Vol. 38 (2007) *ACTA PHYSICA POLONICA B* No 1

OPTICAL MODEL PARAMETERS FROM A STUDY OF THE ABSOLUTE ELASTIC SCATTERING CROSS SECTIONS FROM THE ^{93}Nb (t,t) ^{93}Nb EXPERIMENT

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(Received August 22, 2006; revised version received October 18, 2006)

The absolute differential scattering cross sections have been measured from the (t,t) experiments on the ^{93}Nb at $E_t = 12$ MeV using a tandem accelerator and a multichannel magnetic spectrograph. Optical model parameters have been obtained from an analysis of the data with an optical-model search programme.

PACS numbers: 25.55.Ci

1. Introduction

Study of nuclei in the region around mass $A = 100$ has been of significant interest due to the occurrence of shape transition from spherical to deformed as a function of increasing neutron number [1–5]. A broad programme has been made to study the level structures of Nb and Mo nuclei with the (t,p) reaction. Accurate measurements of absolute elastic scattering cross sections are essential to obtain the optical model parameters which are necessary to carry out the distorted-wave Born approximation (DWBA) calculations to analyze the double stripping (t,p) experimental data from these nuclei. Triton elastic scattering data from ^{93}Nb are not so far available in the literature. The present work describes the results of the (t,t) elastic experiments on the ^{93}Nb at $E_t = 12$ MeV and the angular distributions are measured for a wide range of angles up to 180°.

2. Experimental details

12 MeV triton elastic scattering experiments were carried out using the tandem Van de Graaff accelerator at the Atomic Weapon Research Establishment (AWRE), Aldermaston with emulsion plates in the 24 angles of

the multiple gap magnetic spectrograph [6]. The spectrograph consists of 24 broad range magnetic spectrographs of Browne–Buechner [7] type and is arranged to have a common magnetic circuit. The 24 channels provide scattering angles at 7.5° intervals in the angular range 5° to 87.5° and 92.5° to 175°. In the present experiments, the triton beams were focused as a rectangular spot 1.55 mm wide and 1.0 mm high on the target. The scattering products were detected by Ilford K2 emulsion plates 50 μm thick mounted in the focal plane of each channel. The target was approximately 100 μgcm^{-2} thick. The measurements were made at 24 angles between 5° and 175°. The target was self-supporting, isotopically 100% enriched and was obtained from the Oak Ridge National Laboratory. The exposed zones of the (t, t) plates were scanned in strips 0.24 mm wide at intervals of 0.25 mm. The triton tracks in the emulsion plates were identified easily as they were clean and distinct.

3. Optical model analysis

The calculations for the optical parameters were carried out using the optical model search programme. The potential was of the form

$$\begin{aligned} U(r) \; &= \; V_{\mathrm{c}}(r) - V(1+e^{x})^{-1} + 4iW\frac{d}{dx\prime}(1+e^{x\prime})^{-1} \\ &\quad + \left(\frac{\hbar}{m_{\pi}c}\right)^{2} r^{-1}(V_{\mathrm{so}}+iW_{\mathrm{so}})\frac{d}{dr}(1+e^{x_s})^{-1}\sigma L \,, \end{aligned}$$

where $x = (r - r_0A^{1/3})/a_0$, $x\prime = (r - r_1A^{1/3})/a_1$, $x_{\mathrm{s}} = (r - r_{\mathrm{s}}A^{1/3})/a_{\mathrm{s}}$ and σ is the Pauli spin operator for nucleons. The Coulomb potential $V_{\mathrm{c}}(r)$ is due to a uniformly charged spherical nucleus of radius $R_{\mathrm{c}} = r_{\mathrm{c}}A^{1/3}$ and charge Z. The Coulomb radius was $1.3A^{1/3}$ fm. V and W are the depths of the real and imaginary potential wells, V_{so} and W_{so} are the real and imaginary depths of the spin–orbit potential. The $r_0A^{1/3}$ and $r_1A^{1/3}$ are the mean radius of the real and imaginary wells, and $r_{\mathrm{s}}A^{1/3}$ is the mean radius of the spin–orbit potential well and a is a measure of surface diffuseness. Some molybdenum optical starting parameters were inserted to initiate the search and the starting values for the search were those from Ref. [1]. The search programme was then allowed to adjust these parameters iteratively so as to minimize the quantity

$$\chi^2 = 1/N\sum^{N}[\{\sigma_{\mathrm{th}}(\theta i) - \sigma_{\mathrm{exp}}(\theta i)\}/\Delta\sigma_{\mathrm{exp}}(\theta i)]^2 \,,$$

in which σ_{th} and σ_{exp} are, respectively, the calculated and experimental values of the differential cross sections at centre of mass angle θ_i, $\Delta\sigma_{\mathrm{exp}}$ is taken as the experimental error and N is the number of experimental angles.

4. Results and discussions

The ^{93}Nb (t,t) ^{93}Nb experiments were carried out at $E_t = 12$ MeV and the multi-gap spectrograph enabled to measure the full angular distribution simultaneously over 24 angles ranging from 5° to 180°. In the (t,t) experiments on ^{93}Nb, each emulsion plate was exposed to two triton bursts. One was of 101 μC and the other was 1001 μC. The longest exposure is required to give reasonable scanning statistics at backword angles, while the shorter exposure enables groups to be countable on channels 5 to 7 (35° to 50°). On scanning the emulsion plates, groups of tracks of tritons corresponding to two bursts were distinctly observed for the forward channels (35° to 50°) and the number of tracks in two different groups on the same channel agreed well in proportion to their exposure strengths. Groups of tracks on the plates in the first four forward channels (5° to 27.5°) were too dense to scan even for the shorter burst 101 μC.

