superconductivity

What is superconductivity

History of superconductivity

Meissner Effect

Applications

WHAT IS ELECTRICAL CONDUCTION ?

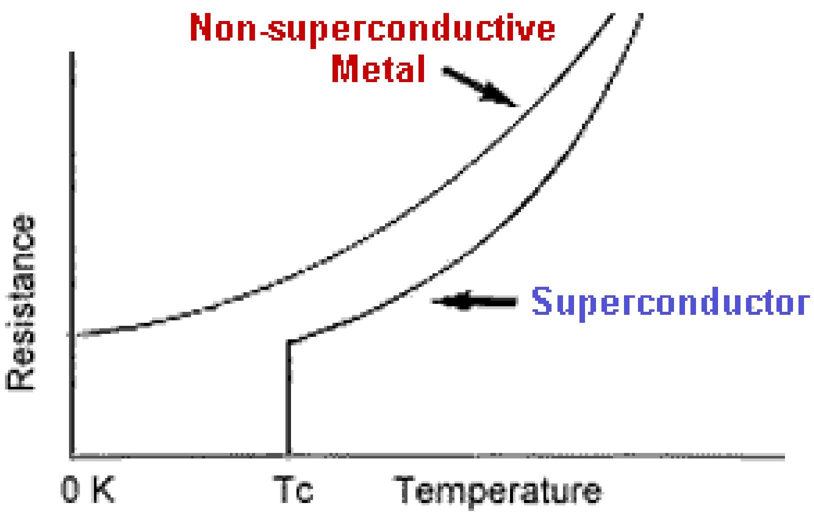
- Passage of electrical charge (Positive or Negative) from one part to other parts of the material under the influence of electrical potential.
- Materials are divided into three main categories on the basis of their Electrical resistivity(ρ= a R / l) expressed in Ohm.
- Conductors --------------------------- 10^{-8}-10^{-3}
- Semiconductors -------------------- 10^{-3}-10^{+3}
- Insulators(Dielectrics) ----------- 10^{+3}-10^{+15}

What is superconductivity ?

- **Superconductivity** is a phenomenon occurring in certain materials generally at very low temperatures, characterized by exactly zero electrical resistance and the exclusion of the interior magnetic field (the Meissner effect).

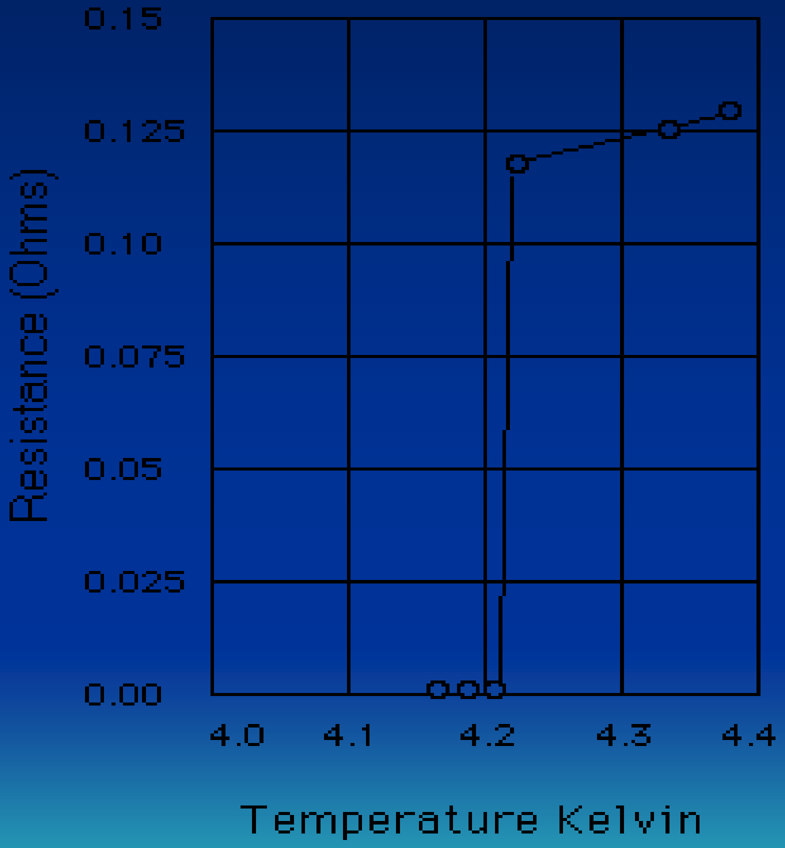
In simple words

For some materials, the resistivity vanishes at some low temperature: they become *superconducting*.



Superconductivity is the ability of certain materials to conduct electrical current with no resistance. Thus, superconductors can carry large amounts of current with little or no loss of energy.

