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Progress Report on the Direct Measurement of $\alpha(E)$ for ^{239}Pu

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1. Introduction

A measurement of the ratio of the capture to fission cross-sections ($\alpha(E)$) for ^{239}Pu is being made between 10 eV and 100 keV using the Harwell 45 MeV electron linear accelerator time-of-flight spectrometer. The experimental arrangement and method have previously been described [1] and so in the present paper only an outline of the method is given. The provisional results available at the present time are presented and discussed.

2. Experimental Method

The experimental arrangement consists of a fission neutron detector and a gamma-ray detector. If, for a given time-of-flight channel, the number of fission and capture events are n_f and n_c respectively, then the number of counts in the gamma-ray detector N_γ and in the fission neutron detector N_n are given by

$$N_\gamma = \epsilon_1 n_f + \epsilon_2 n_c \qquad (1)$$
$$N_n = \epsilon_3 n_f + \epsilon_4 n_c \qquad (2)$$

where $\epsilon_1, \epsilon_2, \epsilon_3$ and ϵ_4 are the efficiencies of the two detectors for fission and capture events. In reference [1] it was shown that

$$\frac{n_c}{n_f} = \alpha \frac{\left(1 + \sigma_{nn} \left\langle \frac{(1-T')}{\sigma_{nT'}} \frac{\alpha'}{\alpha} \frac{\sigma_{nf'}}{\sigma_{nf}} \right\rangle + \ldots\right)}{\left(1 + \sigma_{nn} \left\langle \frac{(1-T')}{\sigma_{nT'}} \frac{\sigma_{nf'}}{\sigma_{nf}} \right\rangle + \ldots\right)} \qquad (3)$$

where σ_{nT}, $\sigma_{n\gamma}$, σ_{nf} and σ_{nn} are the total, capture fission and scattering cross-sections. The triangular brackets denote averages and represent the probability of a scattered neutron causing a further reaction; the primed quantities are the values of the cross-sections and the transmission (T) of the sample appropriate to the energy of the scattered neutrons,

$$\alpha = \frac{\sigma_{n\gamma}}{\sigma_{nf}} \quad \text{and} \quad \alpha' = \frac{\sigma_{n\gamma'}}{\sigma_{nf'}}$$

These equations are simplifications because they do not allow for the

0.005" aluminium can round the sample or the small ($1.07^{0}/o$) fraction of aluminium in the sample. However, except near the aluminium resonances the corrections for the scattering of the incident neutrons in the aluminium are expected to be small and can be neglected.

It can be seen from equation (3) that if $\alpha' = \alpha$ then $\frac{n_c}{nf} = \alpha$. In practice α is a function of neutron energy but in general the variations are much smaller than the variations in cross-sections. Therefore, since the samples are thin the ratio $\frac{nc}{nf}$ is expected to be nearly equal to α and can be obtained from equation (4)

$$\frac{n_c}{n_f} = \alpha S = \frac{A \frac{N_\gamma}{N_n} - 1}{B - C \frac{N_\gamma}{N_n}} \qquad (4)$$

where S is the multiple scattering correction and $A = {}^{\epsilon_3}/_{\epsilon_1}$, $B = {}^{\epsilon_2}/_{\epsilon_1}$ and $C = {}^{\epsilon_4}/_{\epsilon_1}$. As described in reference [1] it can be assumed that all the efficiencies ($\epsilon_1, \epsilon_2, \epsilon_3$ and ϵ_4) are independent of incident neutron energy.

3. Results

At the present time values of N_γ and N_n as a function of neutron energy have been obtained for two ^{239}Pu samples of thickness 0.000579 and 0 00120 atoms per barn. These samples which are 2" in diameter contain $0.7^{0}/o$ ^{240}Pu. Transmission measurements have been made at the same energy resolution with five samples of thickness ranging from 0.0243 to 0.00029 atoms per barn. From these data the total cross-section values required for multiple scattering corrections are being obtained. The incident neutron flux has also been measured by a $^{1}/8$" thick Li-glass scintillator (NE 905) of known relative efficiency. The performance of the γ-ray detector has been checked by making γ-ray yield measurements on Ag, Pt, Au, Ta and ^{238}U samples and the results show that detector efficiency is proportional to the γ-ray energy.

