thought to leave no more than 2 or 3 percent uncertainty in the cross section obtained directly from the comparison.

The cross section obtained from many runs for excitation of the 850-kev level in Fe^{56} by neutrons of 2.45-Mev energy scattered at 90 degrees is 0.085 ± 0.003 barn/steradian, taking account of the relative abundance of Fe^{56} in natural iron.

Thanks are due J. L. McKibben, R. K. Smith, and R. Hood for help and suggestions in various phases of this work.

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* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] Earlier measurements using this technique with oscillographic recording of the data are described by the author [L. Cranberg, Los Alamos Report LA-1654, April, 1954 (unpublished)].

[2] An early application of this principle to millimicrosecond techniques is described by N. F. Moody, Elec. Engr. **24**, 289 (1952). The circuit used in this work was designed and built by C. W. Johnstone, W. Weber, and H. Lang, Los Alamos Scientific Laboratory, following suggestions by J. L. McKibben, Los Alamos Scientific Laboratory, and J. H. Fraser, Chalk River Laboratory.

[3] G. W. Hutchinson and G. G. Scarrott, Phil. Mag. **42**, 792 (1951). A modified model due to J. D. Gallagher, following suggestions by J. L. McKibben, Los Alamos Scientific Laboratory, was used in this work.

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Scattering of 30- to 95-Mev Photons by Protons*

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We have measured the elastic scattering of gamma rays by hydrogen, a process which has received theoretical attention[1] as a source of information regarding the proton. The source was the 98-Mev bremsstrahlung from the betatron with beam pulse stretched to 100 microseconds. The collimated beam was brought in vacuum through a heavy shielding wall with an inset electron-sweep magnet. The target was styrofoam-walled, with thickness 0.18 g/cm² or 0.0043 radiation length. The liquid hydrogen was in a cylindrical container five inches in diameter, with axis perpendicular to the three-inch diameter gamma beam. The hydrogen was 0.84 g/cm² or 0.014 radiation length thick.

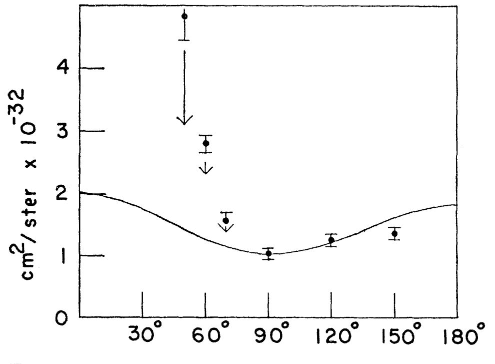

Fig. 1. Experimental points and theoretical curve of differential cross sections.

The detector was a converter-telescope. A 2.1-g/cm² carbon filter preceded the anticoincidence plastic scintillation counter which was then followed by a 7.4-g/cm² lead converter and a threefold telescope with 5.2 g/cm² of aluminum absorber interspersed. The central efficiency of the counter was calculated using the measured electron efficiencies at several energies and partial thicknesses of lead. Edge effects were accounted for by comparing the efficiency of the counter with over-all and central illumination by the 98-Mev bremsstrahlung.

The bremsstrahlung flux from the nickel target was put on an absolute scale with the induced C^{11} activity in polyethylene foils and the data of Barber, George, and Reagen.[2]

Data were collected at angles from 50–150 degrees. Approximate counting rates were three per minute with target full and two with target empty. The resulting cross sections are shown in Fig. 1. The counter efficiency has been adjusted for the energy loss to proton recoil. This correction is substantially independent of gamma energy and ranges from -13 percent at 150 degrees to -3 percent at 50 degrees. The product of efficiency and number of quanta in the bremsstrahlung spectrum rises from a threshold near 20 Mev to a value which remains constant within 20 percent from 40 to 89 Mev, so the cross section reported is approximately evenly weighted over this range with mean energy of 64 Mev.

At small angles, multiple effects will become evident. Of these, the conversion of gammas and subsequent large-angle bremsstrahlung is expected to be most important. Scattered-electron counts at most are three times the gamma counts and the anticoincidence is more than 98 percent effective. Shower effects may be distinguished experimentally by their quadratic dependence upon target thickness. We have not varied the hydrogen thickness, but have used carbon targets of several thicknesses. The effects thus observed have been transposed for hydrogen and result in the correction indicated by the downward arrows in Fig. 1. The correction is uncertain on this basis and its angular dependence is more rapid than is expected for large-angle bremsstrahlung. We plan experiments with variable hydrogen thickness to clarify the small angle data.

