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Atomic inner-shell processes studied by integral measurements at MeV/u energies

Motivation

(1) Inner-shell ionization cross sections

The X-ray excitation in the light ion - atom collisions has been intensively studied in the last decades in order to develop and test theoretical approaches, as well as to build a database of X-ray production cross sections for applications, like the particle induced X-ray emission (PIXE). A rather good understanding of X-ray production by light ion impact (protons, alpha particles etc.) has been obtained (see e.g. [1] and references therein); however, there are much less data for heavier ions. Direct ionization of the inner- (K- and L-) shells by light ions can be reasonably described by first-order treatments based on non-relativistic plane wave Born (PWBA) and semiclassical (SCA) approximations. These theoretical approaches have been further extended to include higher order effects, like electron binding / polarization, as well as projectile Coulomb deflection or relativistic effects.

In slow collisions with heavier projectiles, molecular-orbital (MO) excitation mechanisms (electron promotion and excitation / ionization from MOs transiently formed during the collision) may come into play. For ex., in slow collisions in the asymmetric collision systems ^{48}Ti, ^{52}Cr, ^{56}Fe + Pt, studied by us in the last years (only partially published, ref. [2]), the inner-shell vacancy production could not be explained by only direct ionization from atomic states (with possible electron capture contribution); the MO mechanisms, specific for the K-L level matching region, can make important contributions, their importance increasing with Z-projectile of the mentioned collision systems, and even becoming dominant mechanisms of inner-shell vacancy production. In collisions with lighter ions, like ^{12}C, ^{16}O, ^{32}S, ^{35}Cl + Pt collisions, the ionization from atomic states has dominant contribution [2].

The first aim of the present proposal is to obtain new experimental evidence for the quasi-molecular mechanisms of electron promotion and excitation (ionization) in the K-L level matching region. Another aim of integral cross sections measurements is the application of heavier ions to analytical work (PIXE). Using heavy ions PIXE needs to supplement the inner-shell ionization cross section data, for many projectiles, target elements or impact energies. New data are also necessary to overcome some standardization difficulties, due to, for ex., the multiple ionization effects, which induce modifications in the X-ray energies and relative yields.

(2) Radiative electron capture

One of the fundamental processes in atomic collisions is the transfer of an electron from a target atom into a fast-moving projectile. For electron capture into highly charged ions, three different mechanisms should be considered:

- non-radiative electron capture (NREC);
- radiative electron capture (REC);
- resonant transfer and excitation (the inverse of an Auger transition).

In the nonrelativistic domain, the dominant electron transfer process is NREC where the electron is transferred without radiation from a bound target state into a bound state of the projectile. The energy and momentum gained in the capture process are shared between the projectile and the target atom.

On the other hand, for high collision velocities and low-*Z* targets, electron transfer is entirely determined by REC, where the coupling between the electron and the electromagnetic field of the fast-moving projectiles leads to the emission of a photon carrying away the momentum and energy difference between the initial and final electron states [3].

For loosely bound target electrons, REC is almost identical to radiative recombination (RR) of free electrons, which is the inverse of the photoelectric effect. Therefore, measurement of REC cross sections may be a way to indirectly determine photoionization cross sections.

The knowledge of accurate ionization and recombination (charge changing or charge transfer) reaction rates of heavy ions is crucial in different domains, like ionization balance of highly charged ions in hot plasmas, research of X-ray lasers etc.

Proposals

For the present beam, we propose two integral measurements:

(1) Inner-(K- and L-) shell ionization and the quasi-molecular mechanisms of electron promotion and ionization: integral measurements of ionization cross sections of Pt by projectile ^{55}Mn, in dependence of collision energy.

These measurements will provide new insights into the quasi-molecular mechanisms of vacancy production and sharing in the K-L level matching region, by comparing with available theoretical calculations for direct ionization of the 3dσ MO and vacancy sharing.

By using the energy and yield shifts measurements, outer-shell multiple ionization probabilities could be estimated and interpreted in terms of first order models (like the geometrical model).

(2) Radiative electron capture (REC) measurements.

We propose to measure REC cross sections in dependence of bombarding energy in the MeV/u range in collisions like: ^{32}S and/or ^{35}Cl + Ni; thin (both Ni on C backings and self-supported Ni) targets will be used. Due to larger fraction of projectile ions possesing K vacancies, the target X-rays as well as REC yields increase with target thickness. Therefore, we propose to measure X-rays as well as REC yields as a function of target thickness. The mean electron binding energy in the final state as well as the inverse photoionization cross sections will be estimated and compared with theoretical predictions.

Experiment

The collimated ion beams of ^{55}Mn in the first experiment and ^{32}S / ^{35}Cl in the second, charge state and energy selected by a 90^0 analyzing magnet in the energy range of 0.5-2.0 MeV/u, will bombard thin Pt or Ni targets, tilted at 45^0 to the beam direction. The emitted X-ray spectra will be measured with a Ge HP detector, placed at 90^0 to the beam direction. The scattered projectiles are measured by using a thin plastic scintillator foil (110 μm thichness) placed at 90^0, or at a forward angle. The efficiency and the solid angle of the X-ray and particle detectors will be measured using calibrated X-ray and alpha radioactive sources (^{241}Am).

The needed beam time

(1) Because the excitation function will be measured 3 hours/energy at about 15 energies, and taking into account the time for the beam and measuring conditions tuning, we appreciate necessary about 3 days for the collision system ^{55}Mn + Pt.
(2) For the proposed measurements, target-thickness and energy dependences, at selected energies in the range of 0.5-2.5 MeV/u, for ^{32}S or/and ^{35}Cl + Ni, about 7 days will be necessary.

In conclusion, the total needed beam time is 3 + 7 = 10 days, during the present beam period.

References

[1] I. Fijal-Kirejczyk et al., Phys. Rev. A 77, 032706 (2008)
[2] M.M. Gugiu et al., Rom. J. Phys. (in press);
D.E. Dumitriu et al., ICACS 22 (Berlin, 2006)
[3] H.A. Bethe and E.E. Salpeter, “Quantum Mechanics of One- and Two-Electron Atoms” (New York: Academic Press, 1957).