Superconductivity in the Alkali Metal Lithium at Extreme Pressures

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Of the 52 elements now known to be superconductors, 23 only exhibit this cooperative quantum state if subjected to sufficiently high pressures. In the simple free-electron picture, none of the alkali metals are expected to become superconducting. In the first experiments on Li under nearly hydrostatic pressure, we show that for pressures above 200,000 atmospheres Li becomes superconducting at temperatures as high as 15 K. These experiments uncover new physics of direct relevance to a number of outstanding problems in condensed matter physics.

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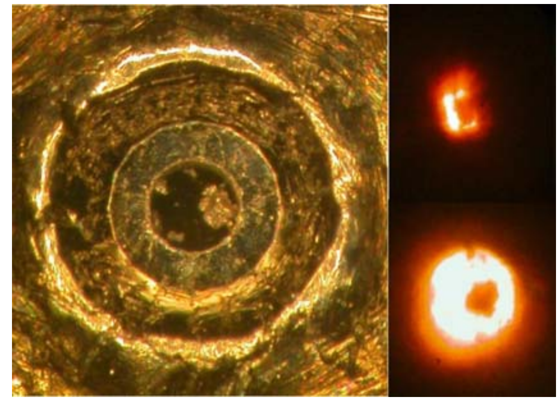
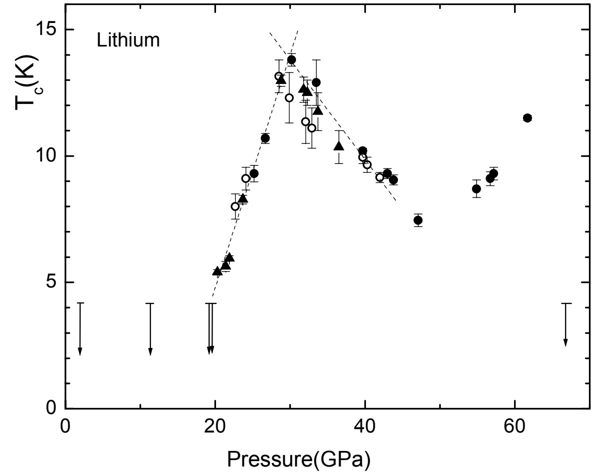


(left & lower right) Li sample is seen in 0.25mm dia. hole in metal gasket at ambient pressure. (upper right) Li sample has been compressed by 300,000 atm. pressure.



Superconducting transition temperature of Li versus pressure to 670,000 atmospheres.

Of the 52 elements that are known to become superconducting, 23 refuse to do so unless subjected to sufficiently high pressures. The latest “high-pressure” superconductor is lithium (Li), the 3rd element in the periodic table and the lightest of all alkali metals. In the left photo a tiny Li sample is seen resting in a 0.25 mm dia. hole drilled through a gold-plated rhenium gasket which serves as the pressure cell. In the lower-right photo the sample is viewed through opposing diamond anvils at ambient pressure; in the upper-right photo the same sample is strongly compressed by a pressure of 300,000 atm. transmitted by solid helium which surrounds the sample. These are the first high-pressure experiments on Li where a pressure medium was used, resulting in nearly hydrostatic pressure conditions and allowing the first quantitative determination of Li’s fascinating superconducting phase diagram (see lower figure). It is seen that a pressure of 200,000 atm (20 GPa) is required to make Li superconducting. The superconducting transition temperature, T_c increases rapidly from 5 K to nearly 15 K at 30 GPa, contrary to what is found for normal simple-metal superconductors. This strong increase is highly anomalous and points to new physics which occurs when the ion cores begin to overlap under extreme compression. The abrupt changes in slope dT_c/dP at 30, 50, and 65 GPa likely indicate structural phase transitions which compete with the superconductivity. Similar effects may occur in many other highly compressible substances. These results are crucial for predicting the behavior of metallic hydrogen under extreme compression, the only substance predicted to be superconducting near room temperature. This work was published in the October 17, 2003 issue of *The Physical Review Letters*.

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Education:

One undergraduate (Brett Beckett), two graduate students (Shanti Deemyad and James Hamlin), and one senior scientist from Russia (Vladimir Tissen) contributed to this work. Deemyad received her Ph.D. in May 2004 and joins Isaac Silvera's group in the Department of Physics at Harvard University as a postdoctoral associate in August 2004. Beckett and Hamlin will perform related experiments on further alkali metal systems. In this project students become acquainted with a multitude of important general experimental techniques, as well as with cutting edge diamond-anvil-cell high-pressure technology.

Societal Impact:

The discovery of superconductivity above room temperature could lead to a technological revolution worldwide. The most likely candidate is metallic hydrogen which can only be synthesized at pressures beyond those currently available in the laboratory (4 million atmospheres). The current and proposed experiments on Li and other alkali metals provide important information of direct relevance to the metallic hydrogen problem.