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HIGH-RESOLUTION PHOTOFISSION
MEASUREMENTS IN ^{238}U and ^{232}Th

MASTER

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Abstract

High intensity proton beams have been used to generate gamma rays of well defined and variable energy from the (p,γ) reaction on a number of targets. Spectra of photofission fragments of ^{238}U and ^{232}Th have been measured at gamma ray energies from 5.8 to 11.5 MeV. The photofission cross sections have been determined and preliminary values of barrier parameters derived by fitting the data to model predictions.

(A)

Since financial support became available considerable progress has been made in advancing the project.

New uranium and thorium fission foils have been acquired, bringing the total number of foils of each metal presently in our possession to one hundred. All foils have been covered on both sides by a $100 \mu\text{g}/\text{cm}^2$ layer of gold to protect them from oxidation.

The absolute efficiency of the Ge(Li) detector for gamma rays in the energy range from 1 to 12 MeV has been measured.

The absolute efficiency, Ω , of the 8μ Kimfol film for counting fission fragments was determined experimentally as a function of the depth, j , in the foil from which the fission fragment emerges and the angle, α , relative to the normal to the foil at which it is emitted. This efficiency is shown in Fig. 1 for ^{252}Cf fragments passing through gold. In order to apply the efficiency curves to the photofission measurements in which thick foils of uranium and thorium were used corrections have to be made for the difference in the energies of the fission fragments of ^{252}Cf , ^{238}U and ^{232}Th and the differences in stopping powers of gold uranium and thorium for these fragments. To check the accuracy of our efficiency determination we computed the probability of spontaneous fission for ^{238}U from the spontaneous fission data which we had to take for all our fission foils in order to determine the nature of the background in our photofission measurements. We obtained $\lambda_{\text{sf}} = 6.4 \times 10^{-17} \text{y}^{-1}$ in good agreement with $\lambda_{\text{sf}} = 7 \times 10^{-17} \text{y}^{-1}$ the accepted value in fission track dating. A paper describing the efficiency determination is being prepared for publication. An abstract has been submitted to the Washington meeting of the APS.¹²

Techniques have been perfected for handling proton beam currents of up to $250 \mu\text{A}$ on target. The beam wobbler has been replaced by the target wobbler described in our original proposal.

A computer program has been written for determining the photofission cross sections from the measured spectra of the fission fragments.

As a result of these developments routine acquisition of data has become possible.

To check our experimental setup and procedures, which have been discussed in detail in our original proposal, we have carried out measurements of 11 spectra of photofission fragments of ^{238}U and ^{232}Th at gamma ray energies ranging from 5.8 to 11.5 MeV. The spectra for uranium are plotted in Fig. 2(a), (b) and (c), those for thorium in Fig. 3(a), (b), and (c) as a function of the gamma ray energy for each (p, γ) resonance. The cross sections averaged over the energy range covered by each spectrum are listed in Tables 1 and 2 and plotted in Figs. 4 and 5. The results of other measurements are shown for comparison. Our results are in good agreement with those of Caldwell et al¹ at energies above 7 MeV. The results of Veyssiere² for ^{232}Th are considerably lower. Since our data for thorium was obtained simultaneously with the data for uranium which is in good agreement with the data obtained by other groups we think that the ^{232}Th data of Veyssiere is incorrect.

In Figs. 6 and 7 we have compared the fission probability obtained from the existing photofission data with the theoretical predictions of the statistical model described by Back and Britt.³ The low energy photofission data have been taken from Dickey et al⁴ in both cases. The heights of barriers A and B as well as the other barrier parameters are consistent with the values obtained in the analysis of particle induced fission data.⁵ In the case of ^{238}U we have reproduced the fits to the experimental data obtained by Gavron et al⁶ by assuming an additional axially asymmetric barrier C which by increasing the level density at higher excitation energy brings the calculated fission probability into agreement with experimental results. In the case of ^{232}Th no reliable experimental data other than ours exists at energies above 9 MeV. Our data yields fission

probabilities considerably higher than those obtained in calculations which assume the presence of barriers A and B only and shown by the dashed curve. With an additional barrier C of the same symmetry as for ^{238}U the best fit to the data is obtained with $E_C = 7.45$ MeV, however the calculated probability shown by the dotted line is higher than the experimental one in the energy region around 8 MeV. A better fit is obtained when barrier C is assumed to have D_2 symmetry and $E_C = 6.95$ MeV as can be seen from the solid line. In order to determine with confidence the symmetry and the height of barrier C considerably more extensive measurements of the photofission cross section have to be done at higher energies.

