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G.F. Knoll, W.P. Pönitz

GESELLSCHAFT FÜR KERNFORSCHUNG M.B.H.

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A MEASUREMENT OF THE ^{235}U FISSION CROSS SECTION AT 30 AND 64 keV

G. F. KNOLL* and W. P. PÖNITZ
Institut für Angewandte Kernphysik, Kernforschungszentrum Karlsruhe,
Federal Republic of Germany

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Abstract—The fission cross section of ^{235}U was measured absolutely at 30 keV neutron energy using kinematically collimated neutrons at the threshold of the $^{7}Li(p, n)^{7}Be$ reaction. The number of fission events in a 1·2 mg/cm^2 U_3O_8 foil was determined by counting fission fragments in a gas scintillation detector. The neutron flux was measured both by counting of the induced ^{7}Be activity in the target and through a parallel measurement of the induced ^{198}Au activity in a gold foil. Another measurement was made at 64 keV using the $^{3}H(p, n)^{3}He$ reaction at threshold as the neutron source. The flux was normalized in this case by assuming a value for the ^{197}Au capture cross section ratio at the two energies. Values obtained for the fission cross section are 2·19 ± 0·06 barns at 30 keV and 1·78 ± 0·13 barns at 64 keV.

1. INTRODUCTION

THE recent emphasis on fast reactor design has underscored the need for accurate nuclear data in the keV energy region. The fission cross section of ^{235}U is not only of primary importance in reactor calculations but also often serves as a standard against which other intermediate energy cross sections are measured. Although its measurement has been given considerable attention, values obtained for the absolute fission cross section by different experimenters often are not consistent within quoted errors. Recent measurements by WHITE (1965) between 40 keV and 14 MeV and by PERKIN *et al.* (1965) at 24 keV tend to lie about 15 per cent lower than a 1958 compilation of earlier data (HUGHES and SCHWARZ, 1958) in the keV energy region. An adjustment of this magnitude is of major importance.

We have therefore made a measurement of the absolute fission cross section ^{235}U at 30 keV using two independent methods for determination of the neutron flux. The first of these makes use of the associated activity of the source reaction $^{7}Li(p, n)^{7}Be$ and does not require the knowledge of any other cross section. The second method assumes a value of 604 ± 25 mb for the ^{197}Au capture cross section at 30 keV given by a compilation of recently published data. A further measurement at 64 keV was made by assuming a knowledge of the ratio of the ^{197}Au capture cross sections at the two energies.

2. EXPERIMENTAL PROCEDURE

2.1 *Measurement at* 30 *keV*

An outline of the measurement system is shown in Fig. 1. A pulsed proton beam from the Karlsruhe 3 MeV Van de Graaff accelerator was bunched to 1 nsec pulse width and limited by an aperture of 9 mm diameter before striking a water-cooled target. The target was prepared by evaporating a thick layer of LiF onto a copper backing followed by a covering layer of aluminium. The proton energy was adjusted to lie approximately 2 keV above the threshold of the $^{7}Li(p, n)^{7}Be$ reaction at which

* Permanent address: The University of Michigan, Ann Arbor, Michigan, U.S.A.

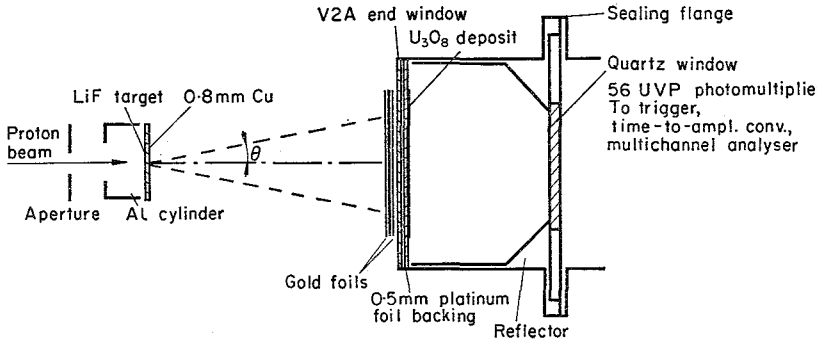

FIG. 1.—The experimental set-up.

