5.3 STATUS OF RADIATION BIOLOGY RESEARCH AT IUAC USING HEAVY IONS

During the last one year, project from Kalyani University is focusing on the high LET radiation induced gene expression studies. The aim of the project is to measure several apoptotic parameters and monitor the expression of few genes in human cervical epithelial carcinoma (HeLa) cells irradiated with carbon beam and compare the effects in presence and in absence of PARP inhibitor in HeLa cells. Towards this goal, beam time has been taken by the user and initial analysis job employing cell cycle analysis using FACS, Comet Assay, and Western Blot etc.

A project from MMC College Ghaziabad would study high LET radiation action on breast cancer cells CHAGO. The student is being trained in cell culture and other molecular biology techniques related to the project at the laboratory at IUAC. The beam time would be taken shortly.

5.3.1 Induction of Apoptosis and Cell Cycle Alteration of Human Cervical epithelial Carcinoma (HeLa) cells in response to high LET radiation $^{12}C^{6+}$

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Fig 1A

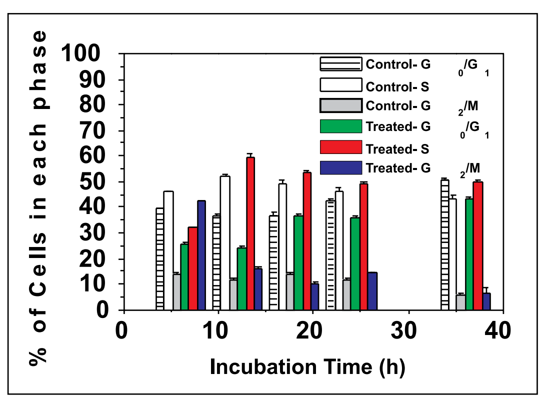

Fig 1B

Fig 1. A, Nucleosomal ladder; lane 1-untreated control, lane 2-5 ladder in Hela cells for 24 h incubation after treatment with 0.5 Gy, 1.0 Gy, 2.0 Gy, and 10.0 Gy of $^{12}C^{6+}$ beam. B Cell cycle distribution at various time points after treatment with 1.0 Gy of $^{12}C^{6+}$ beam.

The most important consequence of high LET radiation is DNA double strand breaks, which may give rise to change in cell cycle pattern by activating cell cycle checkpoints [1], activating DNA repair enzymes like Poly (ADP-ribose) polymerase (PARP) and finally can lead to cell death through apoptosis [2] or necrosis. We observed that dose-dependent (Fig.1A) as well as time-dependent (Fig not shown) increase of induction of apoptosis by $^{12}C^{6+}$ (62 MeV, average LET 287 kev/µm, fluence 0-4×10^6/cm^2) in HeLa as detected by nucleosomal ladder formation. The cell cycle distribution at different time point after treatment with 1 Gy $^{12}C^{6+}$ showed that cells were arrested after 6 h of irradiation at G_2/M check point followed by arrested at G_0/G_1 check point after 18 h as shown in Fig 1B.

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5.4 ATOMIC PHYSICS RESEARCH

We have continued to understand more and more the unusual features of beam-foil experimental data. Such features indicate new phenomena having important relevance to various branches of physics. Last year we have reported the measurement of wake field intensity and ion energy loss at the solid surface. This year we report the measurement of radiative resonant energy transfer from bulk plasmon to atomic levels during beam-foil excitation. Further, we made a dedicated beam line in beam hall II to study the effect of hyperfine structure on inner shell ionization and report the preliminary results also.

Atomic and molecular physics experiments in the low energy ion beam laboratory have been yielding interesting results as previous years. Position sensitive multi-hit time-of-flight measurement system is used to study the fragmentation dynamics of complete and incomplete fragmentation process at high velocities also as presented below.

