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Review

Interaction of charged particles with insulating capillary targets – The guiding effect

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A B S T R A C T

The guiding of charged particles through microscopic and, more recently, also macroscopic capillaries is a remarkable effect discovered in 2002 by Stolterfoht and coworkers. After an initial charge-up phase, a beam of charged particles entering an insulating capillary can be effectively steered along the tilted capillary axis. The effect results from self-organized charge-up of the capillary wall which subsequently deflects ions electrostatically thereby inhibiting close collisions with the capillary walls. Indeed, in the case of multiply charged projectile ions the projectiles transmitted through the capillary keep their initial charge state indicating that the ions never touched the inner walls. We will review both the existing experimental data as well as theoretical models for this phenomenon and similar guiding processes for energetic charged particles collected over the past 10 years.

Contents

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1. Introduction

More than 15 years ago, a first report on the interaction of ions with internal walls of capillary targets appeared [1]. Using this technique, the group of Yamazaki successfully investigated the neutralization of highly charged ions (HCI) in front of surfaces. As much of the information on the neutralization process is lost upon impact of the projectile on an extended planar surface, the geometric properties of transmission through capillary targets promised to develop into a tool to study the electron transfer from the target to the projectile as a function of the impact parameter, i.e., the distance of closest approach in a "near miss" collision with the capillary exit surface. Indeed, many of the predictions of the classical-over-the-barrier (COB) model [2], e.g., the distance of first electron transfer [3–5] or the primary quantum number of the excited shell into which charge transfer takes place [6,7] could be verified. Incidentally, while many experiments were performed using metallic capillaries [8], the investigations started out using targets made of Al_2O_3, an insulator with a band gap of 8.8 eV at room temperature [1]. In order to prevent charging up the insulator assumed to deflect projectiles before entering the capillaries, the target was flooded with thermal electrons from a tungsten filament to compensate for its insulating properties.

Discovery of the guiding capabilities of insulating capillaries was reserved to the group of Stolterfoht who used capillaries etched into polyethylene terephthalate (PET) *because of* its insulating properties. Preliminary results of their work on ion-beam guiding was presented at the Highly Charged Ions conference HCI2000 in Berkeley [9]. One of the key ingredients of guiding, ion reflection from charged insulating planar surfaces, had been reported already before by Briand et al. in 1996 [10].

It took the Stolterfoht group another two years until in 2002 their landmark paper *Transmission of* 3 keV Ne^{7+} *Ions through Nanocapillaries Etched in Polymer Foils: Evidence for Capillary Guiding* [11] with refined results of their transmission experiment appeared. They could show that an ion beam could be deflected along the axis of an insulating capillary *without changing the projectile charge state*. Remarkably, even at $\psi = 10°$ tilt angle of the capillary target relative to the direction of the incoming ion beam, projectile transmission was found to amount to more than 10% of the transmission at $\psi = 0°$ tilt angle (Fig. 1, left panel). Additionally, the target retained a "long-time memory" of its charging history as its guiding capabilities were conserved for hours (Fig. 1, right panel).

The qualitative interpretation outlined in [11] was based on the notion of the internal wall of the capillary being charged up by incoming ions. HCI's entering the capillary at a later time are deflected