point the entire neutron yield in the laboratory system lies in a forward directed cone with half apex angle $\theta = 12°$. Under these conditions the neutron energy at the cone edge is about 30 keV and between 43·2 and 18·7 keV at 0°. The neutron energy spectra were calculated previously (PÖNITZ and BRUDERMÜLLER, 1963) for opening angles of 5 and 10°. The mean neutron energy is about 30 keV which is in agreement with the result of WESTON and LYON (1961) who have calculated an average neutron energy of 30·2 keV. To relate the cross section to 30 keV it was assumed that the cross-section shape varied as $1/E$. The correction was found to be very small (0·2 per cent). One of the two methods used to measure the neutron flux utilizes the 53-day ^{7}Be γ-ray activity produced in the target (PÖNITZ, 1966). The measurement was begun with a fresh target so that an absolute determination of the ^{7}Be activity after irradiation yields directly the total number of neutrons produced. Checks on possible loss of activity from the target to surrounding materials showed that essentially all the activity was retained in the target.

2.2 *Measurement at 64 keV*

A similar arrangement was used in conjuction with the ^{3}H(p, n)^{3}He reaction to generate neutrons at 64 keV. In this case the bunching system could not be used and measurements were made with a 10 nsec pulse width. A proton energy of about 4 keV above threshold was used to generate a neutron cone of $\theta = 12°$ half apex angle. The average neutron energy is about 63·9 keV (WESTON and LYON, 1961).

Identical detector geometries were used for both the 30 and 64 keV measurements. At a distance of 8 cm from the target, the cone of neutrons was intercepted by a 0·3-mm thick gold foil mounted against the end window of a xenon-filled scintillation chamber containing the 1·203 mg/cm^2 U_3O_8 fissile sample. Both the gold foil and uranium sample were of 50 mm diameter and subtended a sufficient solid angle at 0° to insure that the entire neutron cone passed through each. Additional gold foils were mounted around the circumference of the measuring foil to detect any possible spreading of the cone to a larger diameter than 50 mm. In all cases, no activation of these foils could be detected. The gold and uranium foils were placed as close as possible to each other to minimize corrections for the effect of scattered neutrons.

The fissile sample was prepared by the Euratom laboratories at Geel, Belgium, and consisted of 23·63 $\pm$ ·03 mg U_3O_8 (99·5% ^{235}U) electrosprayed on a 0·5 mm thick platinum backing. The non-uniformity of deposition was measured using the α-activity of the sample. To do this a ZnS-detector with an aperture of 5 mm diameter

was used. The α-activity was measured as a function of the radius of the foil for several different directions. The largest deviation in the uniformity of deposition was found to be 4 per cent. Because only a part of the foil was irradiated by neutrons a correction $1{\cdot}009 \pm 0{\cdot}005$ was necessary. Therefore the effective thickness of the ^{235}U sample was 1·022 mg/cm². The sample was mounted in the gas scintillation chamber within 3 mm of the 0·2-mm thick end window through which the neutrons enter. At the opposite end, the chamber was viewed by a 56UVP photomultiplier through a quartz glass window. All massive elements of the chamber (quartz window, sealing flange, etc.) were located at least 50 mm from the uranium foil to minimize backscatter. A 50 Ω fast output signal from the photomultiplier was fed to a trigger which served to start the time-to-amplitude converter. The stop signal was derived from a beam pick-up located near the target.

The fission events were recorded on a time spectrum in order to permit discrimination against room-scattered background. In the case of the 1 nsec pulses, the time resolution was sufficient to separate the small contribution of neutrons backscattered from the chamber materials from the prompt yield. In order to avoid activation of the gold foil by thermal or epithermal neutrons, for which the cross section is large, the measuring foil was sandwiched between two 0·03 mm gold foils.

A long counter located at 0° was used to monitor the time dependence of the neutron yield during the irradiation. Since the half-lives of ^{198}Au and ^{7}Be are long compared with the irradiation times, the corrections introduced by taking into account the time dependence of the activation source were small.

3. DETERMINATION OF THE NUMBER OF FISSION EVENTS

In order to reduce the counting rate due to the natural α-activity of the uranium to a negligible level, the threshold at the fast trigger was set at approximately 25 MeV. Corrections were applied to the observed number of fissions to account for those lost below this threshold as well as those events for which neither fission fragment escapes from the foil.

