Simple analytic expressions for the opacity of highly conducting materials

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Infrared spectra have been used to probe the mineral composition of dust in cosmic space. It is commonly accepted that silicate dust is responsible for mid-infrared features. However, pure silicates are much more transparent at near-infrared wavelengths and do not account for the near-infrared emission common to a variety of astronomical objects such as AGB star circumstellar dust, white dwarf circumstellar dust disks, and protoplanetary disks (e.g., Draine & Lee 1984; Reach et al. 2009; Varga et al. 2024). Potential sources of the near-infrared opacity are metallic iron and/or carbon with high refractive indices. However, the opacities of such conducting dust are poorly understood from an analytical standpoint.

In this study, we investigate if the analytical expressions for the opacity of insulating materials (Kataoka et al. 2014) are also applicable to conducting materials with refractive indices much higher than unity. The expressions by Kataoka et al. (2014) are based on Mie calculations and show the opacity can be well approximated by the combination of three distinct closed-form expressions. When the particle size is larger than the wavelength, geometric optics applies, and the optical properties of the grains can be understood by tracing the ray inside the material. Within the geometric optics regime, there are optically thin and optically thick regimes depending on the absorption of incident light within the particles. For conducting particles, we find that the larger refractive indices make the wavelength inside the particles become shorter, causing the particles to enter the geometric optics regime at smaller particle sizes. Therefore, the Rayleigh regime only applies to very limited conditions. Furthermore, we find that because light rays are reflected many times within the sphere due to a higher refractive index, most of the geometric optics regime is characterized by the optically thick regime.