



# Superconductivity is cool

**Dhananjay Kumar and Devdas Pai**  
**Department of Mechanical Engineering**  
**North Carolina A & T State university**



Medizinische Hochschule  
Hannover

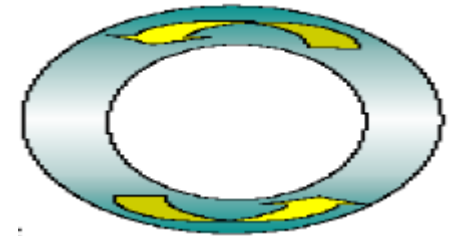


# What is a Superconductor?



## Zero electrical resistance

A Superconductor has ZERO electrical resistance below a certain (critical) temperature  $T_c$ . Once set in motion, a persistent electric current will flow in the superconducting loop FOREVER without any power Loss



## Magnetic flux expulsion

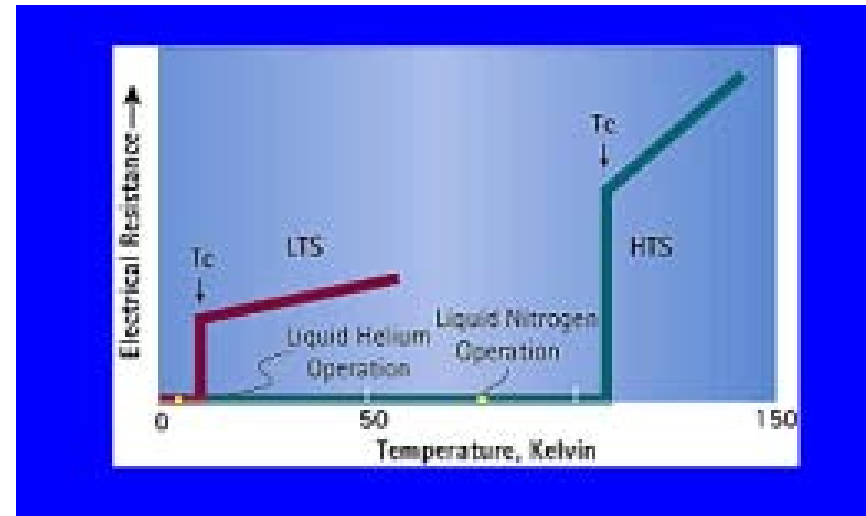
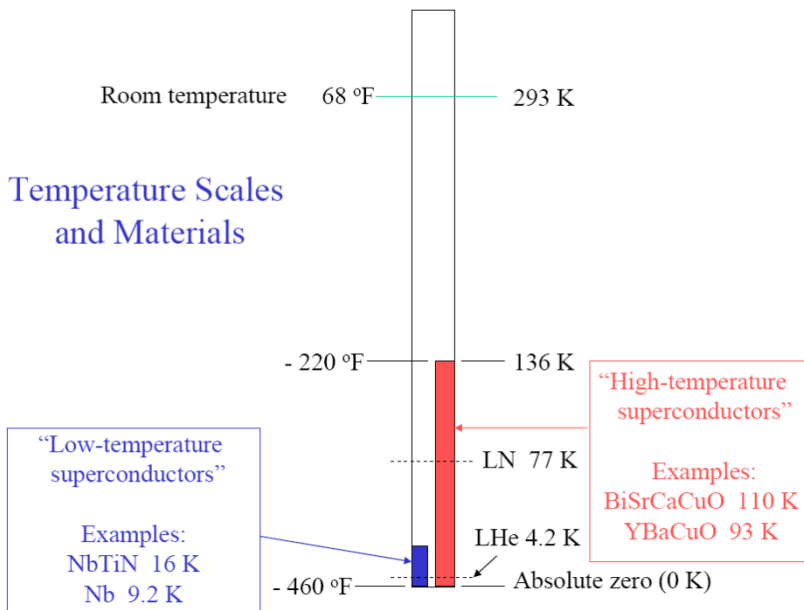
- A Superconductor EXCLUDES external magnetic fields by means of induced currents



# Types of Superconductors: How cold/cool are they?

- (1) Low temperature superconductors ( around liquid helium)
- (2) High temperature superconductors (around liquid nitrogen)

