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PHOTOFISSION CROSS SECTION OF ^{238}U in the Quasi-Deuteron Region*

by

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Summary. — The photofission cross section of ^{238}U induced by monochromatic and polarized photons has been measured using the LADON facility at the Frascati National Laboratory. The experiment has been performed at six different energies in the range 46-72 MeV by detecting the fission fragments either in uranium-loaded nuclear-track emulsion plates or in uranium-mica sandwiches. Results are consistent with existing data, however they suggest the opportunity of further investigation in this energy range.

Key-words: Photofission; Uranium-238; Quasi-deuteron; Monochromatic photons; Nuclear-track emulsion; Mica detector.

PACS. 25.85. - fission reactions.

1. – Introduction

The photofission of heavy nuclei has been systematically investigated during the last three decades, mainly at the giant resonance and above the meson photoproduction threshold regions ([1]). The photofission below the pion threshold has been mainly studied using photon sources by electron bremsstrahlung or by positron annihilation in flight, but recent data from tagged photons are also available ([2,3]).

The aim of this work was to measure photofission cross sections in the energy region covered by the LADON photon beam to realize an additional independent check of the modified-quasi--deuteron (MQD) model. Furthermore, exploiting the polarization of the beam we search for a possible asymmetry in the angular distribution of the fission fragments when using uranium-loaded nuclear-track emulsion plates. Unfortunately, the collected statistics was not enough to clearly show some kind of anysotropy.

2. – Description of the experiment

In this experiment we used two kinds of target-detector systems: uranium-loaded nuclear-track emulsion plates and sandwiches of mica foils with thin uranium layer. The first consists of nuclear emulsion quantitatively loaded with complex solutions of an uranium salt in such a way that the recording properties of the nuclear emulsion are not altered during the loading, storing and processing stages. At the same time, the exact amount of the loading element is well known and evenly distributed. To avoid the fading of the latent image, the nuclear emulsion were vacuum sealed and stored at low temperature. To prepare, instead, the uranium-mica sandwiches we selected clean, freshly cleaved sheets of muscovite mica and pre-etched them in 49% hydrofluoric acid to produce large, diamond-shaped, pits of "fossil" tracks. This allows to distinguish them from tracks produced during the irradiation. The mica sheets were then covered, on one side, with a layer of uranium-oxide. The method we used allows to get a total annealing of any primordial track inside the mica and to obtain a quite uniform extra thin uranium film . So the self-absorption of heavy nuclear fragments is negligible. Finally, the mica sheets were enveloped with two sheets of a heat-sealable plastics and vacuum packed to form a sandwich. Both kinds of target-detector system were prepared at the CBPF chemical laboratory.

These targets were exposed to a monochromatic and polarized photon beam, obtained by backward Compton scattering of the laser light on the electrons circulating in the ADONE storage ring at the Frascati National Laboratory of the INFN ([4,5]). During this experiment, the main features of the LADON beam were a satisfactory energy resolution (up to about 10% FWHM, at maximum energy), an extremely low bremsstrahlung background (about 5% integrated over the whole spectrum above 2 MeV), an intensity of about 10^5 photons/s, and an almost complete linear polarization.

During irradiation of the fissionable samples, the beam was continuously monitored by means of a pair spectrometer whose spectra were collected by a real-time data acquisition system. The beam was also monitored by a 10-in×10-in NaI(Tl) crystal whose threshold stability was periodically checked; it allows us to measure the integral of the photon counting. Finally, the bremsstrahlung contribution was estimated, switching off the laser light, before starting each irradiation.

The experimental layout is schematically shown in Fig. 1 and in Table 1 there are shown the irradiation conditions of the targets. After irradiation the emulsions were processed using a special technique ([6]) to obtain very legible fission tracks in spite of the background from alpha particles. The mica sandwiches were instead opened and immerged in a diluted nitric acid solution to remove the uranium layer before to be etched. Etching proceeded with 40% hydrofluoric acid during 1 h at room temperature. Track counting and track analysis were carried out by using conventional optical microscopes (Leitz, Ortholux). Calibrated eyepieces made it possible to determine the scanning areas of the various plates accurately. These quantities along with the total number of tracks are also reported in Table 1.

