5.4 ATOMIC PHYSICS

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Beam-single-foil and beam-two-foil experiments are being carried out in collaboration with universities. This year a HPGe is added to the set up as reported in the section 4.5 of this Annual Report. Results obtained from an experiment using Ti-beam has encouraged us to investigate in greater detail the mechanism of an excited state interacting with a thin carbon foil. Besides observed data gives a tentative clue of studying atomic physics aspects from nascent ions produced from a nuclear transfer reaction between the projectile beam and carbon target. In order to establish some of interesting facts like ternary recombination, experiments with Ni and Fe beams have been done.

1. Experimental evidence on intrashell transition in He-like Ti

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Fluorescence yield for highly charged ions containing only a few electrons may significantly be affected by the 2s-2p transitions, as has been noted in studies of x-rays from Si^{+q} when q varies from 2-11 [1]. Based on this observation, one might guess that 2s-2p probabilities are often large compared to those for excitation from one shell to another, since the 2s-2p energy splitting is relatively small. If the probability for excitation within an atomic shell is large, then electrons may jump back and forth rapidly between the sublevels during a collision [2]. McGuire et al [2] have estimated the 2s-2p transition probabilities for collisions with high velocity projectiles. Later, Cheng et al [3] observed the conversion of the heliumlike 1s2p $^3P_2$ state in the 1s2s $^3S_1$ state on collision with 700MeV Kr^{34+} on thin carbon foil. They attributed this fact on 2s-2p transition within the foil. In order to investigate this fact in a quantitative way we have made an attempt to see how does intrashell transition alter the data on a single collision and on a few collisions.

In our beam-single-foil and beam-two-foil experiment, 143 MeV Ti beam was passed through 90 $\mu g/cm^2$ carbon foil to produce heliumlike Ti 1s2p $^3P_2$ states. As these excited states decaying to their ground states, transition lines are observed as per the concerned transition rates (0.8×10^9/sec). Now if we let the excited states undergo a collision with a thin foil heliumlike Ti 1s2p $^3P_2$ state may convert to heliumlike Ti 1s2s $^3S_1$ state which decays through M1 to the same ground state. But now the transition rate (3.76×10^7 /sec) changes drastically and as a result, the normalized intensity would clearly reflect the effect as shown in fig 1. Further, measurements were done with two and three collisions also to show the fact of intrashell transitions collision after collision.

Carbon foil thickness of the second foil was estimated with the prescription given in [2]. The foils were made two fold so that thickness would be correctly measured by α-particle energy loss technique. Results shown in fig.1 gives an experimental evidence of the intrashell transitions in highly charged Ti-ions. Similar measurements have been made with 164MeV Ni-beam and analysis is yet to be done.

