POPULATION OF EXCITED ROTATIONAL LEVELS OF INTERSTELLAR H$_2$

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Abstract. The population of the rotational levels of vibrational and electronic ground state of interstellar H$_2$ has been calculated; different possible excitation and de-excitation mechanisms including the ultraviolet pumping and formation and destruction of molecules have been considered. The values of temperature, density and radiation field towards ζ Oph, ε Per and ζ Pup have been obtained by comparing the theoretical distributions with the observations. The results indicate the presence of a high temperature low density diffuse cloud towards ζ Pup and low temperature high density clouds towards ζ Oph and ε Per.

The results of this work were presented at the February, 1974 meeting of the Astronomical Society of India (Joshi and Tarafdar, 1974).

1. Introduction

Many interstellar molecules have been observed in the last few years, hydrogen molecule being the most abundant among them (Carruthers, 1970; Smith, 1973). Spitzer et al. (1973) and Spitzer and Cochran (1973) have recently reported the observations of rotational level populations of the ground state of interstellar H$_2$ for $J \leq 6$. The observations indicate that processes other than collisional transition may play a major role in determining the population of the various levels. We have calculated here the population distribution among the rotational levels of interstellar H$_2$, taking into account the various processes likely to be operative in the interstellar space.

2. Basic Equations

The various processes known to govern the population of rotationally excited levels of interstellar molecular hydrogen are

(1) collisional excitation and de-excitation;
(2) radiative de-excitation;
(3) absorption to and induced emission from higher electronic levels;
(4) formation of molecules;
(5) destruction of molecules; and
(6) ortho-para conversion.

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For steady state, the equations are

\[
\frac{dN_0}{dt} = 0 = -N_0(K_{\text{e}}n_H + R_d + RPO + \sum_{\sigma, v} B(1, 0, 0; \sigma, v, 1)I) + \\
N_1 ROP + N_2(R_2 + K_2n_H) + RF_2n_HN + \\
\sum_{\sigma, v} N(\sigma, v, 1)\{A(\sigma, v, 1; 1, 0, 0) + B(\sigma, v, 1; 1, 0, 0)I\},
\]

(1)

\[
\frac{dN_1}{dt} = 0 = -N_1(K_{\text{e}}n_H + R_d + ROP + \\
\sum_{\sigma, v} \{B(1, 0, 1; \sigma, v, 0) + B(1, 0, 1; \sigma, v, 2)I\} + \\
N_3(R_3 + K_3n_H) + RF_1n_HN + RPO N_0 + \\
\sum_{\sigma, v} [N(\sigma, v, 0)A(\sigma, v, 0; 1, 0, 1) + B(\sigma, v, 0; 1, 0, 1)I] + \\
N(\sigma, v, 2)\{A(\sigma, v, 2; 1, 0, 1) + B(\sigma, v, 2; 1, 0, 1)I\}],
\]

(2)

\[
\frac{dN_j}{dt} = 0 = -N_j(K_{\text{e}}n_H + R_j + K_jn_H + R_d + \\
\sum_{\sigma, v} \{B(1, 0, J; \sigma, v, J - 1) + B(1, 0, J; \sigma, v, J + 1)I\} + \\
N_{j+2}(K_{j+2}n_H + R_{j+2}) + N_{j-2}K_{(j-2)n_H} + \\
RF_jn_HN + \sum_{\sigma, v} [N(\sigma, v, J - 1) \times \\
\{A(\sigma, v, J - 1; 1, 0, J) + B(\sigma, v, J - 1; 1, 0, J)I\} + \\
N(\sigma, v, J + 1)\{A(\sigma, v, J + 1; 1, 0, J) + \\
B(\sigma, v, J + 1; 1, 0, J)I\}]
\quad \text{for } J > 1
\]

(3)

\[
\frac{dN(\sigma, v, 0)}{dt} = 0 = -N(\sigma, v, 0)\{A(\sigma, v, 0; 1, 0, 1) + \\
B(\sigma, v, 0; 1, 0, 1)I\} + N_1B(1, 0, 1; \sigma, v, 0)I,
\]

for \( \sigma > 1 \)

(4)

\[
\frac{dN(\sigma, v, J)}{dt} = 0 = -N(\sigma, v, J)\{A(\sigma, v, J; 1, 0, J - 1) + \\
A(\sigma, v, J; 1, 0, J + 1) + B(\sigma, v, J; 1, 0, J - 1)I + \\
B(\sigma, v, J; 1, 0, J + 1)I\} + N_{j-1}B(1, 0, J - 1; \sigma, v, J)I + \\
N_{j+1}B(1, 0, J + 1; \sigma, v, J)I
\quad \text{for } \sigma > 1 \text{ and } J > 0,
\]

(5)

where

- \( N_j \) = column density of \( \text{H}_2 \) in the rotational level \( J \) of the electronic and vibrational ground state in \( \text{cm}^{-2} \).

- \( N(\sigma, v, J) \) = column density of \( \text{H}_2 \) in rotational level \( J \), vibrational level \( v \) and electronic level \( \sigma \) in \( \text{cm}^{-2} \). The level \( \sigma = 1 \) corresponds to the lowest electronic state \( (X'\Sigma) \). The summation over \( \sigma \) starts from \( \sigma = 2 \).

- \( N \) = column density of hydrogen nuclei in \( \text{cm}^{-2} \).