ON THE MECHANISM OF H_2 FORMATION IN THE INTERSTELLAR MEDIUM

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ABSTRACT. The problem of the formation of molecular hydrogen in interstellar clouds is revisited. The role played by cosmic ray bombardment under certain circumstances is considered mainly in the light of the low formation rate of H_2 on grains due to the reduced mobility of adsorbed H atoms on their amorphous surfaces at interstellar temperatures.

1. H_2 PRODUCTION RATE AND SURFACE MIGRATION

The direct formation of molecular hydrogen by a radiative association of two H atoms in gas phase do not occur because the formed molecule cannot release the excess formation energy by radiative transitions.

The mechanism which is now accepted for the formation of H_2 uses interstellar grains as a catalyst (Hollenback and Salpeter, 1971). In this model H atoms, which stick onto grains migrate on their surface till they encounter another H atom. The energy of the reaction which forms H_2 is then released to the grain avoiding the problem of the two body reaction in the gas phase.

Hollenback and Salpeter (1971) in their works assumed a cubic crystal structure and that hydrogen atoms could be adsorbed in regularly spaced sites. At interstellar temperatures, where thermal hopping occurs at very low rates, the mobility (which is fundamental for the mechanism to work) of hydrogen was assured by tunneling. The diffusion timescale of 10^{-12} sec is so short that adsorbed H atoms will encounter before evaporating, forming hydrogen molecules.

Under this assumption one can estimate the production rate of H_2 for diffuse and dense clouds. Assume a density $n_H \sim 10$ cm and a kinetic temperature $T \sim 80K$ for the former and for the latter $n_H \sim 10^4$cm and $T \sim 10^4$ cm and $T \sim 10K$, then for $n_g \sim 4x10^{-13}\ n_H$ one obtains:

$$R(H_2) \sim 7.2x10^{-16}\ cm^{-2}\ s^{-1} \text{ for diffuse clouds}$$

$$R(H_2) \sim 4.8x10^{-13}\ cm^{-2}\ s^{-1} \text{ for dense clouds}$$

Recently Smoluchowski (1983) has quantitatively shown that the orig-

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inal approach by Hollenback and Salpeter (1971) should be revised in order to consider the effects due to the possible non-crystalline structure of grains. This would be important for silicate or amorphous carbon grains, but not graphite grains, in diffuse clouds and for dirty ice covered grains in dense ones.

The most important difference between the two types of structure is the lack of periodicity among molecules of amorphous surfaces. This gives rise to a variety of sites where atoms can be adsorbed and would result into a rapid localization by tunneling of hydrogen to a site of lowest energy in its vicinity.

The probability of encountering another adsorbed H atom by surface migration would be strongly reduced and H_2 formation by this mechanism could happen only when the accidental adsorption of two hydrogen atoms occurs within a distance of few Ångstrom. Smoluchowski estimates that the rate of production of molecular hydrogen should then be reduced by at least three orders of magnitude.

2. COSMIC RAY BOMBARDMENT

In recent years (see e.g. Brown et al., 1982; Pirronello, 1984) energetic (keV-MeV) particle bombardment of ices of astrophysical interest has shown together with huge erosion yields also chemical processing of the irradiated layer. Simple molecules like H_2, O_2, N_2 are ejected during the bombardment (Brown et al., 1982; Ciavola et al. 1982), while more complex ones like formaldeyde remain trapped after synthesis in the ice (Pirronello et al., 1982).

Molecular hydrogen, in particular, is formed, and immediately released in gas phase, very efficiently in any H rich compound irradiated like H_2O, CH_4, NH_3 and in mixutures of them.

Some astrophysical applications of these results have been already performed (Cheng et al., 1982; Pirronello et al., 1983; Pirronello et al., 1984; Pirronello, 1985).

In the case of dense clouds where grains accrete dirty ice mantles, these laboratory results can be used to estimate the production rate of H_2 $R(H_2)$ induced by cosmic rays.

In this case we have

$$R\,(H_2) = Y\,(H_2)\,J\,n_g\,S$$

where $Y\,(H_2)$ = measured H_2production yield per ion
J = cosmic ray flux
n_g= number density of grains
S = grain cross section

For the mantle we assume a composition of 52% H_2O, 38% CH_4 and 10% NH_3; for the cosmi ray composition we choose H:He:C as 10^3: 10^2: 1 and a total flux of about 10 ions cm^{-2} s^{-1} which should give an ionization rate of 10^{-16} s^{-1}, a value not anymore considered that high (Lepp and Delgarno, 1987).

In these hypotheses at temperatures below 20K if we use results of

CH_4 and NH_3 erosion yields by Johnson et al (1983) with a production rate of molecular hydrogen estimated according to the results of Brown et al. (1982) for water ice we get for dense clouds:

$$R_{CR}(H_2) \sim 6.4 \times 10^{-13} \text{ cm}^{-2} \text{ s}^{-1}$$

The obtained result shows that such a mechanism of H_2 production can be considered at least competitive in dense clouds with the surface reaction between H atoms; to conclude we should like to mention that in regions where grain temperature excedes about 40K this mechanism can be dominant over the other one because evaporation of H atoms has a shorter time scale than sticking.

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