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Charge exchange and X-ray emission in 70 MeV/u Bi–Au collisions

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Abstract

Charge exchange and X-ray emission for 70 MeV/u highly charged ions of Bi^{q+} [$77 \leqslant q \leqslant 82$] colliding with thin Au targets [$21 \leqslant t$ in μg/cm$^2 \leqslant 225$] were measured at the heavy ion synchrotron SIS at GSI. For the innermost shells this beam energy implies a quasiadiabatic collision regime. The charge state distribution of the emerging ions was measured by a position sensitive CVD-diamond detector after being analyzed by a magnet spectrometer. Charge exchange cross sections have been deduced from the target thickness dependence of the charge state distribution. Electron capture at distant collision dominates completely over ionization at close collision. The X-ray emission from the collision partners were measured by solid state detectors, Ge(i). The K X-ray emission for closed and open incoming projectile K vacancies gives access to vacancy transfer in the superheavy quasi-molecule transiently formed during collision for the innermost shells.

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Keywords: Ion–atom collisions; Charge exchange; K X-ray emission; High Z systems

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1. Introduction

Heavy ion–heavy atom collisions with highly charged projectiles at moderate collision velocities give access to the coupling of the inner-most shells in transiently formed superheavy quasimolecules [1] and hence also to the region of supercritical fields. At the heavy ion synchrotron SIS at GSI, the heaviest ions ($Z\alpha \rightarrow 1$) are available both in the highest charge states (bare, H-like, etc.) and at the same time also at moderate velocities ($v_{\rm ion} < v_{\rm k}$) [2].

The present study[1] has been undertaken to deduce the charge exchange evolution and charge state cross sections of a relativistic heavy ion penetrating through a very thin solid foil cf. [3] and to correlate the same with X-ray emission cross sections determined for the collision system. The electron/vacancy transfer in inner shells of superheavy quasimolecules is then elucidated. From the charge state evolution, we can to some extent deduce the conditions for quasimolecular collisions inside the solid as a function of penetration depth. Hence, we can extrapolate to vanishing target thickness, i.e. to single collision conditions. In particular we are interested in collisions with an incoming K vacancy of the projectile (Bi^{82+}) which means that we are far off the equilibrium charge state. Here, electron capture in distant collisions dominates completely over ionization in charge exchange. For close collisions and inner shells we are in the adiabatic collision regime. The adiabaticity factor η for the K-shells [$\eta = (v/u)^2$] $\leqslant 0.5$ and the inner shell vacancy transfer can be considered within the quasimolecular picture using diabatic correlation diagrams.

2. Experimental details

A SIS beam of 70 MeV/u Bi^{q+} [$77 \leqslant q \leqslant 82$] was bombarded on thin Au targets of 21, 42, 79, 150 and 225 μg/cm^2 thicknesses (the thinnest ones, 21 and 42 μg/cm^2 targets had ultra thin carbon backings of 11 and 12 μg/cm^2, respectively). The schematic experimental set-up with top view is shown in Fig. 1. The target foils were positioned perpendicular to the beam direction. The projectile and target X-rays emitted were detected by two intrinsic Ge detectors positioned in one plane at 60° forward to the beam direction and by a Si(Li) detector positioned off plane at 45° relative to the two Ge detectors (the latter not shown in the Fig. 1). One of the Ge detectors [7Ge(i)] with dimensions of $25 \times 25 \times 12$ mm^3 was granular with 7 independent stripes of 3.57 mm each (observation angles in the range of 49.2°–70.9° in steps of 3.6°). Whereas the single crystal Ge detector [Ge(i)] with an active area of 500 mm^2 and a crystal thickness of 15 mm had a 4 mm thick Ta collimator with an aperture of 5.8×38 mm^2. Both the detectors had aluminium absorbers in the front to reduce the very high count rate of the L X-rays as compared to the K X-rays of interest. The active solid angles of the 7Ge(i) and Ge(i) detectors were 0.1993sr and 0.0493sr, respectively. The Si(Li) detector (active area 200 mm^2) was used for the detection of the L X-rays.

The ejectiles after being charge state analyzed by a spectrometer were detected by a one-dimensional position-sensitive diamond detector [4,5] (Fig. 1). This newly developed detector (active area of 60×40 mm^2) consists of 32 gold stripes deposited on a polycrystalline chemical vapour deposition (CVD) diamond layer. The stripes are 1.8 mm broad with a 0.2 mm pitch and have an independent read out.

3. Results and discussion

3.1. Charge exchange

Only five primary charge states of the emerging Bi^{q+}-ions could be detected in the focal plane by the position sensitive CVD-diamond particle detector. Thus, the magnetic field of the spectrometer has been shifted after each measurement so as to observe the other lower intensity charge states (Bi^{q-4}, Bi^{q-5}, Bi^{q-6} etc.) keeping an overlap of one charge state for normalization. Fig. 2 shows for example such a "composite charge state distribution" obtained in the particle detector for Bi^{82+}

[1] Part of the Ph.D. thesis work of P. Verma.