A calculation of the absolute fission rate induced by a moderated Po–Be neutron source in standard geometry was first made by recording the pulse-height spectrum from the slow pulse output of the photomultiplier over a measured period of time. This spectrum, with the alpha contribution subtracted, appears in Fig. 2 together with a calculated energy spectrum for fission fragments escaping from 1·48 mg/cm² thickness of UO_2 (KAHN *et al.*, 1965). The two curves are normalized to equal number of events. The measured pulse-height spectrum is considerably broader than the calculated energy spectrum due to light losses in the chamber and resolution effects. The fission pulse-height spectrum could be accurately measured down to an energy of about 14 MeV. The fraction of events lying below this point was obtained from the calculated curve and corrected for differences in the foil thickness and chemical composition, giving a net value of 7·5 per cent of the total area. In our estimates of the uncertainty in our cross-section values, we have allowed for a possible 20 per cent uncertainty in extrapolated area. The calculations given by KAHN *et al.* were also used to estimate the fraction of all fissions lost by complete absorption of both fission fragments in the foil. The calculated value of 8·75 per cent for a 1·203 mg/cm² U_3O_8 foil is in good agreement with previous estimates (WHITE, 1965).

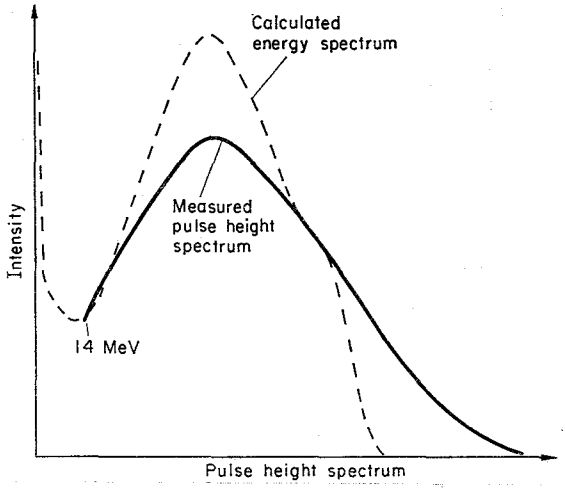

FIG. 2.—The pulse-height spectra of the fission fragments.

By applying the above corrections to the area under the pulse-height spectrum above 14 MeV, the absolute fission rate induced by the standard source was measured. The same source and moderator were then used during the cross-section measurements to calibrate the overall fission counting efficiency of the chamber with the fast trigger threshold in use at the time. The measured counting rate divided by the absolute fission rate, corrected for source decay, gives the efficiency directly. This calibration counting rate was checked at intervals throughout the measurements to insure against long-term bias drifts.

4. DETERMINATION OF NEUTRON FLUX

4.1 ^{7}Be *activity method*

In the measurement at 30 keV, it is possible to determine the number of neutrons generated by measuring the ^{7}Be activity with a half-life of $53{\cdot}37 \pm 0{\cdot}11$ days (LANDOLT-BÖRNSTEIN, 1961) which is induced in the target through the ^{7}Li(p, n)^{7}Be reaction. The measurement was begun using a fresh LiF target, and after irradiation, the ^{7}Be γ-ray activity was determined using a 4×3 in. NaI(Tl) crystal.

The relation between the number of counts in the photopeak, Z, due to γ-rays from the decay of ^{7}Be, and the total neutron yield, Q_{n}, may be written:

$$Z_{\mathrm{Be}} = \varepsilon_{\mathrm{Be}} Q_{\mathrm{n}} \bar{T}_{\mathrm{Be}}/T \tag{1}$$

$$\bar{T}_{\mathrm{Be}} = \frac{1}{\lambda}(1 - \mathrm{e}^{-\lambda T})(1 - \mathrm{e}^{-\lambda\theta})\,\mathrm{e}^{-\lambda t} \tag{2}$$

where $\varepsilon_{\mathrm{Be}}$ represents the probability of a count in the photopeak per ^{7}Be decay, λ is the decay constant of ^{7}Be, T is the irradiation time, θ is the counting time, and t is the time between the end of the irradiation and the start of counting.

