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Measurement of proton induced γ-ray emission cross sections on Al from 2.5 to 4.1 MeV

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ABSTRACT

Differential cross section for proton induced γ-ray emission from the reaction ^{27}Al(p,p′γ)^{27}Al (E_γ = 844 and 1014 keV) were measured for proton energies from 2.5 to 4.1 MeV, at 90° and 45°, using a 29 μg/cm^2 Al target evaporated on a self-supporting thin Ag film. The γ-rays were detected by two HPGe detectors with nominal 50% and 25% relative efficiency, respectively for the detector placed at 90° and at 45°. Absolute γ-ray differential cross sections were obtained with a method not dependent on the absolute values of the collected beam charge; the overall uncertainty was estimated to be better than 8%, at both angles and at all the beam energies.

1. Introduction

Particle induced γ-ray emission (PIGE) technique with proton beam is commonly used for the analysis of light elements in the materials, typically as a complementary technique to proton induced X-ray emission (PIXE). In particular, in the study of atmospheric aerosols, PIGE measurements of aluminum [1] can be used to assess and to correct the underestimation of PIXE in quantifying the concentration of the low-Z crustal elements, like Na, Mg, Al and Si, due to X-ray self-absorption inside the aerosol mineral dust particles (dimensions up to several micrometers), in order to obtain a quantitative analysis of the dust aerosol load [2].

Accurate and reliable values of the cross sections for prompt γ-ray emission are needed for quantitative PIGE analysis not relying on the use of reference standards [3]. A few papers have been published, also in recent years, on the measurements of proton induced γ-ray emission on Al, both as differential cross section [4] or thin target yield [5], in the proton energy range suitable for PIGE analysis, up to several MeV. These cross-section data are measured with an energy step often exceeding the energy loss of the proton beam in the employed target, possibly missing some fine structures in the cross section.

In order to provide basic data for practical applications of PIGE in ion beam analysis, this paper deals with the measurements of differential cross sections for proton induced γ-ray emission from the reactions ^{27}Al(p,p′γ)^{27}Al (E_γ = 844 and 1014 keV) in the proton energy range 2.5–4.1 MeV, at angles 45° and 90° in the laboratory frame of reference.

2. Experimental

The experimental work was conducted at the HVEE 3 MV Tandetron accelerator at the INFN LABEC laboratory in Florence [6]. The measurements were performed at proton energies from 2.5 to 4.1 MeV in steps from 3 to 10 keV. The proton beam energy was calibrated using an aluminum thick target and the resonances at 991.86 keV (Γ = 70 eV) and 1683.57 keV (Γ < 0.2 keV), respectively in the (p,γ) and (p,p′γ) reactions on ^{27}Al [7], and a native aluminum oxide thin target and the resonances at 2876 keV (Γ = 4 keV) and 3470 keV (Γ = 1.53 keV) in the proton elastic scattering, respectively on ^{27}Al [7] and ^{16}O [8]. A fit to the four calibration points using a linear relation between the proton energy (E) and the set terminal voltage (TV), $E = 2 \cdot a \cdot TV + b$ gave the results a = 1.0002 ± 0.0007 keV/kV and b = 12.1 ± 1.5 keV (cov(a,b) = −0.890); after the calibration the proton beam energy is thus known better than 0.1%.

The measurements were carried out using a scattering chamber installed on the +30° line of the accelerator. After the accelerator tank, the beam is focussed by an electrostatic quadrupole triplet and then defined in size by a remote-controlled 4-sectors slit, before being directed into the +30° beamline by the switching magnet; a magnetic quadrupole doublet located half-way along the line, 3.5 m upstream of the target, focuses the proton beam to

