OPTICAL PROPERTIES OF ROUGH GRAINS : A THEORETICAL STUDY

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ABSTRACT. Recent work on the light scattering by large rough particles has led us to propose a model based on the high-energy approximation, the laws of geometrical optics and a mathematical description of the properties of the particle roughness. The influence of the various parameters of the model including those characterizing the roughness on the total intensity and the polarization is presented.

Collections of micrometeoroids in the stratosphere show that a part of interplanetary dust is composed of large rough particles w.r.t. optical wavelenghts (Brownlee, 1978 and this volume). Light scattering by these particles can be interpreted on the basis of several independent scattering processes which may be treated separately : forward diffraction, Fresnel reflection, non-polarized reflection and transmission (Giese et al, 1977). Perrin and Lamy, (1983) proposed a model which describes these different processes. The forward diffraction is treated in the context of the high-energy approximation, based on a high-energy formulation of relativistic quantum scattering, where the expression of the scattering potential involves the complex index of refraction of the grain and a Fermi type distribution of the amplitude of the asperities; away from the forward direction, this approximation is supplemented by the Fresnel reflection and the transmission of light through the particle which are treated by the method of Wolff (1975 and 1980) adapted to our problem, using a geometrical description of the rough curved surface. The reflected intensity has two partially polarized components: one from the single reflection and the other one from the double reflection. The description of the roughness of the surface involves the following parameters (Fig.1) :

- a : mean radius of the grain.
- d_p : mean amplitude of asperities.
- w_p : mean angular aperture of roughness.
- x_F, x_B, $x_L = x_R$: effective angular parameter for respectively forward, backward, lateral left and right double reflection.

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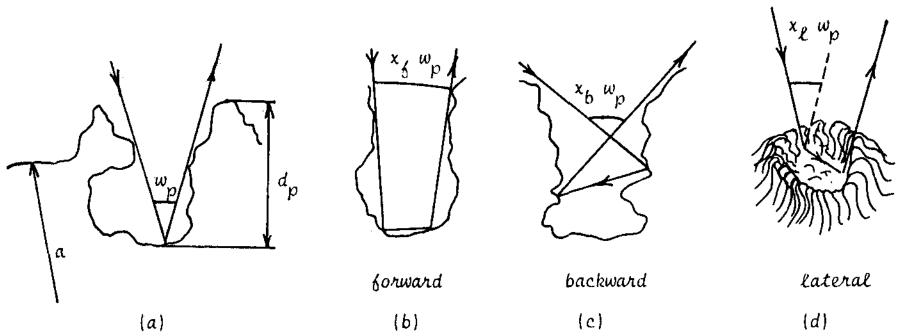

Fig.1 Parameters of the roughness

The parameters d_p and w_p characterize the large scale roughness, for instance pits on the surface of the particle. For a pit at a given phase angle, it is then possible to check if a single reflection may take place and to obtain the analytic expression for the reflected ray. The parameters x characterize the small scale roughness inside the pits and control the double reflection. For example, in the case of the forward double reflection (Fig. 1b), the roughness inside the pit causes a double reflection such that, the angle between the incident and reflected beams outside the pit is equal to $w_p/2$, so $x_F = 0.5$. Obviously, when $x_F = 1$, the double reflection becomes a single reflection. For a real particle, these parameters can be estimated using, for example, a SEM photograph. The good agreement between experimental results (Weiss, 1981; Weiss-Wrana, 1983) and the calculations (Perrin and Lamy, 1983) illustrated in Fig. 2, shows that this description of the particle roughness is sufficient to account for the properties of the scattered light intensity and polarization provided the complex part of the imaginary index is less than 0.05.

We already started to study the influence of the above parameters on the efficiency factors of rough particles (Lamy and Perrin, 1983). In this present contribution, we start to investigate their influence on the intensity as well as the polarization of the scattered light. Each parameters (including further the index of refraction) is allowed to vary in its range of validity, the others being kept constant. We have specifically investigated the following important features :

- the relative importance of the diffraction lobe,
- the maximum value of polarization and the corresponding scattering angle,
- the negative branch of polarization,

for the nomical case of a particle characterized by :

a = 20 µm d_p = 0.5 µm w_p = 90°
x_F = 0.5 x_B = 10 $x_L = x_R$ = 4
$n = 1.803 - 2.5 \times 10^{-3}\, i$ for λ = 6328 Å

