Superconductivity and Magnetism

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Outline

1. **Motivation**
2. **Resistance**
3. **Properties of Superconductivity**
   - **A. Meissner Effect**
   - **B. Zero Resistance**
4. **Quantum Locking, Levitation and Type II SC**
5. **Fe Pnictides**

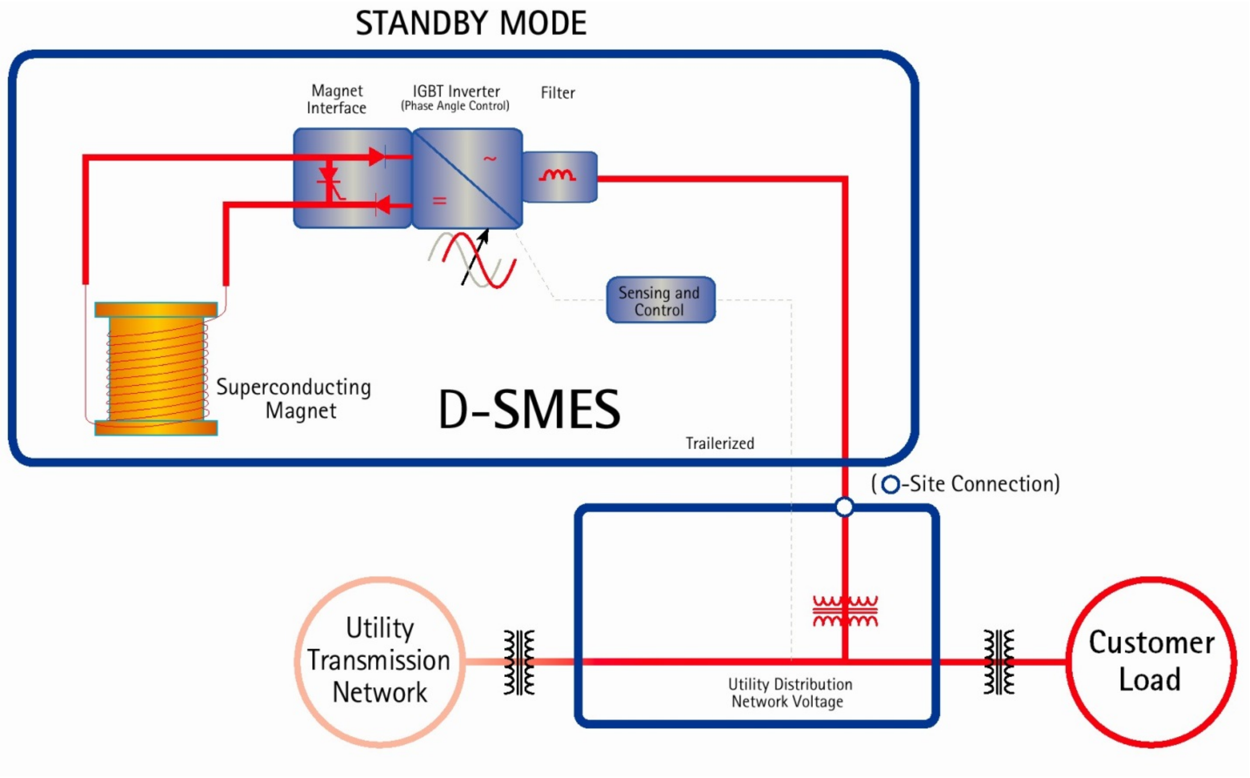
1. Motivation For Studying Superconductivity

A. Energy storage

B. Levitation –Friction Free Trains

C. Energy Transportation

A. Energy storage



Energy stored = ½ L I^2

B: Levitation:

http://www.youtube.com/watch?v=Ws6AAhTw7RA

C. Electrical Energy Transportation

Transmitting electricity at high voltage reduces the fraction of energy lost to resistance, which varies depending on the specific conductors, the current flowing (measured in kilo-Amperes (kA.)) and the length of the transmission line. For example, a 100 mile 765 kV line carrying 1000 MW of energy can have losses of 1.1% to 0.5%. A 345 kV line carrying the same load across the same distance has losses of 4.2%.[8] For a given amount of power, a higher voltage reduces the current and thus the resistive losses in the conductor. For example, raising the voltage by a factor of 10 reduces the current by a corresponding factor of 10 and therefore the **I^2R (power) losses** by a factor of 100, provided the same sized conductors are used in both cases. Even if the conductor size (cross-sectional area) is reduced 10-fold to match the lower current the I^2R losses are still reduced 10-fold. Long-distance transmission is typically done with overhead lines at voltages of 115 to 1,200 kV.

