Probing hydrogen under extreme conditions

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(Phys.org) -- How hydrogen--the most abundant element in the cosmos--responds to extremes of pressure and temperature is one of the major challenges in modern physical science. Moreover, knowledge gleaned from experiments using hydrogen as a testing ground on the nature of chemical bonding can fundamentally expand our understanding of matter. New work from Carnegie scientists has enabled researchers to examine hydrogen under pressures never before possible. Their work is

published online in *Physical Review Letters.*

To explore hydrogen in this new domain, the scientists developed new techniques to contain hydrogen at pressures of nearly 3 million times normal atmospheric pressure (300 Gigapascals) and to probe its bonding and electronic properties with infrared radiation. They used a facility that Carnegie manages and operates at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory in partnership with NSLS.

Observing hydrogen's behavior under very high pressures has been a great challenge for researchers, because it is in a gas state under normal conditions. It is known that it has three solid molecular phases. But the structures and properties of highest-pressure phases are unknown.

For example, a transition to a phase that occurs at about 1.5 million times atmospheric pressure (150 Gigapascals) and at low temperatures has been of particular interest. But there have been technological hurdles in examining hydrogen at much higher pressures using static compression techniques.

It has been speculated that under at high pressures, hydrogen transforms to a metal, which means it conducts electricity. It could even become a superconductor or a superfluid that never freezes--a completely new and exotic state of matter.

In this new work, the research team, which included Carnegie's Chang-sheng Zha, Zhenxian Liu, and Russell Hemley, developed new techniques to measure hydrogen samples at pressures above 3 million times normal atmospheric pressure (above 300 Gigapascals) and at temperatures ranging from -438 degrees Fahrenheit (12 Kelvin) to close to room temperature..

“These new static compression techniques have opened a window on the behavior of hydrogen at never-before-reached static pressures and temperatures,” said Hemley, director of the Geophysical Laboratory.

The team found that the molecular state was stable to remarkably high pressures, confirming extraordinary stability of the chemical bond between the atoms. Their work disproves the interpretations of experiments by other researchers reported last year indicating a metallic state under these conditions. Evidence for semimetallic behavior in the dense molecular phase was found in the new study, but the material must have electrical conductivity well below that of a full metal.

Meanwhile, in another paper also published in Physical Review Letters, a team from the University of Edinburgh and including Carnegie’s Alexander Goncharov report evidence for another phase of molecular hydrogen. They found it at the relatively high temperature of 80 degrees Fahrenheit (300 Kelvin) and under pressures above 220 Gigapascals. They suggest that the structure of hydrogen in this new phase is a honeycomb made of six-atom rings, similar to the carbon structure of graphene.

Provided by Carnegie Institute

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