NO. 88 WAVELENGTH DEPENDENCE OF POLARIZATION. VI. MOLECULAR SCATTERING AT THE SKIN OF THE PARTICLES*

by T. GEHRELS

ABSTRACT

The pronounced shape (called "characteristic curve") of the wavelength dependence of interstellar polarization is qualitatively explained with molecular scattering at the surface of interstellar particles.

FIGURE 1 shows the characteristic curve of polarization sometimes observed on interstellar particles (see Paper V); it may be explained as follows. Let Fig. 2 represent an interstellar particle with cross section about $0.3\,\mu$, and assume that the "dirty ice" model is the correct one (refractive index $m \cong 1.3$). Presumably, the particle originated by molecular accretion, and the elongated shape may be caused by chance collision and cohesion of two lumps. The accretion has progressed further, and the skin consists of loosely bound molecules. Figure 1 shows a polarization maximum near 5600 Å, with a slow decline in the ultraviolet, and a steep drop in the infrared.

The shape in the visual and ultraviolet is similar to that for polarization dilution by multiple molecular scattering. That is, single isotropic scattering would show 100% polarization at $1/\lambda = 0$ and at 90° phase, and, by multiple scattering, the polarization decreases as $1/\lambda$ increases. The shape on the right in Fig. 1 is seen in the calculations by Coulson, Dave, and Sekera (1960) for multiple molecular scattering (see Fig. 3 of Gehrels 1962).

How 90°-phase molecular scattering may occur at the skin of interstellar particles is seen as follows. Let the illuminating light source be a star behind the particle of Fig. 2. A molecule at A scatters the incident starlight in all directions, by primary molecular scattering. The light scattered towards the observer by A, but via neighboring molecules B and B', will have predominant vibration perpendicular to the long axis of the particle. The light scattered via A and C (or A and D) has vibrations parallel to the long axis of the particle. However, the light scattered by A towards C is lost to the observer, while that scattered towards D reaches the observer, if at all, only after further multiple scattering. Because of the elongated shape of the particle, the electric vector maximum is predominantly perpendicular to the long axis of the particle.

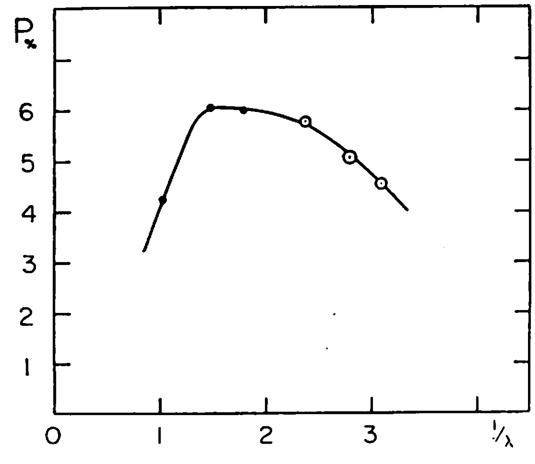

FIG. 1. Observed percentage interstellar polarization. The abscissas are in reciprocals of microns. Computations for refractive index $m \cong 1.3$ and particle diameter $2a \cong 0.3\,\mu$ reproduce this curve.

Longward of a characteristic wavelength in the infrared, the molecular scattering (dependent on λ^{-4}), rapidly decreases in strength; the light mostly bypasses the particle with only inappreciable scattering by the accreted molecules. The characteristic wavelength depends on the particle size and refractive index. In Fig. 1 for $2a = 0.3\,\mu$, for example, the discontinuity occurs near $1/\lambda = 1.3$.

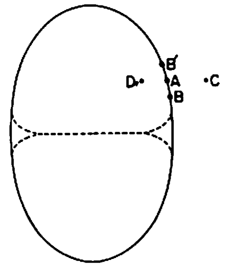

FIG. 2. Cross section perpendicular to the line of sight through an interstellar particle.

The accreted molecules presumably are lightly packed, but they may not be independent scatterers. However, independent scattering is not a required condition, and at least the polarization is not affected by interference effects (p. 87 of van de Hulst 1957; also see p. 396). Whether or not loose binding of the surface molecules is essential, remains to be seen.

The present interpretation attempts to explain small-scale phenomena. It is compatible with the theoretical work on light scattering by small particles, of Mie and others, that treats the particle as a whole. Particularly the discontinuity at $1/\lambda = 1.3$ in Fig. 1 is not obvious in the usual calculations (Chap. 15 of van de Hulst

---

*Reprinted with permission from the *Astronomical Journal*, Vol. 71, No. 1, Feb. 1966 — No. 1336.

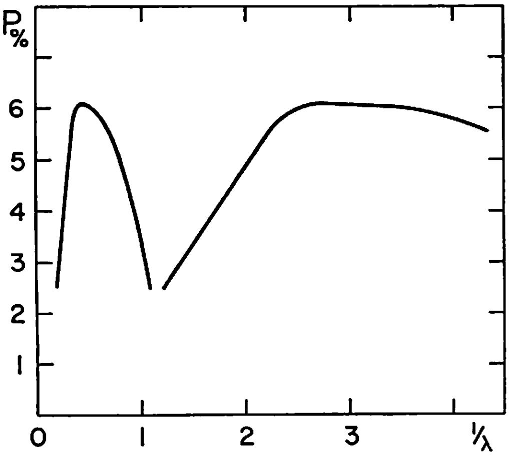

FIG. 3. Percentage interstellar polarization computed for refractive index $m=1.3$ and particle diameters $2a=1.1\ \mu$ (curve on the left) and $2a=0.17\ \mu$ (right).

1957), but it is understood with the above interpretation on molecular scattering.

Figure 3 gives the characteristic curves for $2a=1.1$ and $0.17\ \mu$. They are computed for long cylinders with refractive index near 1.3 (van de Hulst 1957, Chap. 15). The curves are normalized so that the maxima agree with that of Fig. 1.

An alternate fit to the observed variety in interstellar absorption (Johnson 1965) and polarization (Paper V) is with a variety of refractive indices. The curves of Fig. 3 could then have $m \cong 2.1$ (left) and 1.2 (right) for $2a=0.3\ \mu$ (and Fig. 1 still is for $m=1.3$). From the present observations of interstellar absorption and interstellar polarization we cannot decide if there is a variety in $2a$, in m, or in both.

REFERENCES

Coulson, J. L., Dave, J. V., and Sekera, Z. 1960, *Tables Related to Radiation Emerging from a Planetary Atmosphere with Rayleigh Scattering* (University of California Press, Berkeley and Los Angeles).

Gehrels, T. 1962, *J. Opt. Soc. Am.* **52**, 1164.

Gehrels, T., and Silvester, A. B. 1965, *Astron. J.* **70**, 579 (Paper V).

Hulst, H. C. van de 1957, *Light Scattering by Small Particles* (John Wiley & Sons, Inc., New York).

Johnson, H. L. 1965, in *Nebulae and Interstellar Matter*, Vol. 7 of *Stars and Stellar Systems*, edited by L. H. Aller and B. M. Middlehurst (University of Chicago Press, Chicago).

Acknowledgments. The work is supported by the National Aeronautics and Space Administration (NsG-733).