So 0.04×10^6 watts = 40,000 Joules are lost per sec as heat per line which is enough to light 400 x 100 watt light bulbs continuously--- If R =0 then no energy would be lost in transit

2. Resistance:

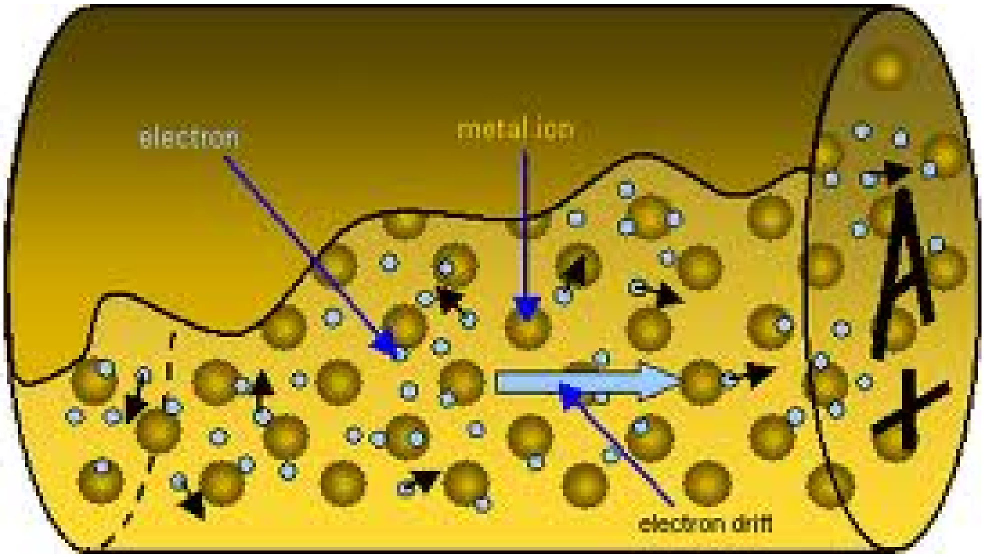
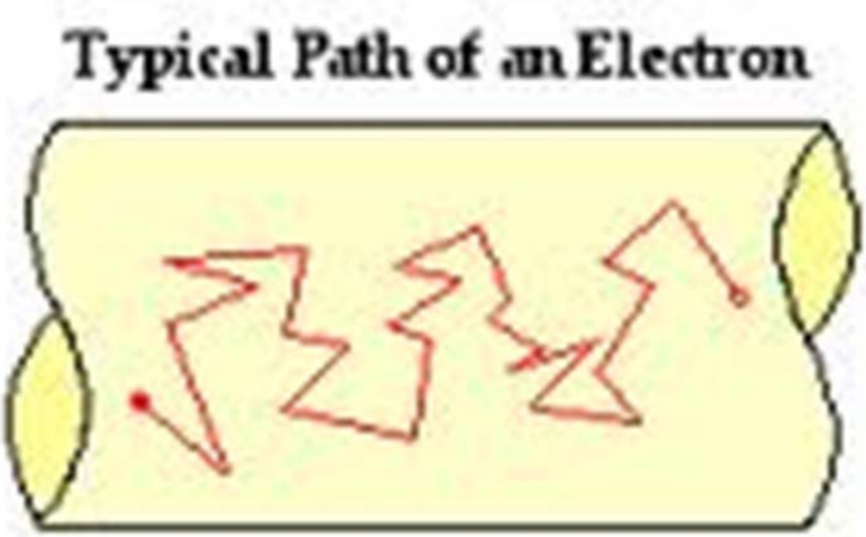


Figure 1


Typical Path of an Electron

Some terms:

