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Absolute photofission cross sections for ^{235,238}U in the energy range 11.5–30 MeV

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Absolute photofission cross sections of ^{235}U and ^{238}U have been measured with quasimonoenergetic photons from e^+ annihilation and direct fragment detection between 11.5 and 30 MeV. The results obtained in the energy range of the giant dipole resonance (up to 18 MeV) are compared with those from previous experiments.

Reliable data on photofission cross sections can only be obtained using monochromatic γ sources. In the giant dipole resonance (GDR) region there are three data sets which were measured with quasimonochromatic photons from positron annihilation in flight: cross sections for ^{235}U,[1] and later on for several actinide nuclei at Saclay[2] and Livermore,[3] respectively. In the latter two experiments the fission events were detected via the fission neutrons; using this method the fission neutron multiplicity $\bar{\nu}$ must be known or measured. Its application is limited to energies below the $(\gamma,3n)$ threshold at ≈ 18 MeV. Above this energy the $(\gamma,3n)$ and fission channels cannot be distinguished since $\bar{\nu} \approx 3$ for actinide nuclei. The cross sections reported by Livermore and Saclay groups[2,3] have similar energy dependences but different normalizations; in the ^{238}U case the Livermore photofission cross sections exceed those from Saclay by about 20%. This disagreement has important consequences for the extraction of the strength functions for other multipoles by the analysis of both inclusive[4] and exclusive[5] electrofission experiments.

The aim of the present study was to check the absolute scale of the photofission cross section in the GDR range by a direct fragment detection technique. Furthermore, we wanted to connect the GDR photofission data with those as recently obtained in a tagged photon experiment[6] (39–105 MeV) at Saclay using the same fragment detection setup.[7,8]

The present experiments have been performed at the Giessen positron annihilation facility.[9] The positrons were created in an e^--e^+ converter (W target) between the two accelerator sections, accelerated, and then deflected by an energy analyzing 50° achromatic bending system (Fig. 1). A 123 mg/cm^2 Be disk served as the annihilation target. The positron current was measured in a Faraday cup. An optimal beam adjustment was achieved by using rotating scintillator rods in front of the annihilation target, a plastic scintillator in the Faraday cup, and a small NaI detector behind the fission chamber as beam monitors. A collimating system (10 cm Ni, 20 cm Pb) limited the γ-beam spot on the targets to a diameter of 5 cm. The relative energy resolution of the photon beam was about 2.5%.

As fragment detectors we used two multiple parallel plate detectors (MPPD),[7] containing 77 mg/cm^2 of ^{238}U and 62 mg/cm^2 of ^{235}U (enriched to 93%), respectively. The target material was deposited directly on the counter foils. The

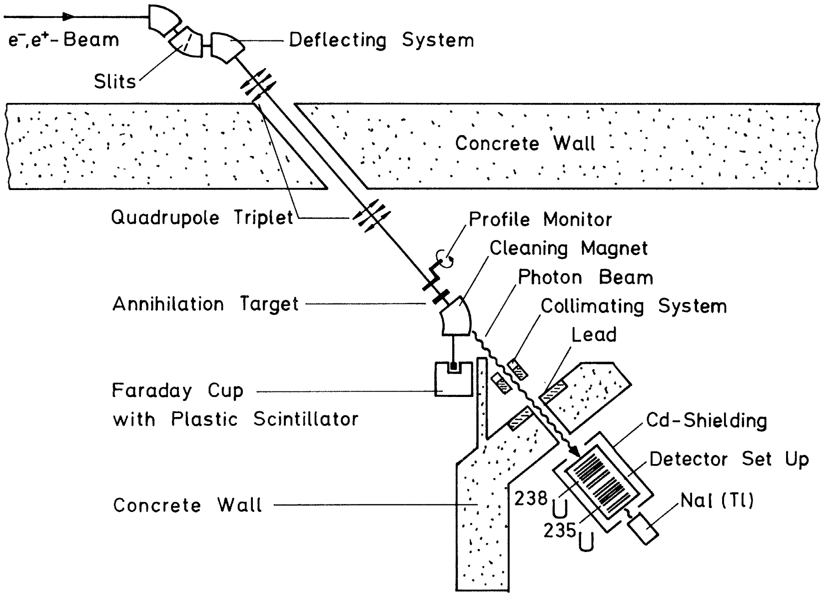

FIG. 1. Schematic diagram of the experimental setup at the Giessen linear accelerator. See text for details.

