Determination of Coulomb Barrier using X-ray Spectroscopy Technique

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Introduction

The interface between atomic and nuclear physics is a region of interplay of different quantum dynamical effects. Around the Coulomb barrier, one may explore the interesting behaviour of different atomic and nuclear processes. Careful study of these processes can explore the physics around the Coulomb barrier region and may give a way to measure the barrier too. Though numerous experimental work and theoretical calculations are found in literature for determination of Coulomb barrier [1]. Nevertheless, the atomic techniques have not yet been employed for this purpose. In the present work we are reporting a novel method to extract the Coulomb barrier energies in two body systems using x-ray spectroscopy technique.

Experiment Setup

Well-collimated ion beam of ^{58}Ni at 41.6-156 MeV and ^{56}Fe at 40-136 MeV were bombarded on 80 μg/cm^2 natural carbon placed at 45° to the beam axis. The x-rays produced in the reactions were detected in two germanium ultra-low energy detectors (GUL0035, Canberra Inc., with 25 μm thick Be entrance window, resolution 150 eV at 5.9 keV) placed at ±90° to the beam axis to minimize the Doppler shift. Detectors were kept outside the chamber at 16 cm (LEGe1) and 65 cm (LEGe2) away from the target. A typical x-ray spectra observed with LEGe1 detector for Ni on C at 144 MeV is shown in FIG.1. Calibrations were done for the x-ray detectors using ^{60}Co and ^{241}Am standard radioactive sources. To normalize the spectra two 300μm thick SSBD detectors were placed at 10° to the beam axis. The beam was dumped in a Faraday cup.

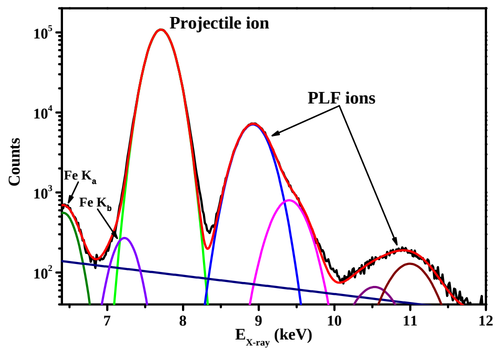

FIG. 1: A typical x-ray Spectra observed as in the reaction ^{12}C(^{58}Ni,X) at 144 MeV

Results and Discussion

It is clear from the spectrum of 144 MeV ^{58}Ni on C that it contains mainly three structures as shown in Fig. 1. In our earlier work the first peak (7-8.4 keV) is recognized to have originated from the projectile ion x-ray, whereas second and third peak (8.4-11.5 keV) belong to the projectile-like fragment ions emanating from the nuclear reactions [2, 3]. In the present work, we have determined the projectile K x-ray production cross section and plotted against the beam energies, as shown in Fig. 2. The curves show a departure from the expected (gradually increasing) trend around certain beam energies. Derivative of this spectra w.r.t. beam energy exhibits a clear dip representing the Coulomb barrier and can be defined as K-vacancy excitation function as

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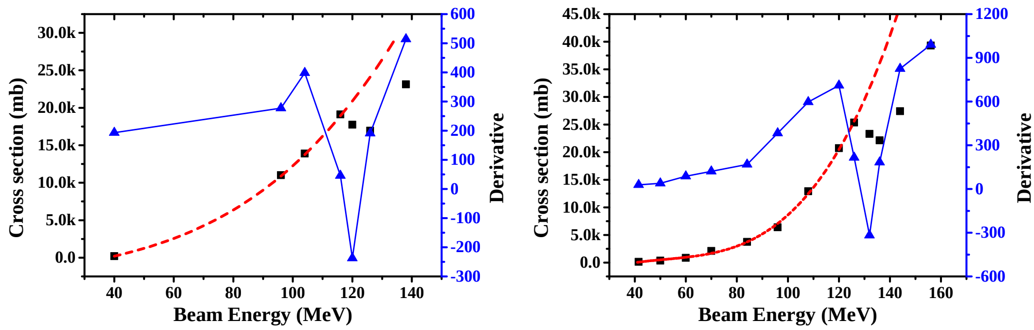

FIG. 2: K-shell ionization cross section versus beam energies (a) Fe and (b) Ni beam on 80 μg/cm^2 C-foil. Error bars are tiny and smeared in the symbol size. All solid lines are to guide eye only. Theoretically expected curves should be smooth throughout (dashed), whereas the experimental data (square) exhibit dips around the corresponding Coulomb barrier energies as more clearly visible in the derivative curve (triangle).

TABLE I: Comparison on the Coulomb barrier energies (MeV)

Reaction	Bass Barrier [4]	C.W. [5]	Prox. 77 [6]	CCFULL [7]	Wong [8]	This work
^{56}Fe on ^{12}C	128.34	121.36	123.91	119.80	120.19	119.98
^{58}Ni on ^{12}C	142.16	134.62	137.25	132.94	133.35	134.17

follows

$$D_{xray} = -\frac{d\sigma_{xray}}{dE} \qquad (1)$$

The main reason behind this subtle behavior is the loss of elastic events due to opening of different nuclear channels (formation of nuclear reaction products) around the Coulomb barrier. Due to which projectile flux/cross-section get reduced and therefore the quenching of the K x-ray production cross-section occurs. This technique gives us a novel tool to measure the Coulomb barrier energies in the two body systems. Further, the measured values have been compared with different theoretical predictions [4–8], as given in Table I and found satisfactory.

Conclusions

A novel technique using x-ray spectroscopy is proposed to measure the Coulomb barrier energies in two body systems.

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