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THE NEUTRON CAPTURE CROSS SECTION OF ERBIUM ISOTOPES

by

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Although the total cross section for the capture of neutrons by the element erbium is fairly well known,¹ the cross section of the Er^{168} isotope is unknown, while that of Er^{170} is somewhat uncertain.²

The capture cross sections of Er^{168} and Er^{170} may be obtained by irradiating a quantity of Er in the reactor and measuring the amount of Er^{169} and Er^{171} produced by resolving the total decay into its two components, the two nuclear reactions being.

and

The n, γ reaction on Er^{170} produced an isomeric state of Er^{171} , but this half-life (2.5 sec) is so short that the isomeric state decayed to the ground state by the time the measurements were made; only the ground state of Er^{171} , decaying with a 7.5 hr. half-life, was observed. Gold was used as a flux monitor, because its capture cross section is well known. A cadmium-shielded and an unshielded gold foil were irradiated along with the erbium sample to obtain the thermal flux.

Experimental

The erbium was obtained as Er_2O_3 from the Ames Laboratories in 99.8% purity as determined by spectrochemical analysis. A known weight (0.62 mg.) of Er_2O_3 was sealed in a quartz centrifuge tube with a ground glass stopper. Two 20-mil gold foils, one unshielded and weighing 100.4 mg, the other weighing 90.3 mg, and encased in cadmium, were attached to the quartz tube by Scotch tape, to monitor the flux and also to give a cadmium ratio. The tube and attached foils were irradiated in the central thimble of the Argonne heavy water reactor for 7.5 hours. After removal from the pile, the Er_2O_3 was dissolved in successive small amounts of concentrated nitric

¹S. Bernstein, L. B. Borst, C. P. Stanford, T. E. Stephenson, and J. B. Dial, Phys. Rev., 87, 487 (1952).

²Von Walter Bothe, Z. Naturforsch., 1, 179 (1946).

acid and 3 N nitric acid, followed by a wash with distilled water. After mixing to insure homogeneity, an aliquot of this solution was plated onto a rubber hydrochloride film mounted on a 1-13/16-inch aluminum ring with a 1-inch hole in the center. The backing material of rubber hydrochloride was chosen to avoid the backscattering effect encountered in metallic backing materials. The decay of the Er isotopes produced in the irradiation was followed from this plate (Fig. 1). The plate was placed on the first shelf of a flow-type proportional counter using a 90% argon-10% methane mixture.

The two gold foils were separately dissolved in aqua regia, known dilutions made, and aliquots plated on films as with the erbium. These plates were followed for decay along with the erbium plate to determine the amount of gold formed during the irradiation. From the ratio of the activities of the gold per unit weight irradiated, the cadmium ratio was calculated. From the activities produced and from the known cross section of gold, the flux could be determined.

Results

The decay curve of the Er activities is shown in Figure 1. The plate which was followed for decay also was used as the assay plate for the total activity produced in the irradiation, since a known aliquot of the original solution was plated. The amount of activity present at the end of the irradiation was obtained by extrapolating to zero time. The amount of activity of the separate isotopes was obtained by resolving the decay curve into its two components, the 9.4 day Er^{169} and 7.5 hour Er^{171} , and extrapolating each back to zero time. From the absorption curve of Er, it was possible to make a correction for the absorption of the air and the counter window. This correction was appreciable only in the case of the 0.33 mev 9.4 day Er^{169} .

The efficiency of the counter used was 30%. With this, it was possible to find the disintegration rate of the sample from the extrapolated counting rate.

In the case of the gold, there was only one component present, the 2.7-d Au^{198} . The two gold decay curves were extrapolated to zero time and corrected for absorption. The cadmium ratio was calculated to determine the amount of activation due to neutrons whose energy was below that of the Cd cut-off. The cadmium ratio is equal to:

$$\frac{\text{Activation} / \text{unit weight of unshielded gold}}{\text{Activation} / \text{unit weight of Cd shielded gold}} = 96.24\%$$

A correction had to be made for the self-shielding of neutrons by the gold foil, since its thickness (20 mil) was enough to make this factor appreciable. It was found that the average flux seen by the gold foil was only 67.52% of the average flux present.

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With these data, it was possible to calculate the ratio of the cross sections of the two Er isotopes, and to calculate the cross sections of each, based on the known cross section of gold, by use of the following equations:

$$\begin{aligned}
 1. \quad \frac{\sigma^{168}}{\sigma^{170}} &= \frac{\lambda N^{169}}{\lambda N^{171}} \frac{N^{170}}{N^{168}} \frac{(1 - e^{-\lambda^{171} t})}{(1 - e^{-\lambda^{169} t})} \\
 2. \quad \sigma^{168} &= \frac{\lambda N^{169}}{\lambda N^{198}} \frac{N^{197}}{N^{168}} \frac{\sigma^{197}}{(1 - e^{-\lambda^{169} t})} \frac{(1 - e^{-\lambda^{198} t})}{(1 - e^{-\lambda^{169} t})} \\
 3. \quad \sigma^{170} &= \frac{\lambda N^{171}}{N^{198}} \frac{N^{197}}{N^{170}} \frac{\sigma^{197}}{(1 - e^{-\lambda^{171} t})} \frac{(1 - e^{-\lambda^{198} t})}{(1 - e^{-\lambda^{171} t})}
 \end{aligned}$$

Where λN = Activity at zero time in disintegrations/second.
 The activity of gold was corrected for cadmium ratio and for self-shielding of the neutrons.

N = Atoms of each isotope irradiated.

σ^{197} = Cross section of gold.

λ = Decay constant = 0.6933 / half-life.

t = Total time of irradiation in seconds.

From equation 1, the ratio of the capture cross section of Er^{168} to that of Er^{170} was determined to be 0.2328 ± 0.0123 . From equations 2 and 3, the capture cross section of Er^{168} was found to be 2.03 ± 0.41 barns, while that of Er^{170} was 8.72 ± 1.78 barns. This value agrees within the limits of the error with that reported by Bothe.²

Summary

The capture cross section of Er^{168} as determined from the yield and decay of the Er^{169} produced was found to be 2.03 ± 0.41 barns.

The cross section determined for Er^{170} (8.72 ± 1.78 barns) is the sum of the cross sections for the formation of the isomeric state Er^{171*} and the ground state of Er^{171} , since the isomer with a 2.5 second half-life had completely decayed to the ground state (7.5 hr. half-life) by the time the measurements were made. A cross section of 20 barns for the formation of the excited state of Er^{171*} has been reported.³ Although this is in disagreement with the results reported above, it is not impossible that all the Er^{171} formed was formed as the isomer and then decayed with a 2.5 second half-life to the 7.5 hr ground state.

³J. R. Stehn, private communication.

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Bothe based his value for the cross section of Er^{170} on the cross section of Ho^{165} , which at that time was listed as 49 barns. This value is now given as 64 barns, resulting in a value for the cross section of Er^{170} which agrees within the experimental error with that found here.

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