THE OPTICAL PARAMETERS OF MARE FOECUNDITATIS REGOLITH

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This work presents results of the investigtion of the optical parameters of regolith powder, returned by Luna 10 (albedo, variation of intensity with phase angle, spectrum of diffuse reflectance). It is found that mean values of albedo between 260 and 400 nm, between 400 and 750 nm and between 750 and 1800 nm are equal to 0.086, 0.107 and 0.130 respectively. This result is in agreement with results of earth-based telescopic albedo measurements of the landing site of Luna 16 in Mare Foecunditatis. By measuring the variation of intensity of the specular reflectance with phase angle it was found that the optical properties of regolith differ from those of the earth rocks. There are differences between the spectra of diffuse reflectance and specular reflectance: in the latter the intensity between 500 and 600 nm is somewhat lower, and between 600 and 900 nm it increases more steeply. This difference between the spectra is a possible explanation for the observed variation of lunar surface colour from brown to green with phase angle.

The regolith powder from zone A [1], i.e. from the depth range 0–8 cm, was investigated. The specimens were fine powders with low albedo. The size of particles varied between 2 and 1300 μm, the mean diameter size was 60 μm. A morphological investigation of regolith showed that at the surface at least half the particles were covered with thin films of glass or were scorified. More than 1% of particles was accounted for by glass spheres [1].

The optical characteristics both of the complete specimen and of the separate fractions differing in particle size were measured. The specimens investigated were prepared as follows: The regolith powder was poured into a cylindrical cell 22 mm in diameter and 1 mm in depth without cover glass. Both specimens with rough and with smooth surfaces were measured. The smooth surfaces were prepared by pressing with a glass plate, and the rough surfaces by free cell filling. The specimens composed of relatively large particles (grain size of 200–450 μm) were prepared by free pouring of powder into the cell; the surfaces of the fine-grained specimens were made rough by raking with the point of a needle.

The diffuse-reflectance spectra of specimens between 220 and 1800 nm were obtained relative to an MgO-smoke standard, using a Hitachi Model EPS-3T spectrophotometer with an integrating sphere attachment. The intensity variation of diffuse reflected light with phase angle (scattering coefficient) was measured with a photometric apparatus for angles of observation and of illumination between 0° and 80° on either side of normal. The minimum phase angle was 22°. The light sources were an incandescent tungsten-iodine lamp and deuterium lamp, and the detectors were an IP 18 photomultiplier tube and lead-sulphide cell detector. The photometric apparatus had a monochromator with a diffraction grating mounted according to Fastie's method. The samples were under atmospheric conditions.

Diffuse-reflectance spectra (albedo) of all specimens were similar and had no evident structure. The albedo increased continually between 250 and 1800 nm from blue to red (Fig. 1), the main albedo values were low and equal to 0.086 between 260 and 450 nm, 0.107 between 450 and 750 nm and 0.131 between 750 and 1800 nm. At 1 μm a broad weak absorption band exists, which was also found earlier in earth-based telescopic measurements of lunar reflectance [2]. This band was attributed to electronic transitions in the ferrous ion Fe^{2+}, contained in the crystal lattice of regolith-formed minerals. The Fe concentration determined by chemical analysis of samples was 13.1%.

The general characteristics of diffuse-reflectance spectra of all samples agree very closely with those of lunar reflectance spectra. The measured albedo value is somewhat higher than lunar albedo, but it agrees closely with earth-based telescopic measurements for the Mare Foecunditatis.

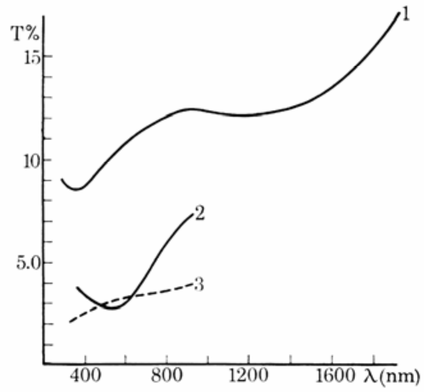

Fig. 1

Fig. 1. Regolith reflectance spectra: 1, diffuse reflectance spectrum; 2, specular reflectance spectrum; angle of illumination 60°; intensity in arbitrary units; 3, normalized diffuse reflectance spectrum; intensity magnitudes normalized to that of specular reflectance at 500 nm.

The bidirectional reflectance measurements (scattering coefficient) were made for wavelengths 330, 365, 400, 500, 600, 700, 800 and 900 nm. The angle of illumination was fixed at 0°, 20°, 30°, 40° and 60°, and the angles of viewing were scanned automatically. For angle of illumination 0° regolith powder shows a steep rise in reflected light intensity with decrease of phase angle, i.e. strong backscatter in the direction of illumination (Fig. 2). These results are in accordance with data obtained for the moon from earth-based observation and those for Apollo 11 samples [3]. The spectral measurements obtained show the same general characteristics of the optical parameters, but the steepness of the curves increased somewhat from red to blue. The wavelength dependence increased with phase angle below 50°.

