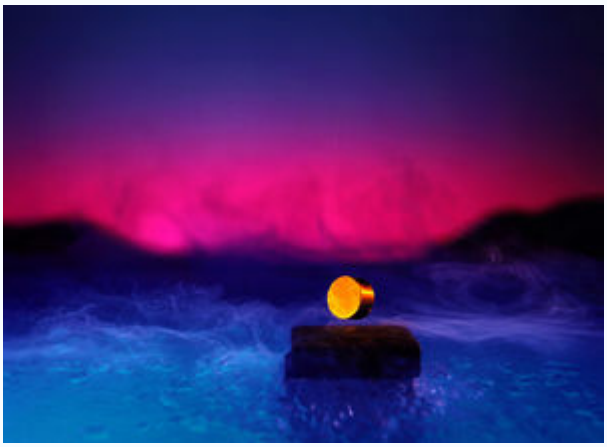
http://en.wikipedia.org/wiki/Superconductivity

Superconductivity



A magnet levitating above a high-temperature superconductor, cooled with liquid nitrogen. Persistent electric current flows on the surface of the superconductor, acting to exclude the magnetic field of the magnet (the Meissner effect). This current effectively forms an electromagnet that repels the magnet.

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

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, on the other hand, drops abruptly to zero when the material is cooled below its "critical temperature". An electrical current flowing in a loop of superconducting wire can persist indefinitely with no power source. Like ferromagnetism and atomic spectral lines, superconductivity is a quantum mechanical phenomenon. It cannot be understood simply as the idealization of "perfect conductivity" in classical physics.

Examples of superconductivity: Superconductivity occurs in a wide variety of materials, including simple elements like **tin** and aluminium, various metallic alloys and some heavily-doped semiconductors.

Superconductivity does not occur in noble metals like gold and silver, nor in most ferromagnetic metals.

In 1986 the discovery of a family of cuprate-perovskite ceramic materials known as high-temperature superconductors, with critical temperatures in excess of 90 kelvin, spurred renewed interest and research in superconductivity for several reasons. **As a topic of pure research, these materials represented a new phenomenon not explained by the current theory. And, because the superconducting state persists up to more manageable temperatures, more commercial applications are feasible, especially if materials with even higher critical temperatures could be discovered.**

Critical temperature (here): is temperatures at which superconductivity is destroyed.

Elementary properties of superconductors

Most of the physical properties of superconductors vary from material to material, such as the **heat capacity** and the **critical temperature at which superconductivity is destroyed**.

All superconductors have *exactly* zero resistivity to low applied currents when there is no magnetic field present.

The existence of these "universal" properties implies that superconductivity is a thermodynamic phase, and thus possess certain distinguishing properties which are largely independent of microscopic details.

Zero electrical "dc" resistance

The simplest method to measure the electrical resistance of a sample of some material is to place it in an electrical circuit in series with a current source *I* and measure the resulting voltage *V* across the sample. The resistance of the sample is given by Ohm's law as $R = \frac{V}{I}$. **If the voltage is zero, this means that the resistance is zero and that the sample is in the superconducting state.**

Superconductors are also able to maintain a current with no applied voltage whatsoever, a property exploited in superconducting electromagnets such as those found in MRI machines. Experiments have demonstrated that currents in superconducting coils can persist for years without any measurable degradation. Experimental evidence points to a current lifetime of at least 100,000 years, and theoretical estimates for the lifetime of persistent current exceed the lifetime of the universe.

