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ELECTROFISSION OF ^{237}Np IN ENERGY RANGE 10–34 MeV

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Measurements of the electrofission cross section for ^{237}Np have been made for the electron energy range from 10 to 34 MeV. An analysis of the experimental results has been performed using the concept of virtual photons. Both isoscalar and isovector E2 giant resonances were taken for the calculation of the contribution E2 transition mode.

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1. *Introduction*

Electro-induced reactions as well as photoreactions can be described in terms of electromagnetic interactions. In the case of the electroexcitation, this interaction takes place through the virtual photon spectrum which differs from the real one in that it depends strongly on the multipolarity of the photons. The DWBA calculations of the virtual photon spectrum performed by Soto Vargas, Onley and Wright [1] exhibit a significantly larger intensity for the electric quadrupole mode (E2) as compared to that for the electric dipole mode (E1). This property of the virtual photon spectrum causes the electro-induced reactions to be a much better tool for studying the contribution of the various multipoles to the reaction mechanism than the photonuclear reactions. From the experimental point of view, the cross sections for the electroexcitations process are roughly (1/137) times smaller than the corresponding cross sections for the photoexcitations. However, it is much easier to obtain well focused intense electron beams than well collimated photon beams.

In the last six years only a few works [2–6] relating to the investigation of the contribution of other than E1 multipole excitation to electrofission reactions have been published.

In the present work, experimental results are presented for the electrofission of ^{237}Np in the energy range 10–34 MeV. The contribution of the electric dipole and quadrupole excitation modes has been calculated using the DWBA calculations of the virtual photon spectrum. The electrofission of ^{237}Np has been investigated by Shotter et al. [2] in the

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energy range 20–120 MeV with an energy step of about 10 MeV. It seems to be reasonable to extend this range to a lower energy with a much smaller step, because the fine structure in the excitation near the successive fission thresholds can be expected as was observed by Rasch et al. [3] and Kneissl et al. [4].

2. *Experimental*

The measurements were performed with the electron beam of the Institute of Nuclear Research 35 MeV betatron in Świerk. The energy calibration was made with an accuracy of 2%, using the thresholds of photoneutron reaction on carbon, nitrogen and copper. The stability of the betatron energy was checked during the time of the measurements. In order to define the beam position, an ionization chamber was placed directly behind the target assembly.

Mica detector sandwiches were used to register the fission fragment in 2π geometry. The sandwich consisted of two mica sheets and two targets in the following order: mica sheet, target of ^{237}Np, mica sheet and target of ^{238}U. The targets were prepared by electrodeposition on a 20 μm aluminum backing. The targets thicknesses (60 μm/cm^2 for ^{237}Np and 330 μm/cm^2 for ^{238}U) were measured by elastic backscattering of 2 MeV protons from the Van de Graff accelerator of INR. The contribution of the background due to fission by bremsstrahlung produced in the targets and mica detectors was estimated to be always smaller than 3%. The mica foils were preetched in 48% HF for 10 h to develop the fossil fission background and for 3 h after the irradiations. The fission tracks were counted under an optical microscope with a 200× magnification.

The absolute values of the reaction cross section have been established using the known ^{238}U(e, e′f) cross section [7]. The measured cross sections for the ^{237}Np (e, e′f) reaction are shown in Fig. 2. Only the statistical errors, not exceeding 3% in most cases are plotted. The error of the absolute normalization is 13%. This includes the error of the absolute value of the ^{238}U (e, e′f) cross section taken from Ref. [7] and the error of target thickness determination.

3. *Analysis of results*

The electron induced fission cross section $\sigma_e(E_0)$ can be analysed in terms of the photofission cross section by means of the virtual photon formalism as:

$$\sigma_e(E_0) = \sum_{\lambda L} \int_0^{E_0} \sigma_{\gamma,f}^{\lambda L}(E) N^{\lambda L}(E, E_0) \frac{dE}{E}, \tag{1}$$

where λL is the mode and multipolarity of photons, E_0 and E are the electron and photon energies, respectively. Here $\sigma_{\gamma,f}^{\lambda L}$ is the partial photofission cross section and $N^{\lambda L}(E, E_0)$ is the virtual photon spectrum. The virtual photon spectrum calculations performed by Wright [1] have been used for the analysis.

3.1. El contribution

The photofission cross sections obtained by Veyssière et al. [8] in the energy range 9.28–16.6 MeV were used for our calculations of the electric dipole contribution.

The photofission cross section for the photons with energy outside of this range has been calculated as:

$$\sigma^{\lambda L}_{\gamma,f}(E) = \sigma^{\lambda L}_{\gamma}(E)P_f(E), \tag{2}$$

where $\sigma^{\lambda L}_{\gamma}$ is the photon absorption cross section and P_f is a fission probability. The dipole absorption cross section has been taken in the analytical form as the sum of the two Lorentz curves with parameters given by Veyssière et al. [8].

