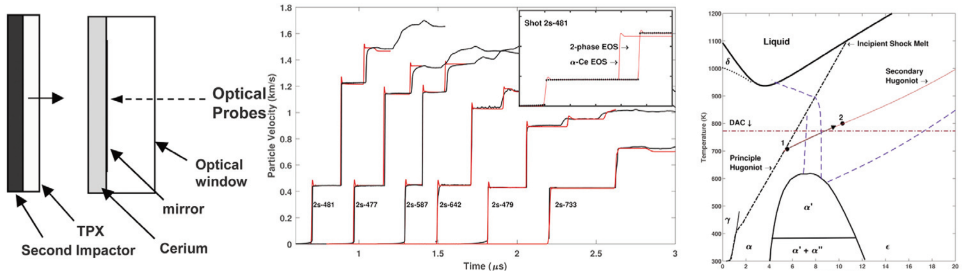
The Advanced Photon Source

Shocking Cerium into a New Phase



Left: Schematic of the experimental configurations for transmission experiment configurations used to generate double-shock loading in the cerium sample. Center: Shock wave profiles measured at the Ce–LiF interface for transmission configuration. Right: Example schematic of the cerium phase diagram showing the relevant phases.

A material's equation of state (EOS)—which indicates its state under various conditions of pressure, temperature, volume, and energy, and relates them to various phases—is a vital part of understanding the material's behavior and response in different environments and applications. However, determining the EOS and complete phase diagrams of some materials can pose daunting challenges. One of these materials is cerium, for which some regions of the phase diagram have proven elusive. Investigators from the U.S. Department of Energy's (DOE's) Los Alamos National Laboratory (LANL) employed the U.S. DOE's Advanced Photon Source (APS) to probe the high-pressure solid phase of cerium through shock-wave experiments that provided a detailed look at the cerium's transition from the α- ε phases. Their work, which provides the first evidence that an α-ε phase transition can be shock-induced in cerium, was published in the *Journal of Applied Physics*. The article had 777 downloads in 2020, the most-read article last year in the "Physics of Matter Under Extreme Conditions" section of the journal.

The principal Hugoniot (which defines conditions on both sides of a shock wave) of cerium has already been measured through traditional shock-wave techniques, but to go beyond it to find the secondary Hugoniot that marks the boundary of the ε-Ce phase requires a more complex approach that uses multiple shock loading. Toward this end, diamond anvil cell (DAC) experiments were conducted at the HPCAT-XSD 16-BM-D x-ray beamline at the APS, while double-shock experiments were conducted at LANL.

In the shock impact work, two different experimental configurations were performed: front surface impact experiments (FSI), which used a cerium impactor; and double-shock transmission experiments, which used a cerium target and a complex projectile launched using high-performance gun systems. The researchers also performed static high-pressure DAC experiments at HPCAT-XSD to complement the dynamic measurements. Together, these different configurations allowed the researchers to study cerium using very different loading paths and time scales. The dynamic studies show that a secondary Hugoniot centered around 5.2-5.7 GPa and extends with the second shock to a peak stress of 25-30 GPa and beyond. DAC data were obtained along an isotherm of 773 K and show that a gradual transition from α-Ce to ε-Ce begins at about 6 GPa. This mixed phase completely changes to ε-Ce at 12.1 GPa for both static and dynamic experiments.

The complete transition to the ε phase is similar to the DAC experiments performed in this work, though the DAC data show a gradual transition from one phase to another. The research team next plans to repeat similar experiments under x-ray diffraction observation to study the evolution of the cerium microstructure across the phase transition.

— Mark Wolverton

See: B. J. Jensen, F. J. Cherne, and N. Velisavljevic‡, "Dynamic experiments to study the α–ϵ phase transition in cerium," J. Appl. Phys. **127**, 095901 (2020). DOI: 10.1063/1.5142508

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