

UCR Physics & Astronomy 50th Anniversary Symposium

High Temperature Superconductivity

Lei Shu
Physics Department
University of California, San Diego



Sep. 2002: Ph. D. student



Apr. 2003: Prof. Douglas E. MacLaughlin

Muon Spin Relaxation and Rotation Studies of the Filled Skutterudite Alloys
 $\text{Pr}(\text{Os}_{1-x}\text{Ru}_x)_4\text{Sb}_{12}$ and $\text{Pr}_{1-y}\text{La}_y\text{Os}_4\text{Sb}_{12}$







ICM 2006



TRIUMF beamtime 2006



Retirement Party 2007



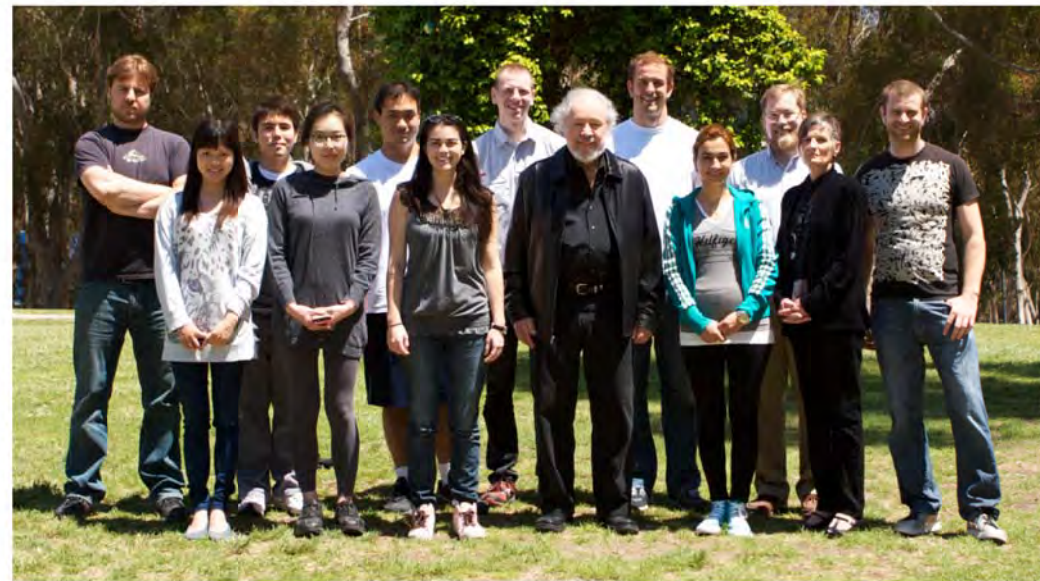
TRIUMF beamtime 2009

Jun. 2007: Ph.D.

