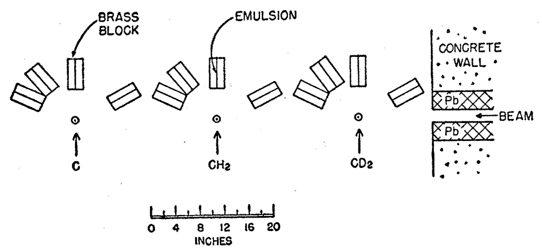

FIG. 1. Schematic diagram of the experiment for the observation of the spectra of photomesons from hydrogen, deuterium, and carbon.

energy distributions of photomesons from carbon and hydrogen have been obtained at angles of 90° and 26° to the photon beam. The mesons were slowed down in $2\frac{1}{2}$-in. wide×4-in. high×5-in. long brass blocks, and the ends of their tracks were observed in 200-μ unbacked Ilford C-3 photographic emulsions embedded radially in blocks, as shown in Fig. 1. The location of each meson track ending was recorded as a function of its depth in the block.

Positive π-mesons are identified by their μ-decay. Negative π-mesons are identified as those which produce nuclear disintegrations (stars), plus a predetermined fraction of those mesons ending without any visible disintegration products.[1] The distribution of mesons in energy is obtained by dividing the emulsions into intervals of equal meson energy, assuming the meson energy to be given by the range in brass corresponding to the distance from the face of the block to the meson ending. (A slight correction of ~10 Mev is applied for the thickness of the target.) The hydrogen distributions were obtained by subtracting the carbon distributions from those of the paraffin.

The number of positive mesons per proton in carbon as compared to hydrogen, averaged over the above energy ranges, is 0.32±0.05 (standard deviation) at 90° and 0.07±0.01 at 26°. This large decrease in production efficiency for carbon at forward angles is qualitatively as expected on the basis of the Pauli exclusion principle, since the recoil momentum of the product neutron is small when the meson is emitted forward. Due to the smallness of the carbon production at small angles, the subtraction procedure, to obtain the H cross section, introduces only small uncertainties at 26°.

The negative-positive ratio from carbon shows no strong dependence on meson energy and has the average value of 1.43±0.13

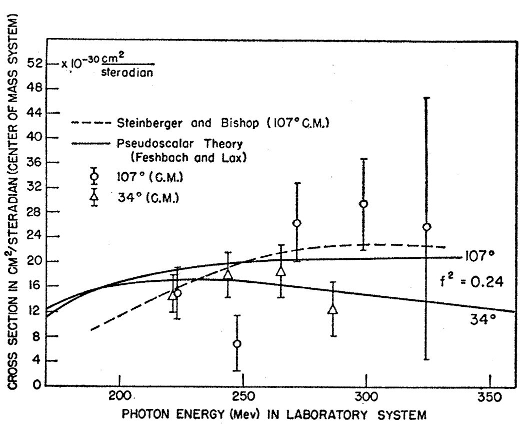

FIG. 2. Comparison of experiment with theory for the differential cross section for photomeson production in hydrogen *vs* photon energy, for mesons emitted at 34° and 107° in the C.M. system. The experimental points have been corrected for nuclear interactions in the brass moderator. The broken curve summarizes the results of Steinberger and Bishop (see reference 8) at 107°. Our cross sections agree within the factor of two in uncertainty about our absolute intensity at the time of exposure. The points as plotted here are normalized to the experimental curve of Steinberger and Bishop. The solid curves are computed from the theory of Feshbach and Lax (see reference 7), for a (pseudoscalar meson with pseudovector-) coupling constant $f^2=0.24$.

at 90° and 1.03±0.25 at 26°. Peterson, Gilbert, and White[3] found a value of 1.30±0.12 at 90°. The energy spectra at 90° are in good agreement with previous experiments[3,4] and with theory.[5]

From energy and momentum conservation and assuming a photon spectrum,[6] the hydrogen distributions are converted into cross sections in the center-of-mass system. In Fig. 2, we plot the experimental cross sections *vs* photon energy for hydrogen together with the predictions of pseudoscalar theory,[7] the Berkeley data[8] at 107°, and our data at 107°. Averaging our cross sections over the approximate range $h\nu=210$ to $h\nu=305$ Mev, we find $\bar{\sigma}(34°)/\bar{\sigma}(107°)=0.80\pm0.18$. This result is not strictly comparable with the observed[8] $h\nu=250$ Mev angular distribution, but together they indicate that the average cross section over this energy range does not drop off extremely rapidly at small angles.[9]

We wish to thank Mmes. T. Kallmes, D. Calhoun, and M. Goode who performed most of the arduous work of scanning the plates.

