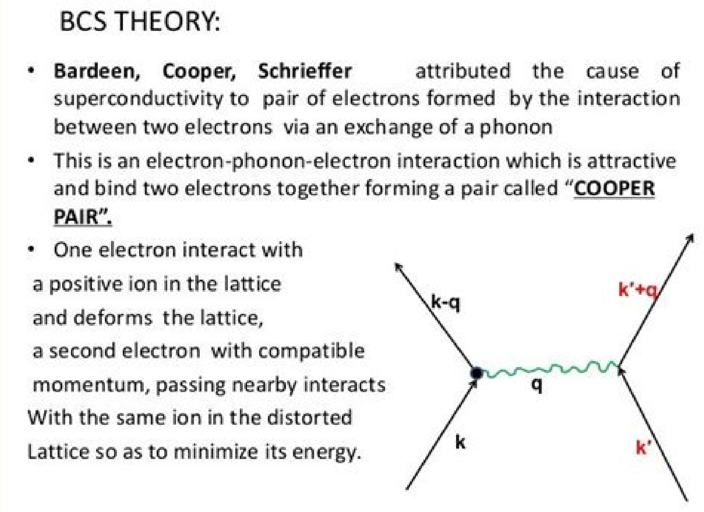
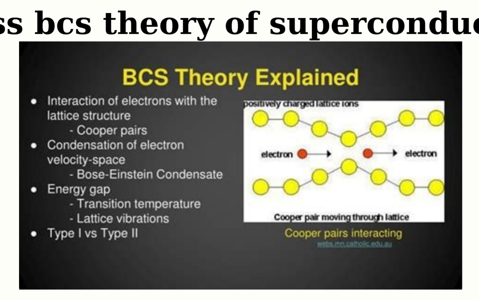
# Bcs theory of superconductivity slideshare

### Salient features of bcs theory of superconductivity.  Theories of superconductivity.  Explain bcs theory of superconductivity.

