CHEMICAL DIAGNOSTICS OF TURBULENT MAGNETIC BOUNDARY LAYERS

S.B. CHARNLEY
Max-Planck-Institut für Physik und Astrophysik
Institut für extraterrestrische Physik
*D-8046 Garching bei München, Federal Republic of Germany.*

ABSTRACT. Results from models of the chemical evolution at the interfaces between hot, highly-ionized, stellar winds and cool, weakly-ionized, molecular clumps are presented.

1. Introduction

Many diffuse astronomical sources consist of clumps of cool, dense plasma embedded in a diffuse, dynamic, hot interclump medium. Mass, momentum, and energy transfer at the interfaces between the clumps and the hotter gas affects very significantly the structures of the flows in the more diffuse gas [1]. At the high Reynolds numbers in astrophysical flows the boundary layer forming at the interface will probably be turbulent. In particular, in regions of low-mass star formation the clumps consist of weakly-ionized molecular material interacting with diffuse gas which is highly-ionized and associated with the stellar winds. This interaction will tend to heat the cool material in a thin region at the clump surface ; the rate of heating depends on the stellar wind velocity, the mass loss rate, the star-clump distance, and the thickness of the boundary layer.

The presence of magnetic fields of strength $\sim 1~\mu G$ in dark clouds would prevent any mixing of the two media. However, due to the large difference in ionization states, ambipolar diffusion across magnetic field lines may occur in the turbulent boundary layer. A theoretical derivation of the heating and mixing rates in turbulent MHD boundary layers would be extremely difficult, as even the basic physics of MHD turbulence is uncertain. Instead, we have examined the effects of various rates on the molecular chemistry of cold clumps. In this manner we hope to discover any chemical abundance variations which may serve to diagnose the underlying interface physics.

We have modelled the physics and chemistry of the interfaces in the nearby ($\sim$ 100 pc), small ($\sim$ 2 pc) dark cloud Barnard 5 (B5) [2,3]. This object contains four IR sources probably associated with T Tauri stars. Winds from the stars interact with clumps in the cloud. Due to its proximity, the structures of the wind-clump boundary layers can, in principle, be studied by emission from atomic and molecular species therein. We have constructed chemical models of these interfaces [4].

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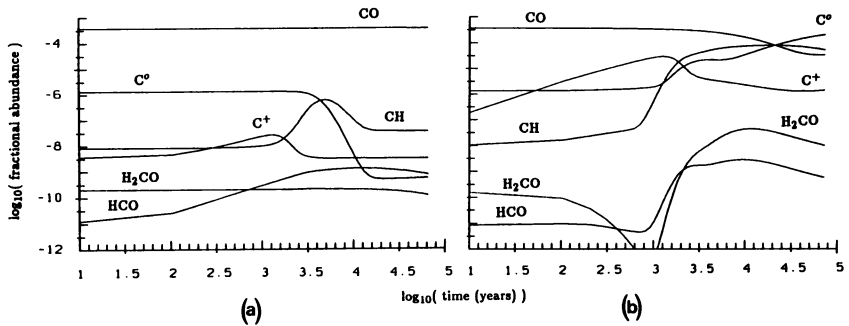
Figure. 1. Chemical evolution in two interface models. The calculation begins from a chemical steady-state and the gas is heated at a rate per particle of 7×10^{-24} erg s^{-1}. In (a) no mixing of ions occurs whilst, in (b), H^+ and He^+ ions are injected with rates per particle of 7×10^{-15} and 7×10^{-16} ions s^{-1} respectively. The interface reaches a steady-state, with a temperature of 1760K and a density of 79 cm^{-3}, in $\sim 7 \times 10^3$ years.

2. Results

We have calculated the evolution of cold (10K), dense $(1.4 \times 10^4 \text{cm}^{-3})$ gas , initially in chemical equilibrium, as it is heated and H^+ and He^+ ions from the stellar winds are mixed into it. The wind-clump interface expands isobarically until eventually a thermal steady-state obtains due to molecular cooling. We find that there are definite chemical distinctions between models with different heating and mixing rates. Figure 1 shows some results from two typical calculations at a high heating rate. Without mixing the chemistry is similar to that occurring in a diffuse hydrodynamic shock. The major chemical effect of mixing is that the reaction of He^+ with CO produces C^+ which leads to large abundances of C^o and CH in the hot gas. At lower heating rates the differences between mixing and non-mixing models are most apparent in the sulphur chemistry [4].

Observations which indicate large abundances of C^o and CH in the B5 interfaces would be strong evidence that mixing is important, and that either ambipolar diffusion or magnetic reconnection driven by turbulence is occurring in them.

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