## Temperature Scales and Materials





# History of Superconductivity

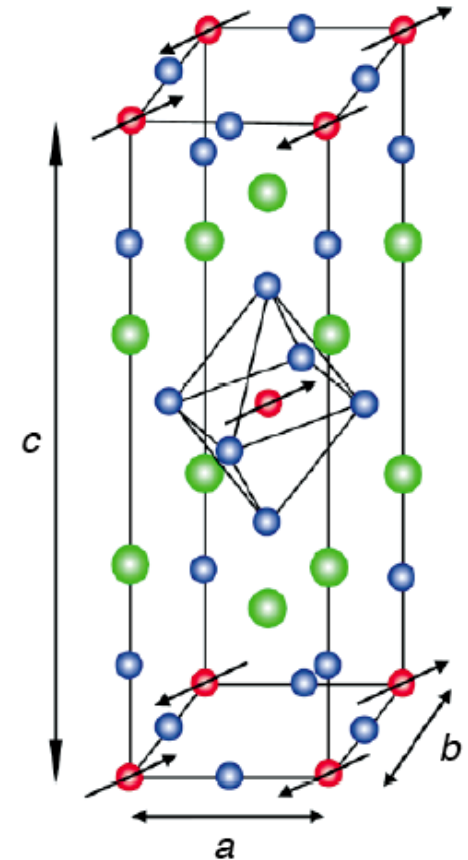
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- **Superconductors:** Materials that have no resistance to the flow of electricity, are one of the last great frontiers of scientific discovery.
- In 1911 superconductivity was first observed in mercury by Dutch physicist Heike Kamerlingh Onnes. In 1913, he won a **Nobel Prize in physics** for his research in this area.
- Theoretical understanding of superconductivity was advanced in 1957 by American physicists John Bardeen, Leon Cooper, and John Schrieffer (above). Their *Theories of Superconductivity* became known as the BCS theory and won them a **Nobel prize in 1972**.
- In 1962 when Brian D. Josephson, a graduate student at Cambridge University, predicted that electrical current would flow between 2 superconducting materials - even when they are separated by a non-superconductor or insulator. His prediction won him a Nobel Prize in Physics in 1973. This tunneling phenomenon is today known as the "Josephson effect" and has been applied to electronic devices such as the SQUID, an instrument capable of detecting even the weakest magnetic fields
- In 1986, a truly breakthrough discovery was made in the field of superconductivity. Alex Müller and Georg Bednorz, researchers at the IBM Research Laboratory, Switzerland, created a brittle ceramic compound that superconducted at the highest temperature then known: 30 K. The discovery won the 2 men a Nobel Prize the following year.



# Era of High Temperature Superconductors

- Müller and Bednorz' discovery triggered a flurry of activity in the field of superconductivity.
- Researchers around the world began "cooking" up ceramics of every imaginable combination in a quest for higher and higher  $T_c$ 's.
- Y-based high temperature superconductors: In January of 1987 a research team at the University of Alabama-Huntsville substituted Yttrium for Lanthanum in the Müller and Bednorz molecule and achieved an incredible 92 K  $T_c$ . For the first time a material (today referred to as YBCO) had been found that would superconduct at temperatures warmer than liquid nitrogen - a commonly available coolant.
- Bi-based high temperature superconductors:  $T_c$  above 100 K
- Thallium based high temperature superconductors:  $T_c \sim$  of 138 K
- Mercuric based high temperature superconductors:  $T_c \sim$  150 K
- Efforts are on to achieve a room temperature superconductor



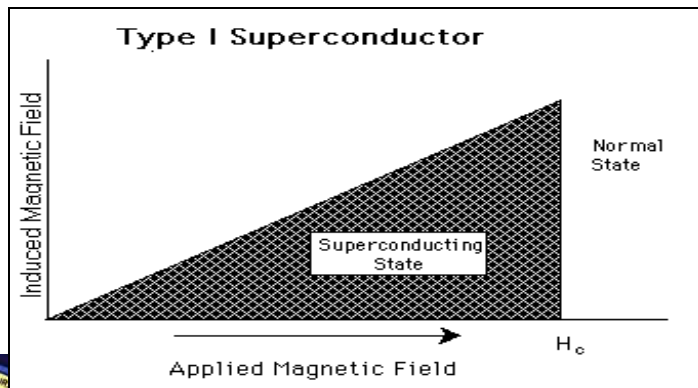
# Types of Superconductors

- **Type I**

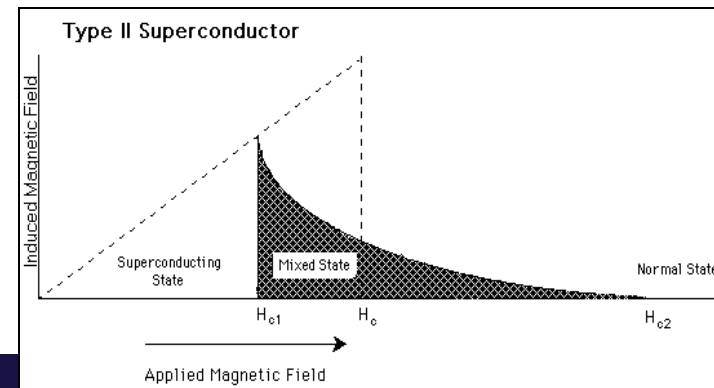
- Expels magnetic field completely at  $H < H_c$
- Ginsburg-Landau parameter,  $\kappa = \lambda / \xi, < 1/\sqrt{2}$

- **Type II**

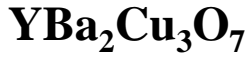
- Expels magnetic field completely at  $H < H_{c1}$
- At  $H_{c1} < H < H_{c2}$ , magnetic field partially penetrates superconductor
- This state is known as mixed state
- Ginsburg-Landau parameter,  $\kappa > 1/\sqrt{2}$



