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Uranium fission cross section measurement for thermal neutrons

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Introduction. The measurement is made using a comparative method.

The ratio between Uranium fission cross section and Lithium cross section of the $Li^6(n\cdot\alpha)H^3$ reaction for thermal neutrons is determined. The measurement is made exposing a number of LiF and U layers to a constant flux of thermal neutrons in an ionization chamber and comparing the number of fission products emitted by Uranium with the number of α and H^3 particles emitted by Lithium. The number of Uranium nuclei present in each U layer is deduced by counting the number of α particles emitted by each layer, whilst the number of Lithium nuclei is found by accurately weighing the LiF layers.

1. — The electron collecting ionization chamber is provided with a grid (fig. 1). The chamber is filled with argon at 5 atm, which is purified by circulation over metal calcium heated at 300° C. The amplifier employed is of the 100 (1) type with rise time of about 0,6 microseconds.

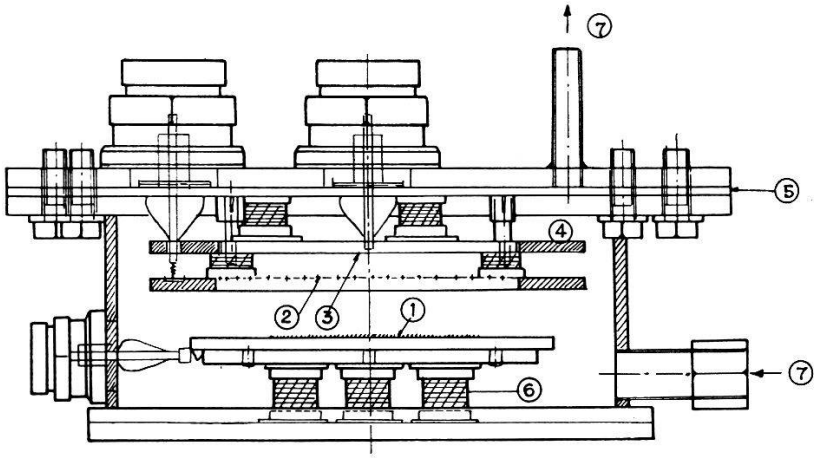

Fig. 1.
Ionisation chamber.
① Layer. ② Grid. ③ Collector. ④ Gard ring. ⑤ Rubber.
⑥ Lucite. ⑦ Gas flow.

Figs. 2 and 3 show the distribution of Uranium α pulses and Lithium α and H^3 pulses obtained by means of a one-channel pulse analyser. Besides being a test of the chamber performance, the above mentioned curves were used in order to cheek the self-absorption and back-scattering corrections.

The counting is performed by integral measurements at suitable values of the bias voltage.

2. — The chamber is sourrounded by paraffin wax: the neutrons source (0.5 g Ra mixed with Be) is placed about 10 cm below the chamber. A 10 cm layer of Pb is placed between the source and the chamber to reduce the γ background.