Fig. 1


0.15
0.125
0.10
0.075
0.05
0.025
0.00
Resistance (Ohms)
4.0
4.1
4.2
4.3
4.4
Temperature Kelvin

- The electrical resistivity of a metallic conductor decreases gradually as the temperature is lowered.
- However, in ordinary conductors such as copper and silver, impurities and other defects impose a lower limit.
- Even near absolute zero a real sample of copper shows a non-zero resistance.
- The resistance of a superconductor, despite these imperfections, drops abruptly to zero when the material is cooled below its "critical temperature".

Believe it or not: An electric current flowing in a loop of superconducting wire can persist indefinitely with no power source.

The History of Superconductors

KAMERLINGH ONNES

- Superconductivity was discovered in 1911 by Heike Kamerlingh Onnes, who was studying the resistance of solid mercury at cryogenic temperatures using the recently-discovered liquid helium as a refrigerant.

- At the temperature of 4.2 K, he observed that the resistance abruptly disappeared. In subsequent decades, superconductivity was found in several other materials.

- In 1913, lead was found to superconduct at 7 K, and in 1941 niobium nitride was found to superconduct at 16 K.

- The next important step in understanding superconductivity occurred in 1933, when Meissner and Ochsenfeld discovered that superconductors expelled applied magnetic fields, a phenomenon which has come to be known as the Meissner effect.

- The complete microscopic theory of superconductivity was finally proposed in 1957 by Bardeen, Cooper, and Schrieffer. This BCS theory explained the superconducting current as a super fluid of Cooper pairs, pairs of electrons interacting through the exchange of phonons. For this work, the authors were awarded the Nobel Prize in 1972.

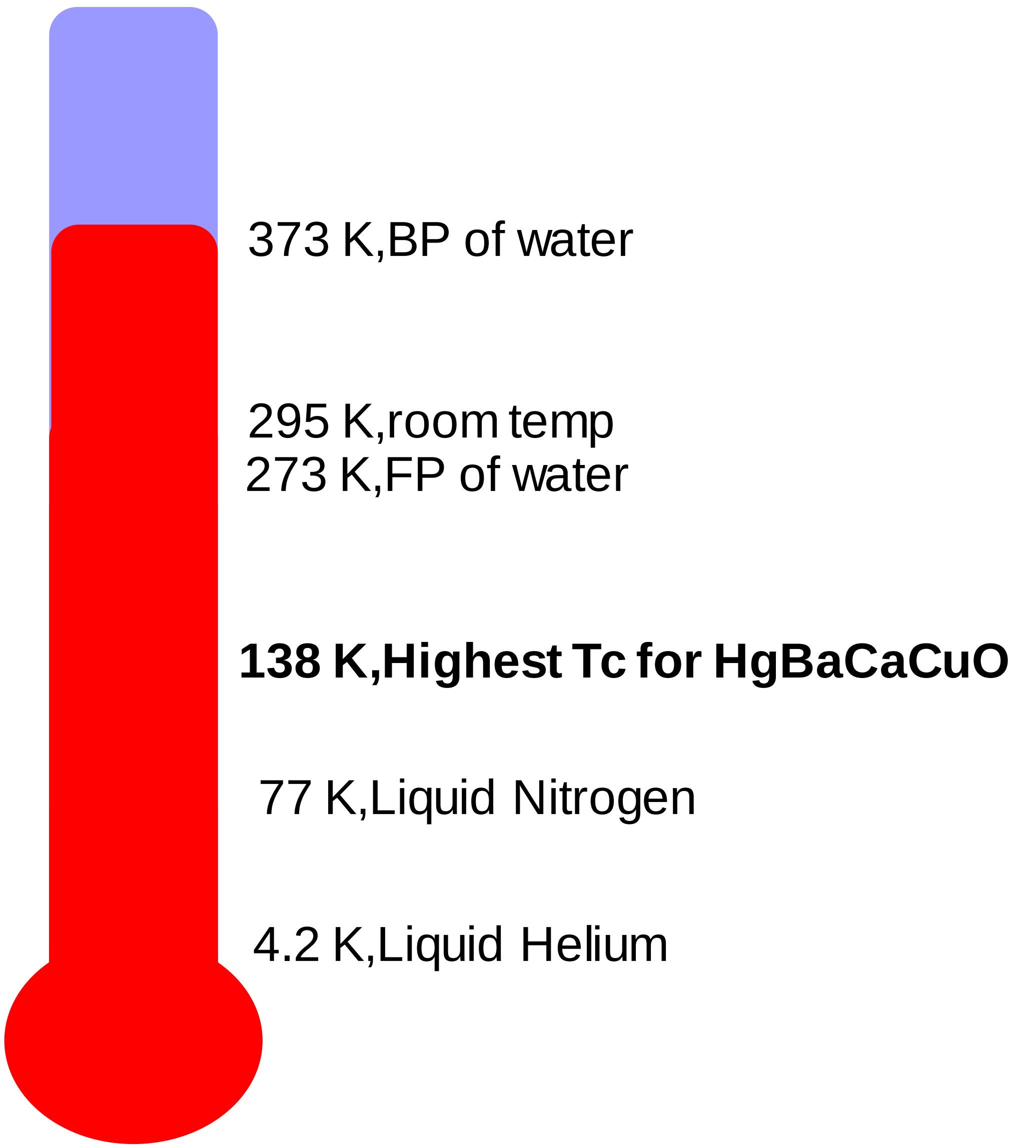
- In 1962, the first commercial superconducting wire, a niobium-titanium alloy, was developed by researchers at Westinghouse, allowing the construction of the first practical superconducting magnets