homogeneous single layers were ≈ 2.5 mg/cm^2 thick, had a diameter of 65 mm, and were separated by 3 mm; the backings, which consisted of 50 μm thick aluminum foils, stopped the backward emitted fragments in order to prevent double counting. Isobutane at 5 Torr pressure was used as the counter gas.

In order to measure absolute cross sections the product of the efficiency, ϵ, times the solid angle, Ω, of the MPPD's has to be known. The efficiency depends on the thresholds of the subsequent discriminators, the gas pressure, and the applied voltage. The quantity $(\epsilon \cdot \Omega)$ was determined online via the α counting rate, N_α, of the MPPD target activity, measured between the beam pulses. A calibration curve $\epsilon(N_\alpha)$ was obtained by comparing the MPPD fission counting rates with those of a pair of parallel plate detectors of known efficiency, which sandwiched a thin target of the same material having a known thickness[8] and were placed directly behind the MPPD.

The number of monoenergetic annihilation quanta can be calculated from the measured number of positrons as described in Ref. 9, where we estimated the accuracy of the methods to be $\leq 10\%$. This value corresponds to photon energies of 20–30 MeV. For lower energies ($\lesssim 20$ MeV) the uncertainties of these photon flux calculations should be reduced to about $\approx 5\%$ as was shown experimentally in Ref. 10. The reliability of our photon flux calibration is demonstrated by the good agreement of our ^{16}O(γ,xn) results with previous Livermore data.[11]

The contribution of positron bremsstrahlung to the total number of fission events was determined in a second run with electrons under the same experimental conditions. Figure 2 shows the fission yields measured in positron and electron runs.

The photofission cross sections obtained for ^{238}U and ^{235}U are shown in Figs. 3(a) and 3(b), respectively. The error bars include all statistical errors due to positron induced events, electron induced events, and efficiency measurements. The systematic error, arising from the photon flux calibration and the detector efficiency determination, is less than 15% (worst case for higher energies). The relatively small error bars at 14.5 MeV result from several runs performed at this energy with different collimator diameters to check the photon flux calibration.

The comparsion with the previous cross section measurements in the GDR range for ^{238}U shows that our data agree well with the Saclay results, whereas the Livermore cross sections are higher [see Fig. 3(a)]. Our results, which were obtained by a different and direct technique, cannot definitely exclude the Livermore data due to the systematic errors in both experiments. However, the good agreement between our results and those of Saclay, particularly at lower photon energies where the systematic errors are smaller, favor the Saclay cross sections. These lower values are also in better agreement with the results of our recent electrofission work.[4]