Jul. 2007 - Apr. 2008 : postdoc at UCR

Jun. 2008 - Oct. 2009 : postdoc at UCSD, Maple's Lab

Sep. 2010 - present



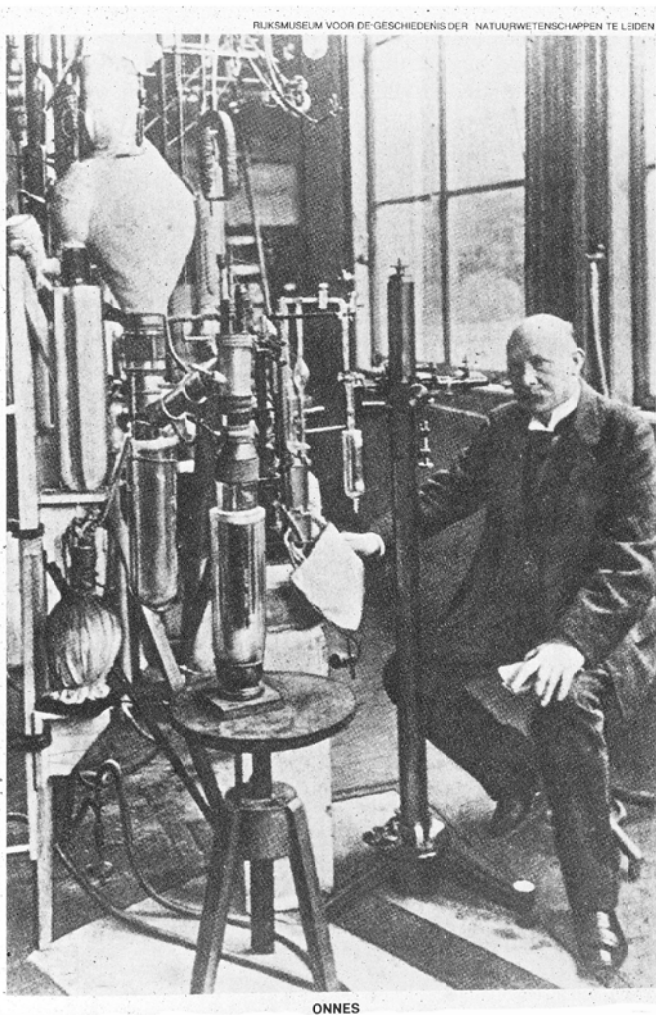


Superconductivity

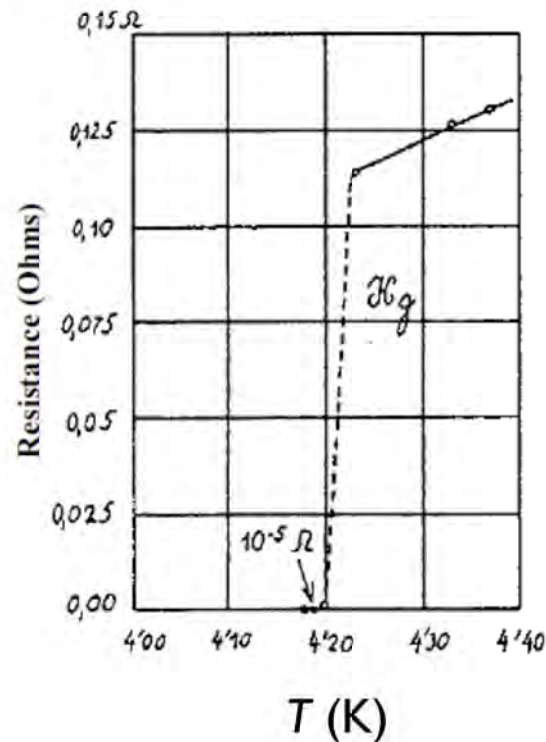
SUPERCONDUCTOR:

An element, inter-metallic alloy, or compound that will conduct electricity without resistance below a certain temperature.

Resistance is undesirable because it produces losses in the energy flowing through the material.



- Heike Kamerlingh Onnes (Dutch)
- Below temperature of liquid helium, 4.2 K (-452 F, -269 C), resistance of Hg disappeared (1911)
- Onnes won a Nobel Prize in physics(1913)

