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Acceleration of ion recombination reaction rates in cold dark clouds through spontaneous polarization charge on CO ice mantles

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Abstract. We propose a role for CO ice mantles in ion recombination reactions, and demonstrate how the subsequent fall in the degree of gas phase ionization decreases the time required for cloud collapse under gravity by a factor of 5-6. Experimental results demonstrate that CO films prepared at cryo-temperatures spontaneously harbour electric fields immediately upon growth. Using what is known from observations about prestellar cloud conditions in the ISM, we explain how this phenomenon can lead to an acceleration in ion recombination reaction rates. The result is a pathway for cloud collapse to occur before cloud disruption by supernova remnants.

Keywords. ISM: clouds, ISM: magnetic fields, molecular processes

1. Overview

Laboratory experiments demonstrate that vapour deposited films of numerous dipolar molecular species condense to form spontaneously polarised layers (Field *et al.* (2013)). Polarisation manifests as a voltage measured at the film-vacuum interface, relative to the film-substrate interface. The polarisation arises from the collective and spontaneous alignment of molecular dipoles throughout the film (Plekan *et al.* (2011)). The evolution of the surface-vacuum voltage is linear with film thickness and so a measure of surface voltage as a function of film thickness reveals the strength of the electric field that the film spontaneously generates. Fields as high as 10^8 Vm^{-1} have been observed (Plekan *et al.* (2011)). A simple, parameterized, mean-field model has been constructed and this model can reproduce the temperature behaviour of the observed electric fields for dipolar films consisting of nitrous oxide, methyl formate, several Freons and, the subject of this article, carbon monoxide (Lasne *et al.* (2015); Rosu-Finsen *et al.* (2016a,b)).

Observations constrain the nature of CO depletion in prestellar cores, indicating a relatively pure CO ice coating on top of compact amorphous water ice on dust grain surfaces (Ford & Shirley (2011)). Laboratory experiments demonstrate that CO ice layers of this nature spontaneously harbour, on average, an electric field of 6.7(0.5) mV per ML of CO, when grown between 20 and 24 K (Rosu-Finsen *et al.* (2016a)). This internal electric field gives rise to a polarisation charge, q_p, at the surface of the CO layer, where $q_p \ \alpha \ a$; a = grain radius. Using B68 as a model and taking 95 % depletion of all gas

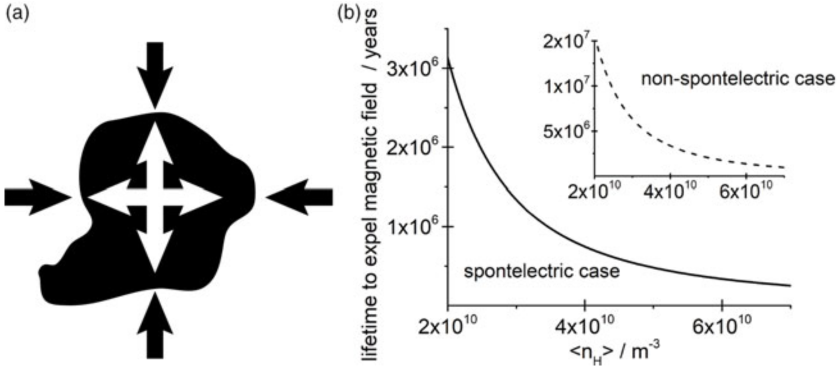

Figure 1. a) Schematic model of magnetic and thermal pressure inside the cloud (white arrows) acting against gravitational pressure (black arrows), which acts to collapse the cloud. b) Ambipolar diffusion lifetimes required to expel the magnetic field completely from a prestellar core as a function of the average number density of H atoms. Curves both including and excluding the effect of polarised CO ice mantles are included, and inclusion of the polarised mantles decreases the lifetime by a factor of 5-6. Modified from Rosu-Finsen *et al.* (2016a).

phase CO over 10^5 yr, this yields a maximum surface polarisation charge $q_p = +5.5(0.4)$ per dust grain. We note that a single dust grain will never achieve this maximum charge build up because the rate of CO depletion is lower than the rate of ion collisions with the dust grain. Rather, the persistent build-up of a positive polarisation charge serves to move the average charge on a dust grain away from -1. This in turn further accelerates the rate of ion collisions with that dust grain. The slow build-up of polarisation charge on the CO ice layer allows surface ion recombination reactions rates, *e.g.*, $H^+ + e^-$, to dominate gas phase reactions rates by a factor of *ca* 40 (Rosu-Finsen *et al.* (2016b)).

The timescale for ambipolar diffusion to drive a collapsing cloud to be magnetically supercritical directly depends on the concentration of ions and neutrals in the gas phase (Flower & Pineau des Forêts (2003)). The inclusion of polarised CO ice layers significantly decreases the concentration of gas phase ions on shorter time scales than non-polarised ice layers and so the corresponding timescale for ambipolar diffusion is much reduced, see Figure 1 (Rosu-Finsen *et al.* (2016b)). The removal of the magnetic field allows for cloud collapse to proceed between 5-6 times faster, within the timeframes set by models and before cloud disruption by a passing super nova remnant. This potentially greatly enhancing the star formation rate in galaxies.

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