Studies of the scattering/absorption properties of minerals

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An understanding of the scattering and absorption properties of a planetary regolith is important for understanding remote sensing data from spacecraft and earth-based telescopes. One way to study these properties is to measure the reflectance of powdered minerals and mineral mixtures in the laboratory. This has been and continues to be a major task of many laboratories. However, the possible combinations of mineral mixtures, grain sizes, and viewing geometries are virtually infinite. Another approach to this study is by radiative transfer models. The Hapke reflectance theory (Hapke, 1981) is one such theory that has been verified by several investigators (e.g. Clark et al., 1986 and references therein). Using the Hapke theory, the scattering and absorption properties can be quickly computed as a function of wavelength, grain size, and viewing geometry for pure minerals as well as mineral mixtures.

Reflectance spectra were computed for water ice and ammonia ice mixtures as functions of weight fraction, grain size, and viewing geometry to simulate possible outer-solar-system satellite surfaces. This exercise has shown several interesting aspects of scattering and absorption from a particulate surface that have not been previously realized. As might be expected, as the grain size of a pure water ice or pure ammonia ice is increased from very small ($< 1\mu m$), the absorptions increase in depth. However, at some grain size, depending on the fundamental band strength, the bands become saturated and their apparent depth decreases. This band saturation is described in Clark (1981) for water ice.

In a mineral mixture, if the grain sizes are held constant and the weight fractions are varied, the observed absorption bands change along with the weight fraction. As the weight fraction increases, the apparent absorption bands for that species tend to become more apparent (Figure 1). However, if the grain sizes are varied and the weight fraction is held constant, the apparent absorption bands still vary (Figure 2)! This is because the photons are encountering grains according to the projected surface area (of the grain), so either weight-fraction or grain-size changes will affect the relative surface area encountered. The implications of this fact are profound for laboratory studies of mineral mixtures. A simple weight-fraction series is not adequate for deriving a calibration curve of abundance. The calibration curve depends strongly on the grain sizes. Because of band saturation, the relative band depths are not the same at different grain sizes when the grain-size ratios (of minerals in a mixture) are held constant. The only solutions are either to measure all possible grain sizes and weight fractions to derive calibration curves, or to use a radiative transfer model like the Hapke reflectance theory.

As a next step in the understanding of scattering in a particulate surface, viewing geometry was added to the model calculations. It was found that viewing geometry had only a small effect on the reflectance

levels and observed band depths. Generally, it was found that extreme viewing geometry ranges (incidence and emission angles near 80°) were similar to changes in grain size of only factors of two or three.

Everyday experience gives a qualitative understanding of viewing geometry effects on a multitude of objects; a colored object or a typical powdered mineral can be held at different orientations and the colors do not change significantly. However, if two powders are mixed or ground to smaller grain sizes, the colors can change dramatically, even if the viewing geometry is not changed.

In conclusion, reflectance spectra of planetary surfaces are most affected by the weight fraction and grain sizes of the minerals in the surface. The reflectance can range from 1.0 to about 0.01 by changing the grain size or weight fraction, a factor of 100. Viewing geometry changes the reflectance by about 25% or less.

References

Clark, R.N., Water Frost and Ice: The Near-Infrared Spectral Reflectance 0.65-2.5 μm, *J. Geophys. Res.*, **86**, 3087-3096, 1981.

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Hapke, B., Bidirectional reflectance spectroscopy 1. Theory. *J. Geophys. Res.* **86**, 3039-3054, 1981.

Figure Captions

Figure 1. The reflectance spectra for mixtures of water and ammonia ice are shown for a constant grain size. As the weight percent of ammonia is increased, the ammonia bands (e.g. the 2.2-μm bands) become more prominent.

