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MEASUREMENT OF 24.3 KEV ACTIVATION CROSS SECTIONS WITH THE IRON FILTER TECHNIQUE* BNL 19787

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Using high-resolution detection techniques, intensities of specific activation lines from $^{197}Au(n,\gamma)$ $^{238}U(n,\gamma)$, $^{127}I(n,\gamma)$, and $^{115}In(n,\gamma)$ {54 min + 2.2 sec} were recorded, using the BNL HFBR iron-filtered neutron beam. From a comparison with the reaction $^{10}B(n,\alpha\gamma)$, cross sections at 24.3 keV were determined.

(24.3 keV neutron activation cross sections, relative ^{10}B standard)

I. Introduction

The measurement of the neutron capture cross section leading to the population of a ground state unstable against beta decay, or an isomeric state in the product nucleus, is a simple one in principle. A large number of such measurements have been conducted, using a variety of methods, which cover a wide range of neutron energies impinging on different target nuclides.

These measurements have suffered, however, from the difficulties of using a proper standard for normalization of the neutron flux and the sometimes large self shielding and multiple scattering effects that have to be accounted for.

In the present experiment we report the results of such measurements on four different nuclei using the activation method and counting intensities for selected strong gamma rays emitted in the decay of the product nuclei or their daughters.

The cross sections studied were those of In-115, I-127, Au-197 and U-238. Two main points dictated the selection of the nuclei to be used. U-238 was studied because of the importance of this cross section in reactor calculations. The other three were studied since they are widely used as standards in capture measurements.

II. Experiment

The availability of a strong neutron beam ($\sim 10^7$ n/sec) allows the use of thin targets to obtain adequate counting statistics. This reduces multiple scattering effects considerably. The neutron beam was derived from the High Flux Beam Reactor at Brookhaven through a filter composed of 9 inches of iron, 14 inches of aluminum and 2 inches of sulfur. A sheet of cadmium, 0.8 mm thick, was placed at the exit opening of the neutron collimator, which has a square cross section area of 1" x 1".

The neutron beam energy profile derived from such a filter is shown in Fig. 1. The flux is seen to peak at about 24.25 keV and to have a full width at half maximum of 2 keV. The beam is free of thermal neutron as well as gamma contamination. The fast neutron component is measured at 1.4×10^{-3} of the total flux, while the γ background is less than 0.1 mR/hr.

Because of this distribution in the neutron flux, one has to keep in mind that the cross sections reported here are averaged over the energy interval covered by the neutron beam and weighted by the transmitted flux distribution. The samples and a standard of similar area were placed in the beam, at 45° with the direction of incidence of the neutron beam. Samples either were larger than the beam cross section, which was 1.25" x 1.25" at the sample position, and thus intercepted the full neutron beam, or smaller than the beam size and thus were immersed completely in the neutron beam.

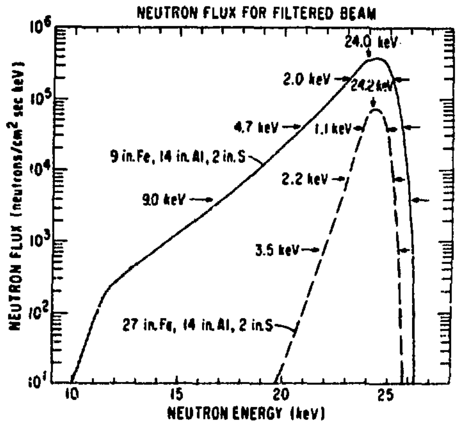

Fig. 1. Energy distribution of the iron-filtered flux. The 9" filter was used for these measurements.

The sample was viewed by a 12 cm^3 germanium detector whose axis was 90° with the neutron beam. The detector viewed the sample through a two inch ^6LiH neutron shield. Gamma spectra were accumulated both during the irradiation of the sample and the subsequent decay after the beam was turned off.

The detector efficiency was determined, for the same geometry, using a series of sources with γ-cascades overlapping the region of interest. The portion of the efficiency curve pertinent to these measurments is shown in Fig. 2, which includes the effect of geometry and shielding.