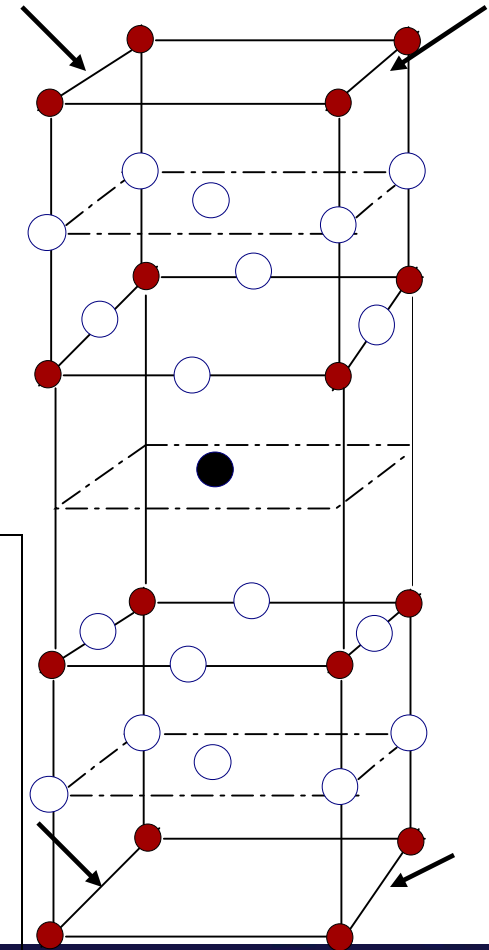
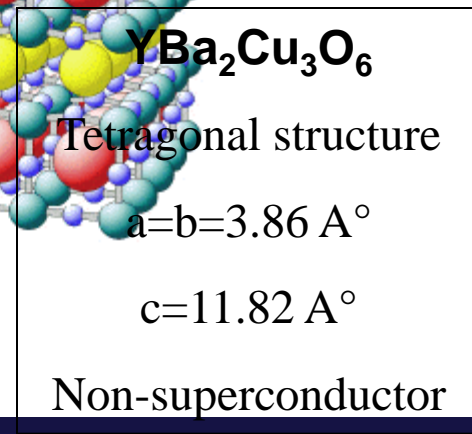
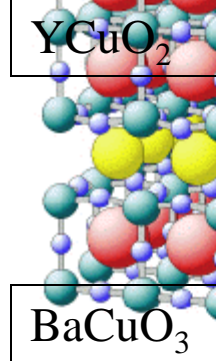
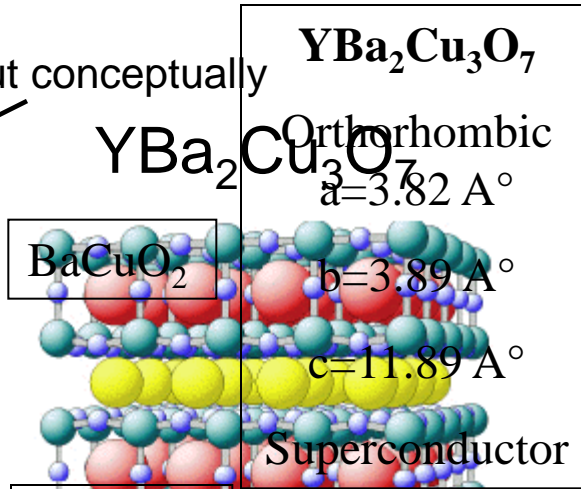
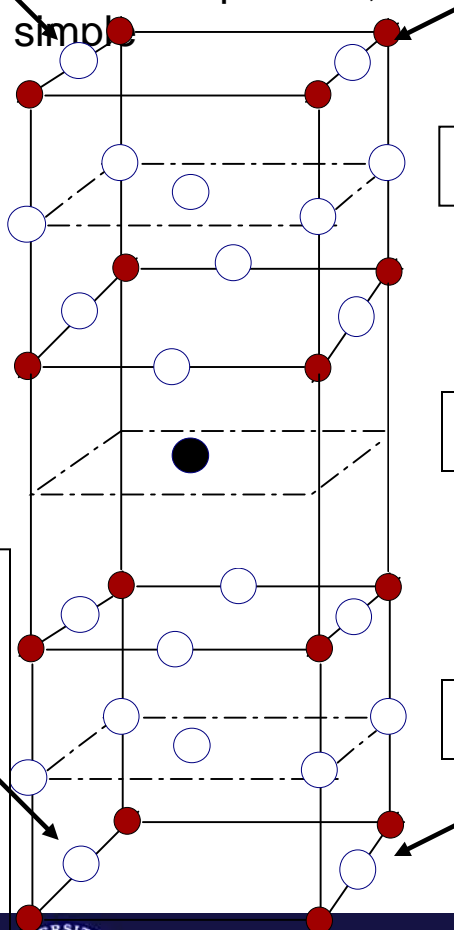
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# Structure of YBCO



