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TEMPERATURE DISTRIBUTION AND LIFETIME OF INTERPLANETARY ICE GRAINS

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Abstract. An improved solution of the temperature distribution of interplanetary ice grains is presented using the refractive index measured at 100° K. The efficiency factors for absorption are obtained from Mie theory and the calculation is carried out for micronic and submicronic grains at 50, 100 and 150° K; corresponding lifetimes are given.

1. INTRODUCTION

The problem of the temperature distribution of interplanetary dust grains has been recently investigated in detail by Mukai and Mukai (1973) and Lamy (1974). The main improvement of these studies consists in using Mie theory to compute the efficiency factors for absorption Q_{abs}, taking into account the dependence of the complex indices of refraction on wavelength.

The case of ice presents particular problems: as shown by the aforementioned authors, ice grains cannot survive at temperature larger than 150° K approximately. We need therefore to consider typical temperatures of 50 and 100° K and use the refractive index $m(\lambda)$ measured at these temperatures. The absorbed energy is consequently radiated in the far infrared so that $m(\lambda)$ and the efficiency factor are required over a very large region. Past computations were based on the compilation of the refractive index at 273° K performed by Irvine and Pollack (1968). We present here an improved solution to the problem by using the refractive index measured at 100° K. The computational procedure and the vapor pressure formula have also been revised and should lead to an increased accuracy. The equations for the temperature and the sublimation rate will be the same as those given by Lamy (1974) and the reader is referred to this article for a complete discussion of the assumptions and techniques of solution. In particular, grains are assumed spherical for simplicity.

2. TEMPERATURE DISTRIBUTION

a) Equation: the equation relating the heliocentric distance R and the temperature T_g of a grain of radius s as given by Lamy (1974) is:

$$\left[\frac{R_\odot}{R}\right]^2 \int_{0.2}^{15} Q_{abs}\, F_\odot(\lambda)\, d\lambda = 4\left[\int_{1}^{300} Q_{abs}\, B(\lambda, T_g) d\lambda + \frac{dE}{dt}\, L_s(T_g)\right]$$

where $F_{\odot}(\lambda)$ is the monochromatic emissive power of the Sun, $R_{\odot}$ its radius; dE/dt is the mass sublimation rate of ice at temperature T_g and $L_s(T_g)$ its latent heat of sublimation at the same temperature. $B(\lambda,T_g)$ is Planck's function:

$$B(\lambda,T_g) = 2 \pi h c^2 \lambda^{-5} \left[\exp \frac{hc}{k \lambda T_g} - 1 \right]^{-1}$$

b) Numerical solution: the efficiency factor Q_{abs} is a function of wavelength λ, of the complex refractive index of ice $m(\lambda) = n(\lambda) - ik(\lambda)$ and of the grain's radius s and was computed, using the rigorous Mie theory, at 192 values of wavelength, between 0.2 and 300 μm, for each of the following 10 values of s: 0.01, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 1 and 10 μm. For the spectral region 1.25 - 300 μm, we obtained $m(\lambda)$ from the experimental results of Bertie, et al. (1969) for hexagonal ice at 100° K (measurement of absorbance and Kramers-Krönig analysis). Below 1.25 μm, results are almost non-existant. For n, the value for 0.579 μm as reported in the Smithsonian Tables (1969) allows to scale the refractive index of water as given by Allen (1973) since $(n_{water} - n_{ice})$ appears to be nearly constant and equals to 0.23 approximately. Our selected values are slightly larger than those retained by Isobe (1971), the difference amounting to 0.04 approximately. For k, the compilation of Irvine and Pollack (1968) shows a similar behavior for ice and water below 0.95 μm. Therefore, we bridged the results of Bertie et al. (1969) and those for water down to 0.2 μm. The error resulting from this approximation is quite negligible since k is very small in this region. The discussion of Irvine and Pollack (1968) shows that the temperature effect is extremely small below 1 μm (where there is no absorption band); therefore, we consider that our data for $m(\lambda)$ are relevant to a temperature of 100° K and certainly apply with good accuracy in the range 50-150° K. Table 1 gives the steps used for the calculation of the integrals whose limits (in μm) appear in the above equation. The solar spectrum in the region 0.2 - 4 μm is obtained from the compilation of Labs and Neckel (1968). Beyond, a black-body model is suitable and we used a temperature of 5500° K in the 4 - 7.5 μm region and 5000° K in the 7.5 - 15. μm region. The calculation of the sublimation term L_s dE/dt will be presented in the third section.

c) Results: figure 1 shows the heliocentric distance as function of the grain's radius for three different temperatures, 50, 100 and 150° K. We see that the previous results are substantially modified as ice grains at a given temperature come now closer to the Sun.