High-temperature superconductivity

- Until 1986, physicists had believed that BCS theory forbade superconductivity at temperatures above about 30 K.
- In that year, Bednorz and Müller discovered superconductivity in a lanthanum-based cuprate perovskite material, which had a transition temperature of 35 K (Nobel Prize in Physics, 1987). It was shortly found that replacing the lanthanum with yttrium, i.e. making **Yttrium barium copper oxide** (YBCO), raised the critical temperature to 92 K, which was important because liquid nitrogen could then be used as a refrigerant (at atmospheric pressure, the boiling point of nitrogen is 77 K)
- This is important commercially because liquid nitrogen can be produced cheaply on-site from air, and is not prone to some of the problems of helium in piping.

- Many other cuprate superconductors have since been discovered, and the theory of superconductivity in these materials is one of the major outstanding challenges of theoretical physics.
- From about 1993, the highest temperature superconductor was a ceramic material consisting of thallium, mercury, copper, barium, calcium, and oxygen,

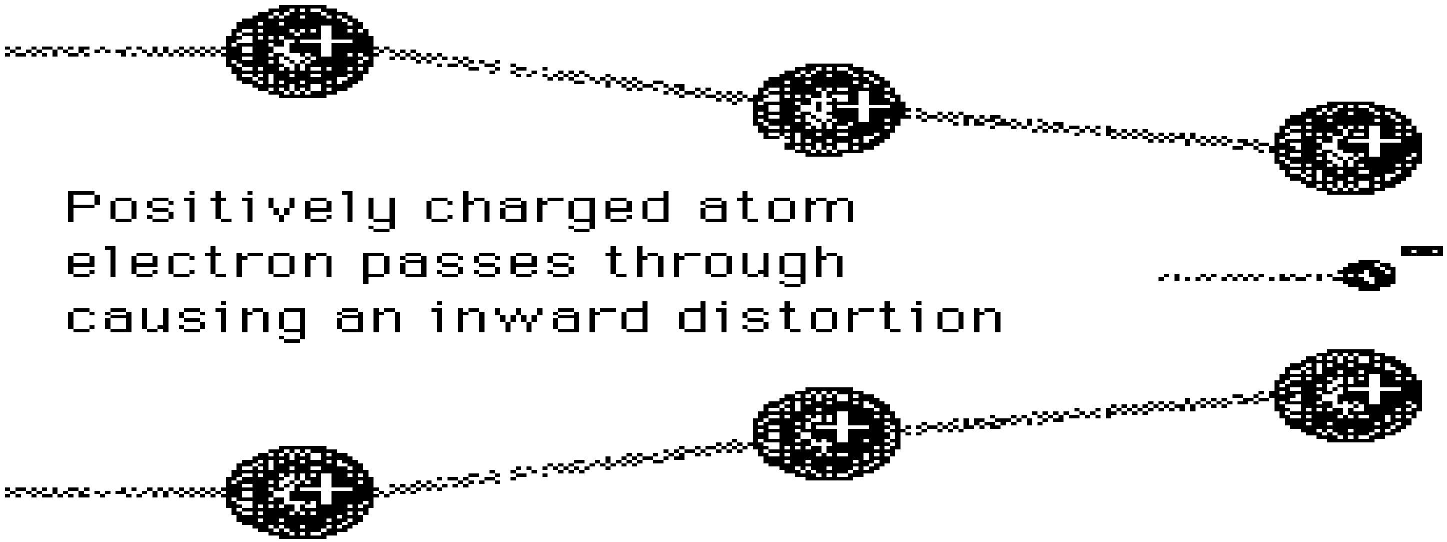
  with Tc=138 K


373 K,BP of water
295 K,room temp
273 K,FP of water
138 K,Highest Tc for HgBaCaCuO
77 K,Liquid Nitrogen
4.2 K,Liquid Helium

