Superconductors – Research

Definition:

A superconductor is a conductor that, below a critical temperature (Figure 1), has a resistivity of 0*. Amongst other things this results in a strange effect whereby a current can travel in a loop indefinitely with no power source**.

Mechanism:

For a long time, the mechanisms behind superconductivity weren't understood and certainly not explained by conventional physics. However, in 1957 the Bardeen–Cooper–Schrieffer (BCS) theory was proposed by (you guessed it) John Bardeen, Leon Cooper, and John Robert Schrieffer.

The theory suggests that there is some amount of attraction between electrons that (at low enough temperatures) allows them to join up into pairs called Cooper pairs (named after Leon Cooper). This attraction is due to the opposite charge between the atoms in the lattice of the material and the electrons which causes the lattice to compress as its attracted to an electron resulting in an area of a more concentrated positive charge that attracts another electron behind it (Figure 2). Despite the way "pair" sounds Cooper pair electrons can be a large distance away from one another (in the range of hundreds of nanometres which is large on the atomic scale (Figure 3)). Cooper pairs only exist at a low enough energy (less than 1 meV) due to the weakness of the interaction.

Due to these Cooper pairs' tendency to "condense" into the lowest energy state (known as a ground quantum state) this results in a minimum energy for excitation (I.E. an electron breaking from its Cooper pair) as most excitations such as scattering electrons cannot occur. This results in superconductivity as no scattering electrons means no resistance (since the scattering of electrons is what causes electrical resistance).

Meisner Effect or "Floating Rocks":

The Meisner effect is the effect by which superconductors repel magnets when cooled below their critical temperature, this results in a sort of "floating" effect (Figures 4 and 5) and is due to the superconductor excluding the magnetic field (Figure 6). This is due to the magnet inducing magnetism on the outside surface of the superconductor (the thickness of which is known as the London penetration depth) which then shields the rest of the superconductor and leads to the property that makes it theoretically useful for maglevs or floating sky islands (Figure 7).

* not "negligible" or "tiny" but complete 0

** now before you start waffling about "perpetual motion" and "free energy" it's more akin to traveling in a vacuum (no resistance) and no work can be extracted. We obey the laws of thermodynamics in this household!

The Fabled "Room Temperature Superconductor":

The idea of a "room temperature superconductor" is that of a superconducting material that doesn't require cooling before exhibiting superconductivity. Many attempts to make such a material have been happened but so far, the closest is LaH_{10} aka Lanthanum decahydride however this is at an absurd pressure of 170 gigapascals (for reference 1atm = 101kilopascals). The highest temperature superconductors that arent at extreme pressures are some absurd formulae such as $Hg_{12}Tl_3Ba_{30}Ca_{30}Cu_{45}O_{127,}$ $Bi_2Sr_2Ca_2Cu_3O_{10}$ (called BSCCO) and $YBa_2Cu_3O_7$. While these have high critical temperature between -135 to -181 respectively, they are nowhere near room temperature and also are absurdly complicated and expensive to manufacture.

Applications:

Due to a superconductors zero resistance superconductors are used to transfer electrical power without incurring any losses from resistance, this is especially useful in particle accelerators due to the high currents needed to produce the massive electromagnetic fields necessary for smashing particles together at 99.9999991% the speed of light.

Additionally, superconductor magnets are some of the most powerful electromagnets currently known and are namely used in particle accelerators (as beam steering magnets), MRI machines, mass spectrometers and tokamaks.

Tokamaks are devices that are used to confine plasma into a torus or "doughnut" shape using a powerful magnetic field***. These are especially useful for confining plasma in thermonuclear fusion reactors

Superconductors are also used to make Josephson junctions which are used to make SQUIDS (superconducting quantum interference devices) for quantum computers****.

Room (or otherwise high) temperature superconductors could be used to increase efficiency in power generation and transmission if/when the energy and monetary cost is outweighed by the efficiency gain. Additionally, power transmission through superconductive wires would allow for transmission of electricity at lower voltages

Due to the Meissner effect (see *Meisner Effect or "Floating Rocks"*) superconductors could be used in maglev (magnetic levitation) trains which have theoretical higher efficiency due to the elimination of friction with a track. This could further extend to vactrains or hyperloop systems which are effectively a maglev train contained within a tube at near zero pressure to remove air resistance and increase the top speed to hypersonic*****.

*** In a way this is somewhat like the Van Allen radiation belts, see my previous write up for more information.

**** I wont even pretend to understand quantum computers.

***** Move out of the way subatomic particles, mum says its my turn to ride the particle accelerator!

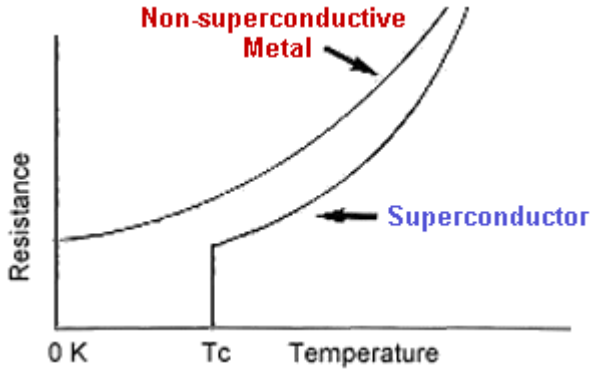

Figure 1: The graph for a superconductor (Credit: CERN)