Shown in the figure is the theoretical scattering from a point proton with the static anomalous moment.[3] Deviations are expected, and these are calculated to be a decrease in the cross section due to the interference between the Thomson scattering and the scattering from the proton's meson cloud. These are of the order of 15 percent at 64 Mev. Our absolute error is estimated as about 15 percent. From our measurements, we conclude that any deviations from the Powell cross section do not greatly exceed the expected amounts and that in the range of angles 90 degrees and above, where our measurements should be valid, there is no marked change in the angular distribution from that of Powell.

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* Research supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] For example, M. Gell-Mann and M. L. Goldberger, Phys. Rev. **96**, 1433 (1954); and R. H. Capps and W. G. Holladay, Phys. Rev. **99**, 931 (1955) with previous references of these papers.

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[3] J. L. Powell, Phys. Rev. **75**, 32 (1949).

Angular Distributions of Protons from $Be^9(He^3,p)B^{11}$

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When nuclei are bombarded with heavy particles, the resulting nuclear reactions may take place by the formation of a compound nucleus or by some direct process such as stripping or possibly by a combination of these processes. Alpha particles, being tightly bound, tend to form a compound nucleus when they are the incident particles, but deuterons, being more loosely bound, generally enter into (d,p) and (d,n) reactions by a stripping process.[1] It is of considerable interest, therefore, to determine whether particles with intermediate binding energies such as H^3 and He^3 nuclei will enter into reactions by a direct process or by compound nucleus formation. Studies of the angular distributions of tritons from (d,t) reactions on Be^9 and C^{13} seem to indicate that H^3 particles can be formed by a direct process.[2] Similarly, the angular distributions of the protons from (He^3,p) reactions may be useful in determining the mechanism of He^3-induced reactions.

Proton groups from the $Be^9(He^3,p)B^{11}$ reaction have been previously observed.[3] The angular distributions of these protons have been investigated at this laboratory using a multiplate scattering chamber with the Naval Research Laboratory 2-Mev Van de Graaff generator. A thin beryllium target evaporated on a 10-microinch nickel backing was bombarded with the 2-Mev He^3 beam, and the reaction protons from the ground state and the first excited state of Be^{11} were detected in 200-micron Ilford C-2 emulsions. Slits subtending a 0.12-degree angle from the target were placed in front of each emulsion, and the total number of tracks for each proton group was counted in each plate.

Figure 1 represents the center-of-mass angular distributions of the protons which leave B^{11} in the ground state (curve p_0) and the first excited state (curve p_1). Interpretation of these curves awaits theoretical analysis, but it is to be noted that the curves exhibit a lack of symmetry about 90 degrees, indicating that the reactions do not proceed exclusively through the formation of a compound nucleus unless levels of opposite parity contribute.

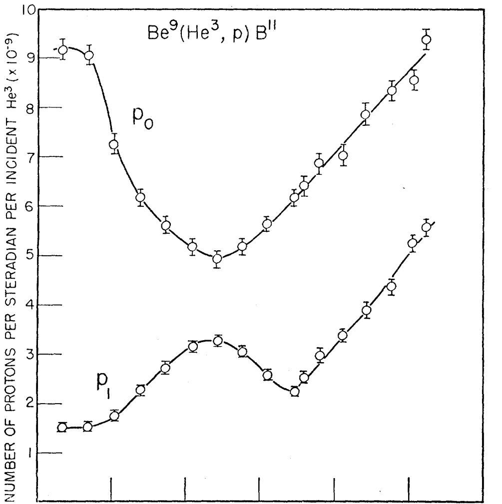

Fig. 1. The angular distributions of ground-state proton (p_0) and first excited state protons (p_1) from the $Be^9(He^3,p)B^{11}$ reaction for 2-Mev He^3 particles.

The angular distributions of the protons for the second and third excited states of B^{11} are also being investigated.

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[2] F. A. El-Bedewi, Proc. Phys. Soc. (London) **A64**, 947 (1951); Holmgren, Blair, Simmons, Stratton, and Stuart, Phys. Rev. **95**, 1544 (1954).

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Coulomb Excitation Directional Correlation*

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Calculations of Coulomb excitation using classical trajectories[1,2] are in good agreement with experiment for the total cross section; for the directional correlation,[2] however, significant discrepancies between this approximate theory and the experiments are found.[3,4] Quantum calculations for the limiting case of no energy loss[5] indicate that this discrepancy might be resolved by similar quantum calculations for the general case. It is the purpose of this note to show that this the case.

Utilizing the formalism and mathematical techniques given elsewhere,[6] the Coulomb excitation gamma corre-