UNIVERSITY of HOUSTON

Physics Research Day

Replication and study of anomalies in LK-99, the alleged ambient-pressure, room-temperature superconductor

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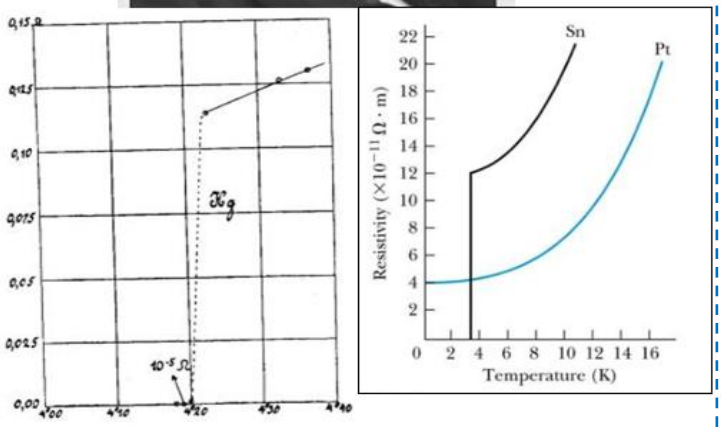
Outline

- Introduction to superconductivity
- Applications & Motivation
- Evidence for Superconductivity in LK-99 by Lee et al./ Our comments
- Replication of LK-99
- Our evidence against superconductivity in LK-99
- Summary

Introduction to superconductivity

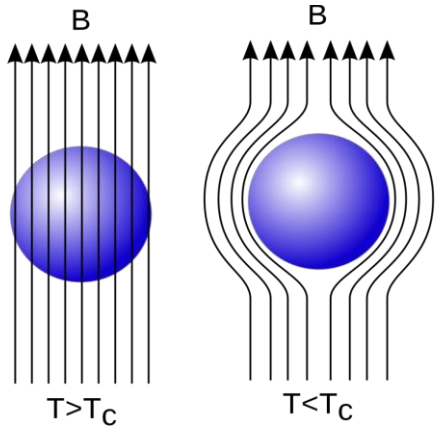
- 1900 - Drude's theory for metals $\rho = \rho_0 + aT^2 + \cdots$

- 1911 – Heike K. Onnes, Discovered Superconductivity



- 1933 – Meissner & Oschenfeld, <u>The Meissner effect</u>

Expulsion of magnetic flux from the interior at $T<T_C$



- 1957 - BCS theory

Describes Superconductivity as macroscopic effect caused by condensation of Cooper pairs

Low Temperature superconductivity: Early predicted max Tc was 23 K

High Temperature superconductivity

- 35 K in LBCO (Müller & Bednorz, 1986)
- 93 K in YBCO (Chu et al. 1987)
- 164 K in $HgBa_2Ca_2Cu_3O_{8+\delta}$ at 32 GPa (Chu et al. 1994)
- 203 K in H_3S at 150 GPa (Eremets et al. 2015)
- 260 K in LaH_{10} at 190 GPa (Hemley et al. 2019)

Applications/Motivation

- Efficient electric power transmission
- Smaller but powerful magnets
- Magnetic levitation
- High-speed computing, etc.

MRI

Maglev train

The need of low temperature or extreme high-pressure limit the applications

Example: H_3S needs 203 K (-90 ^oC) and 150 GPa (1.5×10^6 Atmospheres)

Do we have a superconducting material under ambient conditions?

Motivation

The First Room-Temperature Ambient-Pressure Superconductor

Sukbae Lee[1*], Ji-Hoon Kim[1], Young-Wan Kwon[2†]

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S. Lee *et al.*, arXiv preprint arXiv:2307.12008 (2023). **July 22,2023**

Superconductor $Pb_{10-x}Cu_x(PO_4)_6O$ showing levitation at room temperature and atmospheric pressure and mechanism

Sukbae Lee,[1,a)] Jihoon Kim,[1] Hyun-Tak Kim,[2,3,b)] Sungyeon Im,[1] SooMin An,[1] and Keun Ho Auh[1,4]

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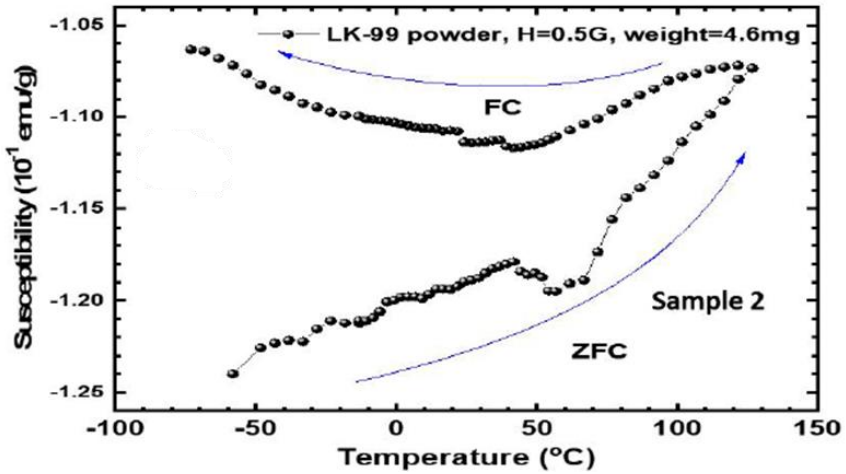
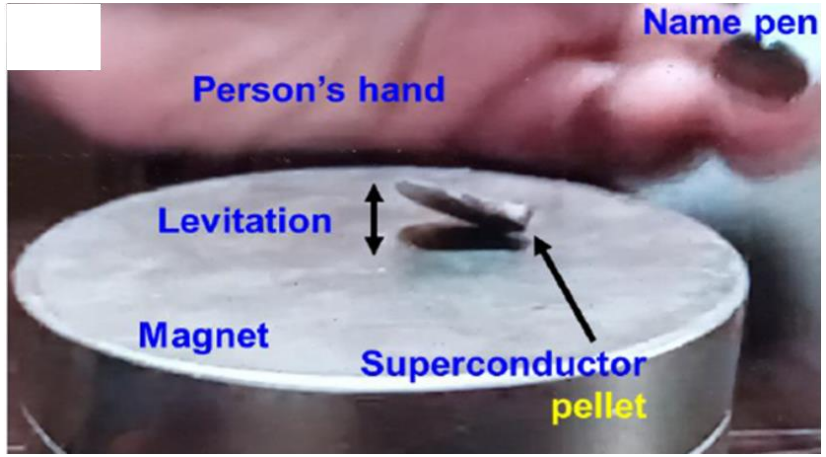
S.Lee at al., arXiv preprint arXiv:2307.12037 (2023). **July 22,2023**