Spectral domain (μm)	Step (μm)
0.2 - 0.4	0.01
0.4 - 0.7	0.02
0.7 - 1	0.05
1 - 6	0.1
6 - 15	0.25
15 - 30	0.5
30 - 100	5
100 - 300	10

Table 1. Steps of integration

3. SUBLIMATION OF ICE GRAINS

The mass sublimation rate in gm sec^{-1} cm^{-2} is (Lamy, 1974):

$$\frac{dE}{dt} = 4.08 \times 10^{-2}\ p\ \sqrt{18/T}$$

The vapor pressure p (expressed in tor) was recently reconsidered by Jancso et al. (1970); their proposed formula is likely to be the most reliable now available:

$$\begin{aligned} \log p\ (\mathrm{Tor}) = & - 2481.604/T + 3.57 \log T \\ & - 3.097 \times 10^{-3}\ T - 1.76 \times 10^{-7}\ T^2 \\ & + 1.902 \end{aligned}$$

The latent heat of sublimation may now be calculated using the Clausius-Clapeyron equation. The lifetime of ice grains may be obtained directly from dE/dt (see Lamy, 1974). Taking an initial radius of 1 μm, we found a lifetime of 6.4×10^{13} sec for a grain at 100° K (located at 3.02 AU) and of 1.4×10^{5} sec for a grain at 150° K (1.3 AU). In this latter case this is only 3×10^{-3} of the period of the corresponding keplerian orbit.

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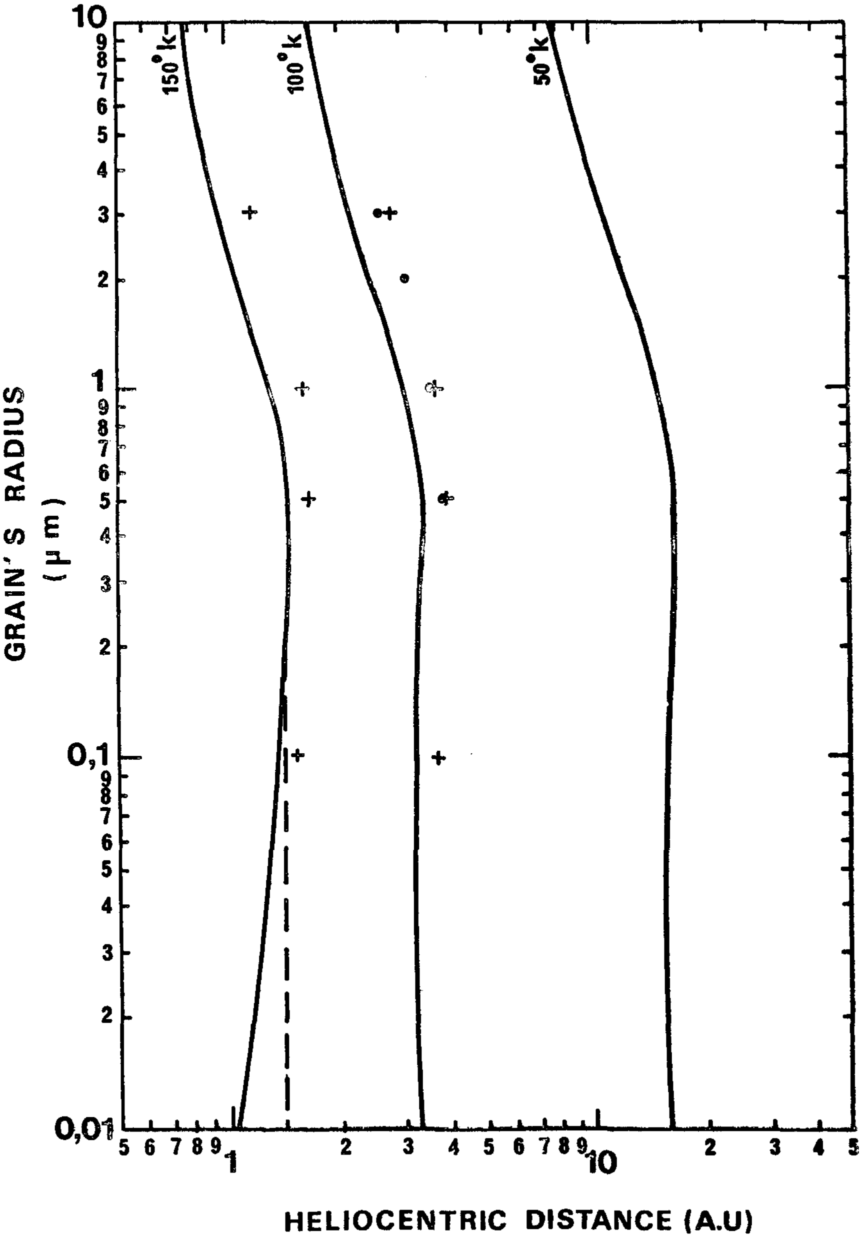

Fig. 1. Temperature distribution of interplanetary ice grains as function of their radius. The broken line corresponds to the result without the sublimation term. The dots are the results of Mukai (1973) and the crosses, those of Lamy (1974).

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