Inelastic Neutron Scattering in Al, Fe, Mg, and Cu†

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Gamma rays emitted from nuclei excited by inelastic neutron scattering were observed. Pulse-height analysis of gamma-ray scintillations which were coincident with scattered neutrons established gamma lines corresponding to excited levels in the residual nuclei. Observed levels are reported for Al, Fe, Mg, and Cu.

THE determination of nuclear energy levels through the inelastic scattering of neutrons has been the subject of several recent investigations. Discrete levels excited in residual nuclei have been established from the energy distributions of either the scattered neutrons[1] or the de-excitation gamma rays.[2,3] In the case of the latter technique, the measurements were complicated by the large background of gamma radiation inherent in most methods of fast neutron production. In the experiment described here[4] the scintillation spectrum of the de-excitation gamma rays was observed in coincidence with scattered neutrons, thereby eliminating this background.

EXPERIMENTAL METHOD

Monoenergetic 3.3-Mev neutrons from $H^2(d,n)He^3$ bombarded a scatterer as shown in Fig. 1. A 1-inch cube of stilbene (shielded from the deuterium target by 1 in. of lead and about 6 in. of paraffin) detected scattered neutrons by means of recoil proton scintillations. A 1-in. diameter by 1-in. thick NaI(Tl) crystal (shielded as shown) detected gamma rays from the scatterer. Photomultiplier pulses from this detector were amplified and differentially analyzed with respect to pulse height by a sliding-channel analyzer operating in coincidence with the pulses from the stilbene crystal.

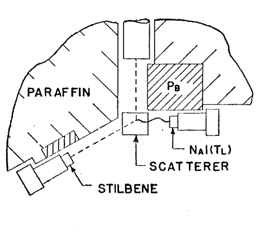

FIG. 1. Experimental arrangement. Neutrons from the target impinge upon the scatterer. The stilbene and NaI(Tl) scintillation crystals detect in coincidence scattered neutrons and de-excitation gamma rays.

The NaI(Tl) crystal was calibrated by means of the 0.51-, 0.66-, 1.28-, and (1.28+0.51)[5]-Mev peaks due to the radiations from $Na^{22}+Cs^{137}$. The curves shown and discussed below are the neutron-gamma coincidence rates (corrected for chance coincidences) *vs* gamma-ray energies (as determined from the calibration) for the indicated scatterers. A curve obtained with no scatterer showed coincidence rates which were negligible relative to those obtained with scatterers in place.

ALUMINUM

The aluminum distribution (Fig. 2) can be accounted for by levels at 0.82, 1.02, and 2.34 Mev. Photoelectric, Compton, and pair peaks fall at relative positions in good agreement with those expected from energy conservation for these three processes. The data are in good agreement with the measurements of Day[3] and with recent results on inelastic proton scattering in Al.[6]

IRON

The spectrum in this case is considerably more complex. Figure 3 shows the 0.4 to 2.2-Mev region, and

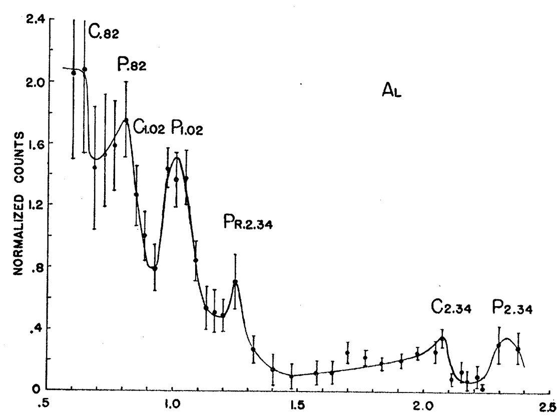

FIG. 2. The gamma-ray spectrum for an Al scatterer. In this curve and those in Figs. 3 and 4 the ordinates are coincidence counting rates normalized with respect to a BF_3-monitoring neutron counter: the abscissas are gamma-ray energies as determined from calibration of the NaI(Tl) crystal (see text).