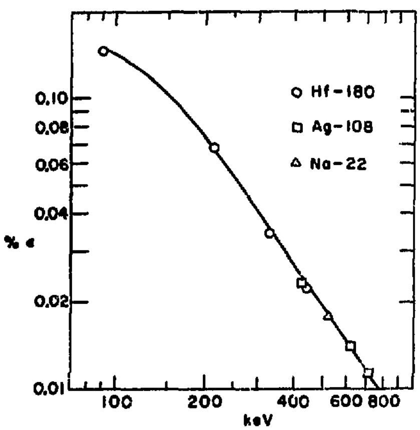

Fig. 2. The efficiency curve for the GeLi detector.

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As mentioned above one of the largest sources of uncertainty in activation measurements is the value for the standard cross section used in the experiment. For a standard the $^{10}B(n,\alpha\gamma)^{7}Li$ reaction was selected since this cross section is well established. A total cross section of 5.9175 barns and a partial $(n,\alpha\gamma)$ cross section of 3.4875 barns as derived from ENDF B-III tabulations, were used.[1]

Boron samples were made of boron powder between two glass plates. The glass was checked for boron content and was determined to be boron-free. The sample was chemically and isotopically analyzed for boron and ^{10}B content. It was found to be 93.14% boron of which 92.818% was boron-10. This sample was used for measuring the gold activation cross section.

Once a value for the gold cross section was established it was used in turn in conjunction with the other three samples as a standard. This was done to avoid the tendency toward settling exhibited by the powder samples, as well as the problem of water absorption and the effects of sample holder walls.

The branching ratios for the different gamma rays emitted in the decay process were taken from the Table of Isotopes compilation.[2]

Typical counting statistics in the experiment ranged from 0.5% for gold to 2.4% for uranium. Errors in sample thickness and non-uniformities were less than 2.0%. Relative detector efficiency error estimates ranged from negligible (for ^{115}In) to 7% for U-238, while errors in half-lives and branching ratios were in the range of 1.0 to 3.0%. Absorption corrections for neutrons and γ-rays were typically less than 5%, except for U-238 where absorption corrections of up to 12% for the low energy γ-rays had to be applied.

III. Results

$^{197}Au(n,\gamma)^{198}Au$

The sample consisted of a gold sheet 1.48×10^{-3} atoms/barn thick combined with a boron sample which was 3.24×10^{-3} atoms/barn thick. We measured the intensity of the 412 keV line, following Au-198 beta decay against the 478 keV gamma ray emitted in the $^{10}B(n,\alpha\gamma)^{7}Li$ process. The sample was irradiated for a period of 61 hours while the gamma ray spectrum was being recorded. Spectra were also recorded during the decay of ^{198}Au for a period of 129 hours.

A third spectrum was obtained with a carbon scatterer in the beam and was used to obtain the beam-dependent room background contribution to the 478 keV boron line. The beam independent room background, which arises from the capture in boron of slow neutrons present on the experimental floor of the reactor, was estimated from the beam-off run while the sample was in place in front of the detector. This correction amounted to approximately 4%.

Using the above-mentioned values for the boron cross section and correcting for the neutron and gamma ray attenuation in the sample, one obtains a cross section of 630 ± 17 mb, exclusive of error in the ^{10}B standard.

$^{238}U(n,\gamma)^{239}U$

The strongest gamma ray emitted in the decay of ^{239}U has an energy of 75 keV. It is difficult to utilize this line in an activation measurement due to the large background expected at this energy in addition to the large variation in detector efficiency relative to the 478 keV boron line energy or the alternative 412 keV gold line energy which we use as standards. However, the daughter nucleus ^{239}Np decays, emitting in the process a large number of higher energy gamma rays, representing transitions in the daughter nucleus Pu-239. Figure 3 shows the portion of the spectrum of interest to this experiment. The 228 keV and the 278 keV lines are the strongest useable lines in the spectrum.

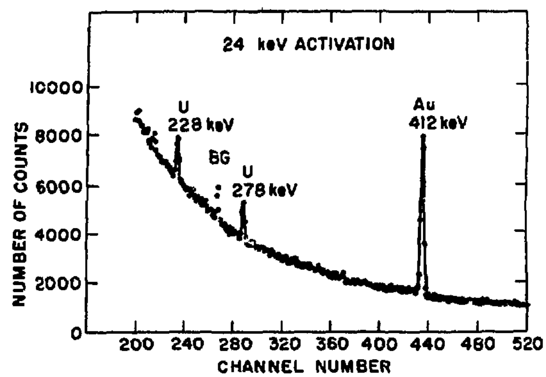

Fig. 3. A portion of the gold-uranium spectrum.

