Polarimetry of the H$_2$ emission from the Orion Molecular Cloud

R. R. Joyce* Kitt Peak National Observatory, PO Box 26732, Tucson, Arizona 85726, USA
Theodore Simon† Joint Institute for Laboratory Astrophysics, University of Colorado and National Bureau of Standards and Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, Hawaii 96822, USA

Received 1982 May 4; in original form 1981 October 6

Summary. We have measured the linear polarization of the $v = 1 \rightarrow 0$ S(1) emission of molecular hydrogen at three positions in the Orion Molecular Cloud. To the north-west of BNKL, at H$_2$ Peak 1 and Peak 5, we find $p \approx 10$ per cent in position angle 110$^\circ$, in good agreement with previous continuum polarization measurements for the nearby source IRS 2. At H$_2$ Peak 2 to the south-east, we find $p \approx 0$ per cent. The absence of H$_2$ emission-line polarization at Peak 2 is inconsistent with the scattering mechanism proposed by Elsässer & Staude and also with the shock-induced grain alignment mechanism discussed by Johnson et al. The observed spatial variations in polarization may be due to small-scale structure in the magnetic field of the cloud, or to local differences in the relative temperatures of the gas and dust.

1 Introduction

Strong infrared polarization has been observed in the vicinity of the Becklin-Neugebauer (BN) and Kleinmann-Low (KL) sources in the Orion Molecular Cloud (Loer, Allen & Dyck 1973; Dyck et al. 1973; Knacke & Capps 1979). Dyck & Beichman (1974) attributed the observed polarization to extinction by magnetically-aligned dust grains. By applying the paramagnetic relaxation theory of Davis & Greenstein (1951), they showed that the required degree of grain alignment could be achieved with magnetic field strengths of several milligauss (cf. Dennison 1977). In very dense molecular clouds, however, the paramagnetic relaxation mechanism becomes inefficient due to randomizing gas–grain collisions and consequently large field strengths are needed to align the polarizing dust grains Thus, Johnson et al. (1981) proposed that grain alignment might be induced by the recombination of atomic hydrogen on grain surfaces. In this model, the H$^+$ is formed by dissociation of H$_2$

* Operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.
† Visiting Astronomer, Kitt Peak National Observatory.

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in a shock wave accompanying high-velocity gas flows observed at infrared and radio wavelengths (e.g. Solomon, Huguenin & Scoville 1981).

The existing polarimetric measurements of the Orion Molecular Cloud (OMC) were made at low spectral resolution, either in broad photometric bands \((H, K, L, \ldots)\) or with circular variable filters at a resolution \(\Delta \lambda / \lambda \approx 2\) per cent. Here we report the first measurements of linear polarization in near-infrared emission lines from the OMC. We have measured the linear polarization of the \(v = 1 \rightarrow 0\) \(S(1)\) line of \(H_2\) \((\lambda = 2.12 \mu m)\) at three positions in the cloud. We undertook these observations in order to learn more about the excitation of the \(H_2\) in the OMC and the relationship of the extended \(H_2\) sources to other energetic, high-velocity gas flows occurring in the same region.

2 Observations

The \(H_2\) polarimetry was carried out on the 1.3-m telescope of the Kitt Peak National Observatory with a polarimeter consisting of, in order of placement in the optical train, a rotating mica half-wave plate, a stationary evaporated grid linear polarizer and a liquid nitrogen cooled grating spectrometer. The spectrometer was equipped with an InSb detector designed for operation at low background; for a source filling the 11 arcsec beam, the resolving power was \(\lambda / \Delta \lambda \approx 500\). At this resolution we did not resolve the narrow \(S(1)\) line; nevertheless, judging by high-resolution spectra (Scoville et al. 1982) and by our previous (Simon et al. 1979) and present observations, we estimate the continuum flux to be negligible at the strong \(H_2\) emission peaks observed in the course of this study.

To measure the linear polarization, we rotated the half-wave plate in intervals of 22.5°, at a fixed orientation of the linear polarizer. At each position angle, we paused for a set of beam-switched observations.

Corrections for instrumental polarization were derived from measurements of unpolarized stars. The half-wave plate/linear polarizer combination essentially eliminated the effects of the large and wavelength dependent polarizing properties of the grating spectrometer; the observed instrumental polarization (due primarily to the dichroic beamsplitter in the IR photometer assembly) was 1.7 ± 0.1 per cent over the 2.10–2.16 \(\mu m\) wavelength range. The position angle calibration, efficiency of the polarimeter and flux calibration were provided by measurements of BN at continuum wavelengths adjacent to the \(S(1)\) line. The efficiency of the half-wave plate/linear polarizer combination was determined in two ways. Laboratory and telescope measurements of polarized light obtained by the inclusion of a second linear polarizer in the beam yielded an efficiency of 0.88. On the other hand, a BN continuum polarization of 21 per cent at 2.12 \(\mu m\), as interpolated from the CVF polarization of Capps (1976), can be reconciled with our data only by assuming a rather low efficiency of 0.70

