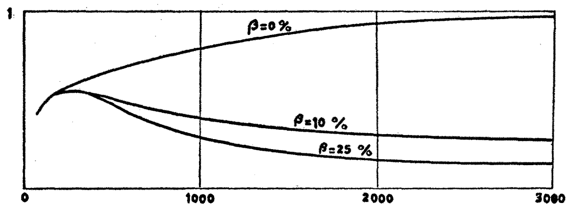

FIG. 1. $(\Delta I/I)\cdot(\Delta B/B)^{-1}$ is plotted against the depth d in m.w.e. for $\beta=0$ percent, 10 percent, 25 percent.

tent, independent of any assumptions about the energy losses of the μ's and the exponent of the power spectrum. A density change in the atmosphere produces a variation ΔB of B. Whereas I_κ is not affected, I_π varies, and one has:

$$\frac{\Delta I}{I}=\alpha\frac{\Delta I_\pi}{I}=\frac{\Delta B}{B}\cdot\frac{\alpha B^{-1}\int_{E(d)}^{\infty}E^{-\gamma}(1+E/B)^{-2}dE}{\alpha I_\pi+\beta I_\kappa}$$
$$=\Gamma\frac{\Delta T}{T}\cdot\text{function of } d.$$

T is the temperature recorded at one altitude; if the atmosphere was really isothermal, the correlation coefficient Γ would be unity. If two recordings were made simultaneously at two different depths, (about 250 and 1000 m.w.e.), the term $\gamma\Delta T/T$ would disappear and the ratio $[\Delta I(250)/I(250)]/[\Delta I(1000)/I(1000)]$ would give some indications about the proportion of μ_κ's in the ground, as can be seen from Fig. 1. Since this is known, it is possible to get back to the proportion of κ-mesons *versus* π (and τ, $V^0\cdots$), provided that some assumptions on the decay of these different particles are made. One should notice that the temperature coefficient cannot exceed 0.4 percent/°C, i.e., the value for $\beta=0$, $\Gamma=1$, $d=\infty$.

[1] C. O'Cealleigh, Phil. Mag. **42**, 1032 (1951); Crussard *et al.*, Compt. rend. **234**, 84 (1952). It is not impossible that $V^\pm$ and κ-mesons are the same particle: Armenteros *et al.* (private communication).
[2] S. Hayakawa *et al.*, Prog. Theoret. Phys. **4**, 287 (1949); **4**, 447 (1949); **5**, 844 (1950).
[3] E. P. George and J. Evans, Proc. Phys. Soc. (London) **A63**, 1248 (1950); Braddick, Nash, and Wolfendale, Phil. Mag. **42**, 1277 (1951).
[4] G. Wataghin and C. M. Garelli, Phys. Rev. **79**, 718 (1950).
[5] L. Michel and R. Stora, Compt. rend. **234**, 1257 (1952).
[6] A. Daudin, J. Phys. **10**, 65 (1949).

A Ferroelectric Ammonium Metaphosphate*

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AMMONIUM phosphate prepared by the method of Tammann[1] is found to be ferroelectric in the range from −193 to +38°C. Conductivity obscures the ferroelectric hysteresis loop above 38°C, although the dielectric constant appears to climb fairly rapidly in the neighborhood of that temperature. No measurements were made below −193°C. The crystal is unstable in a dry atmosphere at room temperature, and must be stored near 0°C.

X-ray measurements demonstrate that the crystal has a monoclinic cell with $a=19.9_5$A, $b=6.91$A, $c=6.28$A, $\beta=98.5°$, space-group C_2 or Cm; and morphology indicates C_2. The density is 1.577 g/cm³. Although Tammann identified the compound as a monometa salt with 3 or 4 H_2O per molecule, a chemical analysis indicates between 5 and 6 H_2O, and x-ray and density measurements show 6 H_2O. The chemistry of the "metaphosphates" is unclear in general, and the precise nature of the compound must apparently await completion of the x-ray structure analysis now in progress. A Patterson projection on (001) indicates the existence of P_2O_6 groups.

* Research supported by OAR.
[1] G. Tammann, J. prak. Chem. **45**, 431 (1892).