5.4.1 Radiative resonant energy transfer during beam-foil excitation

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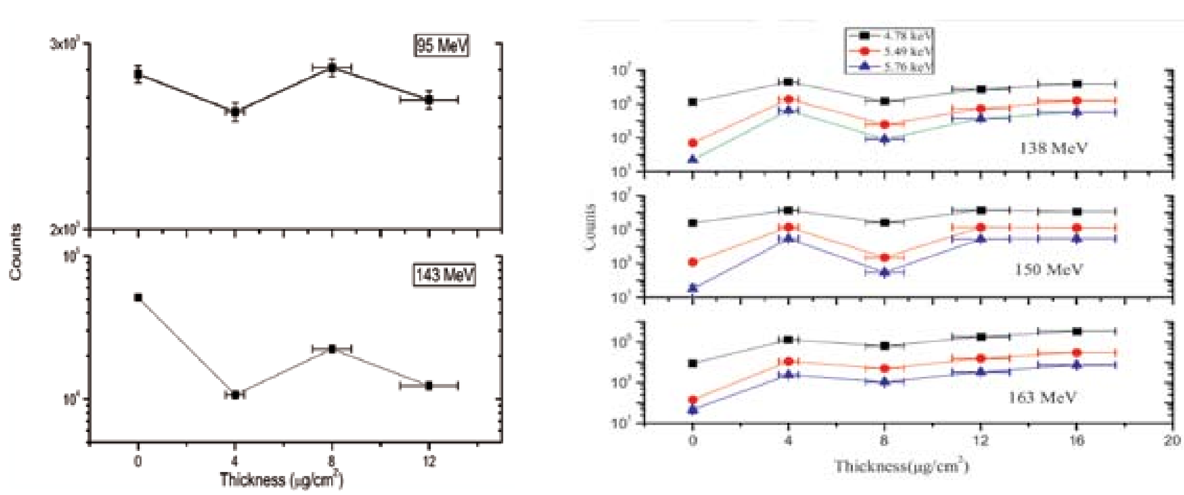
He-like ions are the simplest atomic many body systems and investigations of these species probe many atomic structure and collision problems. For example, our recent experiment showed that the He-like 1s2s $^3S_1$ level makes a transition to close by 1s2p $^3P^o_2$ level and vice verse in He-like Ti ions under collisions with thin carbon foils [1]. This experiment was carried out using the beam-two-foil time-of-flight technique where first carbon foil was used to populate the metastable 1s2s $^3S_1$ and 1s2p $^3P^o_2$ states in He-like Ti-ions. This experimental study clearly demonstrated further that the 1s2p $^3P^o_2$ states in the first foil are mostly populated and the 1s2s $^3S_1$ state is populated to a small degree. In the current experiment, replacing the first carbon foil by an aluminium foil, entirely different features have been observed; level population of 1s2s $^3S_1$ states is much larger than level population of 1s2p $^3P^o_2$ states.

Experiment was performed using our 15 UD tandem Pelletron accelerator. A beam of 95 MeV $^{48}_{22}Ti^{9+}$ or 143 MeV $^{48}_{22}Ti^{11+}$ was passed through a carbon foil of about 60 μg/cm^2 (first foil). A germanium ultra low energy detector (GUL 0035, Canberra Inc.), having a resolution of 145 at 5.9 keV and a 25 μm thick Be entrance window, was used to record the x-ray spectra. Two silicon surface barrier detectors (SBD) were used to monitor the incident ion beam by detecting the elastically scattered projectiles from a 120 μg/cm^2 gold foil fixed at 10 mm downstream from the detector. Vacuum was maintained to better than $1X10^{-6}$ Torr. Next time a beam of 138-163 MeV $^{48}_{22}Ti^{10-12+}$ was passed through an aluminium foil of about 40 µg/cm^2. This time incident ion flux was measured using a deep Faraday cage. This set up is a part of our Doppler tuned spectrometer.

Mean free path for the transition between 1s2p $^3P^o_2$ and 1s2s $^3S_1$ sub levels for present collisions is about 4 µg/cm^2. The fitting of decay curve in the single carbon foil geometry condition provides that the population of the He-like 1s2p$^3P^o_2$ level was much higher (90%) than the He-like 1s2s $^3S_1$ level (10%). The 4.78 keV peak (see Figure 1(I)) intensity shows an oscillatory structure. The first 60 µg/cm^2 carbon foil was replaced by a 40 µg/cm^2 aluminium foil. This time, in addition to the 4.78 keV peak two more peaks at 5.48 and 5.76 keV are observed in the spectra as shown in Fig 1(II). Now oscillatory nature of the intensity when plotted against the second foil thickness shows a major difference. This time, the population of the He-like 1s2p $^3P^o_2$ level was much lower (7%) than the He-like 1s2s $^3S_1$ level (93%). By no means difference of beam energies can explain the occurrence of different kind of levels populated for the first foil of different nuclear charge. Electron capture processes do not explain the difference in level population with different target materials. Contribution from multiple collisions also cannot justify the difference. Plasmon scattering may play important role in this. Bulk Plasmon excitations in amorphous carbon films can be as high as 29.5 ± 1 eV [2]. The energy splitting between the He-like titanium 1s2p $^3P^o_2$ and 1s2s $^3S_1$ levels is 31.7 eV [3]. Whereas bulk Plasmon excitation at the aluminium foil are 16.6 ± 0.7 eV. Evidently, the energy splitting between the two levels is equal to the bulk Plasmon energy which can be transferred to 1s2s $^3S_1$ level to excite the 1s2p $^3P^o_2$ level resonantly causing large population



(a) **(b)**

Fig. 1. X-ray yield as a function of foil thickness of the second foil for first foil (a) 60µg/cm^2 carbon and (b) 40µg/cm^2 aluminium.

