Inelastic Scattering of Neutrons from Iron by Time-of-Flight*

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A SYSTEM of fast-neutron spectroscopy has been developed using the time-of-flight principle and a pulsed-beam technique.[1] Protons from the large Los Alamos Van de Graaff are swept across the target by applying sinusoidal voltage of frequency 3.7 Mc/sec to a pair of deflector plates, so that the target current consists of 7.4×10^6 bursts per second, each of about 2 millimicroseconds duration and 30 μa amplitude. Monoenergetic neutrons are produced by the reaction $T(p,n)He^3$ in a tritium-filled gas target. The scattering samples consist of tubes 2 inches long, with an outside diameter which is 1 inch or less and an inside diameter $\frac{3}{8}$ inch or less, depending on the material. The detector, which is 1.2 meters from the scatterer, is a hydrogenous scintillator coupled to an RCA-5819 photomultiplier, and is enclosed in a shield of lithium carbonate, paraffin, and lead, to reduce background from room- and air-scattered neutrons and gamma rays. A cone of polyethylene shields the detector from the direct neutrons from the target. Detector, shield, and cone assembly may be rotated about the axis of the scatterer.

The spectrum of arrival times of the scattered neutrons at the detector is measured by converting elapsed time to pulse height,[2] and displaying the pulse-height spectrum on a 100-channel analyzer of the Hutchinson-Scarrott type.[3] Elapsed time is measured between a fiducial pulse generated once per rf cycle and the signals obtained from the neutron detector.

The time spectra shown in Figs. 1 and 2 were obtained for a 71.5-gram iron scatterer viewed at 90 degrees, and a 2.2-gram polyethylene scatterer viewed at 37 degrees from the direction of the primary neutrons, which have an energy of 2.45 Mev, and a spread of 125 kev. The backgrounds obtained with the sample removed are also shown. Each channel corresponds to a time interval of 2.3 mμsec. The energy scale has been inferred from the known features of the spectra. The double presentation of the data arises from the fact that in each rf cycle two bursts of target current and neutrons are produced whereas only one fiducial pulse is generated. Each run required about five minutes.

In Fig. 1, one notes structures readily identified as gamma rays, primarily due to inelastic scattering, elastically scattered neutrons, and inelastically scattered neutrons corresponding to excitation of the known levels[4] in Fe^{56} at 850 kev, and in Fe^{54} at 1.4 Mev. In Fig. 2, the elastically scattered neutrons from hydrogen and carbon are clearly resolved. The peak at the end of each run is instrumental.

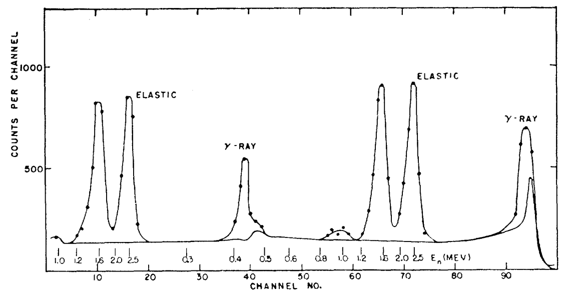

Fig. 1. The time spectrum resulting from the scattering of primary neutrons of 2.45-Mev energy by iron at 90°.

The cross section for inelastic scattering to a particular level may be determined by comparison with the differential (n,p) scattering cross section. This is accomplished by using a polyethylene scatterer viewed at such an angle that the energy of the neutrons elastically scattered from hydrogen is the same as the energy of the inelastic group of interest. Thus, for primary neutrons of 2.45-Mev energy used in the measurements reported here, the elastic scattering from hydrogen at 37 degrees gives neutrons of the same energy as those scattered inelastically from the 850-kev level in Fe^{56}.

To a first approximation, the corrections to the inelastic scattering cross section for multiple scattering and beam attenuation in the samples may be balanced out by proper choice of the dimensions of the iron and polyethylene scatterers. Assume that elastic scattering in iron and carbon does not change the average path length of a neutron in the iron and polyethylene scatterers. Then the corrections may be made approximately by equating the transmission of the iron sample, taking account only of inelastic scattering and absorption, to the transmission of the polyethylene, taking account only of the scattering by hydrogen. In the runs for cross-section determination, these transmissions were each 93 percent. This method of compensation is

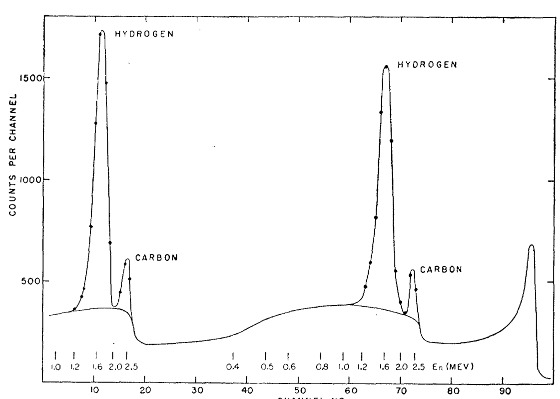

Fig. 2. The time spectrum resulting from the scattering of primary neutrons of 2.45-Mev energy by polyethylene at 37°.

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.

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[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.

[4] R. Sinclair, Phys. Rev. **98**, 1147 (1955).

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/cm^2 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/cm^2 or 0.014 radiation length thick.

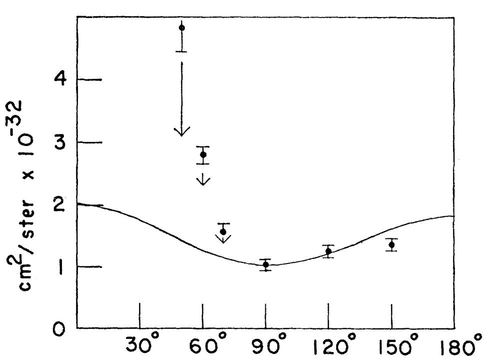

Fig. 1. Experimental points and theoretical curve of differential cross sections.

The detector was a converter-telescope. A 2.1-g/cm^2 carbon filter preceded the anticoincidence plastic scintillation counter which was then followed by a 7.4-g/cm^2 lead converter and a threefold telescope with 5.2 g/cm^2 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