EFFECTS OF PARTICLES $\leq \lambda$ OF LIGHT ON REFLECTANCE SPECTRA; J. E. Hays and J. F. Mustard, Dept. Geol. Sci., Brown University, Providence RI, 02912

Introduction: Reflectance spectra of particulate materials generally exhibit regular and systematic changes in intensity and spectral contrast as a function of particle size [1-6]. For multiple scattering regimes, reflectance increases and contrast decreases with particle size [2, 5, 7], while reflectance decreases with contrast for single scattering regimes (e.g. restrahlen bands). However, with hyper-fine particles (<25 μm) a number of distinct intensity and contrast reversals have been observed in mid-infrared biconical reflectance spectra, principally in the multiple scattering regimes [8]. The most striking change with particle size is seen in the transparency feature. Initially, as particle size decreases, the transparency feature becomes stronger, reaching a maximum for particles between 10-15 μm, and then decreases as particle size continues to decrease. This change in brightness is accompanied by a decrease in the λ of the peak reflectance, and an increasing asymmetry about the peak of the feature [8]. However, biconical reflectance spectra at mid-IR wavelengths may exhibit anomalous behavior due to non-lambertian scattering [5]. To verify the character of these important observations, we have measured the olivine suite in directional-hemispherical reflection (DHR) and in thermal emission, and are preparing a sieved suite of quartz for measurement. The results of the measurements and continued modeling are reported here.

Observations: Spectra of the olivine suite (0-25 μm in 5 μm separates) measured in RELAB-Biconical, DHR, and emission are shown in **Figure 1 (a, b, c)**. In general, the spectra from all three instruments exhibit the same fundamental features as a function of decreasing particle size: 1) Cross-overs of the spectra of one separate under the spectra of the next larger separate; 2) Saturation of the Christiansen feature in the finest separates; 3) Decrease in strength and change in shape of the restrahlen band; and 4) Changes in strength, position, and shape of the transparency feature. There are differences in the character of Christiansen feature and the restrahlen bands. In the DHR and emission spectra near the Christiansen feature, the 10-15 μm separate is the brightest, the 0-5 μm is darkest, and the spectra of the 5-10, 15-20, and 20-25 μm separates are closely spaced in between. In the RELAB spectra, there is a systematic progression from 0-5 μm (darkest) to 20-25 μm (brightest) in the Christiansen feature. For the restrahlen band, the restrahlen peak at 9.8 μm is greater than the peak at 11 μm in the DHR and emission spectra, which is opposite that observed in the RELAB spectra. This is probably the result of sample preparation and/or non-lambertian scattering. Nevertheless, the three suite of spectra all exhibit the same important changes of intensity and contrast, and contain the previously reported effects of hyper-fine particles [8]. A program to measure a suite of quartz sieved to the same constraints as the olivine is underway.

Analysis: The changes in the characteristics and features of the spectra of a particulate surface can be explained through the use of Mie Theory. Extinction efficiency (Qe) is predicted to rapidly decline when the parameter $(n-1)X$ is less than approximately 2 (n is the index of refraction, and $X=(\pi D/\lambda)$, where D is particle diameter, and λ is wavelength) [9]. This was consistent with observed decreases in Qe as a function of particle size ("cross-overs") [8]. Since we are fundamentally interested in effects relative to D, we can solve $(n-1)X$ for the critical diameter (Dc) as a function of λ using the complex index of refraction [10, 11]. This is shown in **Figure 1d** along with RELAB spectra for 0-5 and 20-25 μm separates.

When a majority of particles in a separate are less than Dc (e.g. below the solid line in **Figure 1d**), Qe should be reduced by a factor of 2 or more. In the λ region of 6-9 μm, the average particle size (Da) of the 0-5 and 5-10 μm separates are always less than Dc, and we observe that reflectance, and thus Qe, is very low in all three measurements. For 10-15 μm separate, Da begins close to Dc near 6 μm, and then becomes fully less than Dc near 9 μm. Thus a decline in Qe should be seen in this λ region. We observe a decline in reflectance relative to the larger separates, and a cross-over at 8 μm in the RELAB spectra, consistent with these calculations.

For the λ region of 12-15 μm, Da is greater than Dc for all separates at 11.5 μm. Dc then rises linearly to be ~20 μm at 15 μm. This increasing Dc intersects Da for the separates at progressively larger λ's. For the 20-25 μm separate, Da and Dc never meet, and thus a fully formed, symmetric transparency feature is observed. For the 0-5 μm separate, Da intersects Dc near 12 μm, therefore Qe should decrease continuously between 12 and 15 μm, resulting in an asymmetric transparency feature with the reflectance peak shifted to shorter λ. For larger separates, everything is shifted to longer λ as a function of Da, until an unaffected transparency feature is formed. This progression is observed in all three measurement sets.

Conclusions: Independent measurements of the same suite of hyperfine particles in three separate systems shows that our previous observations [8] are the result of particle size, and are independent of sample preparation and measurement. Understanding of these changes in spectral characteristics and features is necessary in the use of remote spectroscopy on planetary surfaces. Mie Theory can be used to explain the observed affects of particles less than 25 μm on reflectance spectra. For a single mineral, the complex index of refraction, as a function of wavelength, can be used to explain, and possibly predict, the changes in reflectance spectra as a function of particle size.

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