INFLUENCE OF SURFACE ROUGHNESS ON SCATTERING PATTERNS

S. Mukai and T. Mukai
Kanazawa Institute of Technology
Nonoichi, Ishikawa 921
Japan

ABSTRACT. The influence of surface roughness on scattering properties of light is examined in terms of our previous mathematical method(Mukai et al. 1982). We found that albedo for single reflected light increases with an increase of surface roughness. In addition, a higher order of reflection light becomes effective for stronger rough particles.

## 1. INTRODUCTION

Scattering pattern of light by a rough particle has been investigated by several authors with different theoretical methods, e.g. Wolff (1975), Mukai et al.(1982), and Perrin and Lamy(1983). In Mukai et al.(1982), we presented the mathematical treatment based on the stochastic process of multiple reflection of light by surface roughness, and succeeded to explain the observed evidences of scattering patterns by rough particles, i.e. a backward enhancement of intensity, and reduction somewhat of polarization below a scattering angle of 90° compared with the expected results with a smooth surface particle.

Here we shall examine the influence of degree of roughness on the scattering properties of light, which might relate to an albedo of interplanetary dust grain.

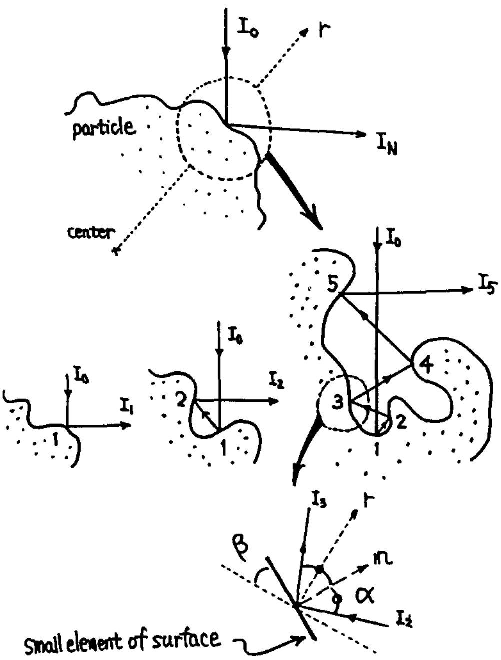


FIG.1. Definition of multiple reflection by surface roughness



R. H. Giese and P. Lamy (eds.), Properties and Interactions of Interplanetary Dust, 235–238.

## 2. ALBEDO FOR SINGLE REFLECTION

The complete mathematical analysis has already been presented in Mukai et al.(1982). Here we therefore simply summarize the model. In our treatment we assume that a particle is larger than a wavelength of light and rough surface of a particle consists of many small elements with different slopes.

In addition, each surface element is also larger than a wavelength of light and a particle has a large absorption coefficient. Then, the reflection of light by each of the surface elements is treated by Fresnel reflection and the refracted light inside the particle is absorbed there.

Incident light on a particle is successively reflected by rough surface. In each reflection, the incident angle $\alpha$ and the angle of slope $\beta$ play an important role, where $\beta$ is measured from the average surface in the reference system(see figure 1). A reflection pattern of small elements on the surface is defined by surface slope distribution function $P(x)$, where $x=\tan\beta$, and Fresnel reflection pattern $\rho(\alpha)$. For surface slope distribution, we apply a gaussian distribution as

$$P(x)=\exp\{-(x/\sigma)^2\}/(\pi^{\frac{1}{2}}\sigma), \qquad (1)$$

where $\sigma$ is a parameter to define a degree of roughness. For example, as shown in figure 2, surface roughness increases with $\sigma$.

A single reflection pattern is obtained in terms of both surface slope distribution and Fresnel reflection. We assume this reflection pattern as a single scattering pattern for a successive order of scattering. Namely, we treat the successive reflection of light by small surface elements as the multiple scattering of light by particles with a single scattering pattern derived above. Using the method of successive orders of scattering to solve the equation of radiative transfer, we sum up each order of reflection.

