BCS Theory: Qualitative treatment

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The modern microscopic theory of superconductivity was developed by Bardeen, Cooper and Schrieffer in 1957, ~~called~~ known as BCS theory.

BCS theory is characterised by the following essential features

1) The electron-lattice interaction leads to an electron-electron attraction, sufficiently strong to overcome their mutual repulsion, and the electrons form bound in the superconducting state. The electrons thus paired constitute a single system so that their motion would be co-related.

ii) The electron-electron interaction is mediated by the exchange of virtual phonons ~~that~~ between the electrons.

III) The pairing of electrons is such that an electron with spin-up and momentum $\vec{k}$ is paired with one of the spin-down and momentum $-\vec{k}$ and the angular momentum is 0. Such a pairing is called ~~the~~ a Cooper pair.

Electron-lattice interactions: Consider a metal with conduction electrons inside the Fermi sphere and two electrons marked 1 and 2 lie just inside the Fermi surface. as shown be

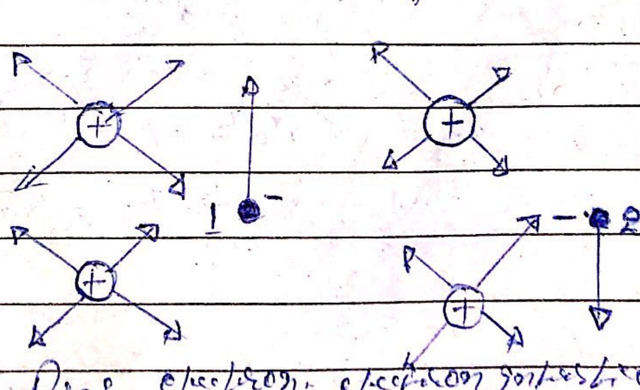

Fig: electron-electron interaction

There is direct coulombic repulsion between them. since electron 1 is near the ion surface, its speed is high enough, due to Fermi velocity which is passes through the packing of positive ion, is attracted by the neighbouring positive ion. Because of high masses the ion respond rather slowly. And by the time ion completely respond to electron-1. This attraction between the electron and the ion-core deforms the lattice.

If now the electron-2 passes by the side of the assembly of electron 1 and the ion core it does not see the bare electron 1 but attracted toward to the ion and electron assembly.

In the language of field theory, the above interaction creates a virtual phonon. Each electron is thus surrounded by a phonon cloud as shown below.

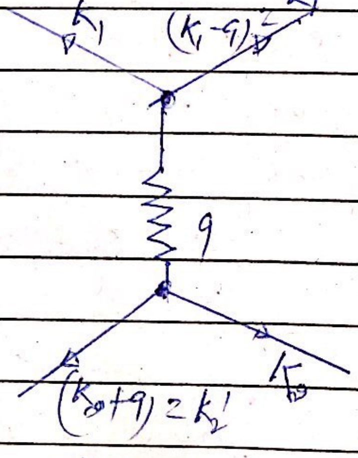

fig phonon-mechanism of pairing

The phonon of momentum q emitted by 1 with momentum k_1 is absorbed by 2 with momentum k_2 which gets scattered by with $k_2 + q$.

The interaction is strongest when 1 and 2 have opposite momenta and spin.

$$\vec{k_1} = \vec{k\uparrow} \; ; \; k_2 = \vec{k\downarrow}$$

So, $k_1 + k_2 = k_1' + k_2'$

i.e. The net k-value of the pair is conserved for the process and because the lattice invariant, the momentum gets transferred between the electrons. The mediating phonons have small energy range is given by

$$\hbar \omega_D = k\Theta_D$$

where
ω_D = Debye resonance frequency.
Θ_D = Debye temperature.
k = Boltzmann constant.

The energy of the pair is lower than the total energy of two free electrons. ~~The electrons in a cooper are thus quasi bound.~~

- Cooper pair (super electron pair) behaves as boson, since the net electron is zero as one electron being spin up and

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other electron having spin down. Thus the cooper pair has zero momentum, zero spin and charge -2e.

- The paired electrons i.e the cooper pairs behave in a material as a single unit to a specific length called the correlation or coherence length ξ. This is the distance within which the gap parameter does not change in a varying magnetic field. The ~~typically~~ typical value of ξ is 100 nm.