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**SOME NEUTRON SPECTRUM MEASUREMENTS
THE THERMAL TOTAL NEUTRON
CROSS SECTION FOR MOLYBDENUM AT
ROOM TEMPERATURE**

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THESIS

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S U M M A R Y

This thesis describes the author's work in the measurement of the total neutron cross-section of molybdenum in the energy range from 2.2 eV to 0.0022eV at room temperature.

The measurements were performed using two time-of-flight spectrometers installed in front of two of the horizontal channels of the ET-RR-1 reactor. One of the spectrometers has its mechanical chopper with per-tinax 160 mm in diameter and having a straight slit $1 \times 25 \text{ mm}^2$ while the other spectrometer has a rotor of the same dimensions but with a cigar - shaped slit, in order to increase the transmission for neutron energies below 5 meV. The rotation rate of the rotors can be controlled in the range 800-3600 r.p.m. within the accuracy of 0.14 %. ^3He gas filled neutron detectors were used during the measurements. The calibration of the spectrometer time scale was done using the γ -ray pulse emitted from the reactor and transmitted through the rotor slit. Molybdenum is considered as one of the important materials in the reactor design; since it is a fission product nucleus, also its thermal neutron cross-section data at neutron

energies > 0.01 eV appear rather scattered over a wide range. Moreover, in the region where coherent elastic scattering is significant, the only available data does not clearly show any resolved Bragg peaks. Thus it seems useful to study the thermal total neutron cross-section for this element, for the precise determination of its thermal absorption coherent, incoherent and inelastic scattering cross-section.

The measurement samples used were prepared using a reactor grade molybdenum in the form of metal sheets. Spectroscopic analysis of the used element was carried out for accurate determination of impurities. The analysis show that the total amount of impurities is very small (50 ppm.) which gives negligible effect on the measured cross-section. X-ray analysis has also been carried out to determine the crystalline structure of the molybdenum sample used. This analysis shows that the molybdenum structure is in confirmation with the body centre cubic structure.

The measurements of the total neutron cross-section of molybdenum were carried out in three regions to obtain suitable counting rates, taking into account

the effect to background ratio as well as the counting rates. In the first run, the measurements were performed in the energy range from 2.2 eV to 0.01 eV. At neutron energies below 0.04 eV the measured cross-section behaviour was found to fluctuate near a constant value ($\sigma_t = 6.09 \pm 0.63$)b. In the second run the measurements were performed in the energy range from 0.02 eV to 0.005 eV. At neutron energies below 0.04 eV, the observed behaviour of the cross-section shows sharp cut-offs at neutron wavelengths corresponding to double interplaner distances of molybdenum crystal structure.

In the third run, the measurements were performed in the energy range from 0.005 eV to 0.0022eV. The measurements in this range were performed at room temperature. A Be block, 20 cm thick, was used in this run to remove neutrons of energies higher than 0.005 eV; consequently increasing the effect to background ratio. The contribution of known close and far -away resonance upon the cross - section value in the thermal region have been calculated using the single level Breit - Wigner formula. The values of both the potential scattering cross - section and effective nuclear radius R were determined for the cross - section.

From the data analysis, the potential scattering amplitude value was found to be in good agreement with that calculated according to optical model with the following parameters: $V_0 = 42$ MeV., and the ratio of the imaginary to the real component of the potential = 0.05 and $R' = 1.48 \frac{1}{A^{1/3}}$.

The coherent scattering amplitudes as well as the coherent scattering cross - sections of molybdenum were determined using the values of the Bragg cut-offs observed in the total cross-section measured at low neutron energies. The resulting values are in good agreement with those obtained using neutron diffraction methods. The measured total neutron cross-section of Mo beyond the cut-off wavelength, at room temperature, provides information about the incoherent scattering cross-section of molybdenum. The one phonon annihilation process was estimated also at long neutron wavelengths and its contribution to the total cross-section at room temperature was found to be very small, since the Debye temperature for Mo is relatively small and can be neglected compared to the absorption and incoherent scattering cross-section.

During the course of this work, the following papers were prepared:-

- 1) Measurement of the total neutron cross - section of molybdenum in the energy range from 2.2 eV to 3 meV.
By H. Salama and H. Mazhar.

