DETERMINATION OF A COHERENT PARAMETER SET FOR COUPLED CHANNEL CALCULATIONS OF ^{238}U NEUTRON CROSS-SECTIONS FROM 10 keV TO 20 MeV[1]

CHRISTIAN LAGRANGE*, Montrouge

Since ^{238}U is a highly deformed nucleus, we employ a deformed optical potential for neutron cross-section calculations. We use two sets of base states: $(0^+, 2^+)$ and $(0^+, 2^+, 4^+)$. In each case, the optical parameter set was chosen so as to satisfy the following experimental constraints: the s- and p- wave strength functions, the potential scattering cross-section at low energy and also the total cross-section from 10 keV to 20 MeV. We discuss and comment the results obtained.

We search for a unique and physically coherent parameter set which would cover the range of incident energies from 10 keV to 20 MeV and notably for nuclei with masses $232 \leq A \leq 242$. Since these nuclei are higly deformed, we employ a deformed optical potential for neutron cross section calculations. For this purpose, a revised version of JUPITOR-1 [1] was used. As test nucleus, we have chosen ^{238}U for which considerable experimental data are avaible.

We require that we have satisfactory fits in the order of a decreasing importance to the following experimental results: the s and p wave strength functions as well as the potential scattering cross section at low energy; the total cross section from 10 keV to 20 MeV.

The different angular distributions for „elastic" scattering from 2 MeV to 15 MeV will permit us to judge the quality of the obtained parametrization. At these energies, it is almost impossible now to distinguish between the elastic and the inelastic scattering to the first excited states. Thus we will compare the experimental results with the calculated values obtained by summing the differential scattering to the included states with energies less than 400 keV.

In coupled channel calculations, it is assumed that the neutron nucleus interaction may be described in the body fixed system by an optical model potential $V(r, \Theta)$ of the form:

$$V(r, \Theta) = -Uf(r; a_1, R_1) + 4ia_2 W_D \frac{d}{dr} f(r; a_2, R_2) + + \lambda_\pi^2 V_{so} \frac{l\sigma}{r} \frac{d}{dr} f(r; a_3, R_3),$$

[1] Contribution presented by D. Didier at the International Symposium on Neutron Induced Reactions at SMOLENICE, September 2–6, 1974.

* Service de Physique Nucléaire, Centre d' Études de Bruyères-le-Châtel, 92120 MONTROUGE, France.

Table 1
Optical parameters for each set of base states

Base states	U MeV	r_1 fermis	a_1 fermis	W_D MeV	$\bar{r}_2$ fermis	r_2 fermis	V_{so} MeV	r_3 fermis	a_3 fermis
$(0^+, 2^+)$	$47.4 - 0.3E$	1.25	0.65	$3 + 0.3E$ $E \leqslant 4$ MeV $3.72 + 0.12E$ $E \geqslant 4$ MeV	1.250	0.70	7.50	1.25	0.65
$(0^+, 2^+, 4^+)$	$47.5 - 0.3E$	1·24	0.62	$2.7 + 0.4E$ $E \leqslant 10$ MeV 6.7 $E \geqslant 10$ MeV	1.260	0.580	7.50	1.24	0.62

Table 2

Comparison between experimental and theoretical values of: s and p wave strength functions and potential scattering cross section for ^{238}U.

	$S_0 \times 10^4$	$S_1 \times 10^4$	σ_{POT} (barns)
Experimental	0.96 ± 0.07	2.20 ± 0.3	10.7 ± 0.2
Theoretical $(0^+, 2^+)$	0.943	1.960	10.362
Theoretical $(0^+, 2^+, 4^+)$	0.949	2.134	10.730

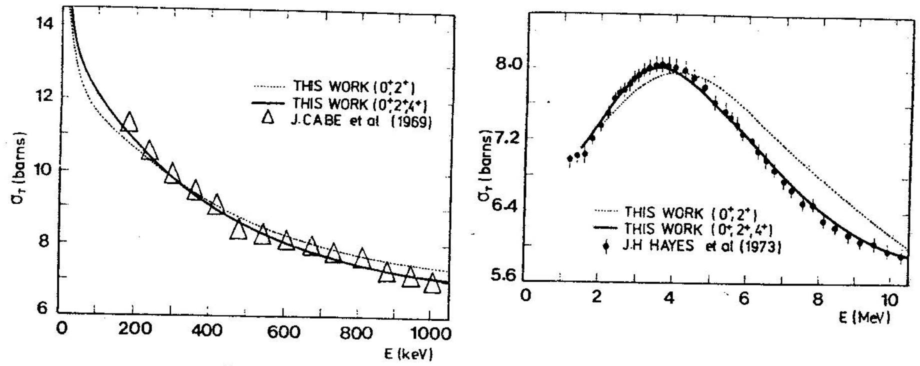

Fig. 1. Total neutron cross section of ^{238}U. The curves are coupled channel calculations using two sets of base states. The optical model parameters are that of Table 1.
a) $0.01 \leq E \leq 1.0$ MeV. Experimental data are from Ref. [5].
b) $1.0 \leq E \leq 10.0$ MeV. Experimental data are from Ref. [6].