The work described in this report constitutes a part of the doctoral thesis of T.R. Yeh. Dr. Yeh defended his thesis in December, 1979 and has been continuing working on the project as a post doctoral research associate.

During the remainder of the present term of the contract we plan to have two runs on the Dynamitron. In addition to taking data at a number of gamma ray energies our aim will be to test the target wobbler, which has been recently installed on the beam pipe, under actual running conditions. In particular we want to determine the optimum frequencies for the horizontal and vertical motions of the target, the long term stability of its equilibrium position, the lifetime of the bellows, etc. The gamma ray energy resolution in measurements with the target wobbler will be considerably improved. We expect to reach with the present geometry an average resolution of ~ 300 eV.

With the acquisition of the additional fission foils the number of polycarbonate films used in a measurement at a particular proton resonance has exceeded 400. The scanning of such a large number of films is a tedious

and time consuming process. We are planning to purchase an automatic scanning system, which employs a high resolution vidicon camera. The coordinates of each track in a film will be stored and processed by a computer. The system most suitable for our needs is available from Hamamatsu Systems, Inc.

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These investigations have been in full compliance with the requirements of the contract. The principal investigator has devoted to the project full time during the months of June and July, 1979 and 50% of his time since September. During the remainder of the current term of this contract the principal investigator expects to devote 50% of his time to the project.

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Captions to Figures

- Fig. 1. The efficiency $\Omega(j, \alpha)$ of the 8μ Kimfol film for counting fission fragments of ^{252}Cf as a function of the thickness of the gold layer through which the fragments have to pass on the way to the film and the angle α at which they are emitted relative to the normal to the film.
- Fig. 2. Photofission cross sections $\sigma_{\gamma f}$ of ^{238}U as a function of gamma ray energy.
- (a) $5.8 \text{ MeV} \leq E_{\gamma} \leq 6.9 \text{ MeV}$
 - (b) $7.3 \text{ MeV} \leq E_{\gamma} \leq 8.8 \text{ MeV}$
 - (c) $8.9 \text{ MeV} \leq E_{\gamma} \leq 11.6 \text{ MeV}$
- Fig. 3 Photofission cross sections $\sigma_{\gamma f}$ of ^{232}Th as a function of gamma ray energy.
- (a) $5.8 \text{ MeV} \leq E_{\gamma} \leq 6.9 \text{ MeV}$
 - (b) $7.3 \text{ MeV} \leq E_{\gamma} \leq 8.8 \text{ MeV}$
 - (c) $8.9 \text{ MeV} \leq E_{\gamma} \leq 11.6 \text{ MeV}$
- Fig. 4 Comparison of the averaged photofission cross sections of ^{238}U with the results of Caldwell et. al., and Dickey and Axel.
- Fig. 5 Comparison of the averaged photofission cross sections of ^{232}Th with the results of Caldwell et. al., Dickey and Axel, and Veyssieue et. al.
- Fig. 6 Comparison of the ^{238}U fission probability P_f with the results of calculations based on the statistical model.
- Fig. 7 Comparison of the ^{232}Th fission probability P_f with the results of calculations based on the statistical model.