The fission probability P_f was calculated under the assumption of a statistical model using a constant temperature level density according to the formula given by Huizenga and Vandenbosch [9] because it was found that this model gave better agreement with experimental data than the Fermi-gas model. The probability P_f can be expressed in terms of Γ_n/Γ_f ratios:

$$\frac{\Gamma_n}{\Gamma_f} = \frac{2TA^{2/3}}{K} \; \frac{1+(E-B'_n)/T-\exp((E-B'_n)/T)}{1-\exp((E-B'_f)/T)}, \tag{3}$$

where the constant K is 10 and B'_n and B'_f are the neutron binding energy [10] and the fission barrier values [11], respectively, which were corrected for the pairing energy according to [9]. The effective higher chance fission thresholds i.e. fission following emission of one, two and three neutrons were calculated under the assumption that the mean kinetic energy of an evaporated neutron is equal to 1 MeV. For each neptunium isotope such a value of temperature T was taken for which Eq. (3) fitted the plateau of experimental values from Ref. [12] well. Calculated values of P_f are shown in Fig. 1a. At 16.6 MeV, a discrepancy appeared between the value of $\sigma_{\gamma,f}$ obtained from Eq. (2) and the value measured by Veyssière. The photofission excitation function, after normalization of the cross section of Eq. (2) at 16.6 MeV photon energy, is shown in Fig. 1b. It should be noticed that this difference is smaller than the experimental error of the measurement of $\sigma_{\gamma,f}$. The influence of the above discrepancy on the resulting calculation of σ^{E1}_{e} was indicated in Fig. 2 (curve (c)) as a shaded area between two curves. The lower and upper curves refer to σ^{E1}_{e} calculated with and without normalization, respectively. The average of the two curves has been taken in the final analysis.

3.2. E2 contribution

Bohr and Mottelson [13] predicted the existence of two E2 modes: isoscalar at $58\,A^{-1/3}$ MeV for which neutrons and protons oscillate in phase and isovector at $135\,A^{-1/3}$ MeV in which neutrons and protons oscillate out of phase. The isoscalar giant quadrupole resonances GQR have been localized experimentally in many nuclei with $A > 40$ at an excitation energy $E_R = 63\,A^{-1/3}$ MeV with a width of about 3 MeV for $A \sim 200$, as is shown in the review paper by Bertrand [14]. The isovector GQR has been observed for $A \sim 200$ at an excitation energy $E_R = 130\,A^{-1/3}$ MeV with the width of about 5 MeV [15].

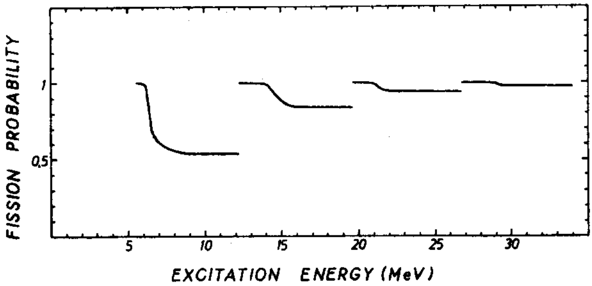

Fig. 1a. Calculated fission probability in the decay of ^{237}Np as a function of the excitation energy

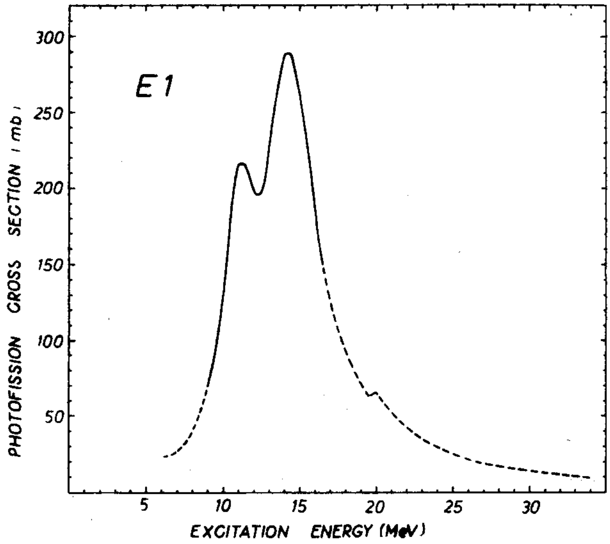

Fig. 1b. Photofission cross section for ^{237}Np versus photon energy. The solid line represents a curve drawn through the data of Ref. [8]. The dashed line was obtained using Eq. (2) as explained in the text