V electron velocity $\sim 10^{4}$ m/s

$V_d = (e\,\tau/m)\ E$ drift velocity $\sim 10^{-3}$ m/s

$I_e = (n_e\,\tau\,A\,e/m)\ E$ electron current

$\tau \sim 10^{-14}$ sec, collision time

$n_e \sim 10^{28}$ e/m^3 free electron density

$\rho = 1/\sigma$ resistivity

ρ (Copper) = $1.7 \times 10^{-8}\ \Omega$-m

$\sigma = (n_e\,\tau e^2)/m$

Resistance $= \rho L/A$

100m of wire with a 10^{-6}m^2, $R \sim 1\ \Omega$

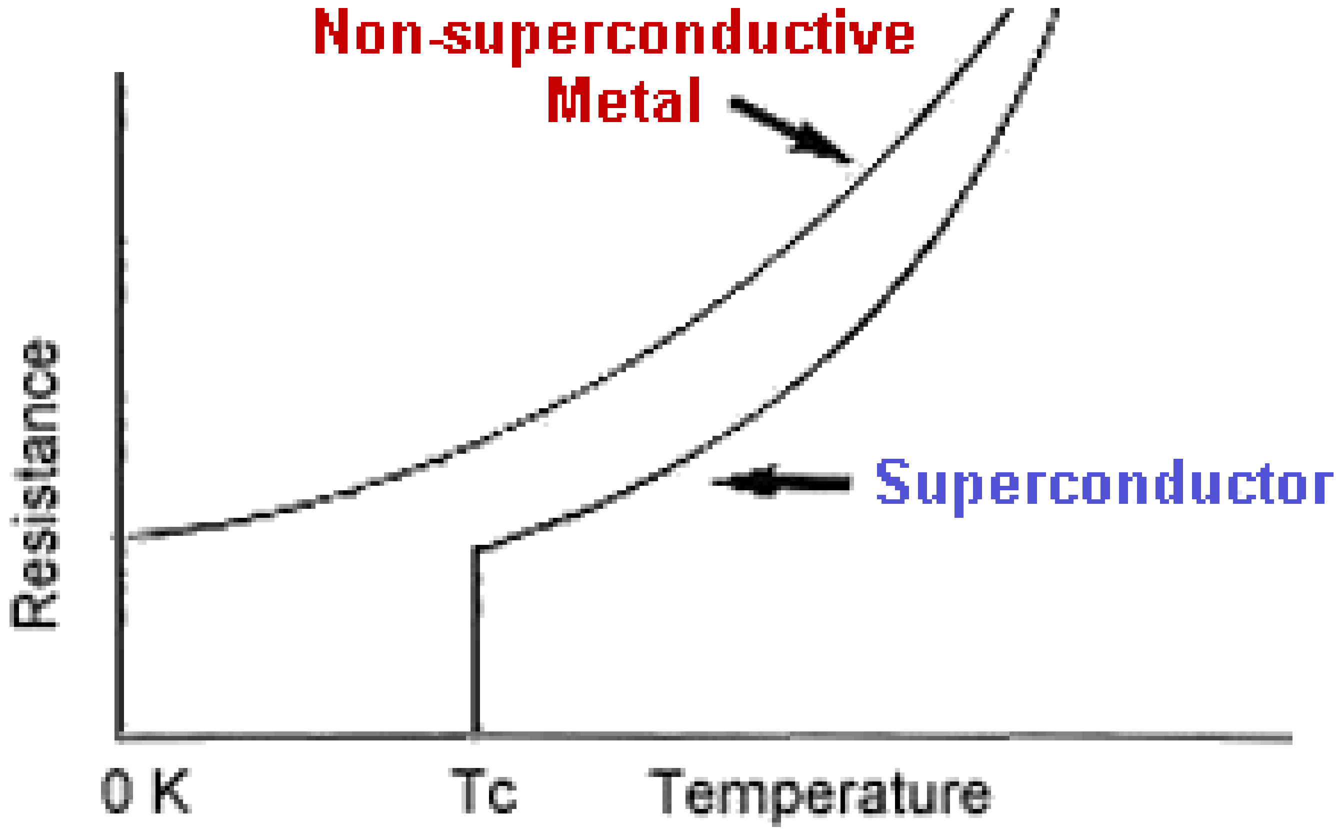
So a wire like that is carrying a 10 Amp current for 1 day uses thermal or heat = 8,640,000 Joules --

enough energy to light 144,000 ---60 watt light bulbs for one second

It is not hard to imagine that a considerable amount of energy could be saved if R=0

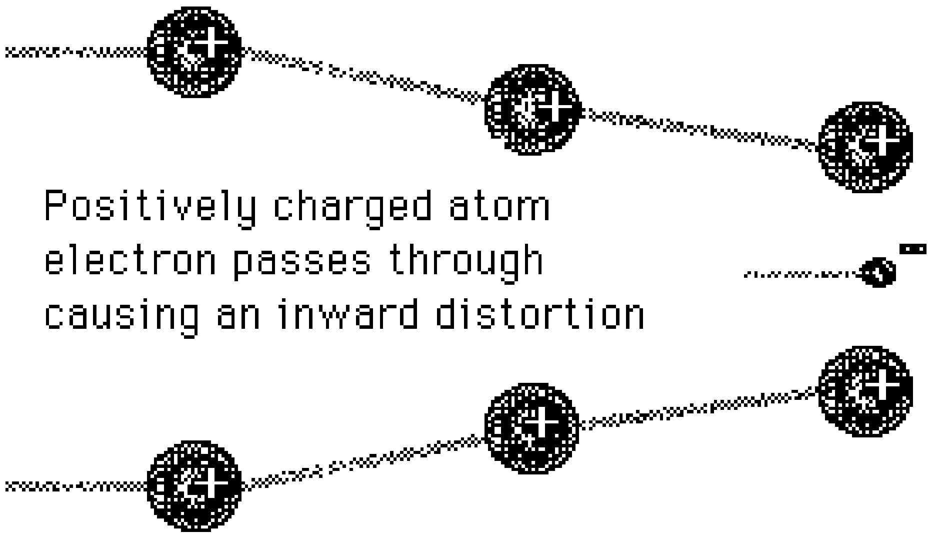
3. Properties Of Superconductors: http://www.lorentz.leidenuniv.nl/history/cold/DelftKes_HKO_PT.pdf

A. **Zero resistance**:



Collective Effect of Electrons coupling together:

Superconducting State



Positively charged atom
electron passes through
causing an inward distortion

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 to the area.