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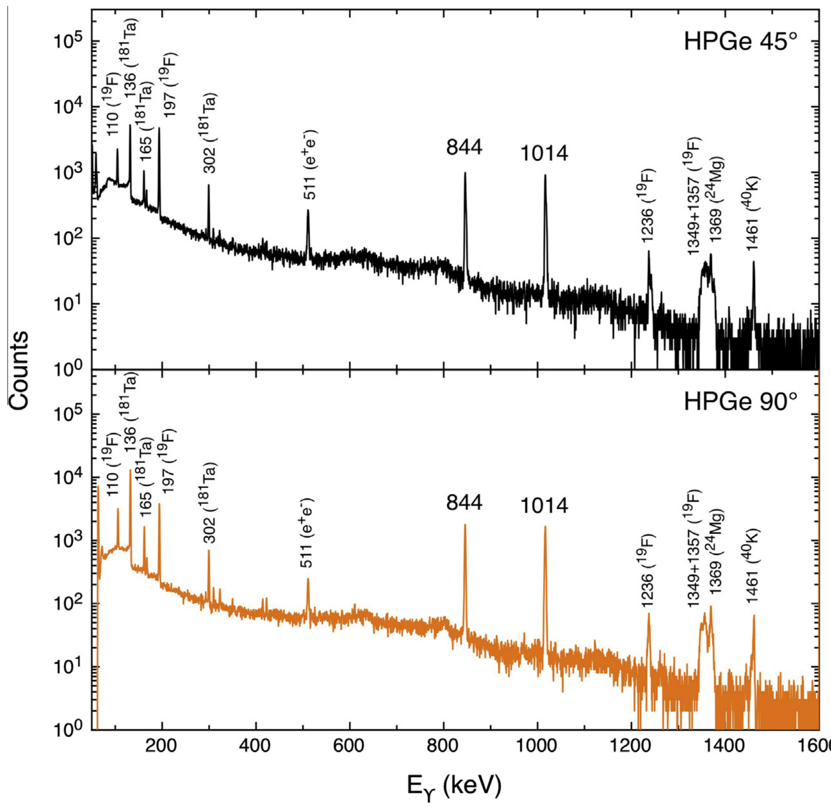

Fig. 1. Gamma-ray emission spectra collected simultaneously at 45° and 90° bombarding the Al/Ag target with 3.3 MeV protons. Contributions from fluorine impurities in the target, from the Ta in the Faraday cup and from natural radiation are visible in the spectra.

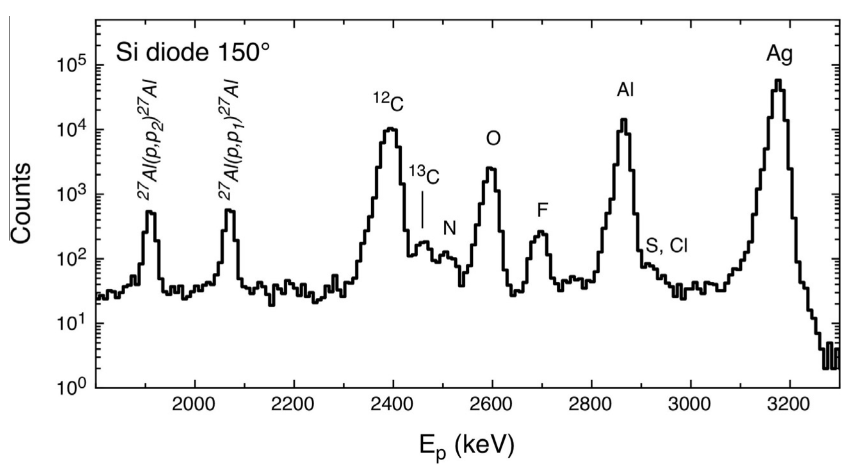

Fig. 2. Proton scattering spectrum obtained at 150° by bombarding the Al/Ag target with 3.3 MeV protons, collected simultaneously with the gamma-ray emission spectra. Contributions from target impurities (mostly C, O and F, and to a minor extent S and Cl), are visible in the spectrum.

dimensions of $1.0 \times 1.0\ mm^2$ on the target. A pair of steering magnets is set 1.5 m upstream of the quadrupole doublet to finely align the beam along the magnet axis; another pair of steering magnets is placed after the quadrupoles to ease the transport of the beam into the scattering chamber through a 3 mm circular Ta collimator located at the entrance of the chamber. The vacuum pressure in the chamber was as low as 1×10^{-6} mbar and pumping was accomplished by means of an hydrocarbon-free system consisting in a dry turbo-molecular pump backed by a scroll fore-pump.

The target was prepared at the IST/ITN in Lisbon and consisted in a 29 $\mu g/cm^2$ Al film evaporated on a self-supporting 102 $\mu g/cm^2$ Ag; in order to obtain the differential cross-sections, we normalized the results by the Rutherford elastic backscattering of protons from Ag, adopting a procedure [9–12] not relying on the knowledge of the absolute number of incident protons (see below). The proton energy loss in the Al target ranged from 2 to 3 keV [13].

The γ radiation was detected by two HPGe coaxial detectors, of nominal efficiency 50% and 25%, and energy resolution 2.0 keV for 1.33 MeV, placed outside the target chamber (behind 2 mm thick stainless steel flanges) at angles of 90° and 45° to the beam axis, respectively, at about 20 cm distance from the target. The crystal size of the detector at 90° is 65.8 mm diameter and 70.2 mm length

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