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LABORATORY SIMULATION OF LIGHT SCATTERING FROM REGOLITH ANALOGUES: EFFECT OF POROSITY†

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ABSTRACT

The surfaces of most atmosphereless solar system objects are referred to as regolith, layers of loosely connected fragmentary debris, produced by meteorite impacts. Measurements of light scattered from such surfaces provides information about the composition and structure of the surface. A suitable way to characterize the scattering properties is to consider how the intensity and polarization of scattered light depends on the particle size, composition, porosity, roughness, wavelength of incident light and the geometry of observation. In the present work, the effect of porosity on bidirectional reflectance as a function of phase angle is studied for alumina powder with grain size of 0.3 μm and olivine powder with grain size of 49 μm at 543.5 nm. The optical constants of the alumina sample for each porosity were calculated with Maxwell Garnett effective medium theory. On using each of the optical constants of alumina sample in Mie theory with the Hapke model the variation of bidirectional reflectance is obtained as a function of phase angle with porosity as a parameter. Experimental reflectance data are in good agreement the model. For the olivine sample the effect of porosity is studied using Hapke (2008).

Key words: bidirectional reflectance: EMT-porosity-regolith-scattering

1. INTRODUCTION

The study of light scattering by planetary regolith has been and continues to a subject of great interest in many different scientific disciplines for many years. Laboratory photometry of regolith-like samples is important for interpreting the phase curves which are being used as a planetary surface characterization tool. Consequently, laboratory based experiments on regolith analogues are becoming more significant, so that in situ data can be analyzed using laboratory results.

2. INSTRUMENTAL DETAILS

The laboratory simulation was performed with the help of a gonio-photometric device at the department of Physics, Assam University, Silchar, India. It consists of two metal arms having a common horizontal axis of rotation. The two arms can be rotated by 90° from the zenith direction. A He-Ne laser at wavelength 543.5 as the source and a CCD as the detector were used. The detector angle and incident angle were varied in steps of 9°. The reflectance r (i, e, g) was calibrated by using a standard Labertian surface of $BaSO_4$ (Sakai & Nakamura, 2005), at a condition i=0°, e= 45°, g=45° where i, e, g are the angle of incidence, emergence and phase angle. The fluctuation of the laser introduces uncertainty, which has been found to be less than 2%. Different values of porosities [equvalent to $(1-\phi)$] were generated by knocking sample tray once, twice or thrice. Four porosities of 0.3 μm alumina and two porosities of 49 μm olivine were prepared in the laboratory. The porosity P of the powder samples was calculated using the relation (Sakai & Nakamura, 2005) P=1-m/ρv, where, m = mass, ρ = bulk density and v = volume of the sample.

3. MODELLING OF EXPERIMENTAL DATA

In order to model the experimental data the following two cases are discussed:

A. For particles with size $\approx \lambda$

1. Effective medium theory: The effective dielectric constant

$$\acute{\varepsilon} = (\acute{n} - \acute{k})^2 \quad (1)$$

of a composite medium, according to Maxwell-Garneet effective medium theory (Maxwell Garnett, 1904) is given by

$$\acute{\varepsilon} = 1 + \frac{3\phi(\frac{\varepsilon-1}{\varepsilon+2})}{1-\phi(\frac{\varepsilon-1}{\varepsilon+2})} \quad (2)$$

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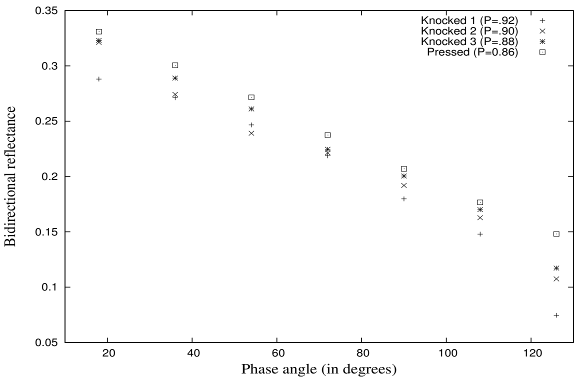

Figure 1. Phase curves of 0.3 μm alumina for four different porosities at wavelength 543.5 nm.

