OBSERVATIONS OF THE V=0 S(2) LINE OF MOLECULAR HYDROGEN AT 12.28μm IN THE ORION MOLECULAR CLOUD

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ABSTRACT

The 12.28μm pure rotational line of molecular hydrogen has been detected in emission from the region of vibration-rotation line emission in Orion. The line shapes, widths, and velocities are similar to those observed in the V=1 → 0 transition at 2.12μm. Constraints imposed by these new results on models of the emitting region are discussed.

INTRODUCTION

Vibration-rotation line emission from molecular hydrogen in the 2μm wavelength region was discovered unexpectedly from an astronomical object about three years ago. Since then these quadrupole transitions have been observed in a growing number of types of objects ranging from molecular clouds and T Tauri stars to planetary nebulae and supernova remnants - objects associated both with the birth and death of stars. The lines are strongest in the Orion molecular cloud where the extinction (Beckwith, Persson, and Neugebauer 1979; Simon et al. 1979) and the spatial distribution of V=1 → 0 S(1) line shapes (Nadeau and Geballe 1979; Nadeau, Neugebauer, and Geballe 1979) indicate that the line arises far behind the optical nebula in a cloud expanding at speeds up to 100 km s^{-1} due to some unknown source or event. From other observations and theoretical work it appears that the acceleration and heating (to 2000 K) of the H_2 results from collisions which are caused by the passage of a shock through the molecular cloud.

At the temperature of 2000 K inferred from the vibration-rotation line measurements, the population of a low rotational level in the V=0 state of H_2 is roughly ten times that for a similar level in the V=1 state. Because the lower rotational levels of the V=0 state will also be populated well below 2000 K it is expected that observations of the associated rotational transitions can provide information about the cooler, post-shock gas. These transitions, however, have A-coefficients typically 100 times less than vibration-rotation transitions. Furthermore,

B. H. Andrew (ed.), Interstellar Molecules, 465–468.

every one of them occurs at a wavelength which is difficult for or inaccessible to ground-based observing and where the terrestrial background is much greater than at the shorter wavelength vibration-rotation lines. In spite of these difficulties the S(2) line at 12.28μm has been detected at a number of positions in Orion. The observations were made in 1979 February and March with a cooled Fabry-Perot and grating spectrometer on the 2.5m telescope of Las Campanas Observatory. The results put new constraints on the structure, temperature, and dynamics of the region of molecular hydrogen emission.

RESULTS AND DISCUSSION

The S(2) line, observed in a 7" diameter aperture, was seen at seven positions including all five of the bright peaks of the 2.12μm V=1 → 0 S(1) line mapped by Beckwith et al. (1978). Typical peak intensities of the 12.28μm line, which was spectrally resolved, are 2 - 3 x 10^{-3} erg s^{-1} cm^{-2} sr^{-1}. At four other positions searched (including that of the Becklin-Neugebauer object) the line was not detected, with 3σ upper limits of 1 x 10^{-3} erg s^{-1} cm^{-2} sr^{-1}.

The column densities in the upper level (V=0, J=4) are approximately 3 x 10^{20} cm^{-2} (after correcting for an estimated 1.5 magnitudes of extinction). With some variation with position in the cloud, this is about a factor of five greater than is predicted from the temperature and column densities observed in the vibrationally excited lines. The upper levels of the latter transitions lie 6000 K or more above the ground state, whereas the upper level of the 12.28μm line corresponds to 1800 K. From this it is apparent that most of the 12.28μm line radiation comes from gas too cool to be vibrationally excited. Qualitatively that is the expected result for the case of rapid shock-heating of the gas followed by slower cooling. The V=1 → 0 lines would in that case be emitted just behind the shock while the 12.28μm line emission would persist further behind (see Fig. 1). The relative intensities of the two lines depend on both the shock velocity and the abundances of rapidly radiating molecules such as CO (see Kwan 1977). Such molecules cool the post-shock gas, thereby decreasing the power emitted by H_2, which is a very inefficient radiator.

