Improved energy resolution of a cyclotron beam for RBS measurements

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Abstract
For RBS (Rutherford Back Scattering) analysis, the quality of the beam is of premium importance because the depth profile resolution of the method is strongly dependent of the energy resolution of the probing beam. A magnetic analyzer, consisting of two 90 left-right bending magnets forming an achromatic doublet has been adapted to the Liege 20 MeV (proton) AVF (Azimuthal Varying Field) cyclotron. The energy resolution of that system has been measured by recording the resonance width of a $^{32}$S($p, p'\gamma$)$^{32}$S (3.38 MeV. $p^+$ lab. energy). We have obtained a value of $\Delta E = \pm 2$keV, reducing by a factor of 20 the natural dispersion of our cyclotron.

We describe our magnetic analyzer system and present the results of our RBS measurements at energies up to 14 MeV $\alpha$.

Key words: RBS, alpha, cyclotron, elastic scattering
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1. Introduction

For RBS (Rutherford Back Scattering) analysis, the quality of the beam is of premium importance because the depth profile resolution of the method is strongly dependent of the energy resolution of the probing beam. A cyclotron, even if it is not considered as a good RBS tool as it has, by construction, a poor resolution (due to the fact that the beam is extracted from a large portion of the spiral path) [1] can be adapted to RBS if its momentum dispersion could be strongly reduced. To improve the energy resolution of the Liege 20 MeV (proton) AVF (Azimuthal Varying Field) cyclotron, its magnetic analyzer has been refurbished and improved. The new system consists of two 90 left-right bending magnets forming an achromatic doublet.

The resolution of the new system has been tested by measuring the width of a $^{32}$S resonance and analyzing RBS spectra of high energy $p$ and $\alpha$ beams.

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2. Experimental arrangement

A schematic drawing of the analyzing system is presented on Fig. 1. The cyclotron is an AVF (Azimuthal Varying Field) cyclotron constructed by the CGR-MeV company (France). It can produce \( p \) and \( \alpha \) beams from 2.5 to 20 MeV and 5 to 25 MeV respectively. For IBA (Ion Beam Analysis) measurements, the beam is sent to two working areas. Area 1 utilizes the unanalyzed beam extracted from the accelerator. That beam has an energy dispersion larger than 50 keV and was not suited for RBS measurements. The newly installed chamber of area 2 uses a high resolution beam line that crosses three magnets. The first one acts as a switching magnet and drives the beam into the two analyzing magnets that act as a high resolution energy spectrometer [2]. The system consists of two 90 left-right bending magnets forming an achromatic doublet. The beam is driven through three collimators situated before, in-between and at the exit of the system. The collimators are made of alumina ceramic disks that luminesce under the beam impact [3]. Small holes (1.7 mm diameter) are drilled at the center of the disks and vacuum CCD cameras, situated along the path, visualize the beam spot on each collimator. These video images, displayed simultaneously in front of the cyclotron operator, are very useful during the beam adjustment phase. The magnetic fields of the two magnets are finely tuned to make the beam pass through each collimator and the magnetic field are monitored by Hall magnetic probes calibrated by a RMN gauss-meter.

3. Results and discussion

3.1. Energy resolution

The improvement in resolution has been measured by recording the resonance width of a \( ^{32}S(p,p'\gamma)^{32}S \) reaction [4]. A PbS thick target was placed at the center of a vacuum chamber situated in area 2 (see fig. 1) and the 2.23 MeV \( \gamma \) rays produced by the nuclear de-excitation of \( ^{33}Cl \) excited levels were detected by a gamma coaxial germanium detector from Canberra. For proton energy close to 3.38 MeV, a sharp change in the gamma ray production is observed when the \( ^{33}Cl \) level at 3.379 MeV \( (\Gamma = 1 \text{ keV}[5]) \) is excited (Fig. 2.)

From the analysis of that curve, we have obtained a value of \( \Delta E = \pm 2 \text{ keV} \) an improvement by a factor of 10 over the natural dispersion of our cyclotron. Let us note that this value is perfectly adapted to RBS measurements.

3.2. RBS measurements

Helium ions are used as the analyzing beam for RBS measurements as a compromise between its high sensitivity and simple energy dependence of the scattering cross section and its good detector energy resolution (poorer for heavy ions). Our new setup has an energy resolution comparable with what can be obtained with electrostatic accelerators but allows to extend the usefulness of alpha beam to energy ranges that were not available previously.

In order to evaluate the performances of our new beam line for RBS surface analysis with high energetic \( \alpha \), we have recorded spectra of two known targets. The first one is formed by a very thin gold deposit on an Al substrate and the other consists of a thin gold layer superposed on a medium thickness silver deposit.

The analysis of those spectra have been performed using the SIMNRA program [6]. The simulation of the spectra presented on Figs. 3 and 4 were performed with RBS cross-sections only be-
Fig. 2. $^{32}S(p,p'\gamma)^{32}S$ resonance at 3.379 MeV($E_{lab}\ p^+$) showing a beam energy resolution of $\pm \ 2\ \text{keV}$

cause, at such energies and ions conjunction, no experimental cross-sections are available [7,8].

By comparing our spectra with the simulated RBS spectra it is obvious that non-RBS effects have to be taken into account. The ratio between the observed cross-sections to Rutherford cross-sections could be estimated following the method described in [9]. By repeating our measurements for different elements, energies and angles, our setup will allow us to extend our knowledge of non-RBS cross-sections to new domains.
4. Summary

We have described the new beam line of the IBA installation of the University of Liege that improves the energy resolution of our cyclotron accelerator by a factor of 20. The resolution achieved, that is comparable to that of electrostatic accelerators, allows to reach energies not available before for p and α beams. Initially designed for the analysis of cultural heritage artifacts, this new extracted beam line will constitute an accurate tool, perfectly suited for the analysis of thick layers such as corrosion or gilding layers, often observed on such artifacts.

Moreover the extension of the use of high energy alpha beams for RBS analysis will find applications and open new perspectives for a wider range of surface analysis. However, to perform with high accuracy such type of measurements, extensions of our knowledge of non Rutherford cross-sections toward higher energies are needed.

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References