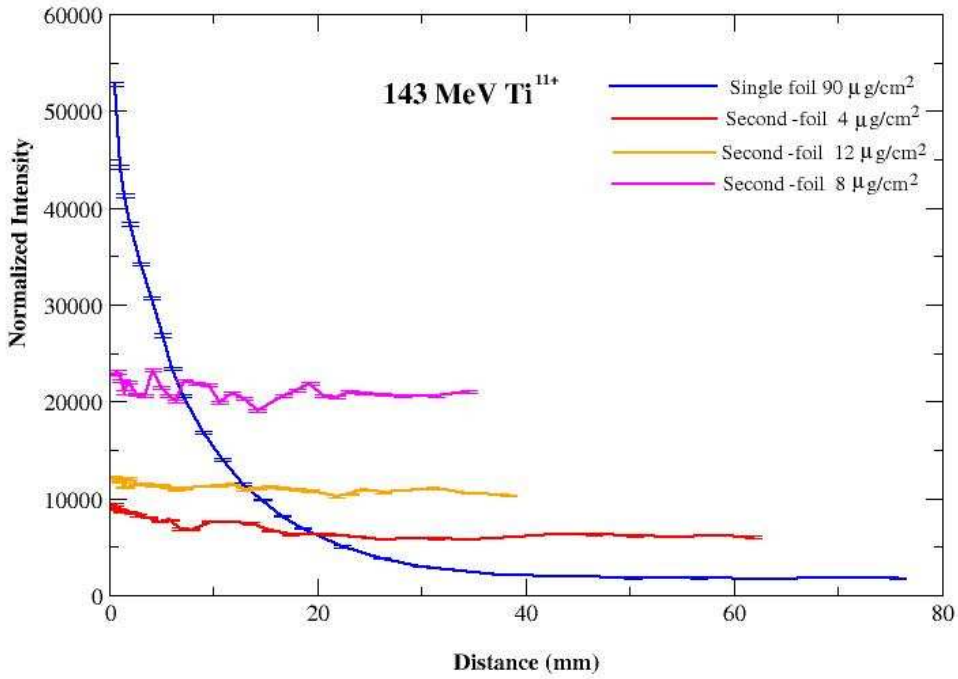

Fig. 1: Normalized intensity of helium like Ti M2 line as a function of distance (143 MeV Ti) shows how the intrashell transisitions play roles on foil thickness of the second foil (i.e., collision after collision).

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5.4.2 Physics with Nascent Atoms: Experiment Evidence of Ternary Recombinations

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Nuclei $^{62}Zn_{30}$ were produced by the nuclear transfer reaction from the carbon target to the 163 MeV $^{58}Ni_{28}$ beam on carbon target projectile. These bare ions can capture electrons from the exit surface of the foil in the bound as well as continuum states to form so called 'Nascent' ions. Electrons in the continuum can populate the high lying states by the process called ternary recombination (TR) as proposed by D'Angelo [1]. Interstingly, excited states $2s^2S_{1/2}$ generated by electron capture at t=0 decay to the ground states before TR process populates the same. This results in separating normal deexcitation from that due to TR induced ones. The delay was found to be 181.6 ps. Similar spectrum has also been observed in the 160 MeV vanadium on carbon experiment as shown in Figure 1. Intensity of 9.3keV peak (H-like M1 line in Zn^{29+}) versus time show a unusual decay trend which can be explained well with the model equation given below.

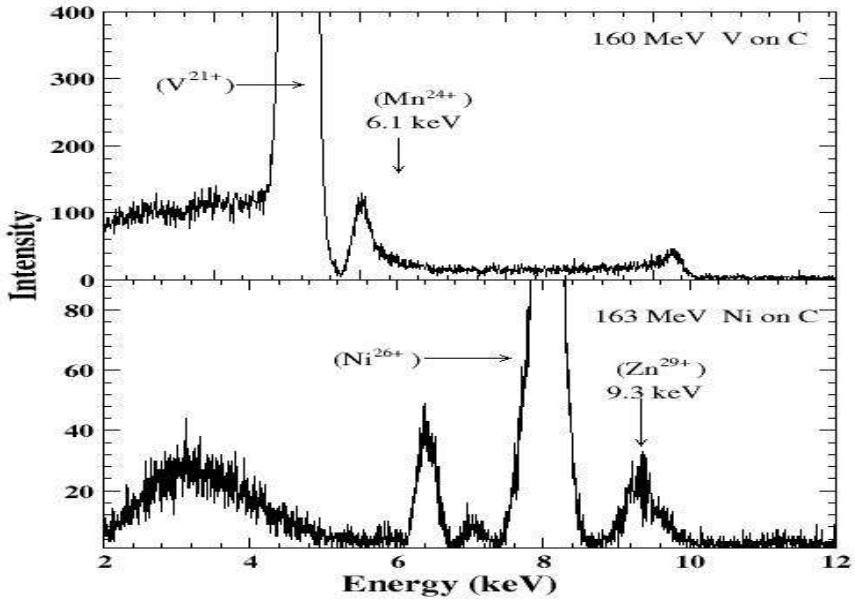

Fig. 1: X-ray spectrum showing the x-ray line originationg from α-transfer reactions

