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VIEWPOINT

Charge state suppression in the impact of swift carbon clusters with amorphous targets

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The investigation of the interaction of energetic carbon cluster beams with solid targets is presently a topic of considerable fundamental and applied interest. For instance, the impacts of various carbon clusters have already provided a lot of useful information on the formation of tracks and on corresponding damage as well [1].

Other obviously related concerns include the fragments' charge state after initial cluster breakup, secondary emission of particles, and sputtering. What makes the impact of swift carbon clusters in the MeV/carbon atom energy range so specific is the unique and very high electronic energy deposition in solid targets, essentially inaccessible to any other kind of particle or photon beams. The enhanced stopping of the correlated charged fragments is thus expected to range well above the usual linear superposition of individual ion stopping in the target. Such a conspicuous effect has already been investigated in detail for pellet compression in the field of particle-driven inertial thermonuclear fusion. More specifically, the direct compression of a capsule with deuterium + tritium fuel in it [2] by an intense fullerene beam has been shown very promising because it allows for the first time the use of a very high adiabat. Moreover, the indirect scenario [3] based on the production of a short photon wavelength hohlraum is also accessible at a radiative temperature twice as large as that produced by more conventional laser or atomic ion beams, which could thus secure a much improved energy conversion to the thermonuclear fuels of the initial driving beam energy. These promising expectations are largely based on cumulative and pairwise vicinage effects enhancing the correlated stopping in a target of the fragments assumed to be endowed with a fixed electric charge. Such a simplistic picture has nevertheless been seriously questioned by a key experiment performed recently at the Orsay Nuclear Institute by Brunelle *et al* [4], who observed that the charge state of the individual ions of the cluster exiting a thin amorphous carbon foil can be suppressed by up to 30% of their value relative to the corresponding ionic charge state of atomic beams at the same energy.

A lot of theoretical effort [1] has then been devoted to explain and fix this rather disturbing experimental observation, further confirmed by other experimental teams [7].

It is gratifying that a nearly definitive if not authoritative numerical simulation of the Orsay experiment by Eran Nardi and Tom A Tombrello [5] is now appearing in this issue of *Journal of Physics: Condens. Matter*. This work considers C_{10} and C_5 clusters in the MeV/carbon atom energy range impacting thin amorphous carbon foils. The spatial evolution of the resulting fragments in a target is simulated with a Monte Carlo code for their scattering off target ions, while the Coulomb explosion itself is reproduced through molecular dynamics. The key point is that the fragment charge state is obtained as a function of penetration depth from a competition between electron ionization and recombination. Both processes are demonstrated to be strongly affected by the other and nearby co-flying fragments in the given target foil. Then Nardi and Tombrello [5] came up with charge suppression estimates for 2 MeV/C C_5 and C_{10} clusters agreeing well with the experimental data for penetration depths remaining below 500 and 250 Å, respectively, while assuming that the interfragment Coulomb interaction is screened by four target valence electrons.

In this regard, it is highly instructive to compare the average charge state of the resulting fragments flowing in the thin impacted foils with that of a single accelerated ion in similar conditions.

The combined simulation proposed by Nardi and Tombrello [5] includes the effects of the intra-cluster Coulomb interaction into the ionization cross-section and in the ionization cross-section as well. The latter is considered within the usual and classical Bohr–Lindhard model [6]. Brunelle *et al*'s results [4] have been very recently confirmed by Chiba *et al* [7] especially for C_5 at 1 MeV/C. More experimental data including other kinetic energies as well as different supermolecules would allow one to pursue the analysis of the cluster breakup along present lines of reasoning [5].

One can also be thinking of replacing the carbon foil target by dielectric or metallic ones to enlarge and deepen the scope of the present Nardi–Tombrello breakthrough [5].

It is not unlikely that other mechanisms could make the basic carbon on carbon interaction scheme advocated here somewhat more complex.

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