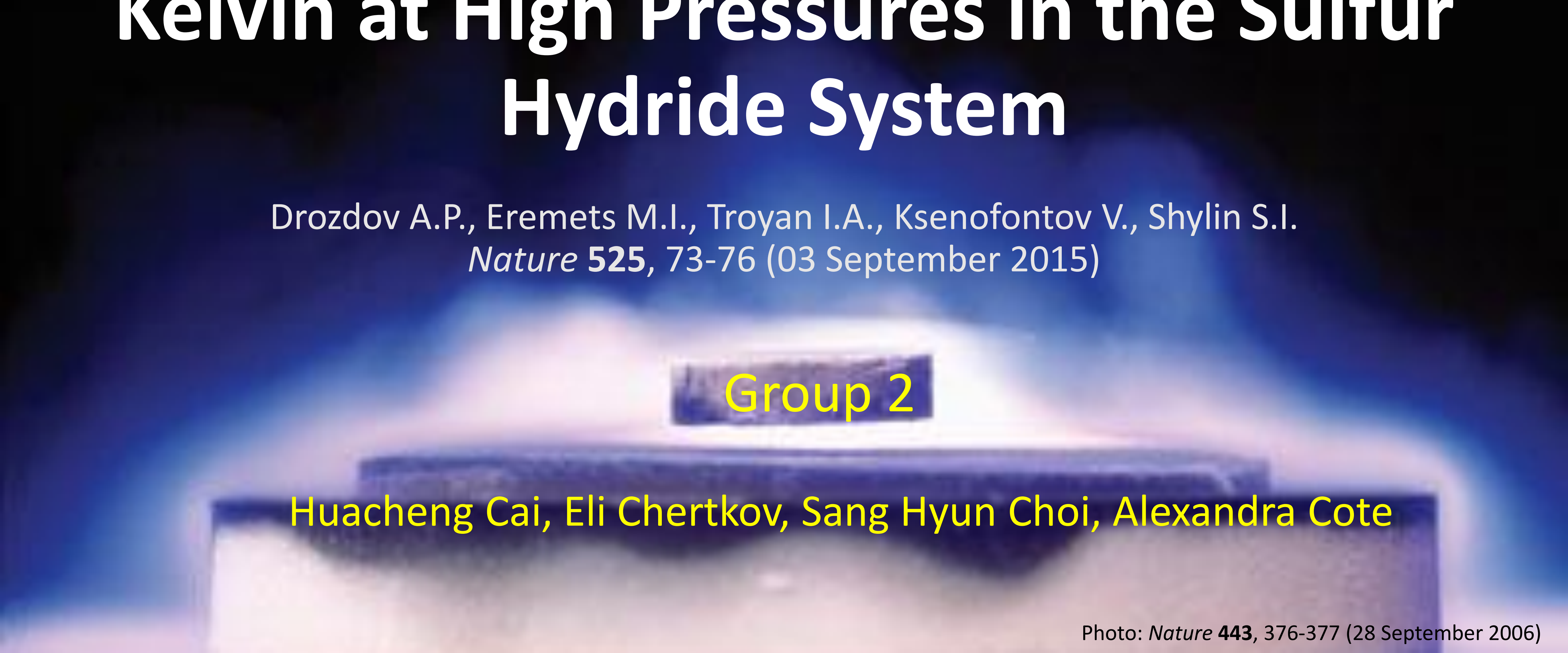


Conventional Superconductivity at 203 Kelvin at High Pressures in the Sulfur Hydride System

Drozdov A.P., Eremets M.I., Troyan I.A., Ksenofontov V., Shylin S.I.
Nature **525**, 73-76 (03 September 2015)

Group 2

Huacheng Cai, Eli Chertkov, Sang Hyun Choi, Alexandra Cote

Photo: *Nature* **443**, 376-377 (28 September 2006)

Outline

Background of superconductivity

Experimental setup

Analysis of results

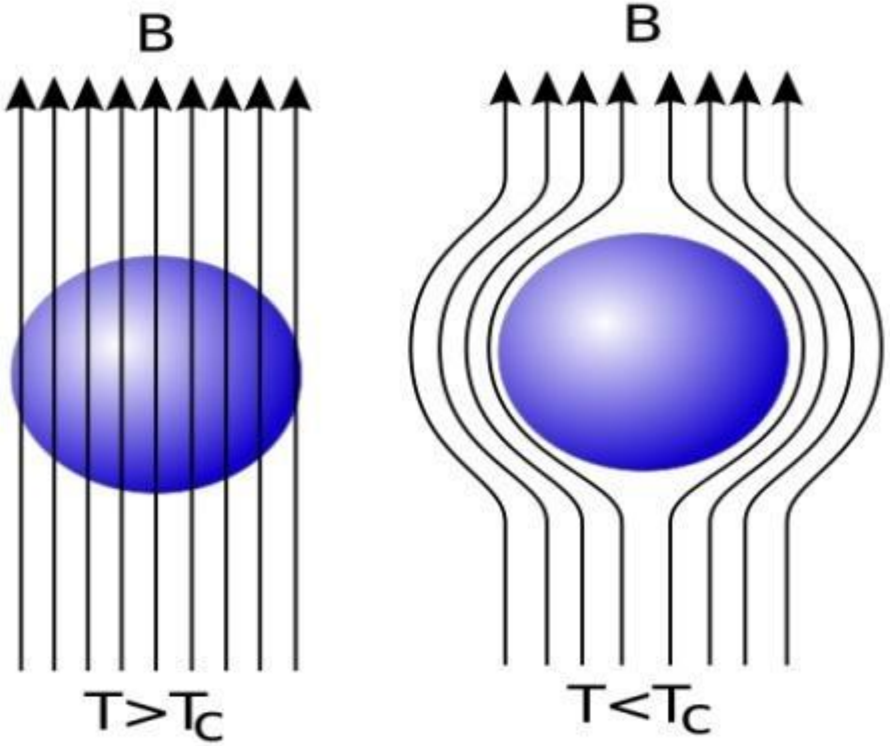
Impact and critique

What is superconductivity?

Observed phenomena:

Superconductors exhibit zero electrical resistivity

Superconductors exhibit an expulsion of magnetic field called the "Meissner effect"



1) http://mri-q.com/superconductivity.html,
2) "EfektMeisnera" by Piotr Jaworski https://commons.wikimedia.org/wiki/File:EfektMeisnera.svg#/media/File:EfektMeisnera.svg

