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Development of a Unique Curve for Thermal Neutron Self-Shielding Factors in Spherical Scattering Materials

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Abstract – *The introduction of an appropriate dimensionless variable, which takes into account, simultaneously, the material absorbing and scattering properties, can express the thermal neutron self-shielding factor of spherical samples by a unique curve. It is shown that the differences between the values calculated by Blaauw and those of the proposed curve are < 1.5%.*

1. Introduction

It has been recognized that thermal neutron scattering inside samples has important effects in neutron absorption experiments [1-4]. Its importance may be reflected in the thermal neutron self-shielding factor G_{th}. For a given total cross-section, the scattering of neutron increases the self-shielding factor since a pure scatterer in an isotropic neutron field has no self-shielding[2].

This paper uses the results published by Blaauw [2] and proposes a unique curve that which describes conveniently the behaviour of the thermal neutron self-shielding factor.

2. Blaauw method for calculation of self-shielding factors

Blaauw[2] computes the self-shielding factor G_{th} of a spherical sample using the Stewart's formula[5] by a two step calculation. First of all, he computes the self-shielding factor without scattering, G_{th}^{0}, using the macroscopic total scattering cross-section Σ_t instead of the macroscopic absorption scattering cross-section Σ_a as though the sample did not scatter neutrons. Stewart used only Σ_a to calculate G_{th}^{0}. Then Blaauw uses the Stewart's formula to correct for scattering effects. Accordingly, the Blaauw values were calculated using the expressions

$$G_{th}^{0} = \frac{3}{X_t^3}\left[\frac{X_t^2}{2} - 1 + \left(1 + X_t\right)e^{-X_t}\right]$$

and (1)

$$G_{th} = \frac{G_{th}^{0}}{1 - \frac{\Sigma_s}{\Sigma_t}\left(1 - G_{th}^{0}\right)}, \qquad (2)$$

where

$X_t = 2R\Sigma_t$

R = sphere's radius

Σ_s = macroscopic scattering cross-section.

3. Results and discussion

Blaauw [2] presents sets of thermal neutron self-shielding factor curves plotted as a function of $X_a = 2\Sigma_a R$ and $X_s = 2\Sigma_s R$. G_{th} have been calculated over a wide range of X_a and X_s values between 0 and 10. Figure 1 presents some of these values for X_a varying between 0 and 10 and X_s=0, 2, 5, 10. It demonstrates that G_{th} decreases with X_a at constant X_s and with X_s at constant X_a.

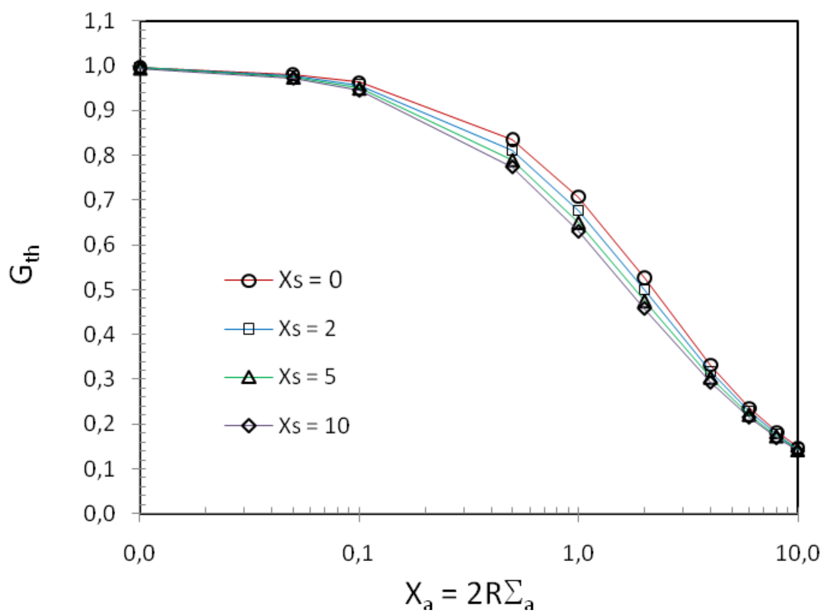

Fig. 1 – Self-shielding factor calculated by Blaauw, plotted as a function of X_a for different values of X_s

In this paper it is proposed to introduce a dimensionless variable, which takes into account, simultaneously, both macroscopic absorption and scattering cross sections. The variable is:

$$X = 2R\Sigma_t\left(\frac{\Sigma_a}{\Sigma_t}\right)^x = 2R\Sigma_t\left(1-\frac{\Sigma_s}{\Sigma_t}\right)^x, \qquad (3)$$

where x is a parameter to be adjusted to the calculated or measured values in order to transform the set of curves into a unique curve. The expression between parenthesis takes into account scattering effects: for a pure scatterer $X = 0$. The results of Blaauw plotted against X are shown in Figures 2, where $x = 0.85$.