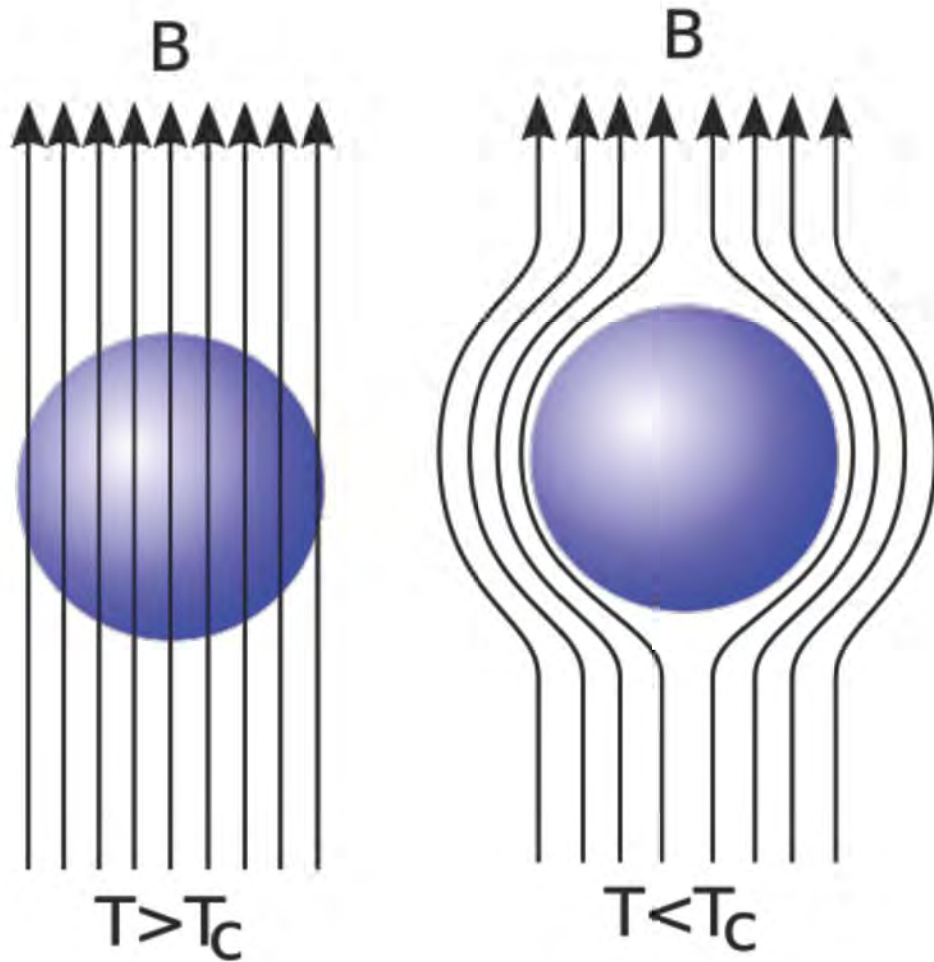


Meissner effect

The expulsion of a magnetic field from a superconductor during its transition to the superconducting state (1933).



Walther Meissner and Robert Ochsenfeld (German)



A magnetic levitating above a high temperature superconductor, cooled with liquid nitrogen

BCS theory

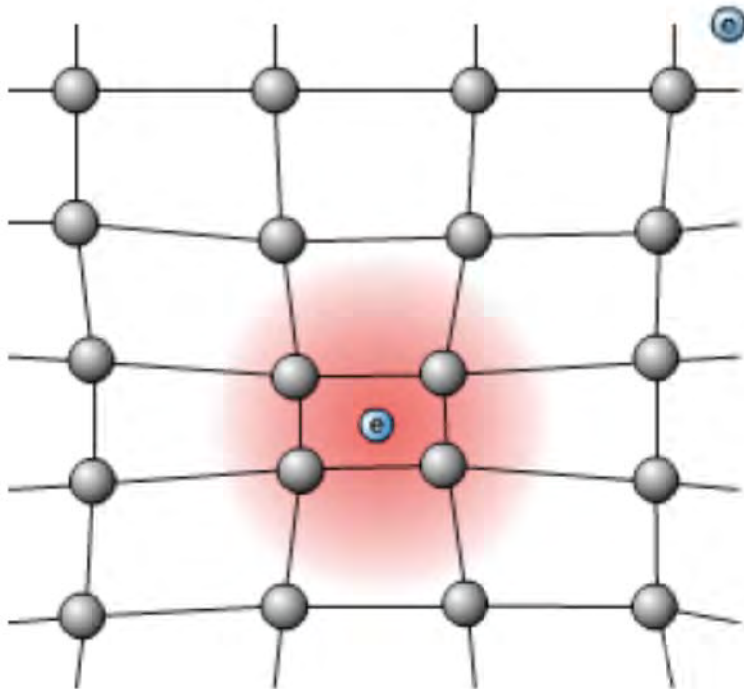
- The first widely-accepted theoretical understanding of superconductivity (1957).
- Nobel prize (1972)
- For elements and simple alloys
- Explained the superconducting current as a superfluid of Cooper pairs, pairs of electrons interacting through the exchange of phonons.