The theoretical differential scattering cross section was calculated using the formula

$$\left(\frac{d\sigma_{\rm th}}{d\Omega}\right)_{E,L} = \frac{1.2958 Z^2}{E_L^2 \sin^4 \frac{\theta}{2}} \quad \text{mb/sr} \tag{1}$$

where Z is the target atomic number, E is the triton energy in MeV and θ is the scattering angle. The experimental cross sections at different angles were equated with the theoretical cross sections at the corresponding angles and a factor K was obtained by using the equation [8]

$$\frac{(d\sigma/d\Omega_{E,L})}{(d\sigma_{\rm th} d\Omega_{E,L})} = K \tag{2}$$

which converts the observed cts/μC into mb/sr. The mean value of K was found to be 0.046 mb$\times\mu$C/sr$\times$cts. The absolute differential scattering cross sections at 12 MeV were obtained using the relation

$$(d\sigma/d\Omega_{E,L})_{12,L} = K \times (\text{cts}/\mu\text{C})_{12}\,. \tag{3}$$

The ratio $\sigma(\theta)_{\rm c.m.}/\sigma_{\rm Ruth}$ is actually of greater signifficance than the differential scattering cross sections itself and so this ratio is found at different angles. The peak value of the experimental cross section at 36.10° was normalized with the peak value of the differential cross section predicted by optical model at the same angle and a normalization is obtained.

Adjustment of optical-model parameters was done automatically by the programme in order to minimize the value of χ^2. The absolute values of the differential cross sections obtained by minimizing χ^2 are shown in Table I. The results are plotted in Fig. 1. Figure 1 shows the variation of the absolute values of differential cross section with the center mass angles. The circles with error bars represent differential cross section and the smooth curve gives the best fit to the data points obtained from optical model calculation. The triton optical-model parameters obtained from an analysis of the absolute differential cross sections are shown in Table II. The values of the parameters obtained in the present work could not be compared with previous data as any other (t,t) work on ^{93}Nb was not available. However, the parameters obtained from the (t,t) scattering at 20 MeV on ^{94}Zr are in reasonable agreement [9] with the present values.

TABLE I

Absolute differential cross sections from the $^{93}\mathrm{Nb}(t,t)\,^{93}\mathrm{Nb}$ experiment.

No.	Angle $\theta_{\mathrm{c.m.}}$	$\frac{(d\sigma/d\Omega)_{\mathrm{c.m.}}}{(d\sigma/d\Omega)_{\mathrm{Ruth}}}$
1	36.10	0.596 ± 0.002
2	43.70	0.455 ± 0.003
3	51.40	0.334 ± 0.005
4	59.00	0.286 ± 0.007
5	66.70	0.232 ± 0.010
6	74.20	0.202 ± 0.013
7	81.80	0.141 ± 0.018
8	89.30	0.111 ± 0.024
9	94.30	0.108 ± 0.026
10	101.80	0.104 ± 0.030
11	109.30	0.082 ± 0.038
12	116.70	0.067 ± 0.047
13	124.00	0.057 ± 0.055
14	131.40	0.057 ± 0.058
15	138.70	0.052 ± 0.064
16	146.00	0.040 ± 0.077
17	153.30	0.041 ± 0.078
18	160.60	0.038 ± 0.084
19	167.90	0.033 ± 0.092
20	175.10	0.031 ± 0.095

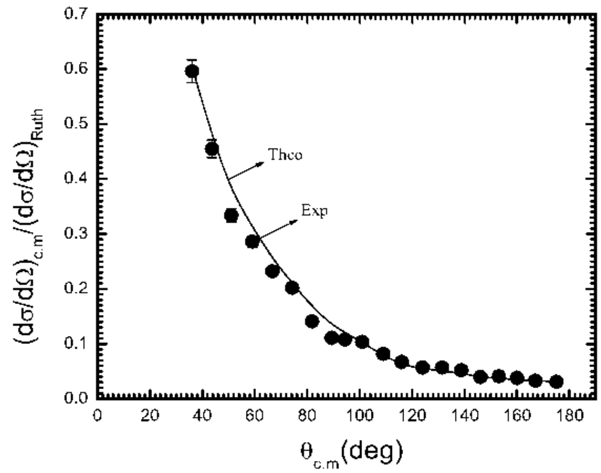

Fig. 1. Elastic scattering of triton from ^{93}Nb.

TABLE II

Triton optical model parameters.

V (MeV)	r_0 (fm)	a (fm)	W (MeV)	r'_0 (fm)	a′ (fm)	V_{so} (MeV)	W_{so} (MeV)	r_s (fm)	a_s (fm)
157.10	1.241	0.667	16.50	1.530	0.798	8.340	1.018	1.588	0.334

5. Conclusion

The absolute differential cross sections are measured from the (t, t) experiment on ^{93}Nb at $E_t = 12$ MeV and the optical model parameters were obtained from an analysis of the data using an optical-model search programme. The triton parameters would be useful in carrying out distorted-wave Born approximation calculations in the double stripping (t, p) reaction on Nb nuclei.

The author likes to thank the operating staff of the tandem accelerator at AWRE, Aldermaston for their cooperation. He is grateful to the University of Bradford for financial support and to S.M. Dalgliesh, Dr. W. Booth and Prof. G. Brown for their valuable help and advice. He would also like to thank the staff of IIT, Dhaka University and Mr. Ashrafur Rahman of the Bose Centre for their help with the optical search programme.

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