THE INTERACTION OF FAST PARTICLES WITH FROZEN GASES IN T TAU NEBULAE: THE PHYSICAL BACKGROUND

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The interaction of energetic particles with frozen gas layers plays a relevant role in a variety of astrophysical scenarii and also in T Tau nebulae because of the large fluxes of particles ejected by these stars during their continuous flaring activity and the observed presence of ice grains at least around the very young star KL Tau (Cohen, 1975).

In order to better understand the problem we will now describe briefly the most important physical processes occurring during ion bombardment of frozen gas layers (mantles).

When an ion (H^+, He^+,....) impinges on a mantle it loses energy through subsequent collisions with atoms and molecules mainly ionizing and exciting them.

The collision time "τ_c" of a proton in the range of energy between 100 keV and 1 MeV is $10^{-17} \div 10^{-18}$ sec. and the mean time between collisions "$\bar{\tau}$" that excite or ionize is about 10^{-16} sec. Secondary electrons produced by primary interactions can lose their energy on a temporal scale about ten times longer than "τ" through a cascade of collisions till when they remain with an amount of energy below the threshold for further ionizations or excitations.

The transfer of this energy which is still in the electronic system, to atoms and molecules may happen by means of the generation of phonons that may establish transient local quasi-thermodynamic equilibrium in a cylindrical region 50 Å wide around the track of the impinging ion if energy remains confined for at least 10^{-12} sec. The occurrence of such an equilibrium can give rise to interesting consequences; two main effects of the energy deposition of fast ions in a frozen gas layer are:

1) ejection of atoms or molecules, and
2) chemical modification of the layer itself.

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The first one takes place because when the transient local quasi-thermodynamic equilibrium is reached the most energetic particles, which are near the surface and belong to the quasi-Maxwellian distribution, may overcome the surface barrier and escape from the solid evaporating (Fig. 1). This effect plays a relevant role in the stability problem of ice grains in T Tau nebulae.

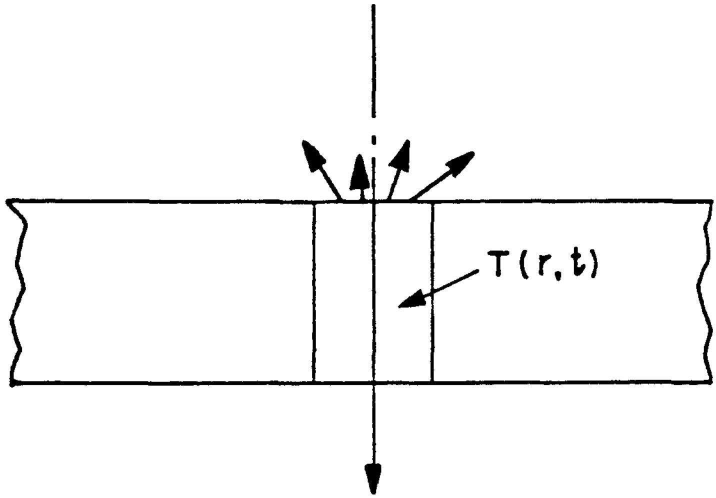

Figure 1. Schematic view of the superficial evaporation (erosion) of the frozen gas layer induced by an impinging ion.

The second effect is due to the breaking of molecular bonds in the target by the fast impinging ion. The cracking fragments, being mobile because in a high temperature region, have a finite chance to recombine forming "new" molecules.

A consequence of such a formation mechanism is that when these molecules are released in gas phase enrich the surrounding medium. This could be an interesting channel to form molecules, observed in space but difficult to obtain by gas phase reactions.

Experimental simulations (Brown et al 1978, Pirronello et al 1981, Brown et al 1982, Ciavola et al 1982) of the interaction between ions and frozen mantles have been performed bombarding thin ice layers (3000-4000Å thick), deposited by vapour on a silicon substrate cooled at 4 K or 77 K, with protons or helium ions accelerated to keV-MeV energies by an ion inplanter or a Van de Graaff.

Erosion yields have been evaluated measuring the thickness of the frozen layer before and after a known dose of projectiles reached the target. The number of removed atoms or molecules versus the projectile dose gives the erosion yield coefficient "Y" (number of atoms or molecules ejected per impinging ion).

The thickness of the layer is obtained measuring the energy lost by 1.5 MeV He^+ ions in the layer itself before and after being backscattered by a thin (250Å) gold marker previously deposited on the substrate.

Huge Y's have been obtained for H_2O, N_2, and other frozen volatiles. Y is regularly temperature independent at low values of the substrate temperature T and strongly dependent from it at higher T, when diffusion processes become relevant.

Chemical modifications of the target due to particles irradiation have been investigated analyzing "in situ" ejected species by a quadrupole mass spectrometer. In particular ice mantles release in a strongly temperature dependent way H_2 and O_2 together with H_2O; furthermore a mixture of equal parts of H_2O and CO_2 prepared in gas phase and deposited on the substrate at 9K has shown, when bombarded by He^+ ions, an high rate of formation of formaldehyde molecules.

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