Lee et al. evidence for Superconductivity in LK-99: Our comments

Unphysical large magnetic susceptibility



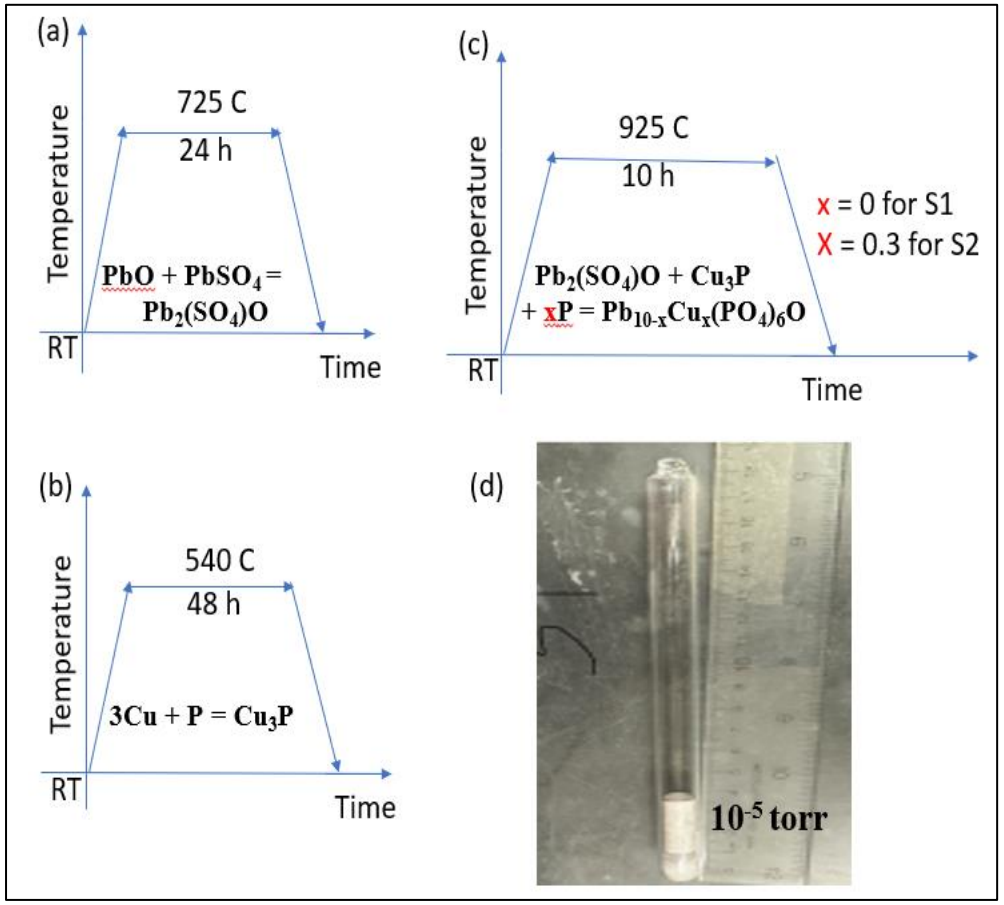
One edge touching the magnet

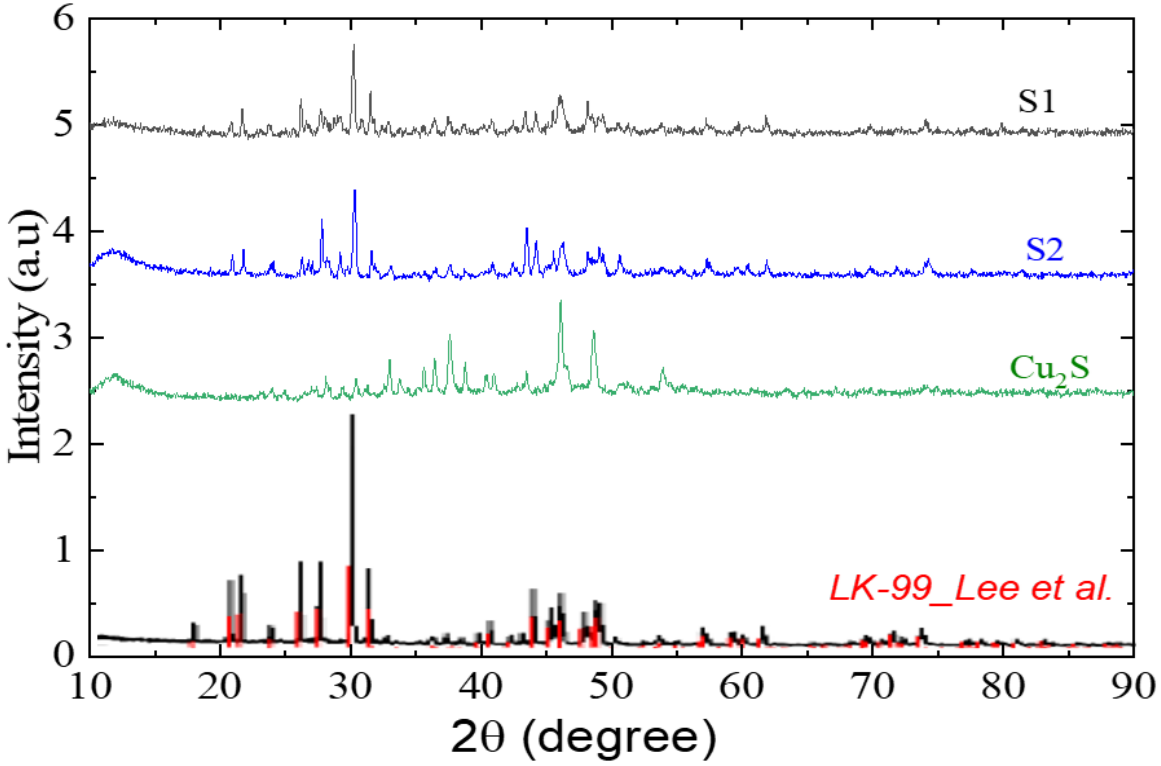


Superconductor $Pb_{10-x}Cu_x(PO_4)_6O$ showing levitation at room temperature and atmospheric pressure and mechanism

