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ON GRAPHITE AND INTERSTELLAR EXTINCTION

It has been argued by Cayrel and Schatzman (1954) and by Hoyle and Wickramasinghe (1962) that graphite particles could be responsible for interstellar extinction. It is the purpose of this Letter to present evidence that further supports this contention. The complex dielectric constant for graphite has been measured as a function of energy by Taft and Philipp (1965). The optical constants as a function of wavelength were obtained from this measurement and are plotted in the insert in Figure 1. A large variation occurs in both n and k at wavelengths below 3000 Å. In view of the results reported in the preceding Letter we were prompted to carry out Mie scattering calculations on graphite. We have used the measured values of the complex index of refraction corresponding to seventeen wavelengths in the calculation for spherical particles. The IBM 7094 computer program for Mie scattering follows van de Hulst (1957). The Oort–van de Hulst (van de Hulst 1949) size distribution, which may not be applicable to the type of particle discussed here, has been used to obtain an integrated cross-section for extinction. The steps were in terms of 0.8×10^{-6} cm for the particle radius with the $1/e$th value of the frequency function being 5.6×10^{-6} cm. In Figure 1 this curve is compared with the mean observed interstellar extinction of Boggess and Borgman (1964) and the further observational results reported in the preceding Letter by one of us. The maximum in the theoretical extincton-curve at $\lambda^{-1} = 4.4$ inverse microns is the signature of graphite. This maximum rapidly increases as the relative size of the particle radius decreases. At the same time, the extinction for $\lambda^{-1} < 2$ decreases. A 50 per cent increase in the relative radius of the particles appears sufficient to produce the variation in the ratio of selective to total extinction observed by Johnson (1965). A maximum in the observed interstellar extinction-curve also occurs at $\lambda^{-1} = 4.4$ microns. The authors feel that this coincidence provides a strong argument in favor of graphite. For the first time there is structure in the extinction-curve, and it can be accounted for by a particular substance. It is, of course, possible that some other material could have the same signature and also be abundant in interstellar space but it seems improbable. The albedo for this particle size distribution is somewhat larger than that found by Wickramasinghe (1963) and may be sufficiently high to account for reflection nebulae (van Houten 1961).

For shorter wavelengths the calculated curve is inconsistent with the observations. It seems unlikely that a particle size distribution could be found that would be satisfactory. The addition of a dielectric material either as a coating of the graphite or as separate small particles could easily bring up the curve. A promising "dielectric" which is already present is graphite itself. Graphite is strongly anisotropic. Our calculations were made with optical constants measured for the electric vector in the basal planes. When the electric vector is perpendicular to the basal planes, the conductivity is at least 100 times smaller (Wickramasinghe 1963) and graphite then acts like a dielectric. Since graphite is presumed to be present in the form of flakes that are almost randomly oriented, a sizable proportion of the flakes will present this thin dielectric face to the radiation.

Both the ratio of crystal axis and the "dielectric" index of refraction are uncertain, thus precluding a quantitative calculation at this time. This conjecture could be observationally checked by polarization measurements at $\lambda^{-1} = 6\ \mu^{-1}$. If graphite is assumed to be the sole cause of interstellar extinction, a reversal in the sign of polarization would be expected when the "dielectric" extinction exceeds that of the conducting plane.

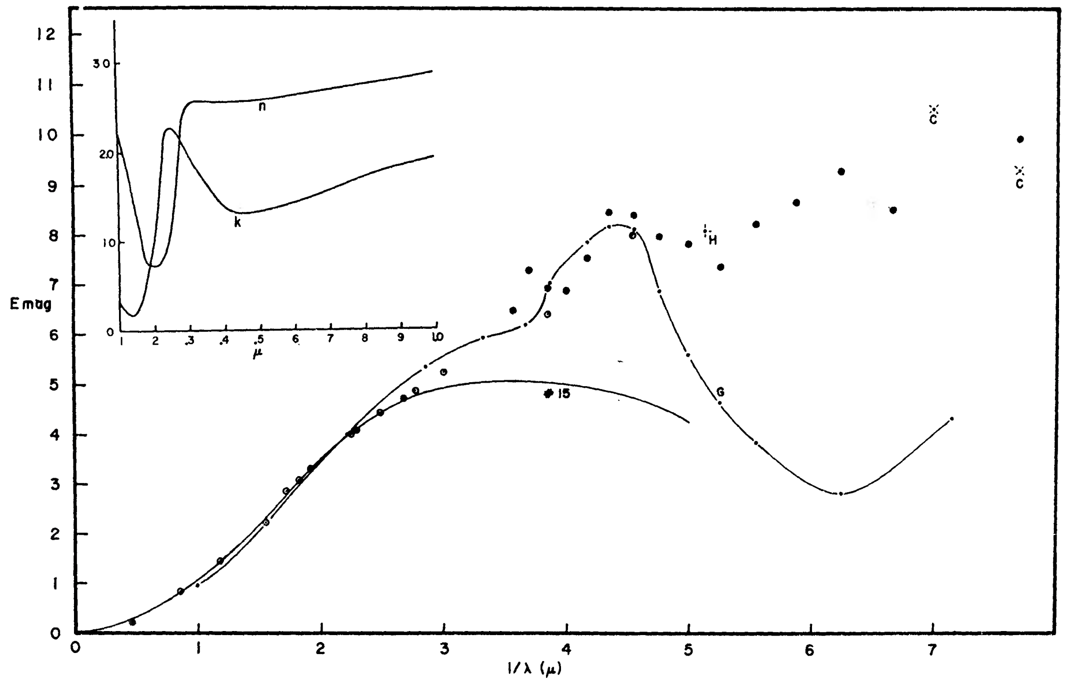

FIG. 1.—Observed and theoretical interstellar extinction. *Large filled circles:* the mean observed interstellar extinction reported in the preceding letter. *Open circles:* mean observed extinction of Boggess and Borgman (1964). Points marked "*H*" and "*C*": observed extinction obtained from others. Curve *G:* theoretical interstellar extinction for graphite grains Curve *15:* Theoretical extinction by van de Hulst (1949). *Inset:* The optical constants for graphite as a function of wavelength.

In addition to the proposal of Hoyle and Wickramasinghe (1962) for interstellar carbon grains, it has recently been pointed out (Donn 1965) that graphite flakes may grow in space if countering effects can be neglected. The exponential whisker-growth mechanism (Sears 1955) was shown to apply. For a plate of 10^{-6} cm thickness, the length reaches 5×10^{-6} cm in 6×10^{8} years for $N_{\mathrm{H}} = 1/\mathrm{cm}^3$ and 6×10^{7} years for $N_{\mathrm{H}} = 10/\mathrm{cm}^3$.

Grains such as these are intermediate in structure and mass between classical grains proposed by van de Hulst (1949) and Platt particles (Platt 1956).

With the assumption of graphite it appears that it will be possible to obtain considerable detailed information concerning the particle size distribution in the interstellar clouds between us and any particular star by means of rocket observations.