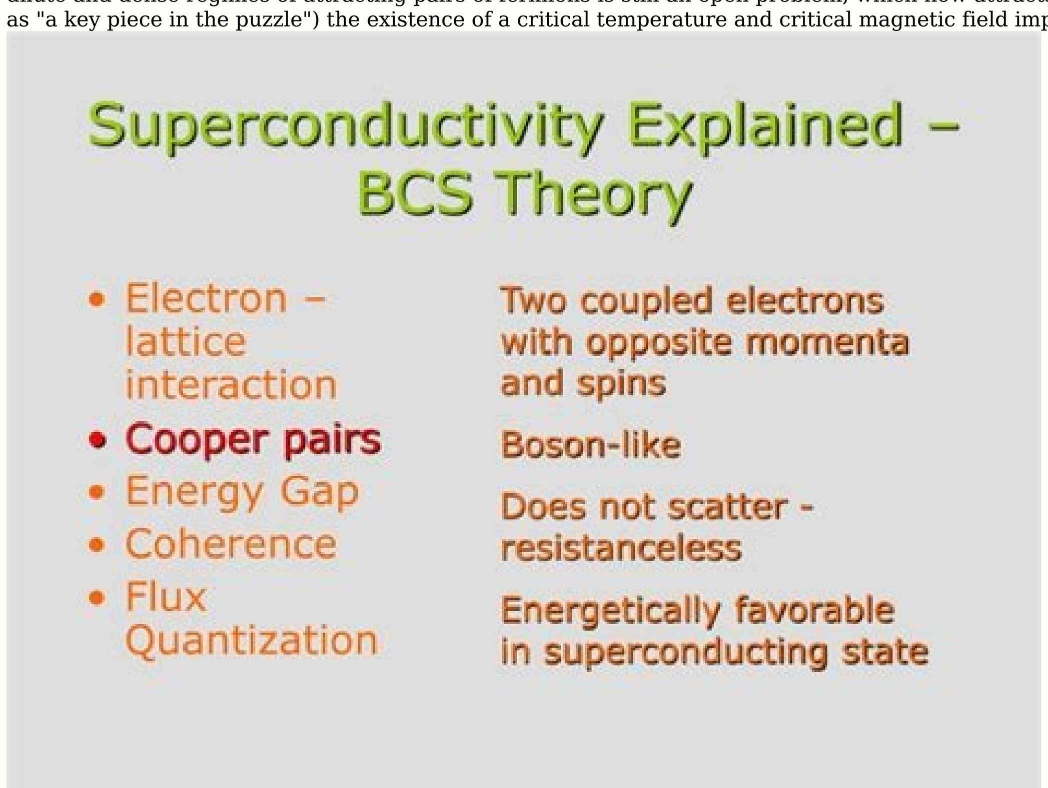



### Discuss bcs theory of superconductivity.




### Superconductivity bcs theory.

Super conductors,properties and its application and BCS theorysmithag7 Superconductivity of materialsSmit Parikh   Indian Institute of Science Education & Research, Kolkata 14 th  December 2010 1 | BCS Theory of Superconductivity, Report by Harsh Purwar  John Bardeen, Leon N. Copper & John R .
Schrieffer's Theory of Superconductivity Harsh Purwar (07MS  –  76) 4 th  Year, Integrated M.S. (Physics) Indian Institute of Science Education and Research, Kolkata Seminar Course (SM  –  411) Submitted on: December 14, 2010  Abstract This report discusses some of the main features of the so called BCS Theory proposed John Bardeen, Leon N. Cooper and John R. Schrieffer in 1957.
Some of the phenomenological theories proposed by Ginzburg and Landau and London Brothers to explain the experimental facts are also briefly discussed. Finally some of the major predictions of the BCS theory are highlighted.   Indian Institute of Science Education & Research, Kolkata 14 th  December 2010 3 | BCS Theory of Superconductivity, Report by Harsh Purwar  Superconductivity –  General Discussion Superconductivity is an electrical resistance of exactly zero which occurs in certain materials below a characteristic temperature . It was discovered by Heike Kamerlingh Onnes in 1911. It is also characterized by a phenomenon called the Meissner effect (Figure 1), the ejection of any sufficiently weak magnetic field from the interior of the superconductor as it 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.
Figure 1: 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 Faraday's law of induction). This current effectively forms an electromagnet that repels the magnet. The electrical resistivity of a metallic conductor decreases gradually as the temperature is lowered. However, in ordinary conductors such as copper and silver, this decrease is limited by impurities and other defects. Even near absolute zero, a real sample of copper shows some resistance. Despite these imperfections, in a superconductor the resistance drops abruptly to zero when the material is cooled below its critical temperature. An electric current flowing in a loop of superconducting wire can persist indefinitely with no power source. Superconductivity occurs in many materials: simple elements like tin and aluminum, various metallic alloys and some heavily-doped semiconductors. Superconductivity does not occur in noble metals like gold and silver, or in pure samples of ferromagnetic metals. In 1986, it was discovered that some cuprate-perovskite ceramic materials have critical temperatures above 90 K (−183.15 °C). These high -temperature superconductors renewed interest in the topic because of the prospects for improvement and potential room-temperature superconductivity. From a practical perspective, even 90 K is relatively easy to reach with the readily available liquid nitrogen (boiling point 77 K), resulting in more experiments and applications. F EW C HARACTERISTIC P ROPERTIES OF S UPERCONDUCTORS The characteristic properties of metals in the superconducting state appear highly anomalous when regarded from the point of view of the independent electron approximation. The most striking features (1) of a superconductor are: ━ A superconductor can behave as if it had no measurable DC electrical resistivity. Currents have been established in superconductors which, in the absence of any driving field, have nevertheless shown no discernible decay for as long as people have had the patience to watch. ━ A superconductor can behave as a perfect diamagnet. A sample in thermal equilibrium in an applied magnetic field, provided the field is not too strong, carries electrical surface currents. These Super conductors,properties and its application and BCS theorysmithag7 Super conductors,properties and its application and BCS theorysmithag7 A summary is not available for this content so a preview has been provided. Please use the Get access link above for information on how to access this content. Super conductors,properties and its application and BCS theorysmithag7 Super conductors,properties and its application and BCS theorysmithag7 Top clipped slide A commemorative plaque placed in the Bardeen Engineering Quad at the University of Illinois at Urbana-Champaign. It commemorates the Theory of Superconductivity developed here by John Bardeen and his students, for which they won a Nobel Prize for Physics in 1972. Microscopic theory of superconductivity BCS theory or Bardeen–Cooper–Schrieffer theory (named after John Bardeen, Leon Cooper, and John Robert Schrieffer) is the first microscopic theory of superconductivity since Heike Kamerlingh Onnes's 1911 discovery. The theory describes superconductivity as a microscopic effect caused by a condensation of Cooper pairs. The theory is also used in nuclear physics to describe the pairing interaction between nucleons in an atomic nucleus. It was proposed by Bardeen, Cooper, and Schrieffer in 1957; they received the Nobel Prize in Physics for this theory in 1972. History Rapid progress in the understanding of superconductivity gained momentum in the mid-1950s. It began with the 1948 paper, "On the Problem of the Molecular Theory of Superconductivity",[1] where Fritz London proposed that the phenomenological London equations may be consequences of the coherence of a quantum state. In 1953, Brian Pippard, motivated by penetration experiments, proposed that this would modify the London equations via a new scale parameter called the coherence length. John Bardeen then argued in the 1955 paper, "Theory of the Meissner Effect in Superconductors",[2] that such a modification naturally occurs in a theory with an energy gap. The key ingredient was Leon Cooper's calculation of the bound states of electrons subject to an attractive force in his 1956 paper, "Bound Electron Pairs in a Degenerate Fermi Gas".