Stable magnetic levitation of a thin slab of graphite over an assembly of magnets

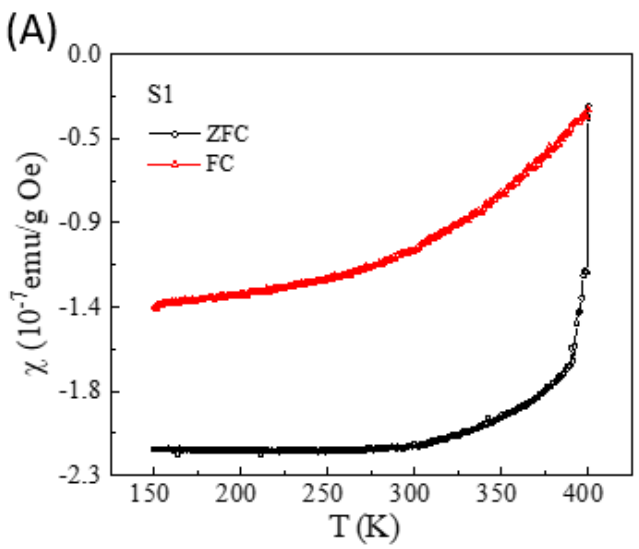
Synthesis: LK-99 Samples/Replication

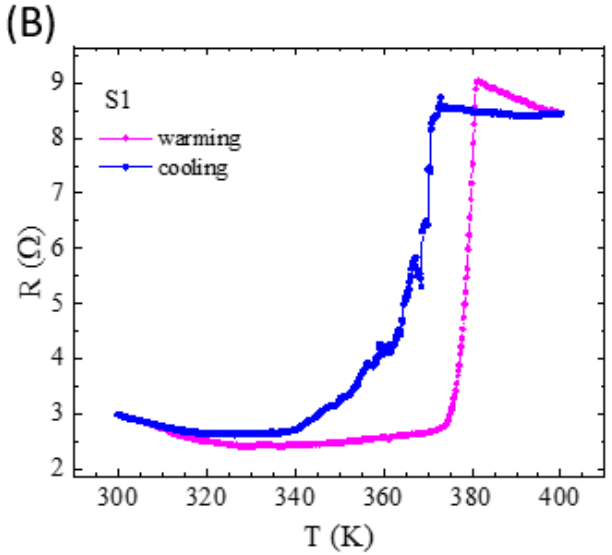


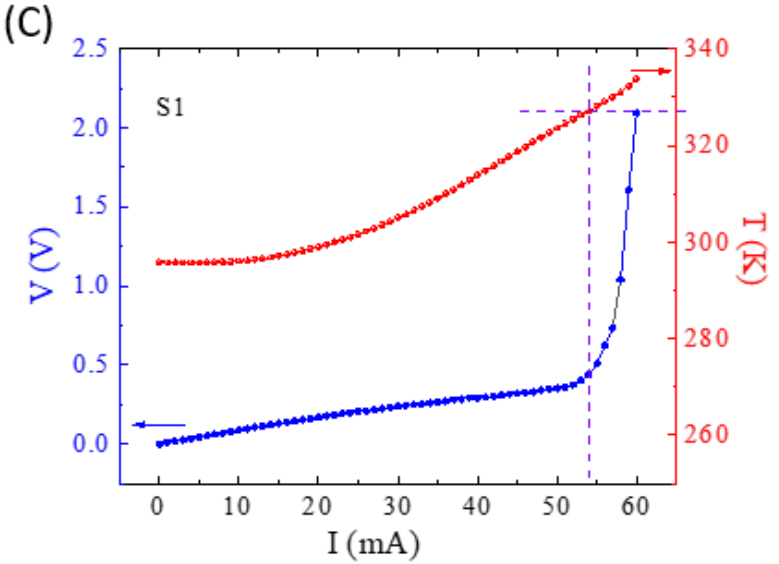


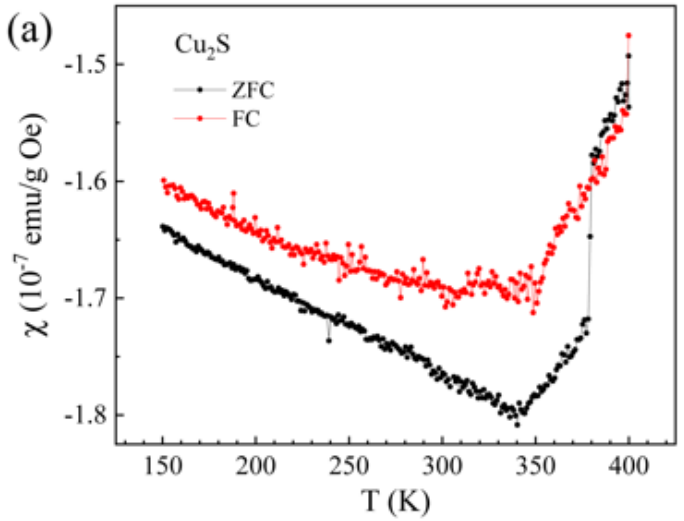
XRD of Samples obtained via Lee et. al synthesis recipe

