Pyroxene Mg# Determination in the 4-8 Micron Range: A Valuable Remote Sensing Tool

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Intro: Pyroxene Mg#, for real?!

Pyroxene has been remotely detected widely in the Solar system, but Visible-Near Infrared (VNIR, 0.5-3 µm) and Mid-Infrared (MIR, 8-15 µm) spectra have only partially constrained its composition. Meanwhile, pyroxene’s characteristics in the Intermediate Infrared (IMIR, 4-8 µm), or “cross-over” range, has not been documented. Here, we study the relationship between Mg# ([Mg/(Mg+Fe)] x 100) and the positions of strong discrete overtone-combination bands in the IMIR.

What is the IMIR? (aka “Cross-over” Range)

The Intermediate Infrared (IMIR) range (4-8 µm) is defined as the wavelength range where interaction of electromagnetic radiation with silicate minerals transitions between volume-scattering of photons in the VNIR and surface-scattering of photons in the MIR. Silicate bands in the IMIR likely caused by overtones and combinations of fundamental bands.

Figure 1. “Cross-over” bands in olivine and pyroxene. (a) Spectra in the visible-near infrared (0.5-3.0 µm) range through to the mid-infrared (8-15 µm) range, with intermediate infrared (IMIR) in grey box. (b) Expanded spectra in the “cross-over” range. Arrows indicate positions of bands in olivine (5.6 and 6.0 µm), as well as the three high-Ca pyroxene (5.1 and 5.3 µm) and low-Ca pyroxene (5.2 µm) bands discussed in this study. Circled numbers refer to the designated band trends in pyroxene.

Our Study: Synthetic and Natural Pyroxene

We compiled reflectance spectra of 72 particulate samples of pure pyroxene and pyroxene-bearing rocks from RELAB database and USGS spectral library. Samples mostly had particle size of <45 µm. Meteorites were particulate, whole-rock samples. References for samples given below.

Figure 2. Pyroxene quadrilateral showing the composition of samples included in this study. See Table 1 for sample information (Kremer et al., in Prep).

Figure 3. Reflectance spectra of synthetic pyroxene in the “cross-over” infrared region, grouped by Ca (wollastonite, “Wo”) content in panels (a-f) Colors of spectra grouped by Wo content are keyed to Mg#: (a) Wo 0, (b) Wo 8-14, (c) Wo 22-29, (d) Wo 38-39, (e) Wo 45-47, and (f) Wo 49-51. Numbered labels refer to sample numbers in Table 1 (Kremer et al., in Prep). Synthetic pyroxene described in Klima et al. (2007, 2011).

Figure 4. (a-c) Spectra of synthetic pyroxene, grouped by Mg#. Colors of spectra are keyed to Wo content, with high-Ca pyroxene in darker grey and low-Ca pyroxene in lighter grey: (a) Mg 0, (b) Mg 35-53, (c) Mg 90. Numbered labels refer to Wo content. Dashed lines and circled numbers indicate the positions of the 5.2 and 5.3 µm bands in high-Ca pyroxene and 5.1 and 5.3 µm bands in high-Ca pyroxene. In (a) positions of the 5.2 and 5.3 µm bands overlap. Synthetic pyroxene described in Klima et al. (2007, 2011).

Figure 5. Reflectance spectra of natural pyroxene from terrestrial (a-b) and extraterrestrial (c) sources in the “cross-over” infrared region. (a) Natural low-Ca pyroxene. (b) Natural high-Ca pyroxene. (c & d) Whole rock spectra of diogenite and enstatite chondrite. Individual labels identify samples in Table 1. Dashed lines indicate of the 5.1 and 5.2 µm bands in high-Ca pyroxene and low-Ca pyroxene, respectively.

Figure 6. Summary of relationships between position of “cross-over” band positions and Mg# in pyroxene. (a) Trends observed between Mg# and 5.1 and 5.3 µm band position in high-Ca pyroxene (squares; Band 2 of Fig 1b) and 5.2 µm band position in low-Ca pyroxene (circles, etc.: Band 2 of Fig 1b). 95% confidence interval for equations (1), (2), and (3) given in table. (b) Band trends diagnostic of Mg# in pyroxene compared to those in olivine (Kremer et al., 2020) in the “cross-over” region, with 95% confidence intervals.

Conclusions: Pyroxene has three strong bands at 5.1, 5.2, and 5.3 µm that allow Mg# to be determined within ±10 and ±23 mol% for low-Ca and high-Ca pyroxene, respectively.