14) Briefly outline BCS theory of superconductivity and describe one experimental evidence for the existance of energy gap.

→ The BCS theory applies well to the conventional low-T_c superconducting materials and explains the phenomenon of superconductivity in them. This microscopic theory was proposed in 1957 by Bardeen, Cooper and Schrieffer, the BCS theory almost 50 years after the experimental discovery of superconductivity. According to the BCS theory, the key microscopic factor behind this phenomenon is the attraction between electrons mediated by the exchange of phonons, such that below T_c within the electronic system there forms a macroscopic manifold of bound electrons pairs (known as the Cooper pairs). Thus the attraction has its origin in the ionic system - the lattice, and the pairing of electrons leads to macroscopic coherence and perfect diamagnetism.

According to this theory, superconductivity arises because of the formation of bound pairs of electrons. For this to occur, a pre-requisite is a strong attractive interaction between pairs of electrons, strong enough to overcome the normal Coulomb repulsion between these pairs.

The BCS attractive mechanism of superconductivity owes itself to the conduction electrons deforming the the crystal lattice, slightly. ~~A simple~~

The ionic lattice of a metal is a periodic crystalline array of positive ions immersed in the sea of conduction electrons. Consider a negatively charged conduction electron traveling through this array of positive ions. As it moves it pulls the much heavier positive ions towards it, though only slightly since the movement of the ion is restrained by neighbouring ions of the ionic lattice, elastically. The maximum displacement of the ions occurs a bit after the fast moving electron has passed. That leaves a region of excess positive charge, behind the electron that passed. This positively charged region attracts (pulls in) a second passing electron towards it. This way, these two electrons get coupled via the 'virtual quanta' of Phonons of the ionic lattice. It is pertinent to take note that superconductivity exists even at T=0, where there are no thermal phonons, which are 'real quanta', which in fact degrade superconductivity.

Effectively, this leads to the formation of mutually attracted pair of electrons, a stable bound Cooper pair, arising from the dynamic distortion of the lattice, called Phonons, and hence the attractive interaction under the BCS theory is known as the phonon-induced electron-electron attraction. The electrons are fermions, but the cooper pairs are bosons, and the superconducting state is characterized by the Bose condensation of Cooper pairs.

17. <u>How are cooper-pairs formed.</u>

→ A Cooper pair is formed by two electrons (spin singlets) having equal and opposite momentum and spin. Thus the angular momentum of a Cooper pair is 0 (it is in s-state), and the pair has a coherence length (~100 nm which is >> atomic spacings). e-ph coupling occurs between two electrons with opposing spin directions and opposite momenta, viz. an electron with momentum K and spin direction ↑, coupled via a phonon with another ~~ele~~ electron with momentum -K and spin direction ↓.

Normally two electrons repel ~~f~~ each other, because of Coulomb interaction. Suppose that, for some reason, the two electrons attract each other. Cooper showed that the two electrons would then form a bound state. ~~This The pairing can be~~ This is very important, because in a bound state, electrons are paired to form a single system, and their motions are correlated. The pairing can be broken only if an amount of energy equal to the binding energy is applied to the system. This pair of electrons is called Cooper pair.

11) How does superconducting transition temp. vary ~~as~~ with magnetic field.

→ The superconducting state of a metal exists only in a particular range of temperature and field strength. The condition for the superconducting state to exist in the metal is that some combination of temperature and field strength should be less than a critical value.

Superconductivity will disappear if the temperature of the specimen is raised above its T_c, or if a sufficiently strong magnetic field is employed. The curves are nearly parabolic and can be reasonably be represented by the ~~seat~~ relation,

$$H_c = H_0 \left[1 - \left(\frac{T}{T_c}\right)^2\right] \rightarrow (1)$$

Where H_c is the maximum critical field strength at the temperature T, H_0 is the maximum critical field strength occuring at absolute zero, and T_c is the critical temperature, the highest temperature for superconductivity. Thus the above equation defines a curve which divides the normal region of the field temperature diagram of the metal from the superconducting region.

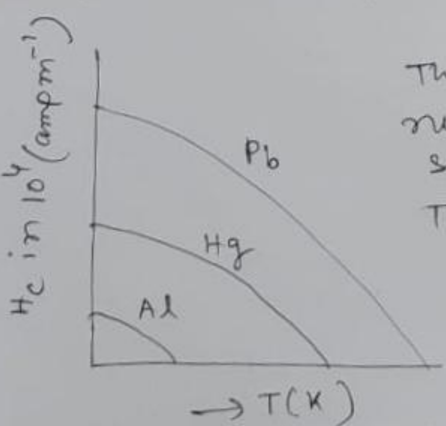

fig-1

The critical field curves for a number of pure metals are shown in figure-1.

This diagram look like the phase diagrams. Inside the curve the material is in the superconducting phase (resistivity approaches zero) and outside the curve, the material is in the normal phase (normal resistivity is restored). Equation (1) is thus the equation of phase boundary.

Describe one experimental evidence for the existance of energy gap.

~~The mea~~ The measured bandgap in type-I superconductors is one of the pieces of experimental evidence which supports the BCS theory. ~~The 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 existance of a critical temperature, the existence of a critical magnetic field, and the exponential nature of the heat capacity variation in ~~they~~ the Type I superconductor

The evidence for interaction with the crystal lattice came first from the isotope effect on the critical temperature.

The band gap suggested a phase transition in which there was a kind of condensation, like a Bose-Einstein condensation, but ~~ele~~ electrons alone cannot ~~condensation,~~ condense into the same energy level (Pauli exclusion principle). Yet a drastic change in conductivity demanded a drastic change in electron behavior.

The measured bandgap in Type I superconductors is one of the pieces of experimental evidence which supports the BCS theory. The BCS theory predicts a band gap of $E_g \approx \frac{7}{2} k T_c$

where T_c is the critical temperature for the superconductor. The energy gap is related to the coherence length for the superconductor, one of the two characteristic lengths associated with superconductivity