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Thickness measurement of ^{10}B and ^{11}B targets using the alpha transmission method

D.T.K. Linh[1], L.X. Chung[1*], L.T. Anh[1], N.T. Anh[2], T.T. Anh[3], M.V. Dien[1], B.T. Hoa[3], P.D. Khue[1], N.T. Nghia[3], and D.T. Tran[4]

[1]*Institute for Nuclear Science and Technology, VINATOM, 179 Hoang Quoc Viet, Hanoi, Vietnam;*
[2]*Hanoi Irradiation Center, VINATOM, 2PXV+473, QL32, Minh Khai, Hanoi, Vietnam;*
[3]*Faculty of Physics, VNU-University of Science, 334 Nguyen Trai, Ha Noi 100000, Vietnam;*
[4]*Institute of Physics, VAST, 18 Hoang Quoc Viet, Hanoi, Vietnam.*

Abstract: Experiments were performed to measure the thickness of ^{10}B and ^{11}B targets using the α-transmission method. These targets were prepared at INFN. A ^{241}Am source provided α particles of 5.486 MeV energy. The results were compared with the supplier's values, showing a good agreement in thickness for the ^{11}B target, while the results for the ^{10}B target were reasonable within the uncertainty range.

Keywords: *target thickness, boron target, α-transmission method.*

I. INTRODUCTION

The information on the target thickness and more precisely the number of particular nuclei per unit area of the target is one of the crucial factors in determining the differential cross-section of nuclear reaction. Usually, this information is the main uncertain source of the cross-section. There are several methods to measure the target thickness including (i) the charged particle transmission method, usually alpha particle [1]; (ii) measurement of the width of resonance from the yield of γ-ray as a function of incident beam energy [2]; (iii) measurement of the elastically scattered light projectiles (alpha or proton particles) based on the known cross-section, especially with Rutherford scattering [1, 3-4]; (iv) weighing; (v) optical method; (vi) chemical method; and so on.

Recently, studies on measuring nuclear reaction cross-sections with online particle detection induced by accelerated beams have been carried out utilizing the Pelletron 5SDH-2 accelerator at VNU-University of Science (HUS) [5-6]. The target thickness information in [5-6] was provided by the supplier with a 10% uncertainty, which resulted in large uncertainties in the obtained cross sections. To verify and proactively assess the target thickness, this report presents the measurement of the 10B and ^{11}B targets by using the α-transmission method. These targets were produced at the National Institute for Nuclear Physics (INFN), in Italy. According to the supplier, these targets' thickness and enrichment are 67.0 ± 6.7 and 76.0 ± 7.6 μg/cm^2, and 90 % and 99 %, respectively, sitting on a 4 μg/cm^2 thick formvar ($C_3H_6O_2$) substrate.

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II. ALPHA TRANSMISSION METHOD

In this method, the target thickness is determined as described in [7]:

$$t = R[A, Z, E(0)] - R[A, Z, E(t)] \quad (1)$$

where, A and Z are the atomic and charge number of the (alpha) ion passing through it. R, E(t), and E(0) are the range in target material ($\mu g/cm^2$), and the ion energies (MeV) before and after passing through it, respectively. For convenience, the unit of t is $\mu g/cm^2$. To convert to μm unit, one can simply divide it by the material density (in $\mu g/cm^3$).

The range of the ion, R, can be calculated by using software or associated with stopping power. For the former, a semi-empirical formula as a function of the mass, charge, and energy of the particle has been developed in [7]

$$R(A,Z,E) = k\frac{A}{Z^2}E^{\gamma} + CA \quad (2)$$

where, E is the energy of the charged particles. *k*, γ, C are constants depending on the material. For the latter, the relation between R and stopping power S, in MeV/μm, is [8]:

$$R(E) = \int_0^{E_0} S^{-1}\, dE \quad (3)$$

The stopping power was experimentally measured and tabulated, for example in [8]. The uncertainty of R is typically 5% [8]. The most well-known software that concerns the stopping power and range of ions in matter is SRIM [9].

In the next section, the experiments to measure the residual energy *E(t)* of α particles after passing through the target will be presented. Combining with the initial energy *E(0)*, its thickness will be extracted using the SRIM code [10].

III. EXPERIMENTAL SETUP

The experimental setup with a target tilted angle (θ) of 30° is schematically presented in Fig. 1. All the setups were placed inside a vacuum chamber operated at 10^{-6} torr. Three experiments with θ of 30°, 10°, and 0° were performed for the ^{11}B target, while two with θ of 30° and 10° were carried out for the case of ^{10}B. The purpose of using different angles was to take into account the target homogeneity.

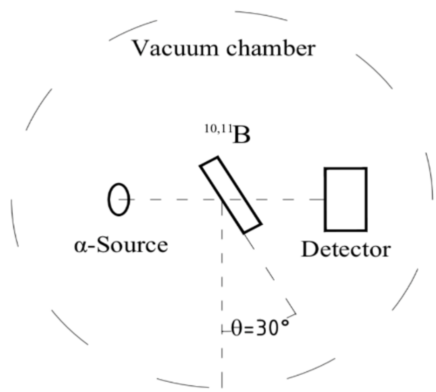

Fig. 1. Experimental setup to measure target thickness. The target tilted angle θ is 30°. Detail is explained in the text.

A ^{241}Am α-source was used, and its four most intensive energies are tabulated in Tab. 1. The 5.486 MeV particles with the highest branching ratio of 84.5% were used in the present analysis.

Tab. 1. The most intensive α-energies emitted from the 241Am α-source [11]

E (MeV)	Branching ratio (%)
5.388	1.6
5.443	13.1
5.486	84.5
5.544	0.3

These targets were placed in the middle of the source and the detector, with a distance of 12.8 cm between them. One S3590–09 Hamamatsu Silicon PIN diode detector was used.

