ORGANO-SILICEOUS BIOMOLECULES AND THE INFRARED SPECTRUM OF THE TRAPEZIUM NEBULA *

F. HOYLE, N.C. WICKRAMASINGHE and S. AL-MUFTI
Department of Applied Mathematics and Astronomy, University College, Cardiff, U.K.

Abstract. A close correspondence exists between the infrared properties of a mixed culture of diatoms and the infrared spectrum of dust in the Trapezium nebula. We argue that this correspondence points to a cosmic microbiological system in which organo-siliceous polymers are an abundant constituent. The high content of Si relative to Mg found in the Earth's crust and in Lunar and Martian surface material is readily explained on the basis of accretion of silicon-rich microbiology.

Figure 1 shows observational points at wavelengths from 8–13 μm for emission by interstellar grains in the Trapezium region of the Orion nebula (Forrest *et al.*, 1975a,b). Interstellar grains in other regions of the galaxy are known to have properties generally similar to this Trapezium material, at any rate so far as the 8–13 μm band is concerned. Partly because of this generality and because the emission of Figure 1 is believed to represent the physically-simple case of an optically-thin source, these observations should be well suited for identifying the nature of the emitting material. Yet attempts to match the observed points of Figure 1 by the calculated emission from a material of known opacity $\tau(\lambda)$ have not been outstandingly successful. The problem resolved itself into finding a material with the relative transmittance values $e^{-\tau}$ given in Table I*, which yield an emission shown by the curve of Figure 1, if heated to a temperature $T = 175$ K. Since the correspondence of the curve to the observed points is not strongly temperature dependent, the required transmittance values would not be much changed for other moderately different temperatures. (Moreover, we shall see at a later stage that observations at wavelengths longer than 15 μm indicate a temperature ~ 175 K.)

The materials preferred by many astronomers, inorganic mineral silicates, are objectionable, it seems to us, from several points of view:

(1) If inorganic mineral silicates are abundant among the grains, a not-negligible quantity of SiO_2 grains would be expected, but so far from showing the smooth shallow dependence on wavelength of the points of Figure 1, the spectrum of SiO_2 consists of two sharp spikes of 8.7 μm and 12.7 μm, as shown in Figure 2 (in the case of spherical particles of radii $\sim 10^{-5}$ cm).

(2) While the spikes of Figure 2 can be considerably suppressed by combining SiO_2 with the oxides of magnesium and aluminium, such bindings are so weak

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* The values are relative to a particular sample of material. For a sample with x times as much material, the transmittance is $e^{-x\tau}$, i.e. the values in Table I raised to the xth power.

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TABLE I
Best fitting transmittance values for correspondence with Trapezium data

$\lambda(\mu\mathrm{m})$	8	8.5	9	9.5	10	10.5	11
$e^{-\tau}$	0.31	0.15	0.040	0.040	0.065	0.12	0.19
$\lambda(\mu\mathrm{m})$	11.5	12	12.25	12.5	13	14	15
$e^{-\tau}$	0.33	0.45	0.50	0.40	0.35	0.35	0.35
$\lambda(\mu\mathrm{m})$	16	18	20	0.22	25	30	
$e^{-\tau}$	0.30	0.20	0.25	0.30	0.30	0.30	

