Optical polarization in the Orion Nebula

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Summary. Optical linear polarization has been measured at 3000 points in the central region of the Orion Nebula. The polarization is attributed to Mie scattering and its pattern indicates the roles of \( \theta_1 \) and \( \theta_2 \) Orionis in the illumination of the nebula.

Solid particles in the Orion Nebula give rise to a variety of effects that can be studied optically, for example, the particles form a medium which scatters the light of stars embedded in it. This process gives rise to linear polarization of the scattered light (see, e.g. Hall 1974, and references therein), and information on polarization coupled with spectral data (on both direct and scattered stellar continuum and nebular emission) will yield information on the number density, size and composition of the particles. This will lead to an indication as to how the particles are formed and also clarify their role in the formation of protostars in the nebula. Details about the particles can also be ascertained by observations of the infrared emission from the extended nebula (Werner et al. 1976) as well as from discrete infrared sources and optical extinction.

All studies of the Orion Nebula are complicated by the problem of finding an adequate model of the geometry, for example for the relative positions of the illuminating stars and scattering dust. In this paper we present the first detailed map of the linear polarization, which clarifies this primary problem of the structure of the nebula and is part of the data for further characterization of the scattering particles.

The observations described here were obtained with the 1-m telescope of the Wise Observatory, Israel, in 1975 March. The B waveband of the UBV system was used. The Durham University polarimeter was used with a 4-cm McMullan electronographic camera: the technique is described elsewhere (Bingham et al. 1976; Pallister 1976).

The polarization map is shown in Fig. 1, superimposed on an electronograph of the Orion nebula taken in H\( \alpha \) radiation by the authors on the 36-in telescope at the Royal Greenwich Observatory. Each measurement of polarization is indicated by a line in the direction of the

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E-vector, proportional in length to the degree of polarization and centred on the point observed. Typical errors in the body of the nebula are 0.5 per cent in degree of polarization and 3° in position angle. On the periphery of the north-eastern quadrant, dominated by the dark bay, the errors are larger and probably account for the irregular structure in the polarization pattern. Each measurement is over a $7 \times 7$ arcsec square, and the 3000 points give an essentially complete map over about 8 arcmin centred between $\theta^1$ and $\theta^2$ Orionis. The foreground polarization (e.g. Breger 1976) is negligible.

The most obvious feature of Fig. 1 is the centro-symmetric pattern to the north, west and south of the Trapezium ($\theta^1$ Orionis); the vectors are mainly normal to the radius vector from the Trapezium (marked $\theta^1$ on the map) and the point of observation. This effect is due to the scattering of light emanating from the Trapezium by the nebular material, the degree of polarization depending mainly on the character of the particles and the scattering geometry.

In the region around $\theta^2$ Orionis, the pattern tends to centre on $\theta^2$ rather than on the Trapezium, suggesting that this area of the nebula is mainly illuminated by $\theta^2$; any simple model of the nebula in which the Trapezium is assumed to be the only source of energy is valid only in the north-western quadrant of this field. There is independent evidence of $\theta^2$ contributing to the illumination of the nebula in the form of bright edges on small condensations near this star, discussed by Münch & Wilson (1962) and Taylor (1976). Their suggestion of the condensations' being illuminated by $\theta^2$ is supported by the pattern of the polarization in this area (the condensations are too small to be seen individually on this map).

An additional remarkable effect is the position of the 'bar' (e.g. Münch & Taylor 1974), said to be an ionization front. (The bar is easily seen in the underlying electronograph of Fig. 1; it runs north-east—south-west and is just above $\theta^2$. Part of the lower edge of the bar can be seen to delineate between areas illuminated by $\theta^1$ and $\theta^2$ as far as the polarization is concerned. The interpretation suggested is that the bar is physically closer to $\theta^1$ than to $\theta^2$ in spite of its projected position. $\theta^2$ and the regions it illuminates, particularly to the east, are then at a different distance. The area about 1 arcmin south-west of $\theta^2$ seems to show angles of polarization between those to be expected from $\theta^1$ and $\theta^2$—this feature is clearly due to a superposition of polarized regions or of different sources of illumination.

Also indicated on Fig. 1 is the position of the Kleinmann—Low (Kleinmann & Low 1967) infrared nebula. Although the direction of the infrared polarization is similar to that observed optically, the polarizing mechanisms may differ, since the optical polarization can arise from scattering of light by randomly aligned particles whereas the infrared effect has been attributed, by Dyck & Beichman (1974), to a polarizing screen of aligned dust grains. Those authors assumed that the alignment was caused by magnetic fields, but we see no evidence for this at optical wavelengths. There is no certainty that the infrared feature has an optical counterpart, but we wish to point out the alternative possibility that the alignment is produced by radiation effects, the source of energy being the Trapezium. Such effects have been discussed in a different context by Harwit (1970).

Returning to further considerations of the optical polarization, although the orientation of the E-vectors is easily accounted for by scattering, the degree of polarization (3—5 per cent) is more complicated to explain. The scattered light is diluted by direct nebular emission which we have attempted to subtract, using the data of Schiffer & Mathis (1974). We find that the resultant source polarization is 7—12 per cent; it cannot be explained solely by Rayleigh or Thomson scattering and seems to be predominantly Mie scattering (by grains of a finite size). We are endeavouring to model the nebula in terms of Mie scattering to give information on the grain size and distribution, from the polarization data.

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Figure. 1. The linear optical polarization of the Orion Nebula (M42) in the B waveband. The small square shows the position of the Kleinmann–Low nebula.
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