OPTICAL MODEL ANALYSIS OF NEUTRON SCATTERING FROM NIOBIUM IN THE ENERGY RANGE 7-12 MeV

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ABSTRACT

Neutron differential elastic scattering cross sections of niobium, results in the energy range 7 to 12 MeV were compared with calculated distributions using a spherically symmetric optical potential. Furthermore, a comparison with a theoretically evaluated data in addition to other similar experimental results is presented. The isospin dependence of the volume integral of the optical potential per nucleon as well as the r.m.s. nucleus radii dependence on mass number are studied.

Keywords: Nuclear reaction ^{93}Nb(n,n); E_n=7-12 MeV; deduced optical model parameters; volume integral of optical model potential, r.m.s. nucleus radii.

INTRODUCTION

Niobium is a medium weight nucleus, having a high density level, and is an available monoisotopic element. Because of its superconductivity noibium is not only used in the reactor design but also of interest as a structural material in fusion research. Numerous analysis of scattering data included the niobium target have been carried out [1-12] to extract the optical model parameters (OMP) and their dependence on both energy and mass number.

The purpose of the present work is to show a spherical optical model (SOM) interpretation for a previously measured angular distribution of elastically scattered neutrons with ^{93}Nb in the energy range 7-12 MeV [13], using the conventional WOODS-SAXON form factors and to search for a set of OMP constrained to have systematic energy dependence. Reasonable success and good agreement with the experimental data were attained.

A second aim of this work, is a simultaneous comparison between the present data and some other similar measurements [4,8,10,12] in addition to theoretically predicted data [14,15,16]. The last goal of this work, is to use the available neutron data at 8 MeV in studying the variation of the volume integral per nucleon for the real part of the SOM (J_v/A) with the asymmetry (N-Z)/A, and the evaluation of the r.m.s. radii $<r^2>^{\frac{1}{2}}$ of niobium nuclei.

EXPERIMENT

The neutron differential elastic scattering cross sections measurements were performed with TANDEM facilities in the Central Institute for Nuclear Research-Dresden, Germany, using a computer-coupled multiangle-detector time-of-flight system with eight detectors. The experimental arrangement for such measurements have been described in earlier papers [11,17]. The experimental results and data reduction are reported in details in reference [13].

SPHERICAL OPTICAL MODEL ANALYSIS

The observed angular distributions over the studied energy range are compared with the experimental results of Etemad[10] at 7 MeV, Holmoqvist and Wiedling[4] at 8 MeV, Pedroni et.al.[12] at 8,10 and 12 MeV and Ferrer et.al.[8] at 11 MeV, in addition to the predicted angular distributions of ENDF/B-6 [14], JENDL-3 [15] and CENDL-2 [16] and they are displayed graphically in Figure (1).

