The elastic scattering of the positive pions is pronounced in the backward direction, an indication of interference of s- and p-waves. The same is true of the charge exchange scattering of the negative pions. The elastic scattering of the negative pions, on the other hand, is approximately isotropic.

A phase shift analysis has been made on the assumption that the scattering takes place in states characterized by isotopic spin $\frac{1}{2}$ and $\frac{3}{2}$ and by angular momentum $S_{1/2}$, $P_{1/2}$ and $P_{3/2}$. The experimental data are well fitted by the following phase shift angles: At 135 Mev, $\mp 1°$, $\pm 19°$, and $\pm 1°$ for isotopic spin $\frac{1}{2}$; $\pm 25°$, $\mp 10°$, and $\mp 35°$ for isotopic spin $\frac{3}{2}$; at 110 Mev, $\pm 15°$, $0°$, and $\mp 25°$ for isotopic spin $\frac{3}{2}$. The angles are given in order for $S_{1/2}$, $P_{1/2}$ and $P_{3/2}$ and have an uncertainty of about $\pm 5°$.

The fact that at 135 Mev six phase shifts suffice to fit nine data demonstrates the fruitfulness of regarding the isotopic spin as a good quantum number. The pion-nucleon interaction is strongest in the $P_{3/2}$ state with isotopic spin $\frac{3}{2}$. However, the interaction in the $P_{1/2}$ state of isotopic spin $\frac{1}{2}$ is comparable. It appears to be responsible for the isotropy found in the π^- elastic scattering. The sizeable interaction found in the s-state of isotopic spin $\frac{3}{2}$ is believed to be responsible for the pronounced backward scattering observed in the other cases.

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[1] H. L. Anderson, *et al.*, Phys. Rev. **85**, 936 (1952).

Scattering and Capture of Pions by Hydrogen*

H. L. ANDERSON AND E. FERMI
Institute for Nuclear Studies, University of Chicago, Chicago, Illinois
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WHEN a negative pion comes to rest in hydrogen, it is promptly captured in a Bohr-like orbit and almost immediately reacts with the proton. As shown by Panofsky and his co-workers,[1] the reaction produces either (a) a neutron and a photon, or (b) a neutron and a neutral pion, with about equal probability. Reaction (b) is closely related to the charge exchange scattering of the negative pion by the proton. The only difference is in the energy which is positive for the scattering, but slightly negative in the Panofsky case. It is the purpose of this note to show how these two phenomena may be correlated.

The experiments, in this laboratory,[2] on the scattering of pions by protons, have been interpreted in terms of the phase shifts of the s and p waves. At low energy, the p phase shifts, which vary as the cube of the momentum, become unimportant compared to the s phase shifts, which are proportional to the momentum. The scattering length a, which is the product of the s phase shift and the de Broglie wavelength, should be constant. From the experiments, $a_{3/2}=(3.8\pm 0.7)\times 10^{-14}$ cm for the state of isotopic spin $\frac{3}{2}$ and $a_{1/2}=(0\pm 1)\times 10^{-14}$ cm for the state of isotopic spin $\frac{1}{2}$.

The cross sections for exchange and nonexchange scattering at low energy can be expressed in terms of $a_{3/2}$ and $a_{1/2}$ by standard procedures of the collision theory. One should take into account the fact that states representing a proton and a negative pion, or a neutron and a neutral pion are linear combinations of pure states of isotopic spin $\frac{3}{2}$ and $\frac{1}{2}$. One finds the two cross sections

$$\sigma_- = 4\pi(a_{3/2}+2a_{1/2})^2/9 = 2\times 10^{-27};$$

$$\sigma_0 = 8\pi(a_{3/2}-a_{1/2})^2 v_0/9v = (4\times 10^{-27})v_0/v,$$

where v and v_0 are the relative velocities of the negative pion with respect to the proton and of the neutral pion with respect to the neutron, respectively.

From this value of σ_0 the rate of capture from the lowest Bohr orbit to give a neutral pion may be as obtained as

$$R_0 = \sigma_0 v/\pi b^3 = 10^{15}\ \text{sec}^{-1},$$

where we have taken for the radius of the mesonic Bohr orbit, $b=2.2\times 10^{-11}$ cm, and for the velocity of the emitted π^0, $v_0=8\times 10^9$ cm/sec.

Unfortunately, a direct measurement of this rate is not available. However, we can use Panofsky's result that the rate of process (a) is equal to the rate of process (b). At low energy, therefore, the cross section σ_π for the process, $P+\pi^-\rightarrow N+\gamma$, must be equal to σ_0. By detailed balancing, the cross section σ_γ for the inverse reaction, which is the photomeson production process, is obtained. The result, near the threshold, is

$$\sigma_\gamma = (p_\pi^2/2p_\gamma^2)\sigma_\pi = \tfrac{1}{2}\times 4\times 10^{-27}\mu_r^2 v_0 v/p_\gamma^2\ \text{cm}^2,$$

where μ_r is the reduced mass of pion and proton and p_π and p_γ are the momenta of pion and photon in the center-of-mass system. Near the threshold $p_\gamma \approx \mu c$ and one finds the photo cross section

$$\sigma_\gamma = 4.0\times 10^{-28} v/c\ \text{cm}^2.$$

In comparing this formula with the measured values[3,4] of the photomeson production process, there is a certain arbitrariness in the extrapolation to the threshold. Moreover, some discrepancy can be expected because our formula refers to the photoeffect on neutrons, whereas the measurements have been on the photoeffect on protons. The agreement is within a factor of 4 in the worst case, Steinberger's[3] lowest point. It is quite close to the extrapolated curve given in Feld's[4] recent analysis of this and newer data.

It should be stressed that the coefficients in our formulas are affected by large experimental inaccuracies, owing to the combined errors in $a_{3/2}$ and $a_{1/2}$. The over-all uncertainty could well be as large as a factor 2.

* Research sponsored by the ONR and AEC.

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The Half-Life of Tantalum-182†

G. G. EICHHOLZ AND L. A. FICKO
Radioactivity Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada
(Received April 9, 1952)

IN the course of investigations into radioactivation methods involving Ta^{182} it was found that no precise value of the half-life of this isotope had been published.[1] It was, therefore, decided to carry out an accurate determination of this quantity, supplementing the value since published independently by Sinclair and Holloway.[2] Table I lists the various values of the half-life quoted in the literature.

Measurements were carried out on a small piece of pure tantalum metal which was irradiated with neutrons in the Chalk River pile. After irradiation the sample was sealed into a Lucite mold of cylindrical shape for protection and ease of handling. The

TABLE I. Data on the half-life of Ta^{182}.

Author	Date	Value, days
Houtermans[a]	1940	99±1
Zumstein *et al.*[b]	1943	117±3
Saxon[c]	1948	113
Cork *et al.*[d]	1949	123.5
Sinclair and Holloway[e]	1951	111±1

[a] F. G. Houtermans, Naturwiss **28**, 578 (1940).
[b] Zumstein, Kurbatov, and Pool, Phys. Rev. **63**, 59 (1943).
[c] D. Saxon, quoted by G. T. Seaborg and I. Perlman, Revs. Modern Phys. **20**, 585 (1948).
[d] Cork, Keller, Sazynski, Rutledge, and Stoddard, Phys. Rev. **75**, 1778 (1949).
[e] See reference 2.