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# Study of Energy Gap for Superconductors

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ABSTRACT

The electrical resistivity of many metals and alloys drops suddenly to zero when the specimen is cooled to a sufficiently low temperature, often a temperature in tlle liquid helium range. This phenomenon, called superconductivity, was observed first by Kamerlingh Onnes in Leideli in 1911, three years after he first liquefied helium. At a critical temperature T, the specimen undergoes a phase transition from a state of normal electrical resistivity to a superconducting state. The important question for electrical conductivity is how the electrons respond to an applied electric field. We shall see that electrons in crystals are arranged in energy bands separated by regions in energy for which no wavelike electron orbitals exist. The present study is an endeavour to study energy gaps in superconductors with special reference to function of temperature.

**KEYWORDS** Electrical Resistivity, Temperature, Superconductivity and Energy Gap

**Superconductivity:**
The term 'Superconductivity' was discovered by K. Onnes in 1911. In his laboratory he noticed that the resistivity of Hg metal vanished abruptly at about 4K. Superconductors have been studied intensively for their fundamental interest and for the promise of technological applications which would be possible if a material which superconducts at room temperature were discovered. Until 1986, critical temperatures (Tc's) at which resistance disappears were always less than about 23K. It can be defined as a phenomenon of exactly zero electrical resistance and expulsion of magnetic fields occurring in certain materials when cooled below a characteristic critical temperature. The electrical resistivity of a metallic conductor decreases gradually as temperature is lowered. In ordinary conductors this decrease is limited by impurities and other defects. Even near absolute zero, a real sample of a normal conductor shows some resistance. In a superconductor, the resistance drops abruptly to zero when the material is cooled below its critical temperature.

**Characteristics of Superconductors:** Superconducting materials exhibit the following unusual behaviour:

1. **Zero resistance:** below the critical temperature of a material (Tc) the DC electrical resistivity ρ is really zero, not just very small.
2. **Persistent currents**. If a current is set up in a superconductor with multiply connected topology it will flow forever without any driving voltage.
3. **Perfect diamagnetism:** A superconductor expels a weak magnetic field nearly completely from its interior**.**
4. **Energy gap:** Most thermodynamic properties of a superconductor are found to vary as $e^{-\Delta/(k_B T)}$, indicating the existence of a gap, or energy interval with no allowed eigen energies, in the energy spectrum. When there is a gap, only an exponentially small number of particles have enough thermal energy to be promoted to the available unoccupied states above the gap. In addition, this gap is visible in electromagnetic absorption: send in a photon at low temperatures (strictly speaking, T = 0), and no absorption is possible until the photon energy reaches 2**Δ**, i.e. until the energy required to break a pair is available.

**Energy Gap:** Electrons in crystals are arranged in energy bands separated by regions in energy for which no wavelike electron orbitals exist. Such forbidden regions are called energy gaps or band gaps, and result from the interaction of the conduction electron waves with the ion cores of the crystal. It is the energy ranged in a solid where no electron state exist for insulators and semiconductors the band gap or energy gap, generally refers to the energy different between the top of the valance band and the bottom of the conduction band, but in superconductors, the energy gap is the energy required to break up a pair of electron usually referred to as cooper pairs or simply put, then energy require to disrupt the state.

The energy gap of superconductors is of entirely different origin and nature than the energy gap of insulators. In an insulator the energy gap is caused by the electron-lattice interaction. This interaction ties the electrons to the lattice. In a superconductor the important interaction is the electron-electron interaction which orders the electrons in k space with respect to the Fermi gas of electrons. The argument of the exponential factor in the electronic heat capacity of a superconductor is found to be ***-E&2kBT*** and not ***-Edk,T.*** This has been learnt from comparison with optical and electron tunneling determinations of the gap ***E.*** The transition in zero magnetic field from the superconducting state to the normal state is observed to be a second-order phase transition. At a second-order transition there is no latent heat, but there is a discontinuity in the heat capacity. Further, the energy gap decreases continuously to zero as the temperature is increased to the transition temperature *T*. A first-order transition would be characterized by a latent heat and by a discontinuity in the energy gap.

Emslay stated that energy gap depend on temperature because of 'thermal expansion'. Energy gap can further be divided into two groups, depending on the band structure, they are:

1. Direct energy gap
2. Indirect energy gap

An indirect band gap means that the minimum energy in the conduction band is shifted by a vector relative to the valence band. The vector difference represents a difference in momentum. Recombination occurs with the mediation of a third body, such as a "phonon" or a crystallographic defect, which allows for conservation of momentum. This recombination will often release the band gap energy as phonons; instead of photons, and thus do not emit light. The minimal-energy state in the conduction band and the maximal-energy state in the valence band are each characterized by a certain crystal momentum (k-vector) in the Brillouin zone. If the k-vectors are the same, it is called a "direct gap". If they are different, it is called an "indirect gap". The band gap is called "direct" if the momentum of electrons and holes is the same in both the conduction band and the valence band; an electron can directly emit a photon. In an "indirect" gap, a photon cannot be emitted because the electron must pass through an intermediate state and transfer momentum to the crystal lattice. In the case of an indirect band gap, the absorption of the light is acompanied by the absorption or emission of one phonon, giving the necessary wave number to reach the minimum of the conduction band.