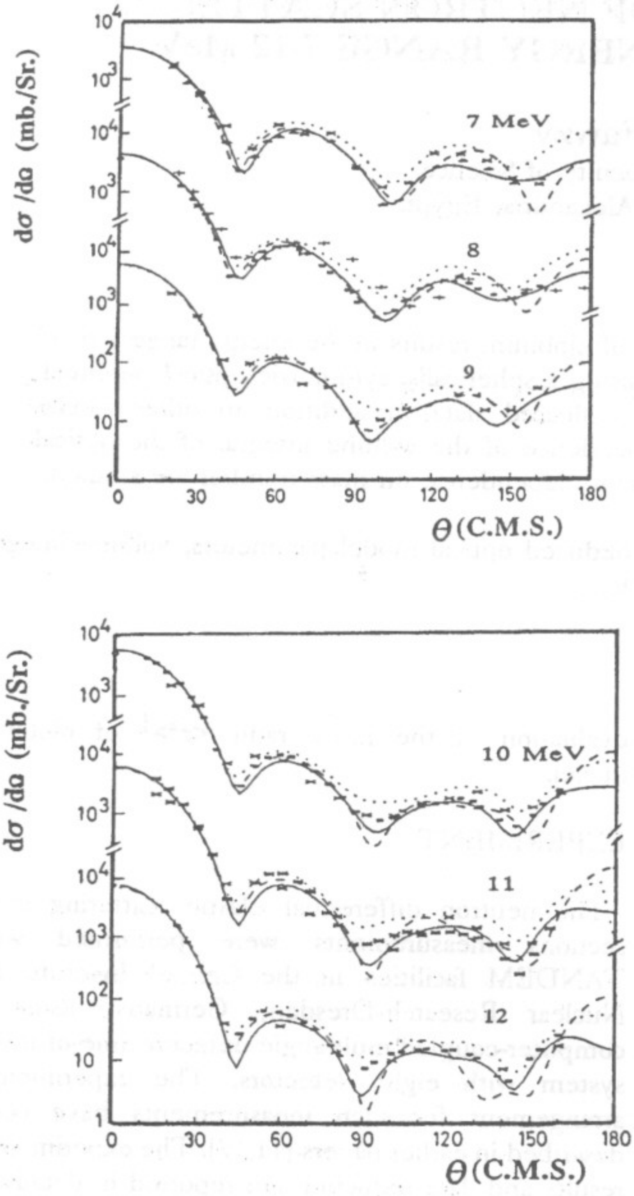

Figure 1. Angular distributions for the elastic scattering of 7-12 MeV neutrons from ^{93}Nb.

—— ENDF/B-VI

...... JENDL-3

------ CENDL-2

x this work, ▲ ref.[10], + ref.[4], ■ ref.[12] and * ref.[8].

This comparison shows that the agreement of the experimental results with evaluated distributions is acceptable but with some discrepancies. Although of these discrepancies, the values of the experimental cross sections are lying within the domain of the evaluated distributions. Furthermore, this comparison reveals a deviation between the results of Holmoqvist [4] and all the other compared result [12,14,15,16] in addition to the present data at 8 MeV. As indicated by Pedroni [12] this deviation may be attributed to the data acquisition and reduction.

The nucleus ^{93}Nb has a 9/2+ ground state and a 1/2- first excited state at 0.0304 MeV. This large angular momentum difference prevents any inelastic scattering contribution to the elastic scattering. In the studied energy region, the fast neutron elastic scattering cross sections of niobium could be described in terms of a spherical phenomenological optical model.

The used SOM has the conventional form:

$$-U(r) = +V_v f(X_R) + i W_v f(X_I) - i W_D 4 a_i \frac{d}{dr} f(X_I)$$

$$-V_{so}\ \sigma.l\left(\frac{\hbar}{m_\pi . c}\right)^2 \frac{1}{r}\frac{d}{dr} f(X_{so})$$

Where the function $f(r)$ has the usual WOODS-SAXON form:

$$f(r) = 1/\{1 + \exp((r - R)/a)\}$$

The imaginary part is the sum of volume WOODS-SAXON term and its surface-peaked derivative. The last term is the well known THOMAS spin-orbit form . Where V (or W) and a are the strength and the diffuseness of the potential SOM respectively, while the radius R is given by $R = rA^{1/3}$. In this work the OMP calculations have been acquired by using the local spherical optical model code ABAREX [18,19]. The optimum values of the used OM potential depths and their corresponding geometrical parameters in the studied energy region are listed in table(1).

Table 1. The optimum values of the OMP (depths-MeV, and geometrical parameters-fm) in the energy range E_n = 7-12 MeV

r_{VR}	a_{VR}	r_{VI}	a_{VI}	r_{DI}	a_{DI}	V_{SO}	r_S	a_S
1.21	0.75	1.20	0.48	1.20	0.48	6.00	1.21	0.55 (E_n <9MeV) 0.75 ($E_n \geq$9 MeV)

The strength of the used real and imaginary potentials could be deduced from the following linear dependence:

$$V_V = 49.95 - 0.25\ E_n$$
$$W_D = 10.20 - 0.21\ E_n$$
$$W_V = 0.00 \quad E_n < 11\ \text{MeV}$$
$$= 0.95 \quad E_n \geq 11\ \text{MeV}$$