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5.4.2 Role of hyperfine structure on inner shell ionization

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The hyperfine interaction in He-like ions induces a small admixture of 1s2p $^{1,3}P_1$ state to the 1s2p $^3P_0$ state. Consequently the forbidden E1 transitions from the 1s2p $^3P_0$ state to $1s^2\ ^1S_0$ ground state become allowed. Similarly, the 1s2p $^3P_0$ state may decay through E1 transitions in addition to the M2 decay. In light of this phenomenon it can be expected that, in case of single vacancy conditions the effect of hyperfine interaction can increase the radiative transition probability for such transitions.

Due to the hyperfine splitting of 2p levels in the atom having a K-shell vacancy the number of possible transitions from $2p_{3/2}$ level increases in comparison to that of

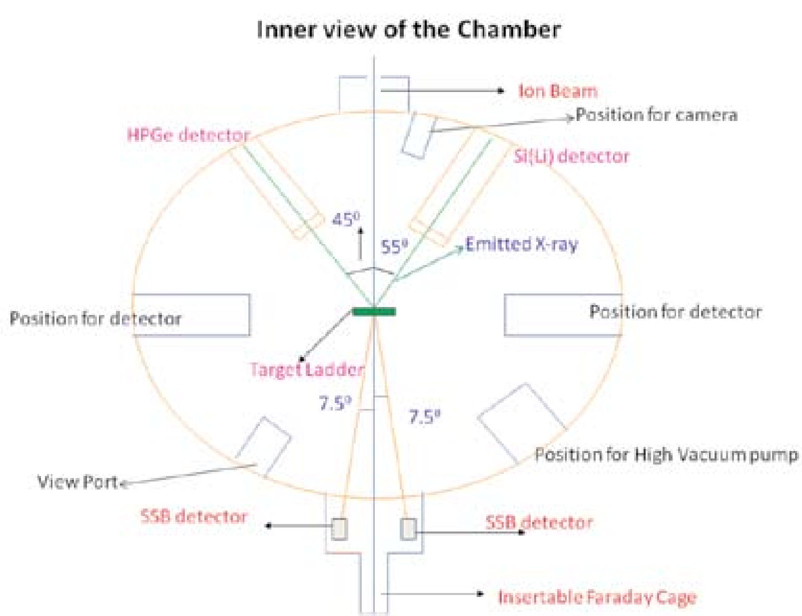

Fig. 1. Experimental setup used in test run

$2p_{1/2}$ level. For example, in an isotope of Sm with non-zero nuclear spin (149Sm, I= $7/2^-$), there will be a change in total angular momentum due to hyperfine interaction. This will lead in splitting of the $2p_{3/2}$ level in to four with F (F=I+J) values from 2 to 5 and $2p_{1/2}$ level in two with F values 3 and 4. So number of transitions is being increased and therefore it is expected that the intensity ratio of $K_{\alpha 1}$ to $K_{\alpha 2}$ may increase for elements with a non-zero nuclear spin.

Experiment was done at the dedicated atomic physics beam line in Beam Hall II. Experimental setup is shown in figure 1. Beam line up to target chamber using retractable Faraday cage has been tested using solid targets. The effect of hyperfine splitting on inner shell ionization cross section was studied using Samarium natural, Samarium-149 and Samarium-150 targets with aluminumized Mylar backing. Silicon induced K x-ray spectra were studied for Samarium-149 and Samarium-150 targets. Beam energies used were 96, 112, 126 and 140 MeV and beam current was kept around 1-3 pnA. Data was taken using Candle program and area under the peaks was also obtained using it. The ratio between their intensities gives clear indications that hyperfine structure plays a definite role on inner shell ionization cross sections.

5.4.3 Orientation Effects in Fragmentation of Molecules by heavy ion impact

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Molecules do not have a spherical symmetry, so the effect of a perturbation on a molecule should exhibit anisotropy. To determine the anisotropy of processes in a collision experiment it is necessary to know the orientation of the molecule with respect to the projectile. Since an ensemble of molecules in a collision experiment contains randomly oriented molecules, we need a technique to determine the orientation of the axis of each molecule that undergoes fragmentation. While this is not possible in general, in the special case, when the fragmentation results in purely ionic fragments, this is possible [1]. The momentum vectors of the fragment ions can be completely determined by multi-particle coincidence momentum imaging, and based on the momentum data, the relative orientation of the fragments within the target molecule at the fragmentation instant can be determined.

We performed this experiment for the the target molecules N_2 (homonuclear, zero dipole moment), CO, NO (heteronuclear, non-zero dipole moment), CO_2 (symmetric, heteronuclear, zero dipole moment). The orientation effect is expected to be the stronger in molecules having a permanent dipole moment.

The beams chosen were O^{6+}, O^{8+}, Si^{10+}, Si^{12+}, all at 5 MeV/u. The charge-state variation was needed in the context of the expected polarisation dependence. Data analysis is in progress.

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