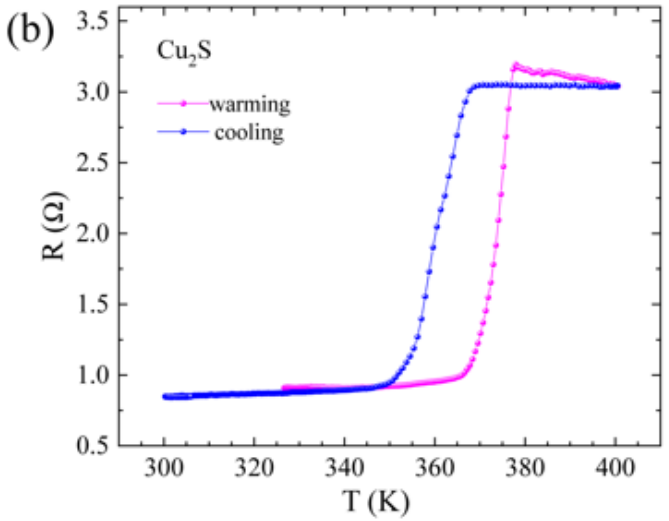
Our evidence against superconductivity in LK-99

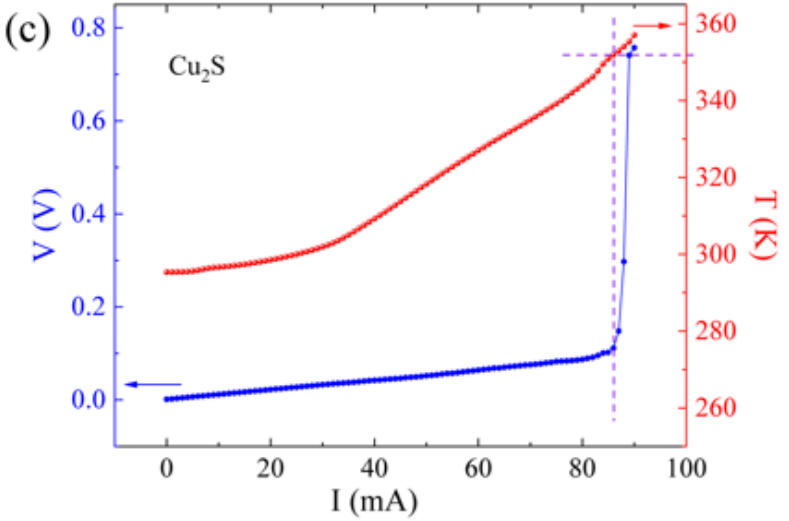




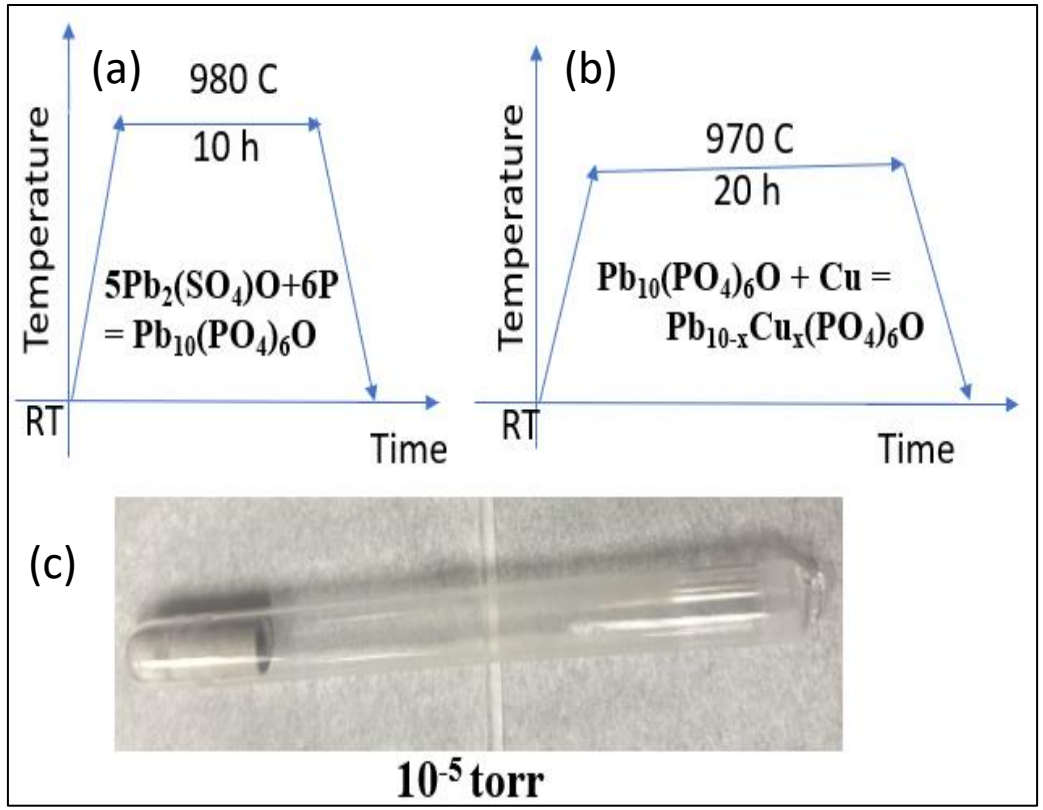


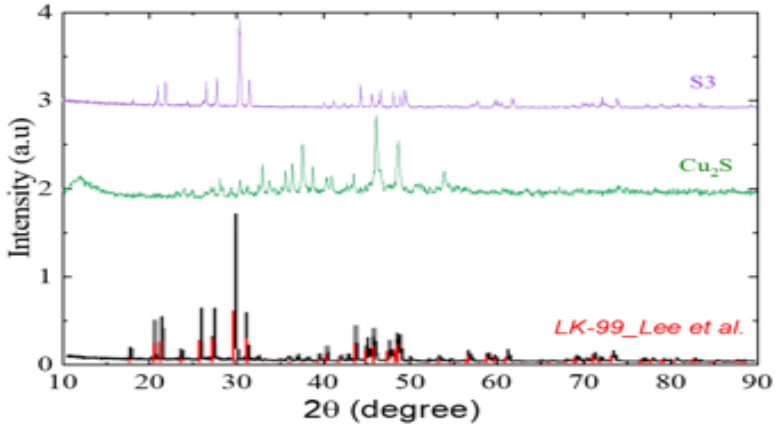


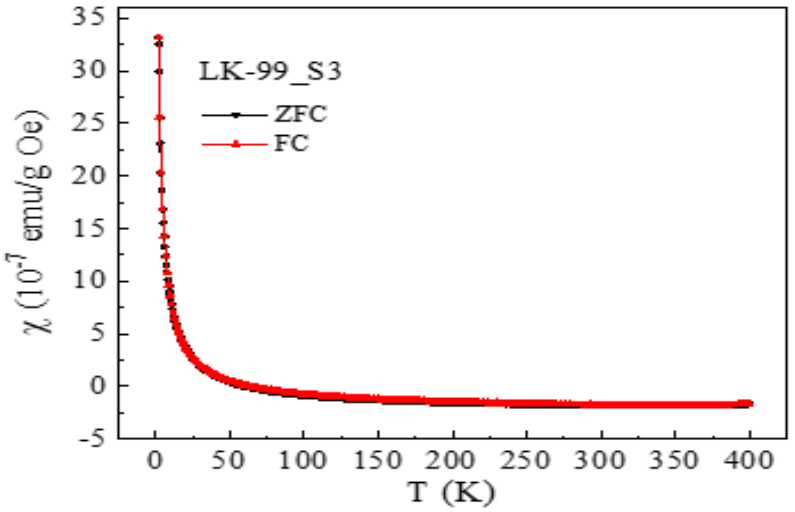




Our evidence against superconductivity in LK-99: LK-99 sample without Cu_2S impurity







S3 is insulating and shows no magnetic anomaly anywhere close to 400 K

Summary

- Demonstrated levitation possibility in non-superconducting materials using a graphite slab on magnets.
- Replicated LK-99 sample: Produced sample mirroring Lee et al.'s synthesis, showing anomalies close to 400 K, attributed to Cu2S impurity.
