# RADIATION TRANSFER AND PHOTOCHEMICAL EFFECTS IN INHOMOGENEOUS DENSE CLOUDS

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ABSTRACT: UV radiation leads to photodissociation and photoionization of molecular species in diffuse clouds and in the extended envelopes of dark regions. In the inner part of heavily-obscured objects, the residual external field may be negligible; alternative mechanisms, such as cosmic-ray-induced $H_2$ emission, appear to be efficient in photodestruction processes. We evaluate the relative importance of these radiation sources, and give some estimates of their effects on the mean lifetime of interstellar molecules, taking into account the cloud structure that significantly affects the penetration depth of UV radiation.

## 1. INTRODUCTION

Evaluation of the radiation field inside interstellar clouds is a crucial step in theoretical investigations of the physical and chemical evolution of interstellar matter. Indeed, the radiation field affects the ionization of interstellar gas and its temperature and the temperature of dust particles, which in turn affects the formation rates of some molecules and the growth of mantles. Finally, it affects the lifetime of the molecules against photodissociation and photoionization.

In diffuse clouds and in the outer parts of dense clouds, photodissociation by interstellar UV photons is the dominant destruction mechanism of the neutral molecules, while in deeper regions inside the clouds, UV radiation is generally assumed to play a negligible role because of screening by dust particles. However, how efficiently and how deeply the UV photons penetrate inside the clouds depends upon the extinction and scattering properties of the dust.

In this work we investigate the level of ambient UV fields as they result from the transfer of interstellar radiation and from the production of cosmic-ray-generated photons. Preliminary results regarding the photodissociation rates of some molecules of astrophysical interest are given.

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## 2. SOURCES AND TRANSFER OF UV PHOTONS

We assume that the cloud is exposed to an external isotropic UV radiation field with intensity (Van Dishoeck, 1985):

$$N_0(\lambda) = 3.24\times10^{15}(\lambda^{-3}-1.58\times10^{3}\lambda^{-4}+6.26\times10^{-5}\lambda^{-5})\text{photons cm}^{-2}\text{s}^{-1}\text{Å}^{-1}$$

Furthermore, we consider the photons generated inside the cloud by the impact excitation of hydrogen molecules by cosmic rays (Prasad and Tarafdar, 1983), taking into account the contribution of both primary protons and secondary electrons. The primary proton spectrum is the one measured by Webber and Yushak (1983), extrapolated down to 1 Mev. The resulting ionization rate is:

$$\zeta = 4 \times 10^{-17}\text{s}^{-1}$$

The total photon flux (photons $\text{cm}^{-2}\text{s}^{-1}$) in a point at distance r from the center of the cloud, except near the boundaries, is given by the superimposition of the residual interstellar field, $T(\lambda)N_0(\lambda)$, and the cosmic-ray induced field:

$$N(\lambda_{v'v''}) = (1-\omega)^{-1}[1-T(\omega,g)]C_{0v'}A_{v'v''}(\Sigma A_{v'v''})^{-1}(N(H_2)/A_{vis})/E(\lambda)$$

Where $\omega$ and g are the albedo and asymmetry factor of dust particles, T is the transmissivity of the medium at $\lambda$, $A_{vv'}$, are the transition probabilities (Allison & Dalgarno, 1970), $C_0$ are the total collisional coefficients, $E(\lambda) = A(\lambda)/A(\lambda_{vis})$ is the extinction scale. The gas to visual extinction ratio is derived from Dickman (1978).

We carried out calculations for spherical clouds and for both homogeneous and inhomogeneous density distributions. More specifically, we considered clouds with a density distribution dropping off as $r^{-n}$ from a constant density core. Because many dark clouds show similar density distribution (Snell, 1981; Arquilla & Goldsmith, 1985), it appears that inhomogeneous models can provide a more realistic picture of the radiation penetration into clouds than the homogeneous ones can. In both cases, the edge-to-center visual optical depth is 10. In the inhomogeneous model, the core radius is one tenth of the total cloud radius. For the homogeneous model, the transmissivity has been computed by using the Spherical Harmonic Method (SHM) as developed by Flannery et al. (1980). For the inhomogeneous model, we used the extension of SHM worked out by Tiné et al. (1991) in order to handle the variable-density model.