Figure 2. The reflectance spectra are shown for 70-weight-percent water ice and 30-weight-percent ammonia ice mixtures with varying grain sizes. As the grain size of the ammonia ice increases, the ammonia bands become smaller and the spectrum appears more like that of water ice.
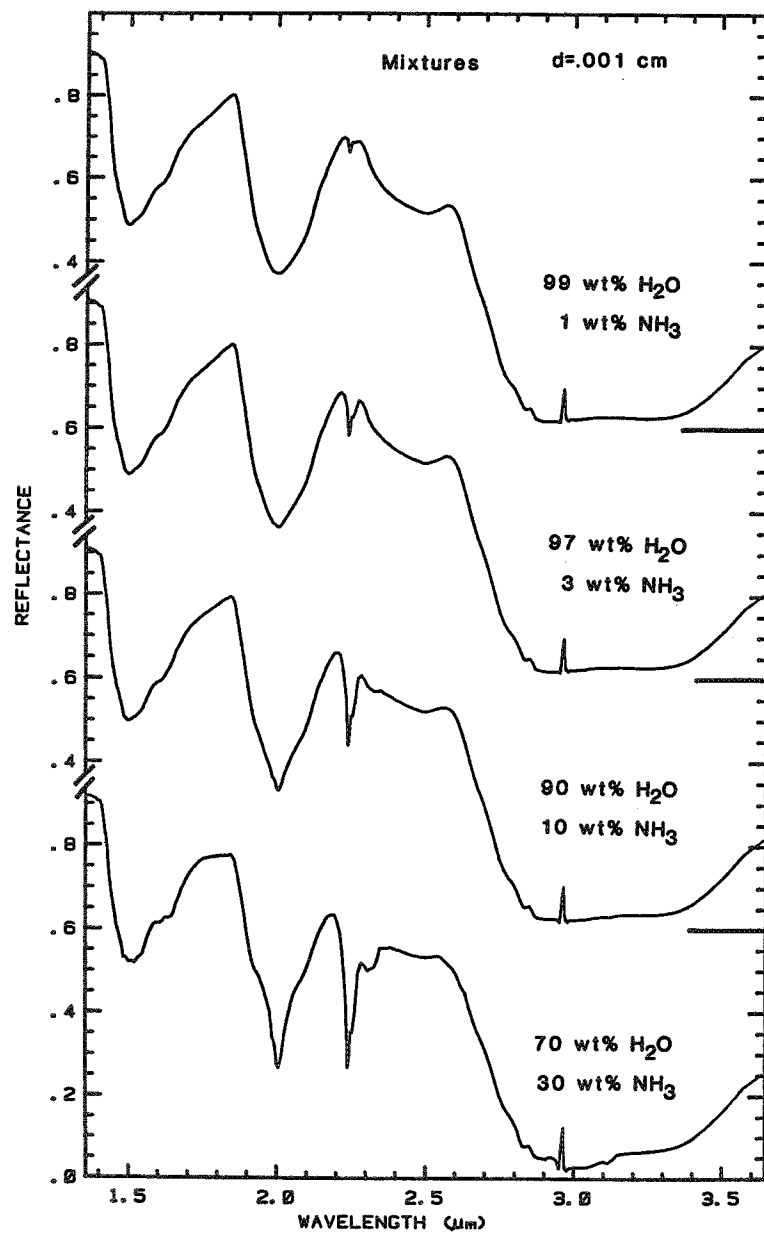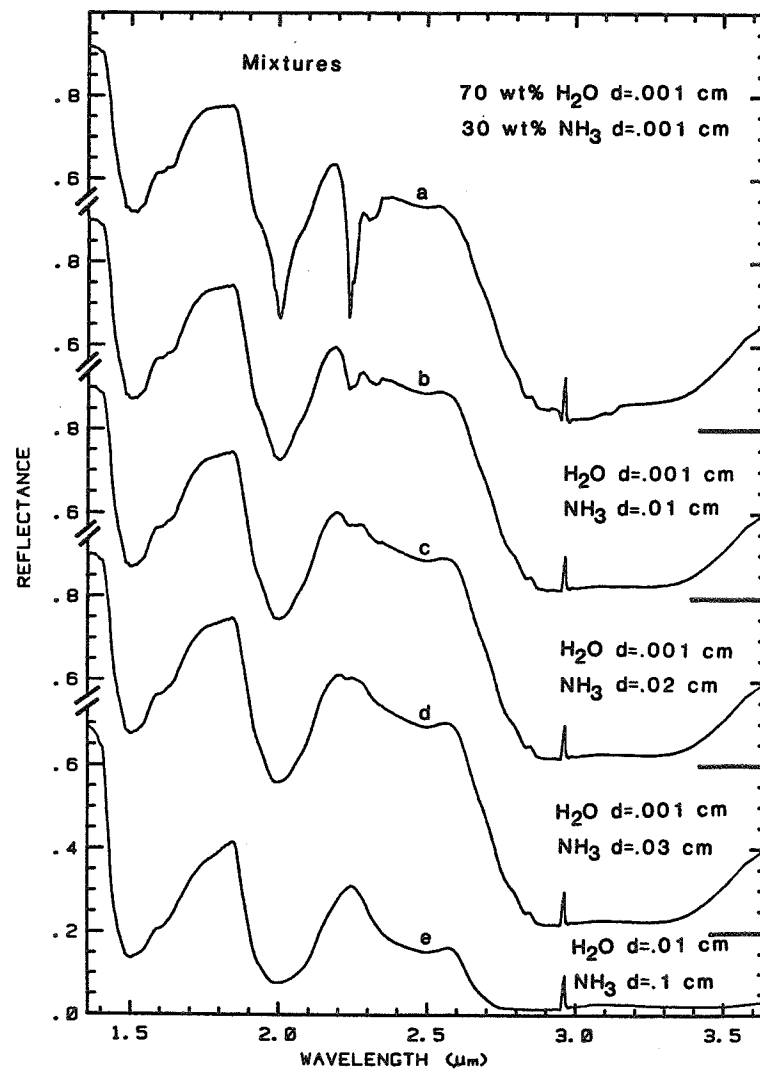
Figure 1

Figure 2