The large widths (up to 55 km s^{-1}) and the shapes of the 12.28μm line are very similar to those observed by Nadeau, Neugebauer, and Geballe (1979) in the 2.12μm line. In all spectra except that at the position of Beckwith et al.'s (1978) Pk 2 the S(2) line is noticeably asymmetric with increased emission on the blue side of the line peak. The velocity of peak intensity at all positions is near + 7 km s^{-1} (LSR), which is also quite close to that observed for the 2.12μm line. It should be noted that the rest frequency of the S(2) line used here, 814.452±.005 cm^{-1}, has been calculated from the accurately measured frequencies of three other pure rotational transitions of H_2. The most recent laboratory measurement of the S(2) line frequency, made over 20 years ago by Stoicheff (1957), significantly disagrees with this calculated frequency. It is important that the S(2) line frequency be remeasured in the laboratory.

Detailed comparison of the 2.12μm and 12.28μm line profiles might allow a test of dynamical models of the emitting cloud. In the model of roughly spherically symmetric expansion suggested by Nadeau and Geballe (1979), the observed asymmetry of the 2.12μm S(1) line shape requires extinction of at least 2 magnitudes within the emitting region. At 12.28μm where extinction is less, perhaps by a factor of 2.5 (Becklin et al. 1978), the red side of the S(2) line should extend to larger positive velocities than the S(1) line. Although at a couple of positions this does not seem to be the case, at most positions the signal-to-noise ratio of the S(2) line does not permit a meaningful comparison.

Further details of this work can be found in Beck, Lacy, and Geballe (1979). The work was supported in part by NASA Grant NGL 05-003-272 and NSF Grant AST 78-24453. The Hale Observatories are operated jointly by the Carnegie Institution of Washington and the California Institute of Technology.

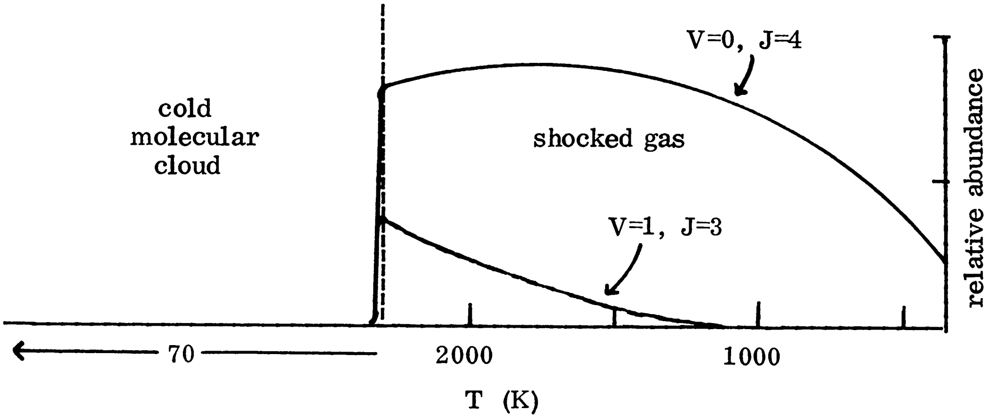

Fig. 1 Effect of a shock on the populations of the upper levels of the V=1 → 0 S(1) and pure rotational S(2) transitions in the Orion molecular cloud.

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DISCUSSION FOLLOWING GEBALLE

Black: Excess emission in the rotational line is inferred by assuming a galactic center extinction curve. What extinction at 12 microns is derived if it is assumed alternatively that all of the excited H_2 is at the temperature determined for the vibrationally-excited molecules?

Geballe: No extinction at all.

Gilra: Have searches been made for the rotational or vibrational-rotational transitions of HD? The effect of the lower densities of HD will be somewhat offset by higher transition probabilities.

Geballe: There have been none so far as I know. Clearly, there are a large number of molecules which may be detectable in the infrared, given the brightness of the H_2 lines.

Beckwith: The 12.28 μm extinction could be as large as 2 magnitudes, a value which is certainly consistent with the curve of Becklin et al. (1978) within the considerable errors. If true, would you not expect the positive velocity edge to be depressed relative to the negative velocity edge, as is the case with the 2 μm lines?

Geballe: Yes, the positive velocity edge would be attenuated, but one might still see a difference in the two profiles if the observations of the 12 μm line had better signal-to-noise ratio. Until such observations are obtained, and until the question of the S(2) rest frequency is answered, an accurate comparison cannot be made.