SUPERCONDUCTORS

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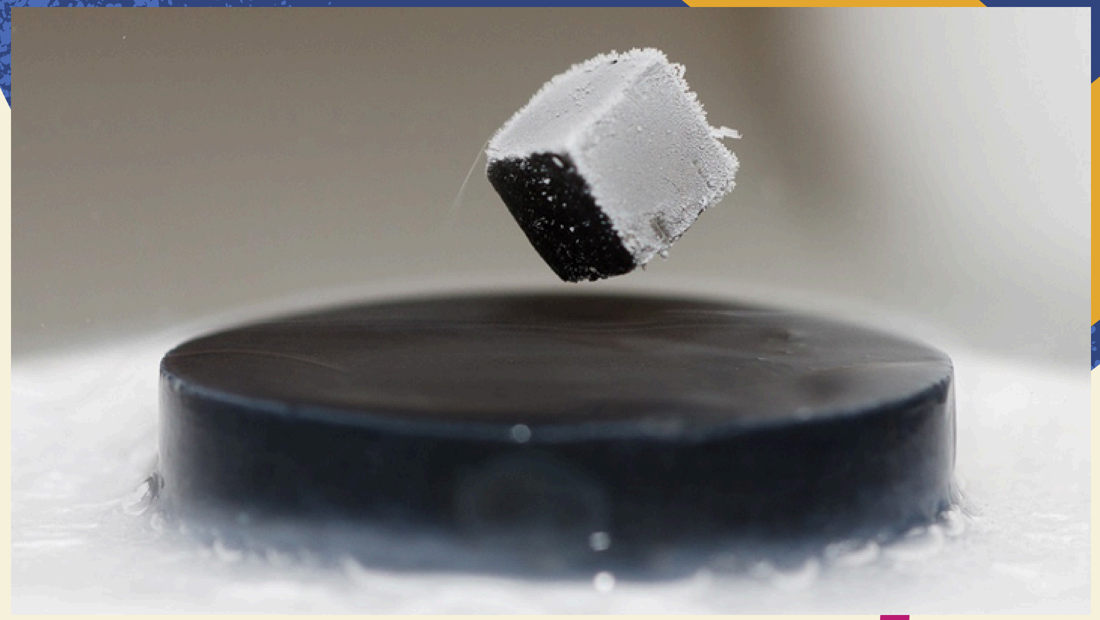
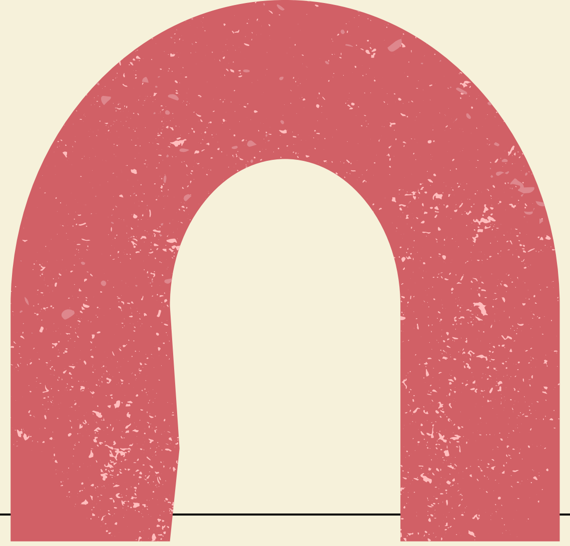
WHAT ARE SUPERCONDUCTORS?



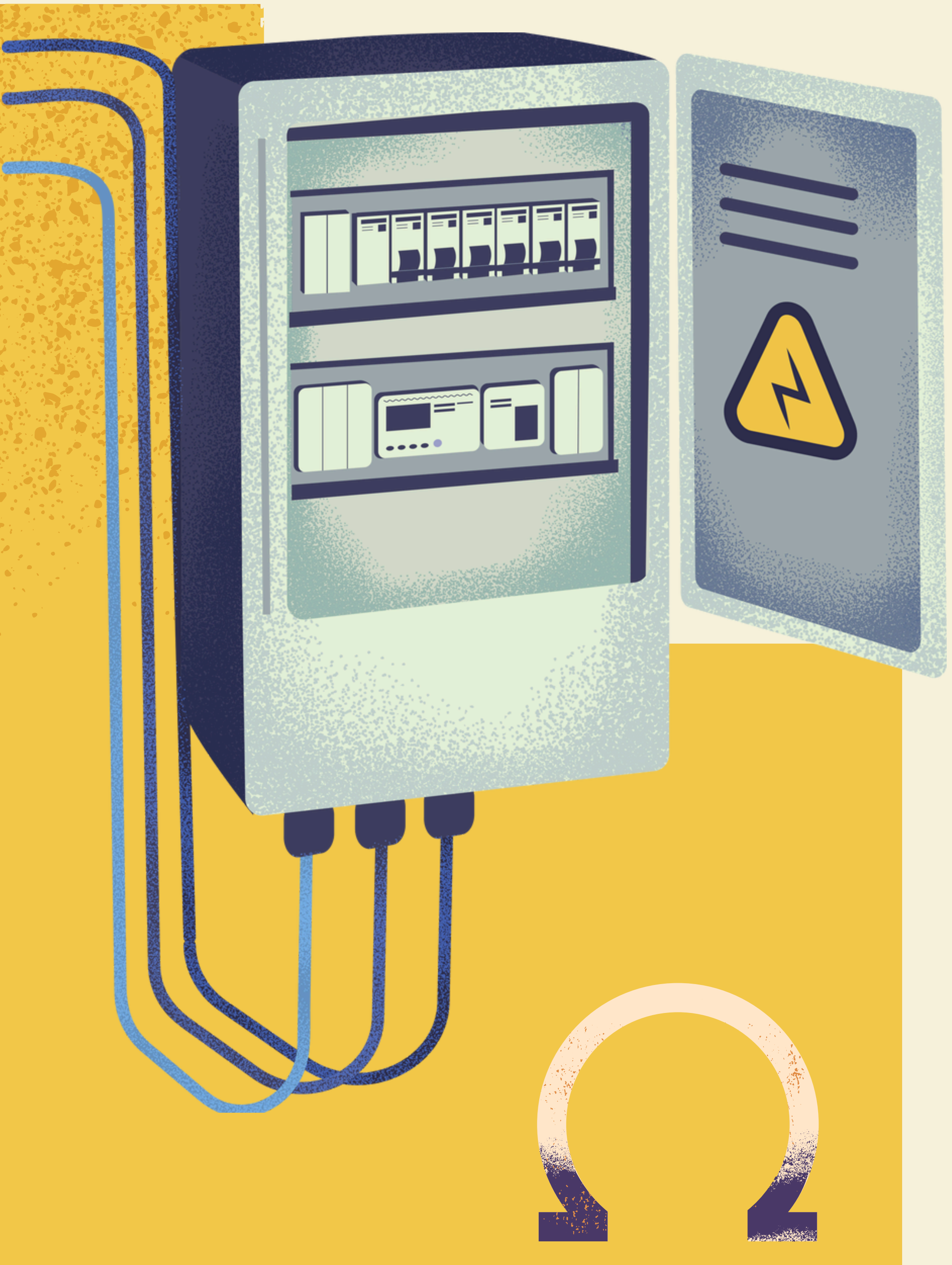
A MATERIAL THAT EXHIBIT NO ELECTRICAL RESISTANCE

ELECTRICAL CURRENTS CAN LAST FOREVER IN THESE CIRCUITS

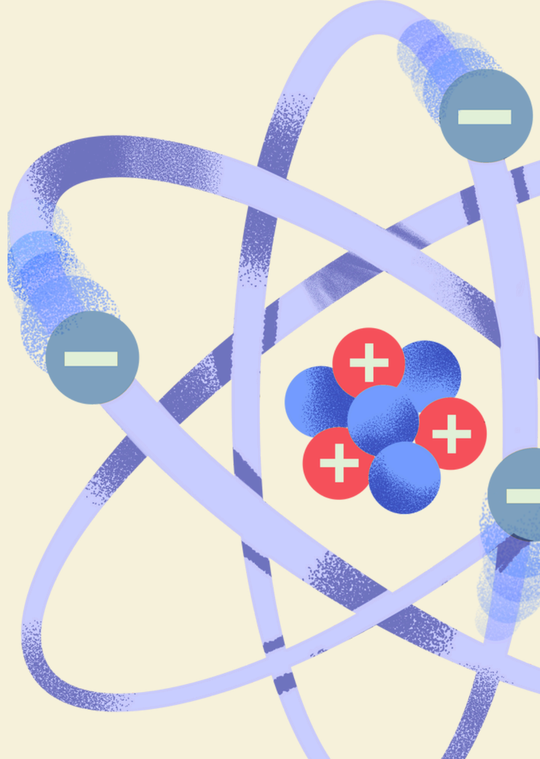
WHAT IS RESISTANCE?