[3] In 1957 Bardeen and Cooper assembled these ingredients and constructed such a theory, the BCS theory, with Robert Schrieffer. The theory was first published in April 1957 in the letter, "Microscopic theory of superconductivity".[4] The demonstration that the phase transition is second order, that it reproduces the Meissner effect and the calculations of specific heats and penetration depths appeared in the December 1957 article, "Theory of superconductivity".[5] They received the Nobel Prize in Physics in 1972 for this theory. In 1986, high-temperature superconductivity was discovered in La-Ba-Cu-O, at temperatures up to 30 K.[6] Following experiments determined more materials with transition temperatures up to about 130 K, considerably above the previous limit of about 30 K. It is believed that BCS theory alone cannot explain this phenomenon and that other effects are in play.[7] These effects are still not yet fully understood; it is possible that they even control superconductivity at low temperatures for some materials. Overview At sufficiently low temperatures, electrons near the Fermi surface become unstable against the formation of Cooper pairs. Cooper showed such binding will occur in the presence of an attractive potential, no matter how weak. In conventional superconductors, an attraction is generally attributed to an electron-lattice interaction. The BCS theory, however, requires only that the potential be attractive, regardless of its origin. In the BCS framework, superconductivity is a macroscopic effect which results from the condensation of Cooper pairs. These have some bosonic properties, and bosons, at sufficiently low temperature, can form a large Bose–Einstein condensate. Superconductivity was simultaneously explained by Nikolay Bogolyubov, by means of the Bogoliubov transformations. In many superconductors, the attractive interaction between electrons (necessary for pairing) is brought about indirectly by the interaction between the electrons and the vibrating crystal lattice (the phonons). Roughly speaking the picture is the following: An electron moving through a conductor will attract nearby positive charges in the lattice. This deformation of the lattice causes another electron, with opposite spin, to move into the region of higher positive charge density. The two electrons then become correlated. Because there are a lot of such electron pairs in a superconductor, these pairs overlap very strongly and form a highly collective condensate.
In this "condensed" state, the breaking of one pair will change the energy of the entire condensate - not just a single electron, or a single pair. Thus, the energy required to break any single pair is related to the energy required to break all of the pairs (or more than just two electrons). Because the pairing increases this energy barrier, kicks from oscillating atoms in the conductor (which are small at sufficiently low temperatures) are not enough to affect the condensate as a whole, or any individual "member pair" within the condensate. Thus the electrons stay paired together and resist all kicks, and the electron flow as a whole (the current through the superconductor) will not experience resistance. Thus, the collective behavior of the condensate is a crucial ingredient necessary for superconductivity. Details BCS theory starts from the assumption that there is some attraction between electrons, which can overcome the Coulomb repulsion. In most materials (in low temperature superconductors), this attraction is brought about indirectly by the coupling of electrons to the crystal lattice (as explained above). However, the results of BCS theory do not depend on the origin of the attractive interaction. For instance, Cooper pairs have been observed in ultracold gases of fermions where a homogeneous magnetic field has been tuned to their Feshbach resonance. The original results of BCS (discussed below) described an s-wave superconducting state, which is the rule among low-temperature superconductors but is not realized in many unconventional superconductors such as the d-wave high-temperature superconductors. Extensions of BCS theory exist to describe these other cases, although they are insufficient to completely describe the observed features of high-temperature superconductivity. BCS is able to give an approximation for the quantum-mechanical many-body state of the system of (attractively interacting) electrons inside the metal. This state is now known as the BCS state. In the normal state of a metal, electrons move independently, whereas in the BCS state, they are bound into Cooper pairs by the attractive interaction. The BCS formalism is based on the reduced potential for the electrons' attraction. Within this potential, a variational ansatz for the wave function is proposed. This ansatz was later shown to be exact in the dense limit of pairs. Note that the continuous crossover between the dilute and dense regimes of attracting pairs of fermions is still an open problem, which now attracts a lot of attention within the field of ultracold gases. Underlying evidence The hyperphysics website pages at Georgia State University summarize some key background to BCS theory as follows:[8] Evidence of a band gap at the Fermi level (described as "a key piece in the puzzle") the existence of a critical temperature and critical magnetic field implied a band gap, and suggested a phase transition, but single electrons are forbidden from condensing to the same energy level by the Pauli exclusion principle.