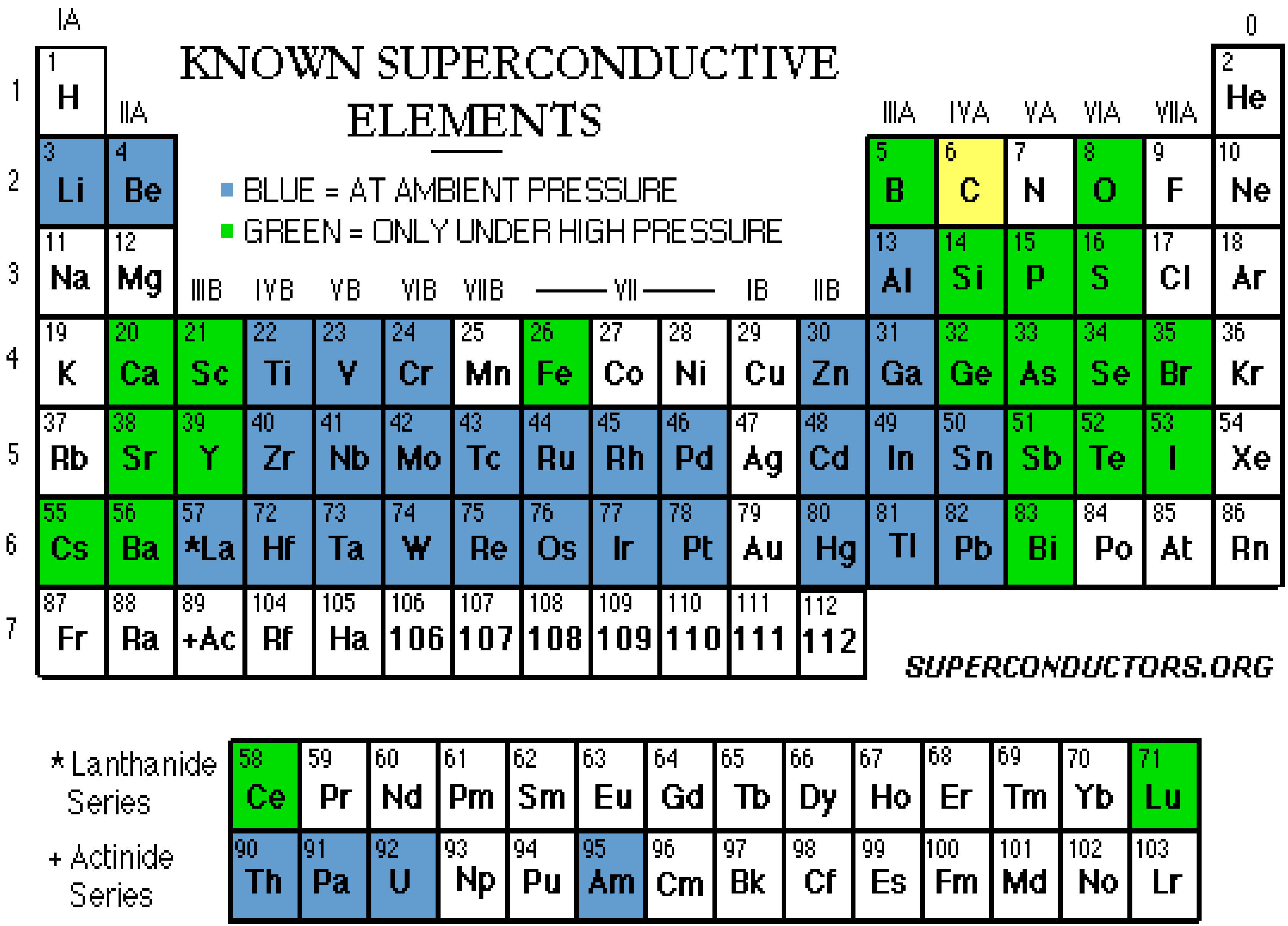
BCS-COOPER PAIRS

- A **Cooper pair** is the name given to electrons that are bound together in a certain manner first described by Leon Cooper. In normal superconductors, the attraction is due to the electron interaction. The Cooper Pair state forms the basis of the BCS theory of superconductivity developed by John Bardeen, John Schrieffer and Leon Cooper for which they shared the 1972 Nobel Prize.
- **A simplified explanation:** an electron in a metal normally behaves as basically a free particle. The electron is repelled from other electrons due to their similar charge, but it also attracts the positive ions that make up the rigid lattice of the metal. This attraction can distort the positively charged ions in such a way as to attract other electrons (the electron interaction). This attraction due to the displaced ions can overcome the electrons repulsion due to the electrons having the same charge and cause them to pair-up. Generally, the pairing only occurs at low temperatures and is quite weak, meaning the paired electrons may still be many hundreds of nanometers apart.