Fig. 4

Some electrons make a transition to a lower energy state where only **elastic** collisions are possible with ions in a metal.

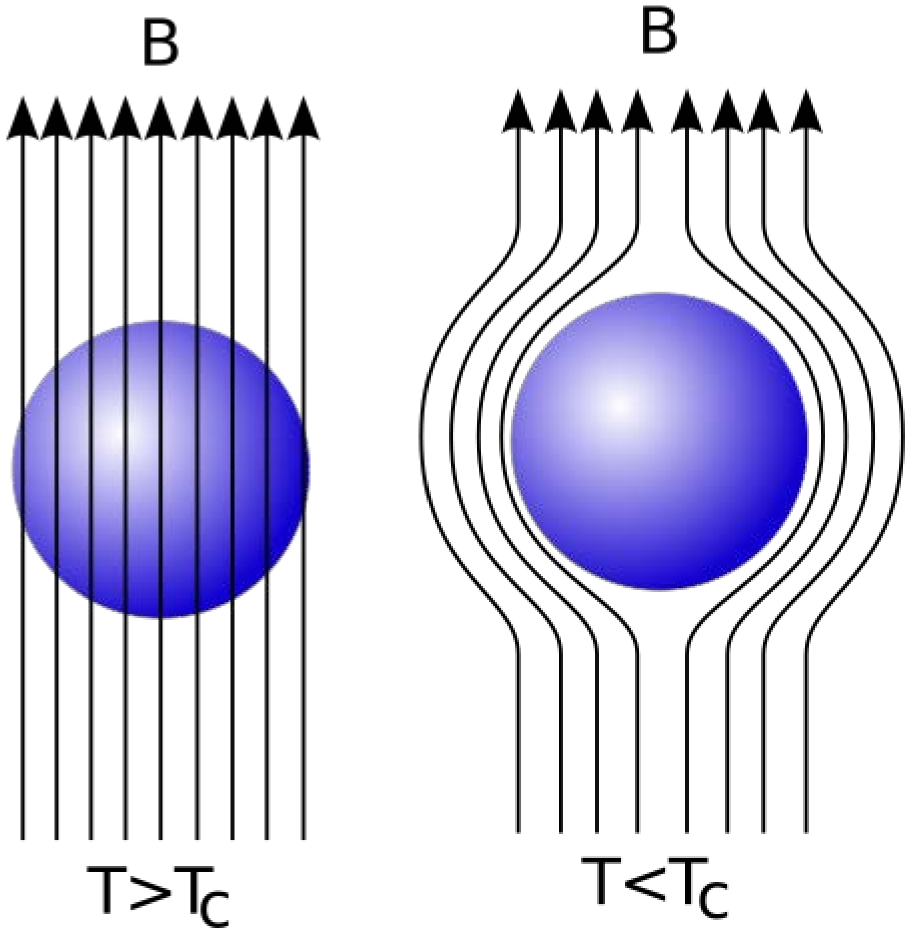
These electrons bind together to form Cooper pairs and the energy is stored in potential energy between or really among many electrons.