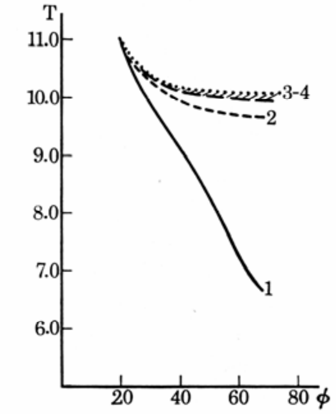

Fig. 2

Fig. 2. Scattering coefficient for angle of illumination 0° plotted against phase angle φ; intensity in arbitrary units, normalized to a single value at $\varphi = 22°$; wavelength: 1, 400 nm; 2, 436 nm; 3–4, 600–900 nm.

For other angles of illumination, the scattering coefficient changed somewhat. The regolith powder showed not only strong backscatter in the direction of illumination, but also a much weaker maximum of light intensity in the direction of specular reflection. This maximum of specular reflection becomes marked for angles of illumination exceeding 30°. For smaller angles it was not measurable, probably owing to its low intensity compared with the intensity of scattered light. The relative intensity of the specular components showed a marked dependence on wavelength, decreasing from blue to red. Typical scattering coefficients for angle of illumination equal to 40° are given in Fig. 3. The intensity of the specular component decreased roughly by a factor of five between 330 and 950 nm.

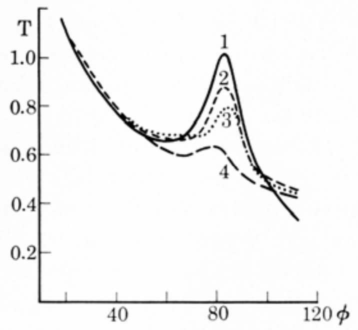

Fig. 3. Scattering coefficient for angle of illumination 40° plotted against phase angle φ; intensity in units used in recording, normalized to a single value at $\varphi = 22°$; wavelength: 1, 330 nm; 2, 400 nm; 3, 600 nm; 4, 800 nm.

As can be seen from Fig. 3, the specular component was measured over a phase angle interval equal to about 40°, i.e. the angle half-width was equal to 20°. In this ease the angle of maximal intensity was shifted slightly in the direction of angles greater than the exact specular angle. When the regolith specimen was replaced by a mirror, the maximum intensity of reflected light was measured at the exact specular angle, where the angle of illumination equals the angle of viewing; the signal half-width was equal to 2°.

The occurrence of a specular maximum in relation to scattering coefficient was recorded for regolith specimens with different particle sizes. This effect was well-defined for specimens composed of particles with grain size 88–127 μm. In this case the powder surface was rough. The intensity of the specular component increased markedly and its angular half-width decreased after surface smoothing.

The occurrence of maximum specular component in relation to scattering coefficient is evidently the specific peculiarity of lunar regolith specimens. A similar effect for earth-rock powder is not described in the literature and was not observed in our own measurements with such specimens. The data of scattering coefficient measurements of basalt, dunite, gabbro-diabase and stony meteorite powder, obtained with just the same photometric apparatus, are in accordance with data in the literature [2]. The intensity of reflected light increased quickly with decrease of phase angle, the albedo of rock powders was too high in comparison to regolith albedo. The specular reflectance component in light scattered from terrestrial rock powder and stony-meteorite Efremovka powder with a rough surface was absent even for angles of illumination equal to 60°. A broad and very weak specular component appeared after strong smoothing of the specimen surface. Its angular halfwidth was more than 30°.

The existence of both the specular component and the characteristic diffuse reflectance of the powder for lunar regolith specimens is probably connected with the morphology of the surface of secondary particles. 42.3% of the regolith fraction with grain size greater than 450 μm is of particles covered with a film of glass, and there is quite a number glass spheres in the fine fraction [1]. It is possible that a quantity of such particles become mutually oriented and form mirror micro-areas on the specimen surface. This consideration is borne out by visual observations of regolith powder, which has a characteristic shine in contrast to terrestrial-rock powder. The specular reflectance spectrum was measured between 350 and 900 nm. This spectrum has the general properties of regolith spectra (absence of evident structure and continuous intensity increase from blue to red), but there is some difference between this spectrum and the diffuse reflectance spectrum. The relative intensity of the specular reflectance component between 600 and 950 nm increases more steeply and between 500 and 600 nm somewhat less (Fig. 1). This difference between the spectra in the region of maximum optical sensitivity is a possible explanation for the repeatedly observed change of regolith and lunar surface colour from brown to green with variation of angle of illumination and angle of viewing.

The effects described were found in determining the optical parameters of regolith; they are inherent properties, which distinguish regolith from earth-rock powder. This is important since regolith chemical composition is similar to that of earth-rock. It is possible that in future these inherent regolith properties will allow the relative content of primary and secondary particles from earth-based observation of different lunar areas to be determined.

References

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