Total Cross Section of Sulphur at Slow Neutron Energies

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The total cross section of elemental Sulphur was measured at neutron energies between 1.6×10^{-3} eV and 100 eV, using a pulsed neutron source and time-of-flight techniques.

The data in the epithermal neutron region were used to extract the value of the bound nucleus scattering length, taking into account the neutron-electron interaction. A similar transmission experiment was also performed on elemental Bismuth.

The thermal neutron total cross section data on Sulphur quoted in the literature [1] are rather old and of poor statistical accuracy. However, high precision data exist for epithermal energies [2], and in a recent measurement [3] which partially covers the thermal neutron energy region. In order to complete the knowledge of the total cross section over the entire thermal range, a transmission experiment was performed on Sulphur using a pulsed neutron source.

The sample was made of high purity (99.999%) elemental Sulphur in powder form [4], with an effective thickness of 0.4215(8) l/barn. The measurements were done using the Bariloche LINAC based neutron source, operated at a frequency of 12.5 Hz. The detection bank consisted of seven ^{3}He proportional counters (10 atm filling pressure, 6″ active length, 1″ diameter), placed at a distance of 17.89 m from the thermal neutron source. The sample-in/sample-out method was employed to minimize the effect of beam power fluctuations, while the spectra normalization was done using the integral counts from a monitoring detector. Each neutron time-of-flight (TOF) spectrum was recorded into 2048 channels of 32 μs width. Other characteristics of the experimental set-up and data acquisition system are given elsewhere [5].

The measured TOF data were corrected for dead time, and the corresponding backgrounds subtracted from the sample and open beam spectra.

Figure 1 shows the measured neutron total cross section of elemental Sulphur at room temperature, between 1.6×10^{-3} eV and 100 eV. A few typical error bars (including statistical as well as sample thickness uncertainties) for isolated points are also shown. The discontinuities observed at low energies are due to the Bragg cut-offs in the elastic coherent component of the total cross section.

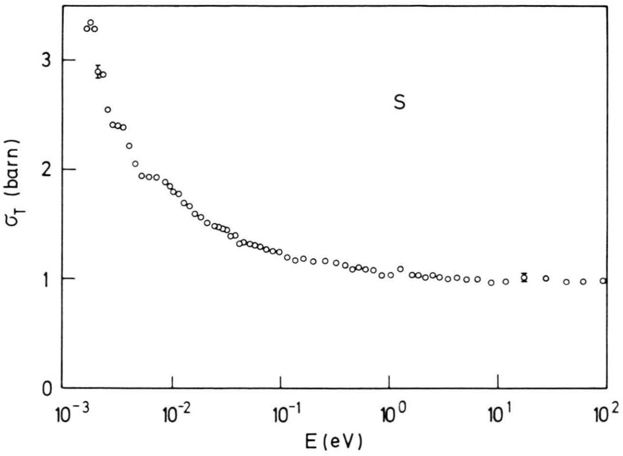

Fig. 1. The measured total cross section of Sulphur. Total error bars in the region between 5×10^{-3} eV and 5 eV are equal or smaller than the symbol size.

The experimental values between 0.1 eV and 20 eV were fitted according to the expression

$$\sigma_t(E) = \sigma_{abs}(E) + [\sigma_c(E) + \sigma_i]\, S(E), \qquad (1)$$

where

$$\sigma_{abs}(E) = \sigma_a (E_0/E)^{1/2}; \quad E_0 \equiv 0.0253 \text{ eV}$$

is the absorption cross section and σ_i is the incoherent cross section. The function $S(E)$ accounts

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for solid state effects and is given by [6]

$$S(E) = \left(\frac{A}{A+1}\right)^2 \left\{1 + \frac{3}{4A}\,\Phi_3(\theta)\,\frac{k_B T_D}{E}\right\} \quad (2)$$

with

$$\Phi_3(\theta) = \int_{-1}^{1} d\varepsilon\, \varepsilon^3 (e^{\varepsilon/\theta} - 1)^{-1}$$

and $\theta = T/T_D$, the ratio of sample temperature T to its Debye temperature T_D.

The coherent cross section over this energy range can be written as [7]

$$\sigma_c(E) = 4\pi\{b_N + Z f(E)\, b_{ne}\}^2, \quad (3)$$

where b_N is the bound nucleus scattering length, Z is the atomic number and $f(E)$ the atomic form factor corresponding to the scattering atoms. The quantity b_{ne} is the scattering length associated to neutron-electron interaction [8].