John Bardeen, Leon Cooper, and John Schrieffer (American)

Original publication: Phys. Rev. 108, 1175 (1957)

Cooper Pair



- More resistant to vibrations within the lattice
- Move through the lattice relatively unaffected by thermal vibrations

BCS theory predicted: max T_c 30-40 K (-243 - -233°C)

BCS theory

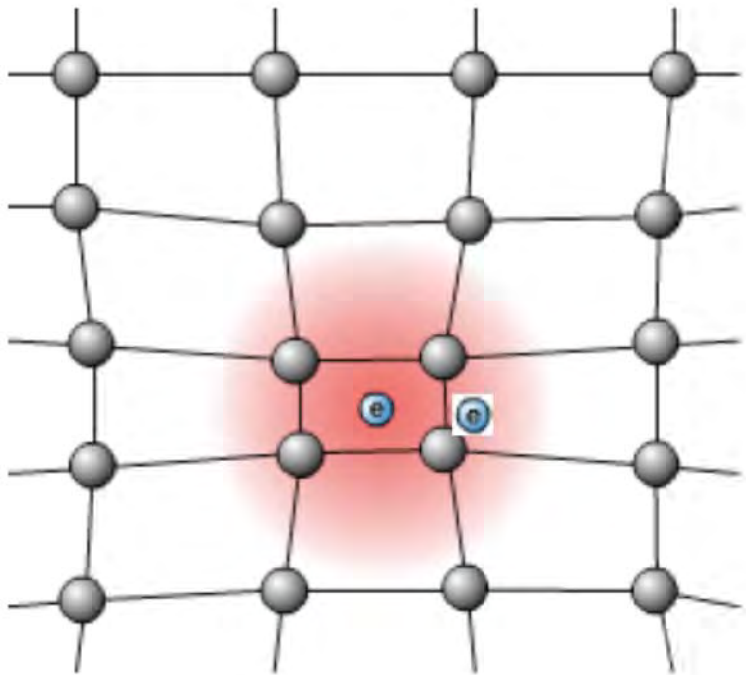
- The first widely-accepted theoretical understanding of superconductivity (1957).
- Nobel prize (1972)
- For elements and simple alloys
- Explained the superconducting current as a superfluid of Cooper pairs, pairs of electrons interacting through the exchange of phonons.



John Bardeen, Leon Cooper, and John Schrieffer (American)

Original publication: Phys. Rev. 108, 1175 (1957)

Cooper Pair



- More resistant to vibrations within the lattice
- Move through the lattice relatively unaffected by thermal vibrations

BCS theory predicted: max T_c 30-40 K (-243 - -233°C)

Breakthrough in superconductivity in 1986

Lager scientists flock to Woodstock of physics

Superconductivity breakthrough has all scientists running amuck
By PAUL RAEBURN
AP Science Editor

Physicists race for new alloys in suddenly hot conductivity field

Scientists Electrified
Revolution For Utilities, Computers Seen

Joining discovery
Scientists rush to find superconductor

Superconductivity a scientific 3 1/2-minute mile
By PAUL RAEBURN
AP Science Editor

covered on the New York Hilton for a hastily scheduled special color and a stampeding abandonment of professorial dignity. Within three minutes, the crowd had seen seats, and nearly "Woodstock" of physics. "It's a phenomenon — there's never been anything like physics," said Stanford University physicist Peter Higgs.

The race was on. The materials, made of lanthanum, copper and oxygen, of so-called neutral beam weapons, a part of President Reagan's "Star Wars" missile defense system. In normal electrical conductors, electrons encounter resistance as they move, in much the same way that a swimmer encounters water.

Superconducting stuff is amazing magnet, too
New York Times News Service

NEW YORK — Scientists have discovered that a new superconducting material can be made into the world's most powerful magnets according to unpublished data from a half-dozen laboratories in the United States and China.

The material, a hard, dark ceramic discovered less than three months ago, already has astounded scientists with its ability to carry electric current with no loss of energy at record high temperatures. Researchers who are investigating the electrical properties of the material find that it is also capable of sustaining unexpectedly large magnetic fields.

