{in}(l)/\sigma_{in}, \qquad \Delta_d = \sigma_d(l)/\sigma_d.$$

The two curves correspond to the angular distributions with largest and smallest curvature.

Figure 2 shows the dependence of the computed absorption coefficient on the distance from the center of the proton. The curve K(r) is most reliable for intermediate values of r, since for small values it is determined by an approximation of the angular distribution for large angles, and for large values by the optical law and the assumption Re F = 0. To make the curve more precise

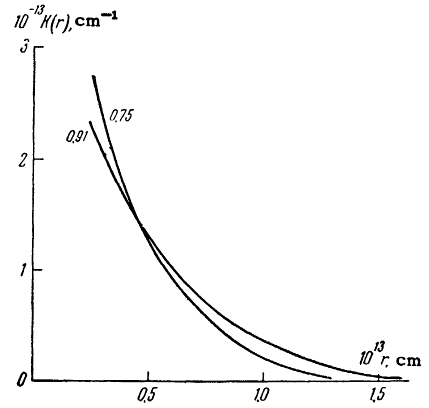

FIG. 2. Absorption coefficient as a function of the distance from the center of the proton. The two curves correspond to the angular distributions with largest and smallest curvatures.

in the extremal regions, measurements of the elastic scattering at small and large angles are needed.

A value of $\sqrt{\langle r^2 \rangle} = (0.83 \pm 0.08) \times 10^{-13}$ cm was obtained for the mean square of the "pion" radius of the proton. This is in good agreement with the value obtained in reference 1 and with the value of the "electromagnetic radius" in reference 4.

A comparison with the curves of references 1 and 2 showed that, within the limits of experimental error, the proton absorption coefficient does not depend on the energy.

It is also important to emphasize that, unlike for high-energy p-p scattering, the experimental data for π^--p scattering can be explained on the assumption of a purely absorbing proton model (Re F = 0). For a more precise check of this conclusion measurements of the elastic scattering in the region of small angles, on the order of several degrees, are necessary.

In conclusion, we express our gratitude to V. S. Barashenkov, under whose guidance this work was carried out.

[1] Blochincev, Barashenkov, and Grishin, Nuovo cimento **9**, 249 (1958); Blokhintsev, Barashenkov, and Barbashov, Usp. Fiz. Nauk **68**, 417 (1959), Soviet Phys.-Uspekhi **2**, 505 (1960).

[2] Blokhintsev, Barashenkov, and Grishin, JETP **35**, 311 (1958), Soviet Phys. JETP **8**, 215 (1959).

[3] Wang Kang-Ch'ang, M. I. Solov'ev, et al., Материалы Киевской конференции по физике высоких энергий (Proceedings of the Kiev Conference on High-Energy Physics), 1959.

[4] R. Hofstadter, Revs. Modern Phys. **28**, 214 (1956); D. R. Yennie et al., Revs. Modern Phys. **29**, 144 (1957).

[5] Tsyganov, Shafranova, Markov, et al., loc. cit. reference 3.

Translated by Z. Barnea
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MEASUREMENTS OF THE ENERGY DEPENDENCE OF RADIATIVE NEUTRON CAPTURE IN IRON, SILVER, AND GOLD AT ENERGIES UP TO 30 kev

A. I. ISAKOV, Yu. P. POPOV, and F. L. SHAPIRO

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

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A spectrometer employing the neutron slowing-down time in lead[1] was used to measure the energy dependence of the cross section for radiative capture of neutrons in chlorine,[2,3] iron, silver, and gold. The measurement procedure and the reduction of the experimental data were described in detail in reference 2.

1. Iron. The measurements were made on samples of varying thicknesses of Armco iron (type "A", approximately 99.7% iron) and iron oxide (chda). The cross section of the (n, γ) reaction was obtained up to neutron energies of approximately 50 kev (Fig. 1). In the region up to 600 ev, the cross section obeys the 1/v law within 3 to 5%. For the iron level at $E_0 = 1180 \pm 80$ ev, a value $\sigma_0\Gamma_\gamma = 74 \pm 7$ ev-bn was obtained (only the statistical error is indicated). This value is half the preliminary result reported earlier.[3]

Measurements of the area of the resonance peak as a function of $\overline{l}^{-1/2}$, where $\overline{l}$ is the effective thickness of the sample, are presented in Fig. 2. The crosses denote the points used to calculate the preliminary value of $\sigma_0\Gamma_\gamma$. The reason for the deviation of the points is not clear, but numerous subsequent measurements, performed with considerably better statistics, lead us to assume the value indicated above for the strength of the level.

If the peak at $E_0 = 1180$ ev is due to one level, then $\Gamma_\gamma \gtrsim 0.8$ ev regardless of the isotope to which this level is assigned. At the same time, the neutron width Γ_n depends substantially on the spin and the isotope to which this resonance is ascribed (in particular, for s neutrons and Fe^{56}, $\Gamma_n \sim 5 \times 10^{-2}$ ev). This level cannot explain the thermal cross section of the iron.

From the results shown in Fig. 1, it follows that for iron the resonant capture integral $R_\gamma = \int \sigma_\gamma(E)\,dE/E$ should differ little, within the range from 0.49 to 2×10^6 ev, from the value $R_\gamma(1/v) = 1.1 \pm 0.03$ bn, calculated by extrapolating the capture cross section from the thermal region in accordance with the 1/v law, namely $R'_\gamma = R_\gamma - R_\gamma(1/v) = 0.12 \pm 0.02$ bn. The principal contribution, 0.1 ± 0.01 bn, is made to this quantity by the 1180 ev level. The contribution of the levels $E_0 = 7$ to 8 kev amounts to approximately 0.01 bn; all the higher levels make contributions that add up to approximately the same value.* The given value of R'_γ is one order of magnitude less than the value obtained by subtracting $R_\gamma(1/v)$ from the experimental data of references 4 — 6. The reason for the discrepancy remains unclear.

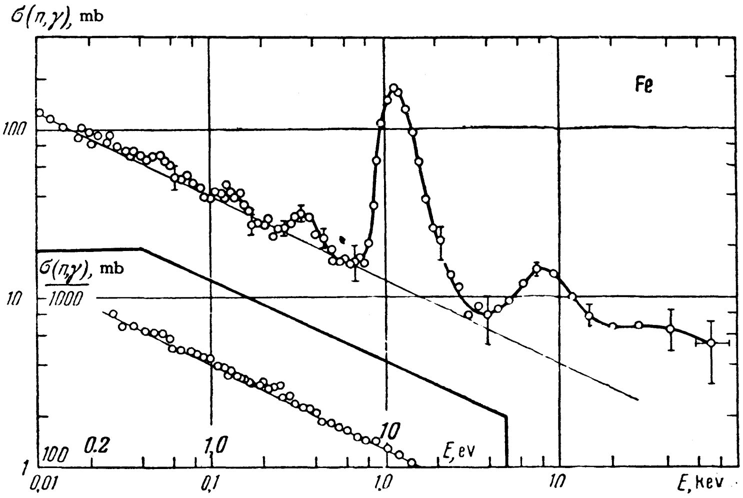

FIG. 1. Energy dependence of the neutron capture cross section in iron. The curve was normalized to the capture cross section $\sigma = 2.53 \pm 0.06$ bn at E = 0.025 ev.[8]