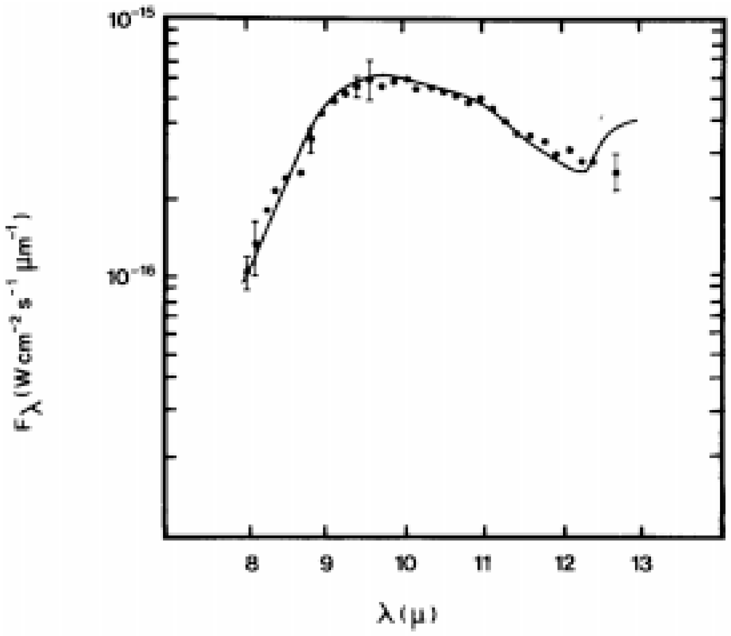

Figure 1. Observed flux from the Trapezium Nebula (Forrest *et al.*, 1975a,b) compared with the behaviour of grains with opacity values set out in Table I (at a temperature of 175 K). Normalisation of curve is to $F_\lambda = 6 \times 10^{-16}$, W cm^{-2} s^{-1} μm^{-1} at $\lambda = 9.5$ μm.

that we doubt if the complex mineral assemblies found commonly in geochemistry would form in mass-flows from stars – the supposed main site of origin of the grains. Indeed we doubt that even SiO_2 would form readily in such outflows, any more than CO_2 forms. Just as carbon emerges mostly from stars as CO, so silicon probably emerges mostly as SiO.

(3) Mineral silicates have infrared spectra with pronounced structure, whereas the observed points of Figure 1 are smoothly varying. It has been argued that since different minerals have different structural details in their spectra, an averaging over many such minerals would tend towards a composite spectrum that was

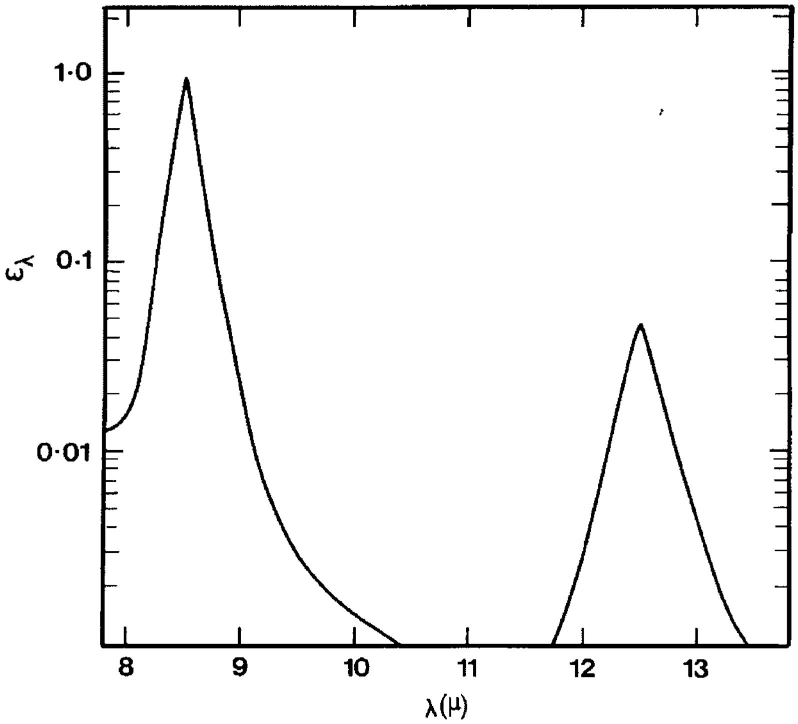

Figure 2. Normalised absorption coefficient of silica (SiO_2) spheres of radii $\sim 10^{-5}$ cm.

smooth. Figure 3 shows the relation of the observed points to a curve calculated from the infrared spectrum of lunar material #14321 (Perry *et al.*, 1972; Knacke and Thomson, 1973) one of the better examples of such a mixture*. The oscillations of the latter are unlike the implacably smooth variation of the observed points.

(4) Mineral silicates are characteristically without adequate opacity at the shorter wavelengths, 8–9 μm.