TABLE 1

$$\sigma_{\gamma f}(\text{mb}) \text{ for } {}^{238}\text{U}(\gamma, f)$$

E_{γ} MeV	Lindgren et al ref. 7	Dickey and Axel ref. 4	Veyssiere et al ref. 2	Mafra et al ref. 8	Yester et al ref. 9	Khan Knowles ref. 10	Manfredini et al ref. 11	Caldwell et al ref. 1	This work
5.868	6.4	$3.2^{+0.5}_{-0.5}$			$3.0^{+0.5}_{-0.5}$	$1.7^{+0.4}_{-0.4}$		$4.5^{+0.5}_{-0.5}$	$8.2^{+0.2}_{-0.2}$
6.177	9.2	$11.4^{+0.7}_{-0.7}$			$5.3^{+0.6}_{-0.6}$	$6.05^{+0.4}_{-0.4}$		$8.2^{+0.5}_{-0.5}$	$16.2^{+1.0}_{-1.0}$
6.875		$10.4^{+0.6}_{-0.6}$		$1.9^{+0.2}_{-0.2}$	$4.8^{+0.6}_{-0.6}$	$6.5^{+0.5}_{-0.5}$	$2.73^{+0.32}_{-0.32}$	$10.4^{+0.5}_{-0.5}$	$31.1^{+0.7}_{-0.7}$
7.374		$10.1^{+0.7}_{-0.7}$		$10.2^{+1.1}_{-1.1}$	$8.0^{+0.6}_{-0.6}$	$8.1^{+0.5}_{-0.5}$	$12.0^{+1.6}_{-1.6}$	$11.8^{+1.0}_{-1.0}$	$11.7^{+0.7}_{-0.7}$
7.949			17^{+2}_{-2}	$14.3^{+1.5}_{-1.5}$	$8.2^{+0.5}_{-0.5}$	$16.5^{+0.5}_{-0.5}$	$18.9^{+6.7}_{-6.7}$	$16.9^{+1.0}_{-1.0}$	$14.1^{+0.2}_{-0.2}$
8.241			22^{+2}_{-2}					$18.5^{+1.0}_{-1.0}$	$18.5^{+0.8}_{-0.8}$
8.724			24^{+2}_{-2}					25	$20.7^{+0.7}_{-0.7}$
8.918			30^{+2}_{-2}	$37^{+1.1}_{-1.1}$			$29^{+1.8}_{-1.8}$	27	$26.6^{+0.3}_{-0.3}$
9.976			54.5^{+5}_{-5}					69	$58.4^{+3.0}_{-3.0}$
10.755			86^{+7}_{-7}					95	$76.5^{+0.5}_{-0.5}$
11.533			91^{+7}_{-7}					100	$88.3^{+0.9}_{-0.9}$

TABLE 2

$\sigma_{\gamma f}$ (mb) for $^{232}\text{Th}(\gamma, f)$

E_{γ} MeV	Dickey Axel ref. 4	Veyssiere et al ref. 2	Mafra et al ref. 8	Yester et al ref. 9	Khan Knowler ref. 10	Manfredini et al ref. 11	Caldwell et al ref. 1	This work
5.868	$1.5^{+1.2}_{-1.2}$			$2.5^{+0.5}_{-0.5}$	$1.7^{+0.5}_{-0.5}$		$2.5^{+0.25}_{-0.25}$	$3.9^{+0.1}_{-0.1}$
6.177	$10.0^{+1.6}_{-1.6}$			$7.2^{+0.5}_{-0.5}$	$7.5^{+0.5}_{-0.5}$		$8.5^{+0.5}_{-0.5}$	$8.7^{+0.7}_{-0.7}$
6.875	$6.3^{+1.1}_{-1.1}$		$2.0^{+0.2}_{-0.2}$	$3.8^{+0.5}_{-0.5}$	$3.0^{+0.5}_{-0.5}$	$2.4^{+0.25}_{-0.25}$	$7.7^{+0.5}_{-0.5}$	$9.5^{+0.4}_{-0.4}$
7.374	$7.9^{+1.2}_{-1.2}$		$2.9^{+0.4}_{-0.4}$	$4.5^{+0.5}_{-0.5}$	$7.2^{+1.0}_{-1.0}$	$3.25^{+0.56}_{-0.56}$	$6.7^{+0.5}_{-0.5}$	$5.6^{+0.4}_{-0.4}$
7.949	$9.5^{+2.7}_{-2.7}$		$5.1^{+1.4}_{-1.4}$	$2.7^{+0.6}_{-0.6}$	$13.0^{+1.0}_{-1.0}$	$6.9^{+2.5}_{-2.5}$	$6.9^{+0.5}_{-0.5}$	$6.6^{+0.1}_{-0.1}$
8.241					$15.0^{+1.0}_{-1.0}$		$7.8^{+0.5}_{-0.5}$	$6.8^{+0.5}_{-0.5}$
8.724							$10.3^{+0.7}_{-0.7}$	$8.0^{+0.5}_{-0.5}$
8.918		$7.0^{+2.0}_{-2.0}$	$8.4^{+3.5}_{-3.5}$			$5.8^{+0.9}_{-0.9}$	$10.7^{+0.7}_{-0.7}$	$12.0^{+0.3}_{-0.3}$
9.976		$14.0^{+2.5}_{-2.5}$						$26.0^{+1.9}_{-1.9}$
10.755		18.0^{+3}_{-3}						$24.4^{+0.4}_{-0.4}$
11.533		$23.0^{+3.0}_{-3.0}$						$33.4^{+0.8}_{-0.8}$

Fig. 1

^{238}U

Fig. 2(a)

^{238}U

Fig. 2(b)

Fig. 2(c)

Fig. 3(a)

Fig. 3(b)

^{232}Th

Fig. 3(c)

Fig. 4

Fig. 5

Fig. 6

Fig. 7