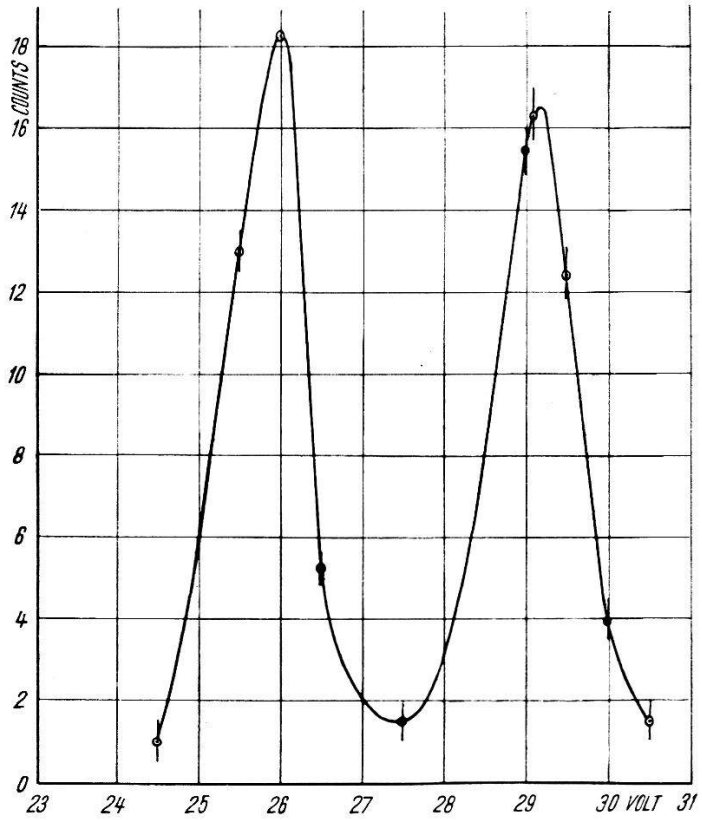

Fig. 2.

U-α-rays spectral distribution curve.

The contribution of fast and epithermal neutrons has been taken into account by repeating measurements with a 0.8 mm cadmium shielding surrounding the chamber.

3. — The U layers were prepared by Dr. ZIMMER (2) of our Chemical Laboratory following an electrolytic method on steel disks.

The LiF layers were prepared by vacuum evaporation also on steel supports, using very pure LiF.

The weighs of LiF layers was determined by accurately weighing the support before and after evaporation by a microchemical balance. Another support not submitted to evaporation was used in order to cheek the calibration of the balance; this caution was taken because the two mentioned different weighs were taken at

about an hour interval from each other, which is the time required for LiF layer preparation.

Care was taken in order to dry the supports and to keep them dry during evaporation and weighing processes.

4. — The thickness of the chosen layers was small enough to minimize absorption for the particles emitted from the layer itself.

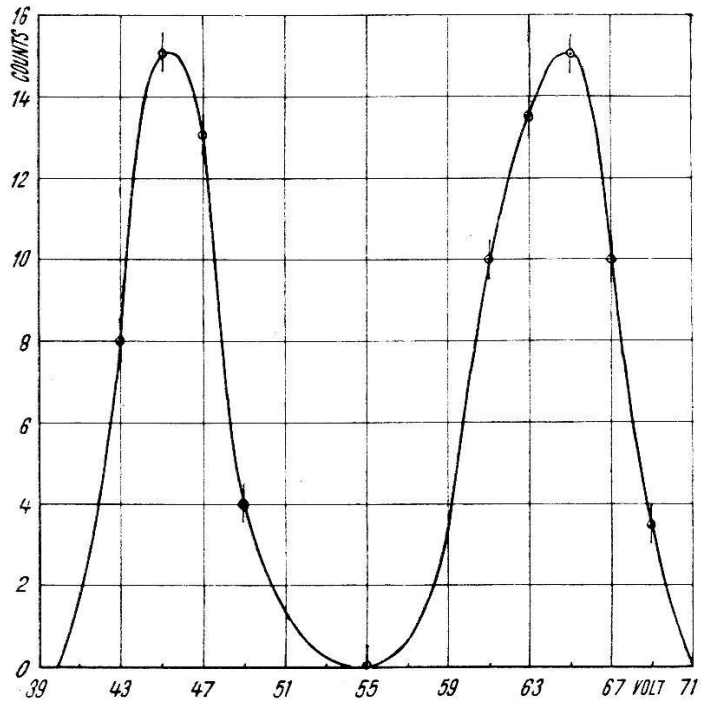

Fig. 3.

α and H^3 from Li^6 (n, α) H^3 reaction, spectral distribution curve.

The absorption is evaluated together with the correction due to back-scattering of particles over the support, using for U α particles the formula (3)

$$n_0 = \frac{2\,n(E)}{1 - d/4\left(\frac{1}{R_{\mathrm{I}} - R(E)} + \frac{1}{R_{\mathrm{II}} - R(E)}\right) + 0.4\,\Phi(E)}$$

where n_0 = total number of particles emitted
$n(E)$ = total number of counts at bias voltage corresponding to energy E
d = thickness of the layer in mg/cm²
R_{I} and R_{II} = range of U_{I} and U_{II}, α particles
$R(E)$ = range of E energy α particles
0,4 Φ (E) = back-scattering term

and analogous formulae in the other cases.