<table>
<thead>
<tr>
<th>Name</th>
<th>(\lambda) ((\mu m))</th>
<th>(p) (per cent)</th>
<th>(\phi) (°)</th>
<th>Ref.</th>
<th>Flux (w cm(^{-2}) sr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(H_2) Peak 1</td>
<td>2.12</td>
<td>8.1 ± 1.5</td>
<td>107 ± 5</td>
<td>1</td>
<td>(6.3 \times 10^{-10})</td>
</tr>
<tr>
<td>(H_2) Peak 2</td>
<td>2.12</td>
<td>1.1 ± 2.8</td>
<td>109 ± 73</td>
<td>1</td>
<td>(3.0 \times 10^{-10})</td>
</tr>
<tr>
<td>(H_2) Peak 5</td>
<td>2.12</td>
<td>11.3 ± 0.9</td>
<td>129 ± 2</td>
<td>1</td>
<td>(6.1 \times 10^{-10})</td>
</tr>
<tr>
<td>IRS 2</td>
<td>2.2</td>
<td>10.8 ± 1.0</td>
<td>136</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>BN</td>
<td>2.2</td>
<td>18.4 ± 0.6</td>
<td>115</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

References
1  \(H_2\) emission-line polarization, this paper.
2  Broadband \(K\) polarization from Lonsdale et al. (1980).
for our system. We have chosen to use this latter value for consistency with the earlier measurements, since it may include other systematic effects in our observations.

The linear polarization was measured at the strongest peaks of S(1) emission; i.e. in accordance with the nomenclature of Beckwith et al. (1978), at H$_2$ Peaks 1 and 5 located north-west of BN and Peak 2 to the south-east. We summarize our results in Table 1 and Fig. 1, and for comparison we also provide 2.2 $\mu$m broadband polarization measurements of BN and IRS 2 (Lonsdale et al. 1980). There are no substantial disagreements between the previous continuum measurements and our emission-line polarimetry at Peaks 1 and 5; however, to within the observational uncertainties, we find that H$_2$ Peak 2 is unpolarized.

Also listed in Table 1 are the measured values of surface brightness determined by scans of the S(1) line with our 11 arcsec beam. These are within 20 per cent of those obtained from the low-resolution map of Beckwith et al. (1978). Any continuum flux at Peaks 1, 2 and 5 was less than 10 per cent of the line peak and could not significantly affect the polarization of the S(1) line flux.

3 Discussion

Within the context of the paramagnetic relaxation grain alignment model, the apparent differences in emission-line polarization could be accounted for by differences in the amount of 2 $\mu$m extinction along the line-of-sight to the H$_2$ emission peaks, or by changes in the degree of fractional alignment of the polarizing dust grains across the face of the molecular cloud. Changes in the proportion of aligned grains could be attributed to local fluctuations in magnetic field strength, magnetic properties of the grains, or relative temperatures of the gas and dust.
Estimates of the foreground extinction to the H$_2$ emission peaks, based on the relative strengths of the $v = 1 \rightarrow 0$ S and Q branch lines, yield similar values ($A_{\nu} \approx 40$ mag) for Peaks 1, 2 and 5 (Beckwith, Persson & Neugebauer 1979; Simon et al. 1979). Because of the possibility of internal extinction in the H$_2$ source, however, these estimates of $A_{\nu}$ are uncertain. Scoville et al. (1982) have inferred a lower extinction, $A_{\nu} \approx 12 - 20$ mag, from H$_2$ spectra obtained with a Fourier Transform spectrometer at several positions in the OMC, including Peaks 1, 3 and 5. Furthermore, the $O(5)/S(1)$ and $O(6)/S(2)$ flux ratios measured by Simon et al. (1979) at the unpolarized H$_2$ Peak 2 imply $A_{\nu} \leq 15$ mag in the direction of this peak.

The present observations of Peak 2 appear to be inconsistent with the predictions of the Elsässer & Staude (1978) scattering model for highly polarized protostars. If the IR line emission in Orion is the result of single scattering (at nearly 90°) within reflection nebulae associated with the infrared cluster, the H$_2$ peaks should be highly polarized. The H$_2$ polarimetry of Peak 2 provides no evidence for large polarization, although the continuum emission is highly polarized (Werner & Capps in preparation). The polarization of Peaks 1 and 5 might be explained by scattering from a bipolar nebula oriented north–south, associated with IRS 2; however, the continuum polarization (Werner & Capps, in preparation) in the region south of IRS 2 is not oriented in a direction consistent with such scattering.

It is also difficult to reconcile the absence of linear polarization in the $S(1)$ line at Peak 2 with the shock-induced grain alignment model of Johnson et al. (1981), since we are aware of no salient differences, other than polarization level, between the north-west and south-east H$_2$ emission sources. We find a possible correspondence between high levels of polarization and broad $S(1)$ emission-line profiles with blueshifted velocity H$_2$ gas (Nadeau, Geballe & Neugebauer 1981). However, the polarimetry data are not extensive enough to establish a firm correlation. Polarization measurements at 10–20 km s$^{-1}$ resolution could distinguish polarization differences in the red and blue wings of the $S(1)$ line and provide valuable evidence for such a hypothesis. If the shock alignment model is valid, then it is necessary to postulate an efficient disalignment mechanism for Peak 2 or other local conditions (small magnetic field, weak shock, low H$_2$ density, or different grain properties) to explain the lack of polarization at a strong H$_2$ emission site.

References


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