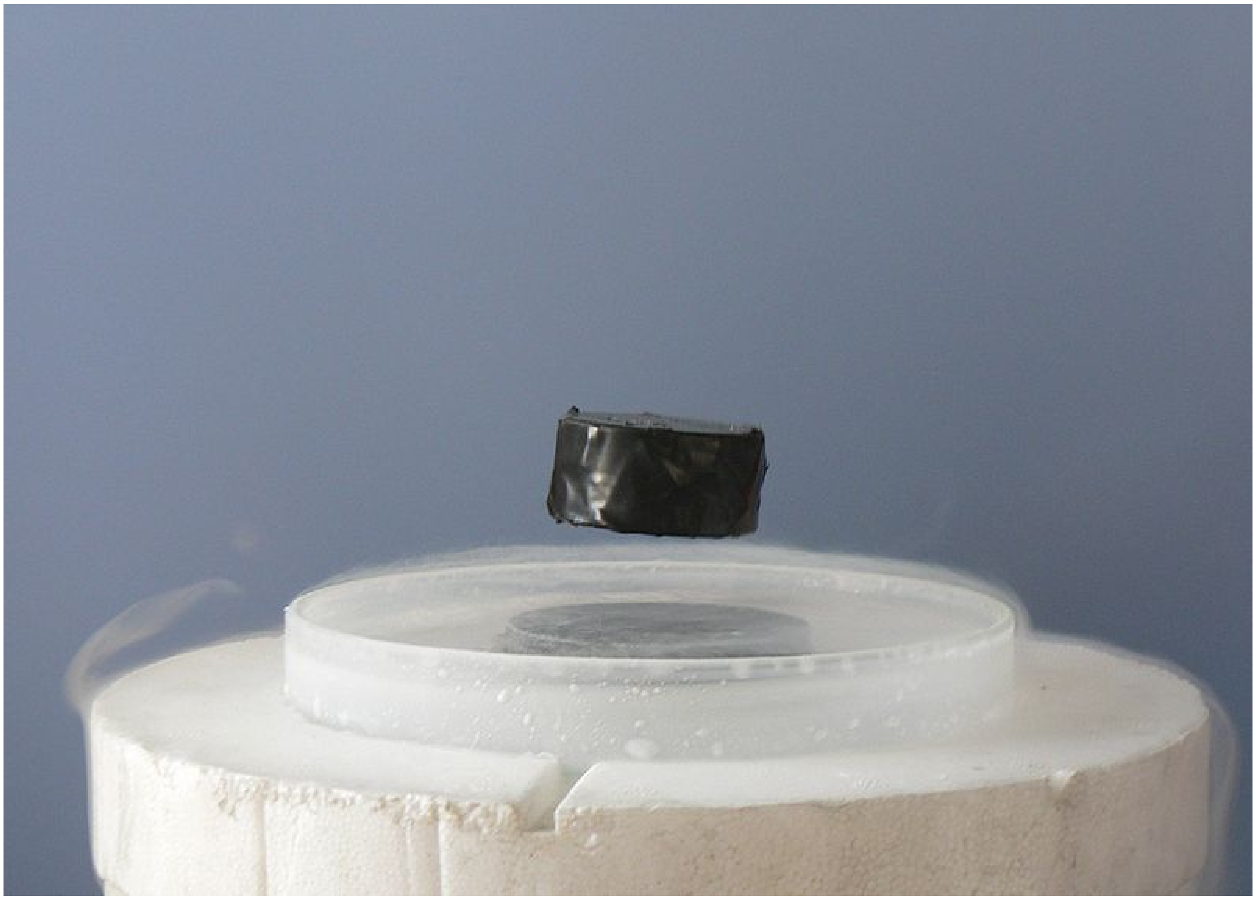
Why? A general rule of nature is that if a system can go to a lower energy it will if the conditions are proper such as temperature. Take water for instance--- freezes at 0 C or 273K

These SC electrons can't lose kinetic energy in the elastic collision process with ions in the metal and the τ (collision time) for the energy loss becomes infinite in a classical description –so σ becomes infinite: $\boldsymbol{\sigma = (n_e \tau e^2)/m}$

The current, I, remains constant as result for all time.

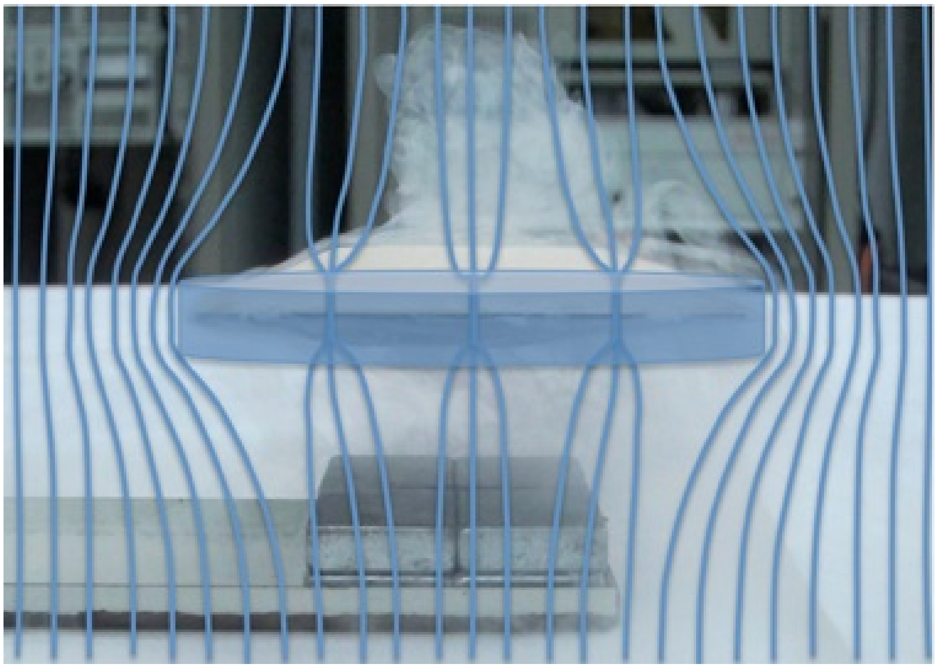
B.**Meissner Effect**: In 1933 Meissner and Ochsenfeld discovered another property of superconductors, which is in fact believed by many to be an even more basic characterization. This phenomenon, which is popularly called the Meissner effect, has to do with the magnetism of a superconductor. You're no doubt familiar with the fact that iron has remarkable magnetic properties. Iron tends to draw to it the lines of magnetic force of a magnet. That's why iron is often used to make electromagnets. It helps to guide the magnetic lines of force around in space where you wish to have them. The superconductor is just the opposite. It's what is called a perfect diamagnet. A superconductor excludes the lines of magnetic force. If you bring a small bar magnet up to a superconductor, the superconductor bends the lines of force away from and doesn't allow them to penetrate. B= Magnetic Field





