Proton induced reactions of ^{27}Al at low energies

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Introduction

Study of low energy proton induced reactions has several important implications for basic and applied nuclear physics and astrophysics research.

In the main sequence stars, proton- proton (p-p) cycle and CNO (carbon-nitrogen-oxygen) cycle are the main sources of energy production. The astrophysical reaction rate is greatly affected by the resonance reactions occurring in the stellar environment. The nucleosynthesis in hydrostatic hydrogen burning not only involves nuclei in the CNO mass range, but also heavier nuclei in the mass A = 20–40 range, like ^{23}Na, ^{27}Al, ^{31}P, and ^{35}Cl. The most likely processes involved are β-decays, (p,γ) and (p,α) reactions. The competition between these processes determines the resultant path of nucleosynthesis [1]. Low energy proton induced reactions on stable nuclei thus play significant role. For unstable target nuclei, these reactions have competing β-decays, which are much faster.

The characteristic temperature of hydrostatic hydrogen burning is ≈ 55 MK. The Gamow peak for the ^{27}Al + p reactions is located at $E_0 \pm \Delta/2$= 95 ± 25 keV [1]. At these energies, the limits of the estimated ratio of the rates of (p,γ) and (p,α) reactions range from about 0.04 to 100 for ^{27}Al. Thus the uncertainties do not permit an unambiguous conclusion regarding the existence of a MgAl cycle [1].

So far, none of the relevant reaction rate has been measured at such low energies. To estimate the total reaction rates at these energies, precise and elaborate measurements at higher energies are warranted to determine yields from as many different resonant and non-resonant reaction components as possible (narrow resonances, broad resonances, and direct processes) [1, 2].

On the application domain, particle induced gamma-ray emission (PIGE) is an analytical technique sensitive to the isotopic concentration of elements in surface regions of solids [3]. In this technique, characteristic prompt gamma-rays of different relevant nuclear reactions during the bombardment of targets by a few MeV proton beam are detected. PIGE is particularly suitable for estimating light elements present as compared to heavy ones since the Coulomb barrier increases with increasing atomic number. Cross-section measurement through gamma detection from thick targets are therefore useful for nuclear astrophysics as well as for PIGE [3].

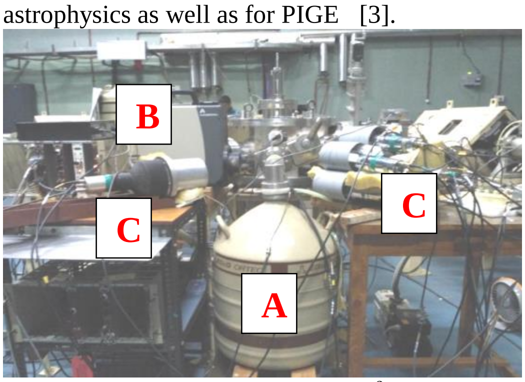

Fig. 1 A) HPGe detector at 0^o, B) BEGe FALCON detector at 90^o, C) NaI(Tl) detectors.

In the present work, low energy proton induced reactions of ^{27}Al has been studied in the energy range (~2.8 - 3.4 MeV). Gamma spectroscopic measurements have been performed (Fig. 1,2). A thick target of ^{27}Al (~3 mm) has been bombarded with proton beam of varying energies to determine the excitation function of different reaction channels (Fig. 3). At these energies, variation of the yields of characteristic gammas (Fig. 2) from different reaction channels, like, ^{27}Al(p,p′γ), ^{27}Al(p,αγ)^{24}Mg and ^{27}Al(p,γ)^{28}Si have been determined for same charge deposited. This experiment was primarily meant to test the possibilities of utilizing the low energy accelerator at Institute of Physics, Bhubaneswar for such measurement.

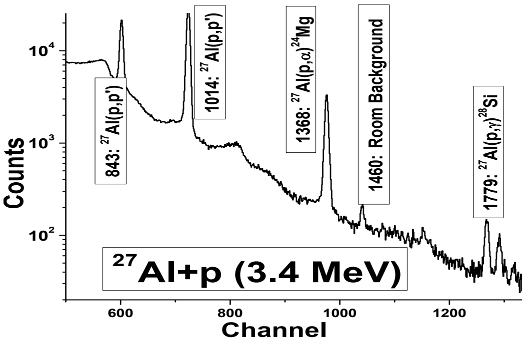

Fig. 2 Spectrum taken by HPGe detector at 0°

Experimental Setup, Analysis and Results

The measurements were carried out at Institute of Physics (IOP), Bhubaneswar. The Ion Beam Laboratory of IOP consists of a NEC model 9SDH -2 tandem Pelletron accelerator with 3MV terminal voltage.

The Al target was placed at the end flange of the 0° beam line. The proton beam energy has been varied from 2.8 MeV to 3.4 MeV. The total charge accumulated at the Faraday cup was noted down after each run. A HPGe detector (~20% efficiency) was placed at 0° w.r.t the beam direction. Another BEGe (broad energy) detector (FALCON) of almost similar efficiency, with ultra-low micro phonic electrical cooling system was placed at 90° (see Fig.1). A few NaI(Tl) detectors were also used to detect high energy gammas with better efficiency. CAEN digitizers and GENIE - 2010 software were used for the data acquisition. For the detector calibration, ^{60}Co, ^{137}Cs and other radioactive sources were used. The typical gamma-ray emission spectra collected with 3.4 MeV incident proton beam on thick targets of Al is shown in Fig. 2. The gamma rays of interest are ^{27}Al (p,p′γ) (E_γ = 844 and 1014 keV), ^{27}Al (p,αγ) ^{24}Mg (E_γ = 1368 keV) and ^{27}Al (p, γ) ^{28}Si (E_γ = 1779 keV). In Fig.3, the excitation function for the variation of beam energy from 3.330 MeV to 3.390 MeV has been shown.

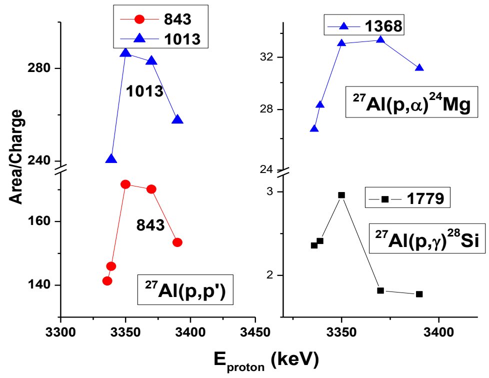

Fig. 3 Excitation function of relevant channels.

Conclusion and Future plan

In this restricted energy range, the (p,α) reaction rate appears to be substantially larger than the (p,γ) channel. The results demonstrate the possibility of such measurements at this centre in larger energy domain and higher precision in future. Further analysis will be done to demonstrate the advantage of utilizing the scintillator detectors for these measurements with light element targets.

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References

[1] Christian Iliadis, Nuclear Physics of Stars, Wiley-VCH Verlag GmbH & Co. KGaA, Boschstr. 12, 69469 Weinheim, Germany, 2015.
[2] R. Timmermann *et al.*, Nucl. Phys. A 477, 105 (1988); A.E. Champagne *et al.*, Nucl. Phys. A 487, 433 (1988); A.E. Champagne *et al.*, Nucl. Phys. A 459, 239 (1986).
[3] A. Jokar *et al.*, Nucl. Instr. Meth. in Phys. Res. B 394, 28 (2017) and references therein.