RESISTANCE IS A MEASURE OF THE OPPOSITION TO THE FLOW OF CURRENT IN AN ELECTRICAL CIRCUIT.



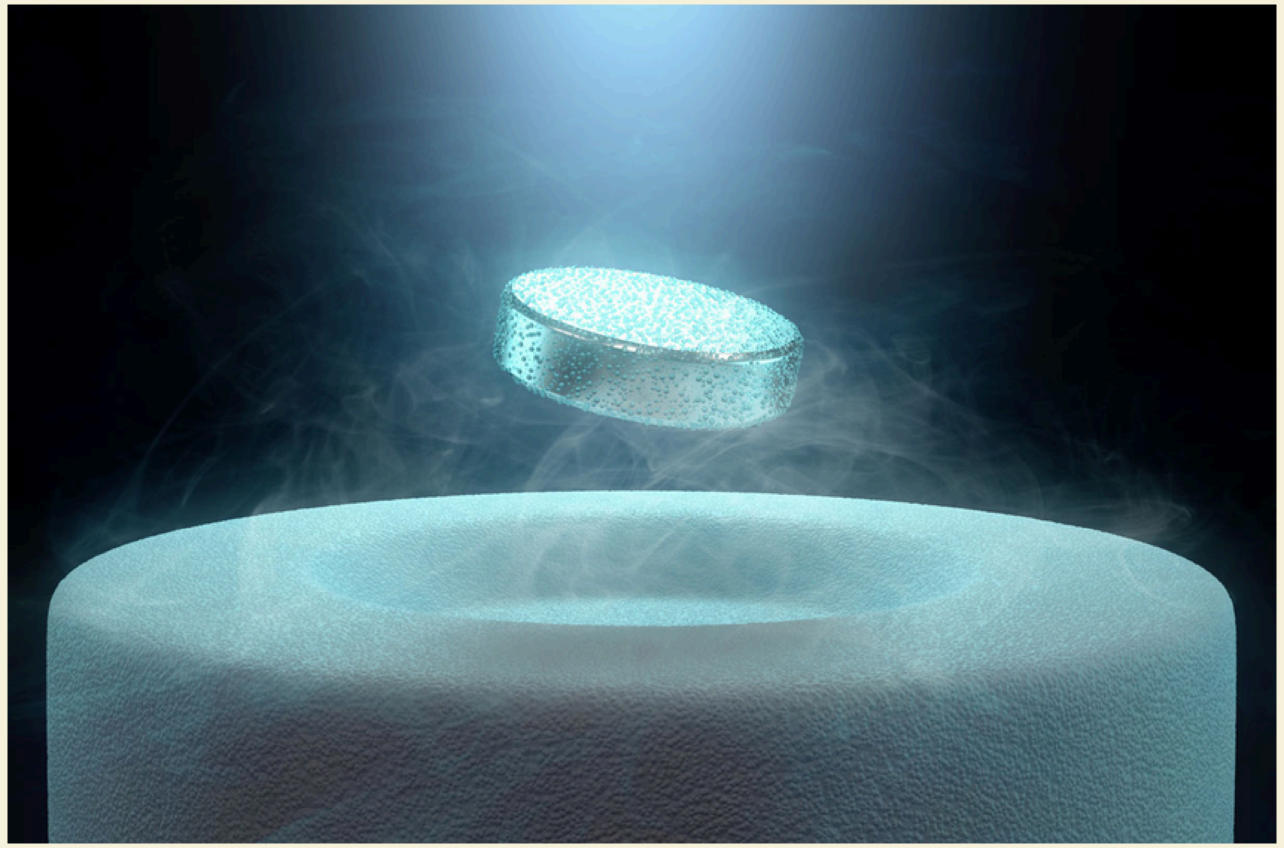
- Materials have some amount of electrical resistance
- They resist the flow of electricity
- Some energy is lost as heat when electrons move through electronics
- For most materials, this resistance remains even if the material is cooled to very low temperatures
- But for superconductors, resistance will decrease to 0

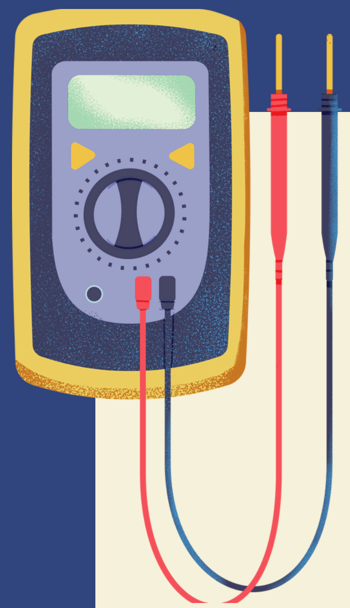


PROPERTIES OF A SUPERCONDUCTOR

1. Exhibits zero resistance below a certain temperature
2. Completely expel magnetic fields

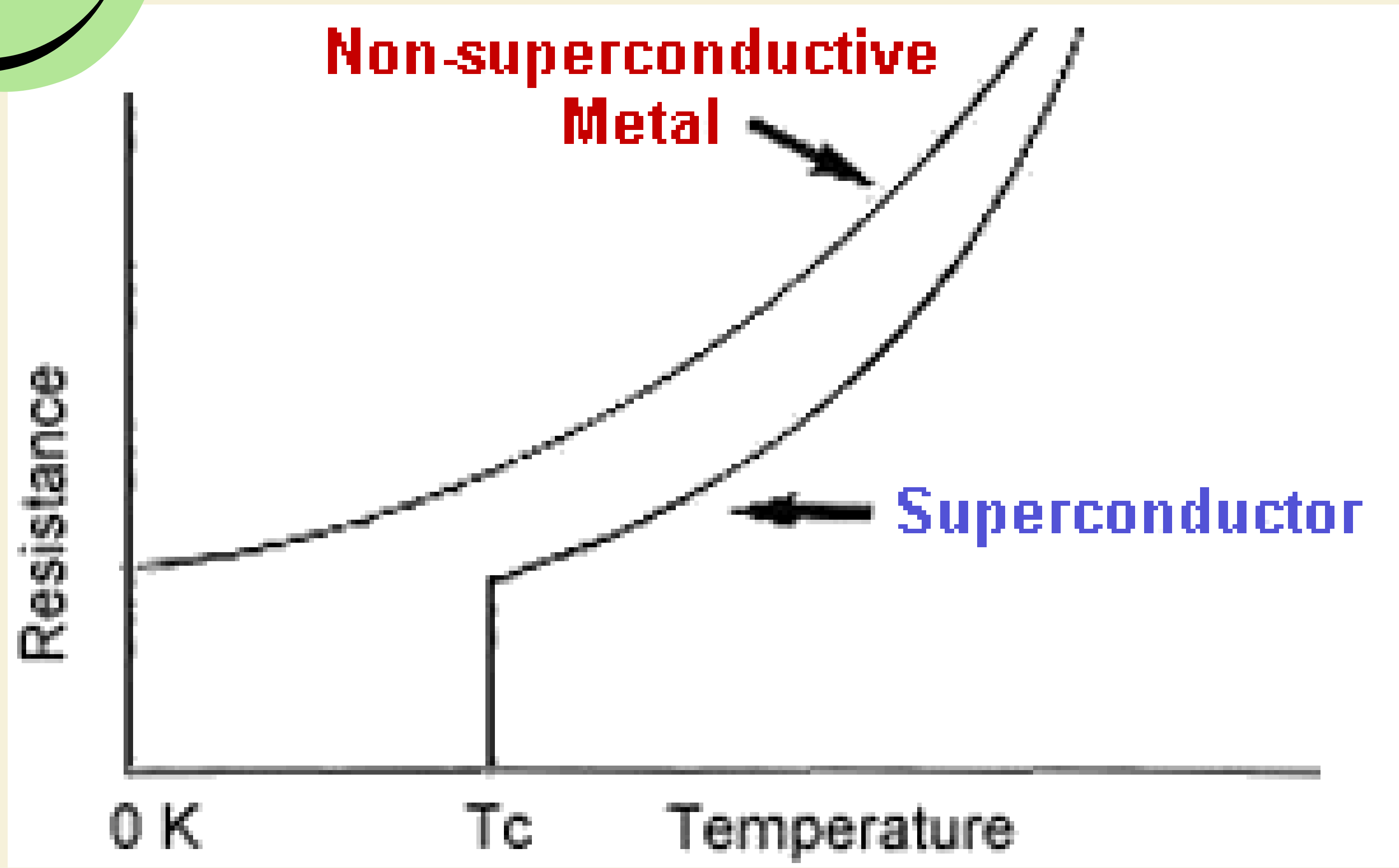
SUPERCONDUCTING MAGNETIC COOLING MACHINE