The site comments that "a drastic change in conductivity demanded a drastic change in electron behavior". Conceivably, pairs of electrons might perhaps act like bosons instead, which are bound by different condensate rules and do not have the same limitation. Isotope effect on the critical temperature, suggesting lattice interactions The Debye frequency of phonons in a lattice is proportional to the inverse of the square root of the mass of lattice ions. It was shown that the superconducting transition temperature of mercury indeed showed the same dependence, by substituting natural mercury 202Hg with a different isotope 198Hg.[9] An exponential rise in heat capacity near the critical temperature for some superconductors An exponential increase in heat capacity near the critical temperature also suggests an energy bandgap for the superconducting material. As superconducting vanadium is warmed toward its critical temperature, its heat capacity increases greatly in a very few degrees; this suggests an energy gap being bridged by thermal energy. The lessening of the measured energy gap towards the critical temperature This suggests a type of situation where some kind of binding energy exists but it is gradually weakened as the temperature increases toward the critical temperature. A binding energy suggests two or more particles or other entities that are bound together in the superconducting state. This helped to support the idea of bound particles - specifically electron pairs - and together with the above helped to paint a general picture of paired electrons and their lattice interactions. Implications BCS derived several important theoretical predictions that are independent of the details of the interaction, since the quantitative predictions mentioned below hold for any sufficiently weak attraction between the electrons and this last condition is fulfilled for many low temperature superconductors - the so-called weak-coupling case. These have been confirmed in numerous experiments: The electrons are bound into Cooper pairs, and these pairs are correlated due to the Pauli exclusion principle for the electrons, from which they are constructed.


**Success of BCS theory**

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ABSTRACT

The most successful theoretical model that gives the first correct explanation to superconductivity is known as BCS theory. In 1957, more than 40 years after the discovery of superconductivity, three physicists, Bardeen, Cooper and Schrieffer, finally found the correct explanation to superconductivity in metals. Hence the model has been named as BCS theory after their initials. They proposed that the electrons form pairs, called cooper pairs before forming a collective quantum wave. Almost all superconducting properties of metals and behavior of characteristic length and other parameters have been explained well by BCS theory. The theory is also used in nuclear physics to describe the pairing interaction between nucleons in an atomic nucleus.

Superconductivity was discovered by Heike Kamerlingh Onnes on April 8, 1911 in Leiden. Superconductivity is a quantum mechanical phenomenon. It is characterized by the Meissner effect. A number of theory have been developed by many scientists to explain different properties of superconductor such as Zero electrical DC resistance, Superconducting phase transition, critical thermodynamic parameters, Meissner effect, London moment, penetration depth, coherence length etc. The first phenomenological theory was London theory. Then in 1950 the phenomenological Gingburg-Landau theory was devised by Landau and ginzburg. It was successful in many aspects including the classification of Type-I and Type-II superconductor. Finally the most successful theory comes in 1957, proposed by Bardeen, Cooper and Schrieffer.

The main idea of the BCS theory relies on the quantum nature of electrons. In a metal, electrons are waves. Each of these electrons is relatively independent and follows its own path independent of other electrons. In a superconductor, the majority of these electrons merge in order to form a large collective wave. In quantum physics, we call it macroscopic quantum wave function or condensate. When the collective wave is formed, it requires each member to move at same speed. In a metal, an individual electron is easily diverted by a flaw or an atom that is too big. In a superconductor, this same electron can be diverted only if, at the same time all other electrons of the collective wave are diverted in the exactly same manner. The flaw in a single atom surely cannot do that, the wave will not be diverted and thus it will not be slowed down[1-2].

BCS derived several important theoretical predictions that are independent of the details of the interaction, since the quantitative predictions mentioned below hold for any sufficiently weak attraction between the electrons and this last condition is fulfilled for many low temperature superconductors - the so-called weak-coupling