Highlights of conventional superconductors

BCS Theory

Formation of Cooper pairs

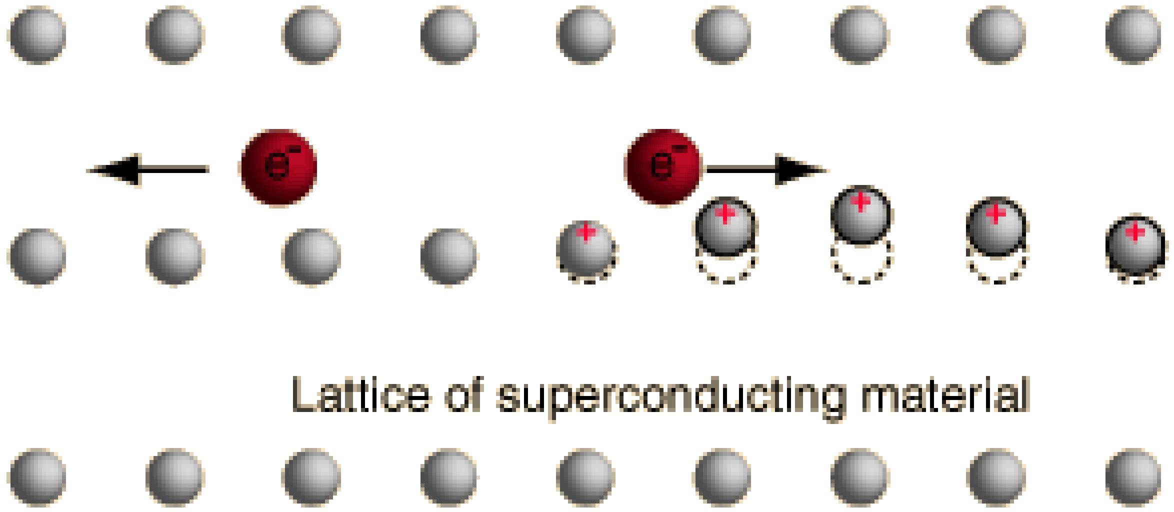
Signatures of superconductivity

Instability of the Fermi surface

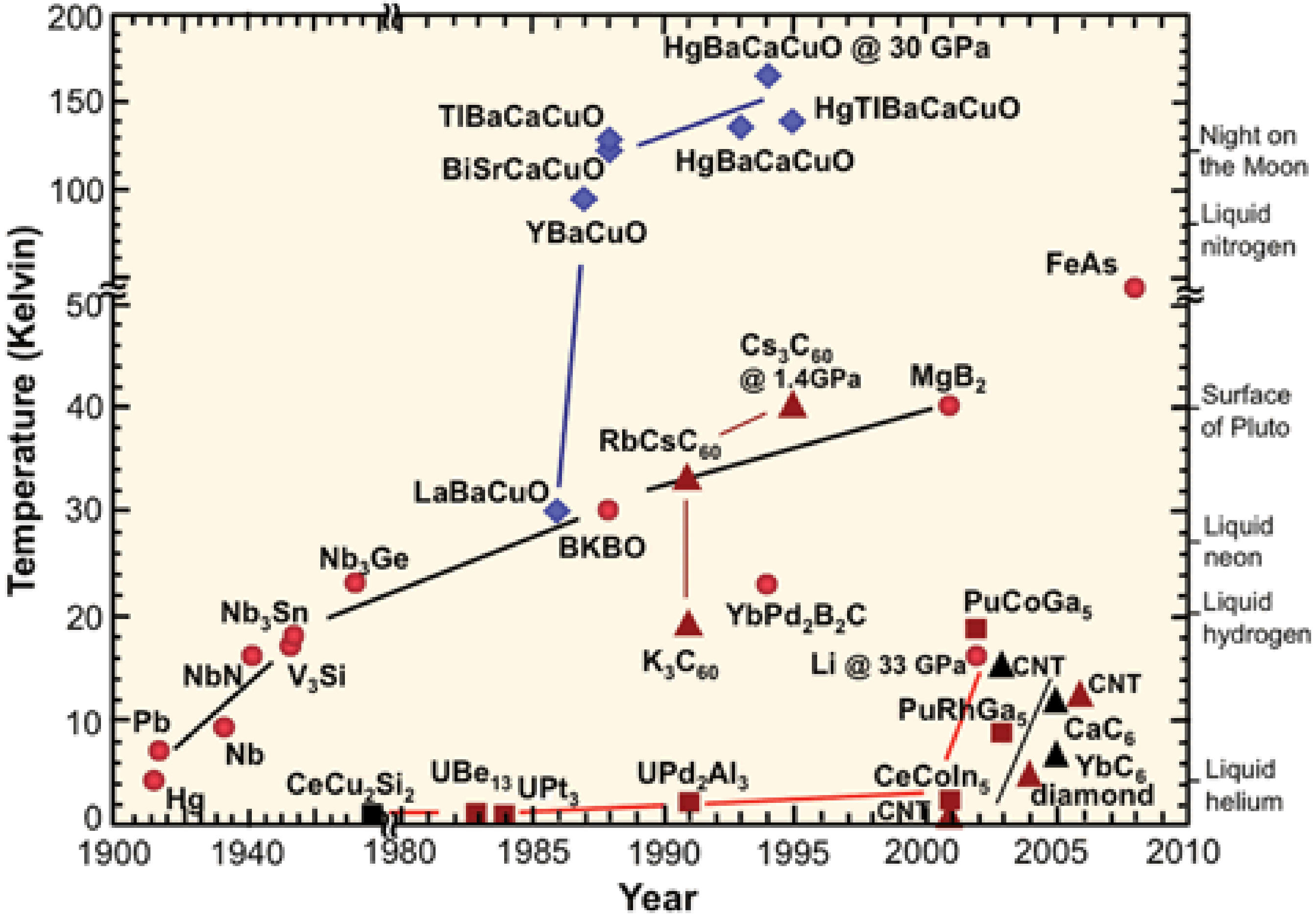
Isotope effect

Exponential rise in heat capacity near T_c

Reduction of energy gap approaching T_c



Where is high T_c now?



What do we need for higher T_c?

- High-frequency phonons ✓
- Strong-electron phonon coupling ✓
- High electronic density of states ✓

H_2S

Outline

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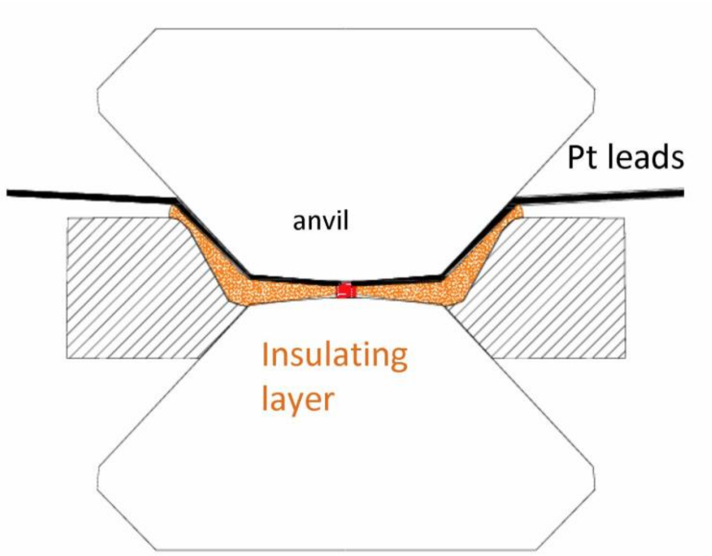
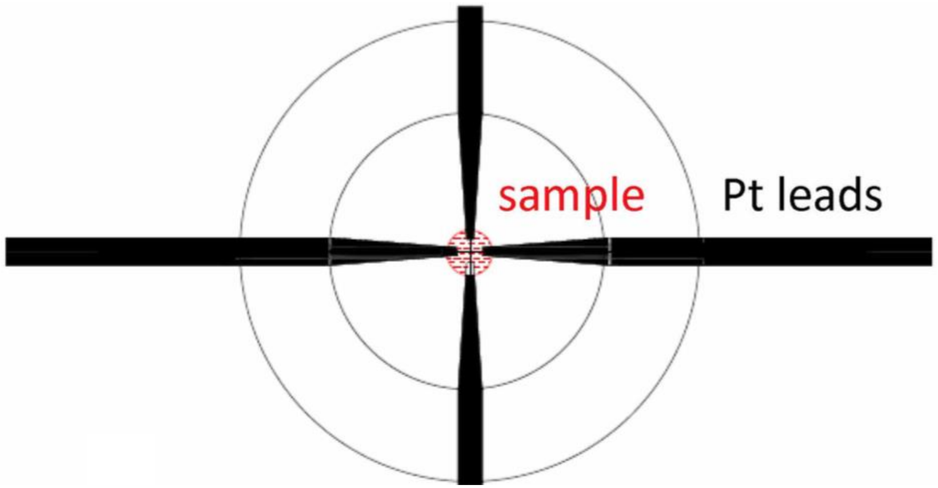
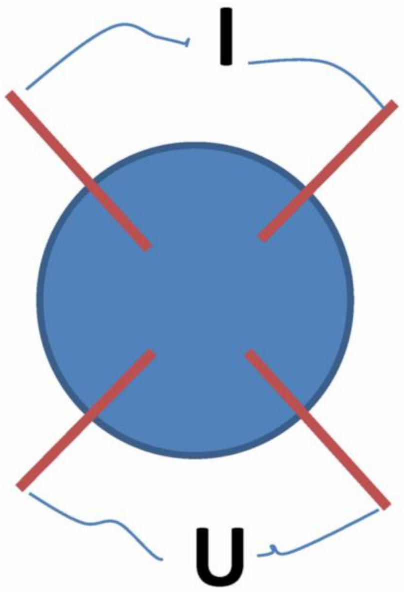
Assembly of the experimental system

