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Photodissociation Rates of Interstellar Molecules in an Intercloud Region

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Photodissociation rates of interstellar molecules CO, HCN, NH_3, H_2CO and HC_3N are derived for a region with the low interstellar extinction.

Сделаны расчёты коэффициентов фотодиссоциации межзвездных молекул CO, HCN, NH_3, H_2CO и HC_3N в области низкой экстинкции.

Jsou vypočteny koeficienty fotodisociace mezihvězdných molekul CO, HCN, NH_3, H_2CO a HC_3N pro oblast s nízkou mezihvězdnou extinkcí.

Rate coefficients of composition and disintegrations for molecular species in the interstellar space are basic numerical data modelling processes in interstellar molecular clouds.

Unlike the rate coefficient for a chemical reaction, the photo rate coefficient varying strongly with the optical properties of the dust-gas interstellar clouds. Therefore, the photodissociation is a significant competing factor between different processes of the molecular formation in the interstellar space. In this paper are recomputed photo rate coefficients of various dissociation channels of HCN, H_2CN, NH_3 in the ground state and for CO $(X^1\Sigma^+)$ and CO $(a^3\Pi)$ assuming that the interstellar radiations flux in the vicinity of the Sun is comparable to the diffuse interstellar radiation in an unobscured region with very low hydrogen density.

The probability of a photodisintegration or the photodissociation rate k_D is

$$k_D = \int_{\lambda_0}^{\lambda_{th}} \Phi(\lambda) \exp\left[-\bar{\tau}(\lambda)\right] \sigma(\lambda) \, d\lambda \,, \tag{1}$$

where $\Phi(\lambda)$ is the photon flux of the interstellar radiation unattenuated by the absorption which is characterized by the effective optical depth $\bar{\tau}(\lambda)$, i.e. $\exp\left[-\bar{\tau}(\lambda)\right]$ is the local transparency of the interstellar space for $\Phi(\lambda)$ at the position of the dissociated molecular species with the cross section $\sigma(\lambda)$. Wavelength limits are

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$\lambda_0 < \lambda_{th}$, where λ_{th} is the long wavelength threshold of the dissociative continuum. In regard to the opacity of the neutral interstellar hydrogen, the short wavelength limit is usually adopted as $\lambda_0 = 91.2$ nm.

Since $\sigma(\lambda)$ is not a continuous function of λ, the photo rate coefficients can be approximated by

$$k_D = \sum_{i=1}^{n} k_D(\Delta\lambda_i) \tag{2}$$

where $\Delta\lambda_i$ is a wavelength interval of about 1 to 2 nm and

$$k_D(\Delta\lambda_i) = \bar{\sigma}(\Delta\lambda_i)\,\Phi(\Delta\lambda_i) \tag{3}$$

$$\Phi(\Delta\lambda_i) = \int_{\Delta\lambda_i} \Phi(\lambda)\,\mathrm{d}\lambda \tag{4}$$

The photodissociation rate coefficients presented in this paper were calculated for so-called clear intercloud regions, where the extinction in the visual spectal range is lower than 0.7 m kpc^{-1}. The interstellar space for which hold this assumption over a distance of several hunderts parsecs can be regarded as unobscured. In previous studies concerning the lifetimes of the interstellar molecules has been adopted the results of Habing (1968) who derived the upper limit for the ultraviolet radiation energy density 5×10^{-17} J m^{-3} nm^{-1} for wavelengths between 100 to 200 nm. Stief et al. (1972) used the constant energy density 4×10^{-17} J m^{-3} nm^{-1} for $\lambda \geqq 91.2$ nm.