- Pure Cu_2S study: Identified a structural phase transition close to 400 K, from monoclinic to hexagonal, indicating impurity-related anomalies.
- Cu_2S-free LK-99 synthesis: Developed a sample without Cu_2S impurity, exhibiting no anomalies and high electrical insulation, concluding impurity's role in observed anomalies, not superconductivity.

Publication

ACCEPTED MANUSCRIPT

Replication and study of anomalies in LK-99—the alleged ambient-pressure, room-temperature superconductor

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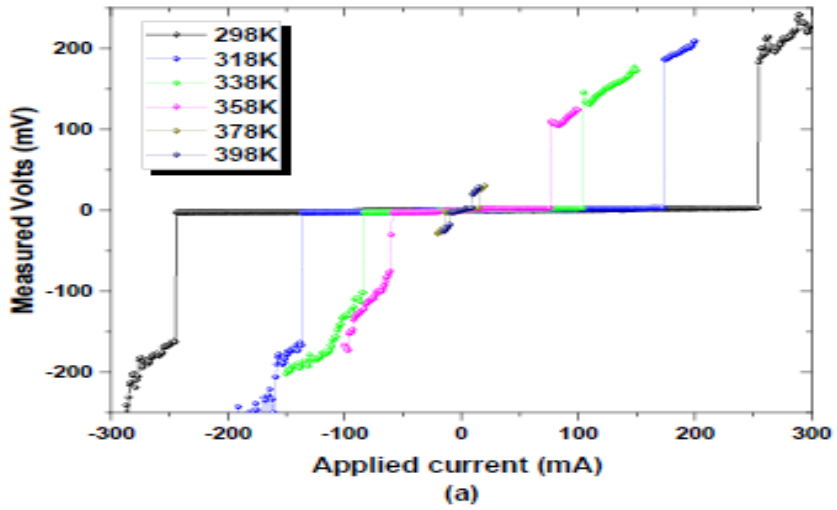
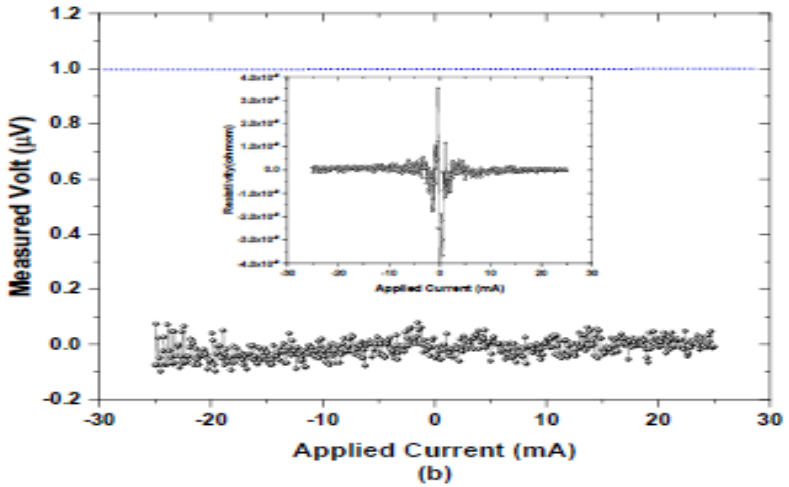
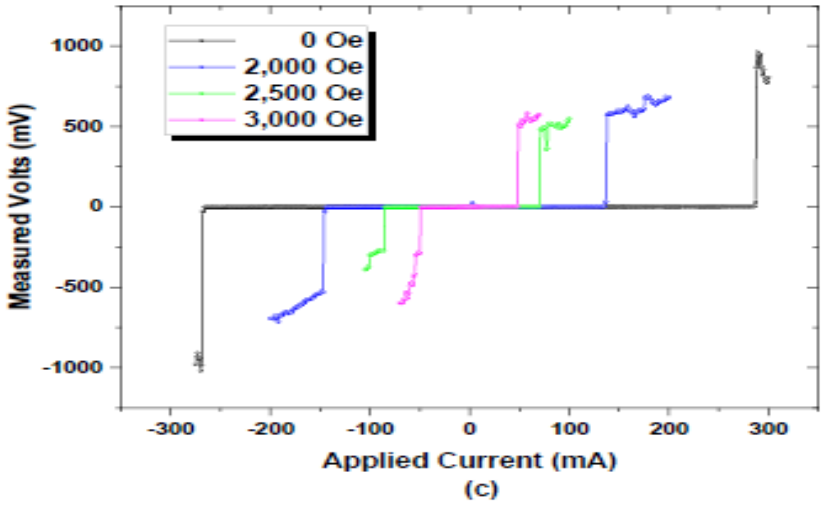
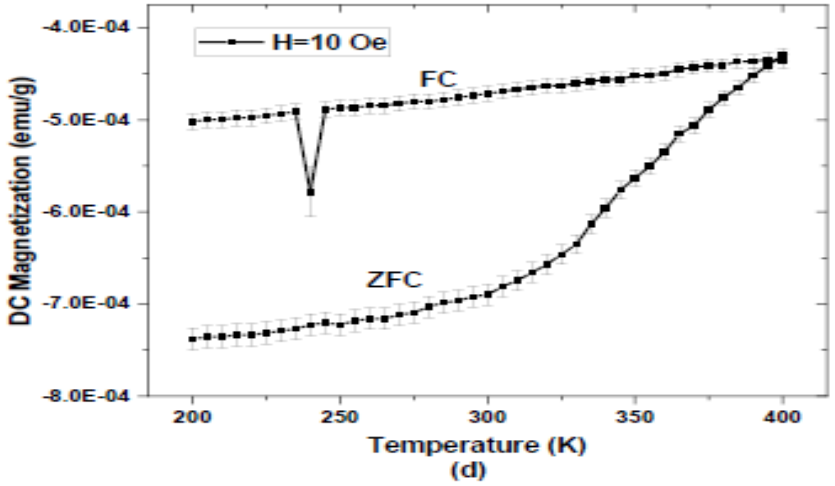
Thank you