The experiment is normalised by assuming the values of α for 17 well-resolved resonances in the energy region below 100 eV. The values of α were mainly obtained from the measurements of η [2] obtained with the same energy resolution. Below 45 eV where the η measurements have reasonable energy resolution the α values were obtained by combining the η results with those obtained by Bollinger et al [3], Ignatev et al [4] and Wang Yung-Chang et al [5]. In order to extract the values of A, B and C from equation (4) used in conjunction with these data, it is necessary to have some idea of the value of S for each of the resonances. If the value of α varies slowly with neutron energy or if $\frac{\sigma_{nn}}{\sigma_{nT}}$ is small, then S must be unity. If, however, $\frac{\sigma_{nn}}{\sigma_{nT}}$ is not small and α increases or decreases with increasing neutron energy then S will be less than or greater than unity. A parameter which will give some idea of how close S is to unity is the product of $\frac{\sigma_{nn}}{\sigma_{nT}}$ and the fractional change in α ($\Delta\alpha$) for a $0.83^{o}/o$ change in neutron energy (average energy loss on scattering). It is found for both samples that if α is plotted against $\frac{N_\gamma}{N_n}$ for the resonances mentioned above, then the deviation of the points from the best curve drawn through them is not a function of the value of the parameter $\frac{\sigma_{nn}}{\sigma_{nT}} \times \Delta\alpha$ and hence it can probably be assumed that the values of S are in general close to unity. It is found for both samples that α can be derived from the calibration curve with an error of $\pm$ 0.1. The error is mainly due to statistics and uncertainties in the values of S.

The reactor physicist requires values of $\langle\sigma_{n\gamma}\rangle/\langle\sigma_{nf}\rangle$ rather than $\langle\alpha\rangle$. In order to obtain these data in a region of poor energy resolution it is necessary that the samples are "thin" ($\eta\,\sigma < 0.15$) so that the neutron and gamma ray yields are proportional to the cross-sections. With the present samples this condition is obeyed above ~100 eV for the thin sample and ~250 eV for the thick one. In addition multiple scattering corrections are expected to be small when the samples are "thin". Therefore, values of $\langle\sigma_{n\gamma}\rangle/\langle\sigma_{nf}\rangle$ can be obtained from the present experiment and the results are shown in Fig. 1. The errors, which are shown for some of the points, are mainly systematic and are due to the combination of three terms

(1) An error in α of $\pm$ 0.1 due to normalisation errors. This includes statistics, multiple scattering and the errors in the values of α used for normalisation
(2) A statistical error which is typically $\pm$ 0.1
(3) A systematic error in background fitting. This varies between $\pm$ 0.05 around 20 keV to $\pm$ 0.25 at 100 eV.

The errors due to multiple scattering above 300 eV are small and tend to cancel and so have been neglected.

4. Discussion

It can be seen from Fig. 1 that the results obtained with the thinned sample are in general systematically higher than those of the thicker sample. However, at ~35 keV and ~3 keV the results agree well. Therefore, since the background is fitted at these energies, this suggests that the differences may well be due to mainly systematic errors in background fitting. The best curve is assumed to be the mean of the results of the two samples and this is shown in the figure. The errors are typically $\pm 20\%$ except in the region above 50 keV where they are ± 0.1 in alpha. The best curve agrees well with the results of Patrick et al [6] which are obtained from σ_{nT} and σ_{nf} data. In the region 100-300 eV where the results of the present experiment are not necessarily expected to be good, the agreement with other data is also good and this suggests the assumption that self-screening and multiple scattering effects are small above ~200 eV is correct. The results in the range 20-30 keV are slightly higher than the data of De Saussure et al [7] but the difference is not significant. Between 50 and 80 keV the agreement between the two sets of data is good.

In the previous paper [1] on the present experiment it was stated that the ratio ϵ_2/ϵ_1 (the ratio of the efficiencies of the γ-ray detector for capture and fission events) was 0.39. This is much smaller than expected because the total γ-ray energy produced in capture and fission is 6.4 and ~8 MeV respectively. The small ratio is thought to be produced by a high efficiency of the γ-ray detector for fissions. This high efficiency is caused by two gamma rays and/or neutrons being detected simultaneously in the two halves of the detector A and B [1]. Such coincidences are expected to occur much more frequently for fission events because of their higher γ-ray multiplicity and the contribution of fission neutrons. These effects should not seriously affect the results because the experiment is normalised and it is not expected that $\bar{\nu}$ (the average number of neutrons/fission) or the fission gamma ray spectra will change appreciably with incident neutron energy [1]. This conclusion is supported by the fact that the results above 20 keV are in reasonable agreement with the data of De Saussure et al [7]. In the next series of runs to be made in the experiment it is planned to investigate these effects.