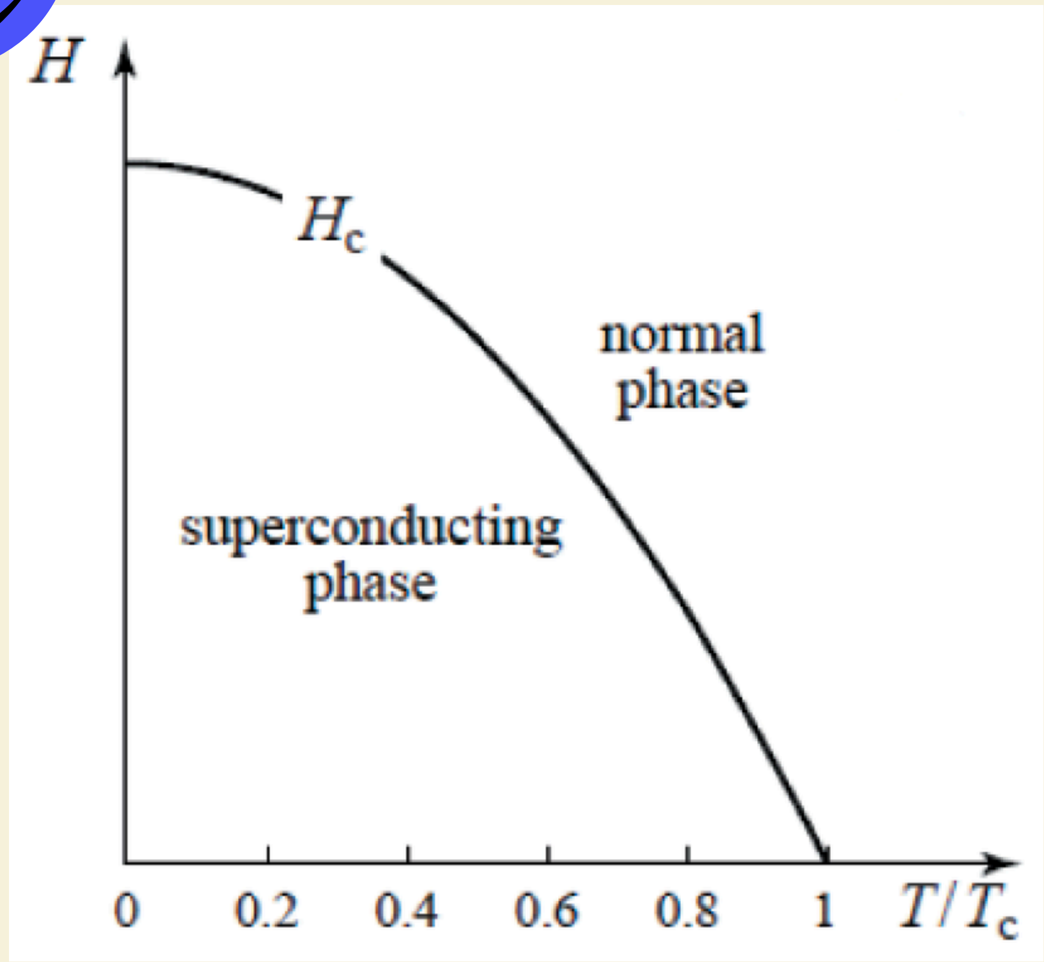


WHEN DOES A CONDUCTOR BECOME A SUPERCONDUCTOR?

1 WHEN IT REACHES CRITICAL TEMPERATURE



2 AND CRITICAL FIELD



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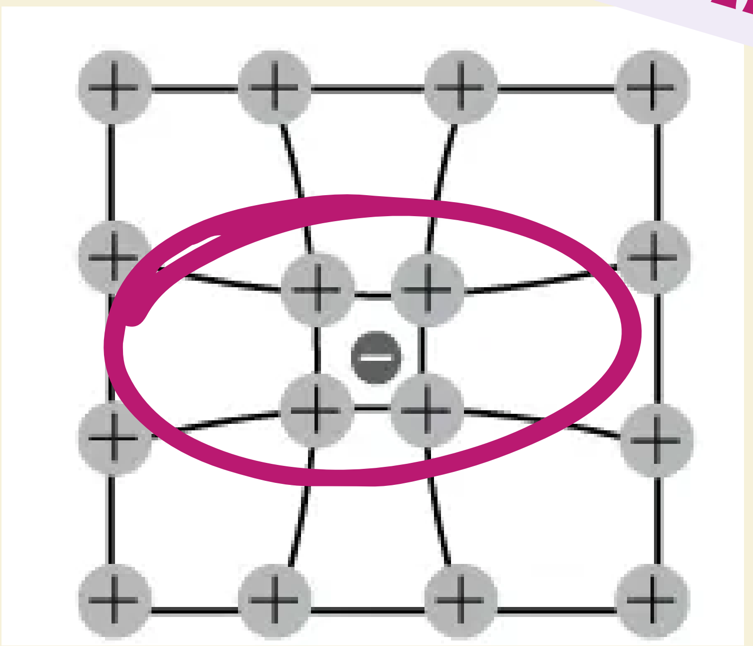
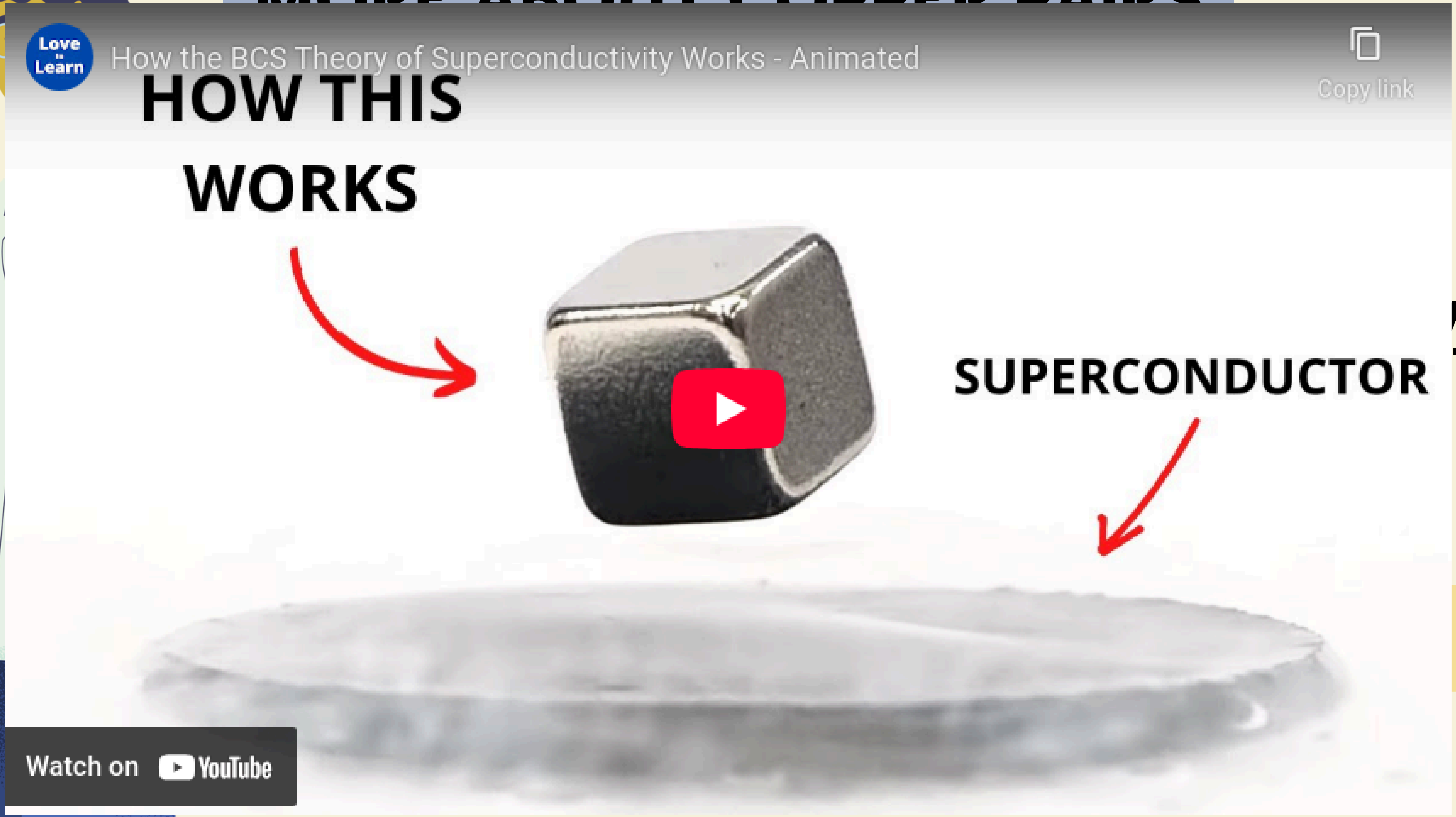
WHY DOES IT BECOME A SUPERCONDUCTOR?

