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Differential cross-section measurements for deuteron elastic scattering on ^{nat}N, suitable for EBS

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The elastic scattering of deuterons on ^{nat}N has been studied in the present work in the energy range of $E_{d,lab}$ = 1000–2200 keV, in steps of 10 keV, at six backscattering detection angles (120°, 130°, 140°, 150°, 160° and 170°), suitable for analytical purposes. The measurements were performed using the 5.5 MV TN11 HV Tandem Accelerator of N.C.S.R. "Demokritos", Athens, Greece and a high-precision goniometer. The target used for the measurements was a self-supported Si_3N_4 thin foil, with an ultra-thin Au layer evaporated on top for normalization purposes. The obtained differential cross-section datasets are compared to already existing ones in literature and the observed similarities and discrepancies are discussed and analyzed, along with the effect of the various nuclear reaction mechanisms in low-energy deuteron elastic scattering.

1. Introduction

Nitrogen is the seventh most abundant element in the solar system and comprises, in molecular form, ca. 78% of the earth's atmosphere. It is composed of two natural isotopes, namely ^{14}N (99.634%) and ^{15}N (0.366%) and finds numerous applications in metallurgy, as well as in semiconductor- and insulator technology. More specifically, the implantation of nitrogen into metals, e.g. steels, titanium, and titanium alloys, increases their hardness and wear resistance, an important feature for cutting tools. The nitrogen diffusion into various metals under mechanical stress still constitutes an open problem for scientific research. Additionally, nitrogen is a common dopant for the creation of n-type semiconductors, and it is also used as an additive to the argon atmosphere during the crystal growing process, while a nitrogen-containing passivation layer prevents the increase and migration of displacements during the annealing process. Moreover, nitrogen is one of the main constituents of common ceramic materials (e.g. BN), industrial glasses, polymers and biological samples.

Thus, the accurate quantitative determination and depth profiling of nitrogen in various targets is of critical importance. At the same time, it constitutes a major challenge for all Ion Beam Analysis (IBA) techniques and has been the subject of extensive, pioneer works in the past, comparing different reactions in specific case studies (e.g. [1,2]). The major problem originates from the fact that nitrogen usually coexists in various complex matrices along with several other low- and medium-Z elements.

Among all IBA techniques, Nuclear Reaction Analysis (NRA) is the most widely used for nitrogen depth profiling studies, usually via the simultaneous implementation of the $^{14}N(d,\alpha_0)$, $^{14}N(d,p_0)$ and $^{14}N(d,\alpha_1)$ reactions, which yield isolated high-energy proton and α-particle peaks due to their high Q-values, with practically negligible background interferences, while, at the same time, permitting the study of deep implanted nitrogen layers. Moreover, the implementation of d-NRA has recently been considerably facilitated by the creation of IBANDL (Ion Beam Analysis Nuclear Data Library, http://www–nds.iaea.org/ibandl/). IBANDL is an especially designed library supported by IAEA, containing experimental differential cross–sections suitable for IBA, which can be directly incorporated in widely used analysis codes. Additionally, an important breakthrough nowadays is the availability of evaluated, and thus more reliable differential cross–section datasets for all these major NRA reactions in nitrogen, which are made available to the scientific community through the on–line calculator SigmaCalc (http://sigmacalc.iate.obninsk.ru/).

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On the other hand, there is a certain lack of coherent experimental differential cross-section datasets for nitrogen, concerning the deuteron elastic backscattering spectroscopy (d-EBS) technique. Very few relevant differential cross-section datasets exist [3–5] and most of them are old, discrepant and not focused on the implementation of IBA techniques. The existence of coherent datasets for elastic scattering is important, as EBS is commonly simultaneously employed for analytical purposes, along with NRA, since they share the same experimental setup, detector and electronic settings. Furthermore, d-EBS is valuable for the accurate determination of the depth profile of the other low- and medium-Z elements coexisting with nitrogen in a target matrix.

In order to address this problem, the elastic scattering of deuterons on ^{nat}N has been studied in the present work for deuteron beam energies and backscattering detection angles suitable for analytical purposes. The measurements were performed using the 5.5 MV TN11 HV Tandem Accelerator of N.C.S.R. "Demokritos", Athens, Greece and a high-precision goniometer.

2. Experimental setup

The experiment proceeded in several distinct phases. As far as d–EBS is concerned, the experiments were performed using the deuteron beam of the 5.5 MV TN11 HV Tandem Accelerator of N.C.S.R. "Demokritos", Athens, Greece. The deuterons, accelerated to $E_{d,lab}$ = 1000–2200 keV, were directed to a large-size, cylindrical scattering chamber (radius: 40 cm) equipped with a high-precision goniometer (0.1°). The final ion energy of the deuteron beam was determined by Nuclear Magnetic Resonance (NMR) with an estimated ripple of ~1.5‰, as verified at the beginning of the experiment – using protons – by the reaction rate of the 991.89 keV resonance of the $^{27}Al(p,\gamma)$ reaction, using a 18% relative efficiency HPGe detector. Since non–linear deviations of the magnet have not been observed in the past, the determined energy offset (~3.3 keV) and ripple (~3 keV) were taken as constant for the limited deuteron beam energy range studied in the present work. These values were subsequently used for the ADC energy calibration, whose linearity was proven to be excellent (better than 0.4%), taking into account the detector pulse height defect as well. Differential cross–sections were obtained using a constant beam energy step of 10 keV, since no fine structure was expected in the measured excitation functions.

