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Electrodynamics of the Josephson Vortex Lattice in High Temperature Superconductor

Dr. Vikash Kumar

Department of Physics, Magdh University, Bodh Gaya

Abstract: ***This paper reveals that Superconductivity is a set of physical properties observed in certain materials where electrical resistance vanishes and magnetic flux fields are expelled from the material. Any material exhibiting these properties is a superconductor. Unlike an ordinary metallic conductor, whose resistance decreases gradually as its temperature is lowered, even down to near absolute zero, a superconductor has a characteristic critical temperature below which the resistance drops abruptly to zero. An electric current through a loop of superconducting wire can persist indefinitely with no power source. The superconductivity phenomenon was discovered in 1911 by Dutch physicist Heike Kamerlingh Onnes. Like ferromagnetism and atomic spectral lines, superconductivity is a phenomenon which can only be explained by quantum mechanics. It is characterized by the Meissner effect, the complete ejection of magnetic field lines from the interior of the superconductor during its transitions into the superconducting state. The occurrence of the Meissner effect indicates that superconductivity cannot be understood simply as the idealization of perfect conductivity in classical physics. In 1986, it was discovered that some cuprate - perovskite ceramic materials have a critical temperature above 90 K (−183 °C). Such a high transition temperature is theoretically impossible for a conventional superconductor, leading the materials to be termed high - temperature superconductors. The cheaply available coolant liquid nitrogenboilsat 77 K, and thus the existence of superconductivity at higher temperatures than this facilitates many experiments and applications that are less practical at lower temperatures.***

Keywords: superconductivity, new trends, temperature, magnetic, conventional, physics, metal

1. Introduction

Superconductors refer to materials with a critical temperature below 30 K, and are cooled mainly by liquid helium (T_c> 4.2 K). One exception to this rule is the iron pnictide group of superconductors which display behaviour and properties typical of high - temperature superconductors, yet some of the group have critical temperatures below 30 K.

By material

Superconductor material classes include chemical elements (e. g. mercury or lead), alloys (such as niobium–titanium, germanium–niobium, and niobium nitride), ceramics (YBCO and magnesium diboride), superconducting pnictides (like fluorine - doped LaOFeAs) or organic superconductors (fullerenes and carbon nanotubes; though perhaps these examples should be included among the chemical elements, as they are composed entirely of carbon).

Several physical properties of superconductors vary from material to material, such as the critical temperature, the value of the superconducting gap, the critical magnetic field, and the 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. The Meissner effect, the quantization of the magnetic flux or permanent currents, i. e. the state of zero resistance are the most important examples. The existence of these "universal" properties is rooted in the nature of the broken symmetry of the superconductor and the emergence of off - diagonal long range order. Superconductivity is a thermodynamic phase, and thus possesses certain distinguishing properties which are largely independent of microscopic details.

Off diagonal long range order is closely connected to the formation of Cooper pairs. An article by V. F. Weisskopf presents simple physical explanations for the formation of Cooper pairs, for the origin of the attractive force causing the binding of the pairs, for the finite energy gap, and for the existence of permanent currents.

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 = V / I. 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 suc has those found in MRI machines. Experiments have demonstrated that currents in superconducting coil scan persist for years without any measurable degradation.

2. Discussion

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 around 20 K to less than 1 K. Solid mercury, for example, has a critical temperature of 4.2 K. As of 2015, the highest critical temperature found for a conventional superconductor is 203 K for H_2S, although high pressures of approximately 90 gigapascals were required. 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 above 90 K, and mercury - based cuprates have been found with critical temperatures in excess of 130 K. The basic physical mechanism responsible for the high critical temperature is not yet clear. However, it is clear that a two - electron pairing is involved, although the nature of the pairing remains controversial.

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.

The Meissner effect is sometimes confused with the kind of diamagnetism one would expect in a perfect electrical conductor: according to Lenz's law, when a changing magnetic field is applied to a conductor, it will induce an electric current in the conductor that creates an opposing magnetic field. 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 this – it is the spontaneous expulsion that occurs during transition to superconductivity. 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.

A superconductor with little or no magnetic field within it is said to be in the Meissner state. The Meissner state 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 inter mediate state consisting of a baroque pattern of regions of normal material carrying a magnetic field mixed with regions of superconducting material containing no field. In Type II superconductors, raising the applied field pasta critical value H_{c1}leads to a mixed state (also known as the vortex state) in which an increasing amount of magnetic flux penetrates the material, but there remains no resistance to the flow of electric 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 super fluid, sometimes called fluxons because the flux carried by these vortices is quantized. Most pure elemental superconductors, except niobium and carbon nanotubes, are Type I, while almost all impure and compound superconductors are Type II. Conversely, a spinning superconductor generates a magnetic field, precisely aligned with the spin axis. The effect, the London moment, was put to good use in Gravity Probe B. This experiment measured the magnetic fields of four superconducting gyroscopes to determine their spin axes.

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 lanthanum barium copper oxide (LBCO), a lanthanum - based cuprate perovskite material, which had a transition temperature of 35 K (Nobel Prize in Physics, 1987). It was soon found that replacing the lanthanum with yttrium (i. e., making YBCO) raised the critical temperature above 90 K.

This temperature jump is of particular engineering significance, since it allows liquid nitrogen as a refrigerant, replacing liquid helium. Liquid nitrogen can be produced relatively cheaply, even on - site. The higher temperatures additionally help to avoid some of the problems that arise at liquid helium temperatures, such as the formation of plugs of frozen air that can block cryogenic lines and cause unanticipated and potentially hazardous pressure buildup.

3. Conclusions

Nobel Prizes for superconductivity

1) 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".
2) John Bardeen, Leon N. Cooper, and J. Robert Schrieffer (1972), "for their jointly developed theory of superconductivity, usually called the BCS - theory".
3) 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 super current through a tunnel barrier, in particular those phenomena which are generally known as the Josephson effects".
4) Georg Bednorz and K. Alex Müller (1987), "for their important break - through in the discovery of superconductivity in ceramic materials".
5) Alexei A. Abrikosov, Vitaly L. Ginzburg, and Anthony J. Leggett (2003), "for pioneering contributions to the theory of superconductors and superfluids"

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