Above is the levitation of a superconductor below its transition temperature which is an example of this flux expulsion but we find there is also more going in this case ----quantum locking effect mentioned earlier if the it is a very thin SC wafer

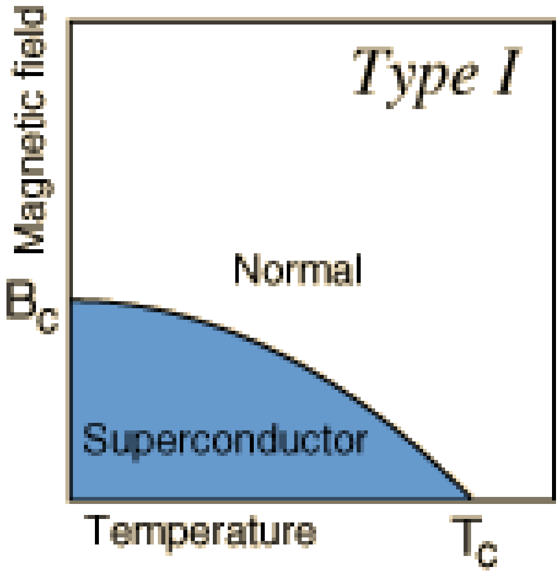
4. Quantum Locking

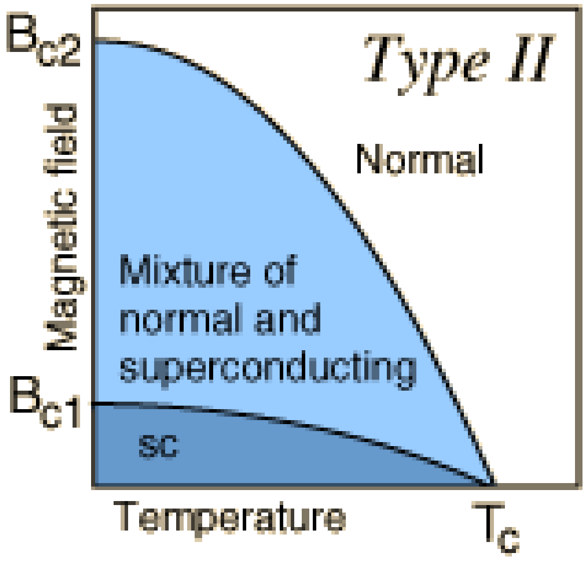


Superconductors hate magnetic fields (when cold enough), and normally would just repel the magnetic force and float in a wobbly fashion. But because the superconductor is so thin in this case, tiny imperfections allow some magnetic forces through. These little magnetic channels are called flux tubes [pictured here].

The flux tubes cause the magnetic field to be "locked" in all three dimensions, which is why the disk remains in whatever position it starts in, levitating around the magnets.