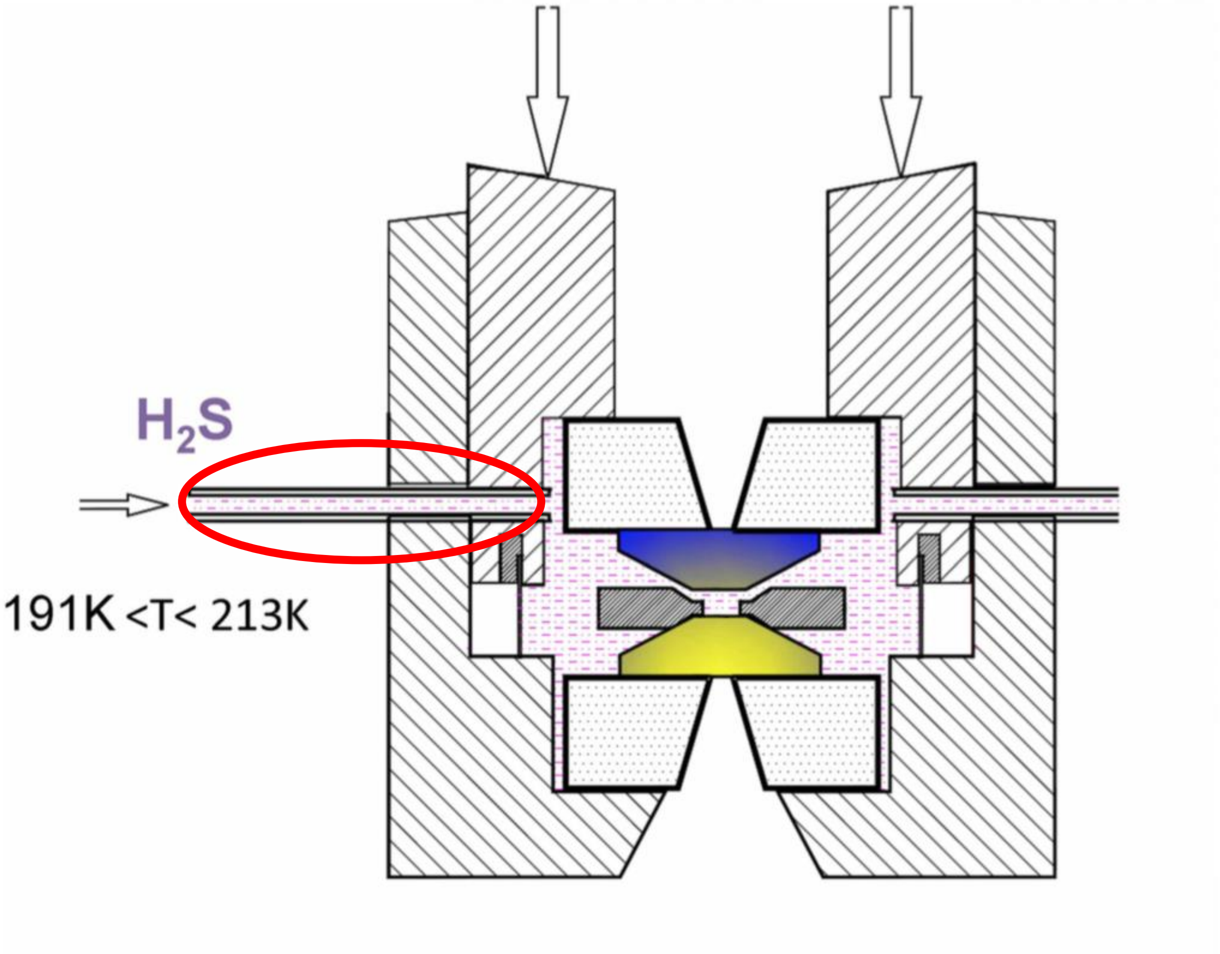






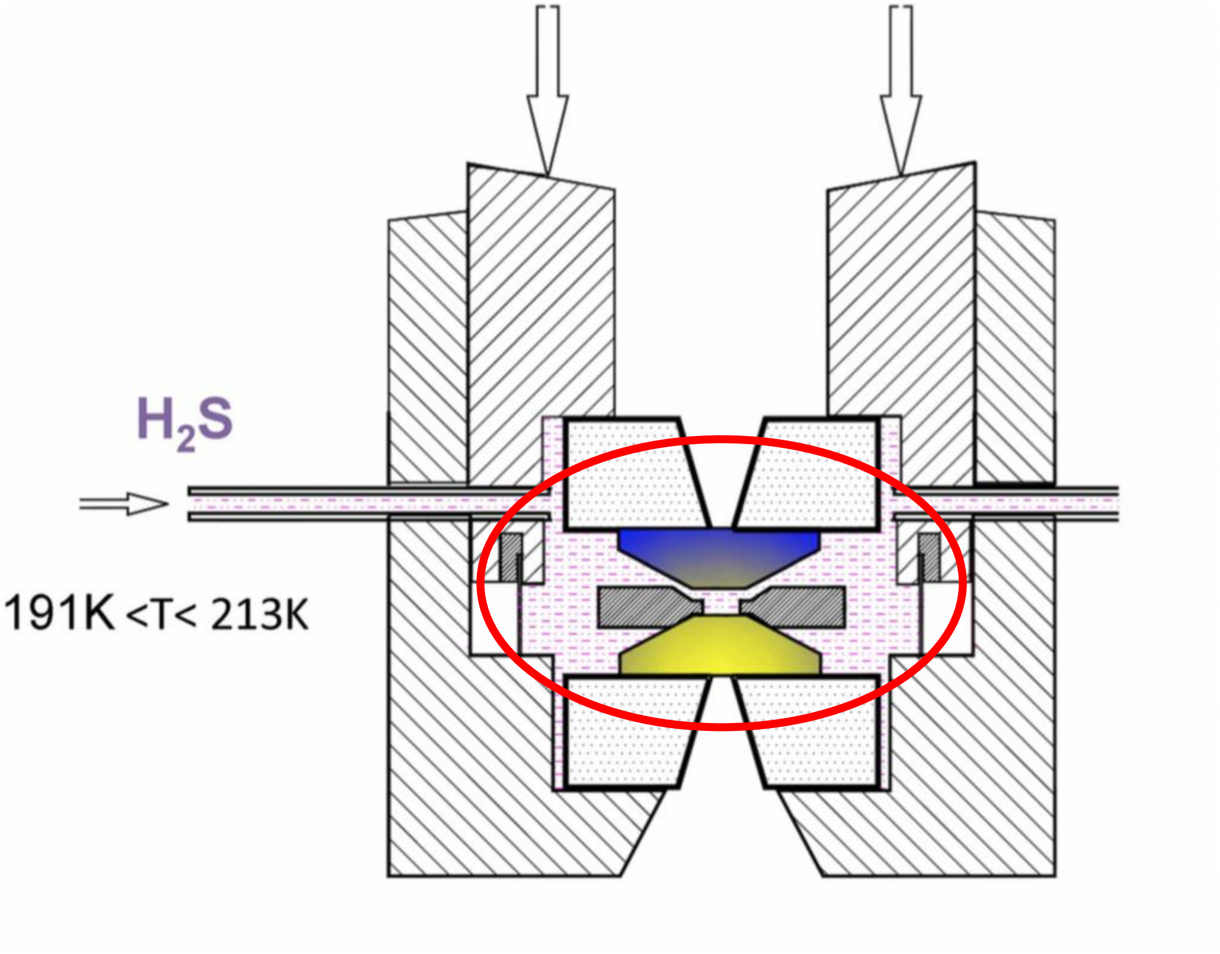
- Insulating gasket: $CaSO_4$ (do not react with H_2S)
- Pt leads sputtered on diamond anvil cell (DAC)
- Van der Pauw methods (for 2-D sample, electrodes on perimeter)

Loading the H_2S sample



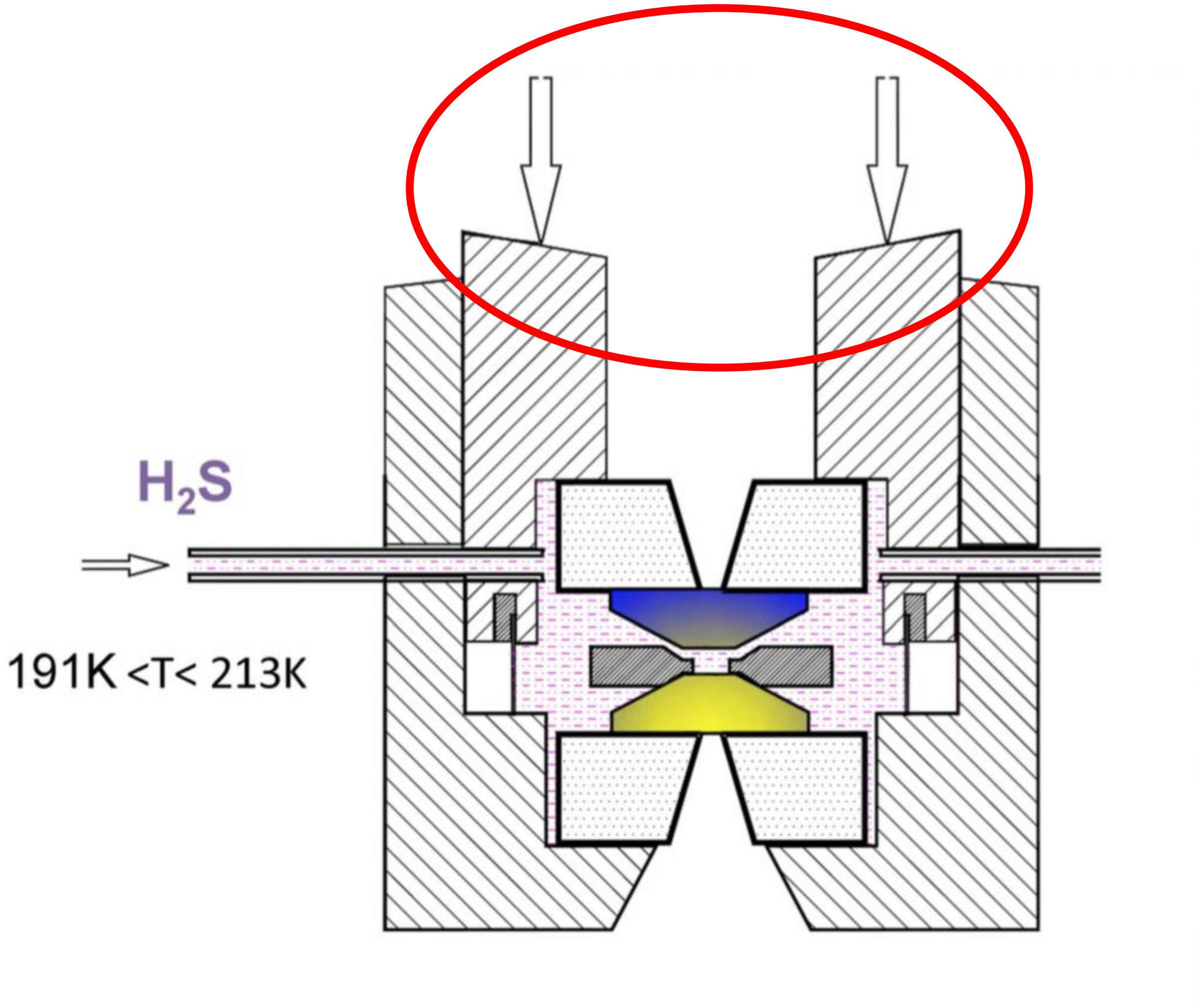
1. Gaseous H_2S passed through the capillary in to a rim