Two separate measurements were carried out. The first measured the uranium cross section relative to that of boron-10. The second used gold as a standard. The uranium samples in both experiments were 4.7×10^{-4} atoms/barn thick. The boron sample was the same used in conjunction in the gold measurement. The sample was irradiated for 65.5 hours. The decay spectrum was accumulated for 46.5 hours.

In the second measurement the sample was made small enough to be entirely covered by the neutron beam. The gold sample was 6.13×10^{-4} atoms/barn thick. The samples were irradiated for a period of 55 hours. The decay run was 84 hours. The two measurements agreed within statistical errors. The cross section averaged over the two measurements was found to be 475 ± 36 mb.

$^{115}In(n,\gamma)^{116m}In$(54.0 min + 2.2 sec)

The cross section for populating the 60 keV isomeric state in In-116 was determined by counting the 417 keV gamma ray relative to the 412 keV gold line. Figure 4 shows that portion of the spectrum relevant to this experiment. Three separate measurements were taken with different sample sizes and thicknesses. Gold was used as a standard in all three measurements. The thickest gold sample was 1.45×10^{-3} atoms/barn thick, while the In samples were less than 4.85×10^{-4} atoms/b thick. The runs were typically about 20 hours irradiation time and a few hours decay time. A cross section of 469 ± 28 mb was obtained from the average of three measurements.

$^{127}I(n,\gamma)^{128}I$

Iodine was obtained in powder form and packaged between glass plates. The 441 keV gamma ray emitted in the decay of ^{128}I was used to measure the activation cross section.

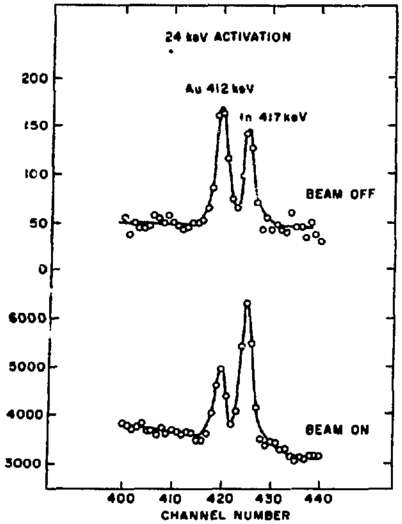

Fig. 4. A portion of the gold-indium spectra.

Two measurements were carried out; one relating to the cross section of gold, and the second relative to the cross section of In. The I samples were 4.80 x 10^{-3} atoms/barn thick while the gold was 1.54 x 10^{-3} atom/barn and the indium was 5.84 x 10^{-4} atoms/barn thick. The runs consisted of a 22 hour irradiation time for the gold-reference run and two hour irradiations for the In-reference run. Decay times of a few half lives were taken. An average cross section of 722 ± 47 mb was obtained when averaging the two runs.

IV. Discussion of Results

^{197}Au

The present result of 630 ± 17 mb is in good agreement with the results of Macklin[3] at Oak Ridge. Macklin has measured the Au capture cross section relative to a ^{6}Li flux monitor. When this cross section, measured in 250 eV intervals, is folded into the spectral distribution of the 24 keV Fe-filtered beam, a value of 622 mb is obtained. The agreement between the two methods is excellent.

^{238}U

The interpolated value for $\gamma\,^{238}U(n,\gamma)$ at 24.3 keV in the ENDF/B IV evaluation[4] is 487 mb. The present value of 475 ± 36 mb is in good agreement with this evaluation.

^{127}I

Activation results with a Sb-Be source from Robertson[5] yield a value of 832 ± 26 mb, while the corrected sphere transmission results of Schmitt and Cook[5] yield 768 ± 90 mb. The same data as interpreted by Bogart and Semler[6] yield 800 ± 80 mb. The present result of 722 ± 47 mb is significantly lower than the Sb-Be measurement, but in agreement with the transmission measurements.

^{115}In (54 min + 2.2 sec)

This activity can be accurately measured by the present technique since the daughter ^{116}Sn contains a γ-ray at 417 keV, close to 412 keV Au standard. The present value of 469 ± 28 mb is lower than the value of 580 ± 40 reported by Chaubey and Seghal,[7] who used an Sb-Be source. Their value is, however, based on $\sigma_{act}(I)$ = 820 mb at 24 keV. Renormalized to the value measured here, the Chaubey and Seghal result would be 511 ± 35 mb, in reasonable agreement with our measurement.

References

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