3. – Experimental results and discussion

Our results on the photofission cross sections of ^{238}U are given in the last column of Table 1 and shown in Fig. 2. Only statistical errors are quoted. To evaluate the cross section from the number of fission events we must take into account the contributions from the tail of the giant-resonance and from the continuous background due to the bremsstrahlung gamma-rays. As previously quoted, the last one turns out to be negligible. The contribution from giant-resonance can be estimated from

$$\int_{k_T}^{k_U} \sigma_{GR}(k)\, n(k,k_{max})\, dk \quad .$$

where σ_{GR} is the cross section in the giant resonance region, $n(k,k_{max})$ is the normalized energy distribution of the photon beam, k_T is a threshold value where the product $\sigma_{GR}.n$ becomes negligible, k_U is the upper end-point energy ($\sim$ 30 MeV) of the giant-resonance region, and k_{max} is the maximum energy of the beam. We parametrize σ_{GR} with a Lorentz-shaped function:

$$\sigma_{GR}(k) = \frac{\sigma_0}{1 + \left[\frac{k^2-k_0{}^2}{k\Gamma}\right]^2} \quad .$$

where σ_0 = 154 mb, k_0 = 14 MeV and Γ = 5.417 MeV have been obtained from a best-fit on the data of ref. [2]. Also the contribution from giant-resonance tail appears to be negligible — lesser than a few percent — at all energies.

Finally, we can write the number N_e of fission events as:

$$N_e = N_a.\phi.\varepsilon \int_{k_T}^{k_{max}} \sigma(k).n(k,k_{max})\,dk \quad ,$$

where N_a is the number of ^{238}U atoms, ϕ the total number of photons and ε the detector efficiency which is largely independent from energy. Because of the peak shape of the $n(k,k_{max})$ distribution we developed $\sigma(k)$ in a power series about the mean energy of the beam:

$$\sigma(k) \simeq \sigma(\bar{k}) + \left.\frac{d\sigma}{dk}\right|_{\bar{k}} (k-\bar{k}) + \ldots \quad ,$$

where

$$\bar{k} = \int_{k_T}^{k_{max}} k.n(k,m_{max})dk \quad .$$

Keeping only the 0^{th} term in k, we get $\sigma(\bar{k}) = N_e/N_a\phi\varepsilon$.

In Fig. 2 we also report the data from Ref. ([3]), while the dotted line represents an evaluation of total photoabsorption cross section according to Levinger's modified quasi-deuteron model ([7,8]):

$$\sigma^t_{MQD}(k) = \frac{LNZ}{A}\,\sigma_d(k)\,\exp(-D/k) \quad ,$$

where k is the photon energy, L is Levinger's factor, N is the neutron number, Z is the atomic number, A is the mass number, $\sigma_d(k)$ is the photodisintegration cross section of the free deuteron, and D is the damping parameter. We assume $L \approx \frac{A^{2.147}}{NZ}$ and D = 60 MeV, as deduced from the systematic study reported in Ref. ([9]), while the $\sigma_d(k)$ values are taken from Ref. ([12]).

In our opinion, even if all data seems to be consistent, a further investigation in the region between 20 and 80 MeV will give a better insight of the fission mechanism. In particular, data suggest that the fission probability is not very close to unit in this energy region, so that an accurate model is needed for the photofission reaction.

* * *

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Figure Captions

Fig. 1 - Schematic view of the experimental layout.

Fig. 2 - Photofission cross sections. Filled circles: this experiment; open circles: M. Ries et al. [2]; cross: H. Ries et al. [3]. The full line is from Ref. [10], the dashed line is from Ref. [11] and the dotted line represents the photoabsorption cross section evaluated by the modified quasi-deuteron model [7,8,9].