Lee et al. evidence for Superconductivity in LK-99



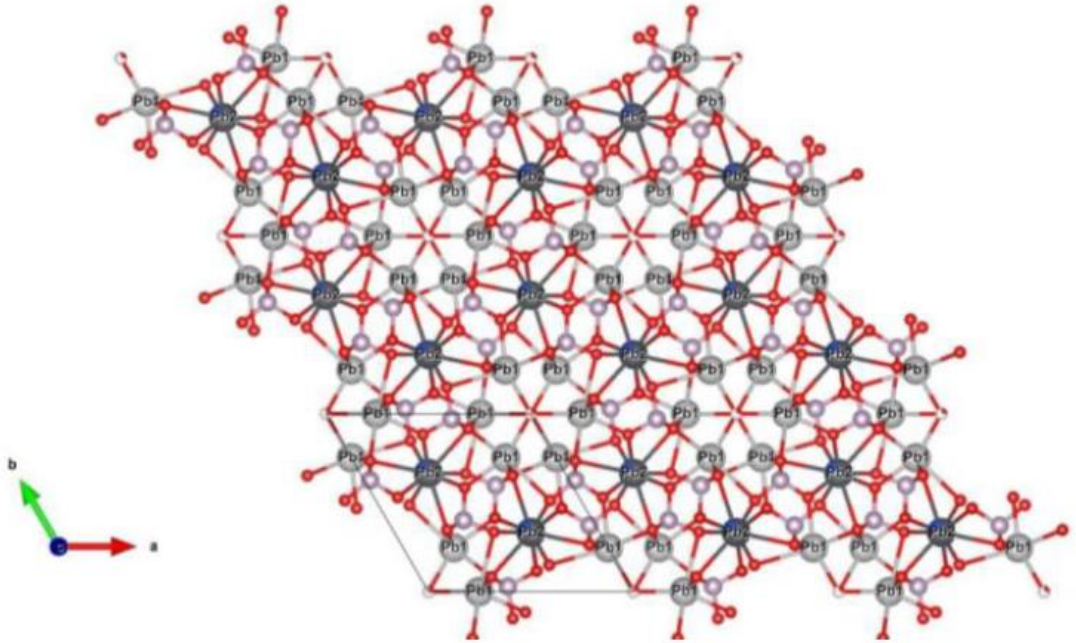






The First Room-Temperature Ambient-Pressure Superconductor

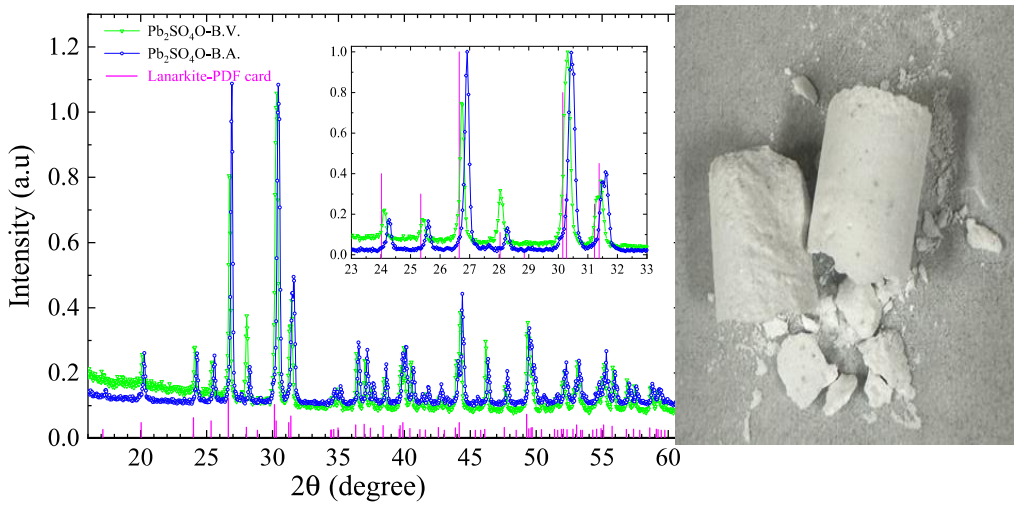
Supplementary slides

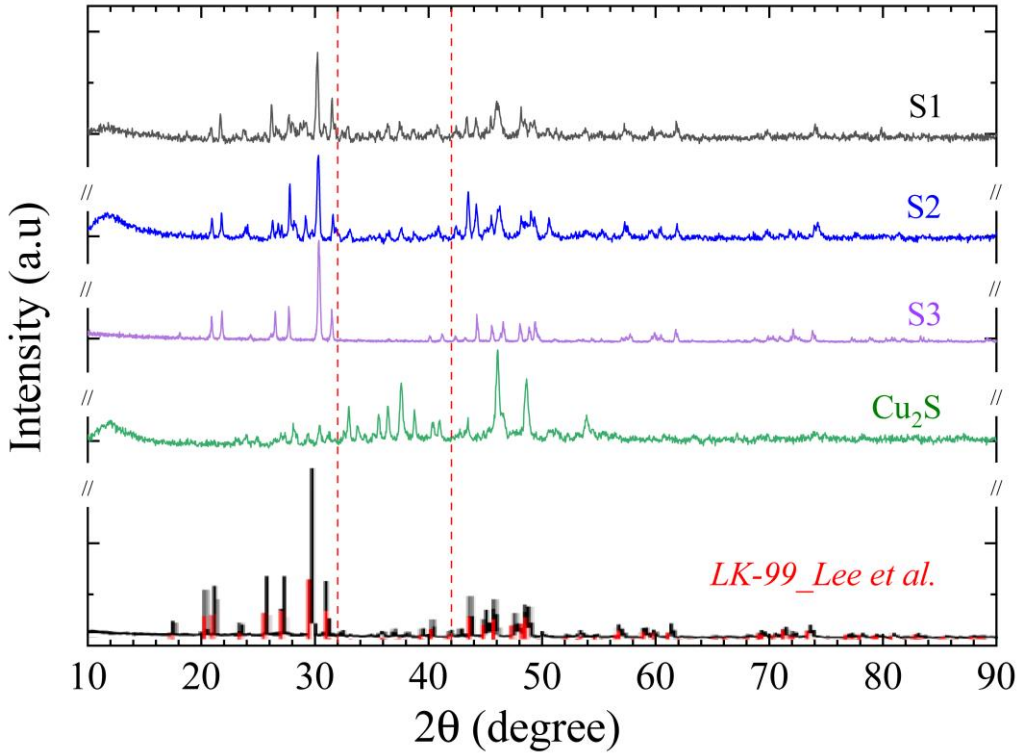