BARDEEN-COOPER-SCHRIFFER (BCS) THEORY - FORMATION OF COOPER PAIRS IN SUPERCONDUCTORS



- Normally, when electrons move through a lattice-like structure in metal, they will vibrate, resulting in resistance
- When temperature is low enough (critical temperature), these atoms will vibrate significantly less
- When they pass through, they attract the atoms around them slightly, creating a local positive charge which creates an attractive force between electrons. They can interact with each other through vibrations in the lattice called Phonons.
- The electrons will become form "Cooper pairs", which moves through the circuit without any resistance

MORE ABOUT COPPER PAIRS



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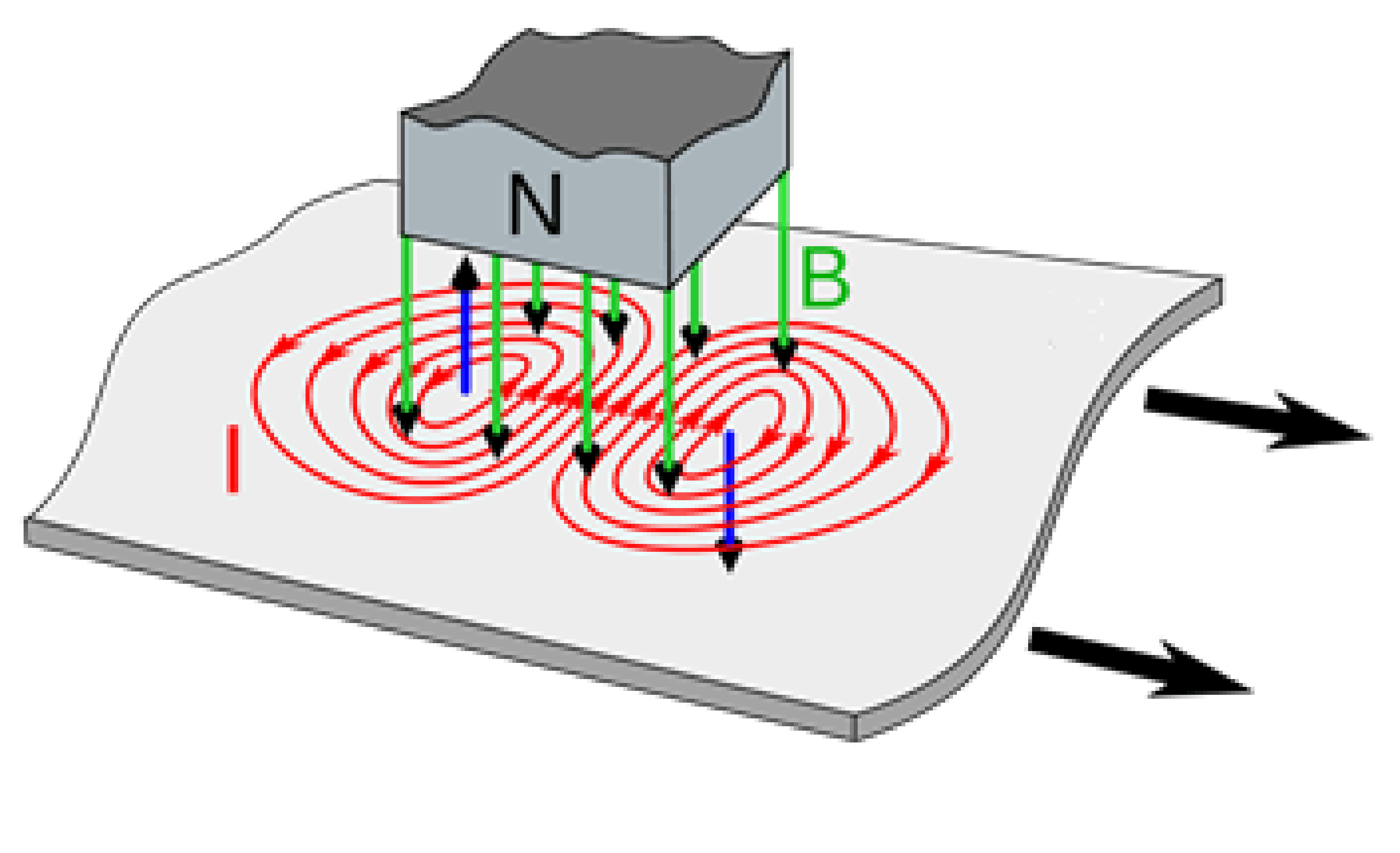
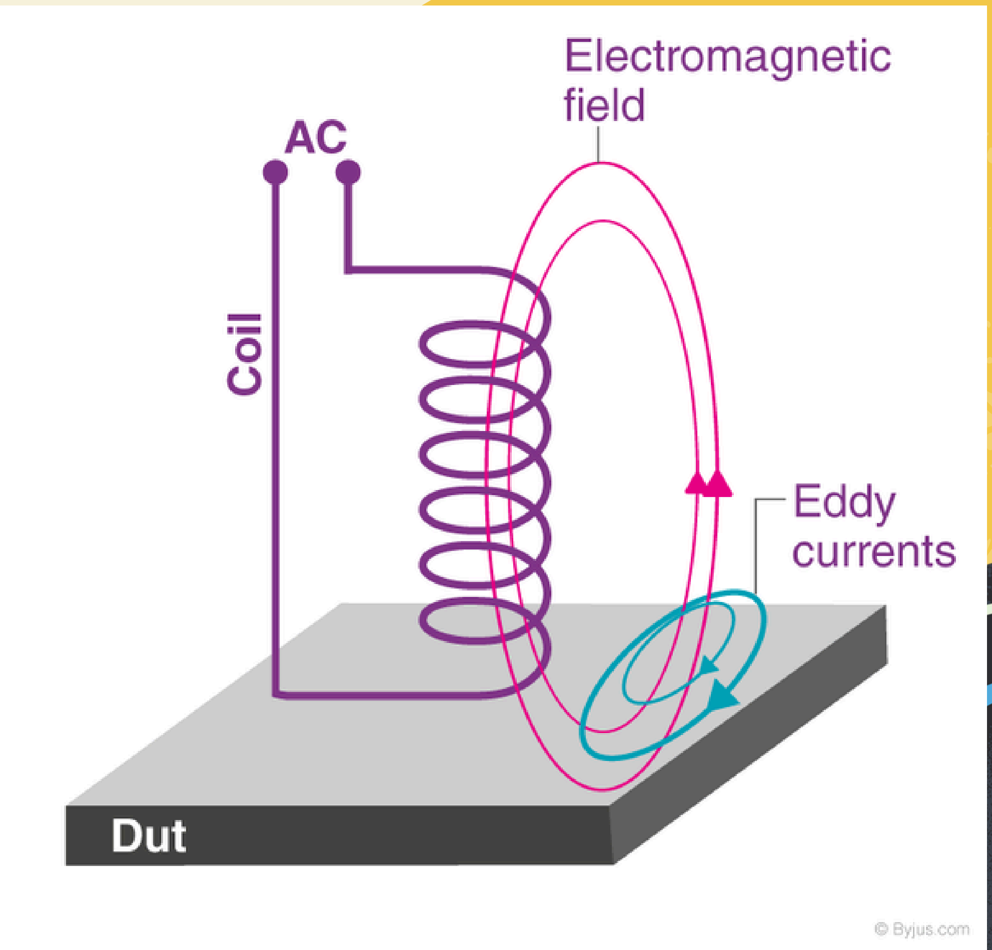
EDDY CURRENT