Since the reflected intensity depends on an incident angle through a Fresnel reflection pattern, an albedo for single reflection $\omega$ by each surface element depends on the slope of the surface element, i.e. the degree of surface roughness. This is derived from the fact that Fresnel reflection of a larger incident angle produces higher

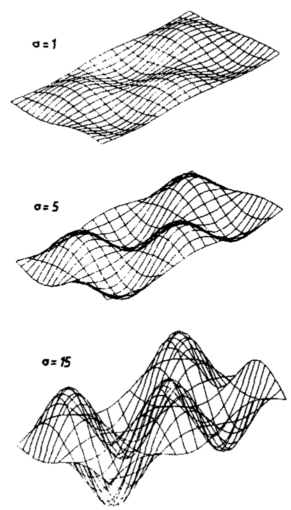


FIG.2. Sample of surface roughness, where $\sigma$ is a parameter to define the roughness shown in eq.(1).

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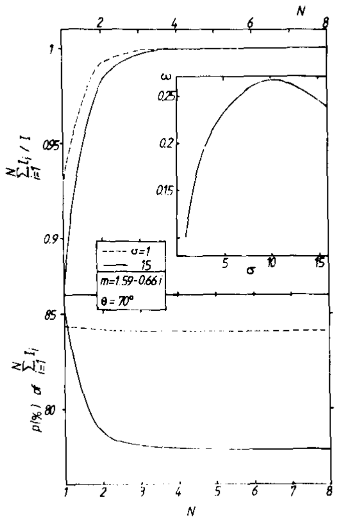


FIG.3. Intensity I and polarization p of multiple reflected light. Small figure shows an albedo ω of single reflection with roughness σ.

reflectance. In general, surface roughness causes an increase of reflection of a larger incident angle, therefore an albedo increases with σ as shown in figure 3.

In order to examine a contribution of higher order reflected light on total reflected intensity, we show in figure 3 the intensity and polarization as a function of order of reflection N.

The higher order of reflection becomes significant as roughness increases because an albedo increases with roughness. For example, the fourth-order of reflected light by surface roughness cannot be neglected for σ=15. Subsequently, polarization for σ=15 is clearly reduced by a contamination of highly ordered, reflected light because the degree of polarization becomes smaller after reflection.

## 3. SCATTERING BY A LARGE ROUGH PARTICLE

In order to compare the above results with experimental data, we should integrate the reflected intensity by each local place on the particle

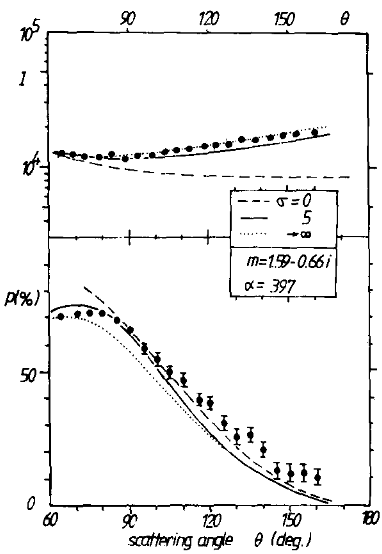


FIG.4. A comparison of expected scattered light by rough particle with experimental data by Weiss-Wrana(1983)(filled circles).

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surface all over the surface.

Figure 4 shows the intensity and polarization of scattered light as a function of scattering angle $\theta$. Below $\theta=60^0$, diffraction of light becomes dominant. We have omitted that region here to simplify discussion.

It is found in figure 4 that as roughness increases, a higher order of scattered light increases a backward enhancement of intensity and reduces the degree of polarization. Therefore, the degree of roughness should be considered as one of important factors for scattering by a particle with rough surface.

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## DISCUSSION

ZERULL: Is your theoretical approach also able to reproduce the branch of negative polarization? If not, could it be modified appropriately?

MUKAI: Negative polarization occurs when the multiple reflected light becomes important. For absorbing particle, roughness on the surface of particle can produce negative polarization, but smooth surface never make this. For dielectric particle, the refracted light penetrated inside the particle produces negative polarization due to internal multiple reflection. In addition, roughness on the surface enhances this feature. Our model treatment can provide the reduction of polarization for absorbing particles and will be able to reproduce the negative polarization when it is extended to dielectric particles.

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