One interesting point to note here is that electron capture in the continuum (ECC) takes place at t=0 and since then transfer of electrons from ECC to Ryberg states continues until the electrons in the continuum gets exhausted. As a result, the $2s^2S_{1/2}$ level may be populated by a time varying population factor of ECC. Thus, decay of the 9.3 keV line could be expressed with the following equation.

$$I(t) = I_1 e^{-t/\tau} + \Theta(t-t_0)\, I_2\, [(t-t_0)/t_n]\, (1-e^{-(t-t_0)/t_0})\, (1+e^{-(t-t_0)/\tau}) \qquad ...(1)$$

First term of the above equation denotes the decay of the 2s $^2S_{1/2}$ level and intensity I_1 is due to the electron capture from the foil to 2s $^2S_{1/2}$ level of the bare Zn nuclei. Obviously, τ (135.6 ps [2]) is the mean life of the 2s $^2S_{1/2}$ level of H-like Zn. The second term contains the growth of the 2s $^2S_{1/2}$ level which is caused by the transfer of

electrons from the continuum to the state 2s $^2S_{1/2}$ and the decay of 2s $^2S_{1/2}$ so grown. Intensity factor in the second term is a time varying function as explained above and it could be expressed as $I_2[(t-t_0)/t_n]$. A step function

$$\Theta(t-t_0) = 1, \quad \text{if } t>t_0$$
$$0, \quad \text{if } t<t_0$$

Observed intensity data as a function of time contains two different contributions, one prompt and another delayed. In order to exclude the effect of prompt from the delayed phenomenon, contribution of the prompt or first term of equation (1) is subtracted and data so obtained indicate a nice physical structure. The collisions among the electrons in the continuum can produce electrons of different velocities. The velocity of the electron determines the state in which the recombination will take place. Depending on this, cascade from the recombined state to 2s $^2S_{1/2}$ state will take different time. It is very clear from curve (a)-(b) of Fig.2 that recombination is prominent at some higher state. These states could be even high Rydberg states for very slow electrons recombine there. Effect of the recombination at comparatively lower states are deleted from Fig. 2(c) so that rest of the data reflect the effect of prominent recombination in the high Rydberg states. Data so obtained could be fitted with second term of equation-1.

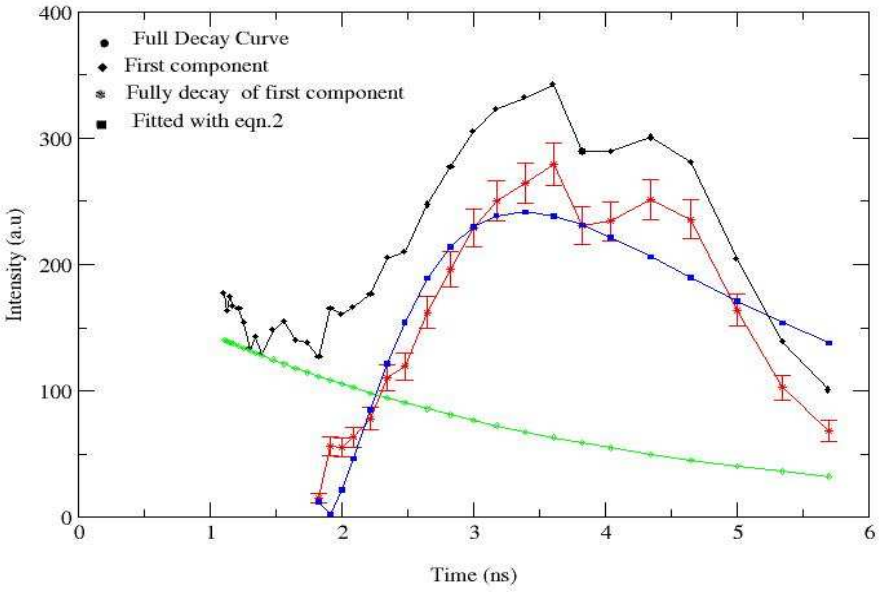

Fig. 2. Decay curve of the 9.3 KeV Zn line measured with 163 MeV Ni beam passing

During the fit, τ was kept fixed with its theoretical value (135.6ps)[2]. The values for the time t_0 and the exponent n so obtained have been given in table 1. The average value of time t_0 and exponent n are found to be 181.6p and 3.55, respectively. Error associated with these parameters was quite high within 25% due to low statistics and fitting.

