POLARIZATION OF RADIO MOLECUAR LINES

AND MAPPING OF MAGNETIC FIELD DIRECTION

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ABSTRACT

Two level calculations by others for the linear polarizations expected for molecular emission lines from interstellar clouds are extended by considering a number of coupled rotational states of a diatomic molecule. Higher transitions commonly have strengths comparable with that of the J=1-0 transition so that depolarization due to coupling between the various J-states might be expected to reduce the predicted linear polarization. The significance of the null observational results obtained recently by Wannier, Scoville and Barvainis is assessed. The inclusion of additional states tends to decrease the maximum polarizations, though the calculated polarization is increased under conditions for which "superthermal" excitation occurs.

INTRODUCTION

Linear polarization of the emitted radiation is likely to occur when the radiation field within the emitting region is not isotropic. Anisotropy of the radiation in gas clouds can occur because of the optical depths for the escape of line radiation are not the same in all direction. Goldreich and Kylafis (1981, 1982) have examined the influence of anisotropy caused by velocity gradients in producing linear polarization of thermal radio emission lines from molecular clouds. At radio frequencies, the Zeeman splitting of molecular rotational lines is normally much greater than the natural line width. Then, the direction of the net linear polarization can be utilized as an observational diagnostic for the direction of magnetic field. For their idealized model, they find that linear polarization up to 10-20 % does occur. Wannier, Scoville and Barvainis (1983) performed an extensive search for linear polarization in CO, HCN and CS emission lines, but no linear polarization has been detected. An approximation in the Goldreich and Kylafis calculation is to include only two levels and obtain explicit results for only the J=1-0 transition of CO. Coupling of the J=1 state to the J=2 and higher states by radiation and by collision would be expected to scramble the populations of the magnetic substates and to reduce the predicted linear polarization.

NUMERICAL RESULTS

The treatment for the J=1-0 transition of diatomic molecule by Goldreich and Kylafis can be readily extended to multilevel problems. The equations of radiative transfer for the intensities having two polarizations are solved with the large-velocity-gradient approximation. All of our results are obtained for either (a) the one dimensional case in which the velocity gradient is only along the magnetic field or (b) the two dimensional case in which the

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velocity gradient is present only in the plane prependicular to the magnetic field. The two dimensional case is that of a cloud expanding with constant velocity and may be a more realistic simulation of a molecular cloud. Results are given for various ratios of the collision rate to the radiative decay rate C/A for the J=1-0 transition.

We have compared the multilevel (J up to 4) calculations for the CO molecule with those including only the J=1 and 0 levels. The peak polarization in the J=1-0 transition is decreased by about a factor of two as a result of including the higher J-levels. Cascading from the higher levels increases the intensity (the superthermal effect), however. For C/A=0.1, the multilevel calculation actually gives higher values for Q^2+U^2. The higher transitions exhibit less polarization. For the J=1-0 transition, the fractional polarization is largest for the smallest C/A considered (about 7% for C/A=0.01). However, the critical quantity for detecting the linear polarization is Q^2+U^2 and this decreases at low C/A because of the intensity decrease. For the two dimensional geometry, Q^2+U^2 does not exceed about 0.25 K for CO and CS molecules.

In the one dimensional geometry, the velocity gradient is along the magnetic field so that the photons escape along the field. We consider line-of-sight to the observer that is perpendicular to the magnetic field. The optical depth is infinite and the observed intensity (temperature unit) is equal to the excitation temperature. The polarizations computed for this geometry may be unrealistic because the superthermal excitation strongly influences the result and such excitation apparently has not been observed for CO. The maximum fractional polarization (approximately 12-14%) is similar to that found by Goldreich and Kylafis. The temperature of linear component can go up to about 3.5 K for C/A=1.

CONCLUSIONS

Though noise levels of about 0.1-0.2 K (one standard deviation) were achieved in a few cases in the search by Wannier et al. (1983), no definite polarization was detected. If three standard deviations or more is accepted as the detectable limit, this level of sensitivity would be marginal for detecting polarization of CO and CS as is expected from our calculations unless the one dimensional case is applicable. Our explicit treatment of polarization for the J=2-1 transition shows that it tends to be somewhat less than predicted for J=1-0, and the latter is the preferable transition with which the linear polarization is seeked.

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