We discovered about five years ago that the infrared spectra of polysaccharides have a broad, smooth absorption band centred at about 9.5 μm that gave what we then felt to be a tolerable fit to the Trapezium data (Hoyle and Wickramasinghe, 1977). The main shortcoming of the polysaccharide spectra was a lack of opacity around 11 μm, which caused our calculated curve to fall away at this wavelength more steeply than the observations. To overcome this difficulty we suggested mixing polysaccharide grains with a low molecular weight hydrocarbon (Hoyle *et al.*, 1978), which had the required effect of approximately doubling the opacity at 11 μm. This was at a stage when we were thinking of a prebiological origin for all the grains, with a hydrocarbon seeming then at least as plausible a material as a carbohydrate. But with our later preference for a biological origin of grain

* The silicate particles are assumed to be heated to 175 K in this calculation.

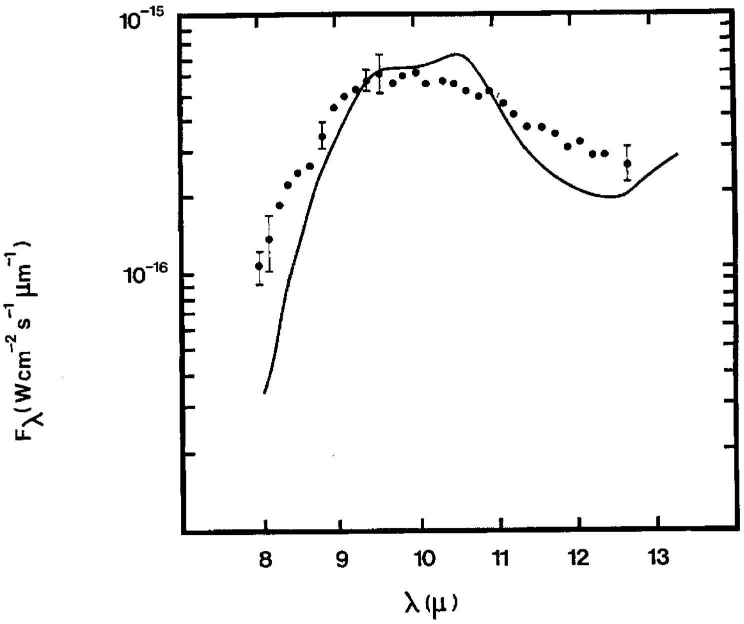

Figure 3. Observed flux from the Trapezium Nebula (Forrest *et al.*, 1975a,b) compared with the behaviour of moonrock grains heated to 175 K. Moonrock data from Perry *et al.* (1972) for rock #14321. Normalisation is to $F_\lambda = 6 \times 10^{-16}$ W cm^{-2} s^{-1} μm^{-1} at $\lambda = 9.5$ μm.

materials, a carbohydrate-hydrocarbon mixture became less attractive, especially as the accumulation of data at 3.4 μm began to put constraints on the quantity of hydrocarbons one was permitted to have. Indeed, a comparison of data over the 2.9–4 μm band with data for the 8–13 μm band for such objects as GC-IRS7 revealed a deficit of opacity by a factor of $\sim$ 2 even at 9.5 μm, a circumstance which eventually convinced us that some form of grain (other than a polysaccharide) must be contributing appreciable opacity quite generally in the longer waveband (Hoyle and Wickramasinghe, 1981).

With hydrocarbons seemingly not an attractive possibility, what could this other form of grain be? With mineral silicates also not attractive for the reasons given above, it was natural to think of a siliceous material based on SiO, rather than on SiO_2; and just as a polysaccharide can be thought of as formed by eliminating water molecules in a suitable way from the formaldehyde polymers $(COH_2)_n$, so one might think of a siliceous polymer derived from $(SiOH_2)_n$, (Hoyle and Wickramasinghe, 1981). The problem for this point of view was the practical one of obtaining a suitable substance for examination in the laboratory.

