PLANCK MEAN EFFICIENCY FACTORS FOR SIX MATERIAL CANDIDATES AS INTERSTELLAR GRAINS

A. BLANCO, A. BORGHESI, E. BUSSOLETTI
S. NICOLAZZO and A. M. ZAMBETTA*

Istituto di Fisica, University of Lecce, Italy

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Abstract. Planck mean absorption cross-sections have been computed for spherical grains composed of graphite, iron, ice, olivine, amorphous quartz and a lunar silicate. Experimentally determined infrared optical constants have been used for all these materials. Ice mantle particles and planetesimal particles (iron core and olivine mantle) have also been considered with values of outer and inner radii covering a wide range of astrophysical conditions.

The results given both graphically and in a tabular form are discussed and compared with those of other authors. The relationships of mantle and core properties are also critically discussed.

1. Introduction

The theoretical analysis of many physical processes concerning dust grains requires the calculation of the Planck mean absorption cross-sections $\langle Q_{abs} \rangle$ and of the Planck mean radiation pressure cross-sections, $\langle Q_{pr} \rangle$, of the grains. Particularly simple is the case of the infrared wavelength range where the only dominant factor is $Q_{abs}$ and where $Q_{pr}$ reduces simply to $Q_{pr} \approx Q_{abs}$ because the scattering efficiency factor $Q_{sca}$ is always much smaller than $Q_{abs}$.

Calculations of $\langle Q_{abs} \rangle$ and $\langle Q_{pr} \rangle$ have already been performed by Gilman (1974) for four materials (olivine, iron, silicon carbide and graphite) in a frequency range varying from one material to another, corresponding to a range of temperatures from 10 K up to $4 \times 10^4$ K. This wide range of frequencies has been covered partly by using measured optical constants available in the literature, and partly by means of extrapolations based on dispersion formulae found by Spitzer and Kleinmann (1961).

The availability of experimentally determined optical constants in the infrared has allowed us to repeat these calculations with a twofold aim. It is possible on the one hand to check the validity of the assumptions of Gilman and, on the other, to provide in a tabular form the values of $\langle Q_{abs} \rangle$ which will surely be of help for much future work of astronomers.

We have considered here six materials – olivine, quartz, iron, a lunar silicate, graphite and ice. We have then calculated the mean absorption cross-sections by using the Mie theory for spherical grains in two cases: (1) pure materials, (2) ice-mantle grains. In addition, according to Nandy and Wickramasinghe (1973), we have

* C.E.C.U.S., University of Lecce.

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also considered planetesimal particles which it has been suggested are present in circumstellar envelopes of T Tauri stars. Previous calculations of Planck mean cross-sections (or their equivalent) have been reported for some of these materials by Greenberg (1971) and Wickramasinghe (1972).

2. Optical Constants

We report in the following the list of materials that we have considered in our computations. The values of the dielectric constants here used are reported in a paper by Bussoletti and Zambetta (1975).

(a) Ice. The optical constants $n$ and $k$ have been taken from the review paper of Irvine and Pollack (1968). They are known for the range $0.7 \mu m$ to $152 \mu m$ and represent the best values available in the literature up to date.

(b) Graphite. The usual graphite optical constants found in the literature are those reported by Werner and Salpeter (1969): $n=6.5$ and $k=0.47 \lambda$. A more careful analysis of the data of Taft and Phillipp (1965), who are the source of information, has suggested to us to assume either the values $\varepsilon^{(1)}=4-i10 \lambda$ (already suggested by Wickramasinghe and Guillaume, 1965), or $\varepsilon^{(2)}=6-i6(1+\lambda)$. Both cases have been considered and they will be hereafter referred as graphite-1 and graphite-2.

(c) Olivine $[(\text{Mg, Fe})_2 \text{SiO}_4]$. Results about the measurements of optical properties of olivine are reported by Huffmann (1975), Day et al. (1974) and Day (1975). The infrared dielectric constants of small spheres with radius less than $0.1 \mu m$ have been measured by Huffmann, Steyer and Day at the University of Arizona. The value of $\varepsilon'$ and $\varepsilon''$ in the range $3 \mu m$ to $250 \mu m$ have been provided by Prof. D. R. Huffmann (private communication) in form of tables.

(d) Amorphous quartz $[\text{SiO}_2]$. The optical constants have been measured by Steyer et al. (1974) and published only for the wavelength range $7.14 \mu m$ to $25 \mu m$. The dielectric constants that we have used here have been provided by Prof. D. R. Huffmann (private communication) and are known for the range $1 \mu m$ to $50 \mu m$.

(e) Lunar silicate 14321. This material is representative of samples from the Apollo 11, 12 and 14 missions. Its percentage chemical composition and the dielectric constants have been measured by Perry et al. (1972). The sample is constituted by $\text{SiO}_2$ (50\%), and $\text{Al}_2\text{O}_3$ (18\%). Smaller percentages of $\text{MgO}$, $\text{FeO}$, $\text{CaO}$ and $\text{TiO}_2$ are also present.

The dielectric constants are known in the range $5 \mu m$ to $1000 \mu m$. These data have been kindly provided by Dr R. F. Knacke of Stony Brook University.

(f) Iron. In this case we have used the values of $n$ and $k$ reported by Greenberg (1968): $n=2.45 \lambda^{1/2}$, $k=2.45 \lambda^{1/2}$.

3. Calculations

The Planck mean of a function $Q(\lambda)$ is given by