

Observation of Solid Ramp-Compressed Sodium Above 300 GPa:

Extreme pressures can induce significant changes in a material's structural and optical properties. At ambient conditions, elemental sodium can be well described by the nearly free-electron model, making it ideal for testing *ab initio* models at extreme compressions. Increasing pressure prompts a series of solid-phase transformations in Na, ultimately producing an electrider structure where the electrons occupy the interstitial regions or voids between the atoms.¹ Electrideres are associated with remarkable changes in electronic behavior; Na was observed to become optically transparent at 200 GPa in diamond-anvil cell (DAC) experiments.² In addition, the melting curve of Na decreases with increasing pressure over a wide range of pressures (over 100 GPa), dropping to below room temperature at 118 GPa then rising dramatically between 125 GPa and 140 GPa (Fig. 1).^{3,4}

Prior to this work, no structural data existed beyond 200 GPa and no melting temperature data existed beyond 140 GPa. Nominally, our laser-driven experiments isentropically compress Na (purple curve); therefore, Na will melt in the bcc phase and, if the melting curve continues to sharply increase, a solid phase will be observed at pressures greater than 140 GPa.

To explore this high-pressure behavior, a Laboratory Basic Science (LBS) proposal was used to study ramp-compressed Na using the OMEGA EP laser. Nanosecond *in-situ* x-ray diffraction was performed to determine the crystalline structure using the powder x-ray diffraction image-plate (PXRDI) diagnostic.⁵ The absence of diffraction peaks was used to infer the occurrence of melting. The targets comprise Na samples (10- to 50-mm thick), sandwiched between single-crystal diamond pushers and rear windows (LiF, MgO, or diamond). Laser velocimetry was used to determine the *in-situ* pressure of the Na sample.

A solid phase of Na was repeatedly observed for pressures greater than 300 GPa (Fig. 2). In contrast to the highly textured diffraction pattern collected by Ma *et al.*, a more powder-like distribution of the Na grains was observed. Indexing this structure as hP4 results in a reproducible, sixfold compressed phase of Na. For thick samples and low pressures (<200 GPa), no diffraction lines were observed, indicating that the Na melted. This and the presence of diffraction peaks above 300 GPa suggests that the Na melts and then resolidifies on nanosecond time scales, and that the melting temperature greatly increases above 140 GPa. These are the highest pressure observations of solid Na to date. In these experiments, no evidence was found that the Na became transparent at high pressure. Analysis of these results continue.

Omega Facility Operations Summary: The Omega Facility conducted 208 target shots in April with average experimental effectiveness (EE) of 99.0%. One hundred forty-one shots were carried out on the OMEGA laser with EE of 99.3% while OMEGA EP conducted 67 shots with EE of 98.5%. The ICF program accounted for 57 target shots for experiments led by LLE and LLNL while 90 shots were carried out for the HED program by LANL, LLNL, and SNL. The NLUF program had 12 target shots for a Princeton-led experiment while the LBS program had 39 shots for four experiments led by LLE and LLNL. A single experiment led by CEA accounted for ten target shots.

1. Miao and Hoffmann, *Acc. Chem. Res.* **47**, (2014); 2. Y. Ma *et al.*, *Nature* **458**, 182 (2009); 3. E. Gregoryanz *et al.*, *Science* **320**, 1054 (2008); 4. M. Marques *et al.*, *Phys. Rev B* **83**, 184106 (2011); 5. J. R. Rygg *et al.*, *Rev. Sci. Instrum.* **83**, 113904 (2012).

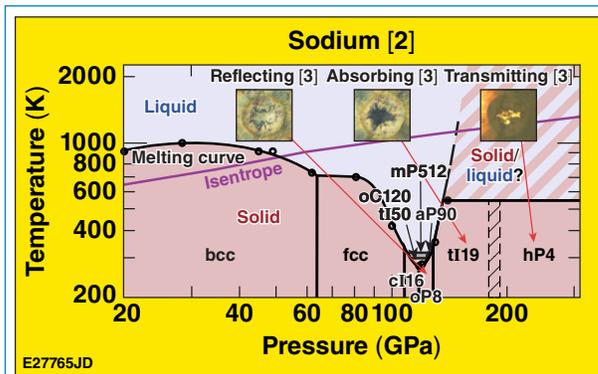


Figure 1. Phase diagram of Na taken directly from Ref. 4, based on Refs. 2 and 3. The highest pressure data for Na, before this work, are at 200 GPa from diamond-anvil cell x-ray diffraction experiments.² The melting curve above 140 GPa is extrapolated (black dashed line), and in the striped region, the existence of solid or liquid Na is unknown.

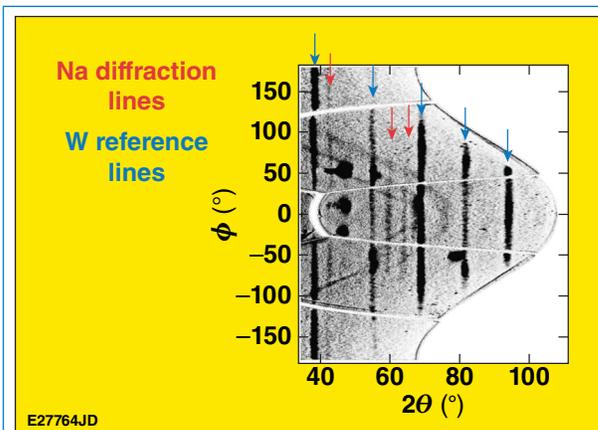


Figure 2. Background subtracted 2θ - ϕ projection of a Na x-ray-diffraction pattern ($\lambda = 1.48 \text{ \AA}$) near 300 GPa. The red and blue arrows label Na and pinhole calibration diffraction lines, respectively.