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FISSION CROSS SECTION OF TH^{232} AND U^{235} FOR 14 MEV NEUTRONS

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Abstract

A microphotographic technique was employed to determine the fission cross section of Th^{232} and U^{235} relative to the fission cross section of U^{238} for 14 Mev neutrons. Photographic plates in contact with foils of U^{238}, Th^{232} and U^{235} ("28", "02" and "25") of known thicknesses were simulataneously exposed to the 14 Mev neutron flux. A determination of the number of tracks per unit area of plate per unit mass of foil permitted a determination of the relative cross sections. The Los Alamos Van de Graaff, utilizing the $T(d,n)He^4$ reaction, comprised the neutron source. The measurements yielded the following results:

$$\frac{\sigma_F\text{"28"}}{\sigma_F\text{"02"}} = 3.6 \pm 0.3$$

$$\frac{\sigma_F\text{"28"}}{\sigma_F\text{"25"}} = 0.63 \pm 0.07$$

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Fission Cross Section of Th^{232} and U^{235}

For 14 Mev Neutrons

Introduction

With the availability of an intense monoenergetic source of 14 Mev D-T neutrons from the Van de Graaff, it became feasible to extend to this energy the measurements reported by Williams et al.(1) on the fission cross sections of U^{235} and Th^{232}. Instead of measuring the cross section of U^{238} ("28") and Th^{232} ("02") relative to U^{235} ("25"), we measured the cross section of "25" and "02" relative to "28" since the absolute cross section of "28" was simultaneously being measured by Taschek, Hemmendinger, et al.

The intense neutron source was obtained by using 0.6 Mev deutrons on a thick target of tritium. The neutron energy was thus determined to be 14 Mev ± 0.5 Mev.

Experimental Method

The microphotographic technique (2), (3), (4) was utilized for making the measurements to be discussed in this paper for the following reasons: we were desirous of determining the amount of work involved in making measurements with this technique; it was possible to make the necessary exposures while the Van de Graaff was being run for other experiments; we felt that although these measurements were being made with counters, an independent check on these rather important results by a completely different method would indeed be worth while.

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(1) Williams, LA 520.
(2) Borst and Floyd, AM 2278.
(3) Phillips, Rosen, Taschek, LA 673.
(4) Phillips, Rosen, Taschek, LAMS 616.

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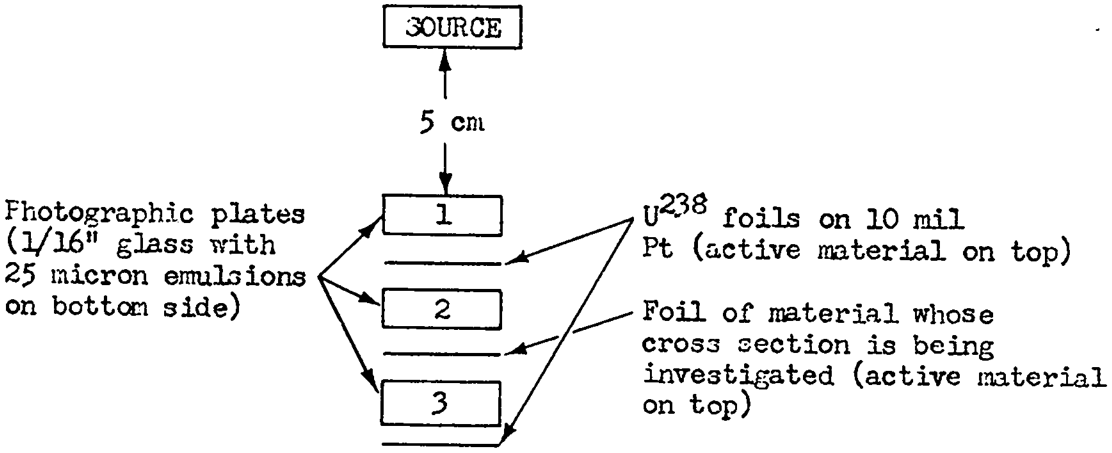
The photographic plates used in these experiments were 25 micron Eastman NTC fission particle plates, batch No. 333,202. They were processed by developing for two and one-half minutes in D-19 at 70 degrees F, washing for one minute in distilled water at 65 degrees F, fixing for 90 minutes in F-5 at 68 degrees F, and then washing for one hour in tap water at approximately 68 degrees F. When processed in this way the plates were found to be quite insensitive to gammas, betas, protons, and alpha particles, although intense exposure to alpha particles did produce general background which showed up as randomly spaced grains. This became somewhat troublesome for the plates in contact with "25" where the plate was exposed to an integrated flux of approximately 10^7 alphas per cm^2 during the course of the neutron exposures. Even so, easily recognizable fission tracks were obtained. (Figure 1.)



