Nuclear Instruments and Methods in Physics Research B 107 (1996) 62–66

ELSEVIER

NIM B
Beam Interactions with Materials & Atoms

The dynamics of target ionization by fast highly charged projectiles

R. Moshammer [a,*], J. Ullrich [a], M. Unverzagt [b], W. Schmitt [b], P. Jardin [c], R.E. Olson [d], R. Dörner [b], V. Mergel [b], H. Schmidt-Böcking [b]

[a] *Gesellschaft für Schwerionenforschung, m.b.H., Planckstr. 1, D-64291 Darmstadt, Germany*
[b] *Institut für Kernphysik, August-Euler-Strasse 6, D-60486 Frankfurt, Germany*
[c] *Centre Interdisciplinaire de Recherches avec les Ions Lourds, Rue Claude Bloch PB 5133, 14040 Caen, Cedex, France*
[d] *Department of Physics, University of Missouri-Rolla, Rolla, MO 65401, USA*

Abstract

We report on the first kinematically complete investigation of single target ionization by fast heavy ions, on the measurement of all low energy electrons down to zero emission velocities and on the determination of the projectile energy loss on the level of $\Delta E_p/E_p \approx 10^{-7}$. This has been achieved by combining a high-resolution recoil-ion momentum spectrometer with a novel 4π electron analyser. The complete momentum balance between electron, recoil-ion and projectile for single ionization of helium by 3.6 MeV/u Ni^{24+} was explored. Low energy electrons are found to be ejected mainly into the forward direction with a most likely longitudinal energy of only 2 eV. The electron momentum is not balanced, as might be expected, by the projectile momentum but is nearly completely compensated by the recoil ion. Surprisingly, the momenta of the helium-atom "fragments", the electron and the He^{1+} recoil ion, are considerably larger than the total momentum loss of the projectile: the target atom seems to dissociate in the strong, long ranging projectile potential. The collision has to be considered as a real three-body interaction.

1. Introduction

In spite of the importance of target ionizationconcerning energy loss and straggling of fast heavy ions in matter our understanding of the full dynamics of an ionising ion atom encounter is still not yet complete. The momentum transfer between the projectile and all participating particles, namely the recoiling target-ion and the emitted electrons, reveals important information about the dynamics of the ionization process. The detailed understanding of the macroscopic effects resulting from ion–matter interactions like ion tracks in solids, damage of biological tissue, heating of plasmas, requires the reliable and quantitative knowledge on the facets of energy and momentum transfer in one single collision. The measurement of the full kinematics yields highly-differential cross sections and is therefore a stringent test of available theoretical models.

Theoretically, considerable progress has been achieved within the last decade in the description of the ionization collision dynamics of both sample and complicated systems. In multiple ionization events induced by fast heavy-ion impact electrons were predicted to be ejected collectively [1], opposite to the recoil-ion into forward direction and onto the side of the incoming projectile [2]. The recoil-ion was found to compensate the electron (sum) momentum in distant collisions, being scattered backwards with a transverse momentum exceeding that of the projectile. According to the calculations the projectile is deflected to the recoil-ion side (negative deflection angle) for a major part of the ionising collisions.

Experimental studies of target ionization by energetic heavy-ion impact have been mainly restricted to total cross section measurements and to studies differential in the momentum of only one of the outgoing particles. Only few coincidence studies have been reported so far [3,4] and therefore most of the above stated theoretical predictions could not yet be proven in detail. Experimentally this is an extremely challenging task since a considerable fraction of the electrons are emitted with energies below 50 eV and the recoiling target-ions of interest have energies in the sub-meV regime. Only recently efficient recoil-ion detection techniques, based on ultracold supersonic jet-targets (COLTRIMS), have been developed which are sensitive on such small energy transfer [5,8]. Efficient methods for the detection of low-energy electrons have been missing for electron energies below 5 eV. Thus the coincident high-resolution spectroscopy of the electron and the recoiling target-ion, which is the only way to prove in detail the theoretical predictions, was beyond the experimental capabilities.

* Corresponding author.

0168-583X/96/$15.00 © 1996 Elsevier Science B.V. All rights reserved
SSDI 0168-583X(95)00844-6