The adopted data concerning the interstellar flux in this study were those obtained from models of ultraviolet stellar spectra combined with satellite observation in UV region (Witt and Johnson 1973, Gondhalekar and Wilson 1975) and interstellar radiation flux between 175 nm to 50.4 nm which was derived by Grewing (1975) from the fractional ionization of the interstellar gas. Grewing's results can be roughly approximated by black-body radiation with $T = 1.1 \times 10^4$ K and are representative for intercloud space in the vicinity of Sun, where the density of the interstellar gas and consequently also the density of absorbing dust grains is low. According to a study concerning the interstellar reddening and intercloud density in the solar vicinity made by Kunde (1979) value of 0.02–0.05 H atoms cm^{-3} can be suggested as the intercloud density. Owing to the low density of neutral hydrogen no cut of or depression around $h\nu \geqq 13.6$ eV can be expected, and the flux in the spectral range $\lambda \leqq 91.2$ should be considered. The effect of an enhanced interstellar absorption at 210 nm, however, remain even for unobscured regions because the scattered interstellar radiation dominates in this spectral range (see Table 1).

For regions with absorption in visual $A_v = 1.086\tau_v \geqq 0$ is the rate coefficient

$$k_D(\bar{\tau}) = k_D \exp\left(-a\bar{\tau}_v\right) \tag{5}$$

where a is the optical depth factor and $\bar{\tau}_v$ optical depth at $\lambda \sim 550$ nm. Although a

Table 1. Interstellar Photon Flux

λ nm	$\Phi(\lambda)$ $\frac{\text{photons m}^{-2}\text{s}^{-1}}{(0{\cdot}1\text{ nm})}$
428	$9{\cdot}81 \times 10^9$
375	$2{\cdot}31 \times 10^9$
333	$1{\cdot}52 \times 10^9$
300	$1{\cdot}18 \times 10^9$
219	$8{\cdot}75 \times 10^8$
150	$2{\cdot}37 \times 10^9$
100	$1{\cdot}19 \times 10^8$
75	$4{\cdot}5 \times 10^6$
60	$1{\cdot}7 \times 10^7$
50	$1{\cdot}7 \times 10^3$

is a function of $\sigma(\lambda)$ and $\bar{\tau}(\lambda)$ values of the optical depth factor are averaged for pass-band $\lambda_{th} - \lambda_0$ and mean interstellar extinction curve obtained by Nandy et al. (1975). The formula 5 can be used only up to $A_v \sim 4$ and is not applicable for dark clouds. Results are summarized in Table 2.

Table 2. Photodissociation Rate Coefficients for Intercloud Regions

Molecule	Decay product	Treshold λ_{th} [nm]	Rate coeff. k_D [s^{-1}]	Optical depth factor a	Source of λ_{th}	Source of $\sigma(\lambda)$
CO ($X^1\Sigma^+$)	C + O	111·8	$1{\cdot}22 \times 10^{-11}$	4·6	[8]	[5] [1]
CO ($X^1\Sigma^+$)	$CO^+ + e$	88·5	3×10^{-12}	(6)	[8]	
CO ($a^3\Pi$)	C + O	243·2	$2{\cdot}20 \times 10^{-9}$	2·5	[8]	[15]
CO ($a^3\Pi$)	$CO^+ + e$	154·0	5×10^{-10}	3·0	[8]	[15]
HCN	H + CN	195·0	$4{\cdot}1 \times 10^{-10}$	3·0	[16]	[14] [17]
NH_3	$NH + H_2$	317·0	$1{\cdot}8 \times 10^{-10}$	2·7	[10]	[12] [13]
NH_3	$NH_2 + H$	279·0	$7{\cdot}0 \times 10^{-10}$	2·6	[10]	[11]
H_2CO	$H_2 + CO$	374·0	$1{\cdot}42 \times 10^{-12}$	1·7	[2] [7]	[6] [9]
H_2CO	H + HCO	349·0	$1{\cdot}08 \times 10^{-12}$	1·6	[3]	[2]
H_2CO	H + H + + CO	275·0	$1{\cdot}06 \times 10^{-9}$	2·6		
H_2CO	all channels		$1{\cdot}4 \times 10^{-9}$	2·3		
HC_3N	$HC_2 + CN$	163·2	$4{\cdot}23 \times 10^{-9}$	2·6	[16]	[4] [18]

Comments to Table 2. The optical depth factor a is applicable up to $\tau_v \simeq 4$ only. References for λ_{th} and $\sigma(\lambda)$:

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