The extinction law has been studied with regard to a large number of stars located in different galactic regions and astrophysical environments. The Mean Extinction Curve (MIEC, Savage & Mathis, 1979), usually adopted for correcting the observations for reddening and in computing the radiation transfer inside interstellar clouds, can actually be considered as representative of the extinction properties of dust in the diffuse medium and in old associations (Aiello et al., 1988). However, in dense clouds and in regions of recent star formation, dust grains are likely to have different properties: in particular, their size distributions appear to be biased towards large radii, which results in a more or less marked flattening of the extinction curve in the far UV spectral region. Therefore, the use of MIEC for computing the radiation field inside the clouds could be completely inappropriate and lead to large errors (Aiello et al., 1984; Mathis, 1990).

Cardelli et al. (1989) found some analytical expressions which relate the extinction scale to the observed values of R, the ratio of the total-to-selective extinction. This latter is considered to be one of the indicators of local properties of dust particles. Indeed, there is quite a strong correlation between the level of extinction and the values of R: the extinction curves towards dense clouds and regions of recent star formation are in general associated with values of R which are larger than the ones associated with MIEC.

In the present computations, therefore, we shall consider two borderline cases: $R = 3.2$, a value characteristic of the diffuse medium, $R = 4.2$, as representative of dense regions.

Albedo and g are poorly known in the UV. The results of different studies are conflicting, in particular with regard to g. For some guidelines we can turn to the existing dust models. The values of $\omega$ and g computed for the MNR model (Draine, 1986) for the far UV are in the ranges 0.4 - 0.5 and 0.5 - 0.6, respectively. Close values are suggested by some observational studies (Lillie & Witt, 1976; De Boer, 1986). We adopt $\omega = 0.4$ and $g = 0.6$ as plausible choices for a low R regime.

Because of the total lack of observational data, the UV scattering characteristic of dust particles inside dense clouds can only be a matter of speculation. From a size distribution biased towards large radii, high values of albedo and g are expected. In Case 2 we tentatively adopt $\omega = 0.5$ and $g = 0.7$ for the high R limit.

## 3. RESULTS

The results of our transfer computations have been applied to a determination of the photodissociation rates of various interstellar molecules. The cross-sections for photodissociation were derived from Lee (1984) and from a compilation kindly provided by E. Herbst. Figures 1-4 show the rates, as a function of the radial distance from the cloud center, for 4 molecules of particular interest from the point of view of prebiotic evolution: $H_2O$, HCN, $NH_3$, $CH_4$. Figure 5 shows the contribution of external radiation and internal photons to the photodissociation rate of $CH_2O_2$.

The effects of cloud structure, as well as of the internal photons, are evident. The latter dominate in the innermost part of the clouds in all the models considered, and are capable of slowing down the decay of photodissociation rates. However, it is evident that the internal field dominates in the deeper part of the cloud in all the models considered; but, the "region of dominance" narrows with a steepening in the density gradient and with an increase in R.

## FIGURES

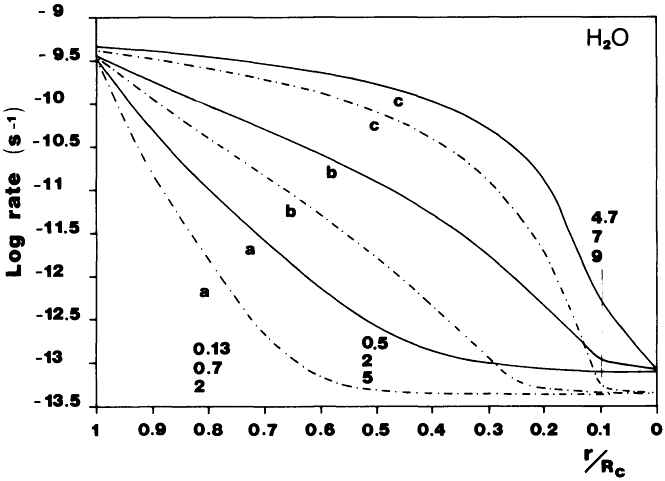

Figure 1. Photodissociation rates for $H_2O$ as a function of the distance from the cloud center: $R_c$ = cloud radius. Dotted line - R = 3.2. Continuous line: R = 4.2. a-cloud with uniform density; b-n = 1; c-n = 2. The visual optical depths corresponding to $r/R_c$ = 0.8, 0.5, 0.1 (core edge) are also indicated.