The value of $\varepsilon_{\mathrm{Be}}$ was obtained from a previous calculation (PÖNITZ, 1966) of $\varepsilon_{\mathrm{Be}}/\varepsilon_{\mathrm{Au}}$ obtained from the photoefficiency of the NaI(Tl) detector and measured transition probabilities in the decay of ^{7}Be and ^{198}Au. The absolute value of $\varepsilon_{\mathrm{Au}}$ was also measured in this previous work using a $4\pi\ \beta$–γ coincidence technique.

This neutron yield must be corrected for absorption and scattering in the materials between the target and uranium foils to give the effective neutron flux at the foil. These materials are a 0·8-mm thick copper target backing, three gold foils with combined 0·36 mm thickness, 0·21 mm chamber end window of V2A (73% Fe, 20% Cr, 7% Ni), and a 0·5 mm platinum backing for the uranium foil.

The fraction of neutrons passing through the copper target backing which either do not interact or are scattered in the direction of the detector (assuming isotropic scattering) is given by:

$$g(d_{\mathrm{Cu}}) = \mathrm{e}^{\Sigma_t d_{\mathrm{Cu}}}\left[1+\frac{\Sigma_s}{\Sigma_t}(1-\mathrm{e}^{-\Sigma_t d_{\mathrm{Cu}}})\frac{R^2}{4\pi D^2}\right] \tag{3}$$

where Σ_t and Σ_s are the macroscopic total and scattering cross sections for copper, d_{Cu} is the copper thickness, R is the radius of the uranium foil and D is its distance from the target. In this case the neutrons which are scattered in the direction of the detector have nearly the same energy as primary neutrons and will be indistinguishable from neutrons which have passed through the copper without interacting.

On the other hand, the remaining materials are all located in the immediate vicinity of the uranium foil and scattering events can give rise to neutrons travelling through the uranium foil at angles approaching 90°. As a consequence the effective foil thickness for these scattered neutrons is larger than that for primary neutrons, and the scattered flux must be treated separately.

Defining, for the gold, V2A, and platinum $g(d) = \exp(-\Sigma_t d)$, the number of target neutrons striking the uranium will be:

$$Q_{\mathrm{n,Prim}} = Q_{\mathrm{n}} g(d_{\mathrm{Cu}}) g(d_{\mathrm{Au}}) g(d_{\mathrm{V2A}}) g(d_{\mathrm{Pt}}) \tag{4}$$

$$Q_{\mathrm{n,scatt}} = Q_{\mathrm{n,Prim}} \sum_{\mathrm{Au,V2A,Pt}} \Omega_{\mathrm{U}} \cdot \frac{\Sigma_s}{\Sigma_t}(1-g(d)). \tag{5}$$

The number of fission events generated in the uranium sample can then be written as the sum of two terms:

$$C_{\mathrm{U}} = N_{\mathrm{U}} \sigma_{\mathrm{n,f}} [Q_{\mathrm{n,Prim}} \cdot f(d_{\mathrm{U}}, \theta) + Q_{\mathrm{n,scatt}} \cdot f(d_{\mathrm{U}}, \theta_s)] \tag{6}$$

In this expression, N_{U} is the number of uranium atoms per unit area, $\sigma_{\mathrm{n,f}}$ is the fission cross section, $f(d_{\mathrm{U}}, \theta)$ is the geometric correction to the foil thickness corresponding to the distribution of primary neutrons over the cone of half apex angle θ, and $f(d_{\mathrm{U}}, \theta_s)$ is the corresponding correction for the scattered neutrons. The geometric correction for the primary neutrons may be approximated as:

$$f(d_{\mathrm{U}}, \theta) \cong \frac{\int_0^{\theta} \frac{\sin\theta}{\cos\theta}\,\mathrm{d}\theta}{\int_0^{\theta} \sin\theta\,\mathrm{d}\theta} \cong 1 + \frac{\theta^2}{4}. \tag{7}$$

[For $\theta = 12°$, $f(d_{\mathrm{U}}, \theta) = 1{\cdot}011$.] With the geometric approximation $\theta_s = \pi/2$ and $\Sigma_{\mathrm{U}} d_{\mathrm{U}} \ll 1$, it can be shown (BECKURTS and WIRTZ, 1964) that $f(d_{\mathrm{U}}, \theta_s) = 2$. The net result is that an increase in the amount of scattering in the gold, V2A, or platinum will increase the fission rate induced by the scattered flux by nearly the same amount as the primary fission rate is decreased, and the total number of fissions will remain

nearly constant. Consequently the cross section calculated from equation (6) will be sensitive only to the amount of scattering assumed for the copper target backing.