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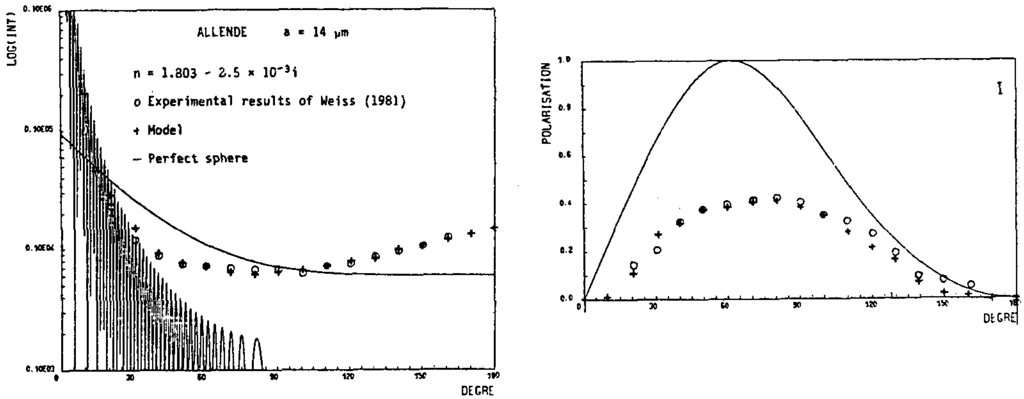

Fig.2 The square of amplitude function and the polarization for a rough particle of Allende meteorite of mean radius equal to 14µm. The solid line gives the result of Fraunhofer diffraction and of Fresnel reflection for a perfect sphere having the same radius and the same index of refraction. The error bar for the experimental polarization values appears in the upper right-hand corner.

We characterize the diffraction lobe by the ratio of the scattered intensities at 10° and 30°. The parameter which has the greatest influence is the mean amplitude of asperities d_p as illustrated in Fig.3; the ratio I(10°)/I(30°) increases dramatically with increasing d_p.

Several parameters control the location θmax and the value of maximum polarization Pmax such as the real part of the refractive index and the radius of particle. However, the most critical parameter is the imaginary part n_i of the refractive index. For our nominal case, Fig.4 shows the rapid decrease of the angle θmax from 100° to 80° when n_i increases from 1×10^{-4} to 5×10^{-3} correlated with a substantial increase of Pmax, from 0.05 to 0.7 approximately. There seems to be some sort of "saturation effect" outside the 1×10^{-4} - 5×10^{-3} interval as both θmax and Pmax vary only slightly.

The negative branch being the consequence of the double reflection, it is controlled by the parameters χ. In fact, it is caused by the lateral double reflection. When $\chi_L = 1$, this component does not exist and the polarization remains positive. When $\chi_L > 1$, the negative branch appears as illustrated in Fig.5 obtained for the nominal case ($\chi_F = 0.5$ and $\chi_B = 10$). However, the magnitude of the negative branch, as characterized by the minimum (negative) polarization P_{min} and the angle of null polarization θ_o, depends also upon the relative importance of the forward and backward double reflections. Fig.6 obtained for $\chi_L = 4$ shows how the negative branch evolves rapidly as a function of χ_F. When the forward double reflection decreases, the relative importance of the lateral component increases and P_{min} may reach quite large negative value ($\simeq$ -5%) while θ_o decreases drastically.

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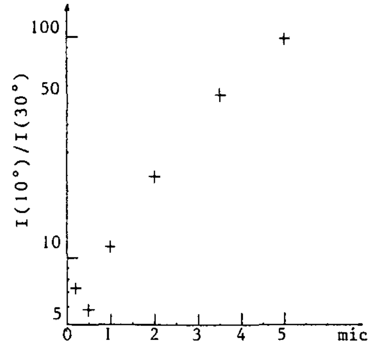

Fig. 3 Diffraction vs roughness

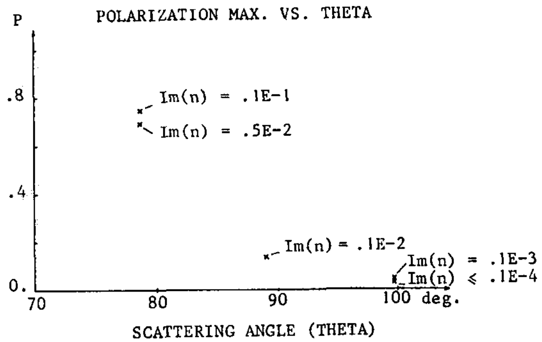

Fig. 4 Maximum polarization vs theta

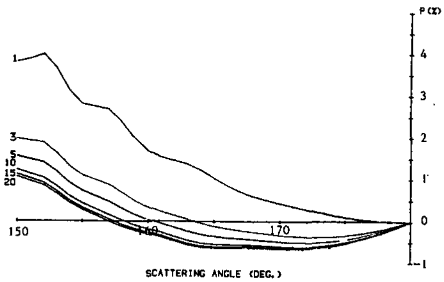

Fig. 5 The negative branch of polarization for various x_L

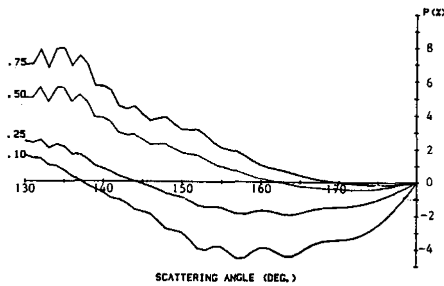

Fig. 6 The negative branch of polarization for various x_F

Although this study is far from being complete, it appears quite possible, in an inverse way, to deduce the values of the parameters from the observed scattered intensity and polarization and thus, to infer the physical characteristics of the particle.

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