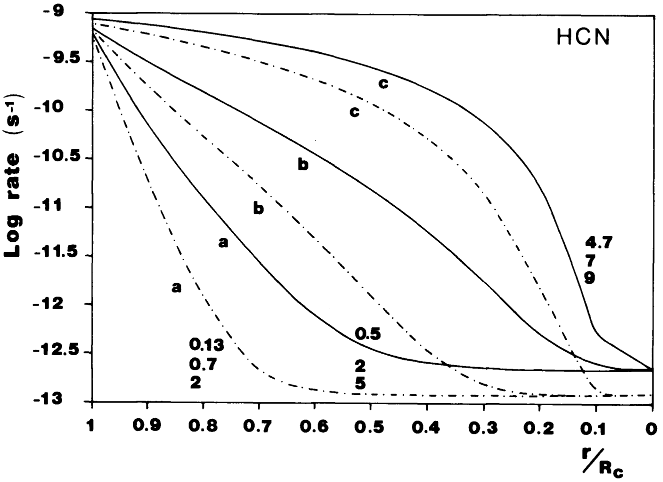

Figure 2. The same as Figure 1 for HCN

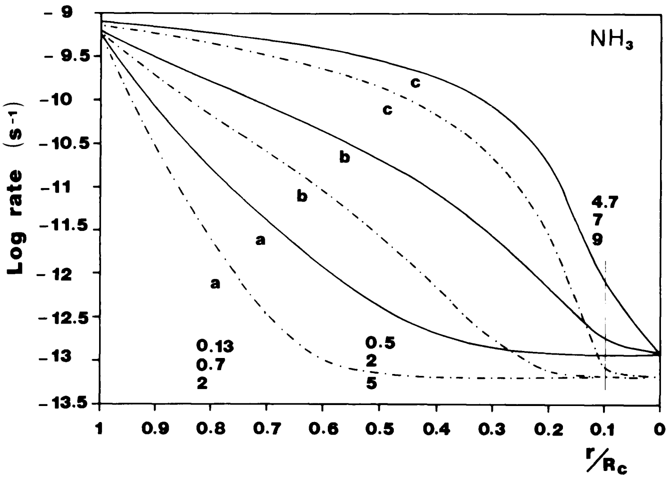

Figure 3. The same as Figure 1 for $NH_3$

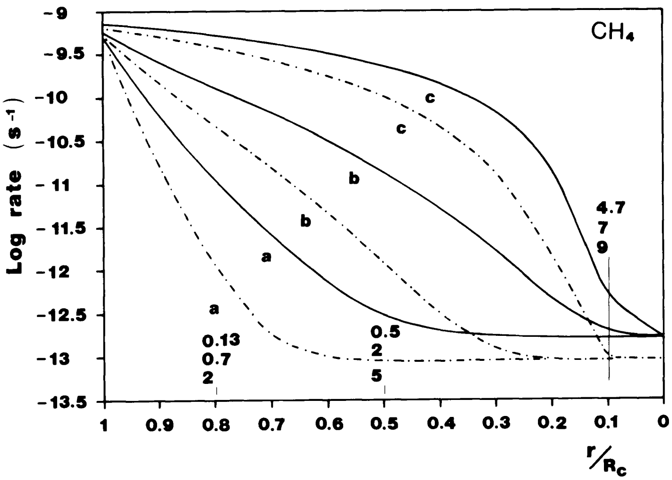

Figure 4. The same as Figure 1 for $CH_4$

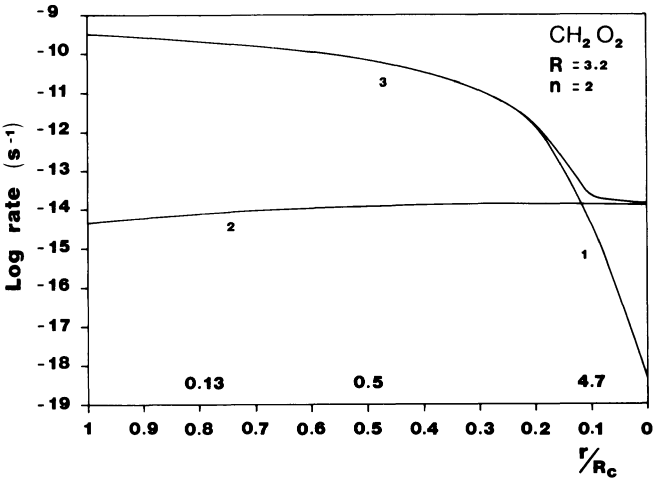

Figure 5. The contribution to the photodissociation rates by external radiation and internal photons for the $CH_2O_2$ molecule. 1) external radiation; 2) cosmic-ray-induced photons; 3) total rates.

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