They're spectacular — they're the range where people can

MAY 11, 1987 \$1.95

TIME

Wiring the Future

CONTRA ARMS The Widening Web

THE SUPERCONDUCTIVITY REVOLUTION

724404

First high temperature superconductor

In 1986, a brittle ceramics compound: Ba-La-Cu-O, $T_c = 30$ K (58 K)

Alex Müller and Georg Bednorz (Switzerland)

Nobel Prize (1987)



Cuprates

- In 1987, $\text{Y}_{1.2}\text{Ba}_{0.8}\text{CuO}_4$ (YBCO) $T_c = 93$ K (> 77 K, the boiling point of nitrogen)
- In 1988, $\text{BiSrCaCu}_2\text{O}_x$ (BSCCO) $T_c = 108$ K, and $\text{Tl}_2\text{Ba}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ (TBCCO) $T_c = 127$ K.
- In 2009, $\text{HgBa}_2\text{Ca}_2\text{Cu}_3\text{O}_x$ (HBCCO), $T_c = 135$ K, the highest-temperature superconductor at ambient pressure. $T_c = 164$ K under high pressure.

Iron arsenides

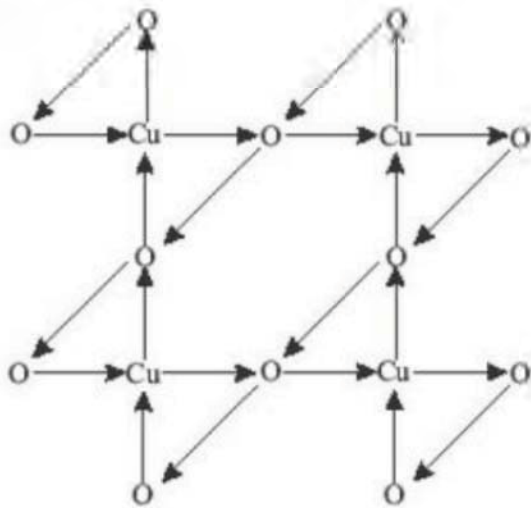
- In 2008 $\text{SmFeO}_{1-x}\text{F}_x\text{As}$, $T_c = 55$ K

High Temperature Superconductivity Theory

- Varma's theory

Electric current loops (1996)

First directly verified by a French-German team, led by Philippe Bourges (2006)



Distinguished Professor: Chandra Varma

Applications of Superconductors

- **Efficient Electricity Transportation**

- Efficient conductors

- Efficient in generating electricity (99%)



- Magnetically levitated trains (MAGLEV)

The highest recorded speed: 361 miles per hour, Japan 2003

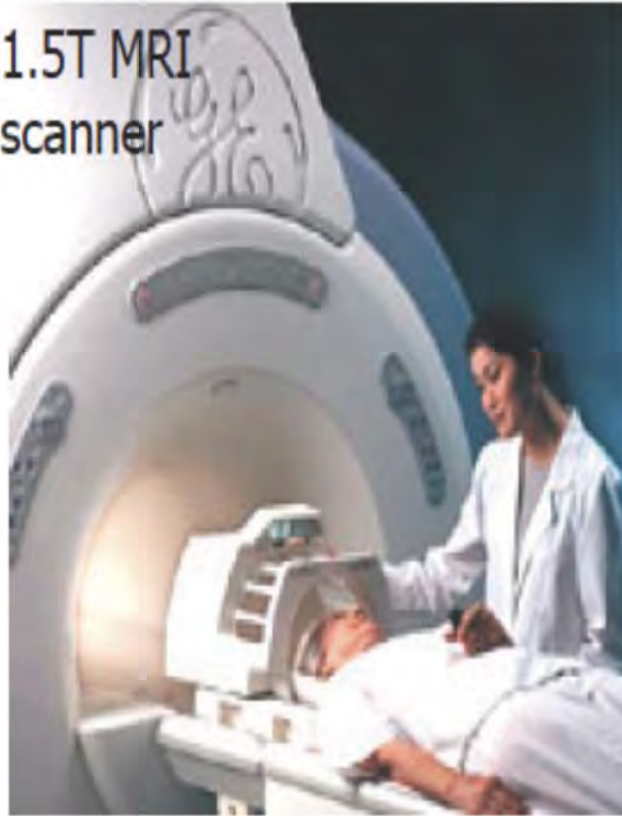


- Magnetic Resonance Imaging (MRI)

