SPECTRA OF LUNAR GLASS SIMULANTS: NEW OLD DATA FOR REFLECTANCE MODELING.

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Introduction: Silicate glasses are a key component of the regoliths of airless planetary bodies. Glass is produced by impact melting of target rocks and minerals. Glass created during micrometeoroid bombardment welds rock, mineral and glass fragments to produce the agglutinates found in the lunar regolith. In addition, explosive volcanism can produce pyroclastic glasses. Optical constants for glasses of the relevant compositions are therefore needed in order to carry out radiative transfer modeling of the reflectance spectra of agglutinates, macroscopic impact melt deposits, and pyroclastic deposits. We have recovered reflectance spectra for 20 synthetic glasses studied by E. N. Wells that were not previously widely available. These data greatly expand the range of iron and titanium glass compositions for use in spectral modeling, and should be useful for studies of the Moon, Mercury, and asteroids.

Radiative Transfer Modeling: The radiative transfer model of Hapke [1, 2] permits the bidirectional reflectance of an intimate mixture of particles to be predicted. In order to perform this forward modeling, the optical constants of the phases of interest must be supplied. Lucey [3] developed a Hapke-based method to compute optical constants from reflectance spectra of powdered samples of olivine and pyroxene. Wilcox et al. [4] obtained optical constants for the seven synthetic lunar glasses made under reducing conditions by Bell et al. [5; Table 1], and derived a formula for calculating the optical constant "*k*" as a function of iron and titanium content.

Well Glasses: Wells [6] conducted an analysis of synthetic lunar glasses, with the goal of understanding crystal-field and charge-transfer absorption bands caused by Fe and Ti ions. Because of the large number of samples, transmission measurements were not practical and instead absorption coefficients were obtained from measurements of the reflectance spectra of powdered samples. A small subset of the data he obtained was published in a paper in *Science* in 1977 [7]. However, the dissertation contained spectra and compositional information for several dozen other glasses. This includes glasses melted in a vacuum, consistent with the reducing conditions expected on airless planetary bodies, and oxidized samples melted in air. The Wells glasses (Table 2) cover a wider variety of compositions than the seven samples of [5], particularly combinations at low Fe and low Ti contents (Fig. 1). The base glass used by both [5] and [6] contained SiO_2, Al_2O_3, CaO, and MgO. The Wells spectra (~0.20 to 2.50 μm) cover a wider wavelength range than the Bell et al. data (0.40 or 0.50 to 2.50 μm).

Table 1. Bell et al. glass compositions [5].

Sample Name	FeO, wt.%	TiO_2 , wt.%
F3T3	16.66	9.27
F3T2	16.47	6.45
F2T3	11.04	10.27
F3T1	14.99	3.33
F1T3	5.53	11.00
F3T0	19.97	0.00
F0T3	0.00	11.66

Table 2. Wells vacuum-melted glass compositions [6].

Sample number	FeO, wt.%	TiO_2 , wt.%
1*	14.7	2.7
2*	2.6	0.5
3*	4.3	0.0
10	0.4	0.0
11	1.1	0.0
12	7.2	0.0
14	17.4	0.0
28	0.0	1.0
29	0.0	2.5
30	0.0	5.0
31	0.0	7.5
32	0.0	10.0
33	0.0	15.0
39*	15.5	10.6
40*	17.4	5.2
41*	17.5	1.0
43	8.6	10.2
44	7.8	5.1
45*	9.0	1.0
47	3.5	5.1

*Reflectance spectrum shown in [6], others have *W*-spectra.

Digitizing and Converting the Spectra. We have digitized spectra for the vacuum-melted glasses from the Wells dissertation. He presented bidirectional reflectance plots (incidence angle = emergence = 30°, phase = 60°) for seven of the samples (Fig. 2). However, most of his figures depict the "bidirectional remission function" $W = (1-\varpi)/\varpi$, where ϖ is the singlescattering albedo. Further, many of these were plotted in energy space, with the *x*-axis in terms of wavenumbers rather than wavelength. Therefore, we converted the "*W*-function" spectra to ϖ, and then back to bidirectional reflectance using the early form of the Hapke bidirectional reflectance equation presented in the dissertation. Spectra in wavenumbers tend to have a very high density of points in the shorter-wavelength (ultraviolet-visible) portion of the spectrum and a coarser spacing in the near infrared. Hence we resampled the reflectance spectra to a standard, evenly spaced set of wavelengths after conversion from wavenumbers. For a few spectra, the dissertation presented both reflectance and *W*-function spectra for the same sample. For these we found good agreement between the original reflectance and the reflectance obtained by inverting the *W*-spectrum (Fig. 3). This gives us confidence that our procedure is operating correctly.