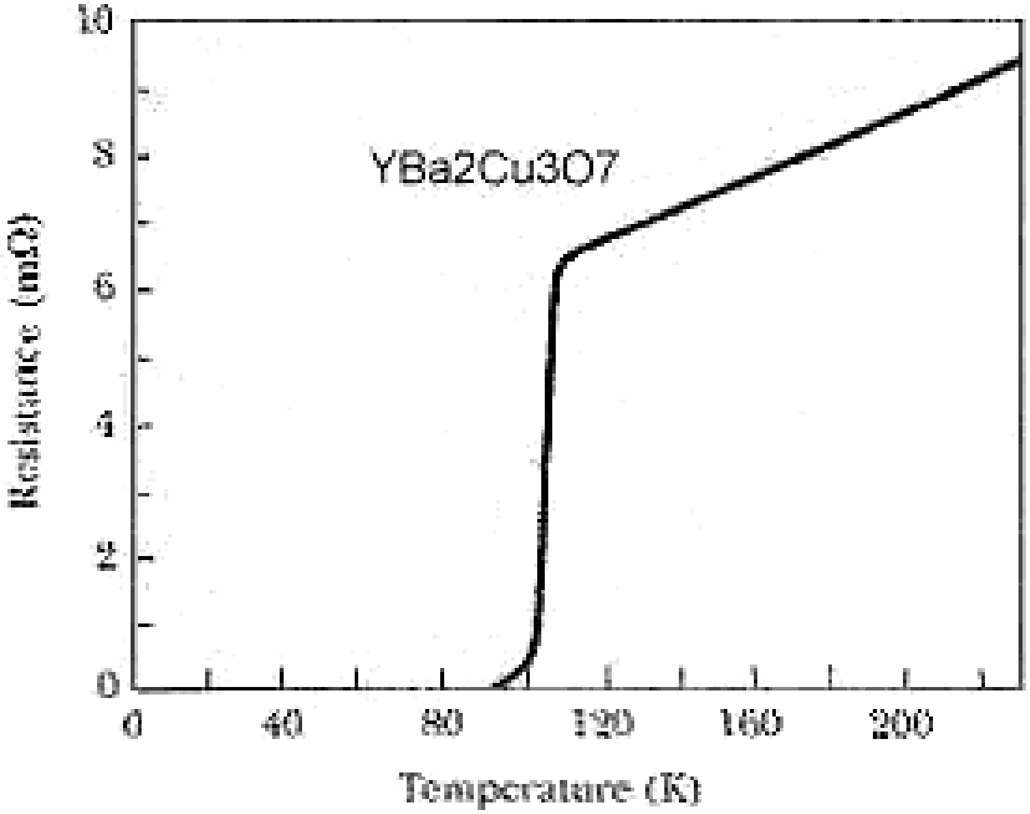
Flux pinning is the phenomenon where a superconductor is pinned in space above a magnet. The superconductor must be a type-II superconductor due to the fact that type-I superconductors cannot be penetrated by magnetic fields. The act of magnetic penetration is what makes flux pinning possible. At higher temperatures the superconductor allows magnetic flux to enter in quantized packets surrounded by a superconducting current vortex.





Material	Transition Temp (K)	Critical Field (T)
NbTi	10	15
PbMoS	14.4	6.0
V_3Ga	14.8	2.1
NbN	15.7	1.5
V_3Si	16.9	2.35
Nb_3Sn	18.0	24.5
Nb_3Al	18.7	32.4
$Nb_3(AlGe)$	20.7	44
Nb_3Ge	23.2	38

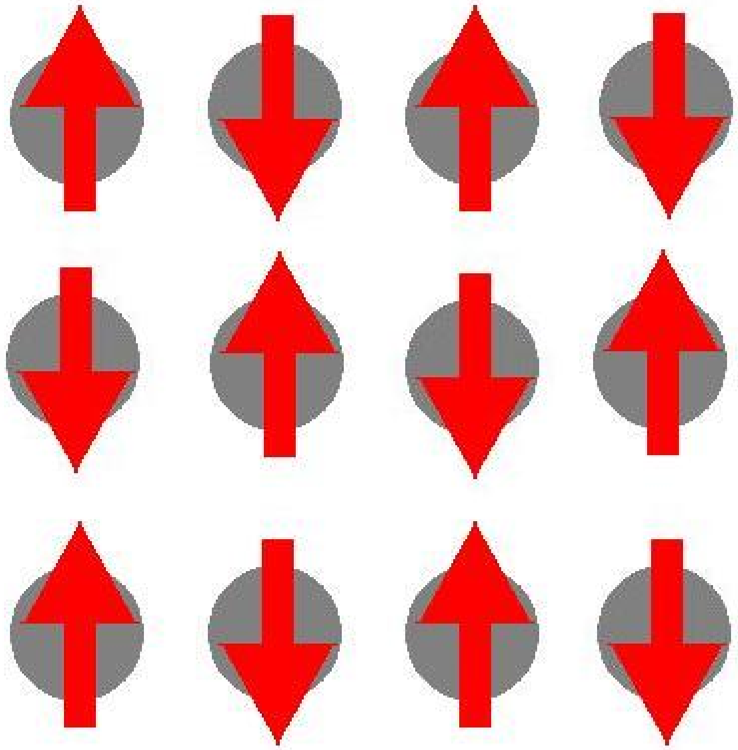
From Blatt, Modern Physics



5. Fe Pnictides SmFeAsO

The close proximity of superconductivity to magnetism is well known for about twenty years. What happens is a material that is magnetic is doped with a either electrons or holes and then interestingly a superconductor is born. The theoretical mechanism for this process is still undiscovered.