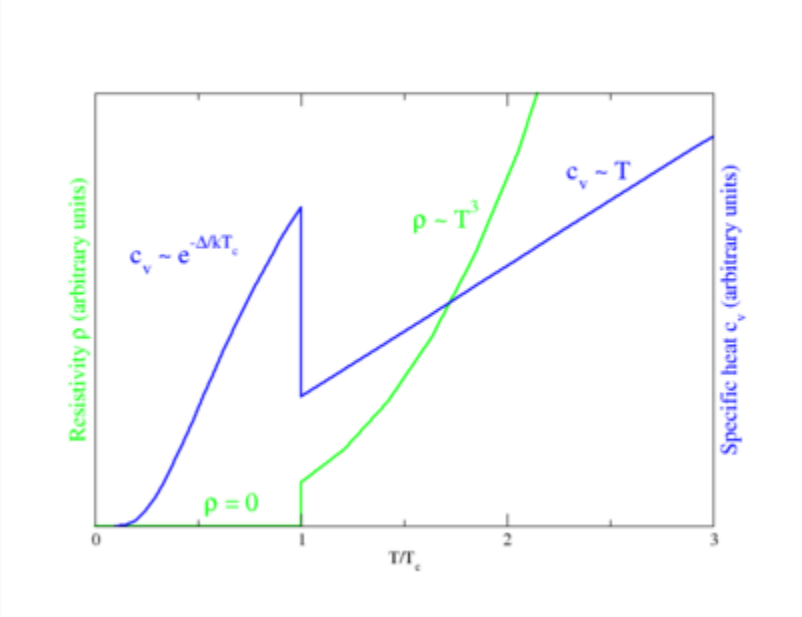
In a normal conductor, an electrical current may be visualized as a fluid of electrons moving across a heavy ionic lattice. The electrons are constantly colliding with the ions in the lattice, and during each collision some of the energy carried by the current is absorbed by the lattice and converted into heat (which is essentially the vibrational kinetic energy of the lattice ions.) As a result, the energy carried by the current is constantly being dissipated. This is the phenomenon of electrical resistance.

The situation is different in a superconductor.

In a conventional superconductor, the electronic fluid cannot be resolved into individual electrons. Instead, it consists of bound *pairs* of electrons known as Cooper pairs. This pairing is caused by an attractive force between electrons from the exchange of phonons. Due to quantum mechanics, the energy spectrum of this Cooper pair fluid possesses an *energy gap*, meaning there is a minimum amount of energy ΔE that must be supplied in order to excite the fluid. Therefore, if ΔE is larger than the thermal energy of the lattice (given by kT, where k is Boltzmann's constant and T is the temperature), the fluid will not be scattered by the lattice. The Cooper pair fluid is thus a superfluid, meaning it can flow without energy dissipation.

In the new type II superconductors (including all known high-temperature superconductors), **an extremely small amount of resistivity appears at temperatures not too far below the nominal superconducting transition when an electrical current is applied in conjunction with a strong magnetic field (which may be caused by the electrical current). This is due to the motion of vortices in the electronic superfluid, which dissipates some of the energy carried by the current. If the current is sufficiently small, the vortices are stationary, and the resistivity vanishes. The resistance due to this effect is tiny compared with that of non-superconducting materials, but must be taken into account in sensitive experiments. However, as the temperature decreases far enough below the nominal superconducting transition, these vortices can become frozen into a disordered but stationary phase known as a "vortex glass". Below this vortex glass transition temperature, the resistance of the material becomes truly zero**.

Superconducting phase transition



Behavior of heat capacity (c_v) and resistivity (ρ) at the superconducting phase transition

In superconducting materials, the characteristics of superconductivity appear when the temperature *T* is lowered below a critical temperature T_c. The value of this critical temperature varies from material to material. Conventional superconductors usually have critical temperatures ranging from less than 1 K to around 20 K. **Solid mercury, for example, has a critical temperature of 4.2 K.**

As of 2001, the **highest critical temperature found for a conventional superconductor is 39 K for magnesium diboride (MgB_2)**, although this material displays enough exotic properties that there is doubt about classifying it as a "conventional" superconductor.

Cuprate superconductors can have much higher critical temperatures: $YBa_2Cu_3O_7$, one of the first cuprate superconductors to be discovered, has a critical temperature of 92 K, and mercury-based cuprates have been found with critical temperatures in excess of 130 K.

The explanation for these high critical temperatures remains unknown. (Electron pairing due to phonon exchanges explains superconductivity in conventional superconductors, but it does not explain superconductivity in the newer superconductors that have a very high T_c.) Currently the material with the highest known critical temperature is $InSnBa_4Tm_4Cu_6O_{18}$ with a critical temperature of 150 K.[citation needed]

Meissner effect

When a superconductor is placed in a weak external magnetic field H, the field penetrates the superconductor for only a short distance λ, called the London penetration depth, after which it decays rapidly to zero. 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.

In Meissner effect the superconductor expels *all* magnetic fields, not just those that are changing. Suppose we have a material in its normal state, containing a constant internal magnetic field. **When the material is cooled below the critical temperature, we would observe the abrupt expulsion of the internal magnetic field, which we would not expect based on Lenz's law**.

The Meissner effect breaks down when the applied magnetic field is too large.