Superconducting State



As a negatively charged electron passes between the metal's positively charged atoms in the lattice, the atoms are attracted inward. This distortion of the lattice creates a region of enhanced positive charge which attracts another electron



KNOWN SUPERCONDUCTIVE ELEMENTS
BLUE = AT AMBIENT PRESSURE
GREEN = ONLY UNDER HIGH PRESSURE
IA IIA IIIB IVB VB VIB VIIB VII IB IIB IIIA IVA VA VIA VIIA 0
1 2 3 4 5 6 7
1 H 2 He
3 Li 4 Be 5 B 6 C 7 N 8 O 9 F 10 Ne
11 Na 12 Mg 13 Al 14 Si 15 P 16 S 17 Cl 18 Ar
19 K 20 Ca 21 Sc 22 Ti 23 V 24 Cr 25 Mn 26 Fe 27 Co 28 Ni 29 Cu 30 Zn 31 Ga 32 Ge 33 As 34 Se 35 Br 36 Kr
37 Rb 38 Sr 39 Y 40 Zr 41 Nb 42 Mo 43 Tc 44 Ru 45 Rh 46 Pd 47 Ag 48 Cd 49 In 50 Sn 51 Sb 52 Te 53 I 54 Xe
55 Cs 56 Ba 57 *La 72 Hf 73 Ta 74 W 75 Re 76 Os 77 Ir 78 Pt 79 Au 80 Hg 81 Tl 82 Pb 83 Bi 84 Po 85 At 86 Rn
87 Fr 88 Ra 89 +Ac 104 Rf 105 Ha 106 106 107 107 108 108 109 109 110 110 111 111 112 112
SUPERCONDUCTORS.ORG
* Lanthanide Series
58 Ce 59 Pr 60 Nd 61 Pm 62 Sm 63 Eu 64 Gd 65 Tb 66 Dy 67 Ho 68 Er 69 Tm 70 Yb 71 Lu
+ Actinide Series
90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm 97 Bk 98 Cf 99 Es 100 Fm 101 Md 102 No 103 Lr

Terms

- Liquid nitrogen :- **Liquid nitrogen** is nitrogen in a liquid state at an extremely low temperature. It is produced industrially by fractional distillation of liquid air . It is used for cooling a high-temperature superconductor to a temperature sufficient to achieve superconductivity .
- Ceramic(Yttrium- Barium-Copper-Oxide):-

  Yttrium barium copper oxide, often abbreviated YBCO, is a crystalline chemical compound with the formula $YBa_2Cu_3O_7$. This material, a famous "high-temperature superconductor", achieved prominence because it was the first material to achieve superconductivity above the boiling point (77 K) of liquid nitrogen.

Liquid nitrogen

Yttrium barium copper oxide

- Meissner effect :- The **Meissner effect** is an expulsion of a magnetic field from a superconductor during its transition to the superconducting state**.**

