Theoretical Model and Experimental Confirmation of Unusual X-ray Intensity of Projectile-like Fragment Ions

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Introduction

The motivation for studying heavy ion reactions at energies below the Coulomb barrier (CB) have importance in stellar evolutions [1]. In last decade a series of experiments in our lab showed that such studies could be efficiently performed using x-ray spectroscopy techniques. However, an unusual fact is found that ratio between x-ray intensity of projectile-like fragment (PLF) ions and that of projectile which was much larger than one usually expects on the ground of the cross-sections in atomic and nuclear events. In order to find out the possible reason, we formulate a model and then designed an experiment to ratify it.

Proposed Formalism

The charge state of the incoming projectile ions is much lower than that of the projectile ions as represented by the x-ray lines emanating from it. So, firstly they have to undergo through the ionization process to come to high charge state and secondly, electronic excitation in the ion-solid collision can produce certain excited states leading to x-rays in the spectra. Thus, the projectile x-ray yield equation can be written as:

$$Y_P^X = \sigma_{exc}.N_P.F_q.N_T.\Omega.\epsilon \qquad (1)$$

Whereas the x-ray production from the PLF ions follows different route. Here, PLF ions have to be formed from the nuclear reaction in the first instance and then they have to go through certain electron capture process. Hence, the PLF x-ray yield can be set as:

$$Y_{PLF}^X = (\sigma_{trans}.N_P.N_T).N_T.\sigma_{sec}.\Omega.\epsilon \qquad (2)$$

Here, Y_P^X = Projectile x-ray yield
Y_{PLF}^X = PLF x-ray yield
F_q = Total charge state fraction of He & Li-like ions as calculated from ETACHA [3]
σ_{exc} = 1s to 2p excitation cross-section
σ_{trans} = Measured α transfer cross section
N_T = No. of target atoms = 2.6x10^{18} atoms/cm^2
N_P = No. of projectile ions per second
σ_{sec} = Cross-section for single electron capture to 2p shell of the bare PLF ions
From eq.(1) and eq.(2):

$$\frac{Y_{nuclear}}{Y_{atomic}} = \frac{\sigma_{trans}.\sigma_{sec}.N_T}{\sigma_{exc}.F_q} \propto N_T \qquad (3)$$

Experimental Setup

Besides the projectile x-ray peak, x-ray spectrum shown in FIG.1 displays additional structures, as identified in TABLE I indicating events from α , Li and 2α capture products. The probable reactions given in the table are corroborated by the observation from $\triangle$E-E spectrum given in FIG.2.

TABLE I: Analysis of the x-ray spectrum for 130 MeV Br on C

X-ray centroid (keV)	Reaction	PLF ions
12.03	^{12}C(^{79}Br,^{79}Br)	He-like Br
13.75	^{12}C(^{79}Br,^{81}Rb)	He-like Rb
14.52	^{12}C(^{79}Br,^{81}Rb)	H-like Rb
14.2	^{12}C(^{79}Br,^{82}Sr)	He-like Sr
15.42	^{12}C(^{79}Br,^{83}Y)	He-like Y

To prove the proposed formalism, an experiment was designed where targets of variable thickness were used to measure the x-ray

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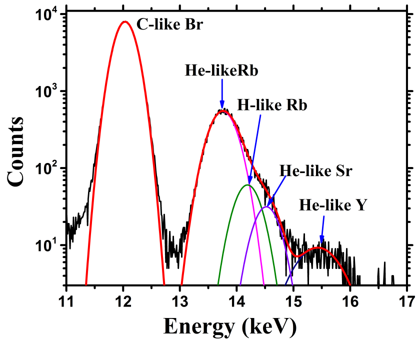

FIG. 1: X-ray Spectra for 130 MeV Br on $80\mu g/cm^2$ thick C target

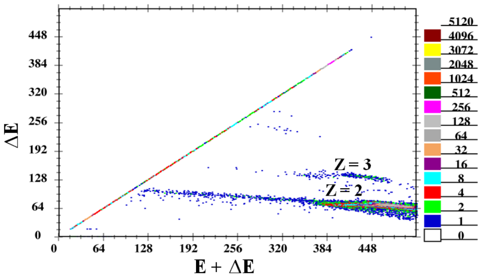

FIG. 2: A typical PI spectra ($\triangle$E v/s $\triangle$E + E) measured in ^{12}C(^{79}Br,X)

spectra. Experiments were performed at General Purpose Scattering Chamber, IUAC, New Delhi. Well-collimated ion beams of ^{58}Ni and ^{79}Br were bombarded at 170 & 130 MeV, respectively on natural carbon target of different thickness 10, 42 & $80\mu g/cm^2$ placed at 45° to the beam axis.

In the experimental setup one set of telescope was placed at 18° to the beam axis and 70 c.m. away from target. Experimental details are described elsewhere in the proceedings.

Results and Discussion

The measured x-ray intensities for each target thickness were used to find the ratio $R = \frac{Y_{nuclear}}{Y_{atomic}}$ and then they were plotted against the target thickness as measured in a strip of a silicon micro-strip detector as shown in FIG.3. The data is fitted very well with a straight line.

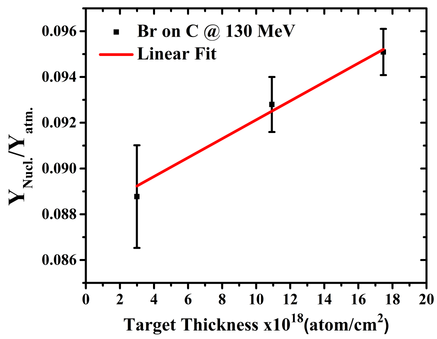

FIG. 3: $\frac{Y_{nuclear}}{Y_{atomic}}$ v/s target thickness for 130 MeV Br on C

Conclusions

The unusually large x-ray intensity from the PLF ions is proved to be realistic. This is because of the fact that electron capture cross-section to the bare PLF ions as well as x-ray transition probability of the excited state so formed, are very large. Now we are in a stage to make use of this technique for studying nucleus-electron interactions, a field at the boundary of nuclear and atomic physics.

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