Новости высокотемпературной сверхпроводимости

А. А. Копасов (аспирант 4 года)
Руководитель: д.ф.-м.н. А. С. Мельников

21 февраля 2019 г.

Outline

1. Theoretical predictions of high-temperature superconductivity in REH_n
2. First experiment (resistance drop)
3. Second experiment (resistance drop, isotope effect, decrease of T_c in an external magnetic field)

1. Metallic hydrogen

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METALLIC HYDROGEN: A HIGH-TEMPERATURE SUPERCONDUCTOR?

N. W. Ashcroft
Laboratory of Atomic and Solid State Physics, Cornell University, Ithaca, New York 14850
(Received 3 May 1968)

Application of the BCS theory to the proposed metallic modification of hydrogen suggests that it will be a high-temperature superconductor. This prediction has interesting astrophysical consequences, as well as implications for the possible development of a superconductor for use at elevated temperatures.

$T_c = 200 - 400$ K was predicted at $P > 400 - 500$ GPa,
H-H distance ~ 1 Å.

PNAS, July 3, 2017, vol. 114, no. 27.

Potential high-T_c superconducting lanthanum and yttrium hydrides at high pressure

Hanyu Liu[a], Ivan I. Naumov[a], Roald Hoffmann[b], N. W. Ashcroft[c], and Russell J. Hemley[d,e,1]

[a]Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC 20015; [b]Department of Chemistry and Chemical Biology, Cornell University, Ithaca, NY 14853; [c]Laboratory of Atomic and Solid State Physics, Cornell University, Ithaca, NY 14853; [d]Department of Civil and Environmental Engineering, The George Washington University, Washington, DC 20052; and [e]School of Applied and Engineering Physics, Cornell University, Ithaca, NY 14853

Contributed by Russell J. Hemley, May 5, 2017 (sent for review March 20, 2017; reviewed by Panchapakesan Ganesh, Jeffrey M. McMahon, and Dimitrios Papaconstantopoulos)

PRL **119,** 107001 (2017) PHYSICAL REVIEW LETTERS week ending 8 SEPTEMBER 2017

Hydrogen Clathrate Structures in Rare Earth Hydrides at High Pressures: Possible Route to Room-Temperature Superconductivity

Feng Peng,[1,2,3] Ying Sun,[3] Chris J. Pickard,[4] Richard J. Needs,[5] Qiang Wu,[6] and Yanming Ma[3,7,*]

[1]*Beijing Computational Science Research Center, Beijing 10084, China*
[2]*College of Physics and Electronic Information, Luoyang Normal University, Luoyang 471022, China and Henan Key Laboratory of Electromagnetic Transformation and Detection, Luoyang 471022, China*
[3]*State Key Laboratory of Superhard Materials, College of Physics, Jilin University, Changchun 130012, China*
[4]*Department of Materials Science and Metallurgy, University of Cambridge, 27 Charles Babbage Road, Cambridge CB3 0FS, United Kingdom and Advanced Institute for Materials Research, Tohoku University, 2–1–1 Katahira, Aoba, Sendai 980-8577, Japan*
[5]*Theory of Condensed Matter Group, Cavendish Laboratory, JJ Thomson Avenue, Cambridge CB3 0HE, United Kingdom*
[6]*National Key Laboratory of Shock Wave and Detonation Physics, Institute of Fluid Physics, CAEP, Mianyang 621900, China*
[7]*International Center of Future Science, Jilin University, Changchun 130012, China*

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1. Pressure dependencies of the superconducting critical temperature in superhydrides

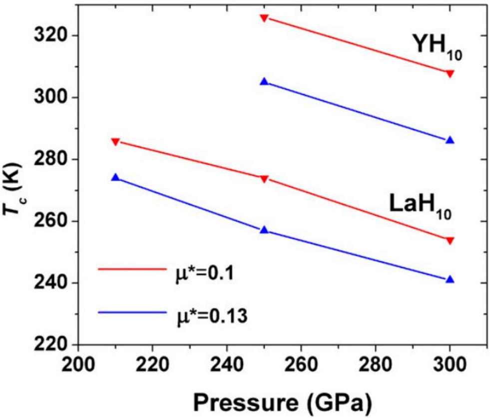

Fig. 7. Calculated T_c of LaH_{10} and YH_{10} as a function of pressure.

1. Superhydride crystal structure

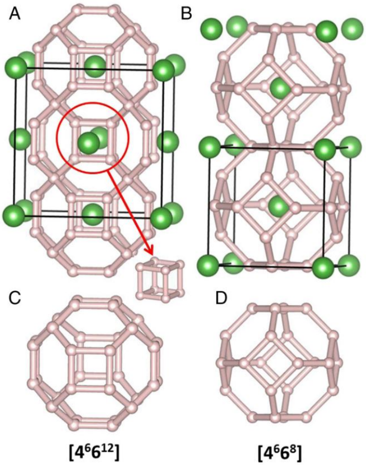

Fig. 3. Crystal structure of sodalite-like LaH_{10} (*A*) and LaH_6 (*B*) at 300 GPa. In the LaH_{10} structure, the red circle highlights the cube hydrogen units. The bottom shows the $[4^6 6^{12}]$ (*C*) and $[4^6 6^8]$ (*D*) hydrogen polyhedra in these structures.