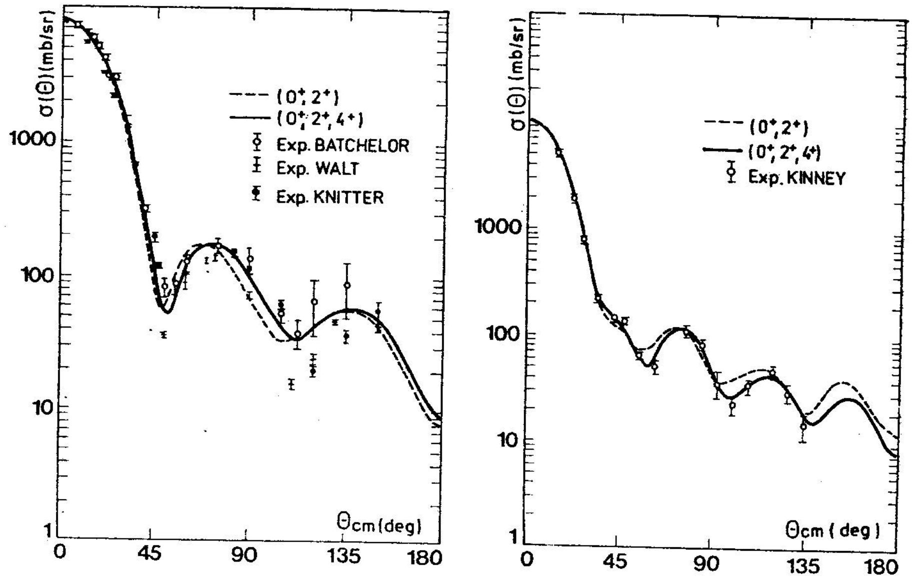

Fig. 2. Total neutron scattering cross section of ^{238}U. The curves are coupled channel calculations obtained by using two sets of base states. The optical model parameters are that of Table 1.
a) E = 4 MeV. Experimental data are from Ref. [7, 8, 9].
b) E = 7.54 MeV. Experimental data are from Ref. [10].

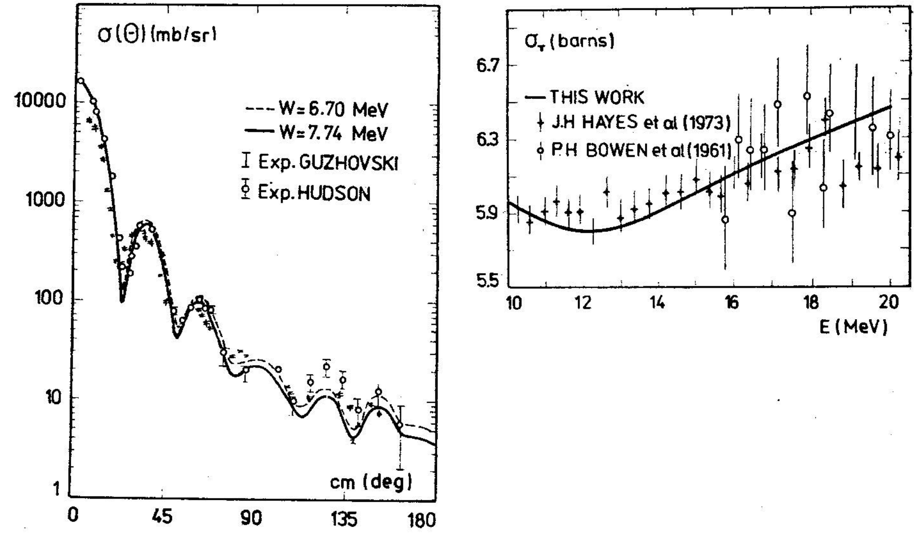

Fig. 3. The curves are coupled channel calculations obtained by using adiabatic approximation. The optical model parameters are that of Table 1 (base 0^+, 2^+, 4^+).
a) Total neutron scattering cross section of ^{238}U at 15 MeV. Determination of the imaginary potential. Experimental data are from Ref. [11, 12].
b) Total neutron cross section of ^{238}U, $10.0 \leq E \leq 20.0$ MeV. Experimental data are from Ref. [6, 13].

where $f(r; a_i, R_i) = \left[1 + \exp\left(\frac{r - R_i}{a_i}\right)\right]^{-1} \qquad (i = 1, 2, 3)$

$$R_3 = r_3 A^{1/3}$$

$$R_j = r_j A^{1/3}[1 + \beta_2 Y_2^0(\Theta) + \beta_4 Y_4^0(\Theta)] \qquad (j = 1, 2)$$

β_2 and β_4 are the deformation parameters.