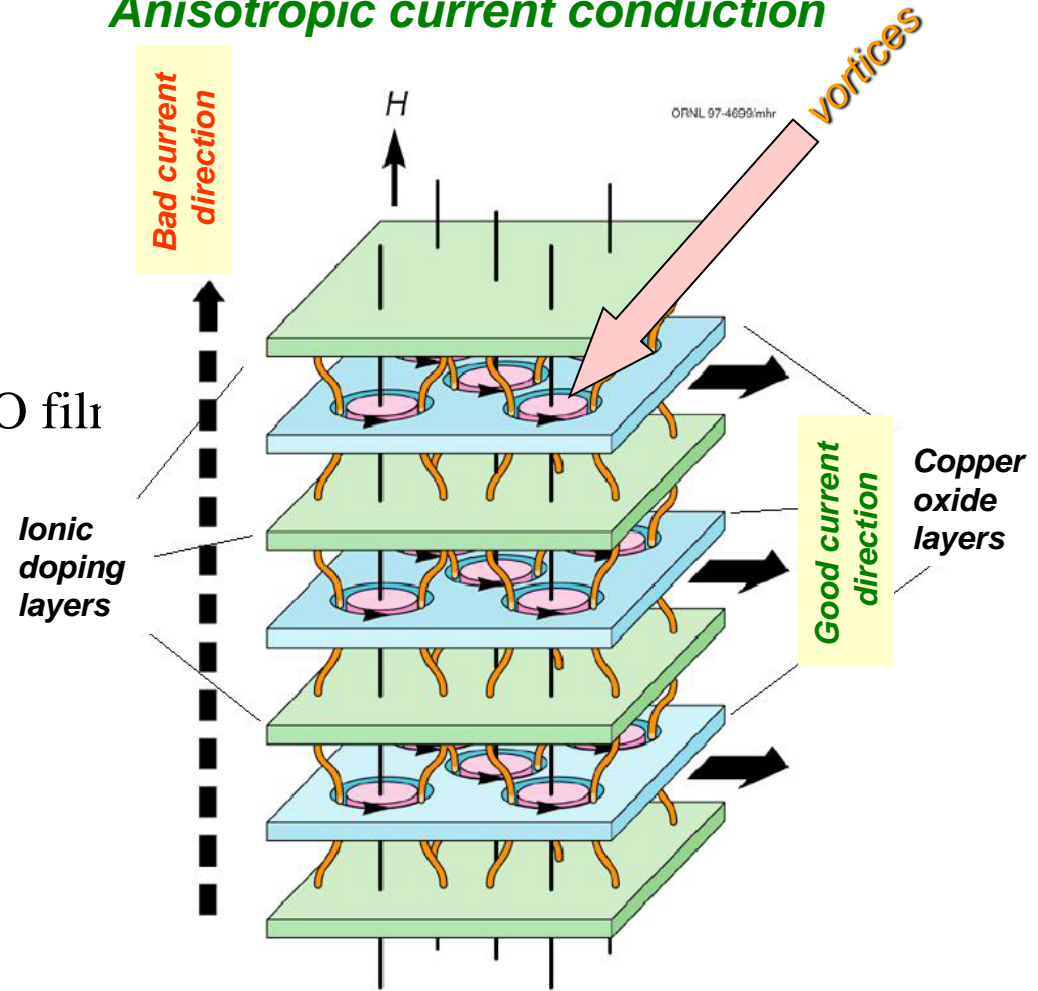
- Looks complicated, but conceptually simple



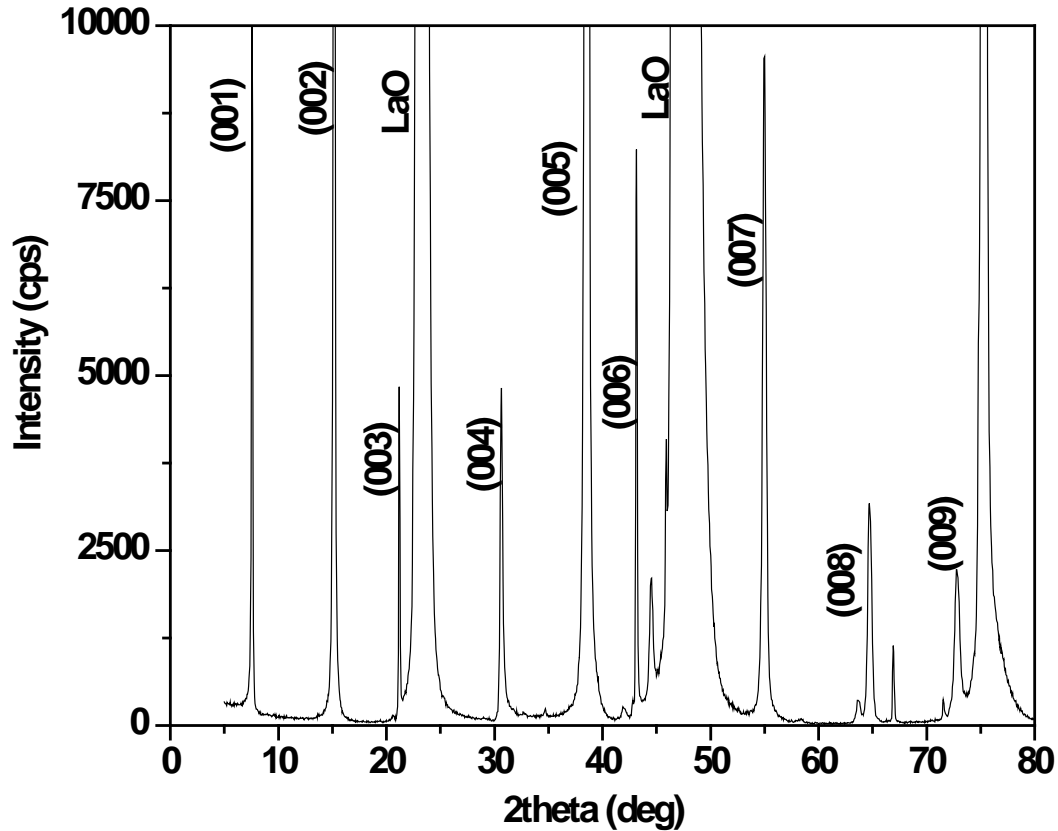
# Anisotropic nature

- YBCO has tendency to grow along
  - *c*-axis
  - *ab*-axis
- For HTSC applications *c*-axis YBCO film are preferred