1. Electronic band structures and phonon spectra in $LaH_{8(10)}$.

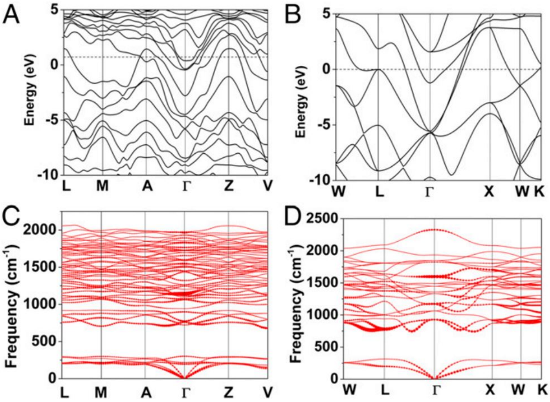

Fig. 6. Calculated electronic band structures of (*A*) LaH_8 and (*B*) LaH_{10} at 300 GPa. The phonon spectrum for (*C*) LaH_8 and (*D*) LaH_{10} at 300 GPa. Red solid circles (*Bottom*) show the EPC with the radius proportional to the respective coupling strength.

1. Phase diagrams of the Y-H system

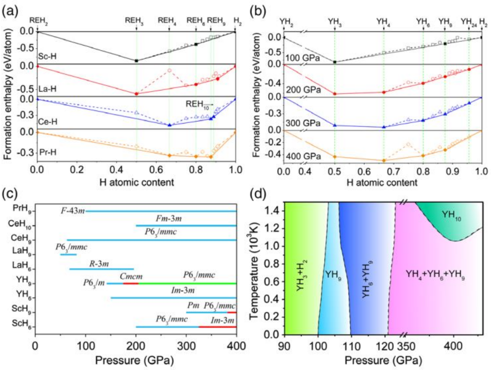

FIG. 1. Phase stabilities of various H-rich RE hydrides (RE = Sc, Y, La, Ce, and Pr). (a) Enthalpies of formation of various H-rich RE hydrides at 200 GPa. (b) Enthalpies of formation of various H-rich Y hydrides under pressure. Dotted lines connect the data points, and solid lines denote the convex hull. (c) Predicted pressure-composition phase diagram of REH_6, REH_9, and REH_{10} clathrate structures. (d) Temperature versus pressure phase diagram of the Y-H system. Dashed lines show the proposed phase boundaries.

2. Experimental synthesis of LaH_{10}

PHYSICAL REVIEW LETTERS **122,** 027001 (2019)

Editors' Suggestion   Featured in Physics

Evidence for Superconductivity above 260 K in Lanthanum Superhydride at Megabar Pressures

Maddury Somayazulu,[1,*] Muhtar Ahart,[1] Ajay K. Mishra,[2,‡] Zachary M. Geballe,[2] Maria Baldini,[2,§] Yue Meng,[3] Viktor V. Struzhkin,[2] and Russell J. Hemley[1,†]

[1]*Institute for Materials Science and Department of Civil and Environmental Engineering, The George Washington University, Washington, DC 20052, USA*

[2]*Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC 20015, USA*

[3]*HPCAT, X-ray Science Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*

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Recent predictions and experimental observations of high T_c superconductivity in hydrogen-rich materials at very high pressures are driving the search for superconductivity in the vicinity of room temperature. We have developed a novel preparation technique that is optimally suited for megabar pressure syntheses of superhydrides using modulated laser heating while maintaining the integrity of sample-probe contacts for electrical transport measurements to 200 GPa. We detail the synthesis and characterization of lanthanum superhydride samples, including four-probe electrical transport measurements that display significant drops in resistivity on cooling up to 260 K and 180–200 GPa, and resistivity transitions at both lower and higher temperatures in other experiments. Additional current-voltage measurements, critical current estimates, and low-temperature x-ray diffraction are also obtained. We suggest that the transitions represent signatures of superconductivity to near room temperature in phases of lanthanum superhydride, in good agreement with density functional structure search and BCS theory calculations.

DOI: 10.1103/PhysRevLett.122.027001

2. Experimental synthesis of LaH_{10}

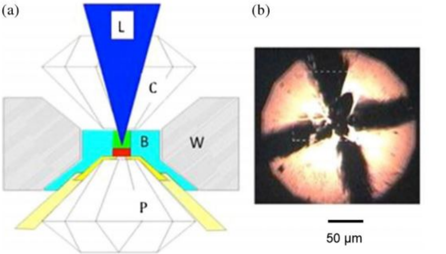

FIG. 1. (a) Schematic of the assembly used for synthesis and subsequent conductivity measurements. The sample chamber consisted of a tungsten outer gasket (W) with an insulating cBN insert (B). The piston diamond (P) was coated with four 1-μm thick Pt electrodes which were pressure-bonded to 25-μm thick Pt electrodes (yellow). The 5-μm thick La sample (red) was placed on the Pt electrodes and packed in with ammonia borane (AB, green). Once the synthesis pressure was reached, single-sided laser heating (L) was used to initiate the dissociation of AB and synthesis of the superhydride. To achieve optimal packing of AB in the gasket hole, we loaded AB with the gasket fixed on the cylinder diamond (C). (b) Optical micrograph of a sample at 178 GPa after laser heating using the above procedure (sample A).

