Dr. Priya Dubey (Guest Lecturer)

School of Studies in Physics, Vikram University, Ujjain

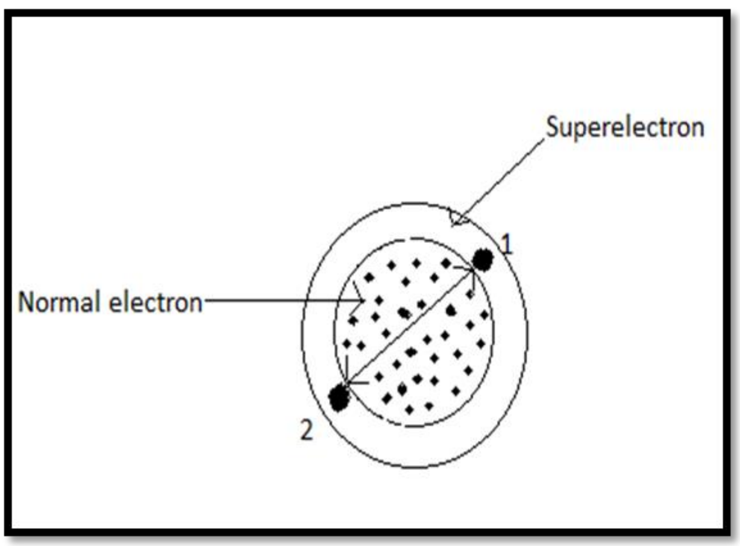
Lecture for M. Sc. Physics IV Semester students

Paper-I: Condensed Matter Physics

Unit 4-: Superconductivity

Qualitative Idea of BCS Theory

The modern theory of superconductivity was promulgated by Bardeen, Cooper and Schrieffer in their classic paper in 1957. The BCS theory has now gained universal acceptance because it has proved capable of explaining all observed phenomena relating to superconductivity. Because their theory is so steeped in quantum mechanics, one cannot discuss it meaningfully without using advanced quantum concepts and mathematical techniques. Therefore, in the interest of simplicity, let us instead give a brief, qualitative, conceptual exposition of the BCS theory.



The basic interaction responsible for superconductivity appears to be that of a pair of electrons by means of an interchange of virtual phonons.

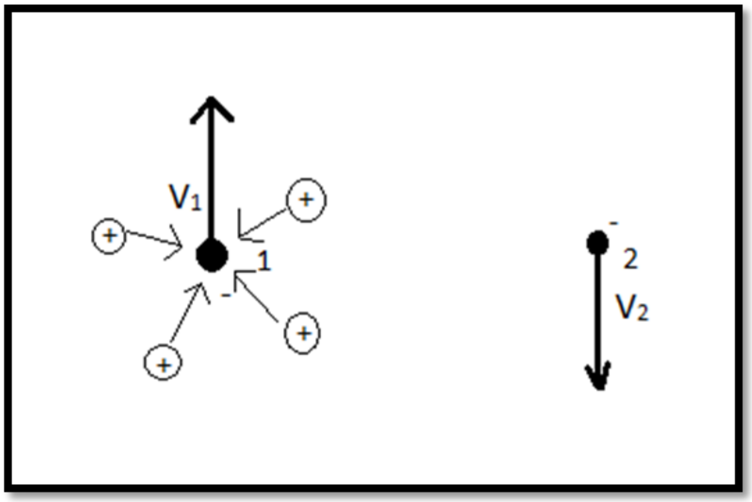
Consider a metal in which the conduction electrons lie inside the Fermi sphere. Suppose that two electrons lie just inside the Fermi surface and repel each other because of Coulomb interaction. But this Coulomb force is reduced substantially on account of the screening due to the presence of other electrons in the Fermi sphere. After the screening is taken into account, the interaction between the two electrons disappears almost entirely, although a small repulsive residue persits.

However something new may occur. Suppose that, for some reason, the two electrons attract each other. Cooper showed that the two electrons would then form a bound state provided they were very close to the Fermi surface. 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.

Our two electrons are called a Cooper pair. The binding energy is strongest when the electrons forming pair have opposite moments and opposite spins, i.e. $\vec{k}\uparrow, -\vec{k}\downarrow$.

We have been talking about the consequences of electron-electron attraction, but how does this attraction come about in the first place?

In superconductive materials, it results from the electron-lattice interaction



Suppose that the two electrons, 1 and 2, pass each other. Because electron 1 is negatively charged, it attracts positive ions towards itself due to electron lattice interaction. Thus electron 2 does not "see" the bare electron 1. Electron 1 is screened by ions. The screening may greatly reduce the effective charge of this electron; in fact, the ions may over-respond and produce a net positive charge. If this happens, then electron 2 will be attracted towards 1. This leads to a net attractive interaction, as required for the formation of the Cooper pair.