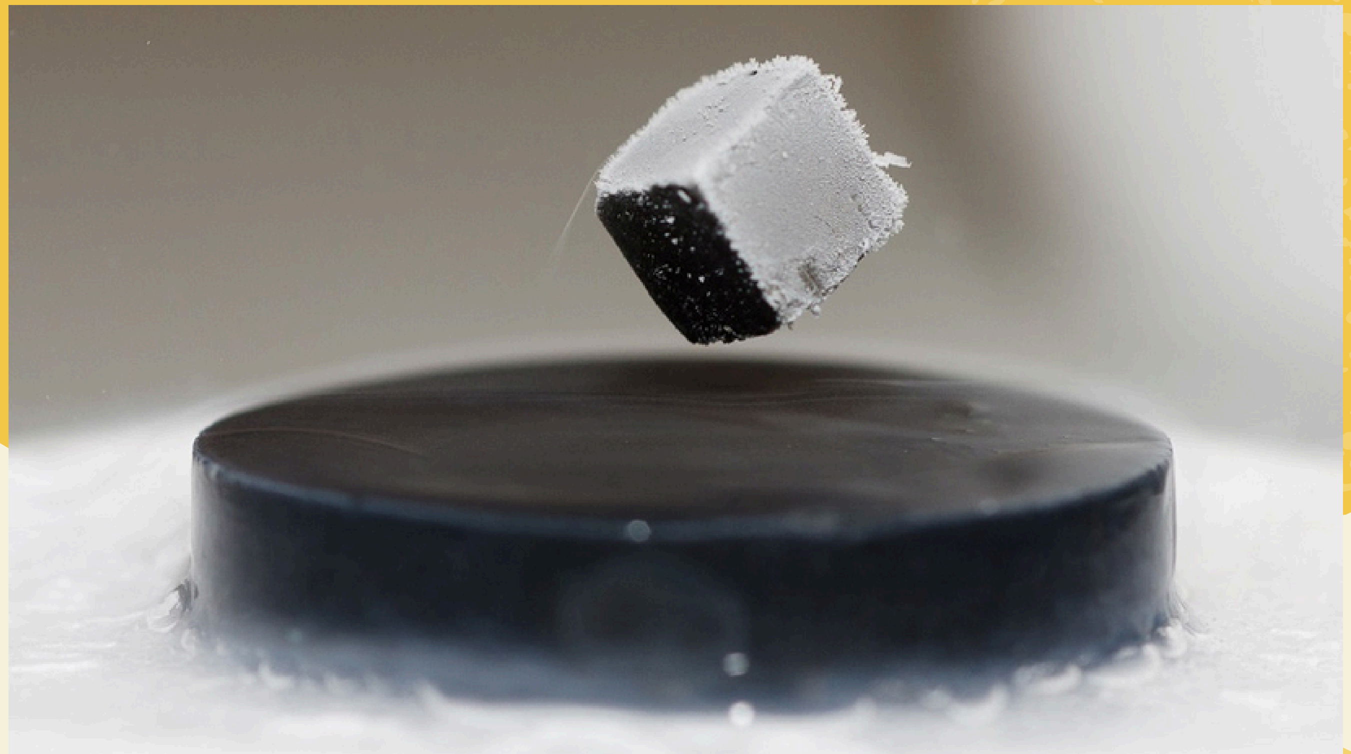
- Eddy currents are loops of electrical current induced in a conductor due to Faraday's law of induction.
- They flow in closed loops, perpendicular to the magnetic field. Eddy currents will produce their own magnetic field. Using Lenz's Law, the direction of these fields will oppose the change of the magnetic field which created it, resulting in a repulsive force

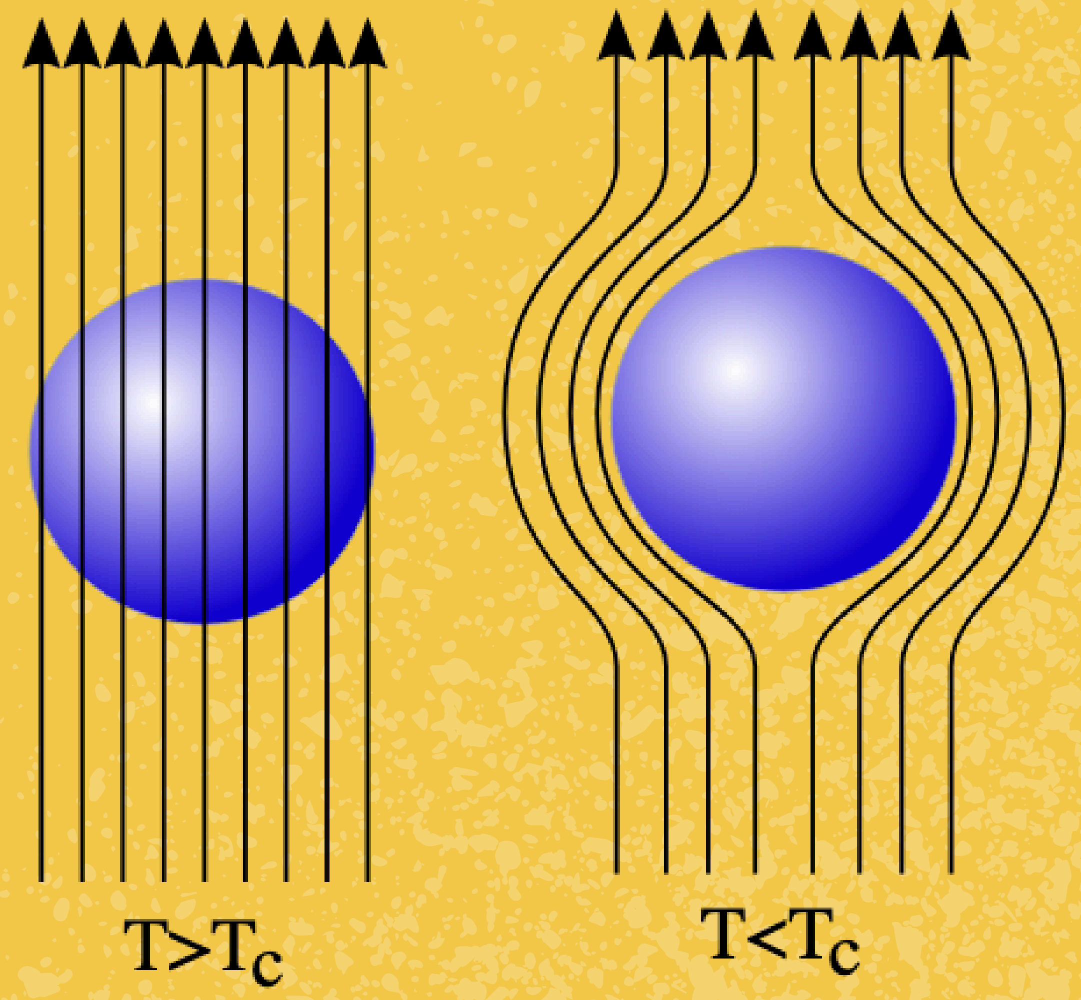




MEISSNER EFFECT

- In normal conductors, eddy currents dissipate after a while due to resistance. However, eddy currents do not dissipate in superconductors. This expulsion of magnetic fields, known as the Meissner effect, creates a repulsive force that can counteract gravity, which is how the superconductor can levitate above a magnet.
- If the magnetic field is above critical field, the magnetic field line will penetrate through the superconductor, preventing the superconductor from transitioning to the superconducting state.