Therefore, in order to break a pair, one has to change energies of all other pairs. This means there is an energy gap for single-particle excitation, unlike in the normal metal (where the state of an electron can be changed by adding an arbitrarily small amount of energy). This energy gap is highest at low temperatures but vanishes at the transition temperature when superconductivity ceases to exist. The BCS theory gives an expression that shows how the gap grows with the strength of the attractive interaction and the (normal phase) single particle density of states at the Fermi level. Furthermore, it describes how the density of states is changed on entering the superconducting state, where there are no electronic states any more at the Fermi level. The energy gap is most directly observed in tunneling experiments[10] and in reflection of microwaves from superconductors. BCS theory predicts the dependence of the value of the energy gap Δ at temperature T on the critical temperature Tc. The ratio between the value of the energy gap at zero temperature and the value of the superconducting transition temperature (expressed in energy units) takes the universal value[11] Δ ( T = 0 ) = 1.764 k B T c , {\displaystyle \Delta (T=0)=1.764\,k_{\rm {B}}T_{\rm {c}},} independent of material. Near the critical temperature the relation asymptotes to[11] Δ ( T → T c ) ≈ 3.06 k B T c 1 − ( T / T c ) {\displaystyle \Delta (T\to T_{\rm {c}})\approx 3.06\,k_{\rm {B}}T_{\rm {c}}{\sqrt {1-(T/T_{\rm {c}})}}} which is of the form suggested the previous year by M. J. Buckingham[12] based on the fact that the superconducting phase transition is second order, that the superconducting phase has a mass gap and on Blevins, Gordy and Fairbank's experimental results the previous year on the absorption of millimeter waves by superconducting tin. Due to the energy gap, the specific heat of the superconductor is suppressed strongly (exponentially) at low temperatures, there being no thermal excitations left. However, before reaching the transition temperature, the specific heat of the

superconductor becomes even higher than that of the normal conductor (measured immediately above the transition) and the ratio of these two values is found to be universally given by 2.5. BCS theory correctly predicts the Meissner effect, i.e. the expulsion of a magnetic field from the superconductor and the variation of the penetration depth (the extent of the screening currents flowing below the metal's surface) with temperature. It also describes the variation of the critical magnetic field (above which the superconductor can no longer expel the field but becomes normal conducting) with temperature. BCS theory relates the value of the critical field at zero temperature to the value of the transition temperature and the density of states at the Fermi level. In its simplest form, BCS gives the superconducting transition temperature Tc in terms of the electron-phonon coupling potential V and the Debye cutoff energy ED:[5] $k_B T_c = 1.134 E_D e^{-1/N(0)V}$ , {\displaystyle k_{\rm {B}}\,T_{\rm {c}}=1.134E_{\rm {D}}\,{e^{-1/N(0)\,V}},} where N(0) is the electronic density of states at the Fermi level. For more details, see Cooper pairs. The BCS theory reproduces the isotope effect, which is the experimental observation that for a given superconducting material, the critical temperature is inversely proportional to the mass of the isotope used in the material. The isotope effect was reported by two groups on 24 March 1950, who discovered it independently working with different mercury isotopes, although a few days before publication they learned of each other's results at the ONR conference in Atlanta. The two groups are Emanuel Maxwell,[13] and C. A.
Reynolds, B. Serin, W. H. Wright, and L. B.
Nesbitt.[14] The choice of isotope ordinarily has little effect on the electrical properties of a material, but does affect the frequency of lattice vibrations. This effect suggests that superconductivity is related to vibrations of the lattice. This is incorporated into BCS theory, where lattice vibrations yield the binding energy of electrons in a Cooper pair. Little–Parks experiment[15] - One of the first[citation needed] indications to the importance of the Cooper-pairing principle. See also Magnesium diboride, considered a BCS superconductor Quasiparticle Little–Parks effect, one of the first[16] indications of the importance of the Cooper pairing principle.

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# BCS Theory of Superconductivity

The properties of Type I superconductors were modeled successfully by the efforts of John Bardeen, Leon Cooper, and Robert Schrieffer in what is commonly called the BCS theory. A key conceptual element in this theory is the pairing of electrons close to the Fermi level into Cooper pairs through interaction with the crystal lattice. This pairing results from a slight attraction between the electrons related to lattice vibrations; the coupling to the lattice is called a phonon interaction.

Pairs of electrons can behave very differently from single electrons which are fermions and must obey the Pauli exclusion principle. The pairs of electrons act more like bosons which can condense into the same energy level. The electron pairs have a slightly lower energy and leave an energy gap above them on the order of .001 eV which inhibits the kind of collision interactions which lead to ordinary resistivity. For temperatures such that the thermal energy is less than the band gap, the material exhibits zero resistivity.

Bardeen, Cooper, and Schrieffer received the Nobel Prize in 1972 for the development of the theory of superconductivity.

Ideas leading to the BCS theory

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# Experimental Support: BCS Theory

Electrons acting as pairs via lattice interaction? How did they come up with that idea for the BCS theory of superconductivity? The evidence for a small band gap at the Fermi level was a key piece in the puzzle. That evidence comes from the existence of a critical temperature, the existence of a critical magnetic field, and the exponential nature of the heat capacity variation in the Type I

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Superconductivity



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