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Total neutron cross section of molybdenum in the thermal range

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Abstract

The total neutron cross section of molybdenum between 1.6×10^{-3} eV and 10 eV was measured for oriented and randomly distributed crystals by the transmission method with pulsed neutron time of flight techniques. The experimental curve for polycrystalline molybdenum was fitted theoretically in the whole energy range, from which the following parameters result:

$\sigma_c^{(nuclear)} + \sigma_i = (5.59 \pm 0.04)b$; $\sigma_{abs}(0.0253\,eV) = (2.50 \pm 0.05)b$
$\sigma_c^{(atomic)} = (5.22 \pm 0.10)b$; $\sigma_i = (0.27 \pm 0.12)b$

The neutron-electron interaction has been considered in the calculation.

Zusammenfassung

Totaler Neutronenwirkungsquerschnitt des Molybdäns im thermischen Energiebereich

Es wurde der totale Neutronenwirkungsquerschnitt des Molybdäns im Energiebereich von $1,6\times10^{-3}$ eV bis 10 eV für orientierte und willkürlich verteilte Kristalle mit Hilfe der Transmissions- und Flugzeitmethode mit gepulsten Neutronen gemessen. An die Meßpunkte für polykristallines Molybdän wurde im gesamten Energiebereich eine theoretische Kurve angepaßt, die zu den folgenden Parametern führte:

$\sigma_c^{(Kern)} + \sigma_i = (5,59 \pm 0,04)b$; σ_{abs} (0,0253 eV) = $(2,50 \pm 0,05)b$
$\sigma_c^{(Atom)} = (5,22 \pm 0,10)b$; $\sigma_i = (0,27 \pm 0,12)b$.

Die Neutron-Elektron-Wechselwirkung wurde bei den Rechnungen berücksichtigt.

INIS DESCRIPTORS

MOLYBDENUM	TIME-OF-FLIGHT METHOD
TOTAL CROSS SECTIONS	COMPARATIVE EVALUATIONS
THERMAL NEUTRONS	C CODES
POLYCRYSTALS	BRAGG CURVE

1. Introduction

Molybdenum is an element considered to be of potential importance as structural material in reactor design. In the region where coherent elastic scattering is significant, the only available data on total neutron cross section do not show clearly resolved Bragg peaks [1] while at higher energies ($> 10^{-1}$ eV) the data appear rather scattered over a wide band [2]. Furthermore, the values of the nuclear constants σ_c, σ_i, σ_{bound} quoted in the literature [1–5] show some inconsistencies among them.

Therefore, an experiment was performed in order to get a set of consistent parameters for scattering and absorption through a measurement of σ_{tot}.

2. Experimental

The time-of-flight transmission method was used with a 25-MeV LINAC. The experimental set up and data treatment are similar to those previously described [6]. A bank of seven He 3 detectors was placed at the end of a 17 m evacuated flight path.

2.1. Samples

A sample was prepared of 99.9% pure molybdenum in a rolled sheet metal form of thickness 5.083 g/cm². An X-ray analysis has shown effects of preferred orientation of the metal microcrystals. A second sample was made transforming the first one into thin lathe shavings, thus destroying orientation.

2.2. Measurements

For each sample twenty runs were made, each consisting in a succession of ten sample in-sample out cycles (free tube-sample-background). Raw data were corrected for dead time, mean emission time of the pulsed neutron source and background. Other corrections have shown to be negligible. The final σ_{tot} was taken in both cases as an average of the twenty partial curves.

The measurements were performed with the samples at the temperature (20 ± 0.5) °C.

3. Results

Fig. 1 shows the total neutron cross section dependence on energy for both oriented and polycrystalline samples in the intermediate energy region. The presence of preferred orientation and extinction effects are clearly seen from the comparison of the powder and metal results. However, the two curves coincide below the first Bragg cut-off and in the free atom region.