An 8 mm diameter collimator was mounted in front of it to avoid the edge effect. The detector's reverse voltage was set to +100 V. This configuration allowed good collimation of the α particles reaching the detector. The electronics for pulse shaping and data acquisition (DAQ) were developed based on VME modules. More details about the detector and the DAQ system are reported in [12].

IV. RESULT AND DISCUSSION

The energy spectrum of the source is shown in Fig. 2. To obtain the energy resolution, the whole spectrum was fitted by the sum of 4 Gaussian functions. The quality of the fit is shown as a solid line.

For the main peak, the Full-Width-Half-Magnitude (FWHM) is equal to 23 keV corresponding to an energy resolution of 4.2%, consistent with the value reported in [12] for this detector type. The alpha source was also used for the DAQ energy calibration.

Fig. 3 presents the energy spectra detected with perpendicular and rotated ^{10}B and ^{11}B targets. The above fitting method was also applied to determine the main peak centroid (or particle energy). The target thickness was determined using the method described in Section II and the SRIM code [10]. The distance from the peak centroid and the dotted lines in Fig. 3 corresponds to the energy shift ΔE of α particle after passing through the target. The results are tabulated in Tab. 2 and graphically compared with the supplier's values in Fig. 4.

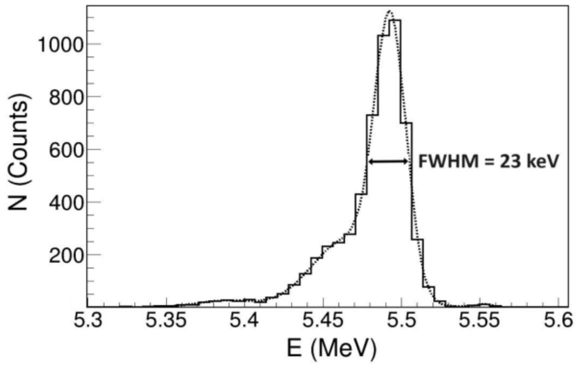

Fig. 2. The α-energy spectrum of the ^{241}Am source. The dashed line is the fit of the spectrum.

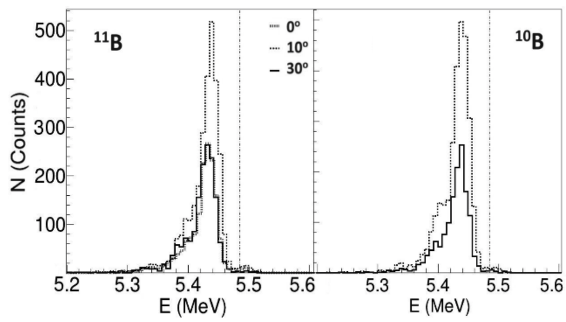

Fig. 3. The α-energy spectra after the ^{10}B and ^{11}B targets with different rotational angles. The spectral magnitudes are due to statistics. The vertical dotted line is plotted at 5.486 MeV.

The present results are 13.7% and 9.1% underneath the values from the supplier for the case of ^{10}B and ^{11}B, respectively. Taking into account the uncertainty, the present ^{11}B target thickness is in good agreement with the supplier. Meanwhile, a small overlap range of the ^{10}B target thickness values obtained by the two cases is observed, see Fig. 4.

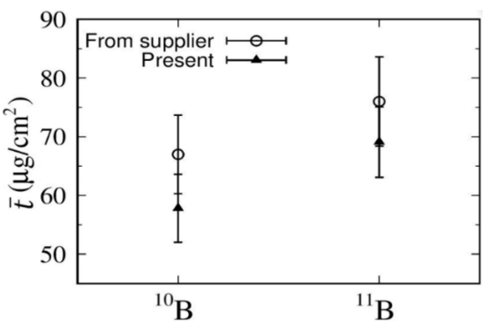

Fig. 4. Target thickness comparison.

Table 2: The ^{10,11}B target thickness determined by the α-transmission method.

Target	θ (deg.)	ΔE (keV)	t (μg/cm^2)	$\bar{t}$ (μg/cm^2)	
				Present	From supplier
^{10}B	10	45.3 ± 1.37	59.9 ± 4.2	57.8 ± 5.8	67.0 ± 6.7
	30	47.9 ± 1.4	55.6 ± 3.9		
^{11}B	0	50.5 ± 1.3	73.6 ± 5.2	69.1 ± 6.0	76.0 ± 7.6
	10	46.0 ± 1.3	66.5 ± 4.7		
	30	53.2 ± 1.3	67.1 ± 4.8		

The lower values obtained by present measurements can come from the following sources. First, the present method is highly sensitive to the parametrization for stopping power S in equation (3), which was based on experimental data [8]. The typical uncertainty is 5 % [8, 9], which was used in the present analysis, but there are cases where the uncertainty is in the 5-10 % range [8]. Secondly, the present work was performed at the end of the other experiments (p+^{10,11}B) using the same targets. This led to the evaporation of the organic formvar substrate due to being heated up, which was not accounted for in the present analysis. As a result, the target thickness was underestimated.

V. CONCLUSION

The thicknesses of ^{10}B and ^{11}B targets prepared at INFN were measured by using the α-transmission method. The obtained 10B target thickness is 57.8 ± 5.8 μg/cm2 overlapping with the uncertainty range of the 67.0 ± 6.7 μg/cm2 value provided by the supplier, while the obtained ^{11}B target.

The present work demonstrates that the α-transmission method is appropriate for measuring the target thickness is. Further studies with mixed α sources, providing different isolated energies, are planned to improve the method's precision.

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