Neutron Capture Cross Section of Gold at 30 kev and 64 kev

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The capture cross section of gold has been measured with kinematically collimated neutrons from the $Li^7(p,n)Be^7$ and $T(p,n)He^3$ reactions. The cross sections at 30.2 kev and 63.9 kev were found to be 0.767 $\pm$0.060 and 0.456$\pm$0.040 barn, respectively.

INTRODUCTION

THE capture cross section of gold in the low kev region of neutron energy has been measured by a number of experiments.[1–6] Gold has a convenient half-life for activation, has only one stable isotope, and may be obtained in very pure metallic foils. Thus gold presents an almost ideal case for the study of capture cross sections. The experimentally measured cross sections of gold between 20 and 150 kev, however, show variations of the order of a factor of two. Because of these unexplained variations, an additional measurement was considered worthwhile.

EXPERIMENTAL TECHNIQUE

The Oak Ridge National Laboratory 5-Mv Van de Graaff generator was used as a source of protons of energy just above the threshold of the $Li^7(p,n)$ and $T(p,n)$ reactions. A proton beam of 1 μamp with a diameter of about $\frac{1}{8}$ in. was used to bombard targets of LiF or ZrT. The targets were thick enough to reduce the proton energy below the threshold of the respective reactions.

For the case of the $Li^7(p,n)$ reaction the average proton energy was adjusted to be 1.73 kev above threshold. Neutron yield measurements indicated that this energy could be held to within 0.3 kev for periods exceeding two hours. Under these conditions the LiF target gave a neutron beam within a cone of about 12° half-angle with an average energy of 30.2 kev. The neutron intensity was approximately 2.0×10^5 neutrons/sec. The ZrT target gave a neutron beam with about the same cone half-angle, and an average energy of 63.9 kev with a proton energy of 4 kev above threshold. The neutron intensity from the ZrT target was about one-third that from the LiF target. The energy spectrum of the neutrons emitted from the LiF and ZrT targets was roughly triangular with widths at half-maximum of approximately 15 and 40 kev, respectively.[2]

With the neutron intensity from the above targets, it was possible to obtain sufficient activation in a $\frac{3}{4}$-in.-diam disk of gold of 0.020-in. thickness with a one- or two-hr irradiation. The disk was placed $\frac{3}{8}$ in. from the target and a background monitor sample was placed in the same plane with a displacement of 1.5 in. A large sheet of 0.020-in. cadmium was placed a few inches behind the sample to prevent thermalized neutrons from being scattered back into the sample. The background sample received a negligible amount of activation in all cases.

The neutron detector used was the 1.5-m graphite sphere described by R. L. Macklin.[7] With this sphere completely surrounding the neutron source, the neutron intensity could be measured with an accuracy of 3%. During the activations the sphere was placed 175 cm from the target and used as a neutron monitor. The relative efficiency of the sphere at the latter position could be measured by placing the sphere around the neutron-producing target and then displacing it by the required distance. The neutron beam impinged within a 40-cm-diam circle on the surface of the sphere during the activations. The response of the sphere was found to be insensitive to small changes in neutron energy or cone angle.

The induced Au^{198} activity in the sample (410 kev γ-ray photopeak) was measured by means of a 3 in. by 3 in. NaI(Tl) well-type crystal and a 20-channel analyzer. In order to avoid corrections for self-absorption of the γ rays in the gold, the sample was dissolved in aqua regia, transferred to a Pyrex counting tube, and the volume made 10 ml before being placed in the crystal well. The calibration of the system was achieved by adding Au^{198} solution of known activity to an unactivated sample solution of standard gold concentration and volume. The Au^{198} solution was calibrated by 4π β-γ coincidence counting.

RESULTS

Two activations were carried out at both 30.2 and 63.9 kev. Both pairs of results were in good agreement. Corrections were made for multiple scattering,[8] reso-

* Operated by Union Carbide Nuclear Company for the U. S. Atomic Energy Commission.

[1] H. W. Schmitt and C. W. Cook, Nuclear Phys. **20**, 202 (1960).

[2] J. H. Gibbons, R. L. Macklin, P. D. Miller, and J. H. Neiler, Phys. Rev. **122**, 182 (1961).