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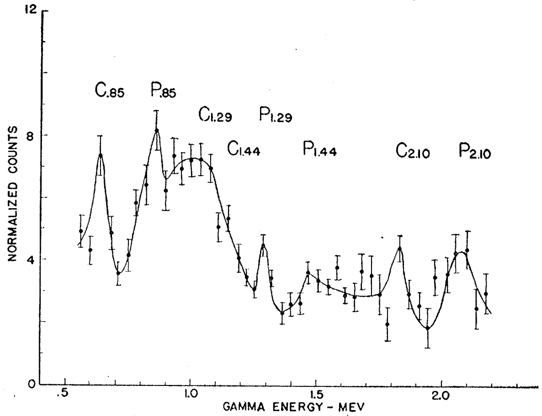

FIG. 3. The gamma ray spectrum for a Fe scatterer.

Fig. 4 shows a more detailed distribution in the 0.8- to 1.4-Mev region. In obtaining the second curve, the resolution of the scintillation spectrometer was improved and the statistical accuracy of the points increased. This curve shows a statistically doubtful peak which could be the Compton break of a 1.15-Mev gamma, the photoelectric peak of which would be obscured by the 1.44-Mev Compton distribution. Exclusive of this possible peak, others can be accounted for by levels at 0.85, 1.29, 1.44, and 2.10 Mev. The three lower levels agree with the results of Day.[3] Although he has observed a gamma line from Fe at 2.2 Mev, it was also present for other scatterers; hence, he suggests[7] that it may have originated from neutrons scattered into his NaI crystal. It is doubtful that neutron scattering in the NaI crystal could produce an appreciable coincidence rate in the experiment reported here, because of the lead and paraffin shield between the gamma and neutron detecting crystals. The fact that no level was observed in this region for Mg supports this view (see below).

MAGNESIUM AND COPPER

Among several other scatterers which were used only Mg and Cu yielded data of sufficient statistical accuracy to show well-defined gamma lines. The corresponding levels for these two elements were as follows: Mg: 1.4 Mev; Cu: 1.13, 1.53, and 2.19 Mev. The Mg level has been observed by several methods.[8] The first two levels in Cu are in fair agreement with known levels[9] in Cu^{65} determined from the beta decay of Ni^{65}. Levels in Cu at 1.1 and 2.2 Mev were reported by Grace *et al.*[2] It is doubtful that the intermediate level reported here could have been detected in their absorption measurements of the gamma-ray energy spectrum.

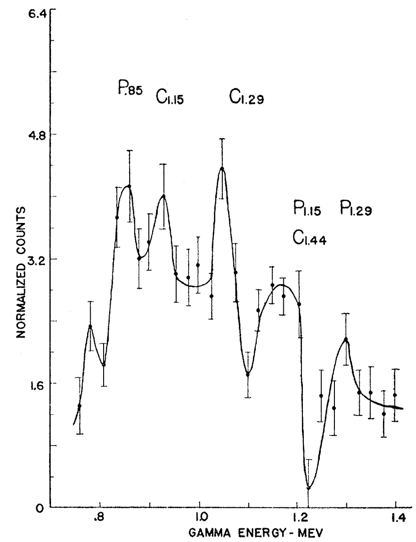

FIG. 4. The 0.8- to 1.4-Mev section of the Fe spectrum obtained with improved resolution.

Note added in proof.—In the pulse-height spectrum for Cu, the Compton break of the 1.13-Mev gamma ray was unusually pronounced and may have obscured a photoelectric peak in the vicinity of 0.9 Mev. Since preparation of this manuscript, Sherrer, Smith, Allison, and Faust [Phys. Rev. **91**, 768 (1953)] have reported a level in Cu at 0.88 Mev and a broad peak at 1.47 Mev. Their latter peak is in fair agreement with the 1.53-Mev peak (also broad) reported above.

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