Abstract

We investigated experimentally and theoretically the energy loss and angular dispersion of light ions transmitted through very thin films ($\sim$ 20 nm) of C, Cu and Ag in the very low energy range ($E < 25$ keV/u). Using self-supported foils of amorphous carbon, and copper and silver polycrystals, we studied the velocity dependence of the energy loss of protons, deuterons and H_2^+ and D_2^+ molecules transmitted in the forward direction. By means of energy spectra measurements for different exit angles we obtained angular-energy distributions, from which the multiple scattering distributions and the variation of the energy loss with the projectiles exit angle were analysed.

The obtained results for the velocity dependence of the inelastic energy loss show the absence of isotopic and molecular effects. The energy loss of light projectiles in carbon targets is proportional to the velocity in the low energy range, in agreement with the theoretical predictions for the stopping power of slow ions by an electron gas. In the case of the transition metals that were investigated, copper and silver, the presence of both free (conduction band) and nearly-free (type "d") electrons gives rise to two different electronic stopping power behaviours. At very low velocities, the energy loss is only produced by the conduction electrons contribution. The nearly-free electrons only contribute to the stopping power for velocities greater than a certain critic velocity. This results in the so-called threshold effect for the excitation of nearly-free electrons, that is observed as a deviation from the proportionality of the electronic energy loss with the velocity. In this work we present the first experimental observation of the existence of both energy loss regimes for hydrogenic projectiles in copper and silver targets.

We measured the angular distributions for H^+ and D^+ of 4, 6 and 9 keV in carbon, copper and silver targets, and the data were compared with a multiple scattering formalism that uses the reduced variables approach. For the amorphous carbon target, a good agreement was found when using the interatomic potentials of Molière, Ziegler-Biersack-Littmark and Lenz-Jensen. In the case of the polycrystalline copper and silver films, the results are better represented by using the power-law potential $V(r) \propto r^{-2.8}$. The experimental data obtained for the angular dependence of the energy loss (*i.e.* the

variation of the ions energy loss as a function of the exit angle, after being transmitted through a thin film) are well described by a theoretical model that has been previously developed in this group.

We also determined the energy loss of Be, B, C and O ions in a wide energy range ($50 \lesssim E \lesssim 1500$ keV/u) on Zn targets, using the Rutherford backscattering technique. These results were analysed with a theoretical formalism that combines two complementary schemes for the description of the contributions to the energy loss of the valence and bound electrons. The influence of linear and non-linear effects in the excitation of target electrons was investigated, achieving a good description of the energy loss in a wide velocities range, that includes the maximum of the stopping power curve.

Finally, we studied a theoretical (non-perturbative) formalism of the semiclassical phase shifts for the description of the energy loss of light and intermediate ions. The model results were evaluated for a series of light projectiles ($Z_1 = 1 - 8$) in zinc and carbon targets, comparing them with the experimental data obtained in this work and with others available in the literature.

Keywords: ION SOLID INTERACTIONS, ENERGY LOSS, ANGULAR DISPERSION