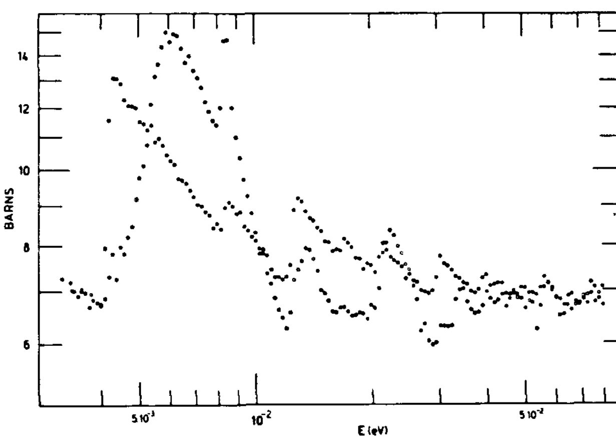

Fig. 1: Comparison of σ_{tot} for (o) oriented large sized grains and (•) powdered molybdenum in the intermediate energy region

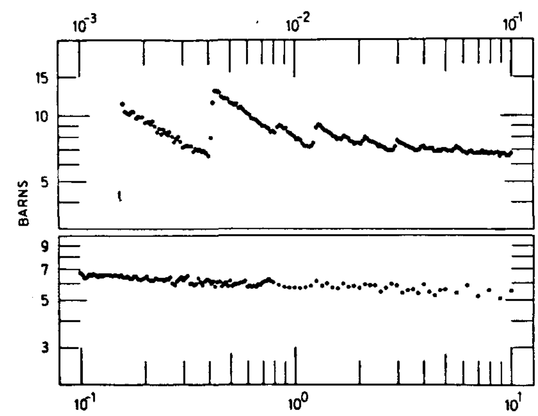

Fig. 2: Measured total cross section of polycrystalline molybdenum

The σ_{tot} for polycrystalline molybdenum is shown in Fig. 2. Total errors assigned to each point are due mainly to statistics and fluctuate around 2% for most of them except at the wings of the curve where they increase up to 6%. A complete set of data is sent to EXFOR Library (NDS, IAEA, Vienna).

4. Theory–Fitting

The total cross section of the polycrystalline molybdenum and its scattering components were calculated through the method already used in [6; 7] as described in [8; 9], by means of our CRIPO computer program.

Assumptions involved are:

a) a Debye model for the phonon frequency spectrum,
b) incoherent approximation for the coherent inelastic scattering component and
c) $1/v$ law for absorption.

The coherent scattering length was considered as energy dependent [10] in order to take into account the neutron-electron interaction [10; 11]. A Debye temperature of 407 K was used in the calculation, according to *Paakari* [12].

A least squares program was used to get $\sigma_{th} \equiv \sigma_{abs}$ (0.0253 eV) and σ_i from the σ_{tot} points, excluding the Bragg peaks region, as in [7]. The value of σ_c must be calculated previously. While in [7] this quantity was calculated as the mean of the values got by considering the measurable Bragg jumps, in this work that value was obtained as follows:

Tentative values of σ_{th}, σ_c and σ_i consistent with our results in the free atom region and below the first Bragg cut-off were chosen. All the calculated components other than σ^{el}_{coh} were

