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Proposal for experiments at Tandem accelerator, Department of Nuclear Physics, IFIN-HH

Inner (K- and L-) shell ionization and quasi-molecular mechanisms of electron promotion and ionization

Motivation

Although the Coulomb interaction, responsible for the atomic interactions is very well known, detailed understanding of inner-shell electron ionization / transfer processes is difficult due to many-body character and therefore continues to be of interest. The collision products: X-rays and/or Auger electrons, secondary electrons and recoil ions can be measured and differential measurements (e.g. in coincidence with the emergent ions) could give us more detailed information on the excitation mechanisms (see e.g. [1] for collisions in the K-L level matching region. Integral measurements provide interesting results involving inner-shell electron ionization / transfer processes. In this case, information about the associated multiple-ionization in the outer shells can be obtained from X-ray or Auger electron spectra analysis [2].

The X-ray excitation in the light ion-atom collisions has been intensively studied 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. [3,4]); 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 semi-classical (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.

The inner-shell vacancy production in slow heavy-ion-atom collisions, in so called K-K, K-L etc. level matching regions is dominated by quasi-molecular excitation mechanisms. Thus, integral and differential measurements in collision systems in the K-L level matching region give information about the collision processes: vacancy production in 3dσ molecular orbital (MO) and vacancy sharing between 3dσ MO and other MOs [1].

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 by using integral as well as differential measurements.

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.

Proposal

For the present beam, we propose K-L shell ionization cross-sections determination of Pb target and ^{51}V , ^{52}Cr, ^{55}Mn projectiles in dependence of collision energy by integral measurements, as well as test measurements of X-ray – X-ray and X-ray – scattered particles coincidences, tests of coincidence installation and preliminary measurements for ^{55}Mn(1.5MeV/u) + Bi collision system.

Integral 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).

Experiment

Integral measurements: the collimated ion beams of ^{51}V, ^{52}Cr and ^{55}Mn charge state and energy selected by a 90^0 analyzing magnet in the energy range of 0.25-2.0 MeV/u, will bombard a thin self-supported Pb target, tilted at 45^0 to the beam direction. The emitted X-ray spectra will be measured with a Si(Li) or 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*: because an excitation function of about 3 hours/energy at about 20 energies is necessary, and taking into account the time for the beam and measuring conditions tuning, we appreciate the needed beam time for these measurements of *8 days*.

Differential measurements. Tests of coincidence installation and preliminary measurements.

For one of collisions systems mentioned *3 days* of tests of coincidence measurements X-ray – X-ray and X-ray – scattered projectile are proposed. This time interval covers the tests for the detectors and the coincidence circuit as well as test measurements of the time spectra – true and random coincidences.

X-ray – scattered particle coincidences, with an X-ray detector placed at 90 degree to the beam direction, and a position-sensible particle detector at a small angle to the beam direction, will be measured. A standard slow-fast coincidence circuit and the multi-parameter acquisition system of the department will be used. The numbers of true and random coincidences at a given impact parameter could be evaluated as follows. The rate $C_{X\text{-}p}(b)$ of true coincidences between X-rays and the scattered particles at a given impact parameter b is expressed by:

$$C_{X\text{-}p}(b) = N_p(b)\, P(b)\, \omega\, \varepsilon_X\, \Omega_X/4\pi,$$

where $N_p(b)$ is the number of scattered particles at the impact parameter b, $P(b)$ - the ionization probability, ω - the fluorescence yield, ε_X – the intrinsic efficiency and $\Omega_X/4\pi$ – the solid angle of the X-ray detector. The number of random coincidences at the given b will be:

$$C_r(b) = N_X\, N_p(b)\, T,$$

where N_X is the X-ray rate in the singular spectra and $T \sim 1\ \mu s$ - the time window of the coincidence circuit.

If we take data from the literature for the collision Ni(1.5 MeV/u)+Pb [5], which is similar to our proposed collision system, Mn(1.5MeV/u) + Bi, then $P(b) \sim 10^{-1}$ or larger for b < 1000 fm, ω~0.3, σ_X~50 kb. Taking some typical values for ε_X~0.5, $\Omega_X/4\pi$~10^{-3} and $\Omega_p/4\pi$~5 10^{-4}, and considering a self-supported target of 100 μg/cm^2 thickness, we find $C_{X\text{-}p} \sim 6$ s^{-1} and $C_r \sim 0.2$ s^{-1}. That means, we shall obtain a rather large number of true coincidences compared with the random ones.

The total needed beam time: 8+3 days.

References

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