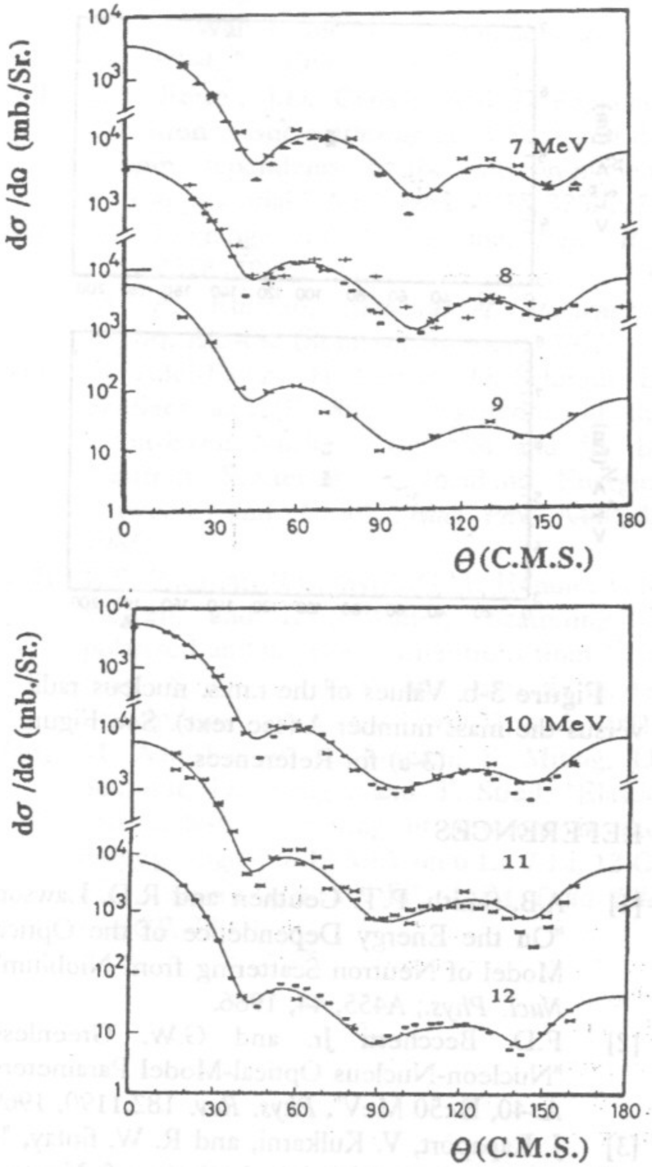

Figure 2. Angular distribution for the elastic scattering of 7-12 MeV neutrons from ^{93}Nb. Solid lines are OMP calculations with optimum values parameters. See Figure (2) for references.

The suffixes V, D, R and I are used to identify the volume, the surface derivative, the real and the imaginary parts respectively. The differential angular distributions obtained with these OMP are shown in Figure (2) and a comparison with the experimental data confirm that these parameters give a successful description of the here obtained data. Moreover, they are in a reasonable agreement with the other experimental data. The calculated cross sections reveal that the compound part is much smaller than the shape contribution and it can be neglected.

As the ^{93}Nb is a spherical nucleus, the coupled-channels effects has no important to be studied.

Considering the results reported here at 8 MeV and those of refs.[2-7,9,12], the volume integral of the real potential per nucleon(J_v/A), shows a linearly decreasing with isospin dependent. In the same time, the r.m.s nucleus radii of the volume- and spin orbit-potentials $<r_v^2>^{\frac{1}{2}}$ and $<r_s^2>^{\frac{1}{2}}$ reveals a tendency to increase linearly with the mass-number A. The same behaviour is remarkable for $<r_{vc}^2>^{\frac{1}{2}}$ which is the r.m.s radii $<r_v^2>^{\frac{1}{2}}$ if one takes into account the correction based on nuclear matter for the r.m.s radii $<r^2>^{\frac{1}{2}}$ in the nucleus surface region [21]. Figure (3-a) reproduces the linear dependence of (J_v/A) on the asymmetry (N-Z)/A at 8 MeV. A graphical representation of the linear dependance of $<r_v^2>^{\frac{1}{2}}, <r_{vc}^2>^{\frac{1}{2}}$ and $<r_s^2>^{\frac{1}{2}}$ on the mass number A is shown on in figure (3-b), and their average predicted values for ^{93}Nb are 4.96 fm, 5.20 fm and 5.46 fm respectively.

CONCLUSION

An optical model analysis of the measured neutron elastic scattering cross sections in the studied energy range shows a reasonable agreement between the experimental and theoretical results. This analysis gave comparable values for the real and imaginary potential depth to those obtained in other similar works. It is concluded that the evaluated results can make better description of the forward angles scattering results.