Loading the H_2S sample



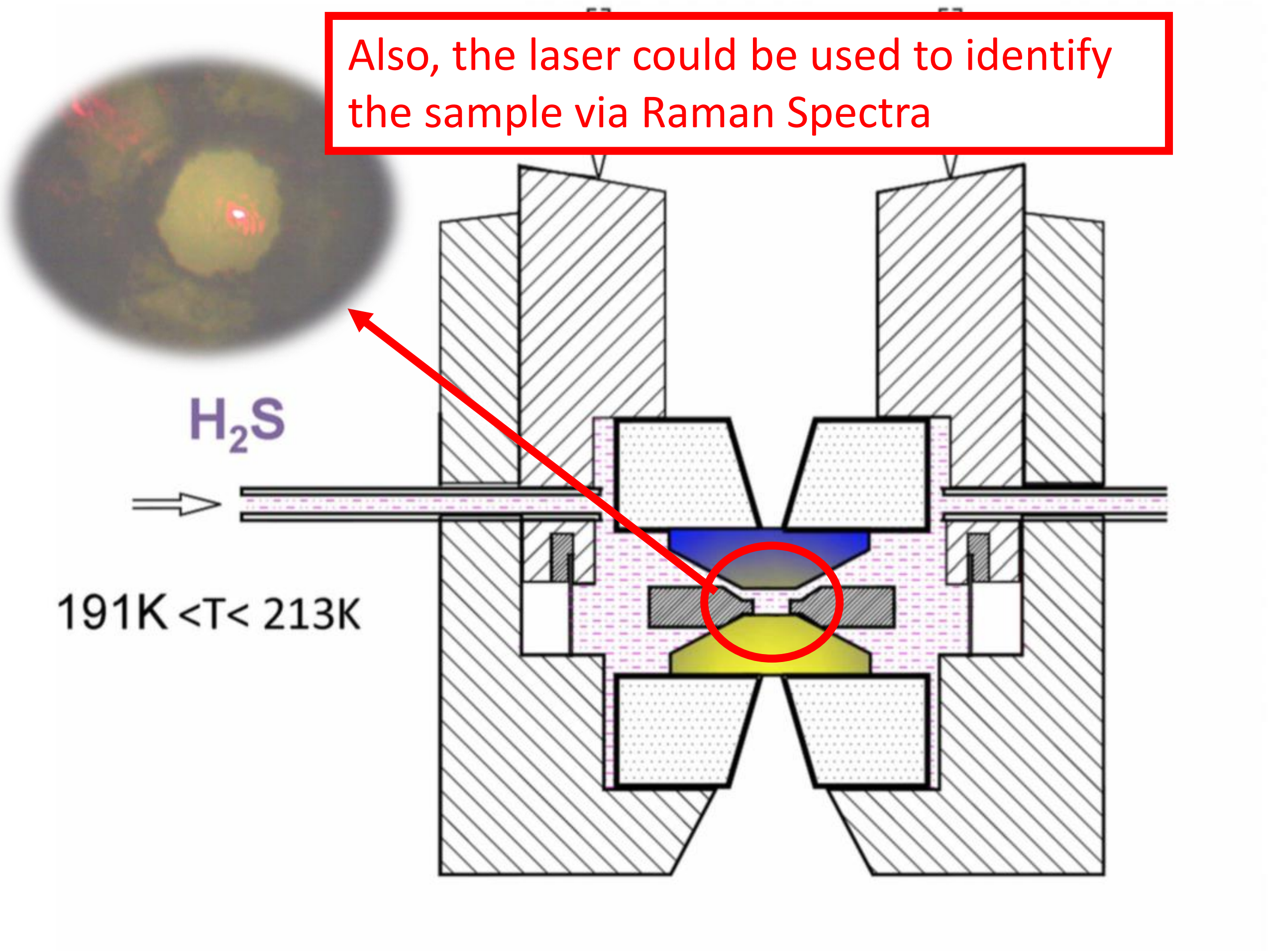
1. Gaseous H_2S passed through the capillary in to a rim
2. Cool down, sample liquefies in temperature about 200K

Loading the H_2S sample



1. Gaseous H_2S passed through the capillary in to a rim
2. Cool down, sample liquefies in temperature about 200K
3. The piston was pushed by screws, to clamp the sample

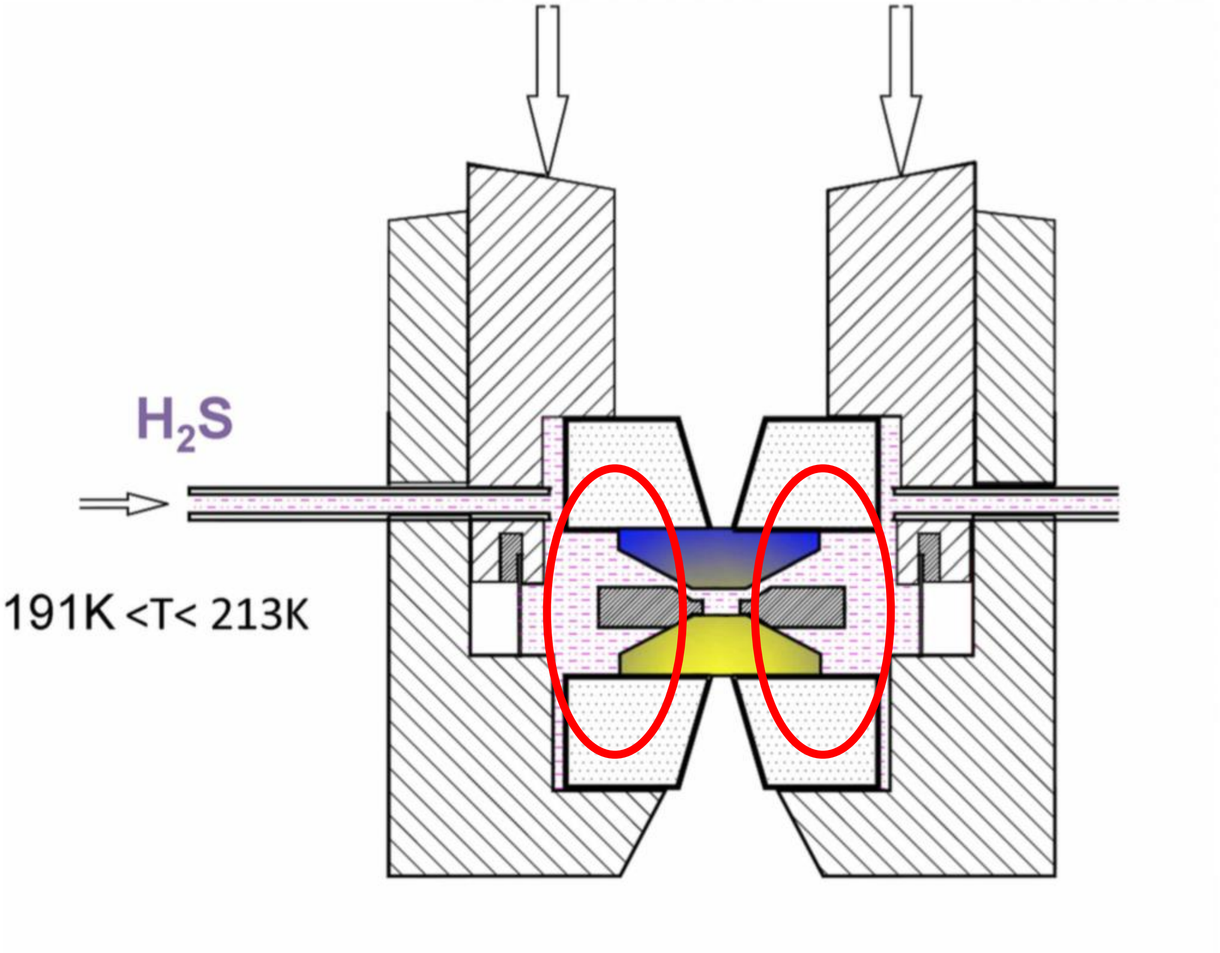
Loading the H_2S sample



Also, the laser could be used to identify the sample via Raman Spectra

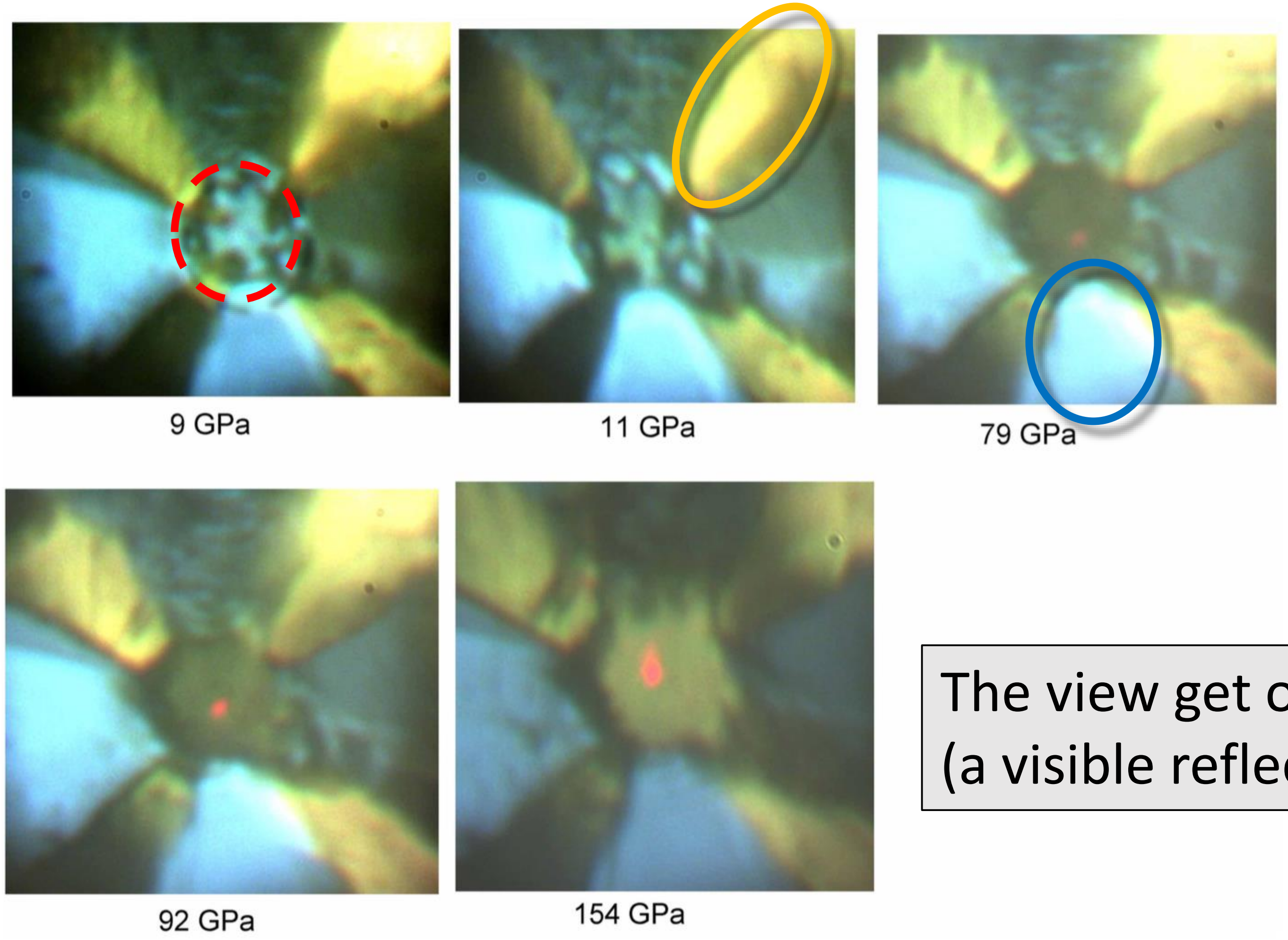
1. Gaseous H_2S passed through the capillary in to a rim
2. Cool down, sample liquefies in temperature about 200K
3. The piston was pushed by screws, to clamp sample
4. Use the interference fringes to adjust the thickness