We have observed TR for the first time. One obvious question can be asked

whether the phenomenon of ECC to bound state could be observed with the projectile ions. Answer is yes, but it can only be observed with two-foil experiments not with single-foil experiments. Analysis is in progress.

Table 1: The data (Fig.2(c)) were fitted with the equation (2) to obtain time t_0 and exponent n. RMS error in the fitting is also given

Beam Energy(MeV)	***T_0 (ps)***	***Exponent n***	***RMS error***
163	187.7	3.65	0.33
160	169.7	3.421	0.3217
156	187.5	3.561	0.4113
Average Value	181.6	3.55	0.25

through 45 μg/cm2 carbon foil: (a) full curve that can be represented by equation(1), (b) only the first component of equation (1), first component of equation (1) is deducted from (a) and (d) data in (c) are fitted with the second term of equation (1).

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5.4.3 Lifetime of $1s2s2p^4P^0_{5/2}$ in Ti^{19+} by beam-foil and beam-two-foil experiments

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In previous studies [1,2] we have employed the beam single-foil [3] and beam two-foil techniques [4] coupled to an iterative multi-component exponential growth and decay analysis [1], to address satellite line blending in lifetime measurements in He- and Li-like vanadium [1] and nickel [2]. In the present study, we employ similar approach to determine the lifetime of the $1s2s2p^4P^0_{5/2}$ level in Ti^{19+} through its x-ray decay channel to the Li - like ground state $1s^2\,2s\ ^2S_{1/2}$. The lifetime for this level has been determined by Dohmann at el [5] through a different method, based on the Auger electron emission process $1s2s2p^4P^0_{5/2}$ - $1s^2\ ^1S_0 + e^-$, in which an electrostatic cylindrical mirror analyser was used. It was noted that there was two standard deviations difference between their experimental result (236 $\pm$ 12 ps) and theoretical estimates (205 ps [6] and 212 ps [7]). We have therefore decided to re-investigate the $1s2s2p^4P^0_{5/2}$ lifetime using the above

mentiond method, rather than Auger electron, emission, in order to determine whether this difference between theoretical and experimental results still persists. Experiment was performed with 95 and 143 MeV ^{48}Ti beam. Using the analysis technique given in [1,2], we have obtained the lifetimes as given in Table 1.

In this work, we have determined the $1s2s2p^4P^0_{5/2}$ lifetime, for the first time through its M2 X-ray decay channel to the Li - like ground state. Theoretical estimates for the $1s2s2p^4P^0_{5/2}$ lifetime lie within the uncertainty bounds of our experimental result. A two standard deviations difference between a previous experimental result (236 $\pm$ 12 ps [5]) and theoretical predictions (205 ps [6] and 212 ps [7]) is not reproduced by our measurements and subsequent analysis. This suggests that larger value obtained in earlier experiment was caused by the cascade feeding as mentioned by Dohmann et al [5]. Further, it may be inferred that theoretical values provide adequate estimates to the $1s2s2p^4P^0_{5/2}$ lifetime for Li-like Ti. The uncertainty in our measurement however is not sufficientlly low to provide conclusive evidence concerning the relative uncertainties of the theoretical results. Lifetime for He-like $1s2p^3P_2$ agree reasonably well with theoretical estimation (see Table1) [8].

Table-1: Lifetime for the $1s2s2p^4P^0_{5/2}$ Li-like and the $1s2p^3\ P^0_2$ He-like ^{48}Ti level.

Upper level	Experimental lifetime (ps) At NSC	At GSI		Theoritical Lifetime ps
$1s2s2p^4P^0_{5/2}$	210±10	236	12[5]	212 [7],205[6]
$1s2p^3\ P^0_2$	404±16	404	40[5]	422 [8]

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