The counts were made at various energies i. e. at various bias voltages of the integral discriminator. The volt-energy calibration was made using the amplitude distribution curve of α U pulses for U and of α and H^3 pulses for LiF (e. g. figs 2 and 3). The R—E curves in air were used for the Li particles; for the U α particles the R—E in Pb curves; for the U fission products the R—E curves in air, reduced by means of the mean stopping power air-U_3O_8 (4).

$\Phi(E)$ was calculated for α of U and for α and H^3 of Li following the method used by Crawford (5). In the case of U fission products, $\Phi(E)$ was neglected.

The absorption corrections were 1% for Uranium and 3—8% for Lithium at different counting energies; the back-scattering corrections about 1,5%.

5. — In the table (1) (2) are set down the results obtained for five LiF layers and two U layers.

Table 1.

Uranium layers.

Number of the layer	α counts per minute	Fissions counts per minute	Fissions per mg of U per minute
U N° 1	2327 $\pm$ 151	0.738 $\pm$ 0.026	0.4763 $\pm$ 0.017
U N° 6	3385.4 $\pm$ 118	1.077 $\pm$ 0.024	0.4778 $\pm$ 0.010

Average value = 0,4774 $\pm$ 1,9%.

Table 2.

LiF layers.

Number of the layer	Weight of LiF mg	Fission counts per minute	Fissions per mg of LiF per min.
Li N° 1	3.55 $\pm$ 0.04	267.30 $\pm$ 2.2	75.30 $\pm$ 1
Li N° 2	1.29 $\pm$ 0.025	92.90 $\pm$ 1	72.00 $\pm$ 1.6
Li N° 3	2.05 $\pm$ 0.1	148.30 $\pm$ 1.4	72.34 $\pm$ 3.6
Li N° 4	2.08 $\pm$ 0.1	136.50 $\pm$ 1.1	65.62 $\pm$ 3.3
Li N° 5	2.08 $\pm$ 0.1	149.40 $\pm$ 1.6	71.82 $\pm$ 3.6

Average value = 73.52 $\pm$ 1.2%.

The values of the countings made at different energies were averaged and corrected as above mentioned; they were, moreover, corrected for the contribution of epithermal and fast neutrons, that is, they are the result of the difference between the values obtained without and with Cd around the chamber.

The value given by KIENBERGER (6): 1502 $\pm$ 1‰ was assumed as the number of α per mg of U per minute.

6. — Assuming the law $\sigma = \sigma_0 v_0/v$ for the fission thermal cross section of U the ratio σ_U/σ_{Li} is given by the formula:

$$\frac{\sigma_U}{\sigma_{Li}} = \frac{N_U}{N_{LiF}} \frac{P_U}{P_{LiF}}$$

where σ_U = fission cross section of U
σ_{Li} = (n, α) cross section of Li
N_U = number of uranium fissions per mg of U per min
N_{LiF} = number of Li fissions per mg of LiF per min
P_U = atomic weigh of U
P_{LiF} = molecular weigh of LiF

Calculating with the tabulated values for N_U and N_{Li} we get

$$\frac{\sigma_U}{\sigma_{Li}} = 0.0596 \pm 2.5\%$$

assuming $\sigma_{Li}/\sigma_{boron} = 0.0948 \pm 0.0013$ (7) and referring it to the values $\sigma_{boron} = 703$ barns (8) at the neutron speed of 2200 m/sec, i. e. $\sigma_{Li} = 66.6 \pm 2\%$ barns we get $\sigma_U = 3.97 \pm 0.12$ barns and for the U^{235} isotope $\sigma_{U^{235}} = 551 \pm 17$ barns.

We notice that on the ratio σ_U/σ_{Li} the error of 2.5% accounts for the statistic errors in the countings, the errors in weighing the LiF layers, and the errors in the corrections which influence the final error by 3—4‰ only. For the σ_U the error resulting is of 3% accounting for a 2% uncertanity of σ_{Li}.

A more detailed description of the measurement is under publication by "Il Nuovo Cimento".

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