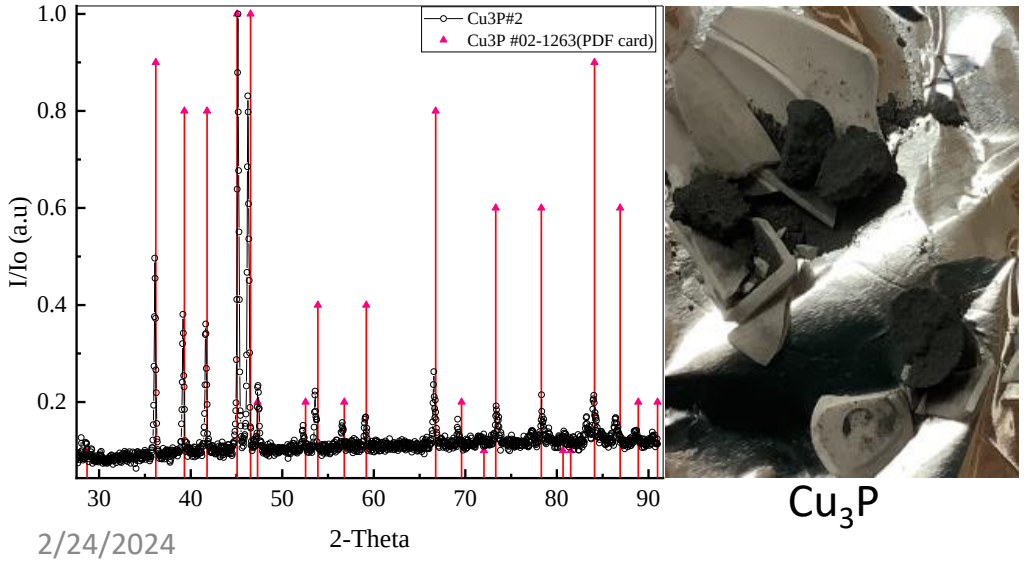
(a)

(b)

Lee et al. LK-99 crystal structure and their bulk sample image


Pb2SO4O-B.V.
Pb2SO4O-B.A.
Lanarkite-PDF card
Intensity (a.u)
2θ (degree)


S1
S2
S3
Cu2S
LK-99_Lee et al.
Intensity (a.u)
2θ (degree)