* This work was supported in part by the joint program of the ONR and AEC.

[1] Our determination of the fraction of negative π-mesons which give rise to zero-pronged (neutron) stars is 35±4 percent in a total of 585 stars, which agrees well with the 32.6±2.1 percent found by W. B. Cheston and L. J. B. Goldfarb, Phys. Rev. **78**, 683 (1950).
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[6] Powell, Hartsough, and Hill, Phys. Rev. **81**, 213 (1951).
[7] H. Feshbach and M. Lax, Phys. Rev. **76**, 134 (1949).
[8] Bishop, Steinberger, and Cook, Phys. Rev. **80**, 291 (1950); J. Steinberger and A. S. Bishop, private communication. Their value for the ratio of cross sections at 58° to 107° (45° and 90° in the laboratory system) for 250-Mev photons is 0.70 (assuming the correction for nuclear absorption suggested by reference 2).
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Photomeson Production from Deuterium*

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(Received January 4, 1952)

WE have measured the energy distributions of the positive and negative π-mesons from deuterium at 90° and 26° to the photon beam. A heavy paraffin target was exposed to the 330-Mev bremsstrahlung spectrum from the M.I.T. synchrotron simultaneously with the exposures of carbon and parafin targets described in the preceding communication. The methods of detection and analysis of data are also as previously described. The observations are displayed in Figs. 1(a) and 1(b).

Special interest is attached to the investigation of photomeson production from deuterium, mainly for two reasons: (1) The deuteron is the simplest nucleus that can be used to study the production of mesons from neutrons since the ratio of negative to positive production gives a comparison of production from neutrons and protons. We find experimentally that the average π^-/π^+ yield ratio from the deuteron is 0.5±0.5 at 90° and 0.90±0.23 at 26°. Our present statistics and uncertain knowledge of the absorption in brass do not permit us to conclude that the apparent decrease of the negative to positive ratio with increasing meson energy and angle is real. White[1] has found a ratio of 0.96±0.10 over the spectrum at 45° and a value of 0.98±0.14 for the ratio at 90° for 70-Mev mesons. Littauer and Walker[2] obtained a ratio of 1.19±0.12 for 50-Mev mesons at 135°.

(2) The photoproduction of a charged meson from a deuteron results in a pair of identical nucleons, whose possible quantum states are limited by the Pauli exclusion principle. Since the initial deuteron state is predominantly $^3S_1$, the possibility of leaving the final two-nucleon system in an S-state depends on the occurrence of "spin-flip" in the charged photomeson production reaction. Thus, there should be a greater reduction of π^+ production in deuterium, relative to hydrogen, for a spin-independent interaction than for a spin-dependent interaction. This is a marked effect

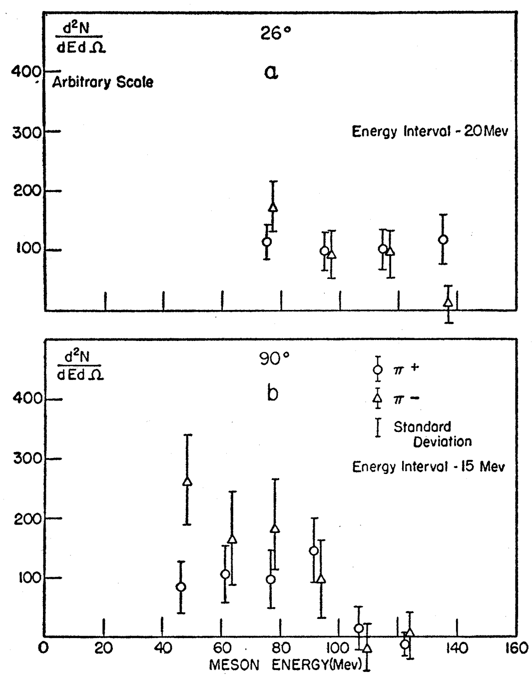

FIG. 1. Negative and positive photomeson yields (per unit solid angle and unit meson energy) from deuterium at 26° (a) and at 90° (b) in the laboratory system.

only at small meson angles, where the two product nucleons come off with a low relative speed.

