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Differential elastic scattering cross sections of protons from Al in 2.4–4.8 MeV energy range

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Abstract Measurement of differential elastic cross section of protons from aluminum was taken at 165° degree in the 2.4–4.8 MeV energy range. The results and measured energy resonances were compared with reported measurements. These data will improve the reliability of backscattering analysis of Al with protons in this energy region.

Keywords Proton elastic scattering · Scattering cross sections · Aluminum

1 Introduction

The application of proton elastic scattering at backward angles for ion beam analysis of light elements is an important tool because of its advantage of large depth probing sensitivity and enhancement of scattering cross sections in general and particularly for energies corresponding to isobaric analog states of the compound nucleus. Earlier measurements of proton scattering from aluminum by Elliot et al. [1] and Mehta et al. [2] were taken with a view to study nuclear reaction mechanism. Nelson et al. [3] reported high energy resolution measurements on Si in 0.92–3 MeV proton energy range with a view to study nuclear structure of ^{28}Si in the region above the binding energy of proton. Rauhala et al. [4] carried out study on proton backscattering from aluminum and titanium in energy range of 1–2.5 MeV and computer data analysis in the non-Rutherford energy region at laboratory angle of 170°. Chiari et al. [5] reported measurements of proton elastic scattering cross section on aluminum in the 0.8–3 MeV energy range at several angles in the backward direction. Li et al. [6] reported proton elastic scattering cross-sectional measurement of protons in the 0.96–2.74 MeV energy range at 160°. Ramos et al. [7] carried out elastic scattering cross-sectional measurement on aluminum at 140° and 178° laboratory scattering angles in the 0.5–2.5 MeV energy range. Siketic et al. [8] reported measurements in an extended energy range of 2.4–5 MeV at 120°, 150° and 165° laboratory angles.

In this paper, we report measurements of proton elastic scattering cross section on aluminum in the 2.4–4.8 MeV energy range at 165° as our silicon detector for the IBA system is fixed at 165°. Our measurements in 3–4 MeV energy range will supplement the only available measurements of Siketic et al. [8] in this energy region and help in the evaluation of the data as undertaken by Gurbich [9]. This measurement will lend confidence to improve reliability of elastic backscattering analysis of ^{27}Al with protons.

2 Experimental details

The measurement was taken using the 5 MeV Pelletron tandem accelerator facility of National Centre for Physics (NCP), Quaid-i-Azam University Islamabad. Some details

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of our facility are given in Ref. [10] and support the validity of the measured cross sections. The calibration of the 5 MV tandem accelerator facility at NCP was done by using oxygen resonance on glass as a target and comparing the results to the aluminum foil. We have two end stations, one at 15° and other at 30°. We use 15° end station for material science research and 30° for nuclear reaction analysis. The 30° end station is equipped with moveable silicon surface barrier detector with a resolution of 23 keV (FWHM).

Targets were prepared by PVD (physical vapor deposition) technique by evaporating aluminum onto gold foils of 159 nm thickness. The sputtered aluminum was of 200 nm thickness. The back-scattered protons were detected with a silicon detector subtending a solid angle of 0.234 mSr at the sample. The target samples were prepared at Pakistan Institute of Nuclear Science and Technology (PINSTECH), Nilore. The thickness of gold and aluminum layers constituting the sample was determined with RBS technique using 2.5 MeV alpha particles with an accuracy of 3 %.

Experiment was carried out at the 30° end station. The beam current was 30 nA during the experiment, and collected charge was 20 μC. The collimator used in the experiment was 2 mm which makes a spot of 3 mm on the target sample. The variation in the energy was about ±3 keV. The scattering chamber at the 30° end station is of stainless steel, and pressure in the scattering chamber was down to 1×10^{-7} torr during experiment. The chamber is equipped with two moveable solid-state surface barrier Si detectors with resolution of 23 keV (FWHM). The proton scattering cross section for aluminum was determined through normalization using the scattering cross section of gold assuming it to be due to Rutherford scattering process. In the calculation of Coulomb scattering of protons from gold, the energy loss in aluminum was taken into account as the aluminum was facing the beam. The proton scattering cross section from aluminum was calculated using the following formula.

$$d\sigma_{Al}/d\Omega = (d\sigma_{Au}/d\Omega)\,(A_{Al}/A_{Au})\,(N_{Au}/N_{Al})$$

where A_{Al} and A_{Au} are counts in the elastically scattered proton peaks from aluminum and gold, respectively, and N_{Al} and N_{Au} are number of atoms per unit area of aluminum and gold layers of the scattering samples, respectively. The normalization of the proton scattered cross section to gold eliminates correction due to dead time and uncertainty of the solid angle. The overall uncertainty of the cross section amounted to about 5 %.

3 Results and discussion

A typical experimental spectrum and simulation of the elastically scattered protons from target sample is shown in Fig. 1 using SIMNRA software [14].

The measured elastic scattering cross sections in the 2.4–3 MeV energy range are shown in Fig. 2 and compared with reported measurements of Chiari et al. [5] and Siketic et al. [8] at this angle. The numerical data for comparisons were taken from IBANDL [11]. The proton energy of the corresponding peak, and structure, are shown in the figure. The shoulders and structures arise from the fact that levels are very closely packed and cannot be resolved.