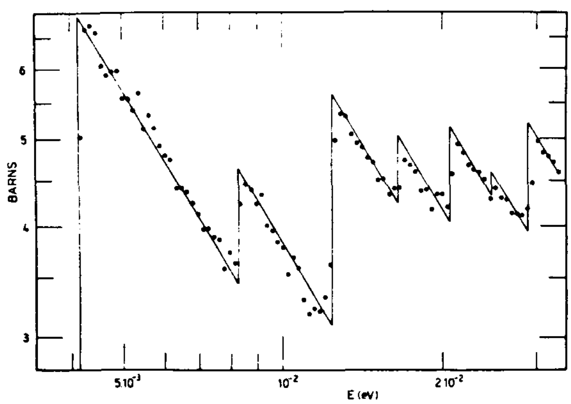

Fig. 3: "Experimental" and theoretical σ^{el}_{coh} curves

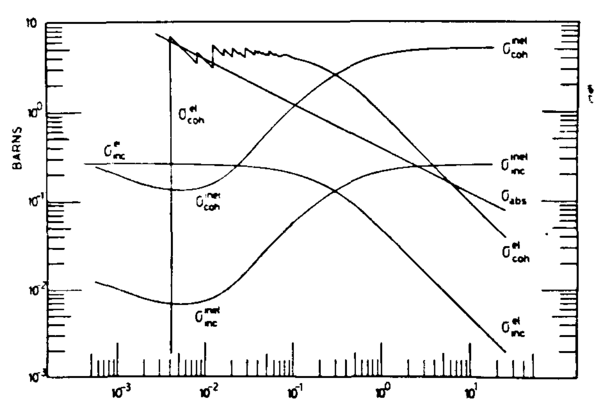

Fig. 4: Theoretical components of σ_{tot}

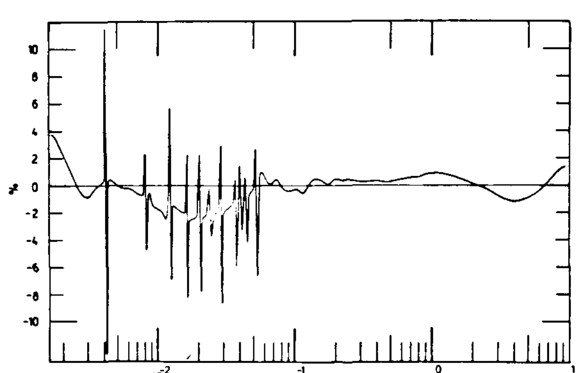

Fig. 5: Relative discrepancy between experimental and calculated values of σ_{tot} for polycrystalline molybdenum

subtracted from the experimental σ_{tot}, thus getting an "experimental" σ^{el}_{coh} curve, which preserves the values of the Bragg jumps, as far as the subtracted curve is a continuous one, and additionally shows the characteristic $1/E$ slopes which can be used as an additional parameter in the fitting (Fig. 3). Actually, no such jump-by-jump fitting was necessary, but an over-all comparison with a $\sigma_c = 1$ theoretical σ^{el}_{coh} curve by superposition, which gave directly σ_c as a scale factor.

The result obtained with this procedure is not critically dependent on the preliminary set adopted.

The final results are:

$$\sigma_c^{(nuclear)} + \sigma_i = (5.59 \pm 0.04)\text{b}$$
$$\sigma_{th} = (2.50 \pm 0.05)\text{b}$$
$$\sigma_c^{(atomic)} = (5.22 \pm 0.10)\text{b}$$
$$\sigma_i = (0.27 \pm 0.12)\text{b}$$

The five theoretical components of σ_{tot} are shown in Fig. 4 and the relative discrepancy with experimental data is shown in Fig. 5.

Table 1: Comparison of our results with previous data

	$\sigma_c^{(atom)}$ (b)
This work	5.22 ± 0.10
Ref. [3]	5.98
Ref. [2]	5.60 ± 0.20
Ref. [1]	6.00 ± 0.40
Ref. [4]	5.20 ± 0.40
Ref. [5]	5.47
	σ_{abs} (0.0253 eV) (b)
This work	2.50 ± 0.05
Ref. [3]	2.65 ± 0.08
Ref. [13]	2.60 ± 0.05
Ref. [1]	2.55 ± 0.10
Ref. [14]*	2.50 ± 0.13

* Corrected using σ_{th} (Au) = 98.7 b [15].

5. Conclusions

Clearly resolved Bragg peaks appear in our measured σ_{tot} curve. In Table 1 we compare our final σ_{th} and $\sigma_c^{(atomic)}$ values with measurements carried out by other methods. The fitting achieved with our set of parameters is quite good in the whole energy range for polycrystalline molybdenum thus making them to be considered as a reliable set.

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