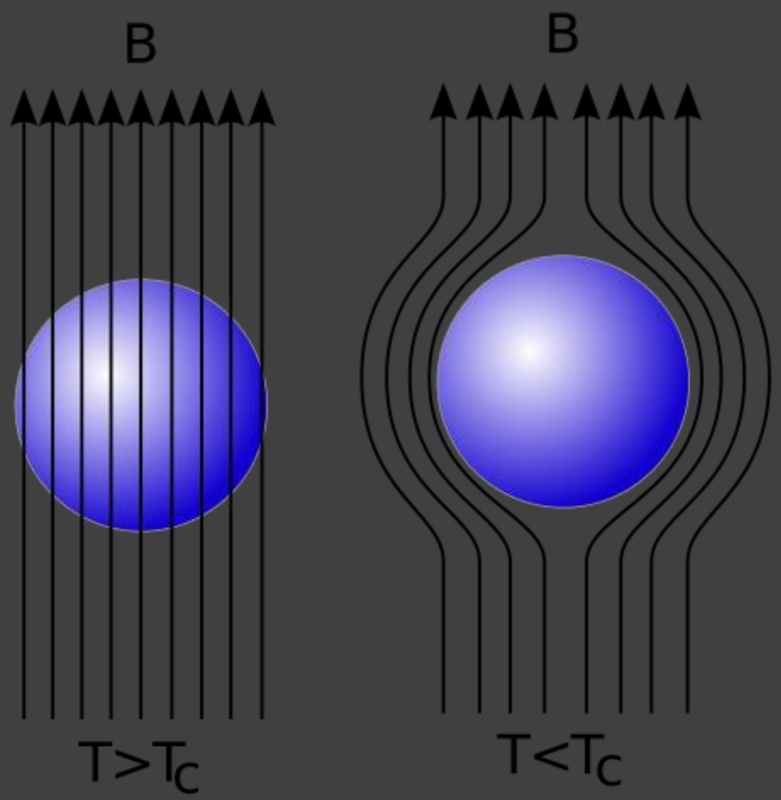
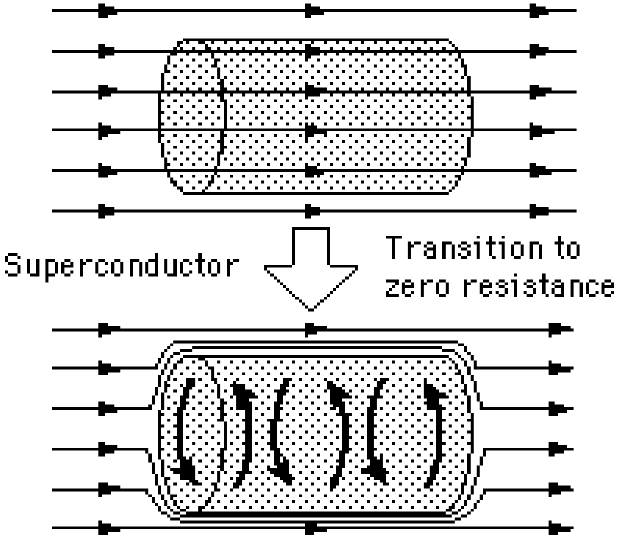
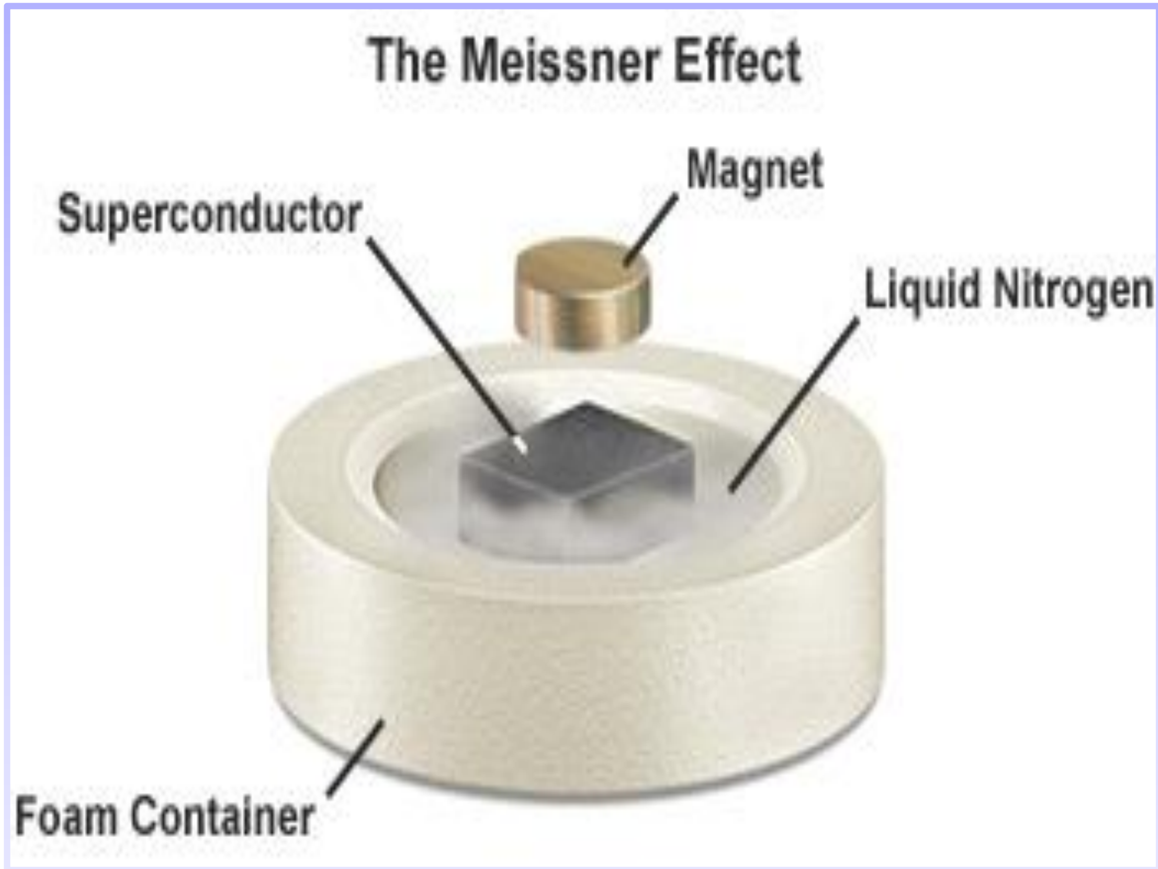


Diagram of the Meissner effect. Magnetic field lines, represented as arrows, are excluded from a superconductor when it is below its critical temperature.

