Experimental and Theoretical Evidence for Heat Being Conducted in Solids by Diffusing Infrared Light

Anne M. Hofmeister, Dept. Earth and Planetary Sci., Washington U., St. Louis MO, USA

Current models of heat conduction consider pseudo-particles known as phonons as the microscopic carrier in non-metals and electrons as the main carrier in metals. These assignments trace to the kinetic theory of gas. In gas, heat and mass move together, whereas heat enters, crosses, and exits a solid, creating a thermal gradient. Because electrons and phonons cannot cross interfaces between unlike materials, we propose that the mechanism in solids is diffusion of light, mostly infrared. Experimental evidence and additional theoretical arguments provide support, while contraindicating scattering mechanisms. Laser-flash analysis is an optimal probe for elucidating heat movement through samples, as it lacks confounding errors of contact losses and spurious radiative gains, and differentiates mechanisms by probing temporal progression of heat across the sample.

Experimental evidence includes the recent discovery that thermal diffusivity (D) depends on the length-scale (thickness, L) of the sample [2021, *Materials 14*, #449]. Below ~ 1 mm, D linearly depends on L, but as L increases above several mm, D flattens to a constant value for any given substance. Crystals, ceramics, glass, metals, alloys, semi-conductors, and insulators of different bond-types all systematically behave in this manner. The behavior is explained by solids being fairly transparent in the near-infrared region such that optical thick conditions needed for diffusion are reached above ~mm thicknesses. This discovery explains slight variations among inter-laboratory comparisons, and calls for further measurement of D as a function of L for solids used as thermal barrier coatings and other applications.

The time-temperature curves of metals and alloys have a weak jump shortly after the laser pulse, consistent with electronic transport being fast and carrying little heat [Criss and Hofmeister, 2017, *Int. J. Modern Phys. B31*, #1750205]. The current microscopic model presumes that electrons can uptake heat from phonons as they travel, which violates the 2^{nd} law of thermodynamics, since the fast, hot electrons travel into cold phonon regions.

Measured temperature and pressure responses of thermal diffusivity and conductivity follow universal rules, consistent with diffusion of radiation, which can neither compress nor expand as does the material. A three parameter radiative transfer model which fits data from 0 K to experimental limits is presented, which may assist the tailored design of materials.