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Thermal diffusivity of aluminous spinels and magnetite at elevated temperature with implications for heat transport in Earth's transition zone

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Abstract

The phonon component of thermal diffusivity (D) from 12 single crystals in the spinel family was measured at temperatures (T) of up to ~2000 K, using laser-flash analysis. Synthetic disordered spinel, 4 gemstones near $MgAl_2O_4$, nearly $ZnAl_2O_4$, 4 "hercynites" $[(Mg,Fe^{2+})(Al,Fe^{3+})_2O_4]$, and 2 magnetites (nearly Fe_3O_4) were characterized using optical spectroscopy and electron microprobe analysis. The magnetic transition in Fe_3O_4 is manifest as a lambda curve in $1/D$, but otherwise, D decreases with increasing T and approaches a constant (D_{sat}) at high T. Part of the decrease in D as T increases results from disordering above ~700 K: these two effects were distinguished by making multiple heating runs. At 298 K, D decreases strongly as either cation substitution or Mg-Al disorder increases, whereas D_{sat} is moderately perturbed by substitutions. For both ordered and (equilibrium) disordered spinels and hercynites, the temperature dependence of $1/D$ is best described by low-order polynomial fits. For spinel, combining our data with previous cryogenic studies of thermal conductivity (k) constrains the T dependence of D and k from ~0 K to melting.

The response of D to disorder, impurity content, and cation mass for the aluminates is used to constrain $D(T)$ for γ-Mg_2SiO_4 and ringwoodite. Pressure derivatives are provided by relationships such as $\partial \ln(k_{lat})/\partial P = \partial \ln(K_T)/\partial P$. Our results show that the phonon contribution to heat transport in Earth's transition zone is high, particularly for large proportions of ringwoodite.

Keywords: Laser-flash method, high temperature, thermal diffusivity, IR spectroscopy, spinel-family minerals, high pressure, aluminates