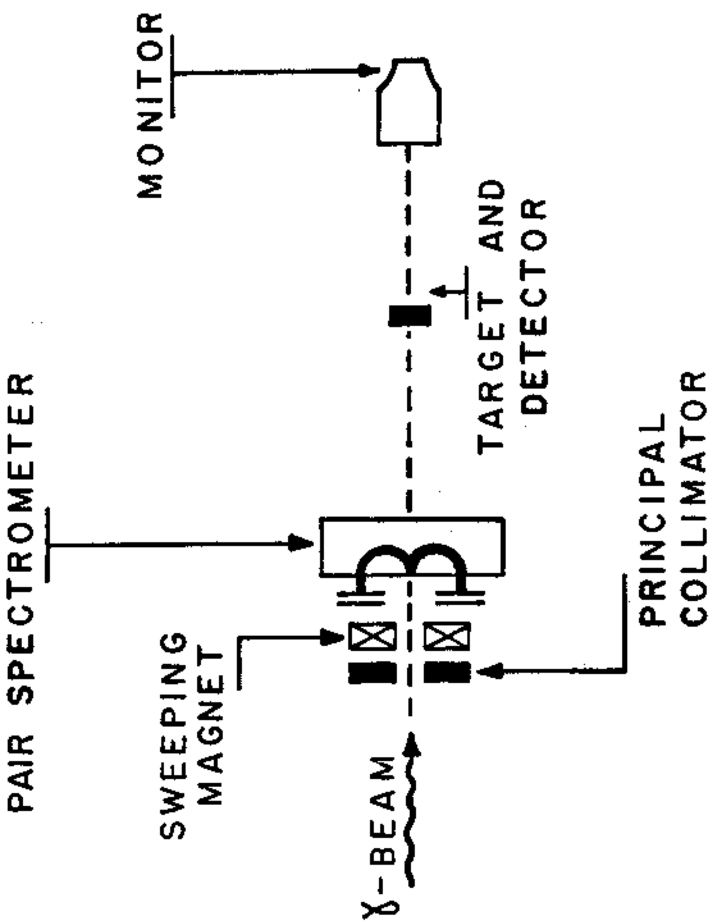
MONITOR
TARGET AND
DETECTOR
PAIR SPECTROMETER
PRINCIPAL
COLLIMATOR
SWEEPING
MAGNET
γ-BEAM