## Anisotropic current conduction

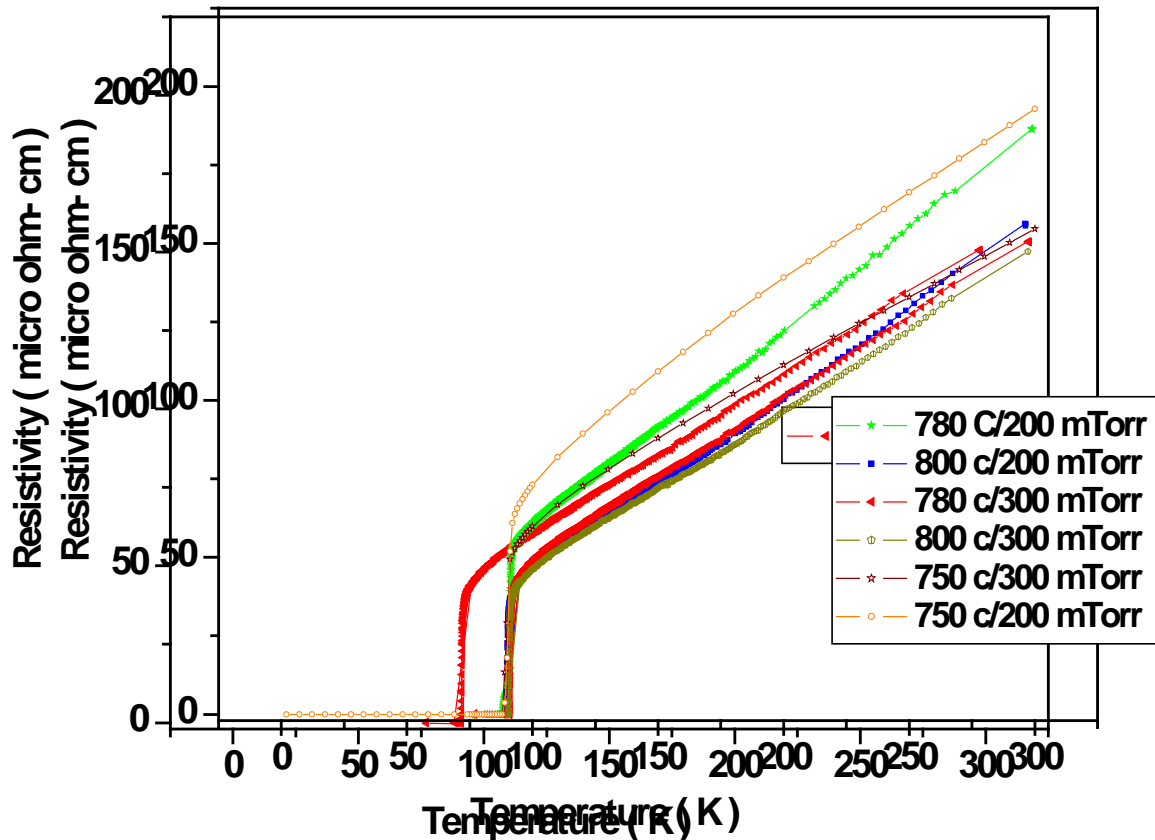


# ' $\theta - 2\theta$ ' X-Ray Diffraction



XRD spectra of YBCO on Lao deposited at 780 °C and 300 mTorr

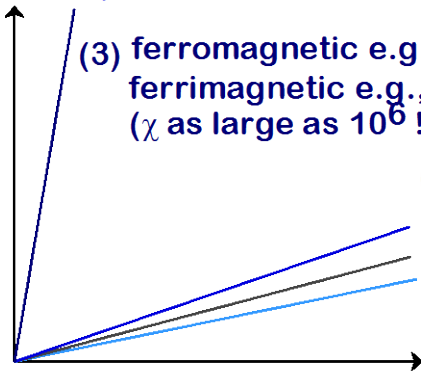
# R(T) characteristics



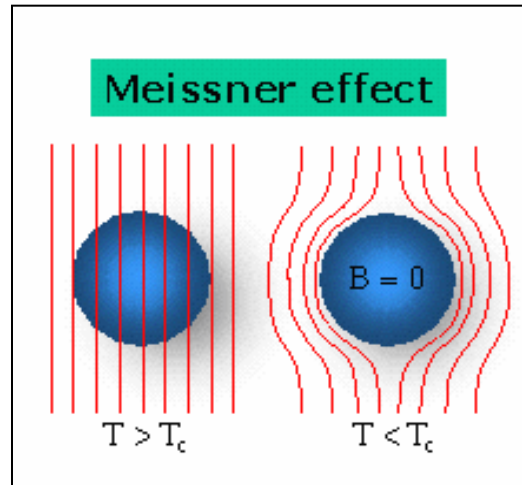
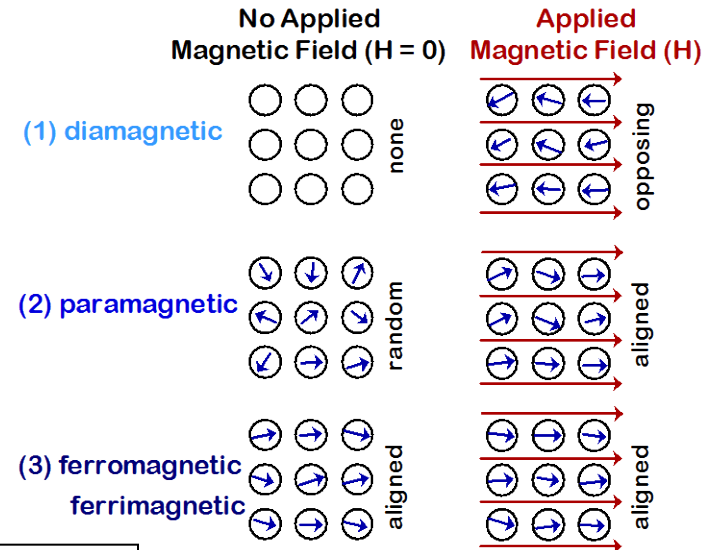