Chew and Lewis[3] and Feshbach and Lax[4] have developed a phenomenological theory of meson production from deuterons. The solid curves sketched in Fig. 2 give the predicted ratio of yield of positive mesons from deuterons, relative to that from free protons, as a function of angle. The yields are averaged over a broad meson energy interval suitable for comparison with the experimental data at each angle. The different curves are for various values of the parameter K^2/L^2 formed from the Hamiltonian $H=\boldsymbol{\sigma}\cdot\mathbf{K}+L$. For $K^2/L^2=0$ there is no spin-dependent interaction. For $K^2/L^2=\infty$ there is only spin-dependent interaction. In evaluating these curves it has been assumed that there is no interaction between the product neutrons.

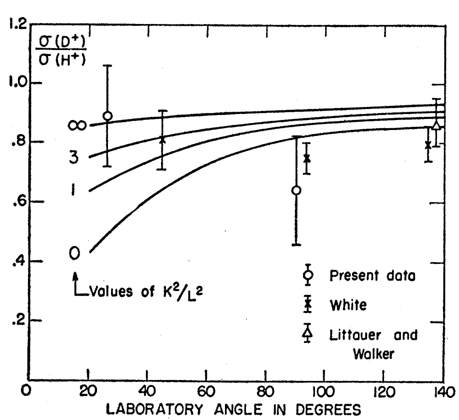

FIG. 2. Ratio of photoproduction of positive π-mesons from deuterium and hydrogen *vs* laboratory angle of meson emission. The solid curves are from the phenomenological theory of Feshbach and Lax (see reference 4), assuming various ratios K^2/L^2 of spin-dependent and spin-independent meson interactions. The experimental points represent our data, the data of White (see reference 1) and of Littauer and Walker (see reference 2).

Our ratios of the total number of π^+ mesons from D and H in the energy range 65 to 145 Mev at 26° and in the 40- to 105-Mev range at 90° are plotted in Fig. 2. White's[1] ratios at 45°, 90°, and 135° and Littauer and Walker's ratios[2] at 145° are also plotted. These data suggest that there is a large spin-dependent interaction.

We are grateful to Professor H. Feshbach for making available unpublished theoretical calculations on photomeson production in hydrogen and deuterium.

* This work was supported in part by the joint program of the ONR and AEC.

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Hyperfine Structure in the Paramagnetic Resonance of the Ion $(SO_3)_2NO^{--}$*

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(Received December 31, 1951)

WE have investigated the paramagnetic resonance absorption of the free radical ion $(SO_3)_2NO^{--}$ (peroxylamine disulfonate ion). In dilute solution, the absorption was first observed at a frequency of about 9000 Mc/sec in fields near

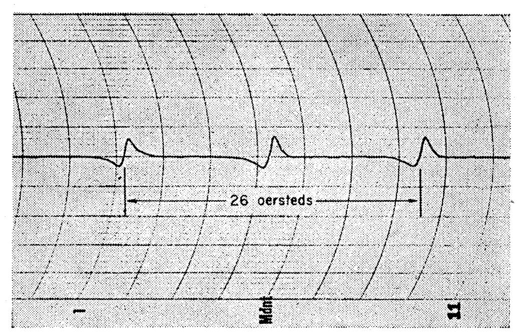

FIG. 1. Paramagnetic resonance derivatives for peroxylamine disulfonate ion at a frequency near 9000 Mc/sec.

3200 oersteds and was found to consist of three evenly spaced peaks of equal intensities (Fig. 1). The *g*-value corresponding to the central peak is 2.0054±0.0004, based upon comparison with that of polycrystalline diphenyl picryl hydrazyl.[1] The interval between adjacent peaks is about 13 oersteds, corresponding to 36 Mc/sec. The breadth of the individual peaks is dependent upon concentration, increasing with increasing concentration.

The simple microwave apparatus used is a klystron-excited wave guide terminating in a crystal rectifier. The crystal signal is amplified and fed into a lock-in detector and recording milliammeter which registers the amplitude of the component coherent with the 60-cycle modulation of the external magnetic field applied to the sample.

Typical is the behavior of solutions in chloroform of the salt tetraphenyl stibonium peroxylamine disulfonate. A solution 0.5*M* in the odd ion, although exhibiting the color of this ion, apparently possesses an absorption too broad for measurement in our apparatus. At 0.25*M*, the three peaks appear, each about 4 oersteds wide. At 0.02*M*, the width between points of extreme slope for each peak is about 0.8 oersted. Several salts, in a variety of solvents, including dioxane, pyridine, alcohol, ether, dimethyl formamide, and water, have yielded apparently identical spectra at low concentrations.