The target was placed at a distance of ~8–12 cm from the detectors. Orthogonal slits (~3.5 × 9 mm^2) were placed in front of the detectors in order to reduce the azimuth angular uncertainty (<±1°), while allowing for an adequate effective solid angle to be subtended by the detectors (namely, ~2.65 msr at 120°, 1.43 msr at 130°, 2.82 msr at 140°, 3.63 msr at 150°, 2.61 msr at 160° and 1.95 msr at 170°). Small cylindrical tubes, with variable length

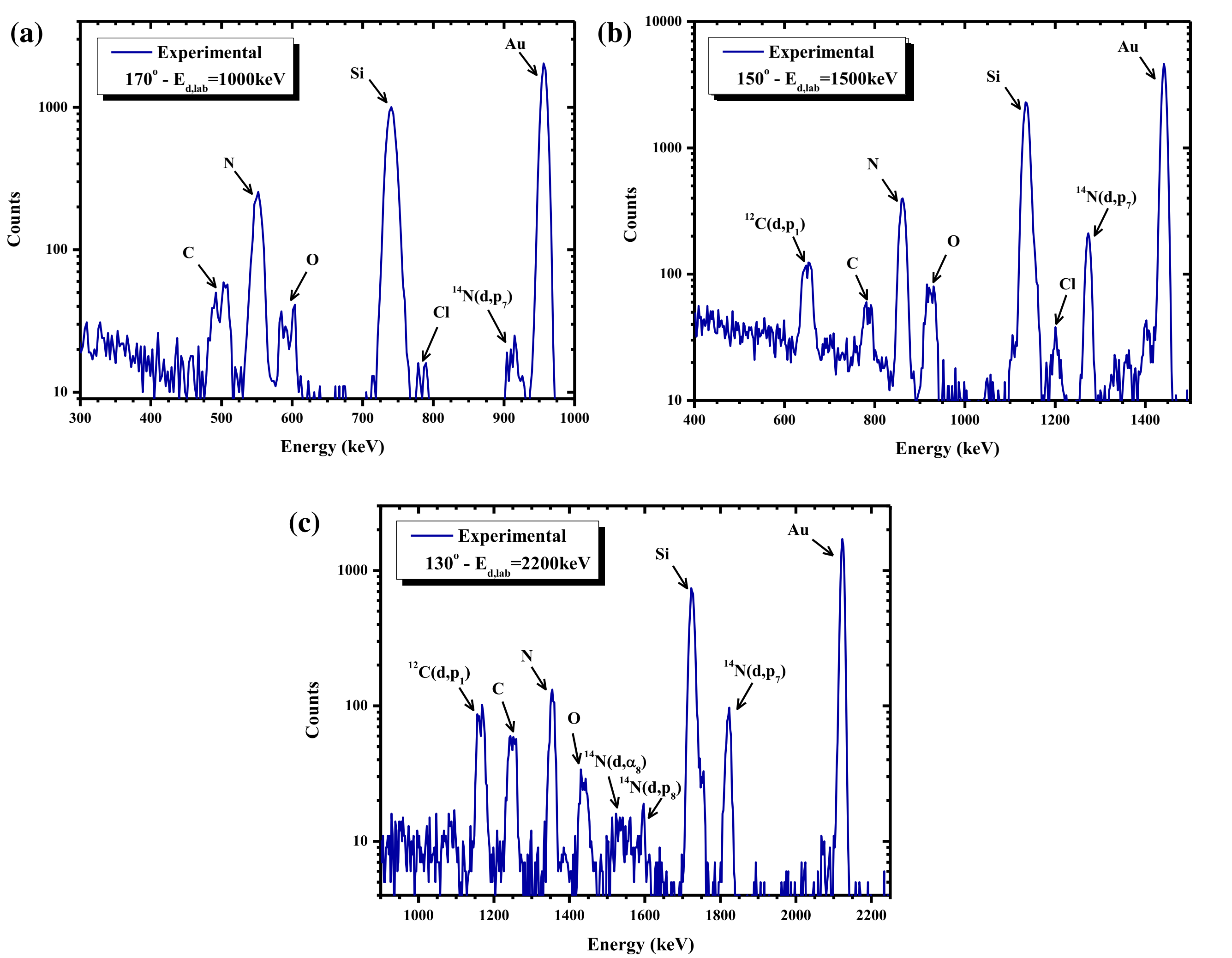

Fig. 1. Experimental deuteron spectra along with the corresponding peak identification taken at (a) $E_{d,lab}$ ~ 1000 keV, 170°, (b) $E_{d,lab}$ ~ 1500 keV, 150° and (c) $E_{d,lab}$ ~ 2200 keV, 130°.