- When a superconductor is placed in a weak external magnetic field, the field penetrates the superconductor only at a small distance, called the London penetration depth, decaying exponentially to zero within the bulk of the material.
- This is called the Meissner effect, and is a defining characteristic of superconductivity.
- For most superconductors, the London penetration depth is on the order of 100 nm.





https://www.youtube.com/watch?v=HRLvVkkq5GE

Table 7.1. Critical Temperatures of Some Superconducting Materials.

Materials	T_c [K]	Remarks
Tungsten	0.01	—
Mercury	4.15	H.K. Onnes (1911)
Sulfur-based organic superconductor	8	S.S.P. Parkin et al. (1983)
Nb_3Sn and Nb–Ti	9	Bell Labs (1961), Type II
V_3Si	17.1	J.K. Hulm (1953)
Nb_3Ge	23.2	(1973)
La–Ba–Cu–O	40	Bednorz and Müller (1986)
$YBa_2Cu_3O_{7-x}$[a]	92	Wu, Chu, and others (1987)
$RBa_2Cu_3O_{7-x}$[a]	$\sim$92	R = Gd, Dy, Ho, Er, Tm, Yb, Lu
$Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$	113	Maeda et al. (1988)
$Tl_2CaBa_2Cu_2O_{10+\delta}$	125	Hermann et al. (1988)
$HgBa_2Ca_2Cu_3O_{8+\delta}$	134	R. Ott et al. (1995)

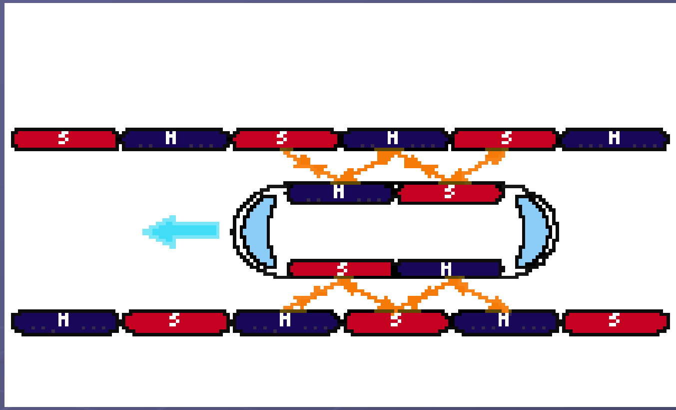
[a] The designation "1-2-3 compound" refers to the molar ratios of rare earth to alkaline earth to copper. (See chemical formula.)

Superconducting magnet

A **superconducting magnet** is an electromagnet made from coils of superconducting wire. They must be cooled to cryogenic temperatures during operation. In its superconducting state the wire has no electrical resistance and therefore can conduct much larger electric currents than ordinary wire, creating intense magnetic fields. Superconducting magnets can produce greater magnetic fields than all but the strongest non-superconducting electromagnets and can be cheaper to operate because no energy is dissipated as heat in the windings. They are used in MRI machines in hospitals, and in scientific equipment such as NMR spectrometers, mass spectrometers, fusion reactors and particle accelerators. They are also used for levitation, guidance and propulsion in a magnetic levitation (maglev) railway system being constructed in Japan.

Applications:

Superconducting Magnetic Levitation

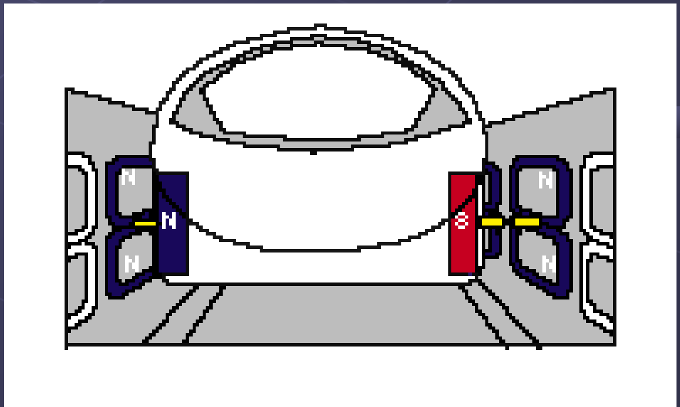


The Yamanashi MLX01MagLev Train

The track are walls with a continuous series of vertical coils of wire mounted inside. The wire in these coils is not a superconductor.

As the train passes each coil, the motion of the superconducting magnet on the train induces a current in these coils, making them electromagnets.