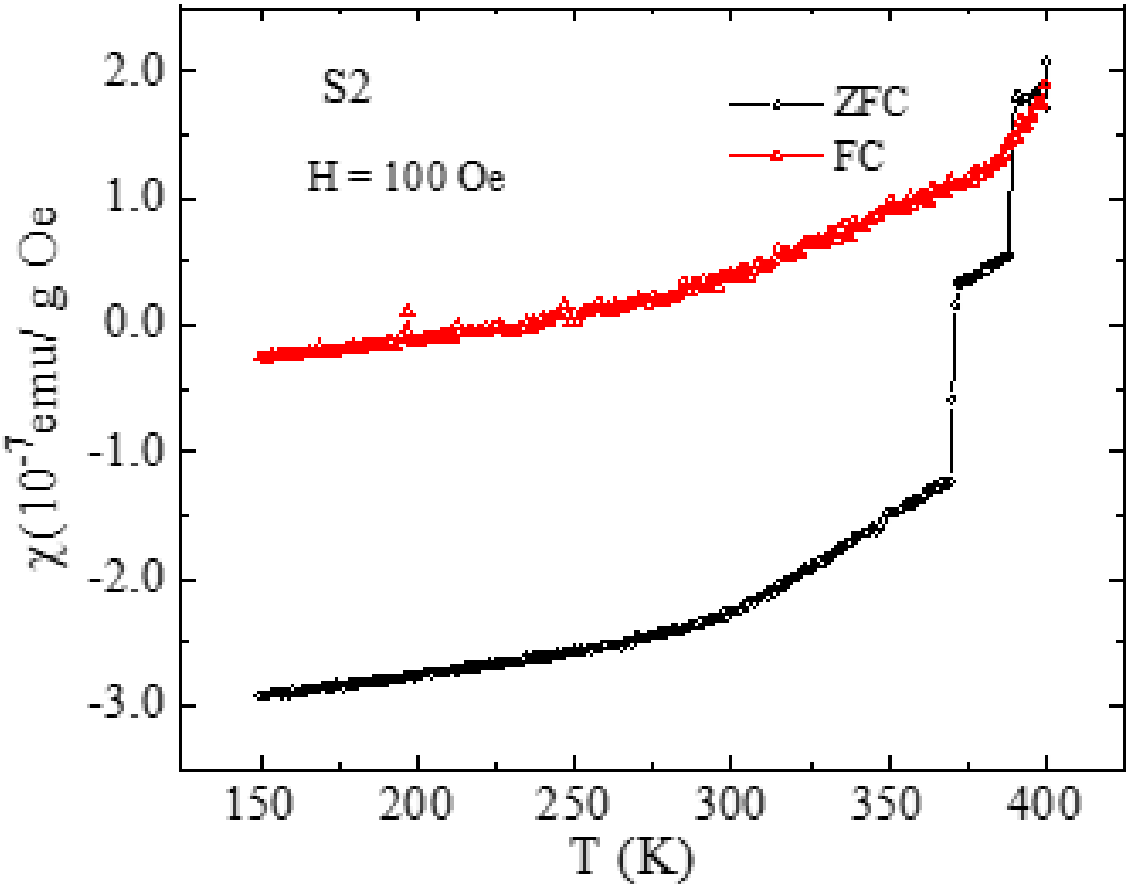

Cu3P#2
Cu3P #02-1263(PDF card)
I/Io (a.u)
2-Theta

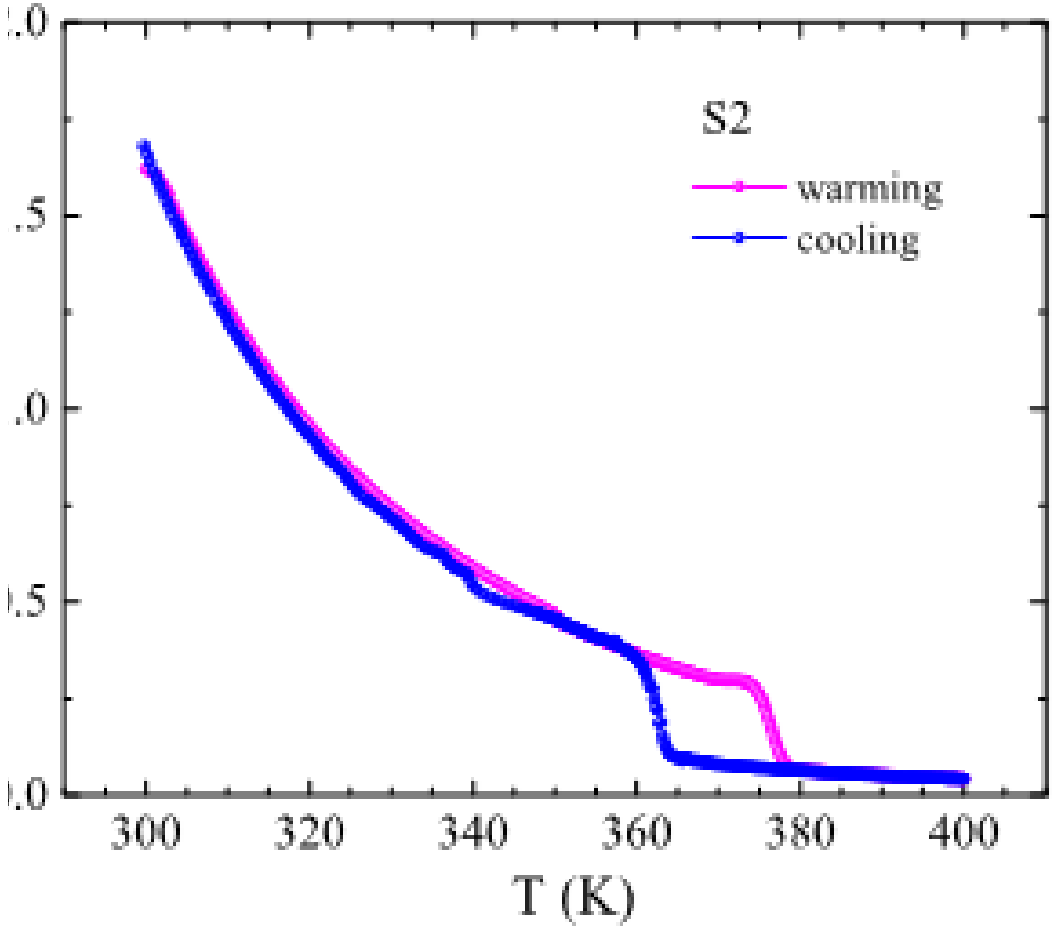
Cu_3P


LK-99

Summary/Conclusion

- With a video of a thin slab of graphite on top of magnets set up, we discussed the possibility of having a levitating non-superconducting material.
- We successively replicated LK-99 sample following closely Lee et al. synthesis recipe. Our samples have very close XRD data to Lee's LK-99 sample including Cu_2S impurity. These samples (S1 and S2) show anomaly in magnetic and resistive data at around 380 K, but not related to superconductivity.
- We studied pure Cu_2S and found a first order phase transition at around 380 K related to the structural phase change from low-temperature monoclinic to high-temperature hexagonal structure.
- We then synthetized LK-99 sample free of Cu_2S impurity following a slightly different route. This sample does not exhibit any of the above anomaly and it's highly insulating.
- We conclude that all anomalies studied are associated with the structural transition of the Cu_2S impurity in their sample and not with superconductivity.


S2
H = 100 Oe
ZFC
FC
2.0
1.0
0.0
-1.0
-2.0
-3.0
150
200
250
300
350
400
T (K)


S2
warming
cooling
300
320
340
360
380
400
T (K)