Nobel prize 2003



1.5T MRI scanner



- Synchrotrons and Cyclotrons (Particle Colliders)

Fermilab (Chicago)



High field accelerator magnets



Nuclear power plant

Small-size SMES

500 kV AC power transmission

Medium-size SMES

Underground power station

Linear catapult

Electric propulsion ship

Compressed air tank

66 kV superconducting cable

Fuel cell

Small-size SMES

LNG combined cycle power generation

Switching station

6 kV uninterruptible power distribution cable

Electric car

Small-size SMES

Distribution substation

Photovoltaic generation

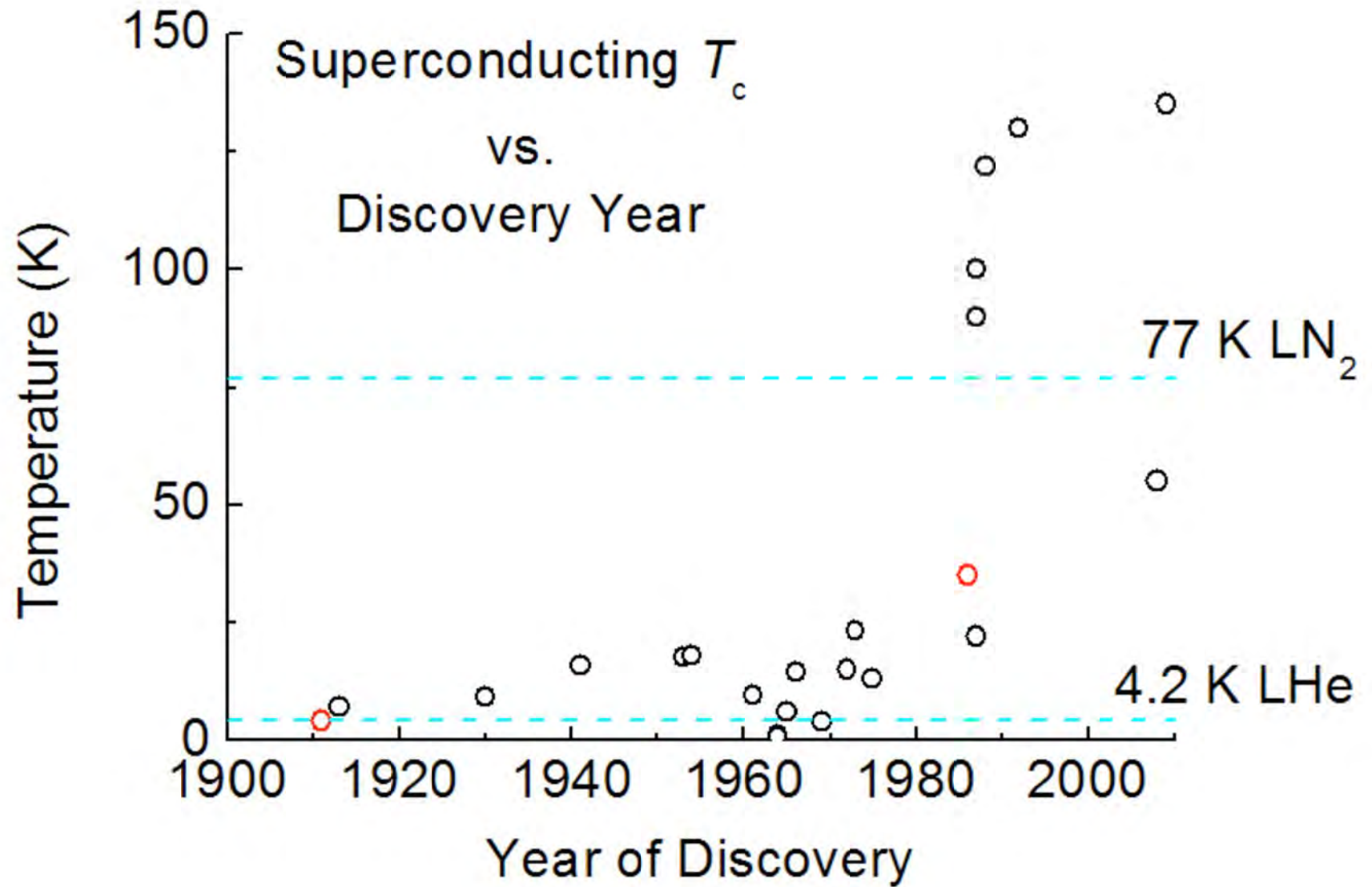
Common duct

Superconducting linear motor car (MAGLEV)



Highest $T_c = 135 \text{ K}$
 $= -138 \text{ }^\circ\text{C}$
 $= -216.4 \text{ }^\circ\text{F}$

room temperature is 300 K



High temperature superconductivity are found in two classes of correlated electron materials:

High temperature superconductivity are found in two classes of correlated electron materials:

Cuprates

Iron arsenides

High temperature superconductivity are found in two classes of correlated electron materials:

Cuprates
Iron arsenides

Rich phase diagrams:
insulating
metallic
spin and charge ordered
superconducting

High temperature superconductivity are found in two classes of correlated electron materials:

Cuprates
Iron arsenides

Rich phase diagrams:
insulating
metallic
spin and charge ordered
superconducting



delicate interplay between
competing interactions

High temperature superconductivity are found in two classes of correlated electron materials:

Cuprates
Iron arsenides

Rich phase diagrams:

insulating
metallic
spin and charge ordered
superconducting



delicate interplay between
competing interactions

emerges from:

- AFM Mott insulating phase (cuprate)
- SDW (iron arsenides)

High temperature superconductivity are found in two classes of correlated electron materials:

Cuprates
Iron arsenides

Rich phase diagrams:

insulating
metallic
spin and charge ordered
superconducting



delicate interplay between
competing interactions

emerges from:

- AFM Mott insulating phase (cuprate)
- SDW (iron arsenides)

Cooper pairing mechanism: spin fluctuations
Magnetism is important to produce high T_c !

High temperature superconductivity are found in two classes of correlated electron materials:

Cuprates
Iron arsenides

Rich phase diagrams:
insulating
metallic
spin and charge ordered
superconducting



delicate interplay between
competing interactions

- layered crystal structures
- anisotropic properties

emerges from:
• AFM Mott insulating phase (cuprate)
• SDW (iron arsenides)

Cooper pairing mechanism: spin fluctuations
Magnetism is important to produce high T_c !

High temperature superconductivity are found in two classes of correlated electron materials:

Cuprates
Iron arsenides

Rich phase diagrams:
insulating
metallic
spin and charge ordered
superconducting



delicate interplay between competing interactions

- layered crystal structures
- anisotropic properties

- emerges from:
- AFM Mott insulating phase (cuprate)
 - SDW (iron arsenides)

Cooper pairing mechanism: spin fluctuations
Magnetism is important to produce high T_c !

Current strategy for searching for high temperature superconductivity is to investigate strongly correlated electron materials, which contain elements with partially-filled d - and f -electron shells, and have low symmetry.

High temperature superconductivity are found in two classes of correlated electron materials:

Cuprates
Iron arsenides

Rich phase diagrams:
insulating
metallic
spin and charge ordered
superconducting



delicate interplay between competing interactions

- layered crystal structures
- anisotropic properties

emerges from:
• AFM Mott insulating phase (cuprate)
• SDW (iron arsenides)

Cooper pairing mechanism: spin fluctuations
Magnetism is important to produce high T_c !

Current strategy for searching for high temperature superconductivity is to investigate strongly correlated electron materials, which contain elements with partially-filled d - and f -electron shells, and have low symmetry.

High temperature superconductivity may be lurking nearby!