We wish to make four remarks: 1) At low energies, the total parametrization was very sensitive to the choice of the deformation parameters. For this reason and because of the large experimental errors with measurements of these parameters, we used the results of a nuclear model based on the Nilson model and the method of Strutinsky [2]. The deformation parameters adopted for ^{238}U are the following: $\beta_2 = 0.216$, $\beta_4 = 0.067$. 2) The optical parameters depend on the choice of the base states [3]. Hence we present in Table 1 two different adapted sets. We use a Legendre polynomial expansion of the potential until the multipolarity order $\lambda = 4$ base (0^+, 2^+) or $\lambda = 8$ base (0^+, 2^+, 4). 3) It does not seem necessary to take complex coupling terms. 4) As we have no deformed spin orbit potential in our code, we have made no search for spin orbit parameters. The values adopted here are near the usual ones.

A) Comparison of the results obtained with two sets of base states and optical parameters. 1) Strength functions (S_0, S_1) and the potential cross section. In each case we determine U, r_1, a_1 so as to obtain a good fit to the potential cross section and to the ratio $\frac{S_1}{S_0}$. Then W_D, r_2 and a_2 are chosen to get a good fit to S_0 and adjust better S_1.

Our calculated values at 10 keV are compared in Table 2 with the experimental results obtained by Van'kov [4]. 2) The total cross section from 10 keV to 10 MeV. The variation of the optical parameters with neutron energy has been determined to reproduce the total cross sections from 10 keV to 10 MeV. We have found in each case that a good preliminary fit to the potential cross section at 10 keV has been necessary to obtain a good fit to the total cross section at low energies. We compare our results to the measurements of Cabe et al. [5] (experimental resolution ± 20 keV) and of Hayes et al. [6] (average of experimental points) in Figures 1a and 1b.

We can see the improvement obtained using the (0^+, 2^+, 4^+) base states. 3) Angular distribution for „elastic" scattering. The Figures 2a and 2b show the comparison of calculated and measured angular distributions. Since there has been no systematic redetermination of parameters, these results permit us to judge the adequacy of the parametrization. Here again a better fit was obtained by using the (0^+, 2^+, 4^+) base states. The different measurements reproduced here have been taken from Ref. [7—10].

B) Determination of the parameters from 10 MeV to 20 MeV. The best parametrization was obtained in the full range of energy from 10 keV to 10 MeV with the base (0^+, 2^+, 4^+). At higher energies, in order to reduce the extensive calculation time, the adiabatic approximation was used with nearly the same set of optical potential parameters. The only new parameter adjustment in this range of energy has been made to adjust W_D so as to match the measured [11, 12] angular distribution near 15 MeV (Cf. Figure 3a). In Figure 3b, the calculated total cross section are compared to the measurements of Hayes et al. [6] and of Bowen et al. [13].

In coupled channel calculations, the choice of the base states is very important to obtain a good description of neutrón-nucleus interactions. The over-all agreement obtained here using the base (0^+, 2^+, 4^+) and the optical parameters in Table 1 is the result of the adopted parametrization procedure. We want to point out some important results. 1) The choice of the real part of the potential is essential to obtain a good fit to the strength functions, potential cross section and total cross section. The choice of the imaginary part premits only to adjust at a lesser degree the calculated values. 2) It is in the energy range 10 keV — 1 MeV that the calculated values are more sensitive to the parameters. 3) The final adjustment of the calculated values of total cross sections in the full energy range seems to be sufficient to obtain a satisfactory fit to the various „elastic" angular distributions.

REFERENCES

[1] Tamura T., Computer program JUPITOR-1 for coupled channel calculations. *ORNL* 4152 (1967), Rev. of Mod. Phys. *37* (1965), 679.

[2] Möller P., Nucl. Phys. *A 192* (1972), 529.

[3] Glendenning N. K., *UCRL 17503* (1967).

[4] Van'Kov A. A., Grigoriev A. A., Filippov V. V., Nicolaev M. N., Bioler B., Kollats Z., Pikelner L. B., *Nuclear data for reactors.* Proc. conf. Helsinki Vol. 1, IAEA Vienna, 1970.

[5] Adam A., Cabé J., Cancé M., Labat M., Lauret M., Longuéve M., *CAE Centre d'Études de Bruyères-le-Châtel*, rapport interne.

[6] Hayes S., Stoler P., Clément J. M., Goulding, Nucl. Sc. Eng. *50* (1973), 243.

[7] Batchelor R., Gilboy W. B., Towle J. M., Nucl. Phys. *65* (1965), 236.

[8] Walt M., Beyster J. R., *LA 2061* (1956).

[9] Knitter M. M., Coppola M., Ahmed N., Jay B., Z. Phys. *244* (1971), 358.

[10] Kinney W. E., Perey F. G., *ORNL 4804* (1973).

[11] Guzhovskii B. Y., At. Energ. *11* (1961), 395, Trad. Soc. J. At. Energ. *11* (1962), 1041.

[12] Hudson C. L., Scott Walker W., Berko S., Phys. Rev. 128 (1962), 1271.

[13] Bowen P. H., Scanlon J. P., Stafford G. H., Tresher J. J., Hodgson P. E., Nucl. Phys. *22* (1961), 640.

Received September 9th, 1974