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R. W. Bauer
J. D. Anderson
S. M. Grimes
V. A. Madsen

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APPLICATION OF A SIMPLE RAMSAUER MODEL TO NEUTRON TOTAL CROSS SECTIONS

R. W. BAUER¹, J. D. ANDERSON¹, S. M. GRIMES², V. A. MADSEN³

¹ Lawrence Livermore National Laboratory, Livermore, CA, USA,

² Ohio University, Athens, OH, USA,

³ Oregon State University, Corvallis, OR, USA

Abstract

The simple nuclear Ramsauer model has been used successfully to fit neutron total cross sections for over three decades, but has not been widely used because the foundations of the model seem so unrealistic. We have shown that the Glauber calculations with the inclusion of refraction and optical model calculations essentially validate this simple model for neutron total cross sections in the neutron energy range of 5-50 MeV. This model yields a simple formula for parameterizing the energy dependence of the neutron total cross section. We have applied the model to nuclei ranging from vanadium to bismuth. Using the simplest parameterization, we obtain fits of the data to within 2.5%. With the addition of a single parameter, we can improve these fits to less than 1.5%.

1 Introduction

The original Ramsauer analysis of scattering cross sections was applied to electron scattering from atoms at energies so low that only a single phase shift, i.e., that for $\ell = 0$, was non-zero. More recently, Lawson¹ and Peterson² have applied the model to total neutron cross sections at MeV energies. In this situation, clearly a number of phase shifts are non-zero. If the condition for maximum cross section ($\delta = \pi/2$) is met at different energies for different ℓ values, the energy oscillations in the total cross section will be damped out. Furthermore, the energy modulations are very sensitive to the magnitude of the imaginary potential. A large value for the absorptive potential will damp out the oscillations. This damping out, for example, appears to occur for the absorption cross section for alpha particles.

The early analysis by Peterson² showed that maxima and minima in the total cross section having the features of the Ramsauer effect could be observed. Peterson, however, did not examine the features of the nuclear potential required to produce this behavior. Franco³ used the Glauber approximation to model the process and determined that the equal phase shift assumption was not required. It was only necessary that the average phase shift vary slowly with energy for Ramsauer maxima and minima to occur. Since he did not include refraction at the nuclear surface, his results did not provide a detailed description of the data.

2 Analysis

A more recent analysis by Anderson and Grimes⁴ examined the effects of including an isospin dependent interaction. Precision total cross sections were fit to a few percent. A paper is currently being prepared for submission to Nuclear Science and Engineering⁵ which examines the effectiveness of a Glauber model including refraction. It is concluded that over a significant energy range from 5 to 50 MeV, the chord length seen by a neutron traversing a nucleus is about twice the radius due to refraction. Thus we conclude that the total cross section should be well represented by

$$\sigma_T = 2\pi (R+\lambda)^2 (1-\alpha \cos\beta). \quad (1)$$

R is the radius of the nuclear potential, λ is the reduced wave length, α is a parameter which is 1 if there is no absorption and is less than 1 if absorption occurs, and β denotes the phase change in passing through the nucleus. Clearly, the "black nucleus" limit corresponds to $\alpha=0$, in which case the total cross section is $2\pi (R+\lambda)^2$. For smaller absorption, the α parameter will multiply the $\cos\beta$ term and allow oscillations to occur.

Finlay and collaborators⁶ have reported total neutron cross sections of a number of elements from 5 to 500 MeV. The following fits are based on these data. The data were first normalized by dividing the total cross section by $2\pi (R+\lambda)^2$ where $R=r_0 A^{1/3}$ and r_0 was 1.37 as compared to 1.35 as found by Peterson². If β reflects the phase difference between transmitted and outside waves, it would have the form of a constant multiplying the difference $\sqrt{E+V_0} - \sqrt{E}$, where the constant included the radius of the nucleus. V_0 is the depth of the nuclear potential, and E is the kinetic energy of the neutron outside the nucleus. We, therefore, initially tried fits with β expressed in the form:

$$\beta = K \{ \sqrt{a+bE} - \sqrt{E} \} \quad (2)$$

Using this form and parameters from standard optical models⁷ we obtain agreement with the experimental data at about the 2.5% level. Somewhat better fits are obtained with the form:

$$\beta = k \{ (\sqrt{a+bE} - \sqrt{E}) + k_1 (\sqrt{a+bE} - \sqrt{E})^2 \} \quad (3)$$

Values for k , a , b , and k_1 were obtained by fitting this form to the lead total cross section values. α is then determined by finding how far above and below $2\pi (R+\lambda)^2$ the data go (typically $\alpha=0.11$ to 0.13). Using $k_1=0.07$, $a=38$ and $b=0.85$ (obtained from the lead data), the other individual elements were fit by varying k only. The variation of the best fit values of k under these constraints as a function of $A^{1/3}$ is shown in Fig. 1. Note the approximately linear variation between these quantities as expected. In Fig. 2, we show comparisons of the reduced cross section $\sigma_T/2\pi (R+\lambda)^2$ with the fit provided by Eq. (1) with β expressed as in the form of Eq. (3). Fig 2a shows the fit for the element tin, and Fig. 2b the fit for lead. In each case only k was varied, but in these cases and in other elements measured by Finlay et al⁶, the k values fall on a straight line relative to $A^{1/3}$ within 1.5%.

3 Summary

The recent analysis supporting the use of Ramsauer models in parameterizing neutron total cross sections has been buttressed by fitting experimental data over a wide range of elements directly. The expression used, however, does not have any parameters reflecting deformation, closed shells or isospin. Although each of these characteristics undoubtedly influences neutron total cross sections, fits to the experimental data are achieved at the 1.5% level. This form should, therefore, be useful in estimating cross sections for targets where experimental data are unavailable. The principal limitations of these fits is that they apply

only to energies above 6 MeV. The treatment of dispersion theory corrections will be needed to represent data at these low energies.

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Fig. 1. The variation of the best fit values of parameter k from Eq. (3), keeping k_1 , a and b constant, as a function of $A^{1/3}$, ranging from vanadium to uranium.

Fig. 2. Comparisons of the reduced cross section $\sigma_T / 2\pi (R+\chi)^2$ with the fit provided by Eq. (1) with β expressed as in the form of Eq. (3). Fig 2a shows the fit for tin, Fig. 2b for lead.

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