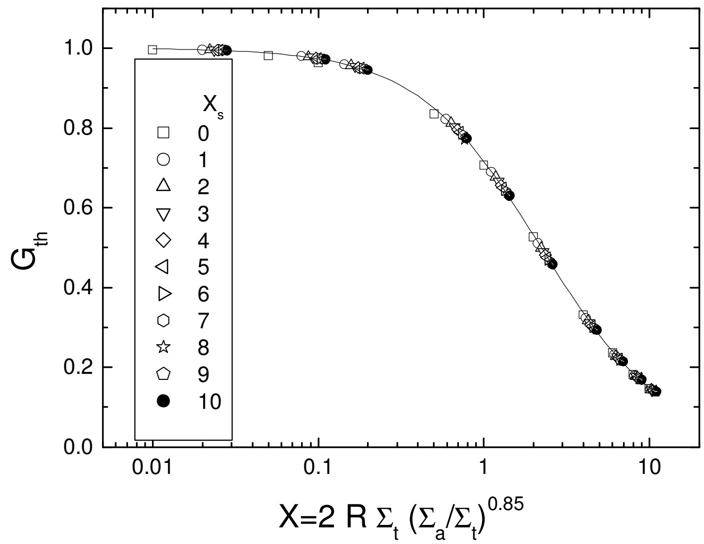

Fig. 2 – Self-shielding factors calculated by Blaauw as a function of X, for x=0.85, and the adjusted curve ($A_1 = 1$; $A_2 = 0$; $z_0 = 2.227 \pm 0.004$; $p = 1.160 \pm 0.002$; $r^2 = 0.9999$).

A sigmoid curve:

$$G_{th} = \frac{A_1 - A_2}{1 - \left(\dfrac{X}{X_0}\right)^p} + A_2 \tag{4}$$

was adjusted to the calculated values. The results show that a unique curve can take into account, simultaneously, the dependence of G_{th} on the absorption and scattering cross-sections. The mean and maximum differences between the adjusted curve proposed in this work and the values calculated by Blaauw are 0.2% and 1.5%, respectively.

Figure 3 compares G_{th} calculated by Blaauw with values calculated by Martinho, Salgado, and Gonçalves[6] using the MCNP code for materials with very different absorption and scattering cross sections. A good agreement is obtained between the Blaauw and our values.

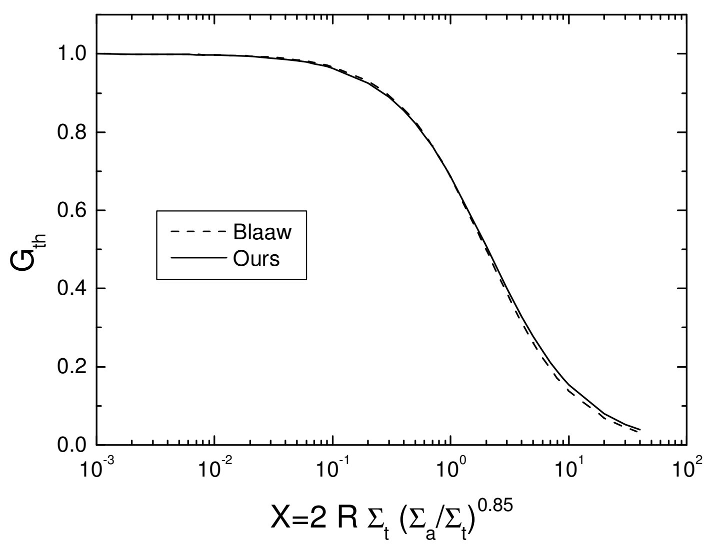

Fig. 3 – Comparison of G_{th} calculated by Blaauw and by Martinho, Salgado and Gonçalves

4. Conclusions

The results presented in this work show that a unique curve can be adjusted to the calculated (or experimental) values of the thermal neutron self-shielding factor for spherical samples. This is obtained through the introduction of a dimensionless variable that takes into account, simultaneously, the scattering and absorption properties of the samples. The differences between the calculated values and those of the proposed curve are < 1.5%.

References

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