Experimental setup: Load



1. Gaseous H_2S passed through the capillary in to a rim
2. Cool down, sample liquefies in temperature about 200K
3. The piston was pushed by screws, to clamp sample
4. Use the interference fringes to adjust the thickness
5. Heat the diamond anvil to evaporate the rest of the sample. Afterwards increase the pressure.

Viewing pressure effects on H_2S



9 GPa

11 GPa

79 GPa

92 GPa

154 GPa

- ○ Insulating gasket
- ○ Electrodes
- ◌ Sample

The view get opaque when the pressure increase (a visible reflective of pressure control)

Outline

Background of superconductivity

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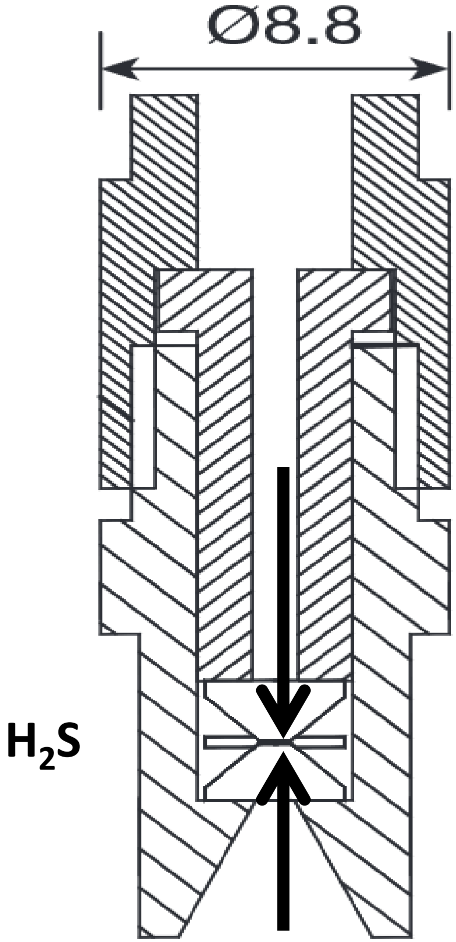
Impact and critique

What to look for in high pressure hydrogen sulfide

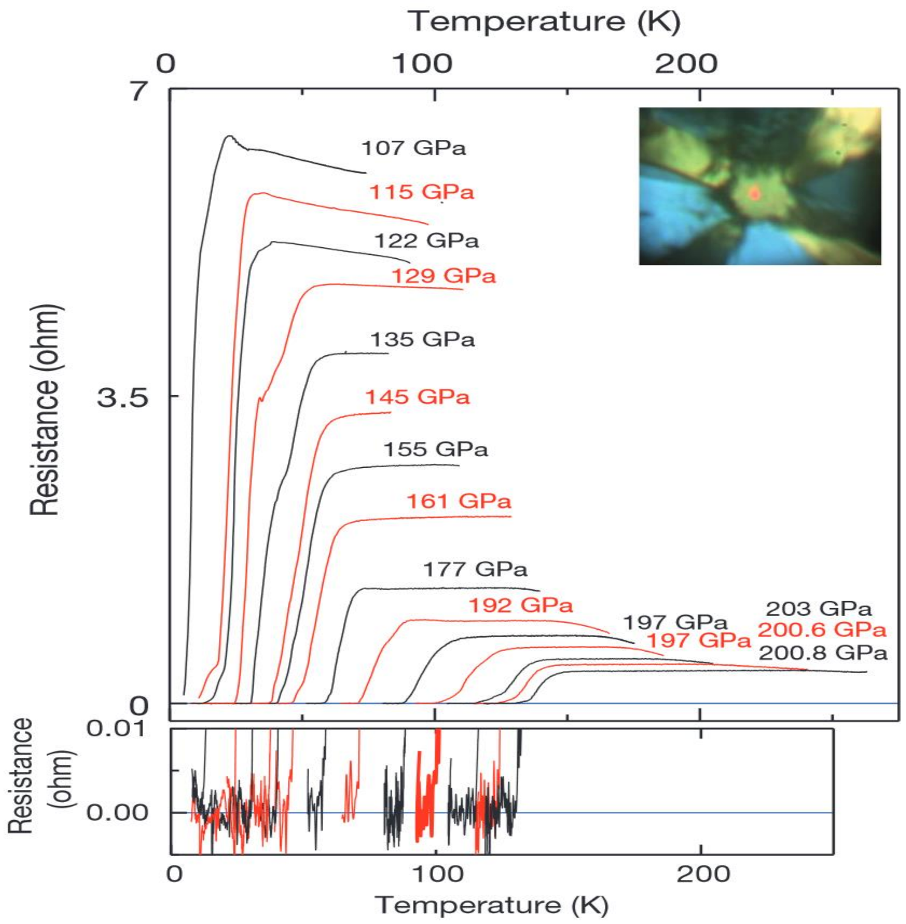
- What is the effect of pressure on critical temperature?
- Is there evidence of conventional (BCS) superconductivity?
  - Does the sample exhibit an isotope effect?
  - Does the sample respond to a magnetic field (type I or II superconductivity)?



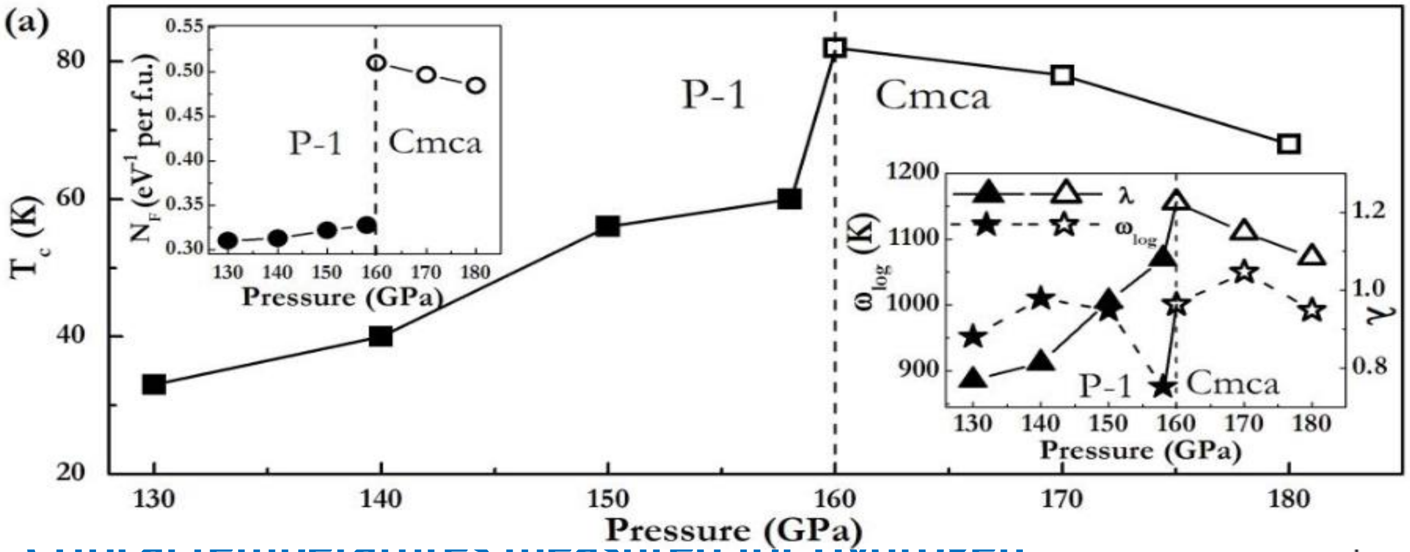
Critical temperature increases with pressure

Main points:

- The sample exhibits a drop in resistivity below a critical temperature
- The peak resistance decreases with pressure



Y. Li, J. Hao, Y. Li, Y. Ma. The metallization and superconductivity of dense hydrogen sulfide. J. Chem. Phys. 140, 174712 (2014).