The electromagnets on the train and outside produce forces that levitate the train and keep it centered above the track. In addition, a wave of electric current sweeps down these outside coils and propels the train forward.



Applications:

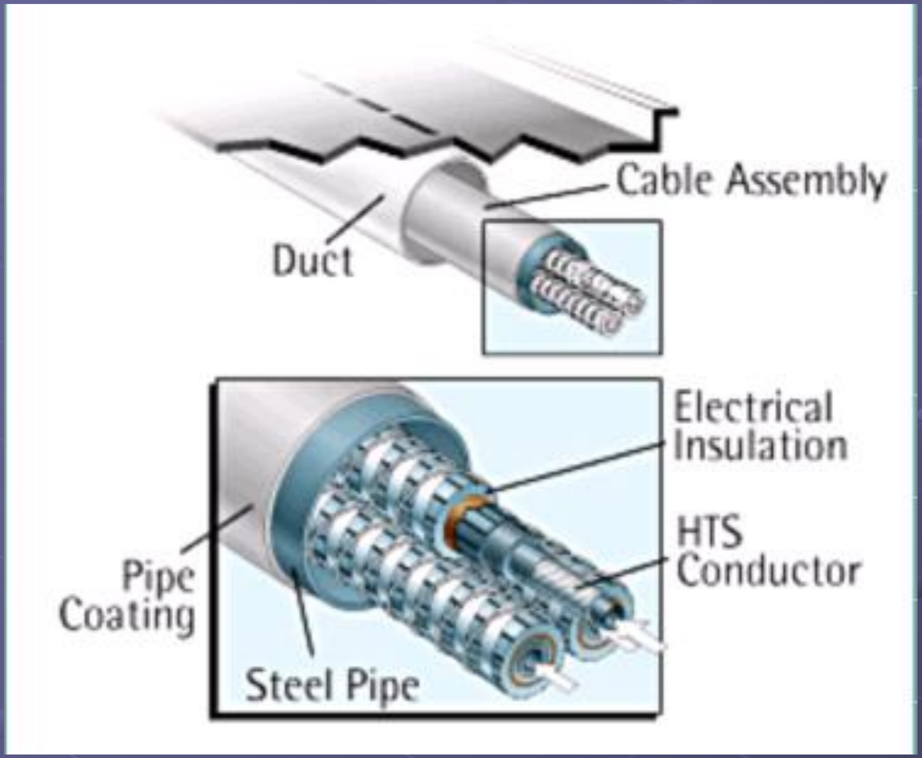
Medical:

MRI (Magnetic Resonance Imaging) scans produce detailed images of soft tissues.

The superconducting magnet coils produce a large and uniform magnetic field inside the patient's body.

Applications:

Power



The cable configuration features a conductor made from HTS (high-temperature superconductivity) wires wound around a flexible hollow core.
Liquid nitrogen flows through the core, cooling the HTS wire to the zero resistance state.

The conductor is surrounded by conventional dielectric insulation. The efficiency of this design reduces losses.

Superconducting Transmission Cable
From American Superconductor

Superconductors may one day fuel superfast computers, which will, of course, benefit intelligence agencies that need to process and analyse vast quantities of data.

With a growing demand for electronics having miraculous characteristics (low noise, low loss, low dissipation, less weight, high resolution, high speed, high frequency, etc), use of electronic and superconductivity properties of materials—together known as 'superconducting electronics' or 'electronics with superconductors'—is turning to be a field with varied applications, including superconducting circuits, superconducting quantum interference devices (SQUIDS) magnetometers, current limiters and electronic filters.

Superconducting electronics is of great interest for several niche applications, like ultrafast routers for communication networks, analogue-to-digital converters working in the microwave field and ultra-sensitive digital receivers, which have no counterpart in the semiconductor world.

NOBLE PRIZES FOR SUPERCONDUCTIVITY

Nobel Prizes for superconductivity

- Heike Kamerlingh Onnes (1913), "for his investigations on the properties of matter at low temperatures which led, inter alia, to the production of liquid helium"
- John Bardeen, Leon N. Cooper, and J. Robert Schrieffer (1972), "for their jointly developed theory of superconductivity, usually called the BCS-theory"
- Leo Esaki, Ivar Giaever, and Brian D. Josephson (1973), "for their experimental discoveries regarding tunneling phenomena in semiconductors and superconductors, respectively," and "for his theoretical predictions of the properties of a supercurrent through a tunnel barrier, in particular those phenomena which are generally known as the Josephson effects"
- Georg Bednorz and Alex K. Muller (1987), "for their important break-through in the discovery of superconductivity in ceramic materials"
- Alexei A. Abrikosov, Vitaly L. Ginzburg, and Anthony J. Leggett (2003), "for pioneering contributions to the theory of superconductors and superfluids"