BARC–TIFR Pelletron Linac Facility Beam Time Request @2024

Title: New momentum spectrometer calibration, followed by fragmentation dynamics study of new molecule**.**

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Motivation of the experiment:

The ionization of atoms or molecules using Highly charged ions (HCI) is of importance for fundamental research as well as their applications in molecular physics and biology to study radiation-induced damage. In molecules, the complexity increases due to being a many-body system. On interaction with the Highly charged projectile, elastic and inelastic processes can take place such as electron capture, transfer excitation, ionization, etc. In the high-velocity regime (>1 a.u.) Ionization dominates. In atoms, interaction with HCI may lead to excitation or electron removal from outer shells or core shells. In the case of core-shell excitation or ionization, the atom relaxes either by radiative decay or auger decay. In the case of molecules, the ionization usually leads to dissociation due to coulomb repulsion. However, in the case of polyatomic molecules, there can be many dissociation pathways. All the bonds can break simultaneously (concerted decay) or they can break sequentially (Sequential Decay).

We have designed and fabricated a new momentum spectrometer called Reaction microscope. Using it we can measure the individual momentum components of the recoil ions and electrons in coincidence, created as a product of an atomic reaction, with sub-atomic scale precision, hence we can perform kinematically complete high-resolution momentum spectroscopy. To verify our spectrometer calibration parameters with the simulation we will first perform some benchmark experiments. Once the reaction microscope performance test is complete we can move towards more complicated reactions such as interatomic Coulombic decay (ICD), Radiative charge transfer (RCT), etc... These can be studied in the case of Van der Waal structures such as dimers, trimers, etc. These systems are of great interest due to low binding energy. In this case, after ionization, the system can relax either radiatively or by ejection of the electron but instead of ejection from the same site(atom), it can be ejected from the neighboring atom. This is known as Interatomic coulombic decay. Dimers of Nobel gas such as Ar, and Ne can made with the help of a supersonic molecular jet. Heteronuclear dimers or cross dimers can also be made through the jet which are not well studied as of now. The reaction microscope will open a new scope of exploration of charge transfer dynamics processes.

Beam details: 30-50 MeV $^{12}C^{6+}$, N^{7+}, $^{16}O^{8+}$, $^{19}F^{9+}$, 1 nA, Hall II (45^0).

Bunching required: Yes.

Number of shifts: 15 required.

Experiment details:

1) **Objective:**

(i) **To test and calibrate the spectrometer:** In the momentum spectrometer fast positive ions coming from the Pelletron-LINAC facility will collide with various atomic and molecular targets. The products of the reaction, the recoil ion and the electron will be extracted in perpendicular direction to the projectile beam and the time of flight (TOF) and hit positions on the position sensitive ion detectors will be recorded as raw data. The start of time of flight signal will be the projectile pulse arrival time. From the time of flight and the detector hit positions the momentum components of the recoil ion and the electron will be calculated. Under certain applied electric and magnetic fields the momentum components will have a one to one mapping with the TOF and the hit positions [1]. From the ion trajectory simulation using SIMION software we have got the momentum components functional dependence with the raw data. To testify the simulation results we need to perform some calibration experiments. For that purpose, we will use C^{6+} + He collision system as the first benchmark experiment [2]. We will be measuring the ionization channels in coincidence. The evaluated fully differential cross-section will be matched with the previous data.

(ii) **Kinematically complete fragmentation experiment of new molecule:** This involves detection of all the ions and electrons produced in the interaction and determining their momenta, energy and angular distribution thus helping us to understand the dynamics of the reaction.

2) Description of experiment

A new spectrometer known as "Reaction Microscope" will be used for the detection of electrons and ions produced in a reaction. This setup is an advancement from the already existing COLTRIMS (Cold Target Recoil Ion Momentum Spectrometer) in a way that it can also detect electrons and their momenta in coincidence. This spectrometer is a two-stage Wiley-McLaren type spectrometer. This consists of an extraction region, acceleration region, and field-free drift region. After the ions are produced in the interaction region the ions are extracted and accelerated with the help of an electrostatic field and after traveling through the drift tube are detected with the help of a Position Sensitive Detector.

The spectrometer overcomes the uncertainties arising to finite size of the interaction region. The Interaction Region (~2 mm) is of finite size instead of a point and this may lead to uncertainties in momentum calculation. Two ions produced in different places in the interaction region may hit the detector at different positions which may lead to uncertainties in transverse momentum. To counter this, we have used an electrostatic lens which projects ions from a different position in the interaction region onto to same position on the detector. This is known as Position Focusing or Velocity Imaging. Also, two ions produced in different places in the interaction region may hit the detector at different times. For this, the geometry and fields in the Extraction and Acceleration region are such that at the detector the ion which was produced far from the detector overtakes the ion produced nearby. This is known as Time Focusing.

It will be ion atom/molecule collision experiment. The cross-section for ionization is of the order 10^{-16} cm^2, target density 10^{11} cm^{-3}. The collision products positive recoil ion and electron will be detected in MCP (Micro Channel Plate) followed by DLA (Delay Line Anode) detector from Roentdek. We need bunched beam with a bunch separation of 12 μsec. Hence chopper has to be used along with bunched beam. The single collision condition to be satisfied, so each projectile bunch will have only one interaction, hence the count rate will be less than beam repetition rate. 1 lakh plus total counts are required for sufficient statistics.

- These experiments are part PhD work of Shri Jibak Mukherjee and Shri Harpreet Singh.

References:

[1] J Ullrich *et al* 2003 *Rep. Prog. Phys.* **66** 1463.

[2] D Fischer et al 2003 *J. Phys. B*: At. Mol. Opt. Phys. **36** 3555.