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Average values of the fission cross section and alpha for ^{239}Pu in the neutron energy range 100 eV to 30 keV

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The experiments measuring eta, alpha and neutron cross sections of ^{239}Pu on the Harwell linear accelerator neutron time-of-flight spectrometer and which were first reported at the Conference on Nuclear Data for Reactors, Paris, 1966 (1), have now been completed. For a more detailed account of the experiments, reference should be made to that paper. A brief outline of the techniques used is given here, together with average values of the fission cross-section σ_F and alpha, the ratio of the capture cross-section σ_c to the fission cross-section, in the energy range 100 eV to 30 keV.

Two experiments covering the energy ranges 10 eV to 2 keV and 50 eV to 30 keV were performed with nominal resolutions of 7.2 nsec/metre and 2.5 nsec/metre respectively. The fission yield as a function of neutron energy was measured for at least three different sample thicknesses by detecting the fast neutrons emitted in the fission process using liquid scintillation counters and pulse shape discrimination to eliminate events due to γ-rays. The total cross-section σ_T was also measured using the same samples and the same resolution conditions. The energy dependence of the incident neutron spectrum was measured using a BF_3 counter, a thin ^{10}B plug and sodium iodide crystals to detect the 486 keV γ-ray emitted in the reaction $^{10}B(n,\alpha\gamma)$ or a thin ^{6}Li-glass scintillator. In all the measurements, backgrounds were determined by the resonance filter technique.

The data were first used to calculate eta (η), the number of neutrons produced per neutron absorbed, making appropriate corrections for multiple scattering in the sample, scattering in the aluminium windows of the sample containers and impurities in the samples. The fission cross-section was then calculated from the equation

$$\sigma_F = \frac{\eta}{\bar{\nu}_p} (\sigma_T - \sigma_s)$$

where σ_s = scattering cross-section of ^{239}Pu
$\bar{\nu}_p$ = average number of prompt neutrons emitted per fission (assumed constant at 2.864)

Since the scattering cross-section was neither measured nor known, it was estimated using the measured total cross-section and resonance parameters or average resonance parameters and the appropriate fluctuation factor where the true values were unknown.

Normalisation of the data was done through eta. The lower energy experiment was normalised to the value of eta as determined by Brooks et al (2) on the peak of the resonance at 10.93 eV and the higher energy data were normalised using values from the lower energy experiment between 50 eV and 100 eV. Peaks of resonances were chosen as the effect on eta of multiple scattering is minimised where the samples are "black". It should be noted that self-screening does not affect the value of eta observed on resonance.

Below 100 eV, self-screening on the peaks of the highest resonances does, however, cause the experimental peak cross-sections to be low and until this effect has been more fully investigated, no results will be given in this region.

Average values of the total cross-section have been given by Uttley (3) in the energy range 100 eV to 30 keV. The results of the present experiment agree well with that measurement.

The average fission cross-section in various energy intervals from 100 eV to 30 keV is given in Table 1, results from both experiments being given up to 1 keV. It can be seen that the two experiments disagree below about 300 eV. This is due to the poorer resolution of the lower energy experiment. When the resolution is poor, it is not possible to make multiple scattering corrections successfully since the measured cross-sections used are incorrect. However, above ~300 eV the cross-sections have fallen to a level which makes at least one sample "thin" ($n\sigma < 0.15$) and the multiple scattering corrections then become very small. When this occurs, true average cross-sections are measured and hence we expect the measured average values of σ_F to agree above ~300 eV.

Estimation of the error associated with each average is very difficult. The process of averaging reduces the combination of statistical errors and an assumed error of 50°/o on the resonant part of the scattering cross-section to $\lesssim$1°/o but systematic errors are not reduced and are much larger than this. Systematic errors arise from such sources as incorrect background subtraction, omission of the correction for neutrons which scatter more than once in the sample and normalisation of the data. It is felt that a value of ±5°/o is a reasonable estimate of the total error. The results in general agree well with those of Shunk et al (4)and above 1 keV there is good agreement with the data of James (5). The average σ_F from 23 keV to 25 keV of 1.63 barns is in excellent agreement with the 24 keV value of 1.66 ± 0.07 barns given by Perkin et al (6).

The capture cross-section σ_c of ^{239}Pu can be obtained from the results of the present experiment using the relation

$$\sigma_T = \sigma_F + \sigma_c + \sigma_s$$

and the assumed scattering cross-section previously mentioned. When Ref. 1 was written, there was some doubt about the behaviour of the scattering cross-section in the region above 600 eV where there is a discontinuity in the average fission cross-section as a function of energy. Since that paper was written, the scattering yield data obtained by Asghar (7) have been examined and although it is not possible to deduce actual cross-sections from these, it is clear that the scattering cross-section behaves in a predictable manner and the estimated values used in the present experiment are not unreasonable. Ratios of average capture cross-section to average fission cross-section are also given in Table 1. Corrections to the average capture cross-section have been made for the ^{240}Pu impurity content in the samples using the data of Moxon (8). The error on the values of alpha arises almost entirely from the uncertainty in the scattering cross-section. This could be as large as 30°/o in the lower energy region falling to ~20°/o in the kilovolt region. The high values of alpha given here support the preliminary values obtained in the direct measurement of Schomberg et al (9).

References

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Table 1

From Energy (keV)	To Energy (keV)	$<\sigma_F>$ Lower energy experiment (barns)	$<\sigma_F>$ Higher energy experiment (barns)	$\frac{<\sigma_C>}{<\sigma_F>}$ Higher energy experiment
0.1	0.2	(14.0 ± 0.7)	17.08 ± 0.85	0.96
0.2	0.3	(14.1 ± 0.7)	15.59 ± 0.78	0.92
0.3	0.4	7.0 ± 0.35	7.22 ± 0.36	1.45
0.4	0.5	7.8 ± 0.4	8.18 ± 0.41	0.56
0.5	0.6	12.9 ± 0.6	13.80 ± 0.69	0.66
0.6	0.7	4.0 ± 0.2	3.69 ± 0.18	2.09
0.7	0.8	4.7 ± 0.2	4.76 ± 0.24	1.16
0.8	0.9	4.3 ± 0.2	4.12 ± 0.20	1.07
0.9	1.0	6.6 ± 0.3	7.00 ± 0.35	0.61
1.0	2.0		3.71 ± 0.18	1.11
2.0	3.0		2.89 ± 0.14	1.34
3.0	4.0		2.78 ± 0.14	1.01
4.0	5.0		2.34 ± 0.11	1.06
5.0	6.0		2.17 ± 0.2	1.19
6.0	7.0		1.99 ± 0.10	1.23
7.0	8.0		2.21 ± 0.11	0.82
8.0	9.0		2.35 ± 0.12	0.63
9.0	10.0		2.01 ± 0.10	0.73
10.0	20.0		1.69 ± 0.08	0.72
20.0	30.0		1.55 ± 0.08	0.65