Horizontal Cross Section

Figure 2

For each of the experiments described, two separate measurements were made. In the first measurement, to be henceforth denoted as Experiment 1, we determined the ratio of the fission cross section of U^{238} to Th^{232},

FIG 1

[redacted]

in the second measurement, to be henceforth denoted as Experiment 2, the ratio of the fission cross section of U^{238} to U^{235} was determined. Since the experimental techniques and procedures were identical in each case, we shall discuss both experiments simultaneously.

For each measurement three sandwiches of photographic plates in contact with fissionable material foils were used, as shown in Figure 2. Two of these sandwiches, designated 1 and 3, were each composed of a U^{238} foil in intimate contact with the emulsion side of a fission particle plate. The third sandwich, designated 2, was made up of a foil of the material under investigation ("02", Exp. 1 or "25", Exp. 2), also in intimate contact with the emulsion side of another photographic plate. The two sandwiches containing the U^{238} (1 and 3) were placed on either side of the sandwich containing the "02" or "25" foil and together served essentially to determine the number of fissions which would have been produced in a U^{238} foil of known thickness if it were at the precise position of the foil in the central sandwich (sandwich 2).

In each experiment the thicknesses of the U^{238} foils were so chosen as to be very nearly equal to the thickness of the foil whose cross section was to be determined, in order to minimize the correction due to self-absorption.

All foils were made by R. W. Potter, using the zapon technique on platinum. The use of platinum permitted reduction to the oxide. The absolute weight of metal and hence the absolute average thickness of each of the foils was determined by Potter to plus-or-minus one percent. It was however found, by exposing alpha-particle plates to the various foils and determining the number of tracks per unit area as a function of position on the foil, that the average foil thickness over small areas (approximately 0.1 mm^2) varied by as much as plus-or-minus 10 percent. It was accordingly necessary to determine

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the average thickness of the foils over the area to be counted in the experiment and this was done by placing alpha-particle plates in contact with the various foils for appropriate times and then determining the number of tracks per unit area second. By utilizing the accurately known specific activities of the samples from which the foils were made, it was then a simple matter to determine the effective average thickness of the foils over the area to be used in the experiment. On the assumption that every alpha with energy greater than 0.5 Mev was counted, the absolute thickness obtained in making the self-absorption correction outlined in Equation 1 gave a value which agreed with Potter's value to well within the accuracy of these determinations. It was arbitrarily decided to use the central square centimeter of each plate and all counting (fission as well as alpha) was done over a representative portion of this area in each plate.

It is of course recognized that in order to make a relative cross section measurement it is not at all necessary to determine the absolute thickness of the active material. It is only necessary to determine the "effective" thickness* as defined below, as long as the detector efficiency is the same for the two materials being compared. The detector efficiency in our case is only determined by self-absorption and hence by the thickness of the material. As is shown in Table I, the foil thickness for each experiment was the same to within 10 percent. By using this fact and Equation 1, it will now be shown that the variation of detector efficiency due to self-absorption in each experiment was less than one percent and can therefore be safely neglected.

It has been shown by Rossi and Staub (5) that the detection efficiency for fission fragments,

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* Effective thickness is defined as absolute thickness multiplied by the efficiency of the detector as determined from the self-absorption of the foil.