The very strong and characteristic resonance at 2.875 MeV arises from the excitation of $T = 1$ isobaric analog state at 14.36 MeV in ^{28}Si, corresponding to the 5.17 MeV state in ^{28}Al [12]. There is in general good agreement of the present measurement with the reported measurements. Our peak cross section of 2.875 MeV resonances agrees with the measurement of Chiari et al. [5].

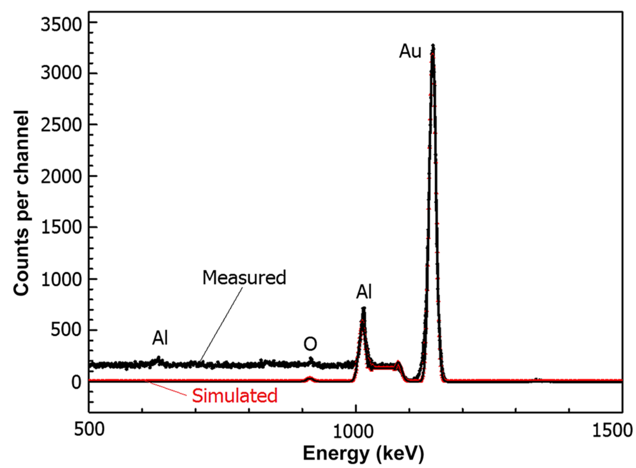

Fig. 1 Experimental and simulated spectrum of 2.887 MeV proton scattered at 165° from aluminum target using SIMNRA software

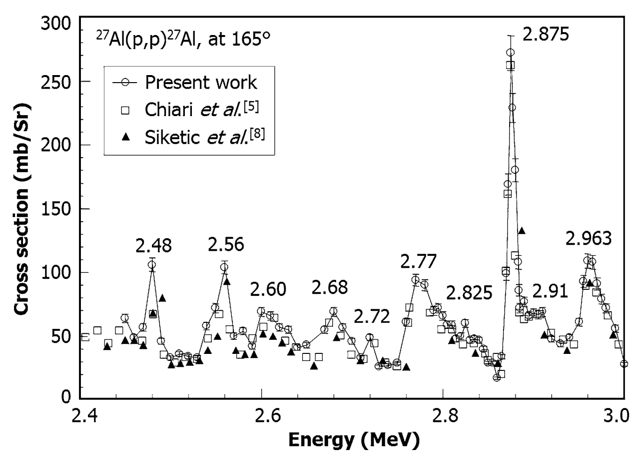

Fig. 2 Comparison of p+Al elastic scattering cross section from the present work with Siketic et al. [8] and Chiari et al. [5] data, in the energy range of 2.4–3 MeV

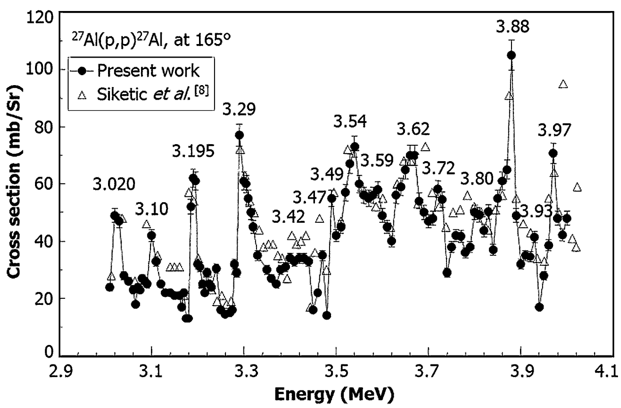

Fig. 3 Comparison of p+Al elastic scattering cross section from the present work with Ref. [8] data, in the energy range 3–4.8 MeV

Table 1 Comparison of observed and reported energy levels in ^{28}Si

Proton energy (MeV)	Energy level in ^{28}Si (MeV)	Reported energy level in ^{28}Si (MeV)[13]
3.020	14.498	14.493
3.100	14.574	14.572
3.195	14.665	14.650
3.290	14.758	14.762
3.420	14.883	14.897
3.470	14.931	14.926
3.490	14.950	14.954
3.540	14.999	15.006
3.590	15.048	15.051
3.620	15.076	15.076
3.720	15.172	15.182
3.800	15.249	15.250
3.880	15.326	–
3.930	15.375	15.385
3.970	15.413	15.402

The present measurement of the proton scattering cross section for 3–4.8 MeV is shown in Fig. 3 and compared with the only available measurement of Siketic et al. [8].

In order to gain confidence in our measurement, we thought it is advisable and informative to correlate the observed proton resonance structure with the available nuclear structure information on ^{28}Si [13]. We have labeled the resonance structure with the corresponding proton energy. The detailed information is given in Table 1. The first column of the Table 1 shows proton resonance energy, the second column shows the corresponding excitation energy in ^{28}Si, and the third column shows the nearest reported [13] excitation energy in ^{28}Si. There is very good agreement of the measured resonances with reported measurements. The 3.88 MeV resonance corresponding to the excitation of 15.326 MeV state in ^{28}Si is being reported for the first time. This resonance has been seen in the present measurement of Al as well as in the measurement reported by Siketić et al. [8].

4 Conclusion

Proton elastic scattering cross sections on aluminum have been measured in the 2.4–4 MeV proton energy range. The results have been compared with reported measurements. The observed resonance structure in the 3–4 MeV energy range has been correlated with possible energy levels in ^{28}Si. The data could be helpful in IBA techniques and could be uploaded at IBANDAL.

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