Atomkernenergie/ Kerntechnik Bd. 39 (1981) Lfg. 3, 207.

- 2) New measurements for the total neutron cross-section of molybdenum in the energy range from 2.2 to 0.04 eV.
By H. Salama and H. Mazhar.

Atomkernenergie/ Kerntechnik Bd. 40 (1982) Lf 9.4, 290.

- 3) Analysis of the total neutron cross - section of molybdenum measured at room temperature and at wavelength neutrons beyond λ_c .

By H. Salama and H.S. Mazhar. Under publication,
in Atomkernenergie - Kerntechnik Journal.

INTRODUCTION

1- INTRODUCTION

Slow neutrons are used mainly in an increasing number of original applications which lead attentively to the importance of studying the interaction of neutrons with matter. Slow neutrons have gained also a great importance as a tool for research and application at present time. The low energy and relatively long wavelength of such neutrons govern their interaction with matter. Since the wavelength of slow neutrons is of the same order as the interatomic distances in crystals, therefore the optical effects are quite marked [1,2].

In pure nuclear physics research, slow neutrons play an important role, since they can be used in the investigation of atomic structure of different materials, at the time when the application of X-rays or electrons seems inconvenient or impossible as in diffraction studies of hydrogenous compounds and alloys of elements with neighbouring atomic numbers.

Information about the vibrational frequency spectrum of the crystal lattice and phonon dispersion curves can be gained from neutron scattering data of

different solids [3]. Moreover, slow neutrons give valuable information about the motion of atoms (or molecules) in liquids, also about the diffusion mechanism. Magnetic dynamics of crystals can be investigated successfully using slow neutrons. Slow neutrons have been successfully used also in the determination of nuclear scattering amplitudes for different isotopes. Moreover, slow neutrons are also important and essential as initiators and perpetuators of nuclear chain reactions in most types of reactors [4].

The probability of interaction between a given nucleus and an incident neutron is conventionally represented by the nuclear cross-section. A great deal of work has been performed in connection with the determination of nuclear cross-sections for neutron reactions but much still remains to be done as the subject has practical and theoretical significance.

The study of nuclear cross - section for neutron reactions attracted a considerable attention, as it was thought with some justification that the information would contribute to a better understanding of complexities of nuclear structure [5].

Neutrons interact with matter in two ways. First, there is a nuclear interaction between neutrons and the ambient nuclei. Secondly, although the neutron is electrically neutral as a whole, there is an electromagnetic interaction because the neutron has a magnetic dipole moment [6].

The leading interaction process is the nuclear reaction. Such reaction may proceed either through the formation of excited nucleus followed by its decay along one of the possible channels, or without the formation of an intermediate nucleus when the neutron is scattered directly by the nuclear force field. The decay channels of the intermediate nucleus may be elastic and inelastic scattering emission of γ -rays (radiative capture of neutrons by the nucleus); emission of charged particles [(n,p) and (n, α) reactions] and nuclear fission [5].

In the thermal neutron energy range, there is no nuclear inelastic scattering. Also, neutron capture followed by fission occur for some few heavy isotopes, while reactions involving the emission of charged particles occur only in few light isotopes. Therefore as we are interested in the thermal energy range, we can pay attention

only to two decay channels namely radiative capture and resonance elastic scattering. Potential elastic scattering has to be taken into consideration which may proceed without the formation of an intermediate nucleus [7] . Interference between potential and resonance elastic scattering may occur. In the thermal energy range and for neutron energies of few electron volts, the scattering cross-section component has a form characteristic of potential scattering, i.e. it is independent of neutron energy, nevertheless, this is not true, the potential scattering will not be pure and there will be a certain contribution to resonance scattering [8] .

For neutrons with energies of about 10^{-4} eV up to 10^{-1} eV, we are interested in the phenomenon of neutron optics such as reflection and diffraction where there is much discussion of the coherent and incoherent cross-section. Since in this region the wavelength of thermal neutrons is of the same order of magnitude as the interatomic distances in crystals, therefore the optical effects are quite marked [1,9] .

The coherent cross - section is the cross section when the scattering centre, participate in the process in