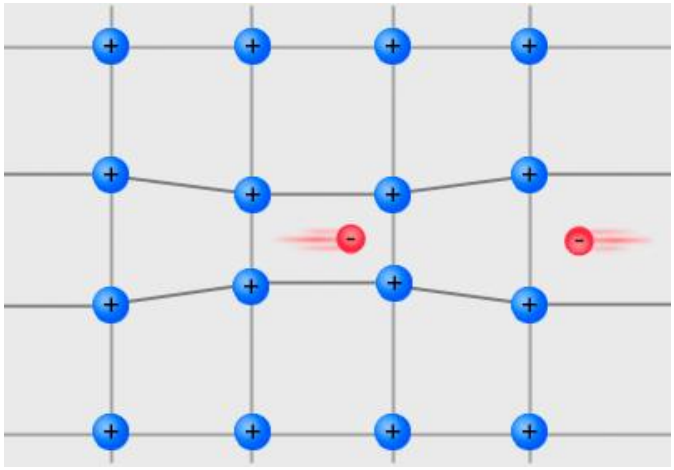

Figure 2: Cooper pairs, squishing the lattice (Credit: Wikimedia Commons)

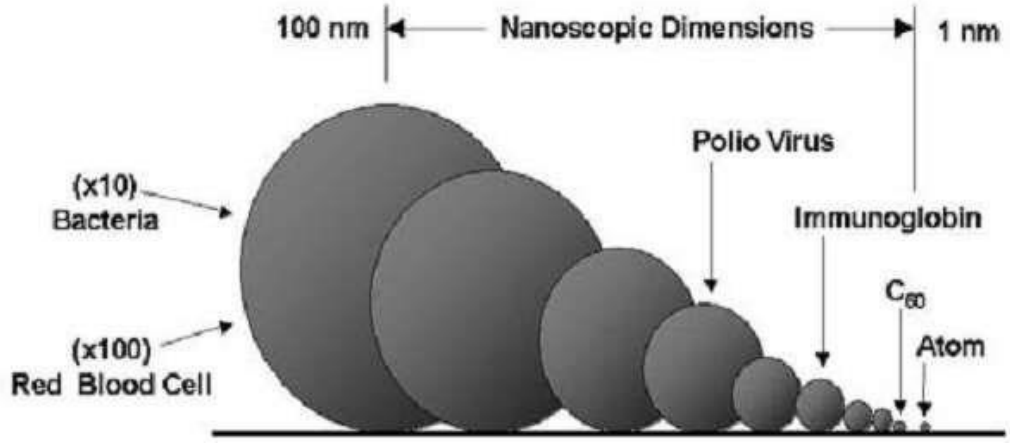

Figure 3: Relative Scales (Credit: ResearchGate)

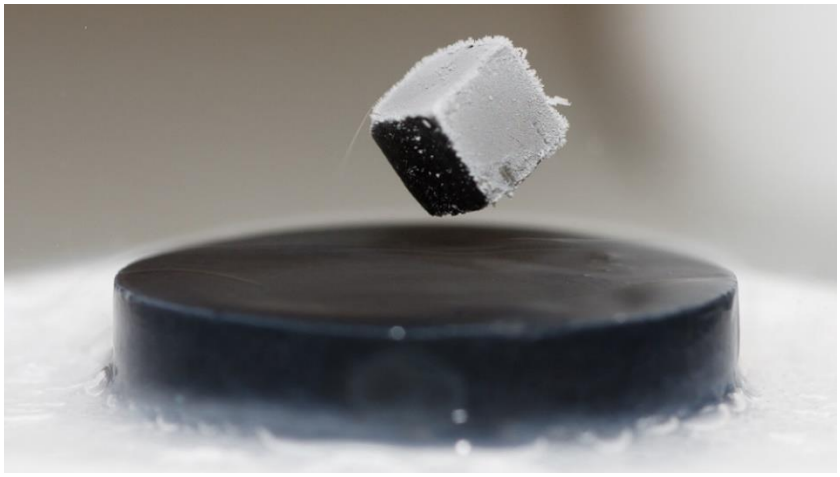

Figure 4: A superconductor appears to levitate above a magnet (Credit: extremetech.com)

Figure 5: A chunk of Avatar's fictional element "Unobtanium" floats above a base, Unobtanium is a "room temperature superconductor" (Credit: James Cameron and 20th Century Fox)

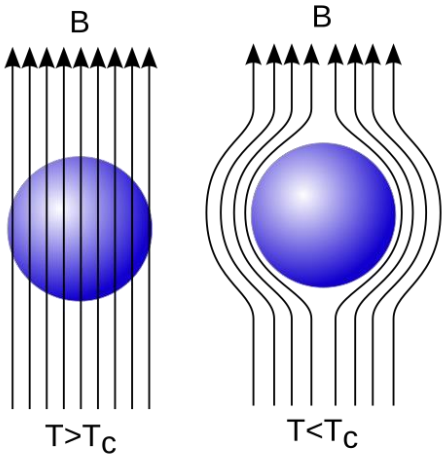

Figure 6: The Meissner effect, magnetic fields are excluded from the superconductor (Credit: Wikimedia Commons)

Figure 7: The floating "Hallelujah Mountains" from Avatar, floating due to the Meissner effect between the Unobtainium (Figure 5) within the rocks and the magnetic core of the moon Pandora on which they are found (Credit: James Cameron and 20th Century Fox)