Magnesium oxide: From Earth to super-Earth

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The mantles of Earth and other rocky planets are rich in magnesium and oxygen. Due to its simplicity, the mineral magnesium oxide is a good model for studying the nature of planetary interiors. New work from a team led by Carnegie's Stewart McWilliams studied how magnesium oxide behaves under the extreme conditions deep within planets and found evidence that alters our understanding of planetary evolution. It is published November 22 by *Science* Express.

Magnesium oxide is particularly resistant to changes when under intense pressures and temperatures. Theoretical predictions claim that it has just three unique states with different structures and properties present under planetary conditions: solid under ambient conditions (such as on the

Earth's surface), liquid at high temperatures, and another structure of the solid at high pressure. The latter structure has never been observed in nature or in experiments.

McWilliams and his team observed magnesium oxide between pressures of about 3 million times normal atmospheric pressure (0.3 terapascals) to 14 million times atmospheric pressure (1.4 terapascals) and at temperatures reaching as high as 90,000 degrees Fahrenheit (50,000 Kelvin), conditions that range from those at the center of our Earth to those of large exo-planet super-Earths. Their observations indicate substantial changes in molecular bonding as the magnesium oxide responds to these various conditions, including a transformation to a new high-pressure solid phase.

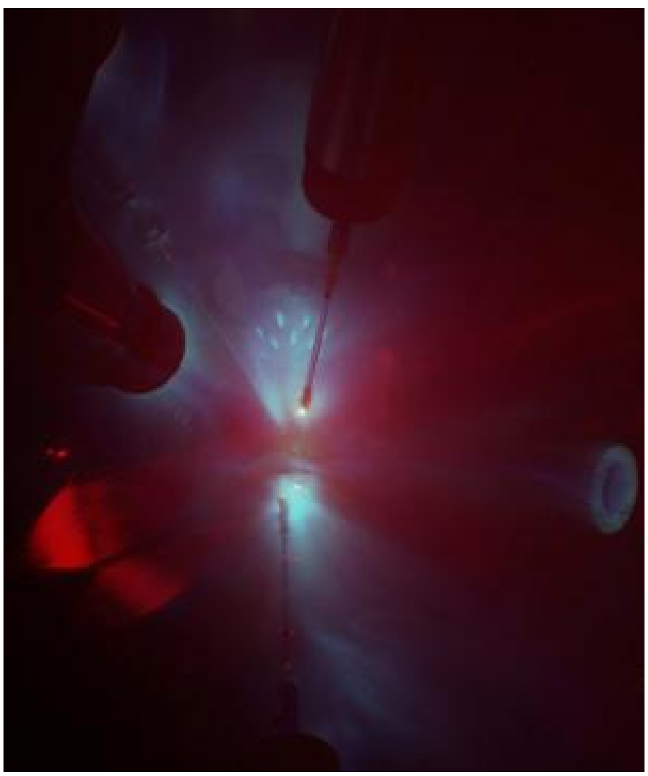

Photo of a laser-shock experiment in progress. Shown is the center of the target chamber, where a sample of material is struck with several high power laser pulses at once. In a brief instant (one billionth of a second), a material initially at low pressure and temperature, similar to the Earth's surface, is artificially heated and compressed to its natural state deep within a planet. This extreme state is quickly studied using probes and telescopes pointed at the target (shown) before it explodes into a cloud of vapor and dust, as seen in this photo. Credit: Eugene Kowaluk, Laboratory for Laser Energetics, University of Rochester

In fact, when melting, there are signs that magnesium oxide changes from an electrically insulating material like quartz (meaning that electrons do not flow easily) to a metal similar to iron (meaning that electrons do flow easily through the material).

Drawing from these and other recent observations, the team concluded that while magnesium oxide is solid and non-conductive under conditions found on Earth in the present day, the early Earth's magma ocean might have been able to generate a magnetic field. Likewise, the metallic, liquid phase of magnesium oxide can exist today in the deep mantles of super-Earth planets, as can the newly observed solid phase.

"Our findings blur the line between traditional definitions of mantle and core material and provide a path for understanding how young or hot planets can generate and sustain magnetic fields," McWilliams said.

"This pioneering study takes advantage of new laser techniques to explore the nature of the materials that comprise the wide array of planets being discovered outside of our Solar System," said Russell Hemley, director of Carnegie's Geophysical Laboratory. "These methods allow investigations of the behavior of these materials at pressures and temperatures never before explored experimentally."

More information: "Phase Transformations and Metallization of Magnesium Oxide at High Pressure and Temperature," by R.S.

McWilliams et al., *Science*, 2012.

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