<u>References</u>

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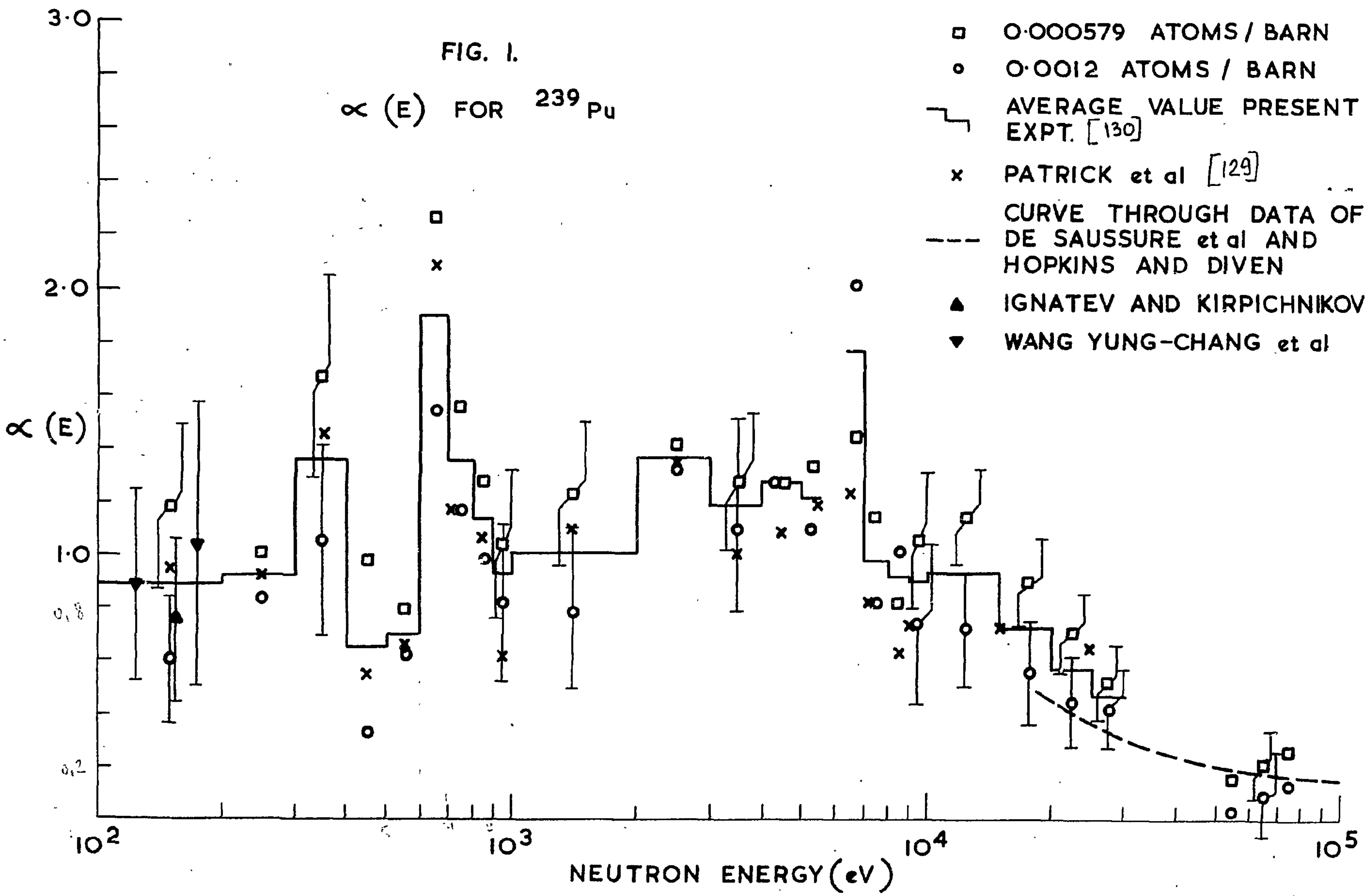
FIG. 1.
∝ (E) FOR 239 Pu
0·000579 ATOMS / BARN
0·0012 ATOMS / BARN
AVERAGE VALUE PRESENT EXPT. [130]
PATRICK et al [129]
CURVE THROUGH DATA OF DE SAUSSURE et al AND HOPKINS AND DIVEN
IGNATEV AND KIRPICHNIKOV
WANG YUNG-CHANG et al
∝ (E)
3·0
2·0
1·0
NEUTRON ENERGY (eV)
10²
10³
10⁴
10⁵