The number of fission events calculated in equation (6) is due only to primary neutrons plus the scattering sources mentioned previously. Since these scatterers do not appreciably effect the flight time of the neutrons, all such fission events will occur promptly. Other sources of scattering further removed from the uranium foil will result in substantially longer flight times and have been discriminated by using for C_U only the prompt events in the time spectrum.

4.2 ^{197}Au *activation method*

A second procedure was used to calculate the flux of 30 keV neutrons and also served to determine the flux at 64 keV from the ^{3}H(p, n)^{3}He reaction. The number of capture events in the gold foil placed directly in front of the uranium sample was determined by counting its γ-activity after irradiation using the 4 × 3 in. NaI(Tl) crystal. We can write the relation between the number of counts under the photopeak, Z_{Au}, and the number of capture events in the foil, C_{Au}, as:

$$Z_{Au} = \varepsilon'_{Au} C_{Au} \bar{T}_{Au}/T = k\varepsilon_{Au} C_{Au} \bar{T}_{Au}/T \qquad (8)$$

where ε'_{Au} represents the average peak efficiency of the crystal for the disk source and ε_{Au} is the on-axis point efficiency. The factor k was calculated from off-axis point measurements to be 0·980 assuming $\varepsilon(r) = (1 - ar^2)\varepsilon_{Au}$. The value of ε_{Au} was measured previously (PÖNITZ, 1966) using a $4\pi\beta$–γ coincidence technique.

It is convenient to separate the important sources of neutrons which can give rise to capture reactions in the gold into five groups:

(i) Primary neutrons which escape interaction in the copper target backing.

(ii) Neutrons which are scattered in the copper into a solid angle defined by the foil.

(iii) Neutrons which are scattered in the gold foil itself.

(iv) Scattered neutrons from the V2A and platinum.

(v) Scattered neutrons from the chamber flange and quartz window.

Similarly, the sources of neutrons at the fission foil are:

(vi) Primary neutrons which escape interaction in the copper, gold, V2A and platinum.

(vii)–(x), the same as sources (ii)–(v) above, respectively.

In this case we are assuming that source (x), which gives rise to a resolved peak of 1·51 per cent in the 30 keV measurement time spectrum, will be added to the prompt fissions.

Since the solid angles defined by the gold foil and uranium sample are the same for distant sources, source (ii) gives the same effective flux as source (vii), and source (v) the same as source (x). The neutron flux which enters the gold foil can be used as the effective neutron flux for the uranium sample because the decrease in the fission rate due to the outscattering of neutrons by the gold, V2A, and platinum foils is compensated by the increase in the fission rate due to the longer path length of the scattered neutrons. Therefore sources (viii) and (ix) do not lead to any corrections. However, for the gold foil one has to correct for the scattering in the Au-foil and for the backscatter from the V2A and platinum. Since sources (i) and (vi) are far larger

than all the others, the ratio of the effective neutron fluxes incident on the gold and uranium is given by:

$$\frac{\varphi_{Au}}{\varphi_U} = S(d_{Au})\left[1 + \frac{\Sigma_s}{\Sigma_t}(1 - g(d_{V2A}))\right] \cdot \left[1 + \frac{\Sigma_s}{\Sigma_t}(1 - g(d_{Pt}))\right] \qquad (9)$$

where again isotropic scattering was assumed. The factor S represents the correction of source (iii) including resonance self-shielding effects (DRESNER, 1962), and was