Ammonium borane NH_3BH_3 as the hydrogen source!

2. Resistance vs. temperature curves

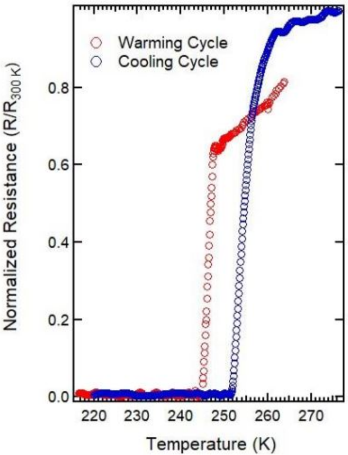

Figure 3. Normalized resistance of the $LaH_{10\pm x}$ sample characterized by x-ray diffraction and radiography (Figs. 1 and 2) and measured with a four-probe technique. The initial pressure was 188 GPa as determined from the Raman measurements of the anvil diamond edge; the pressure after the first cooling (blue) and warming (red) cycle was found to be 196 GPa. The lowest resistance we could record was 20 μΩ after the drop shown in the plot; the 300 K value was 50 mΩ. The measurements were performed using a EG&G model 5209 lock-in amplifier with nominally 10 mA current at 1 kHz with a typical cooling and warming rate of 1 K/min.

3. Second experiment

Superconductivity at 250 K in lanthanum hydride under high pressures

A. P. Drozdov[1], P. P. Kong[1], V. S. Minkov[1], S. P. Besedin[1], M. A. Kuzovnikov[1,6], S. Mozaffari[2], L. Balicas[2], F. Balakirev[3], D. Graf[2], V. B. Prakapenka[4], E. Greenberg[4], D. A. Knyazev[1], M. Tkacz[5], and M. I. Eremets[1]

[1]*Max-Planck-Institut fur Chemie, Hahn-Meitner Weg 1, 55128 Mainz, Germany*
[2]*National High Magnetic Field Laboratory (NHMFL), Florida State University, Tallahassee, Florida 32310, USA*
[3]*NHMFL, Los Alamos National Laboratory, MS E536, Los Alamos, New Mexico 87545, USA*
[4]*Center for Advanced Radiation Sources, University of Chicago, 5640 South Ellis Avenue, Chicago, Illinois, 60637, USA*
[5]*Institute of Physical Chemistry PAS, Kasprzaka 44/ 52, 01-224 Warsaw, Poland*
[6]*Institute of Solid State Physics RAS, Chernogolovka, Moscow District, 142432 Russia*

Superconductivity with a record $T_c \sim 250$ K within the $Fm3m$ structure of LaH_{10} at a pressure $P \sim 170$ GPa.

3. Resistance vs. temperature curves

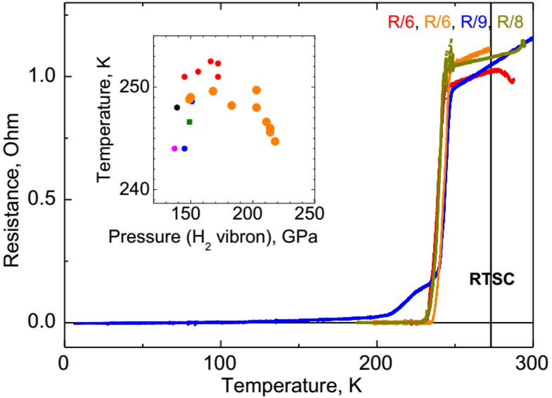

Fig. 1. Observation of superconducting in LaH_{10}. Superconducting transitions in lanthanum superhydride LaH_{10} measured in different samples synthesized from a La+H_2 mixture: red curve corresponds to the sample heated up under 145 GPa displaying T_c of ~244 K, which shifts to ~249 K when the pressure is increased up to 151 GPa (orange curve); dark yellow curve corresponds to the sample heated under 135 GPa with a T_c of ~245 K; blue curve corresponds to a sample heated under 150 GPa with T_c ~249 K. Red, orange and dark yellow curves show the sharpest transitions to zero-resistance upon cooling. Blue curve, as well as many others samples, shows onsets of the superconductive transition around the same temperatures but the sharp superconducting step being distorted by the presence of an impurity phase and/or inhomogeneity in the sample. The resistance of the samples was divided by the shown coefficients for the sake of clarity. A vertical line drawn at 273 K marks the RTSC limit. Inset: pressure dependence of T_c for the 6 different samples.

3. Upper critical magnetic field