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Chapter 2 : Superconductivity - Wikipedia

Study of Decoherence Time of Electronic States in Quantum Dots, Josephson Junctions and Fractional Quantum Hall Effect "Pseudo-Spin" Quantum Computing Devices.

There are many criteria by which superconductors are classified. The most common are: These points are called vortices. Furthermore, in multicomponent superconductors it is possible to have combination of the two behaviours. In that case the superconductor is of Type By theory of operation[edit] It is conventional if it can be explained by the BCS theory or its derivatives, or unconventional , otherwise. Superconductor material classes include chemical elements e. Elementary properties of superconductors[edit] This section needs additional citations for verification. Please help improve this article by adding citations to reliable sources. Unsourced material may be challenged and removed. April Learn how and when to remove this template message Most of the physical properties of superconductors vary from material to material, such as the heat capacity and the critical temperature, critical field, and critical current density at which superconductivity is destroyed. On the other hand, there is a class of properties that are independent of the underlying material. For instance, all superconductors have exactly zero resistivity to low applied currents when there is no magnetic field present or if the applied field does not exceed a critical value. The existence of these "universal" properties implies that superconductivity is a thermodynamic phase , and thus possesses certain distinguishing properties which are largely independent of microscopic details. Both the massive and slim cables are rated for 12, A. 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. If the voltage is zero, this means that the resistance is zero. 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 , years. Theoretical estimates for the lifetime of a persistent current can exceed the estimated lifetime of the universe , depending on the wire geometry and the temperature. In a normal conductor, an electric 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 and Joule heating. 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. The Cooper pair fluid is thus a superfluid , meaning it can flow without energy dissipation. In a class of superconductors known as type II superconductors , including all known high-temperature superconductors , an extremely low but nonzero resistivity appears at temperatures not too far below the nominal superconducting transition when an electric current is applied in conjunction with a strong magnetic field, which may be caused by the electric current. This is due to the motion of magnetic 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. The value of this critical temperature varies from material to material. Solid mercury , for example, has a critical temperature of 4. As of , the highest critical temperature found for a conventional superconductor is K for H_2S, although high pressures of approximately 90 gigapascals were required [9]. Cuprate superconductors can have much higher critical temperatures: 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 critical temperature. Similarly, at a fixed temperature below the critical temperature, superconducting materials cease to superconduct when an external magnetic field is applied which is greater than the critical magnetic field. This is because the Gibbs free energy of the superconducting phase increases quadratically with the magnetic field while the free energy of the normal phase is roughly independent of the magnetic field. If the material superconducts in the absence of a field, then the superconducting phase free energy is lower than that of the normal phase and so for some finite value of the magnetic field proportional to the square root of the difference of the free energies at zero magnetic field the two free energies will be equal and a phase transition to the normal phase will occur. More generally, a higher temperature and a stronger magnetic field lead to a smaller fraction of electrons that are superconducting and consequently to a longer London penetration depth of external magnetic fields and currents. The penetration depth becomes infinite at the phase transition. The onset of superconductivity is accompanied by abrupt changes in various physical properties, which is the hallmark of a phase transition. For example, the electronic heat capacity is proportional to the temperature in the normal non-superconducting regime. At the superconducting transition, it suffers a discontinuous jump and thereafter ceases to be linear. This exponential behavior is one of the pieces of evidence for the existence of the energy gap. The order of the superconducting phase transition was long a matter of debate. Experiments indicate that the transition is second-order, meaning there is no latent heat. However, in the presence of an external magnetic field there is latent heat, because the superconducting phase has a lower entropy below the critical temperature than the normal phase. It has been experimentally demonstrated [10] that, as a consequence, when the magnetic field is increased beyond the critical field, the resulting phase transition leads to a decrease in the temperature of the superconducting material. Calculations in the s suggested that it may actually be weakly first-order due to the effect of long-range fluctuations in the electromagnetic field. In the s it was shown theoretically with the help of a disorder field theory , in which the vortex lines of the superconductor play a major role, that the transition is of second order within the type II regime and of first order i. Meissner effect When a superconductor is placed in a weak external magnetic field H, and cooled below its transition temperature, the magnetic field is ejected. The Meissner effect is a defining characteristic of superconductivity. The Meissner effect is sometimes confused with the kind of diamagnetism one would expect in a perfect electrical conductor: In a perfect conductor, an arbitrarily large current can be induced, and the resulting magnetic field exactly cancels the applied field. The Meissner effect is distinct from thisâ€"it is the spontaneous expulsion which occurs during transition to superconductivity. Suppose we have a material in its normal state, containing a constant internal magnetic field.

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