The following input values were adopted in the fitting process:

$\sigma_a = 0.520\ b$,

$\sigma_i = 0.006\ b$,

$T_D = 172$ K; room temperature value [2],

$b_{ne} = -1.35 \times 10^{-3}$ fm,

and the resulting value for the bound nucleus scattering length turned out to be

$$b_N(S) = (2.864 \pm 0.006)\ \text{fm},$$

whereas for the free-atom scattering cross section we obtained

$$\sigma_{free}(S) = (0.9745 \pm 0.0050)\ b.$$

In Fig. 2 we compare the experimental points of Vertebni et al. [3] and Koester et al. [2] with our adjusted curve, over the energy region where the fit was done. The agreement between the three independent measurements is excellent.

The values of the scattering length and scattering cross section of Sulphur, derived from the fit to our data, are in agreement with those given in [2]. Further, using the latest recommended value for the neutron-electron scattering length [8] together with our value for the bound nucleus, one finds

$$b_{at}(S) = (2.843 \pm 0.006)\ \text{fm},$$

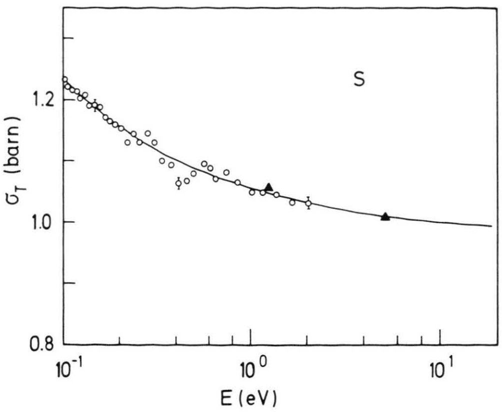

Fig. 2. Total cross section of Sulphur over the region where the fit to our data was performed. The continuous line is the result of using (1) with our adjusted parameters, while the experimental points are from [2] (triangles) and [3] (circles).

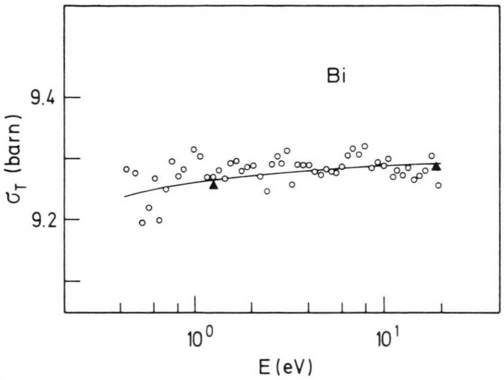

Fig. 3. Total cross section of Bismuth over the region where the fit to our data was performed. The continuous line is the result of using (1) with our adjusted parameters, while the experimental points are from [11] (triangles) and [12] (circles).

in good agreement with Trusted's [9] measurement of the atomic scattering length:

$$b_{at}(S) = (2.847 \pm 0.001)\ \text{fm}.$$

A transmission experiment on Bismuth was performed under the same instrumental conditions as described above. The sample was a rod of solid Bi with a density of 9.798(5) g/cm^3 and an effective thickness of 0.1911(1) barn^{-1}. The measured total cross section revealed in this case strongly preferred orientation effects in the sample structure, extending up to about 0.3 eV. Equations (1) to (3) were then used to fit the data points beyond 0.4 eV, with the following adopted input values:

$$\sigma_a = 0.0338\ b,$$

$$\sigma_i = 0.007\ b,$$

$$T_D = 116\ \text{K}; \quad \text{room temperature value [10].}$$

As a result, we obtained

$$b_N(\text{Bi}) = (8.642 \pm 0.005)\ \text{fm}$$

and

$$\sigma_{\text{free}}(\text{Bi}) = (9.302 \pm 0.010)\ b$$

for the bound nucleus scattering length and free-atom scattering cross section of Bi, respectively. From the combination of the most recent [8] value for the atomic scattering length and our derived b_N, one finds $b_{ne} = -(1.34 \pm 0.08) \times 10^{-3}$ fm, in very good agreement with the latest recommended value [8]. Also, our value for the free-atom cross section coincides with the precision measurement $\sigma_{\text{free}} = (9.300 \pm 0.003)\ b$ from [11].

Finally, we show in Fig. 3 the evaluation (1) using our adjusted parameters, together with experimental points of Waschkowski and Koester [11] and Popov and Samosvat [12], over the energy range where the fit to the present data was done.

New high precision measurements of the total cross section from ~ 1 eV up to the first resonances for both Bi and Pb have been carried out [13], in order to provide additional information about some fundamental neutron properties.

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