TOTAL EFFECTIVE NEUTRON CROSS SECTIONS FOR
As, Se, Sb AND Te IN THE 0.0027-0.0100 ev ENERGY RANGE

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Until now, the total neutron cross sections for arsenic, antimony, and tellurium have been studied only in the neutron energy range above 0.01 ev. Measurements of such cross sections at energies below 0.01 ev are of great interest because, firstly, they extend our knowledge of total cross sections, and, secondly, they make it possible to determine the effect of sample crystal structure on the magnitude of the effective cross section. The total cross section for selenium has been measured in the energy range 0.001-0.01 ev [1]. These measurements, which were made with a crystalline selenium sample, led to a determination of the cross sections for absorption, total and coherent scattering, and to an estimate of the incoherent scattering cross section. The values for the scattering cross section which were obtained in this way differ from those obtained by diffraction measurements.

A neutron crystal spectrometer with a plane mica monocrystal [2] was used in our work. A mechanical monochromator with helical slits [3], placed before the crystal, eliminated high-order reflections. The primary beam, with an angular divergence of $8'$, emerged from a Soller-type collimator located in one of the horizontal channels of the VVR-S reactor.

Two kinds of experiments were done. In the first kind, a second Soller collimator with a divergence of $2'$ was placed on the spectrometer arm. In the second kind, this collimator was absent. Comparison of the results which were obtained by these two types of measurements permitted a determination of the small-angle scattering contribution to the measured transmission. A BF$_3$-filled type SNM-8 counter was used as a detector. The arrangement of equipment is shown in Fig. 1. In the energy range of interest to us, the resolving power of the instrument, $\Delta \lambda / \lambda$, was 0.015 in the first type of experiment, that with two collimators. Samples were in the form of aluminum cylinders 50 mm in diameter with ends 0.5 mm thick. Powders made of the materials under study were compressed within the cylinders. Mean grain size in crystalline samples of selenium, antimony, and tellurium were 10-50 $\mu$, and 0.8 $\mu$ for arsenic samples. Impurity content was less than 0.1% in arsenic, selenium, and tellurium samples. Antimony samples contained about 1% of impurity (mainly lead and arsenic).

Angular measurements were made at intervals of $10'$. Five measurements of the transmission of the monochromatic beam through the sample under study were made at each angle. For these measurements, the relative error in cross section was 1-3%.

Calculation of Total Effective Cross Section

In the energy range under consideration, the total effective cross section for monatomic materials can be expressed as a sum of four terms [1, 4]

$$\sigma_t = \sigma_a + s + E_T(S) + E(S),$$

(1)

where $\sigma_a$ is the effective absorption cross section; $s$ is the effective incoherent scattering cross section; $E_T(S)$ is the cross section for scattering caused by thermal motion of the atoms in a crystal; $E(S)$ is the cross section for scattering caused by Bragg diffraction; $S$ is the effective coherent scattering cross section.

The terms $E_T(S)$ and $E(S)$ can be calculated for a crystal with cubic symmetry [4, 5], and they have the following forms:

$$E_T(S) = S \left[ 1 - \frac{\lambda^2}{P} (1 - e^{-P/\lambda^2}) \right];$$

(2)
Here $\lambda$ is the wavelength of the monochromatic neutron beam; $N$ is the number of atoms per unit volume; $\tau = \frac{1}{d_{\text{hkl}}} \cdot (d_{\text{hkl}})$ is the distance between planes determined by the indexes $\text{hkl}$; $r_T$ is the repetition factor for the family of planes; $F_T$ is the structure factor of the family;

$$P = \frac{12\hbar^2}{Mk_0\Theta} \left[ \frac{\Phi(x)}{x} + \frac{1}{4} \right]$$

where $h$ is Planck's constant; $k_0$ is the Boltzmann constant; $M$ is the atomic weight; $\Phi(x)$ is the Debye function; $x = \Theta/T$ ($T$ is the Kelvin temperature of the crystal; $\Theta$ is the Debye temperature). Application of expressions (2) and (2a) to the case of crystals of a symmetry other than cubic leads to errors in the calculation of the quantities $E_T(S)$ and $E(S)$. For the materials considered, $S$ is 3-10 barns, and errors in the calculation of $P$ of as much as 50% will lead to an error of less than 1.5% in the calculation of the total effective cross section.

We calculated curves $\sigma = f(E)$ for all the elements studied on the basis of relations (1), (2), (2a) using the following values for Debye temperatures [6]: As - 285° K, Se - 370° K, Sb - 200° K, Te - 245° K.

In the case of neutron scattering at small angles, when the scattering angle, $\Theta$, does not exceed 34° and the crystal is spherically symmetric, the following expression for the differential cross section was obtained [7]:

$$\sigma(\Theta) = 4R^4k^4 \delta^2 \left[ \sin R k\theta \frac{\cos R k\theta}{(Rk\theta)^3} \right]^2,$$

where $R$ is the crystal radius; $k$ is the wave number inside the crystal; $\delta$ is the decrement in the index of refraction. This leads to the conclusion that the half-width for small-angle scattering is proportional to $1/R$ and the wavelength, $\lambda$, of the monochromatic neutron beam. A qualitative check of these conclusions can be realized by a comparison of the two kinds of measurements. Indeed, the difference between the results obtained by the two methods is all the greater, the smaller the dimensions of the powder particles used. A half-width of 30° was obtained for arsenic on the basis of expression (3), and the difference was great. For the other elements, the calculated half-width was 1°, which explained the experimental results obtained. The total scattering cross section at small angles has the form [7]

$$\sigma = KL^2,$$

where

$$K = \frac{N^2S}{8\pi^2} R^4;$$

$N$ is the number of atoms per unit volume of the crystal. The wavelength dependence of the difference, $\Delta\sigma$, between the magnitudes of arsenic total cross sections measured in the two ways indicated above is shown in Fig. 2. It is obvious from the figure that the experimental points lie rather well on a parabola whose coefficient $K$ has the value 0.38 if $\Delta\sigma$ is expressed in barns and $\lambda$ in angstroms. Taking this value for $K$, $R$ can be calculated from (4a). In this way, we obtained a value of 0.2μ, and direct measurement of average particle size gave a value of 0.8μ. This difference can be explained by deviation of the crystals from a spherically symmetric shape, and by the fact that scattering at small angles is observed even in the absence of the second collimator because of the small dimensions of the particles.