Problems of metallic hydrogen and room temperature superconductivity

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Metallic Hydrogen and Room-temperature superconductivity (RTSC) are one the most challenging and very long standing problems in solid-state physics. In both, there is a significant progress over the recent years.

In 1935, Wigner and Huntington [1] predicted that solid molecular hydrogen would dissociate at high pressure to form a metallic atomic solid at pressures P~370-500 GPa [1-3]. Besides the ultimate simplicity, atomic metallic hydrogen is attractive because of the predicted very high, room temperature for superconductivity [4]. In another scenario, the metallization first occurs in the 250-500 GPa pressure range in molecular hydrogen through overlapping of electronic bands [5-8]. The calculations are not accurate enough to predict which option is realized. Our experiments indicate the metallization through closing of energy gap. We observed that at a pressure of ~360 GPa and temperatures <200 K the hydrogen starts to conduct, and that temperature dependence of the electrical conductivity is typical of a semimetal. The conductivity, measured up to 440 GPa, increases strongly with pressure. Raman spectra, measured up to 480 GPa, indicate that hydrogen remains a molecular solid at pressures up to 440 GPa, while at higher pressures the Raman signal vanishes, likely indicating further transformation to a good molecular metal or to an atomic state.

Room-temperature superconductivity (RTSC) does not contradict the BCS and Migdal-Eliashberg theories of conventional superconductors – they do not pose an upper bound of temperature T_c for the emergence of superconductivity. But these general theories are not able to predict particular materials and calculate T_c accurately. First principle calculations of T_c appeared in this century, as well as computational tools to predict crystal structures and phase diagrams of materials under given thermodynamical conditions. Many promising superconductors were predicted with these powerful tools that tremendously accelerated and narrowed the experimental search of superconductors with the highest T_c. We will discuss the interplay and synergy between experiments and theories which led to the finding of superconductivity in hydrides [9], in particular, in H_2S and then in H_3S [10]. The very high T_c =203 K in H_3S indicated that RTSC likely could be found in conventional superconductors. Recently, nearly room temperature superconductivity with T_c ~250 K was predicted [11-13] and found in superhydride LaH_{10} [14, 15]. We will discuss prospects for further increase of T_c to room temperature, which naturally is expecting for hydrides at high pressures. We will present recent studies on YHx, CaHx, MgHx- other compounds which are considered as potential RTSCs.

We will consider various directions to explore high temperature conventional superconductivity at low and ambient pressures.

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