



Transport properties of silicate melts: temperature- and composition-dependence of thermal diffusivity and viscosity, and some geologic applications

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Igneous processes have been and continue to be of fundamental importance in shaping the planet, and in transferring heat and material within the Earth. The rates of segregation, ascent, differentiation and emplacement or eruption of magma depend primarily on magma viscosity, which is itself highly variable with temperature and composition. The thermal conditions permitting melt formation, and the rate of cooling once it has formed, are determined by thermal diffusivity (D) and conductivity ($k = D\rho C_P$), where ρ denotes density and C_P denotes specific heat capacity at constant pressure.

We have measured D of a wide variety of synthetic and natural glasses and melts including silica, feldspar and pyroxene end-members, obsidian, dacite and MORB, using laser-flash analysis (LFA). Glasses have low room-temperature thermal diffusivities (~ 0.65 to $0.50 \text{ mm}^2\text{s}^{-1}$) that are only about half the values of their chemically equivalent crystals. As T increases, D of glass decreases, approaching a composition-dependent constant (D_{sat}) near 1,000 K. The decrease in D mirrors the increase in C_P over the same interval, but is less strong, so that k of glasses increases from ambient conditions to the glass transition. Alkali feldspar glasses and obsidian have the highest D_{sat} ($0.55 \text{ mm}^2\text{s}^{-1}$) while diopside has the lowest ($\sim 0.4 \text{ mm}^2\text{s}^{-1}$). Anorthite (An), enstatite (En), An-En, An-En-Q and MORB glasses have intermediate values. Upon crossing the glass transition, D decreases rapidly to values between $\sim 0.3 \text{ mm}^2\text{s}^{-1}$ for diopside melt and MORB, to $\sim 0.5 \text{ mm}^2\text{s}^{-1}$ for alkali feldspar melts and obsidian. Natural glasses that contain crystallites have higher D than crystal-free remelts. Effects of water content were assessed by measuring D of obsidian from Mono Craters, California (0.1 to 1.1 wt.% H_2O). Water has a negligible effect on D at these low concentrations, in marked contrast to its dramatic effect of reducing viscosity and glass transition temperature.

We investigated relationships between melt chemistry, viscosity, and D . Whereas D of a given melt appears to be nearly independent of T , viscosity decreases rapidly with increasing T . However, the two properties are linked by heat capacity: configurational changes occurring in a liquid are associated with the configurational heat capacity C_P^{conf} . Melts with large values of C_P^{conf} , such as diopside, will be less Arrhenian (more fragile) than feldspathic melts, which have small values of C_P^{conf} and are more Arrhenian (less fragile). We observed a strong positive correlation between $C_{P,melt}/C_{P,glass}$ and D_{melt}/D_{glass} , and a strong negative correlation between D_{melt} and melt fragility. Less polymerized melts have lower D_{glass} and D_{melt} , so rhyolitic glasses and melts conduct heat faster than basaltic melts.

Considering isochemical melting, D and k for feldspathic melts are ~ 10 -15% lower than that of the bulk crystal, whereas for pyroxenes this difference is ~ 40 -50%. While differences in D and k between crustal rocks and granitic melts are small, the very low D of basaltic melts mean that 15% partial melt in the mantle at 1200C results in 10-20% reduction in bulk D and k of the partially molten zone. This has important consequences for melt generation, in that partially molten zones preferentially retain heat; for magma transport, in that magma is more thermally insulating than country rocks; and for crystallization of magma chambers, in that conductive heat transfer becomes more efficient as magma crystallizes.