Studying the here obtained data and those of other global systematic analyses, one notices further that the volume integral of the real potential per nucleon has not only an energy and mass number dependence[20] but also an isospin dependence. The r.m.s. radii of the real volume- and spin orbit-potentials have a linearly increasing behaviour with the mass number A. Microscopic calculations based on the improved local density approximation of JLM [21] gave an appreciable increase in the values of the volume potential r.m.s. radii (5%). The linear dependence of the volume integral of the real potential per nucleon on the nuclear asymmetry and the r.m.s radii on the mass number can give a satisfactory test for the good fitting of the deduced OMP in case of their inclusion within the global OMP data base.

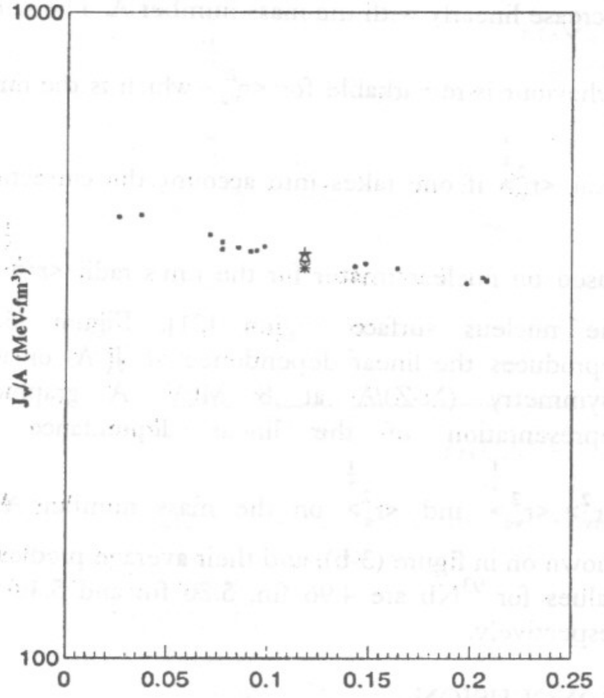

Figure 3-a. Values of the neutron volume integral per nucleon (J_v/A) obtained at E_n = 8 MeV versus nuclear asymmetry (N-Z)/A. x this work, ref.[2,5,6], Δ Ref.[9], *Ref.[3], ◇ Ref. [7], Ref. [12], + Ref. [4].

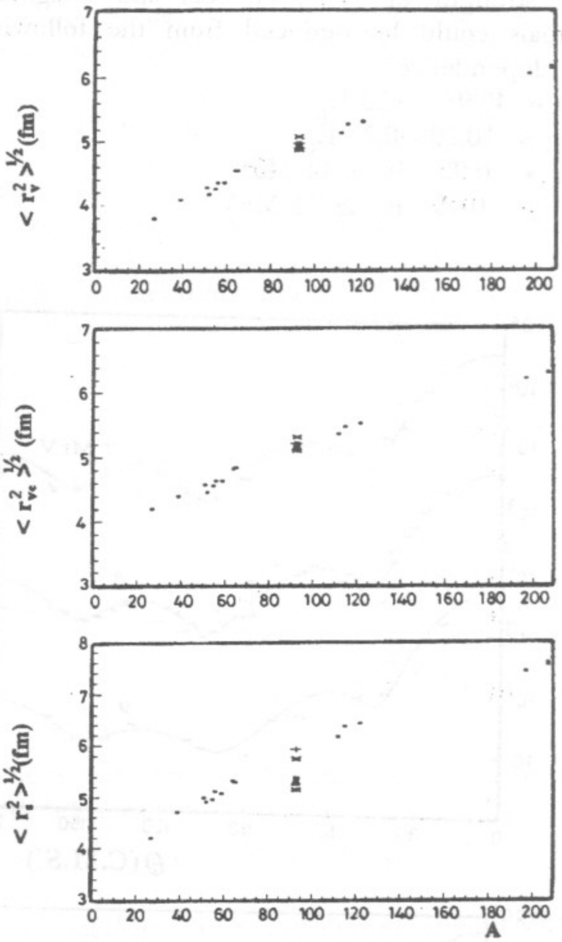

Figure 3-b. Values of the r.m.s. nucleus radii versus the mass number A (see text). See Figure (3-a) for References.

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