Inelastic Scattering of Neutrons by In^{115} and Au^{197}†

A. A. EBEL AND CLARK GOODMAN
Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received July 13, 1953)

The metastable states In^{115m} and Au^{197m} have been produced by bombarding indium and gold foils with neutrons (energy spread ±20 to 40 kev). The excitation curve for gold has a threshold at 0.53±0.02 Mev and shows distinct discontinuities in slope at 1.14±0.03 Mev and 1.44±0.03 Mev corresponding to energy levels that decay to the metastable state at 0.54 Mev. The excitation curve for indium has a threshold below 600 Mev and indicates levels at 0.960±0.04 Mev and 1.37±0.04 Mev. Cross-section values cannot be deduced because of inadequate calibration of the scintillation detector.

INTRODUCTION

NEUTRON excitation of metastable states affords a convenient method of investigating inelastic scattering in certain nuclei. Cohen[1] measured $\sigma(n,n')$ for In^{115} for neutrons above 2 Mev. Taschek[2] obtained four points between 0.6 and 1.5 Mev. Neither of these investigations showed excited states other than that corresponding to the threshold for inelastic scattering. The present work was carried out[3] during 1949–50, but publication has been deferred pending completion of the more informative research on Cd^{111m} recently reported by Francis *et al.*[4] Shortly after the scintillation detector (anthracene) used with indium and gold had been dismantled, it was found that the calibration was inadequate to allow reliable evaluation of the inelastic cross section as a function of neutron energy. Since conclusions concerning the spin and parity of the excited states depend on knowledge of the absolute magnitude of the cross section,[5,6] such information cannot be deduced from the present results. However, our data are useful in two respects: (1) in determining which levels are excited by neutrons of a given energy and (2) in establishing the relative cross section as a function of the neutron energy up to 2.0 Mev for Au and 1.8 Mev for In. When normalized against the recent more extensive measurements made at Los Alamos,[7] it is possible to use our data as a check on the theoretical work of Margolis[6] and as a basis for parity assignments which can be compared with those made by McGinnis[8] based on β activities of adjacent nuclei.

EXPERIMENTAL PROCEDURE

The neutrons used were from the $Li^7(p,n)$ reaction using protons from the Rockefeller generator at MIT. The lower-energy second group of neutrons from this reaction causes no ambiguity in the results. The excitation curve for Au^{197m} shows a slight rise, within the statistical uncertainty, at about 430 kev above the threshold. This minor effect, if real, may be due to the onset of inelastic scattering of the second group of neutrons, but the present results are not conclusive.

Rotating targets of evaporated lithium (15 to 20 kev from geometric peak measurements) were used. The beam was monitored with a long counter (at 0° and 1 meter). The induced isomeric activities were measured with an anthracene crystal (0.5×2×4 cm) cemented with Canada balsam to an RCA5819. A 1 air-cm Al foil, used as a light reflector, covered the crystal. The Au and In foils (3-cm diameter) were placed in a slide which passed into the light-tight Pb shield surrounding the counter. When positioned, the foils were about 3 mm from the face of the crystal. Differential pulse-height analysis was used. The Au foil was placed in a recess at one end of a Bakelite slide ($\frac{1}{8}$ inch thick, 1 and $\frac{1}{2}$ inch wide, and 3 feet in length). After a 15-sec bombardment the proton beam is shut off by means of

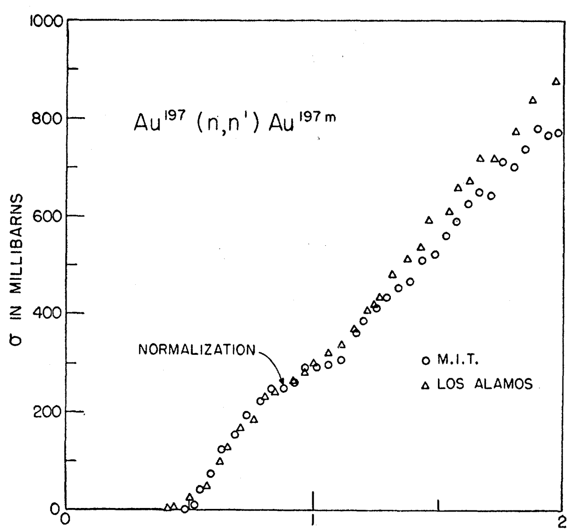

FIG. 1. Neutron excitation of Au^{197m}. The Los Alamos results have been plotted after normalization of the two sets of data at 0.88 Mev. In general the agreement is quite good. Our data indicate levels at 1.14 and 1.44 and possibly at 1.7 Mev which are not evident in the Los Alamos data.