TYPES OF SUPERCONDUCTORS

TYPE 1

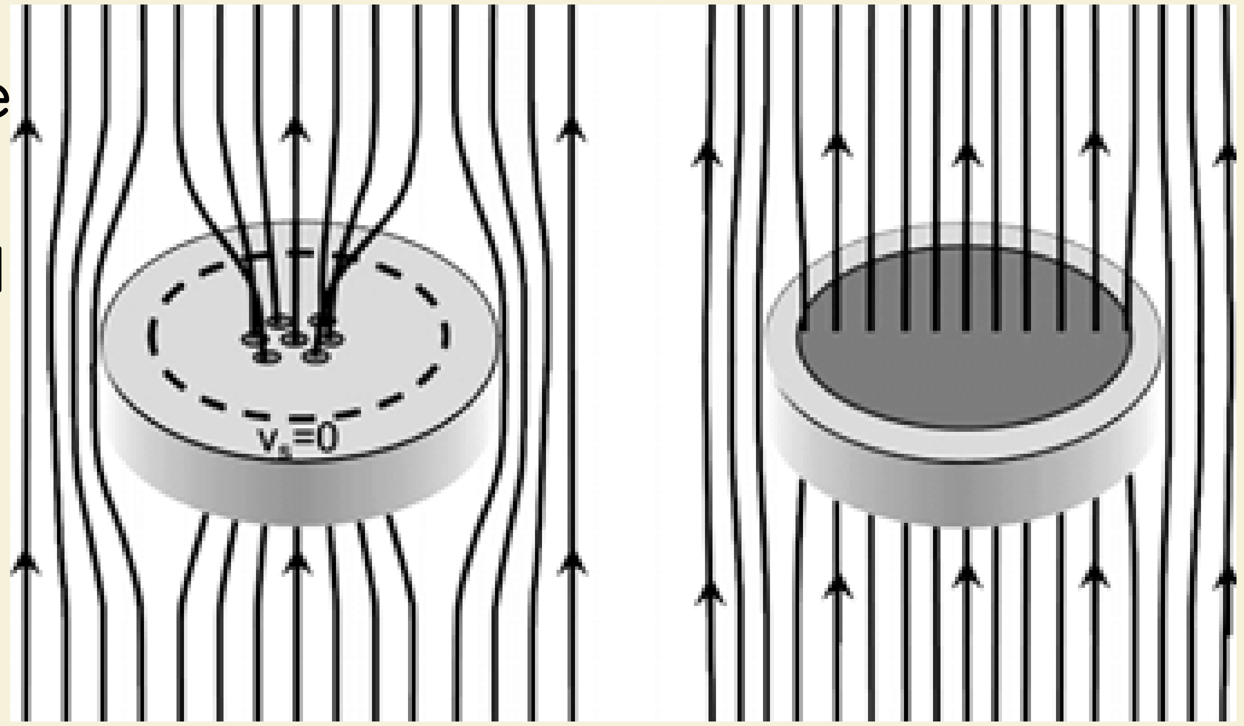
Superconductivity is **suddenly destroyed** when magnetic field strength increases above certain value above critical field

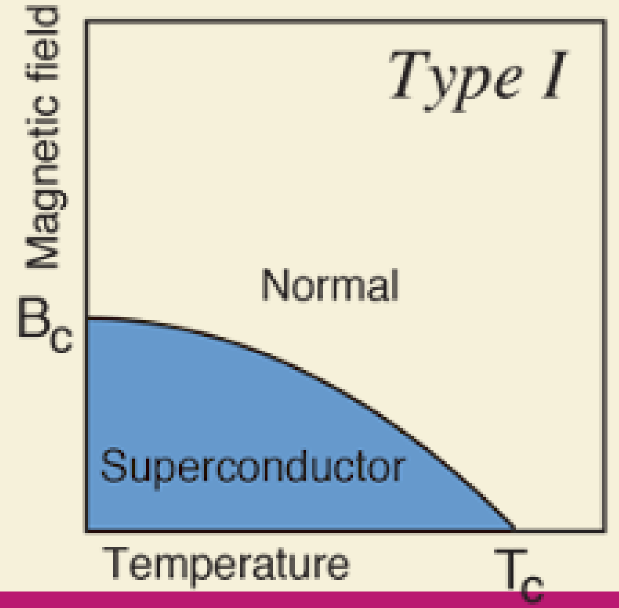
TYPE 2

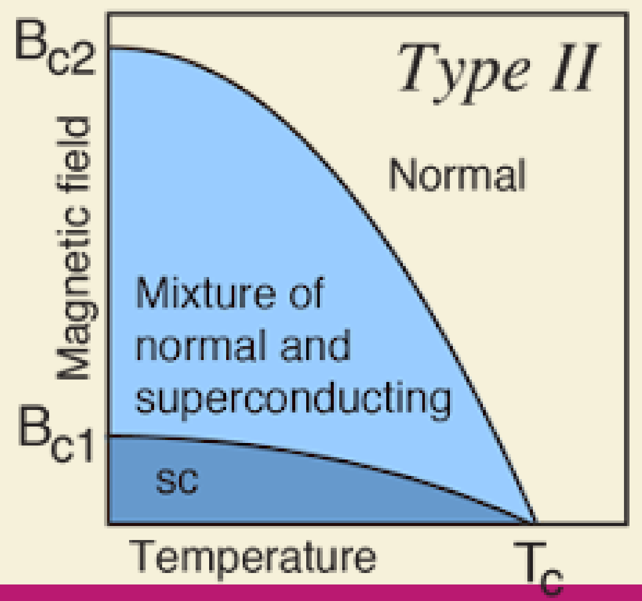
Superconductivity gradually decreases.

Mixed state: Magnetic field vortices (tubes of magnetic flux) where magnetic field can pass through, breaking apart the Cooper pairs

Density of magnetic field vortices increases until it passes second threshold where it transits into non superconducting phase







EXAMPLES OF SUPERCONDUCTORS

Conventional superconductors

These follow the BCS theory

- Aluminium 1.20K
- Mercury 4.15K
- Molybdenum 0.92K
- Lead 7.19K
- Tin 3.72K
- Tantalum 4.48K
- Titanium 0.39K
- Zinc 0.88K

Unconventional superconductors

Physicists are unsure of the mechanism behind this since BCS theory doesn't explain the high critical temperature

Mostly compound and alloys

- Copper oxide compounds (ceramics)
  - Yttrium barium copper oxide (77K)
- Niobium-titanium alloy (11 K)
- Niobium nitride (16 K)
- Carbonaceous sulfur hydride (288.15K)
  - Impractical as it requires extremely high pressure

EXAMPLES OF SUPERCONDUCTORS

Conventional superconductors

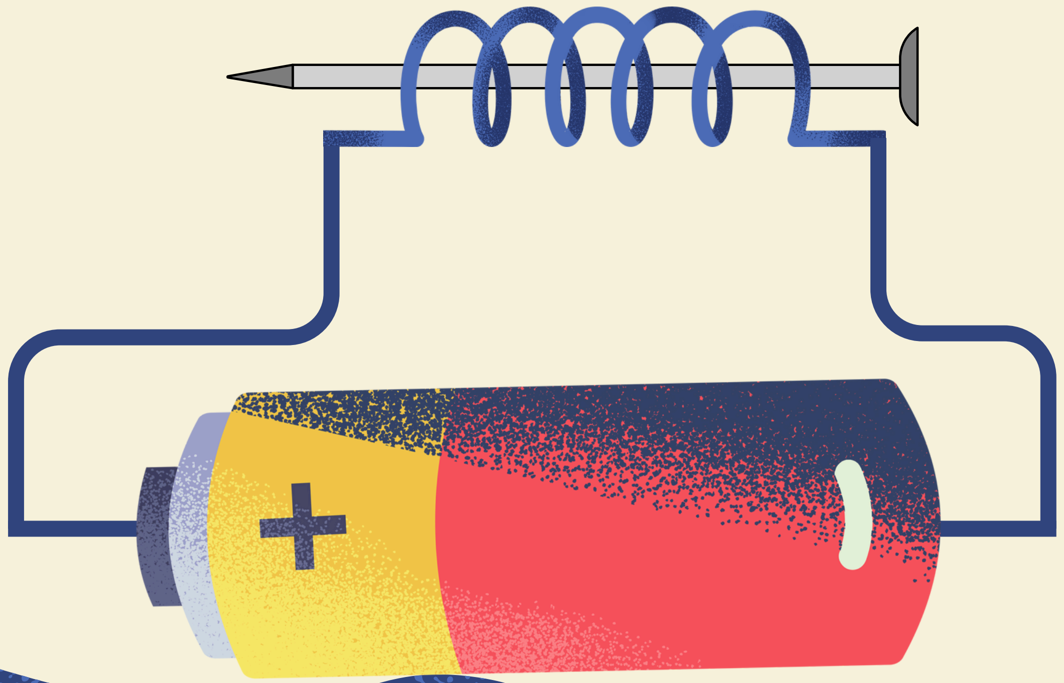
- Mostly Type-1 superconductors
- Very low critical temperatures
  - Require expensive and hard-to-handle coolants, primarily liquid helium
- There is no effect of slight impurity on superconductivity
- Very stable superconducting states
- Sensitive to external magnetic fields and mechanical stress, which can cause a loss of superconductivity