- Using R(T) curves, the critical temperature ( $T_c$ ) was obtained
- $T_c$  of  $\sim 89$  K was measured for all samples
- Resistivity range of 150 – 200  $\mu\Omega$ -cm at room temperature

# What types of magnetism in superconductivity?

Magnetic induction (B--tesla)

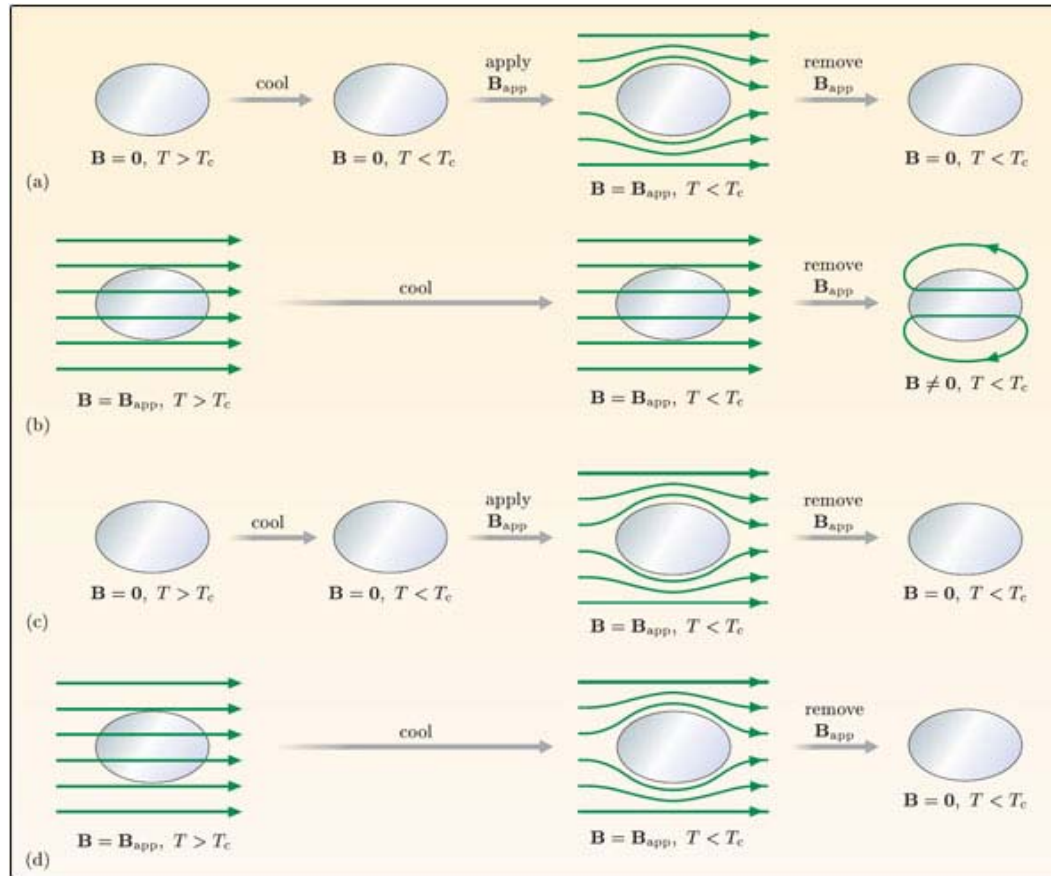


Strength of applied magnetic field (H) (ampere-turns/m)