In this case of the Fe pnictides –SmFeAsO is an antiferromagnet at T =137K-these are prototypical of many systems that become superconducting



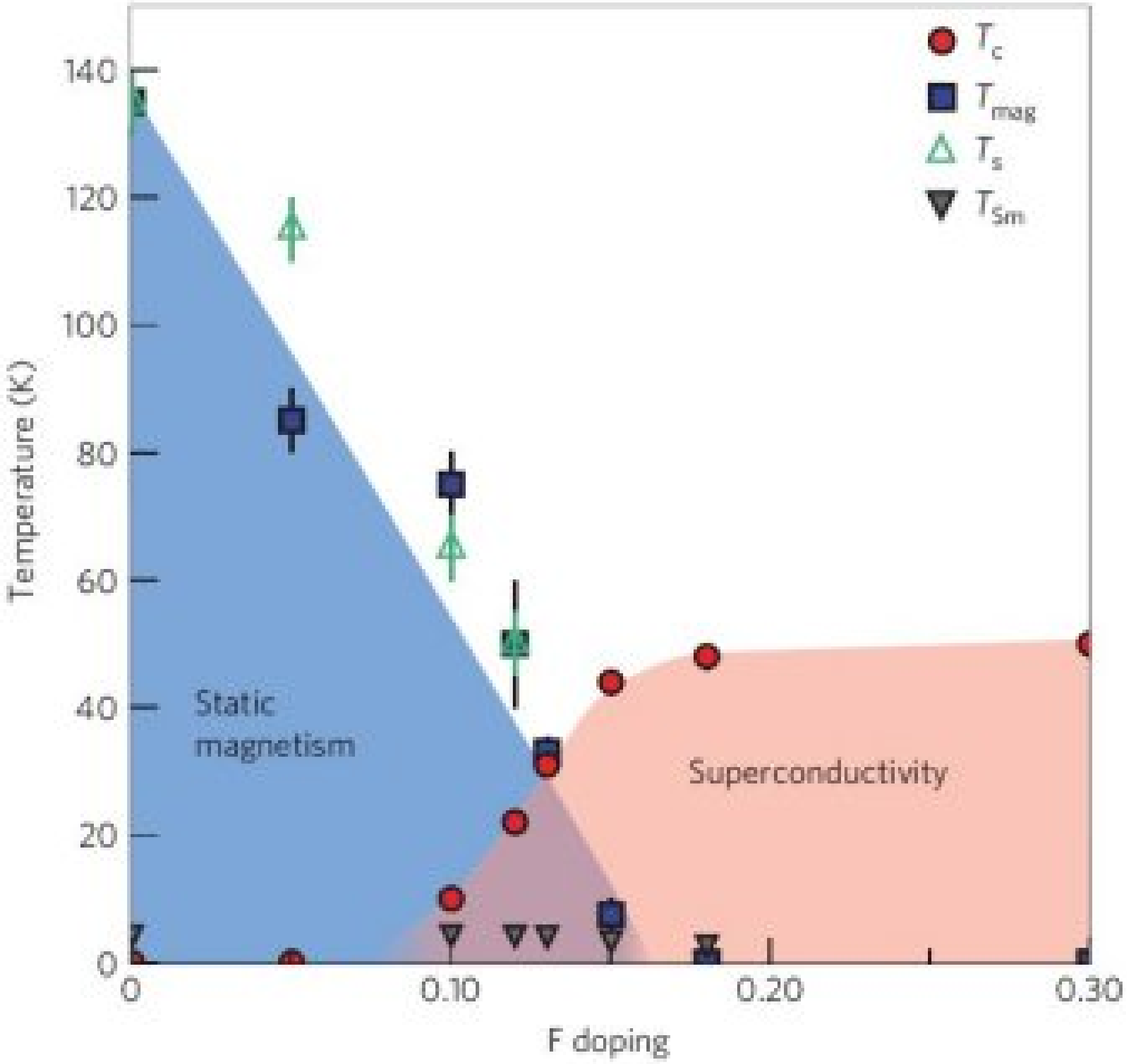
If you add Co to the SmFe0.95Co0.05AsO the compound becomes superconducting at about 5K. As you lower the temperature the signal from the sample shows a magnetic component which is fluctuating in time so it is not static –This shows direct evidence for the coexistence of magnetism and superconductivity at the interface in the phase diagram between superconductivity and magnetism

If you increase the Co content to 0.1 the compound does not show this fluctuating behavior and it is superconducting at 17K

The absence of the of fluctuating magnetism in the

Co= .05 compound and its absence in Co =0.1 shows that the superconductivity is in competition with magnetism at this interface.

G. Long et al … Phy Rev B 84, 064423(2011)



This is seen in the phase diagram for SmFeAsOF which is very similar to SmCoFeAsO