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Elastic properties of minerals and the influence of phase transitions

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ABSTRACT

Elastic anomalies that accompany cation ordering and displacive phase transitions can be understood in terms of coupling between strain components and the driving order parameter in Landau free energy expansions. Non-convergent cation ordering in spinel, $MgAl_2O_4$, is accompanied by changes in individual elastic constants, shear modulus, and bulk modulus that vary linearly with the order parameter. Convergent cation ordering, such as Al/Si ordering in anorthite, is expected to give changes in elastic properties that scale with the square of the order parameter. The elastic anomalies that develop in association with displacive phase transitions show greater diversity, due to the additional influence of the order parameter susceptibility. These are illustrated for the cases of the proper ferroelastic transition at high pressure in stishovite and the improper ferroelastic transition in $SrTiO_3$ perovskite. Low temperature transitions in lawsonite show a more complex pattern of softening and stiffening that depends on coupling with both cation ordering and displacive processes. Variations of the spontaneous strain and elastic constants are indicative of the underlying thermodynamic mechanism for a phase transition. If any such transitions occur in minerals of the Earth's crust or mantle they should be identifiable from their distinctive influence on seismic velocities.

Keywords: Phase transitions, elastic constants, Landau theory, spinel, anorthite, stishovite, $SrTiO_3$, lawsonite