† This work was supported by the U. S. Bureau of Ships and the U. S. Office of Naval Research.
[1] S. G. Cohen, Nature **161**, 475 (1948).
[2] R. F. Taschek, Los Alamos Scientific Laboratory Report LADC 135 (unpublished).
[3] A. A. Ebel, Massachusetts Institute of Technology, Ph.D. thesis, September 1950 (unpublished).
[4] Francis, McCue, and Goodman, Phys. Rev. **89**, 1232 (1953).
[5] W. Hauser and H. Feshbach, Phys. Rev. **87**, 366 (1952).
[6] B. Margolis, this issue [Phys. Rev. **93**, 204 (1954)].
[7] Martin, Diven, and Taschek, Phys. Rev. **93**, 199 (1954).
[8] C. L. McGinnis, Phys. Rev. **81**, 734 (1951).

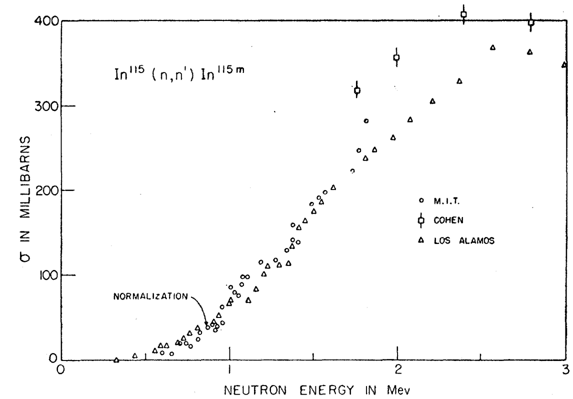

FIG. 2. Neutron excitation of In^{115m}. The uncertainty in the energy assignments for our data is about 40 kev. The early data of Cohen (reference 1) and the recent data from Los Alamos (reference 7) have been used to obtain the cross-section scale. Our data have been normalized with those from Los Alamos at 0.88 Mev. The agreement between the data is fairly good but not quite as good as in the case of Au^{197m}.

a remotely controlled flap valve and the slide is pulled through the slot in the Pb shield surrounding the counter until the foil reaches a predetermined position in front of the crystal of the counter. The rapidly decaying activity ($T_{\frac{1}{2}}=7$ sec) was measured for 15 sec. Multiple activations (5 or more) were made at each proton energy. A second scintillation counter monitored the background during activation measurements. The background was 10 percent or less of the induced activity (150 to 400 counts in 15 sec) for most of the measurements.

Indium foils, 3-cm diameter and 8 mils thick, were irradiated for 4 hours using a 20-kev Li target. Such a long exposure, necessitated by the 4.5-hr half-life of the isomer In^{115m}, introduces a number of experimental uncertainties. The neutron flux varies to some degree during the irradiation, and a simple integration is not sufficient. Six foils were rolled into tiny cylinders mounted on wires and irradiated simultaneously at 0, -15, $+30$, $+45$, $+60$, and -75 degrees with respect to the proton-beam incident on the rotating Li target (evaporated on inner side of tantalum end plate). To obtain sufficient activity, it was necessary to place the foils with the inner edge only 1 cm from the target spot.

After irradiation the foils were counted in rotation 6 to 8 times each over a period of 8 hours, starting with the lowest activity to separate the 54-min In^{116} activity. Differential discrimination of the scintillation pulses was used to increase the ratio of In^{115m}/In^{116} counts.

RESULTS

The neutron excitation curve for Au^{197m}, shown in Fig. 1, has a threshold at 0.53 ± 0.02 Mev and shows distinct discontinuities in slope at 1.14 ± 0.03 Mev and 1.44 ± 0.03 Mev corresponding to energy levels that decay to the metastable state at 0.54 Mev. It is tentatively concluded that the metastable state can be excited directly by $l=3$ neutrons. The spin of this level is probably 11/2 with parity opposite to that of the ground state of Au^{197} (3/2, +).

Interpretation of the experimental results in terms of cross section requires knowledge of (1) the neutron flux on the foil and (2) the efficiency of the counter for the gold x-rays and unconverted gamma rays. The flux can be estimated fairly accurately. Each count on the long counter corresponded to 1800 neutrons per steradian at 0 degrees in the flat region of the lithium yield curve.[9] The 3-cm foil (4.3×10^{21} Au^{197} nuclei) intercepted 0.128 steradian. We have used the recent measurements of Martin *et al.*[7] to normalize our results, see Fig. 1. Based on their data, our counter had an efficiency of about 10 percent.

The neutron excitation curve for In^{115m} is shown in Fig. 2. Despite the scattering of points, there appears to be fairly definite evidence of levels at 0.60, 0.96 and 1.37 Mev with possibly a level at 1.75 Mev. The data of Cohen[1] using neutrons from the *d*-C and *d*-D reactions also are included in Fig. 2, as are the measurements of Martin *et al.*[7] used for normalization.

ACKNOWLEDGMENT

We wish to express our appreciation to the Los Alamos group for the exchange of data prior to publication. We also would like to thank Dr. B. Margolis and Professors H. Feshbach and V. F. Weisskopf for their stimulating suggestions.

[9] Hanson, Taschek, and Williams, Revs. Modern Phys. **21**, 635 (1949).