### Causes of Energy Gap

Goodman, Brown Zemansky and Boorse who were making specific heat measurement discovered how and why the energy gap arose. Let us consider the way in which we build up the periodic table of elements. As one does this, one thinks of the orbits of an atom which one fills with electron. The unique chemical properties are associated with the extent to which one fills or empties an orbit. Here the electron can go only into certain orbits. Here the electron can go only into certain orbits. And only one electron can go into any given orbit.

In a metal, electrons bounce around inside the metal in specific orbits. One way of thinking about these orbits is that some electron move slowly some move somewhat faster. In orbits which are possible can be specific by the speed and direction in which the electrons are allowed to move if we then start putting electrons into a metal to achieve the situation at absolute zero. The first electron we put in would go into the lowest energy absolute zero, the next would into a somewhat higher energy orbit and so on unit we have put in the proper number of electrons. Those last ones we put in have a good deal more energy than the first ones. The energy which they have relative to the first ones is called the Fermi energy. Now suppose we heat this metal to give it a little more energy to all its parts. The electrons are no expectation. Think of those electrons which initially have a rather low amount of energy. If you try to give it more energy, there is a problem because the orbit of the somewhat higher enough are already occupied, and the Pauli principle does not let the electron switch over into an already occupied orbit. Now, let us talk about electron with the Fermi energy, those that were last added, and the one moving around most rapidly. Those electron have nearly energy orbit which are not occupied so if you heat up them. There is in fact a continuous set of energies available to those electrons of Fermi-energy, so they can gradually add energy at the metal is warmed. This brings us to the point of the energy gap.

### The Energy gap in Superconductors

The energy gap in superconductors can be defined as the gap between the energy bands which are fully occupied by electrons, and the bands which are fully empty. The size of the energy band is about 1 eV, which is the required energy to break the band between 2 electrons pairs. At zero temperature, the electrons jump over the energy gap and create holes.

The origin and nature of energy gap of superconductors is totally different than the energy gap of insulators. In an insulator the energy gap is caused by the electron-lattice interaction. This interaction ties the electrons to the lattice. In a superconductor the important interaction is the electron- electron interaction which orders the electrons in k space with respect to the Fermi gas of electrons.

### Energy Gap in Super Conductor as a Function of Temperature

Transition from normal conductor to superconductor involves an explicit change in entropy for the conductor. Various experiments confirm the need for a change in system conduction free energy at the phase transition between a functioning normal metal conductor and the corresponding superconductor. Here we discuss the connection between this free energy difference and the temperature dependent energy gap in a superconductor. A model for the superconductor energy gap, as reflected in the magnitude of the superconductor critical magnetic field, ***Hc***, is developed. Electron free energy differences between dissipative and non-dissipative current flow in metals do not appear to have received much attention in the literature, though non dissipative superconductors have been known since 1911.

When an external critical magnetic field has been applied to a superconductor, if the external field just matches the internal field, which arises due to the M. Ochsenfeld effect, the external field penetrates the superconductor and fills the superconductors' energy gap with its energy, proportional to ***Hc***. When the energy of the external magnetic field is equal to the energy gap of the superconductor, Dirac fermions in the superconducting state absorb this energy and bridge the energy gap to a normal conducting state. The Fermi level increases, to its original ***Tc*** level. Electrons with basic functions that produce dissipative scattering by Fermi contact are available for conduction, and the superconductor quenches.

The reduction of the energy gap as we approach the critical temperature can be taken as an indication that the change carries have some sort of collective nature. That is, the change carries must consist of at least two tins. Which are bound together and the energy is weaken as we approach the critical temperature. Above the critical temperature such collection does not exist and normal resistively prevails. This kind of evidence, along with the isotope effect, which shows that the critical lattices was involved, helped to suggest the picture of paired electron bound together by phonon interaction with the lattice.

Magnitude of the temperature dependent energy gap for a superconductor depends strongly upon the superconductor's internal magnetic field. So it becomes essential to specify the internal magnetic field of a superconductor to make coherent remarks concerning its temperature dependent energy gap. There must be a vacant energy state in superconductor to receive an external magnetic field and the energy associated with the field. For a small range of energies near that of the critical magnetic field, ***Hc***, these energy states lie within the superconductor temperature dependent energy gap. The critical magnetic field for a superconductor at temperature, ***T***, ***Hc*** (***T***) occurs when the energy of the magnetic field is equal to the magnitude of the superconductor energy gap at ***T***. Under these conditions, the internal magnetic field of the superconductor corresponds to ***Hc***. When the superconductor energy gap is occupied with the energy of the external magnetic field, the normal metal conducting bands that became inaccessible at the superconductor normal conductor phase transition are once again available for conduction, and the superconductor quenches.

### Conclusions

With the discovery of high critical temperature superconductors, a new era in the study of superconductivity began in 1986. Superconductor energy gaps arise from changes in system entropy between the superconductor and the normal conductor in the phase transition. On the normal conductor side of the transition the entropy change is associated with the loss of dissipative electron scattering in the phase transition to the superconductor. This entropic contribution to the system free energy gives a term that decreases in magnitude as the temperature decreases. On the superconductor side of the phase transition the change in entropy is associated with an increase in structural coherence in the superconducting phase as temperature decreases in comparison to the normal phase which is non-coherent. The term in the superconductor free energy associated with the increase in structural coherence with decreasing temperature, increases as the temperature decreases. Total free energy for the superconductor as compared to the normal conductor, the energy gap, has the potential to show a maximum above ~0 K for selected cases. Many recent researches in this field suggest that the ratio of the superconductor energy gap to the superconductor critical temperature depends upon the chemical structure of superconductor.

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