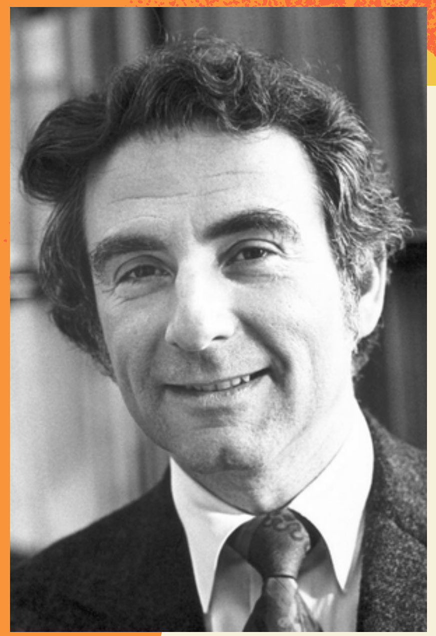
Unconventional superconductors

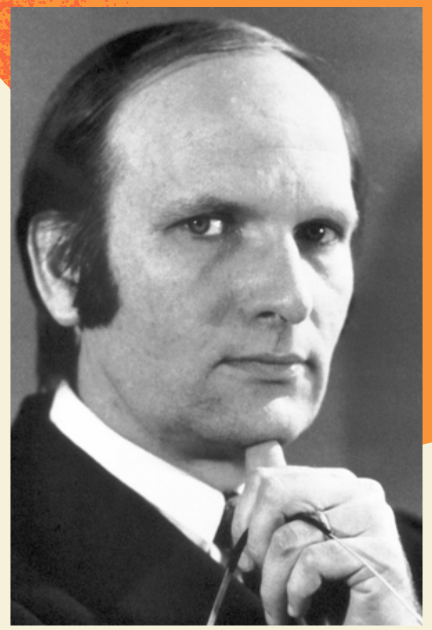
- Relatively higher critical temperatures
  - Can be cooled using liquid nitrogen due to their
- They retain their superconductivity in higher magnetic fields
  - important when constructing superconducting magnets, an application of high-Tc materials
- Ceramic superconductors are suitable for some practical uses but encounters issues. For example, most ceramics are brittle, which complicates wire fabrication.

HISTORY

Heike Kamerlingh Onnes, a Dutch experimental physicist was the first to discover superconductivity.
In 1911, he was using liquid helium to study the resistance of liquid mercury at low temperatures. He discovered that it completely disappeared at temperatures a few degrees above absolute zero.







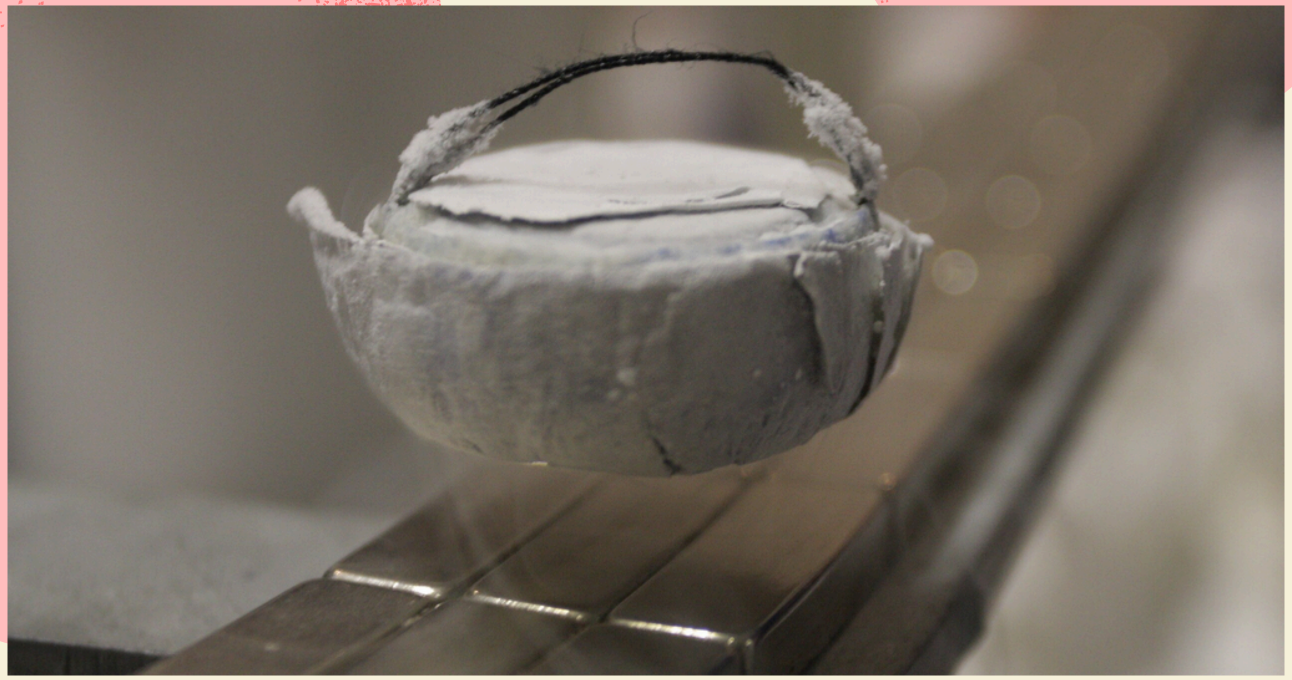
BCS THEORY

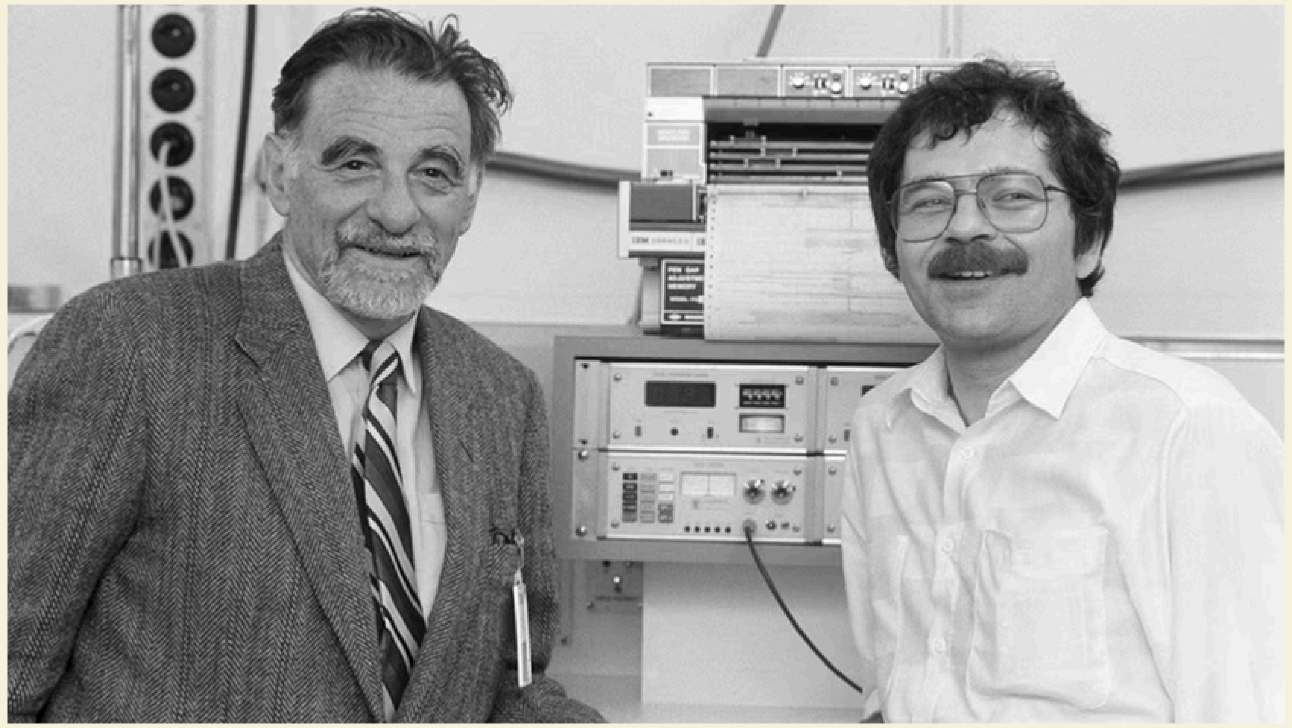
John Bardeen, Leon N. Cooper, and J. Robert Schrieffer for their jointly developed theory of superconductivity, called the BCS-theory