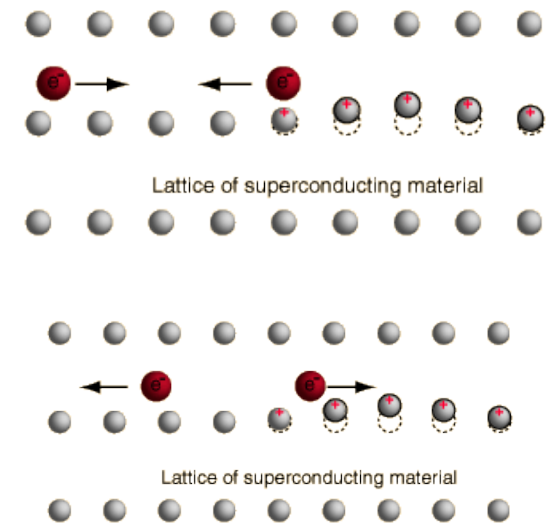
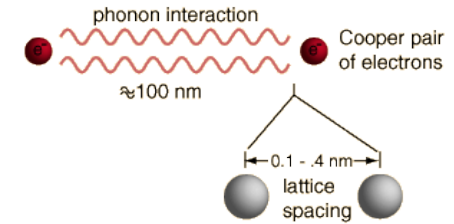
Superconductors:  
Perfect diamagnetic

# Meissner effect: Signature Effect of a superconductor



# Mechanism of Superconductivity

- The behavior of superconductors suggests that electron pairs are coupling over a range of hundreds of nanometers, three orders of magnitude larger than the lattice spacing. Called Cooper pairs, these coupled electrons can take the character of a boson and condense into the ground state.
- This pair condensation is the basis for the BCS theory of superconductivity. The effective net attraction between the normally repulsive electrons produces a pair binding energy on the order of milli-electron volts, enough to keep them paired at extremely low temperatures.
- The transition of a metal from the normal to the superconducting state has the nature of a condensation of the electrons into a state which leaves a band gap above them.
- A passing electron attracts the lattice, causing a slight ripple toward its path.
- Another electron passing in the opposite direction is attracted to that displacement.



# What are superconductors used for?

- If you set up a current in a loop of superconductor there is nothing to stop it and it will continue flowing forever, forming a very powerful electromagnet, that needs no maintenance other than keeping them cold. The strongest man made permanent magnetic fields are produced using superconductors.
- Superconducting magnets are used in MRI (Magnetic Resonance Imaging) which is a way of looking at the soft parts of the body.





# Maglev trains

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- It is possible to use superconducting magnets to produce a levitating train. The idea is to put very powerful light superconducting magnets on the train, then use copper coils in the track which use repulsion to lift the train up to make it levitate.
- It is also possible to use the track magnets to push the train along. Because this force is not limited by friction between wheels and a track it is theoretically possible for a maglev train to go much faster and more importantly accelerate and brake faster than a conventional train.
- Various test maglev trains have been built, in Birmingham, Japan and Germany, although the only one used commercially is a German design built in Shanghi, which uses very strong permanent magnets instead of superconductors.



The JR-Maglev uses superconducting magnets to levitate and for propulsion. © Yosemite dia



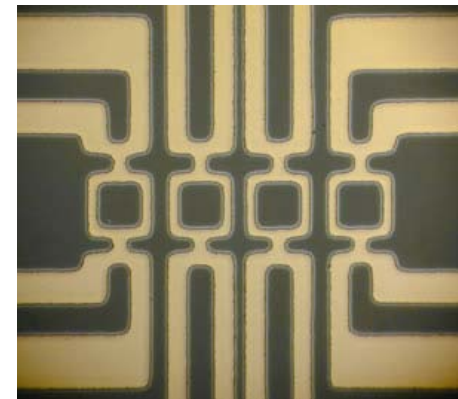
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# Superconducting Sensors

- Due to a subtlety of the quantum mechanics of how superconductors interact with magnetic fields, it is possible to make the most sensitive magnetometers possible called SQUIDs (Superconducting Quantum Interference Devices).
- These can be used to detect submarines, measure the magnetic field produced by your brain, find ore deposits deep underground, sense minute signals from stars etc.

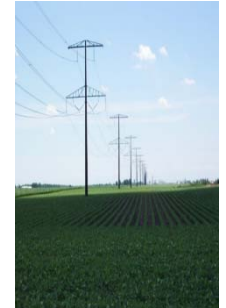




# Power Cables and Supermotors

## Power cables: Space Efficiency

- e.g. 18000 pounds of copper wire could be replaced by 250 pounds of superconductive cable.
- No energy loss due to heat
- Transformers can be made smaller and last longer.
- An annual budget savings of almost 40% could be obtained with the replacement of copper wires with superconducting cables.