(5) Rossi and Staub, LA 1004.

$$F(B) = \left\{ 1 - \frac{t}{2\ (Ro - R(B))} \right\} \quad \text{Equation 1}$$

where $F(B)$ = detection efficiency for fission fragments

t = thickness of foil in mg per cm^2

Ro = range of particles in material of foil (mg per cm^2)

$R(B)$ = range in mg per cm^2 of foil material of a particle which would just be counted if this range is expended in the photographic emulsion.

For the thick foil

t = approximately 0.85 mg per cm^2 U^3O^8

Ro = 10 mg per cm^2

$R(B)$ = approximately 3 mg per cm^2

and F (B) is seen to be approximately 94 percent.

If t changes by 10 percent, F (B) changes by less than one percent. For the case of the thin foils, the situation is even more favorable. To carry out the experiment one had therefore merely to expose three sandwiches at a time (as shown in Figure 1) for an appropriate period. Each set of three plates was accordingly exposed for a two-week period. Larger intervals were not attempted in order to avoid excessive alpha-particle background and fading of the latent images. In Experiment 1 this two-week exposure yielded about two tracks per field at 900 diameters. In Experiment 2, where much thinner foils had to be utilized in order to avoid excessive alpha background from the U^{235} foil, the number of tracks per field was correspondingly less.

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TABLE II

Experiment	Data on $\frac{\sigma_F^{28}}{\sigma_F^{02}}$ (Exp. 1)	Data on $\frac{\sigma_F^{28}}{\sigma_F^{25}}$ (Exp. 2)
t_1 U^{238}	0.82 mg/cm^2 ± 3%	0.103 mg/cm^2 ± 3%
t_2 $\begin{bmatrix} Th^{232} \text{ in Exp. 1} \\ U^{238} \text{ in Exp. 2} \end{bmatrix}$	0.94 mg/cm^2 ± 3%	0.105 mg/cm^2 ± 3%
t_3 U^{238}	0.86 mg/cm^2 ± 3%	0.908 mg/cm^2 ± 3%
C_1 U^{238}	835	218
C_2 Th^{232}	222	
C_3 U^{238}	967	235
F_1 U^{238}	480	993
F_2 Th^{232}	413	
F_3 U^{238}	564	1281
C_2 U^{235}		141
F_2 U^{235}		411

t_1 = thickness of foil in sandwich 1, Figure 1

t_2 = thickness of foil in sandwich 2, Figure 1

t_3 = thickness of foil in sandwich 3, Figure 1

C_1 = number of tracks counted for sandwich 1, Figure 1

C_2 = number of tracks counted for sandwich 2, Figure 1

C_3 = number of tracks counted for sandwich 3, Figure 1

F_1 = number of fields traversed for sandwich 1, Figure 1

F_2 = number of fields traversed for sandwich 2, Figure 1

F_3 = number of fields traversed for sandwich 3, Figure 1

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Approximately one man-month was required to analyze the plates used in these experiments. Table I gives, for each experiment, the effective thickness of metal for each foil as determined from a correlation of the alpha count with the specific activity as outlined above, the number of fields of view traversed for each plate and the number of tracks counted in each plate at 900 diameters.

From the data of Table I we may immediately proceed to a calculation of the relative cross sections. Since the U^{238} contained U^{235} to only one part in 3300 and the Th^{232} contained essentially no other fissionable material, the calculations for Experiment 1 may be made as follows:

For the plate in contact with Th^{232},

No. of tracks per unit area =

$$\frac{\sigma_F^{Th^{232}} \times t^{Th^{232}} (mg/cm^2) \times 10^{-3} \times 6.023 \times 10^{23}}{232} \times \int Flux \qquad \text{Equation 2}$$

In order to obtain a corresponding equation for a hypothetical plate in contact with a U^{238} foil at the precise position of the above Th^{232} foil, we simply calculate the number of tracks per unit of area per unit thickness (to be henceforth denoted by Q) for a U^{238} plate in contact with a U^{238} foil placed at the position of sandwich 2 by taking an average of the Q's recorded in sandwich 1 and sandwich 3. In view of the fact that Q would drop off as $1/r^2$ in the case that the neutron source was essentially a point source, it should be mentioned that if one calculates the Q for the central sandwich from sandwiches 1 and 3, assuming a $1/r^2$ variation in neutron flux, this value would differ by only 0.5 percent from the Q obtained. For a hypothetical plate in contact with a U^{238} foil at the position of sandwich 2 (Figure 1) we therefore have:

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No. of tracks per unit area =

$$\frac{\sigma_F^{U238} \times 10^{-3} \times 6.023 \times 10^{23} \times t^{U238}\,(\mathrm{mg/cm^2}) \times \int \mathrm{Flux}}{238} \qquad \text{Equation 3}$$

Dividing Equation 3 by Equation 2 we get:

$$\frac{\sigma_F^{U238}}{\sigma_F^{Th232}} = \frac{\text{No. of } U^{238} \text{ tracks/unit area}}{\text{No. of Th232 tracks/unit area}} \qquad \text{Equation 4}$$

$$\times \frac{238}{232} \times \frac{t^{Th232}}{\text{Av. } t^{U238}}$$

$$= 3.6 \pm 0.3$$

In order to obtain (σ_F^{U238})/(σ_F^{U235}) an additional consideration enters in view of the fact that the U^{235} foil contained 94.6 percent U^{235} and 5.4 percent U^{238}. This calculation must then be made as follows:

For a hypothetical photographic plate in contact with a U^{238} foil at the position of sandwich 2 we have again an equation identical with Equation 3, with the exception that the number of tracks per unit area per unit thickness (mg per cm^2) must be calculated from the data of the U^{238} foils and photographic plates used in Experiment 2. For the plate in contact with "25" , however, we have:

No. of tracks per unit area =

$$\frac{\sigma_F^{U235} \times 0.945\ t^{U235} \times 10^{-3}\,(\mathrm{mg/cm^2}) \times 6.023 \times 10^{23} \times \int \mathrm{Flux}}{235} \qquad \text{Equation 5}$$

$$+ \frac{\sigma_F^{U238} \times 0.055\ t^{U235}\,(\mathrm{mg/cm^2}) \times 10^{-3} \times 6.023 \times 10^{23} \times \int \mathrm{Flux}}{238}$$

Dividing Equation 3 by Equation 5 we have:

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[redacted]

$$\frac{\sigma_F^{U^{238}}}{\sigma_F^{U^{235}}} = \frac{\dfrac{\text{No. } U^{238} \text{ tracks/unit area}}{1.013 \times \text{No. } U^{235} \text{ tracks/unit area}} \times 0.945\ t^{U^{235}}}{\text{Av. } t^{U^{238}} - 0.055\ t^{U^{235}} \times \dfrac{\text{No. of } U^{238} \text{ tracks/unit area}}{\text{No. of } U^{235} \text{ tracks/unit area}}}$$

$$= 0.63 \pm 0.07$$

In determining $(\sigma_F^{U^{238}})/(\sigma_F^{U^{235}})$ some concern was felt about the possible contribution of thermal and epithermal neutrons to the apparent cross section of U^{235}. Although the precaution of wrapping the plates in 30 mil cadmium was religiously followed, one is still not certain that sufficient epithermal neutrons did not exist to invalidate the "25" measurement. In order to check this point, the cadmium ratio for "25" was obtained. Since this ratio turned out to be one to the statistical accuracy of the results, (plus-or-minus 10 percent), it was felt that this indicated a sufficiently stringent limitation on the number of thermal neutrons to indeed warrant the assumption that epithermals did not exist in sufficient numbers to cause trouble.

Figure 3 gives the ratios of the fission cross section of U^{238} to U^{235} and to Th^{232} as a function of neutron energy. The points below 6 Mev were obtained from the report of Williams et al.$^{(1)}$

Conclusions

In evaluating the above technique, it should be pointed out that the above data was taken during a two-week period while the Van de Graaff was being run for other experiments. The time required for the analysis of the above plates was approximately 300 man-hours. Whenever two investigators analyzed the same area of a given plate, the number of tracks recorded never differed by more than two percent.

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