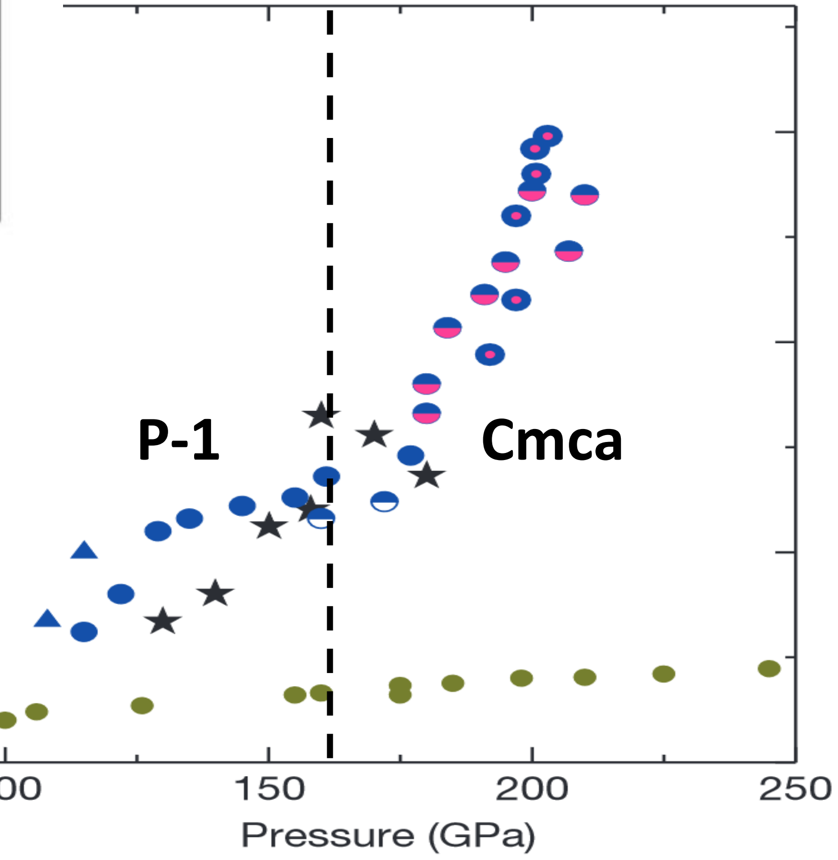
Critical temperatures measured for Hydrogen Sulfide (previous plot) by Drozdov et. al.

Numerically calculated critical temperatures from Li *et al.* (2014).

-- Superconducting transitions estimated for different crystal structures of hydrogen sulfide.

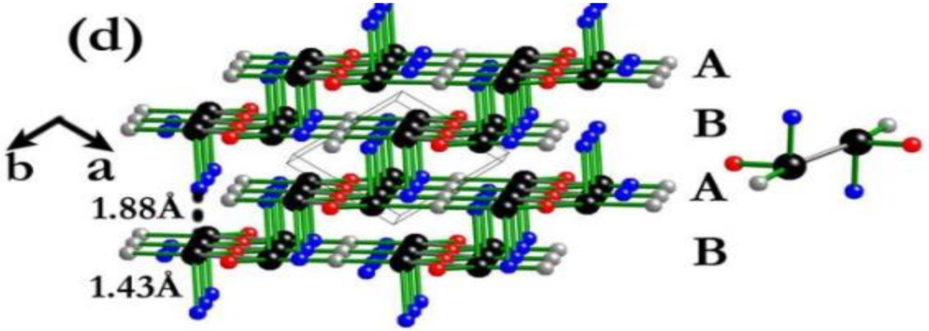
-- Plotted points transition from P-1 to Cmca crystal structures.

Critical temperatures measured for pure sulfur with the same experimental apparatus.

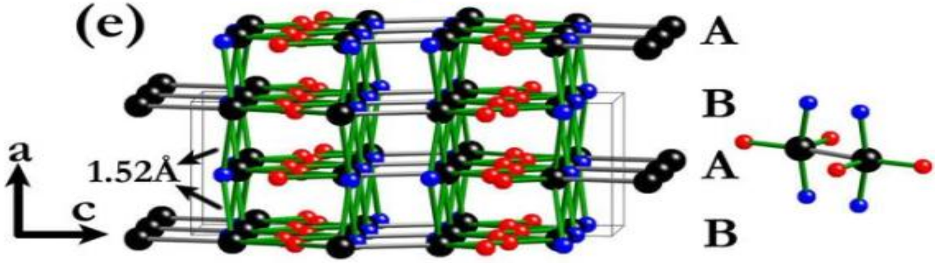


Possible crystal structures of hydrogen sulfide

P-1

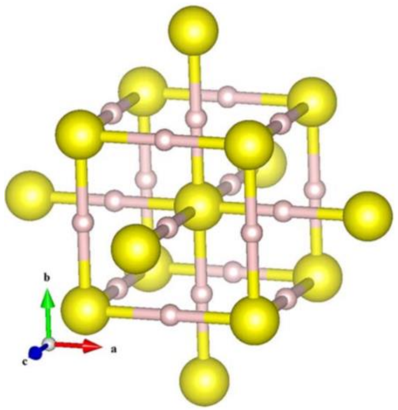


Cmca



Y. Li, J. Hao, Y. Li, Y. Ma. The metallization and superconductivity of dense hydrogen sulfide. J. Chem. Phys. 140, 174712 (2014).

Im-3m



D. Duan, Y. Liu, F. Tian, et. al. Pressure-induced metallization of dense $(H_2S)_2H_2$ with high-T_c superconductivity. Scientific Reports. 4, 6968 (2014).

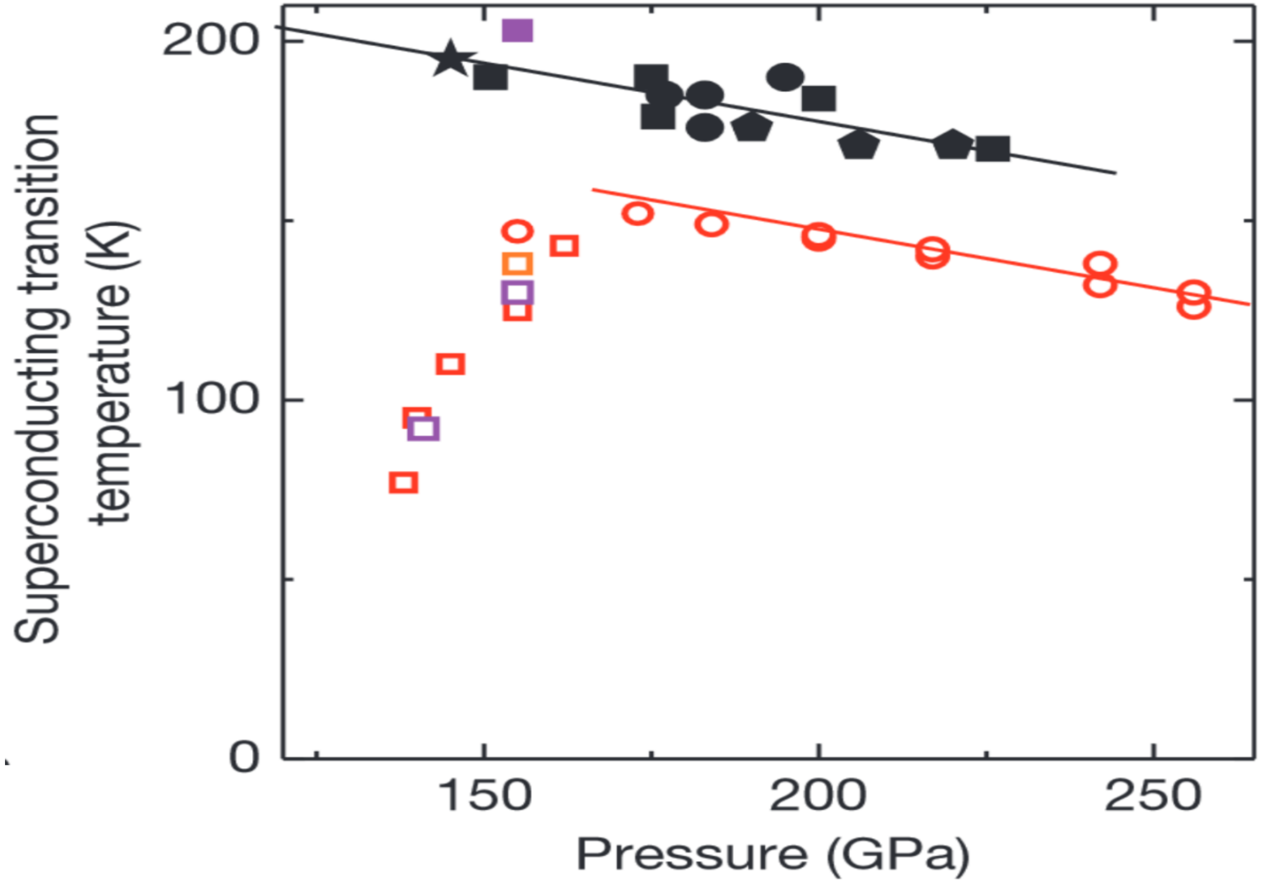
Hydrogen sulfide under pressure exhibits an isotope effect

Sulfur hydride

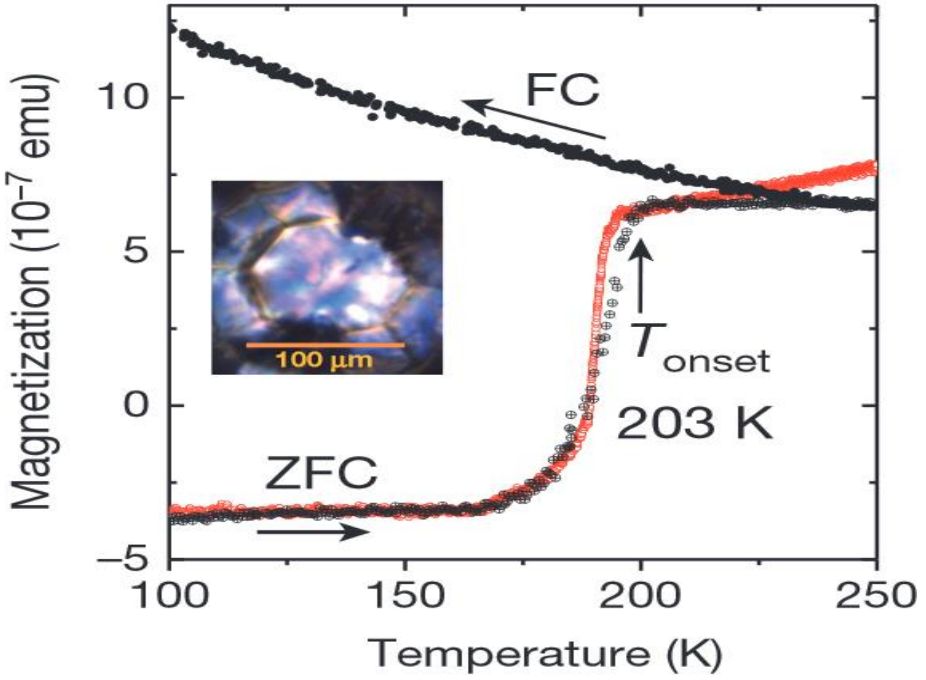
Sulfur deuteride

The larger mass analog of sulfur hydride has lower energy phonon modes and so has worse coupling to the electron modes, leading to lower T_C.