Only belatedly did we realise that, while we had crossed the critical bridge from an abiological to a biological origin for polysaccharides, we were still thinking of $(SiOH_2)_n$ abiologically. Perhaps it would be better to maintain consistency by keeping to biology even for a siliceous as well as for a carbonaceous material?

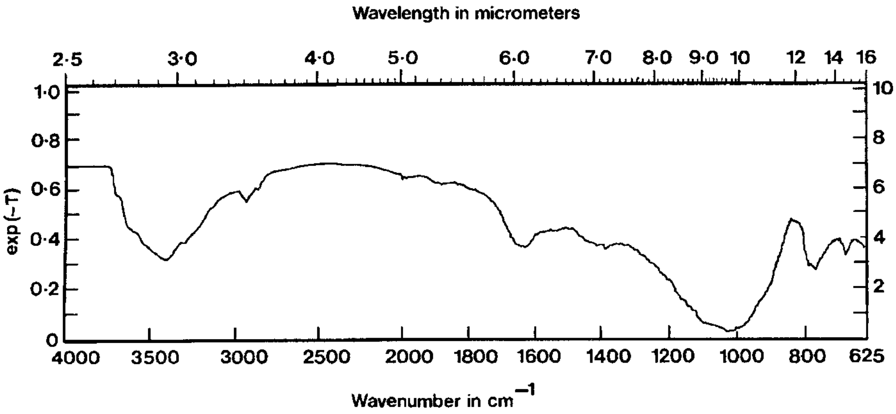

Figure 4. Infrared spectrum of mixed diatom culture in a KBr disc.

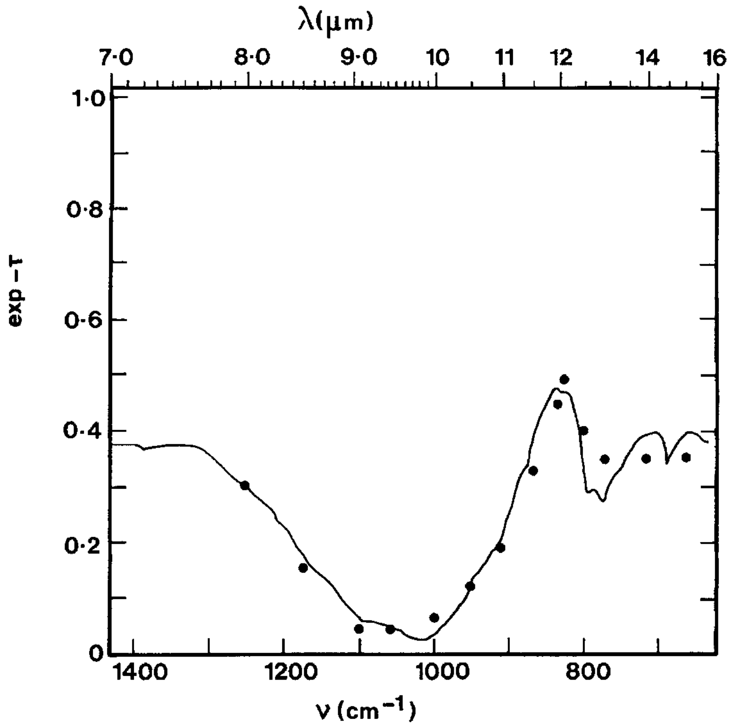

Figure 5. Infrared transmittance of diatoms for $\lambda \geq 8$ μm compared with the best fitting values (Table I) for matching the Trapezium data.