TABLE 1.—THE CAPTURE CROSS SECTION OF ^{197}Au AT 30 keV. ABSOLUTE VALUES DETERMINED LATER THAN 1960

Author	Year	Method	Values/mb
WESTON and LYON	1961	Activation method; Flux determination using the Macklin sphere.	767 ± 60
MOXON and RAE	1963	Moxon–Rae detector; Flux determination using $^{10}B(n, \alpha\gamma)$-cross section, calibration at several resonances	600 ± 60*
HADDAD *et al.*	1964	Large liquid scintillation detector; Flux detector using $^{10}B(n, \alpha)$-cross section; calibration at 1·46 eV	525 ± 100
KONKS *et al.*	1964	Pb-slowing down spectrometer proportional counter; $^{10}B(n, \alpha)$-cross section; calibration at thermal and resonance energies	630 ± 120
HARRIS *et al.*	1965	$^{51}V(p, n)^{51}Cr$-source-activation method; associated activity was measured for the flux determination	640 ± 40
SCHMITT/ BOGART	1960/ 1966	Spherical shell transmission method; Monte Carlo calculation	608 ± 50†
ROBERTSON *et al.*	1966	Sb–Be-source; $MnSO_2$-bath method; activation method	555 ± 50†
BELANOVA *et al.*	1966	Spherical shell transmission method; Bethe calculation	500 ± 50†
Weighted average value			604 ± 25

* This value was determined by averaging the originally measured values over the energy.
† This value was translated from 24·4 keV to 30 keV using $\sigma_{n,\gamma}(30\text{ keV})/\sigma_{n,\gamma}(24\text{ keV}) = 0{\cdot}865$ (HARRIS *et al.*, 1965).

calculated using the approximations given by MACKLIN (1964). The second and the third factors correct for the backscatter of neutrons from the V2A and the platinum.

Finally, the ratio of the number of capture events in the gold foil to the number of fissions in the uranium is given by:

$$\frac{C_{Au}}{C_U} = \frac{N_{Au}\sigma_{n,\gamma}^{Au}}{N_U\sigma_f^U} \cdot \frac{\varphi_{Au}}{\varphi_U}. \qquad (10)$$

Table 1 shows a compilation of values for the capture cross section of ^{197}Au at 30 keV obtained from a variety of experiments. We have not included values

measured previously at this laboratory (PÖNITZ, 1966) since some of the same techniques were used in the present experiment. Also, we have not taken into account the values given by MISKEL *et al.* (1961) and COX (1961) since they are determined relative to the $^{235}U(n, f)$ cross section. The weighted average of $\sigma_{n,\gamma}^{Au} = 604 \pm 25$ mb was used to solve for the fission cross section from equation (10).

5. RESULTS AND DISCUSSION

Table 2 lists the important quantities necessary for the fission cross-section calculations, together with error estimates. Quantities not discussed previously are defined in the table.

TABLE 2.—EXPERIMENTAL AND CALCULATED VALUES NEEDED FOR THE EVALUATION OF $\sigma_{n,f}$

Notation	Value	Error (%)*	Remarks
Z_{Be}	$5{\cdot}058 \times 10^4$	0·8	Counts in photopeak
Z_{Au} (30 keV)	$1{\cdot}097 \times 10^5$	0·5	Counts in photopeak
Z_{Au} (64 keV)	$1{\cdot}07 \times 10^3$	5·0†	Counts in photopeak
C_U (30 keV)	$2{\cdot}820 \times 10^4$	2·0†	Counts in the fission counter
C_U (64 keV)	$3{\cdot}580 \times 10^3$	2·5†	Counts in the fission counter
T (30 keV)	187·3 min	0·2	Irradiation time
T (64 keV)	553·3 min	0·2	Irradiation time
N_U	$1{\cdot}753 \times 10^{21}$ cm^{-2}	1·0	Nuclei per cm^2
N_{Au}	$2{\cdot}598 \times 10^{18}$ cm^{-2}	0·2	Nuclei per cm^2
$\bar{T}_{Be}$	0·09295 min	0·2	See equation (2)
$\bar{T}_{Au}$ (30 keV)	20·49 min	0·2	See equation (2)
$\bar{T}_{Au}$ (64 keV)	6·26 min	0·2	See equation (2)
ε_{Be}	0·01978	1·8†	Photopeak efficiency
ε_{Au}	0·1922	1·0	Photopeak efficiency
k	0·980	0·5	See Section 4.2
$g(d_{Cu})$	0·948	0·8	See equation (3)
$g(d_{Au})$	0·974	0·5	See equation (3)
$g(d_{V2A})$	0·985	0·8	See equation (3)
$g(d_{Pt})$	0·960	0·5	See equation (3)
$f(d, \theta)$	1·011	0·3	See equation (7)
$f(d, \pi/2)$	2·0	5·0	See equation (7)
$S(d_{Au})$ (30 keV)	1·025	0·5	MACKLIN (1964)
$S(d_{Au})$ (64 keV)	1·027	0·5	MACKLIN (1964)
$(\Sigma_s/\Sigma_t)_{Au}$	0·96	2·0	Report BNL-325
$(\Sigma_s/\Sigma_t)_{V2A}$	0·99	2·0	Report BNL-325
$(\Sigma_s/\Sigma_t)_{Pt}$	0·96	2·0	Report BNL-325