Otherwise, the T_C scaling with pressure is identical.

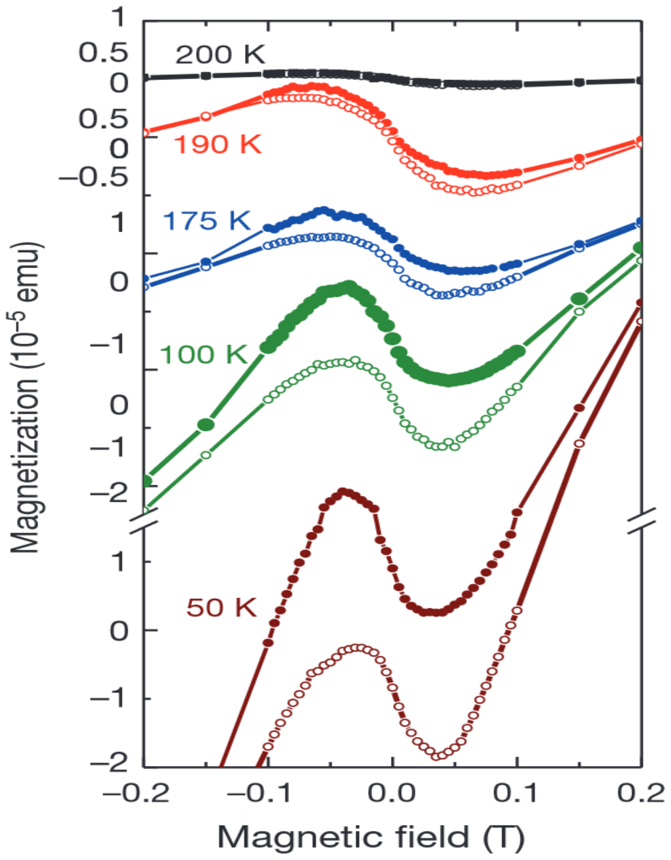


Response to magnetic field



Zero-field cooled (ZFC) and 20 Oe field cooled (FC) magnetization measurements.

Rescaled resistivity measurements for comparison.



Hysteresis loops like this indicate a Type II BCS superconductor

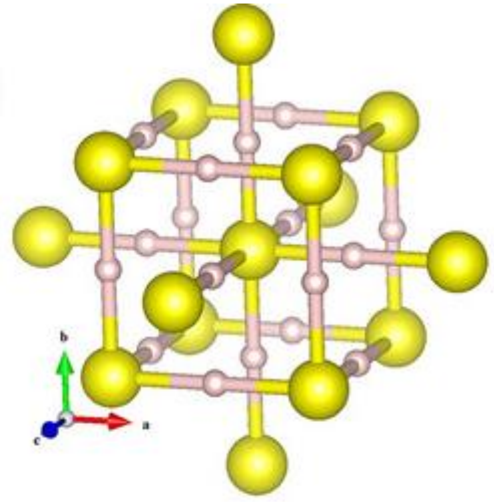
Summary

- Observed conventional superconductivity at 203 K at 155 GPa
- The superconductivity is most likely from H_3S having the *Im*-3*m* structure

Future research prospect:

Room-temperature superconductivity

at ambient pressure



Duan, D. *et al. Sci. Rep.* **4**, 6968 (2014)

Outline

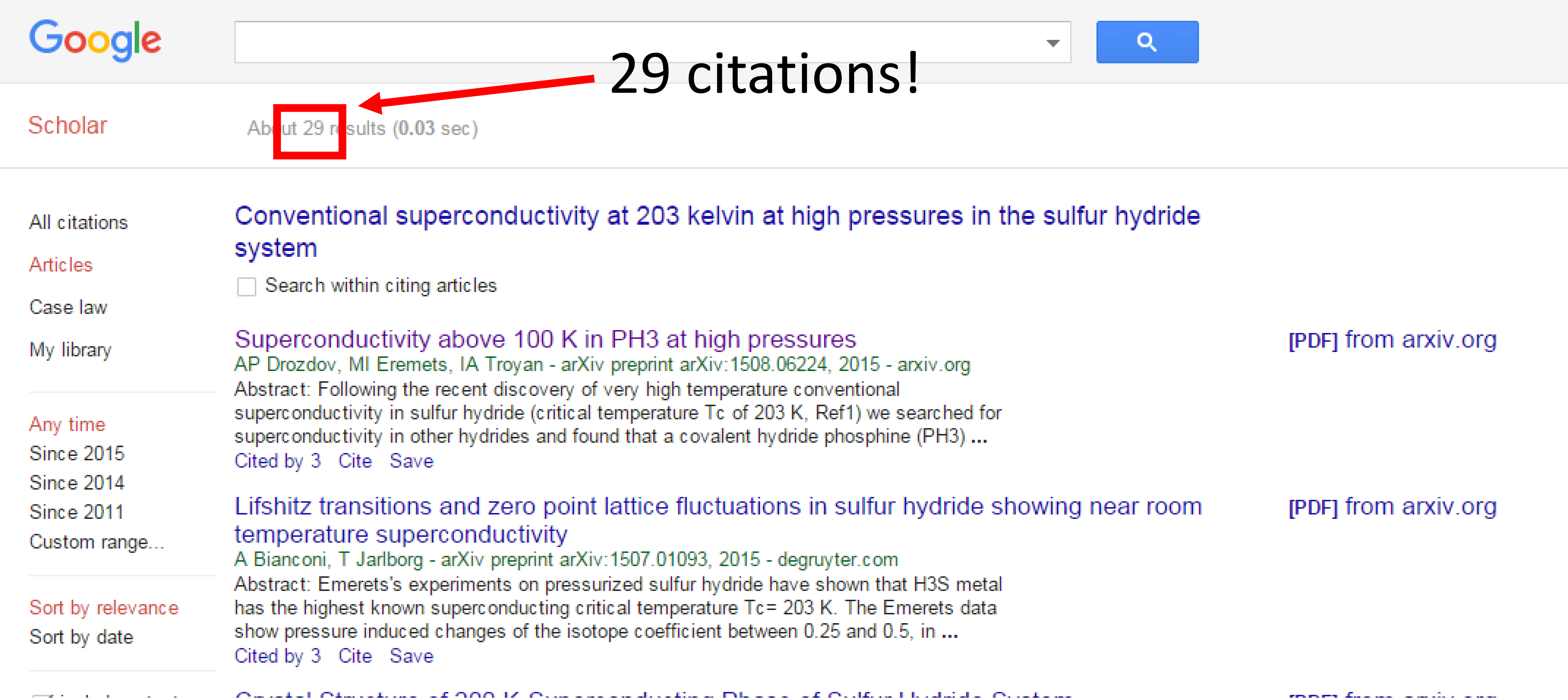
Background of superconductivity

Experimental setup

Analysis of results

Impact and critique

Citations including preprints



29 citations!

About 29 results (0.03 sec)

Conventional superconductivity at 203 kelvin at high pressures in the sulfur hydride system

☐ Search within citing articles

Superconductivity above 100 K in PH3 at high pressures
[PDF] from arxiv.org
AP Drozdov, MI Eremets, IA Troyan - arXiv preprint arXiv:1508.06224, 2015 - arxiv.org
Abstract: Following the recent discovery of very high temperature conventional superconductivity in sulfur hydride (critical temperature Tc of 203 K, Ref1) we searched for superconductivity in other hydrides and found that a covalent hydride phosphine (PH3) ...
Cited by 3 Cite Save