Superconductors can be divided into two classes according to how this breakdown occurs:

In Type I superconductors, superconductivity is abruptly destroyed when the strength of the applied field rises above a critical value H_c. Depending on the geometry of the sample, one may obtain an **intermediate state** consisting of regions of normal material carrying a magnetic field mixed with regions of superconducting material containing no field. **Most pure elemental superconductors (except niobium, technetium, vanadium and carbon nanotubes) are Type I.**

In Type II superconductors, raising the applied field past a critical value H_{c1} leads to a mixed state in which an increasing amount of magnetic flux penetrates the material, but there remains no resistance to the flow of electrical current as long as the current is not too large. At a second critical field strength H_{c2}, superconductivity is destroyed. **The mixed state is actually caused by vortices in the electronic superfluid.**, **Almost all impure and compound superconductors are Type II**.

Theories of superconductivity

Since the discovery of superconductivity, great efforts have been devoted to finding out how and why it works. During the 1950s, theoretical condensed matter physicists arrived at a solid understanding of "conventional" superconductivity, through a pair of remarkable and important theories: the phenomenological Ginzburg-Landau theory (1950) and the microscopic BCS theory (1957). Generalizations of these theories form the basis for understanding the closely related phenomenon of superfluidity (because they fall into the Lambda transition universality class), but the extent to which similar generalizations can be applied to unconventional superconductors as well is still

controversial. The four-dimensional extension of the Ginzburg-Landau theory, the Coleman-Weinberg model, is important in quantum field theory and cosmology.

Applications

Main article: Technological applications of superconductivity

1) Powerful Electromagnets: Superconductors are used to make some of the most powerful electromagnets known (superconducting magnets), including those used in **MRI and NMR** machines and the **beam-steering magnets used in particle accelerators**.

2) Digital circuits: Superconductors have also been used to make **digital circuits in microwave filters for mobile phone base stations.**

Other early markets are arising where the relative efficiency, size and weight advantages of devices based on HTS outweigh the additional costs involved.

3) Promising future applications: high-performance transformers, power storage devices, electric power transmission, electric motors (e.g. for vehicle propulsion, as in vactrains or maglev trains), magnetic levitation devices..

Limitations: superconductivity is sensitive to moving magnetic fields so applications that use **alternating current** (e.g. transformers) will be more difficult to develop than those that rely upon **direct current**.

Two-atom lead superconductor thinnest ever

Materials Today,

http://www.materialstoday.com/view/2839/twoatom-lead-superconductor-thinnest-ever/

29 July 2009

Paving the way for smaller and more efficient devices, a superconducting sheet just two atoms thick has been created at The University of Texas at Austin by Dr. Ken Shih and colleagues [Shengyong Qin, et al., DOI: 10.1126/science.1170775].

Paving the way for smaller and more efficient devices, a superconducting sheet just two atoms thick has been created at The University of Texas at Austin by Dr. Ken Shih and colleagues [Shengyong Qin, *et al*., DOI: 10.1126/science.1170775]. This is the thinnest superconducting sheet ever produced in a metal layer. The ultra-thin material, of lead, is a highly uniform crystalline structure that confines electrons, in 'Cooper pairs', to move through the material in two dimensions or a single, quantum channel without a power source.

Despite the constrained movement, the lead is a good superconductor. "We can make this film, and it has perfect crystalline structure, more perfect than most thin films made of other materials," says Ken Shih. Advanced materials synthesis techniques were used to deposit the lead onto a thin silicon surface, the process providing a layer free from impurities and having a regularised structure. Results show that binding of Cooper pairs remains strongly affected by the substrate and its interaction with the superconducting material.

Previous studies of 2D superconductivity have shown 2D wave function but with an underlying electron behaviour remains in 3D. However, advancements in the growth of epitaxial superconductor thin films with control over crystallinity have enabled the production of ultra-thin films on substrates. Tunneling spectroscopy was used by Shih's team to determine the thickness and the atomic structure, two distinct patterns emerging with different superconducting properties – in particular, the temperature at which superconductivity is evident.

Shih is hopeful that the processes used to produce the two-atom thick layer will lead to further developments that determine the role of the substrate in superconductivity properties and that commercial applications will ensue, in devices such as particle accelerators, quantum interface devices and MRI machines. "To be able to control this material – to shape it into new geometries – and explore what happens is very exciting, my hope is that this superconductive surface will enable one to build devices and study new properties of superconductivity," he concludes.