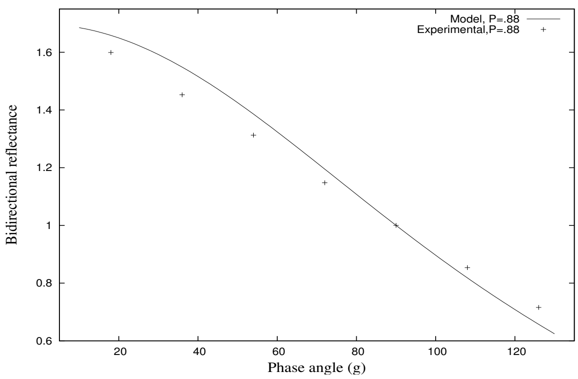

Figure 2. Experimental data points with model for alumina sample.

The filling factor

$$\phi = 1 - P \quad (3)$$

P = porosity of the sample and (n, k) is the R. I. of the constituent. Using 1, 2 and 3 the complex refractive index (n, k) of 0.3 μm alumina is calculated for four porosities.

2. Hapke model: The formula for bidirectional reflectance, according to the Hapke model (Hapke, 1983) is given by

$$r(i,e,g) = (\frac{w}{4\pi})(\frac{\mu_o}{\mu + \mu_o})\{[1+B(g)]p(g)+H(\mu_o)H(\mu)-1\} \quad (4)$$

where $\mu_0 = \cos i$ and $\mu = \cos e$, B_o= the opposition surge amplitude, h = the opposition surge width, w = the single particle scattering albedo and $p(g)$ = the single particle scattering phase function. Typical values for B_o and h of 1.0 and 0.065 were used (Hapke 1993, Deb et al. 2011). In this model w and $p(g)$ were taken from Mie theory. The multiple scattering function $H(x) = \frac{1+2x}{1+2\gamma x}$ and $\gamma = \sqrt{(1-w)}$ were used. This model is used to simulate the experimental data of 0.3 μm Alumina.

B. For particles with size larger than λ

According to Hapke (2008), the bidirectional reflectance from particulate media containing particles of

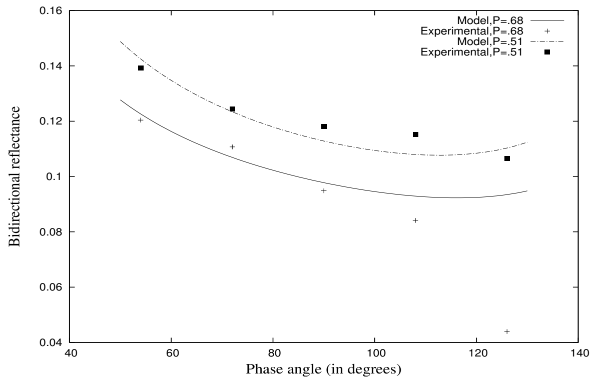

Figure 3. Experimental data points with model (Hapke, 2008), for olivine sample.

size greater than the wavelength is given by

$$r(i,e,g) = K(\frac{w}{4\pi})(\frac{\mu_o}{\mu + \mu_o})\{[1+B(g)]p(g)+H(\mu_o)H(\mu)-1\} \quad (5)$$

where $K = \frac{-\ln(1-1.209\phi^{\frac{2}{3}})}{1.209\phi^{\frac{2}{3}}}$, $H(x) = \frac{1+\frac{2x}{K}}{1+\frac{2\gamma x}{K}}$, and $p(g) = \frac{1-\xi^2}{(1+2\xi\cos g+\xi^2)^{\frac{2}{3}}}$. In this model, we have taken the asymmetry parameter $\xi = -\cos g$. This model is used to simulate the experimental data of 49 μm olivine.

4. CONCLUSIONS

1. Fig. 1 shows the effect of porosity on bidirectional reflectance as a function of phase angle for four different porosities of 0.3 μm Alumina. We found that the bidirectional reflectance increases as porosity decreases.
2. The optical constants of the composite alumina sample for each porosity were calculated with Maxwell Garnett effective medium theory. When using each of the optical constants of the composite alumina sample in Mie theory with the Hapke model it was found that the experimental reflectance data are in good agreement with the model.
3. Fig. 3 shows the bidirectional reflectance of olivine (49 micron) with two porosities, 0.68 and 0.51. As the grain size is larger than the wavelength, Hapke 2008 is used to model the experimental data. In this model the single particle scattering albedo is used as a free parameter and a best fit value was found of $\omega = 0.825$.

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