[3] R. L. Macklin, N. H. Lazar, and W. S. Lyon, Phys. Rev. **107**, 504 (1957).

[4] E. G. Bilpuch, L. W. Weston, and H. W. Newson, Ann. Phys. **10**, 455 (1960).

[5] R. Booth, W. P. Ball, and M. H. McGregor, Phys. Rev. **112**, 226 (1959).

[6] J. A. Miskel, K. V. Marsh, M. Lindner, and R. J. Nagle (unpublished) [See *Neutron Cross Sections*, compiled by D. J. Hughes and R. Schwartz, Brookhaven National Laboratory Report BNL-325 (Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., 1958), S].

[7] R. L. Macklin, Nuclear Instr. **1**, 335 (1957).

[8] H. W. Schmitt, Oak Ridge National Laboratory Report ORNL-2883 (unpublished).

nance self-protection, and radioactive decay in the sample, as well as the dead time in the neutron monitoring system. None of the corrections exceeded a few percent. The resulting capture cross sections were 0.767±0.060 b at 30.2 kev and 0.456±0.040 b at 63.9 kev. The error quoted is the root-mean-square error of the various statistical errors plus the estimated errors in calibrations, corrections, and sample thickness measurements.

In order to check for a systematic error in the neutron monitoring system, a 0.005-in. indium foil was placed directly behind one of the gold foils during one of the 30.2-kev activations. This indium foil was used as a secondary neutron monitor by measuring the induced 54-min-activity. The weighted average experimental value of the capture cross section of the 54-min isomer of indium at 25 kev was derived from two direct measurements[3,5] and a total capture cross-section measurement[1] which was corrected for the 13-second isomer.[9] This capture cross section of the 54-min isomer was corrected to 30.2 kev using the energy variation[2] of the cross section of indium, resulting in a value of 0.678 ±0.047 barn. The indium monitor yielded a capture cross section for gold at 30.2 kev of 0.72±0.09 b which, within experimental error, was in agreement with the graphite sphere monitor.

CONCLUSIONS

The results of this experiment yield a capture cross section for gold which lies between the values found by shell transmission measurements[1] and Sb-Be source activations.[3,5] Table I gives the previously published Au capture cross sections at pertinent neutron energies. The quoted errors in these measurements are such that it is extremely unlikely that the variations are statistical.

The possibility that the Sb-Be activation measurements should have been corrected for multiple scattering was considered, but it was found that this would have been a small effect in at least one of the two cases.[3] Also the possibility that there could be an unusual grouping of resonances in gold at Sb-Be neutron energy was considered but there was no such effect indicated by the capture γ-ray tank measurements, and the probability of such an occurrence would be only a few tenths of a percent.

TABLE I. Published $\sigma_{n\gamma}$ measurements on Au.

E_n (kev)	$\sigma_{n\gamma}$ (barns)	Type of measurement
24	0.585±0.06	Shell transmission[1]
25	1.120±0.11	Sb-Be activation[3]
25	0.890±0.19	Sb-Be activation[5]
28	0.800[a]	Van de Graaff activation[4]
30	0.970	Van de Graaff activation[6]
30	0.515±0.05	γ-ray tank[2]
65	0.332±0.03	γ-ray tank[2]
30	0.767±0.06	Present experiment
64	0.456±0.04	Present experiment

[a] From relative cross-section data which were normalized to absolute cross sections at 200 and 300 kev [A. E. Johnsrud, M. G. Silbert, and H. H. Barschall, Phys. Rev. **116**, 927 (1959)].

There are recent indications[10] that capture γ rays from gold favor high-energy transitions. This could have made the absolute value of the capture γ-ray tank measurements somewhat low, but there is no known reason why the shell transmission measurement should also be low.

Even though the measurements reported herein were undertaken specifically to ascertain which of the earlier measurements was correct, the results contribute little to the resolution of that question.

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[9] R. L. Henkel and H. H. Barschall, Phys. Rev. **80**, 145 (1950).

[10] B. C. Diven, J. Terrell, and A. Hemmendinger, Phys. Rev. **120**, 556 (1960).