The same tendency can be found also in the ^{235}U case

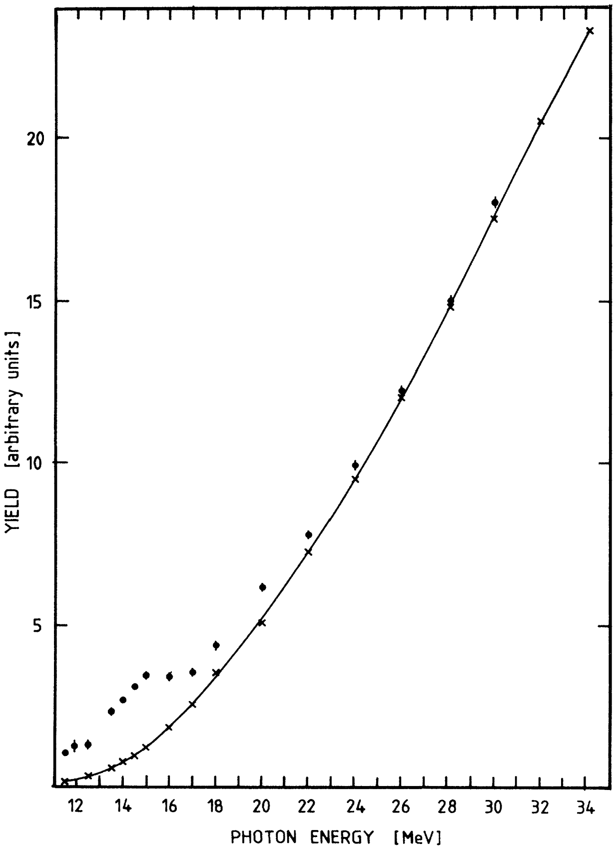

FIG. 2. Experimental yields (here for ^{238}U) are weighted with the detector efficiency. The bremsstrahlung induced yield obtained with electrons is fitted with a polynomial; to improve this fit, the measurements have been extended up to 34 MeV with electrons.

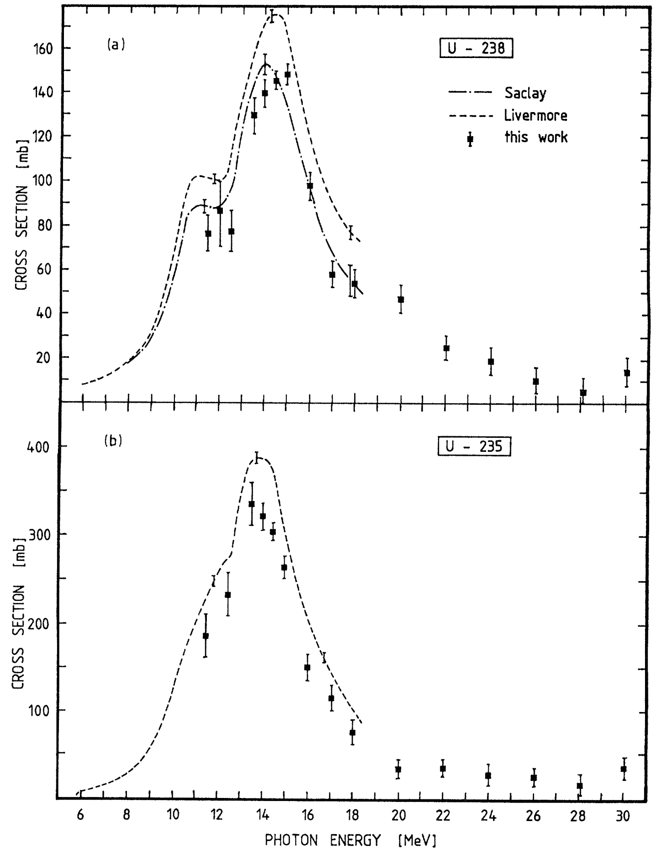

FIG. 3. Experimental cross section $\sigma(\gamma,F)$ for ^{238}U (a) and ^{235}U (b). The dashed lines are smooth curves through the Saclay and Livermore data in the GDR range.

where our values are lower than those by Caldwell *et al.*[3] [see Fig. 3(b)]; unfortunately this nucleus has not been investigated at Saclay. On the other hand, our ^{235}U cross sections clearly exceed those measured in an older experiment by Bowman *et al.*,[1] who found a maximum value of about 200 mb.

In the energy range above 25 MeV the cross section was found to be nearly constant (15–20 mb). This value is in good agreement with the first data points of the above mentioned tagged photon experiments,[6] starting at 39 MeV, where nearly constant values (≈ 17 mb) were also obtained for both isotopes.

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