Fig. 1

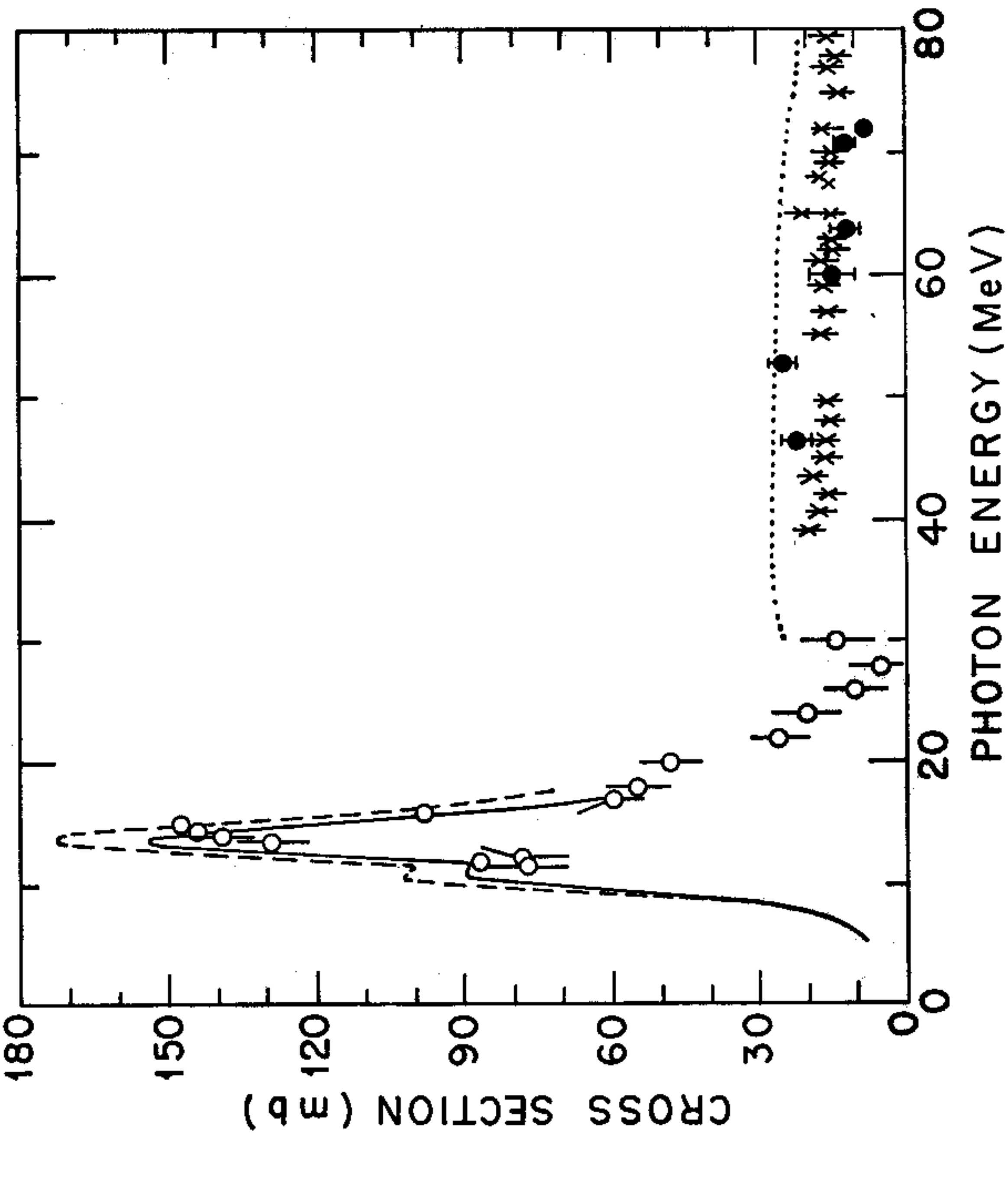
CROSS SECTION (mb)
PHOTON ENERGY (MeV)
0
30
60
90
120
150
180
20
40
80

Fig. 2

Table 1 - Irradiation conditions and cross-section values.

Effective photon mean energy	Number of ^{238}U atoms (cm^{-2})	Scanning area (cm^2)	Total number of tracks	Total dose of photons	^{238}U photofission cross-sections (mb)
46.4	$(7.0\pm0.3)\times10^{18}$	0.171±0.007	257±34	6.79×10^{9}	22 ± 3
52.7	$(8.0\pm0.3)\times10^{18}$	0.129±0.005	258±26	7.04×10^{9}	25 ± 3
(+) 59.7	$(1.5\pm0.1)\times10^{19}$	—	811±43	2.81×10^{9}	14 ± 5
(+) 63.8	$(1.6\pm0.1)\times10^{19}$	—	1296±50	4.75×10^{9}	12 ± 3
70.9	$(8.4\pm0.3)\times10^{18}$	0.104±0.004	104±16	4.32×10^{9}	12 ± 2
71.9	$(9.8\pm0.4)\times10^{18}$	0.163±0.006	51± 7	4.40×10^{9}	8 ± 1

(+) These measurements were realized by using uranium-mica sandwiches, while the others were performed by using uranium loaded nuclear-track emulsion plates.

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