* For the results the main error is due to the errors which are labelled by a dagger, the error of $\sigma_{n,\gamma}^{Au}$ (30 keV), and of $\sigma_{n,\gamma}^{Au}$ (64 keV)/$\sigma_{n,\gamma}^{Au}$ (30 keV).

TABLE 3.—THE RATIOS $\sigma_{n,\gamma}$(30 keV)/$\sigma_{n,\gamma}$ (64 keV) FOR GOLD

Authors	Year	Value
WESTON, LYON	1961	1·682
COX	1961/66	1·577
GIBBONS *et al.*	1961	1·551
HARRIS *et al.*	1965	1·680
PÖNITZ	1966	1·676

At 30 keV, two values are obtained for the ^{235}U fission cross section from equations (6) and (10), corresponding to the two methods of measuring the neutron flux. The results are:

From the ^{7}Be method equation (6): $2{\cdot}162 \pm {\cdot}068$ barns.
From the ^{197}Au method equation (10): $2{\cdot}288 \pm {\cdot}130$ barns.

By weighting these results by the inverse square of their error, a combined 'best' value is obtained of:

$$\sigma_f(^{235}U \text{ at } 30 \text{ keV}) = 2{\cdot}19 \pm {\cdot}06 \text{ barns.}$$

At 64 keV only the gold activation method could be applied. The ratio of the gold activation cross sections at 30 and 64 keV was evaluated from the data listed in Table 3. By taking into account the energy dependence of the other parameters involved in

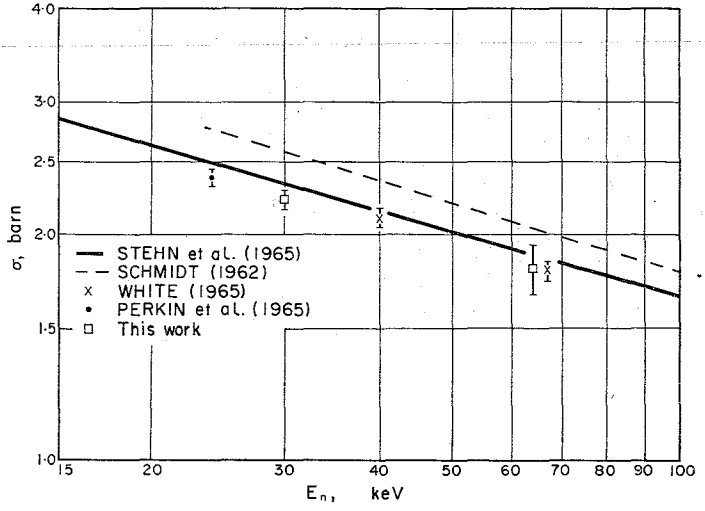

FIG. 3.—Comparison of the results with other data.

equation (10), a value of $0{\cdot}813 \pm {\cdot}052$ is calculated for the ratio of the ^{235}U fission cross section at 64 keV to that at 30 keV. Combining with the 30 keV best value given above:

$$\sigma_f(^{235}U \text{ at } 64 \text{ keV}) = 1{\cdot}78 \pm {\cdot}13 \text{ barns.}$$

These results are plotted on Fig. 3 together with those from a number of other measurements in this region. Also shown are several curves taken from compilations of cross-section data. It can be seen that our points tend to confirm the data of PERKIN *et al.* (1965) which lie somewhat below the compilation curves. Since the determination of neutron flux is normally the most difficult aspect of a cross-section measurement, we feel that the good agreement obtained from two independent techniques in our measurement at 30 keV indicate a reasonable freedom from systematic error. The uncertainty in our point at 64 keV arises primarily from the uncertainty in the gold activation cross-section ratio.

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