Rederiving the Relationship Between Composition and "*k*": With the expanded set of glass spectra, we plan to convert the reflectance values to the optical constant "*k*" using the method of [3]. We can then redetermine the [4] relationship between "*k*" and composition as a function of FeO and TiO_2 content. This improved relationship between "*k*" and composition for silicate glasses will be useful as an input for models of the reflectance of planetary surfaces containing glass. The low-Fe, low-Ti compositions may be of interest for application to Mercury.

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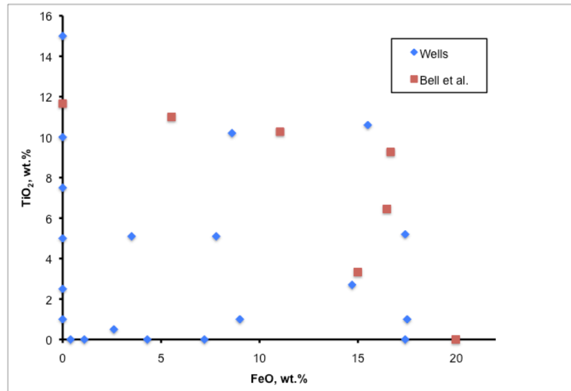
References: [1] B. Hapke (1993), *Theory of Reflectance and Emittance Spectroscopy*, Cambridge Univ. Press, New York. [2] B. Hapke (2001), *J. Geophys. Res. 106*, 10,039–10,073. [3] P. G. Lucey (1998), *J. Geophys. Res. 103*, 1703–1714. [4] B. B. Wilcox et al. (2006), *J. Geophys. Res. 111*, doi: 10.1029/2006JE002686. [5] P. M. Bell et al. (1976), *Proc. Lunar Sci. Conf. 7th*, 2543–2559. [6] E. N. Wells (1977), *Optical Absorption Bands in Glasses of Lunar Composition*, Ph.D. dissertation, University of Pittsburgh, Penna. [7] E. Wells and B. Hapke (1977), *Science 195, 977-979*.

Figure 1 (top of next column). Glass compositions from [5] and [6].



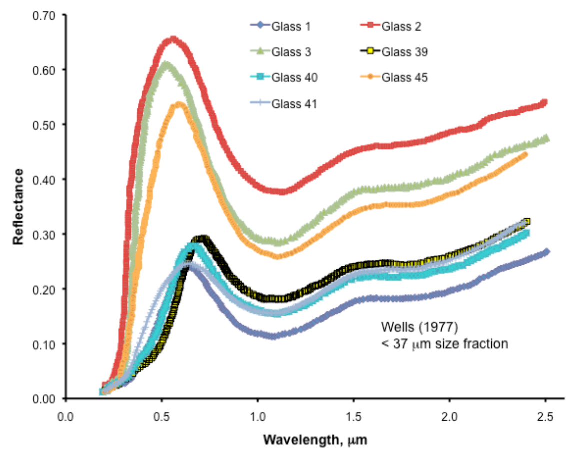


Figure 2. Reflectance spectra digitized from [6].

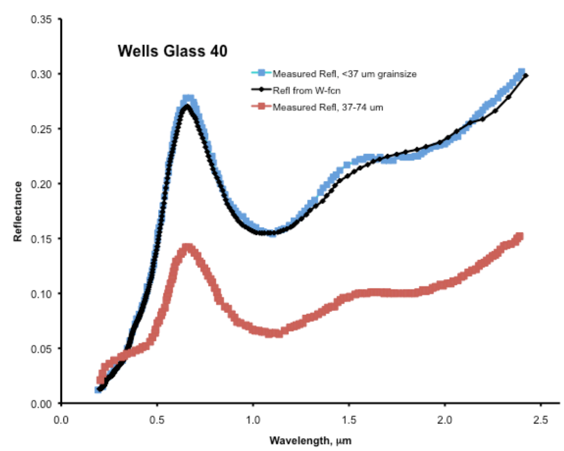


Figure 3. Comparison of measured reflectance spectra for Wells Glass #40 to the reflectance derived from inversion of a digitized *W*-function spectrum for that sample. The blue and black curves agree reasonably well, indicating that we can reliably convert from *W* to reflectance.