- Bardeen: American physicist, the only person to be awarded the Nobel Prize in Physics twice
- Cooper: American theoretical physicist and neuroscientist
- Schrieffer: American physicist

HISTORY

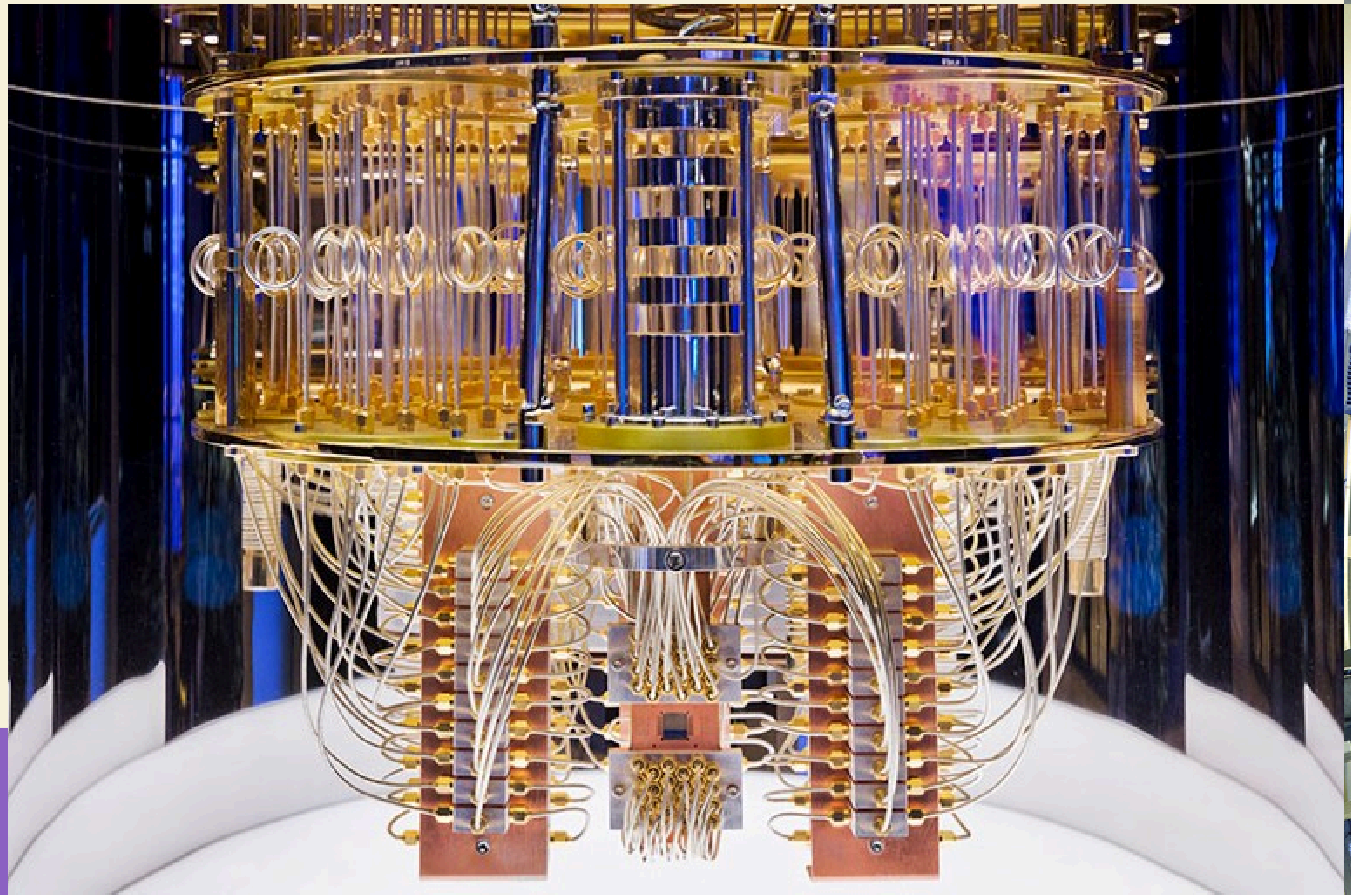
1. Georg Bednorz and K. Alex Müller discovered high-temperature superconductivity and won the Nobel Prize in 1987. They discovered that ceramics, a whole new class of materials, could be superconductors.
2. This sparked a global race. Within a year, other scientists pushed the record to above 90 K using yttrium barium copper oxide, YBCO. This was revolutionary because it meant superconductivity could now be achieved using liquid nitrogen, a cheap coolant.
3. Their work challenged BCS theory, because high-Tc superconductivity couldn’t be explained the same way as low-Tc superconductivity. Even today, the mechanism is still an active area of research.

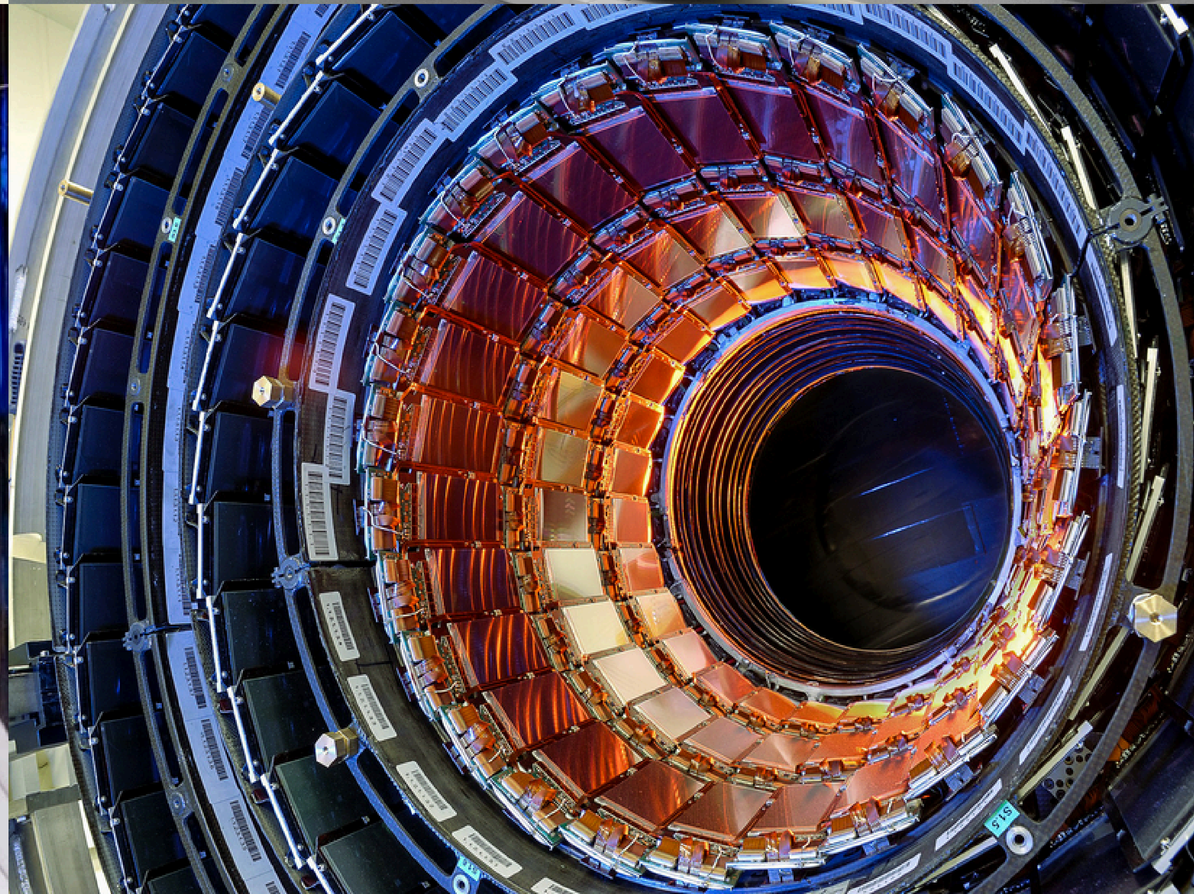




APPLICATIONS OF SUPERCONDUCTORS

- Particle accelerators - large hadron collider (LHC)
- Superconducting coils used in MRI machines in hospitals and medical labs.
- Quantum computers with superconducting qubits





FUTURE OF SUPERCONDUCTIVITY

- High temperature superconductors
  - Superconducting transmission lines: able to conduct electricity with zero loss
  - Efficient superconducting motors or generators
  - Levitating cars, trains without using vast amounts of electricity
- Zero resistance computers with way lower electricity consumption

THANK YOU!

Citations

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