Lifshitz transitions and zero point lattice fluctuations in sulfur hydride showing near room temperature superconductivity
[PDF] from arxiv.org
A Bianconi, T Jarlborg - arXiv preprint arXiv:1507.01093, 2015 - degruyter.com
Abstract: Emerets's experiments on pressurized sulfur hydride have shown that H3S metal has the highest known superconducting critical temperature Tc= 203 K. The Emerets data show pressure induced changes of the isotope coefficient between 0.25 and 0.5, in ...
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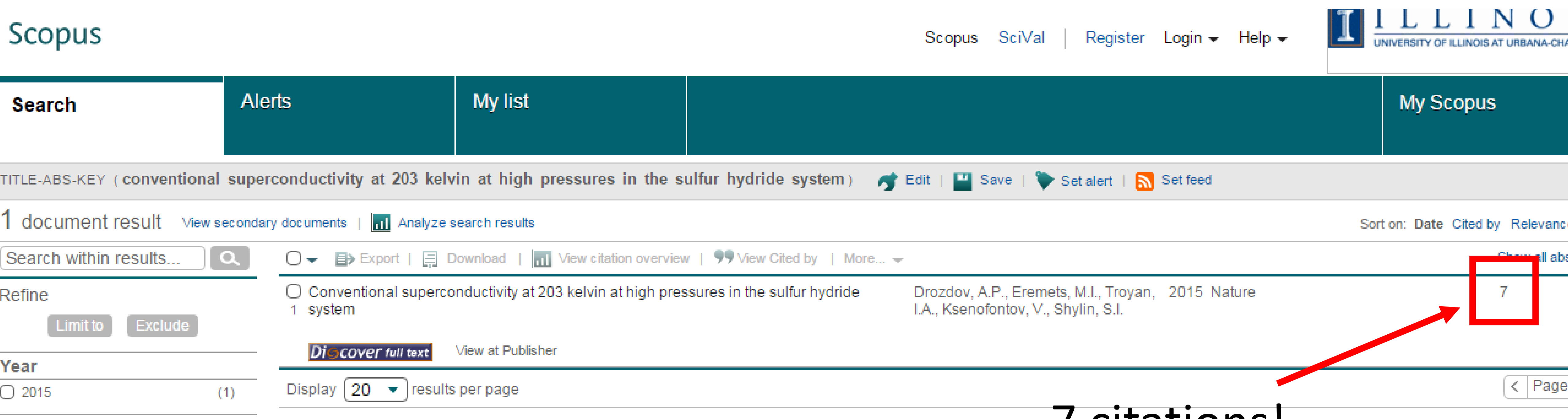
Citations of peer-reviewed journal papers



TITLE-ABS-KEY (conventional superconductivity at 203 kelvin at high pressures in the sulfur hydride system)

1 document result

☐ 1	Conventional superconductivity at 203 kelvin at high pressures in the sulfur hydride system	Drozdov, A.P., Eremets, M.I., Troyan, I.A., Ksenofontov, V., Shylin, S.I.	2015	Nature	7

Year

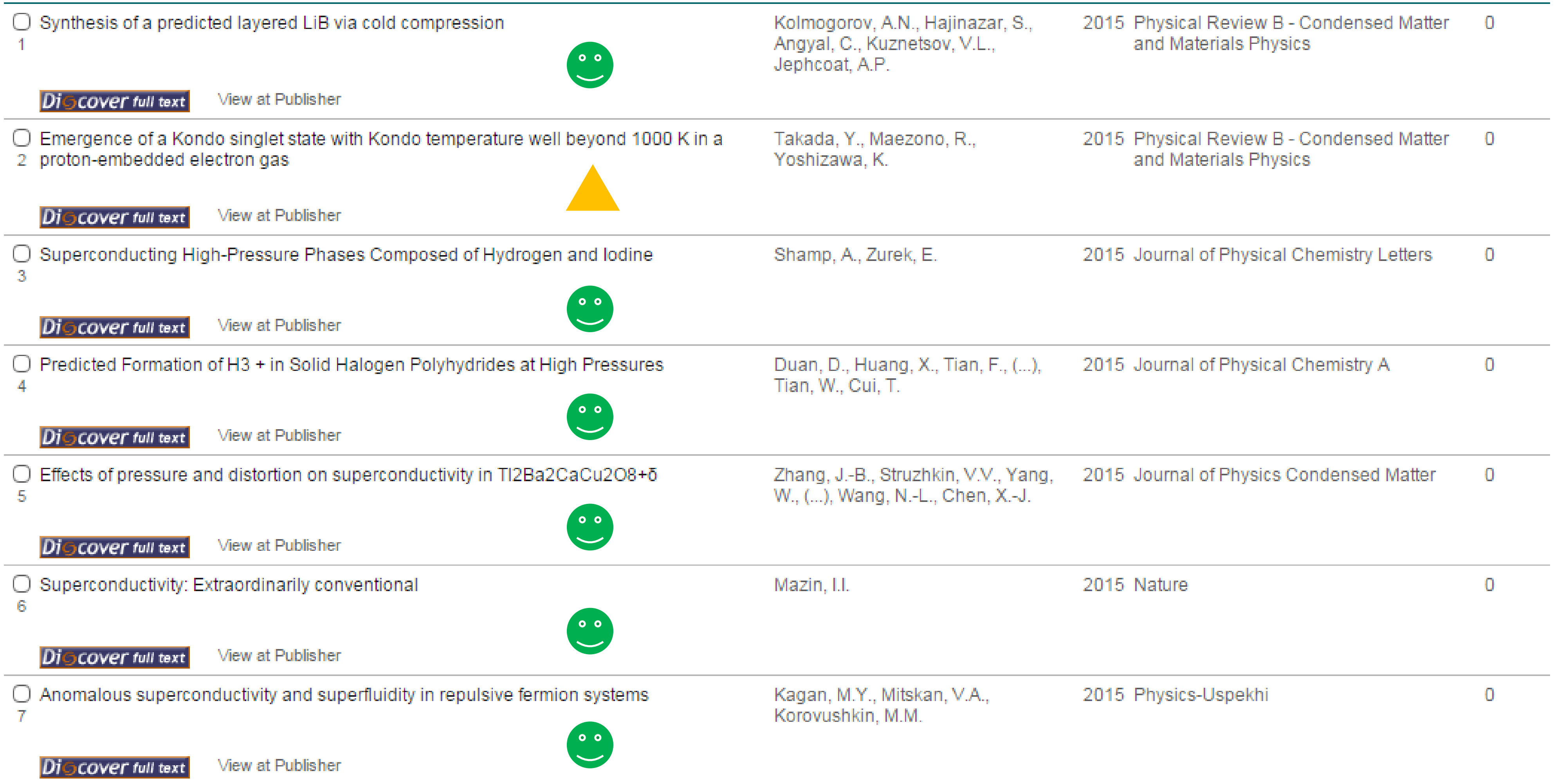
☐ 2015 (1)

Display 20 results per page

7 citations!

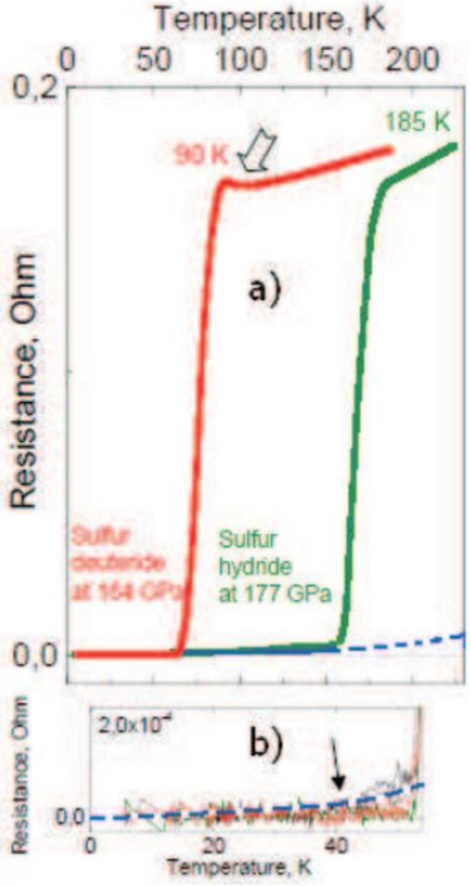
Almost all citations are positive!

☺ Positive
▲ Neutral
✖ Negative



○ 1	Synthesis of a predicted layered LiB via cold compression Discover full text View at Publisher	☺	Kolmogorov, A.N., Hajinazar, S., Angyal, C., Kuznetsov, V.L., Jephcoat, A.P.	2015	Physical Review B - Condensed Matter and Materials Physics	0
○ 2	Emergence of a Kondo singlet state with Kondo temperature well beyond 1000 K in a proton-embedded electron gas Discover full text View at Publisher	▲	Takada, Y., Maezono, R., Yoshizawa, K.	2015	Physical Review B - Condensed Matter and Materials Physics	0
○ 3	Superconducting High-Pressure Phases Composed of Hydrogen and Iodine Discover full text View at Publisher	☺	Shamp, A., Zurek, E.	2015	Journal of Physical Chemistry Letters	0
○ 4	Predicted Formation of H3 + in Solid Halogen Polyhydrides at High Pressures Discover full text View at Publisher	☺	Duan, D., Huang, X., Tian, F., (...), Tian, W., Cui, T.	2015	Journal of Physical Chemistry A	0
○ 5	Effects of pressure and distortion on superconductivity in Tl2Ba2CaCu2O8+δ Discover full text View at Publisher	☺	Zhang, J.-B., Struzhkin, V.V., Yang, W., (...), Wang, N.-L., Chen, X.-J.	2015	Journal of Physics Condensed Matter	0
○ 6	Superconductivity: Extraordinarily conventional Discover full text View at Publisher	☺	Mazin, I.I.	2015	Nature	0
○ 7	Anomalous superconductivity and superfluidity in repulsive fermion systems Discover full text View at Publisher	☺	Kagan, M.Y., Mitskan, V.A., Korovushkin, M.M.	2015	Physics-Uspekhi	0

Critique of the paper



Mazov, arXiv:1510.00123

Commentary paper by Mazov (arXiv:1510.00123)

Sharp drop in resistance is caused by the disappearance of AF spin-fluctuation

Superconducting phase transition happens after magnetic phase transition $T_c < T_D$

Estimated genuine $T_c \sim 40K$

Our evaluation of the paper

Good

- Clearly stated the importance of their work
- Proposed explanation for their observation

Bad

- Not clear about the pressure from which $T_c = 203K$ was obtained
- Not discussing experimental error in detail
- They don’t know what the material really is
- Questionable proposed crystal structure

Thank you!

Photo: *Nature* **443**, 376-377 (28 September 2006)