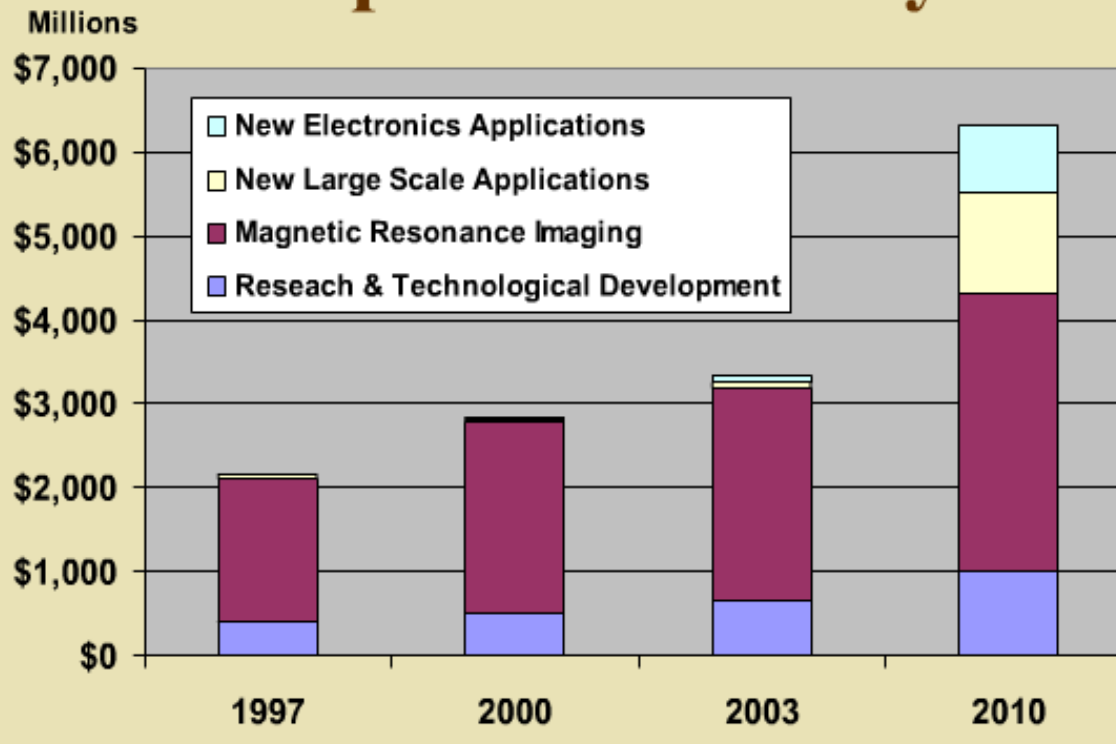


## Supermotors

- Motors account for 70% of the power consumption in domestic manufacturing and 55% in the entire United States.
- Using high-temperature superconducting (HTS) coils instead of traditional copper windings, this supermotor can produce more power in less space, and use less energy while doing it (high efficiency).
- Most cruise ships and large naval vessels are switching to electric propulsion. These units are quieter than traditional
- electric motors.



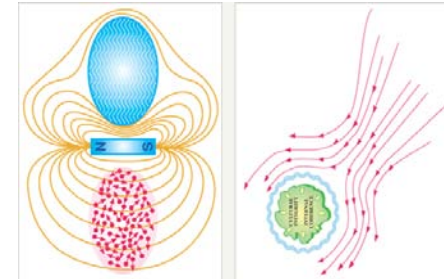
# Worldwide Market for Superconductivity





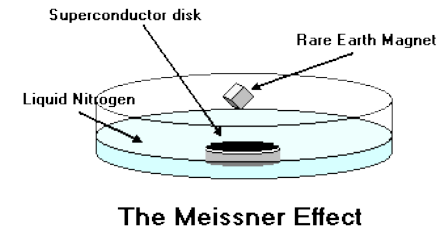
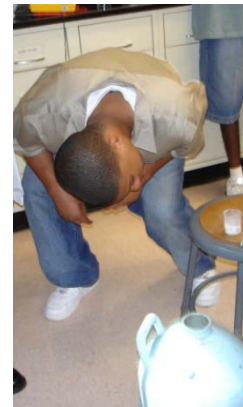
# Learning magnetism, drawing magnetic lines of forces, experience force of magnetic fields

- The students were divided into different groups, each group was supervised by NIRT/CAMSS scientists and graduate and undergraduate students.
- The experiments included drawing line of magnetic forces by sprinkling and tapping iron fillings on a plexy glass plate placed over a bar magnet.
- This experiment was intended to provide the students the idea of magnetic lines of forces being emanated from both the poles of a bar magnet.
- The idea of magnetic lines of forces were used to demonstrate the effect of diamagnetism during superconducting levitation experiment.



# Superconducting Levitation experiment

- The students were first given a demonstration experiment when a YBCO superconducting pellet was dipped in liquid nitrogen and then a small magnet was levitated over that.
- After the demonstration experiment, each student was asked to conduct the experiment himself/herself. The students had fun handling the liquid nitrogen themselves.
- They also froze some oranges and dropped to the floor which gave them an idea how temperature can transform a soft material into hard and brittle material.





# High temperature superconductor assisted bulb lighting

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- This experiment involved making a microbridge in YBCO superconducting films using a pulsed laser.
- The purpose of making the YBCO microbridge was to increase the normal temperature resistance of the films in the range of 400-500 Ohms from the resistance of 4-5 ohms of unpatterned film.
- This YBCO microbridge was connected to an electric bulb and a battery in series. The bulb did not light up.
- When the microbridge was dipped in liquid nitrogen the resistance of the film dropped to zero and bulb was found to be lighting.
- As the liquid nitrogen evaporated, the resistance of the YBCO film increased and the bulb stopped lighting.
- The students poured the liquid nitrogen themselves, made the bulb light-up and light-off.
- They also measured the resistance of the YBCO microbridge as a function of time and found the resistance shooting up back to 400-500 ohms.

