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Melting and vibrational properties of planetary materials under deep Earth conditions

JENNIFER M. JACKSON, California Institute of Technology

The large chemical, density, and dynamical contrasts associated with the juxtaposition of a liquid iron-dominant alloy and silicates at Earth's core–mantle boundary (CMB) are associated with a rich range of complex seismological features. For example, seismic heterogeneity at this boundary includes small patches of anomalously low sound velocities, called ultralow-velocity zones. Their small size (5 to 40 km thick) and depth (about 2800 km) present unique challenges for seismic characterization and geochemical interpretation. In this contribution, we will present recent nuclear resonant inelastic x-ray scattering measurements on iron-bearing silicates, oxides, and metals, and their application towards our understanding of Earth's interior. Specifically, we will present measurements on silicates and oxide minerals that are important in Earth's upper and lower mantles, as well as iron to over 1 megabar in pressure. The nuclear resonant inelastic x-ray scattering method provides specific vibrational information, e.g., the phonon density of states, and in combination with compression data permits the determination of sound velocities and other vibrational information under high pressure and high temperature. For example, accurate determination of the sound velocities and density of chemically complex Earth materials is essential for understanding the distribution and behavior of minerals and iron-alloys with depth. The high statistical quality of the data in combination with high energy resolution and a small x-ray focus size permit accurate evaluation of the vibrational-related quantities of iron-bearing Earth materials as a function of pressure, such as the Grüneisen parameter, thermal pressure, sound velocities, and iron isotope fractionation quantities. Finally, we will present a novel method detecting the solid-liquid phase boundary of compressed iron at high temperatures using synchrotron Mössbauer spectroscopy. Our approach is unique because the dynamics of the iron atoms are monitored. This process is described by the Lamb-Mössbauer factor, which is related to the mean-square displacement of the iron atoms. We will discuss the implications of our results as they relate to Earth's core and core-mantle boundary regions.