Angular Distribution of Pions Scattered by Hydrogen*

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THE angular distribution of the pions scattered by liquid hydrogen has been studied using the well collimated pion beams of the Chicago synchrocyclotron. A pair of 2-inch diameter scintillation counters define the incident beam which passes through them into a liquid hydrogen cell (Fig. 1). The scattered

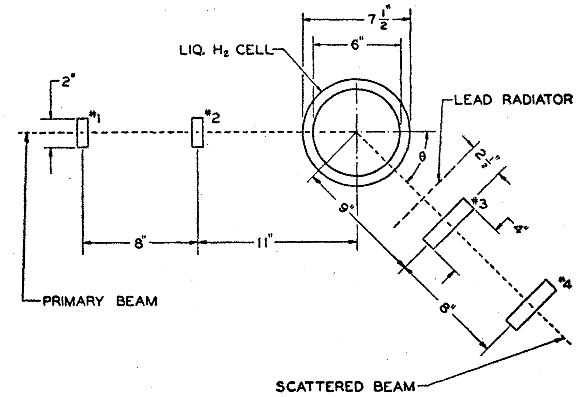

FIG. 1. Experimental arrangement.

particles are detected by two 4-inch diameter scintillation counters at suitable azimuth. A quadruple coincidence of all four counters requires a particle to pass through the first two counters and then to be scattered into the second pair. The quadruple coincidence rate, divided by the double coincidence rate of the first pair, which is recorded at the same time, gives the fraction of the beam which is scattered. The hydrogen cell was designed for rapid insertion and removal of the liquid hydrogen, to distinguish its effect from extraneous scattering. The charge exchange scattering was distinguished from the elastic scattering of negative pions by the insertion of a lead radiator in front of the second pair of counters, in order to enhance their sensitivity to gamma-rays.

The elastic scattering of positive pions at 110 Mev and 135 Mev, and both charge exchange and elastic scattering of negative pions at 135 Mev, were measured. The observations were taken at laboratory angles 45°, 90° and 135°.

The results, in the center-of-mass system, have been expressed in terms of the formula:

$$d\sigma/d\omega=a+b\cos\theta+c\cos^2\theta.$$

This angular distribution is expected when only s- and p-states contribute to the scattering. The values of the coefficients with their statistical errors are presented in Table I.

TABLE I. Coefficients for the differential cross sections.

Primary energy Mev	Process	a 10^{-27} $\frac{cm^2}{sterad}$	b 10^{-27} $\frac{cm^2}{sterad}$	c 10^{-27} $\frac{cm^2}{sterad}$	$\int(d\sigma/d\omega)d\omega$ 10^{-27} cm²
110	$\pi^+\to\pi^+$	3.5±0.6	−4.6±0.8	7.2±1.8	74.5±5.4
135	$\pi^+\to\pi^+$	3.8±2.2	−6.8±2.7	17.5±6.6	121 ±19
135	$\pi^-\to\pi^-$	1.2±0.2	−0.1±0.3	0.3±0.7	16.2±2.3
135	$\pi^-\to\pi^0$	1.1±0.6	−2.5±0.5	6.3±1.9	40.6±2.3

The integrated cross sections listed in Table I are in good agreement with those obtained previously[1] by transmission measurements. For negative pions the contributions of exchange and non-exchange scattering should be added, plus a small contribution of about 0.8×10^{-27} cm² due to the inverse photo effect ($\pi^-\to\gamma$).

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, $\mp1°$, $\pm19°$, and $\pm1°$ for isotopic spin $\frac{1}{2}$; $\pm25°$, $\mp10°$, and $\mp35°$ for isotopic spin $\frac{3}{2}$; at 110 Mev, $\pm15°$, $0°$, and $\mp25°$ 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 $\pm5°$.

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.

This research could not have been done without the active cooperation and advice of Professor Earl A. Long. We thank him and Dr. Lothar Meyer for generous supplies of liquid hydrogen. We are grateful to Messrs. Ronald Martin, Maurice Glicksman and Leo Slattery for contributing their time and skill to the preparation and conduct of these experiments.

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

Scattering and Capture of Pions by Hydrogen*

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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, $a_{3/2}=(3.8\pm0.7)\times10^{-14}$ cm for the state of isotopic spin $\frac{3}{2}$ and $a_{1/2}=(0\pm1)\times10^{-14}$ 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

$$\sigma_-=4\pi(a_{3/2}+2a_{1/2})^2/9=2\times10^{-27};$$

$$\sigma_0=8\pi(a_{3/2}-a_{1/2})^2v_0/9v=(4\times10^{-27})v_0/v,$$

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, $b=2.2\times10^{-11}$ cm, and for the velocity of the emitted π^0, $v_0=8\times10^9$ 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

$$\sigma_\gamma=(p_\pi^2/2p_\gamma^2)\sigma_\pi=\tfrac{1}{2}\times4\times10^{-27}\mu_r^2v_0v/p_\gamma^2\text{ cm}^2,$$

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

$$\sigma_\gamma=4.0\times10^{-28}v/c\text{ cm}^2.$$

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.

[1] Panofsky, Aamodt, and Hadley, Phys. Rev. **81**, 565 (1951).
[2] Anderson, Fermi, Nagle, and Yodh, Phys. Rev., preceding Letter, this issue.
[3] Bishop, Steinberger, and Cook, Phys. Rev. **80**, 291 (1950).
[4] Feld, Frisch, Lebow, Osborne, and Clark, Phys. Rev. **85**, 680 (1952).

The Half-Life of Tantalum-182†

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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.