Pressing Hydrogen to Exotic Quantum States

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Abstract

At very high pressures delocalization of electrons provides a wealth of correlated electron phenomena: e.g., insulator-metal transitions, colossal magnetoresistance, valence fluctuations, heavy fermion behavior, non-Fermi liquid behavior, superconductivity, magnetic order, quadrupolar order, etc. The occurrence of such a wide range of correlated electron phenomena arises from a delicate interplay between competing interactions that can be tuned by pressure, resulting in complex temperature T vs P phase diagrams. In this talk, I will discuss the application of pressure on the simplest element in the universe —The “HYDROGENS”— to understand quantum effects and develop materials with advanced properties.

Efforts to identify and develop new superconducting materials continue to increase rapidly. Solid metallic hydrogen, the elusive phase of atomic hydrogen, is predicted to have exotic properties, such as room temperature superconductivity, superfluidity (if it is a liquid), and metastability. It releases enormous energy if it returns to the molecular phase (400kJ/mole: 35xTNT). This high energy density material can use as rocket fuel that packs nearly four times as much propellant power per kilogram as the liquid hydrogen used in the most powerful rockets today. This would certainly revolutionize rocketry, allowing single stage rockets to enter orbit and chemically fueled rockets to explore our solar system. After more than 80 years of tremendous theoretical progress and a legion of experimental efforts, the most challenging conjecture in condensed matter science remained unproven until recently. We have studied solid molecular hydrogen under pressure at low temperatures. At a pressure of 495 GPa hydrogen becomes metallic with reflectivity as high as 0.85. We fit the reflectance using a Drude free electron model to determine the plasma frequency of 32.5 ± 2.1 eV at T = 5.5 K, with a corresponding electron carrier density of $7.7 \pm 1.1 \times 10^{23}$ particles/cm^3, consistent with theoretical estimates of the atomic density. The properties are those of an atomic metal. We have produced the Wigner-Huntington dissociative transition to atomic metallic hydrogen in the laboratory [1-3]. Finally, I shall discuss future research directions in probing exotic properties of metallic hydrogen such as superconductivity and utilizing metallic hydrogen as a rocket propellant.

Keywords: Hydrogen, Superconductivity, High Energy Density Material

References:

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