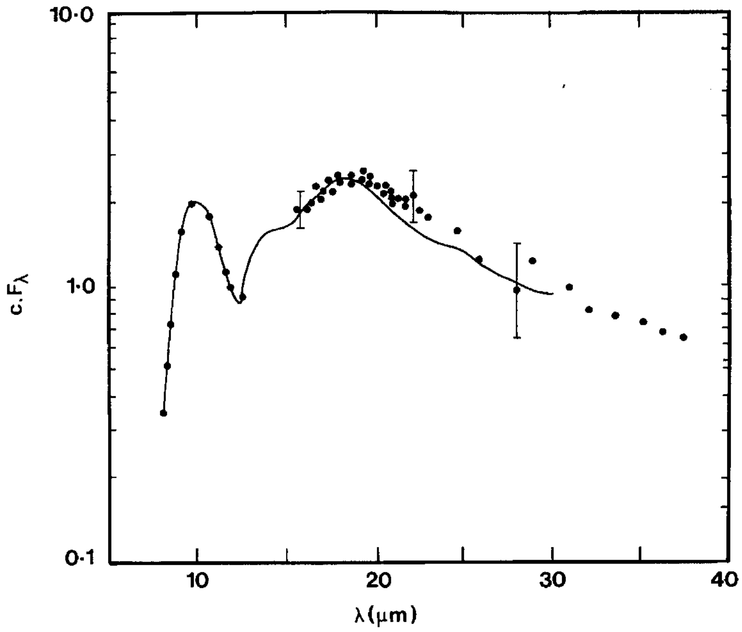

Figure 6. The infrared spectrum of the Trapezium nebula (Forrest *et al.*, 1976) compared with the predicted behaviour of material resembling the diatom culture (Table I). The temperature is taken to be 175 K. Normalisation at $\lambda = 9.5\ \mu$m.

Although they rarely make the headlines, organisms with a predominantly siliceous component in their cell walls (e.g. diatoms) exist everywhere on the Earth and in large numbers. They are to be found in lakes, in stream and river waters, as well as in the sea. With this thought in mind, we obtained a general culture of such creatures from the local river. The infrared spectrum of this culture, remarkably similar to a polysaccharide in its general form, is shown in Figure 4. (The procedure used for obtaining this spectrum is the same as that used in the experiments we have described elsewhere (Hoyle *et al.*, 1982).) Figure 5 is an enlargement of the portion of Figure 4 longward of 8 μm. Also plotted in Figure 5 are the transmittance values of Table I that were required to explain the emissivity of grains in the Trapezium nebula. The only appreciable deviation of the required values (Table I) from the measured transmittance curve for the mixture of creatures in Cardiff river water is that the effect of SiO_2 at 12.7 μm gives a more marked increase of opacity in the laboratory spectrum than the astronomical observations appear to warrant. In this respect, however, the astronomical observations are approaching the strong telluric band at $\sim$ 13 μm (due to atmospheric CO_2) so that perhaps the last word on this matter remains to be said.

Figure 6 compares the emissivity of grains having the transmittance values of Table I (calculated again for $T = 175$ K) with observations over the wider range from 8 μm to 30 μm (Forrest *et al.*, 1976). On this more compressed wavelength scale, the deviations of the observed points from the calculated curve appear negligible. The transmittance values longward of 15 μm are consistent with those used previously for a polysaccharide, but they are not by any means as well attested as those of shorter wavelengths. In effect, because of the near-constancy of $e^{-\tau}$ at the longer wavelengths the calculated curve has the general form of the Planck curve for $T = 175$ K. The agreement of the curve with the observed points at the long wavelengths shows $T = 175$ K to be generally correct, probably to within ± 15 K. This agreement, together with the correspondence between astronomical values and the spectrum of a mixed diatom culture shown in Figure 5 point to a cosmic microbiology in which siliceous biopolymers play an important role.

The input of cosmic micro-organisms on to the Earth (in the manner we have discussed elsewhere) cannot now be thought to be limited to purely carbonaceous organisms. A considerable flux of siliceous micro-organisms similar to diatoms must arrive at the Earth and at the surfaces of other planetary objects as well. The consistently high values of the ratio Si/Mg found in the 'Earth's crust (~ 10), Lunar material (~ 3), Martian material (~ 4) as well as in diatoms ($\gg 10$) tend to support this point of view. Starting from a cosmic ratio of Si/Mg $\cong 1$ inorganically produced silicates must be expected to have roughly equal numbers of Mg and Si atoms. The conventional explanation for anomalously high values of Si/Mg invokes geochemical processing and segregation according to differential buoyancy. Such an explanation seems to us to be far-fetched compared with our present hypothesis involving direct transport of Si-rich micro-organisms.

Acknowledgements

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