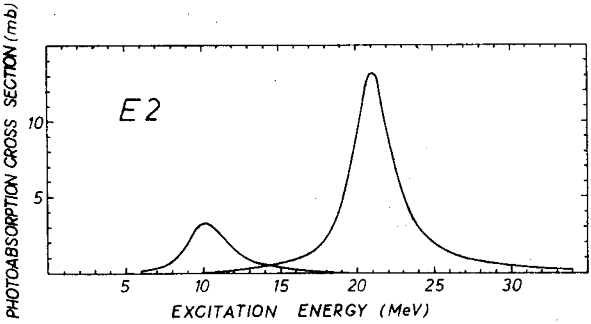

Fig. 1c. Photoabsorption cross section for the isoscalar and isovector components of quadrupole giant resonances as a function of the photon energy

It gives for ^{237}Np resonance energies of about 10 MeV and 21 MeV, respectively. On the basis of the results obtained for ^{238}U [6, 16], the 50% sum rule exhaustion for both GQR modes was taken in our calculations. The 80% sum rule obtained by Neto et al. [5] for ^{238}U gives theoretical values for σ(e, e′f) too high in comparison with the experimental ones.

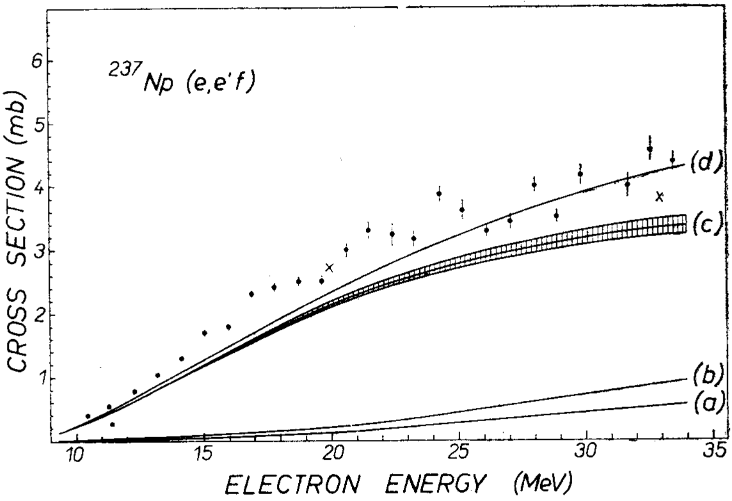

Fig. 2. Electrofission cross section for ^{237}Np versus electron energy. The solid circles represent our results, crosses are taken from Ref. [2]. Curves *a* and *b* represent the electrofission cross section for the isoscalar component E2 and the sum of isoscalar and isovector components, respectively. Curve *c* shows the cross section for electric dipole excitation, the shaded area is explained in the text. Curve *d* represents the sum of the electrofission cross sections for E1 and E2 modes

Fig. 1c shows the photoabsorption cross section for the isoscalar and isovector GQR. The fission probability is the same as for dipole excitation (Fig. 1a). In Fig. 2 (curve *a*) the electrofission cross section for the isoscalar component of GQR is shown, curve *b* represents the sum of the isoscalar and isovector component.

4. *Conclusions*

Measurements of the electrofission cross section for ^{232}Th, ^{238}U and ^{237}Np by Shotter et al. [2] did not allow the obtaining of an absolute value of the contribution of quadrupole excitation into electrofission reactions. It was assumed that only isoscalar resonance contributed to the electrofission cross section. An E2 isoscalar giant resonance was found in the electrofission cross section of ^{238}U by Arruda Neto et al. [5] only. In the analysis of the ratio of electron and positron induced cross sections for ^{238}U and ^{232}Th measured by Kneissl et al. [4] an E2 isovector giant resonance was assumed. The comparison of the final results of our calculations (Fig. 2 (curve *d*) and measured values of the cross section permits one to conclude that only consideration of both modes GQR allows us to get good agreement with the experiment.

The excitation curve demonstrates too broad maxima at the energies 17 MeV and 21.5 MeV. These bumps are several MeV above the effective thresholds of the second and the third chance fissions at 12.3 MeV and 19.7 MeV, respectively. Apart from our experiment, similar effects were observed in angular distribution of Rasch et al. [3] for ^{232}Th and in the measurements of σ^-/σ^+ by Kneissl et al. [4] for ^{232}Th and ^{238}U. This structure can be explained as a predominance of even parity states just above the barrier and due to it the E2 contribution should also be enlarged. The thresholds of higher chance fission are smeared out and shifted towards higher energy both by the kinetic energy of the evaporated neutron and by the fact that the electron energy must be higher than the excitation energy produced.

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