Why is a levitated magnet stable?

A common demonstration of the Meissner effect is to cool a high T_c superconductor ($YBa_2Cu_3O_7$), then place a small and strong permanent magnet on top of it to demonstrate the repulsion of the magnetic field by the superconductor as shown in Figure 6. This repulsion results in the levitation of the magnet. An explanation for this levitation is that the magnet “sees” a mirror image of itself in the superconductor, which is like a magnet floating on top of another identical magnet. This would be true if the superconductor was much larger than the magnet. In practice the superconductor may be only slightly larger than the magnet. This will result in a distorted image of the magnet, especially near the edges of the superconductor. The situation then is similar to trying to balance two magnets on top of each other. If you have ever tried to balance one magnet on top of another, you would have quickly found that it is impossible to do without physically holding it there. Left alone, the magnet will always topple over and never stay levitated. This is a well known effect in physics, a consequence of Earns haw’s theorem, which states that there can never be any stable configuration of magnetic fields that will trap another magnet

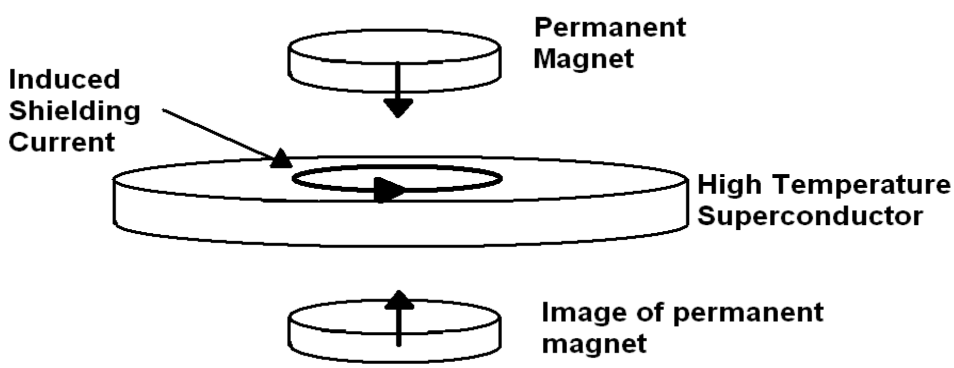

Figure (4):Levitating permanent magnet on top of a high Tc superconductor.

A superconductor with little or no magnetic field within it is said to be in the Meissner state. The Meissner state breaks down when the applied magnetic field is too large. Superconductors can be divided into two classes according to how this breakdown occurs. In Type I superconductors, superconductivity is abruptly destroyed when the strength of the applied field rises above a critical value Hc. Depending on the geometry of the sample, one may obtain an intermediate state[16] consisting of a baroque pattern[17] of regions of normal material carrying a magnetic field mixed with regions of superconducting material containing no field. In Type II superconductors, raising the applied field past a critical value Hc1 leads to a mixed state (also known as the vortex state) in which an increasing amount of magnetic flux penetrates the material, but there remains no resistance to the flow of electric current as long as the current is not too large. At a second critical field strength Hc2, superconductivity is destroyed. The mixed state is actually caused by vortices in the electronic superfluid, sometimes called fluxons because the flux carried by these vortices is quantized. Most pure elemental superconductors, except niobium and carbon nanotubes, are Type I, while almost all impure and compound superconductors are Type II

Superconductivity Theory 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 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

Tcpair" 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. So, Cooper pairs are formed by Coulomb interactions with the crystal lattice. This is also what overcomes resistance. Remember, an electron inside the lattice causes a slight increase of positive charge due to Coulomb attraction. As the Cooper pair flows, the leading electron causes this increase of charge, and the trailing electron is attracted by it. This is illustrated below

The Formation of Cooper Pairs

Cooper pairs are formed from a interaction between electrons and a phonon. A phonon is vibrational energy. Normally, electrons will have too much energy to stay in a Cooper pair, however as the temperature is lowered sufficiently, electrons may be able to form Cooper pairs.

Normally an electron would never be able to interact with another electron due to the repulsive effect of the Coloumb force. (The Coulomb force is the repulsive force between like charges). The idea of superconductivity being intrinsic to the structure was lead by several discoveries to do with the property of superconductors:
 The Meissner effect showed that the magnetic field inside a superconductor was exactly ZERO. The critical temperature was dependent on the mass of the ions in the lattice (the isotope effect). An energy gap between the repulsion of electron is 10-8 per atom.

As an electron moves through a crystal lattice the positive crystal lattice bends towards it forming a 'trough' of positive charge. This charge may be sufficient to attract an electron and form a 'Cooper pair'. The importance of linking electrons into Cooper pairs is the fact that electrons are fermions (particles with non-integer spins), fermion must obey Pauli's exclusion principle which states that no two fermions with the same spin can occupy the same state. However electrons with opposite spins in a Cooper pair add up to an integer spin of 0. This promote the electron pair into the Boson state. Roughly 106 or 107 can all be in the same state, importantly the Cooper pairs provide the energy gap required to be broken/formed in order to transition in and out of the superconducting state.

Problems encountered during the creation of the BCS theory:

Dr. Cooper realized that he was not able to resolve the formation of Cooper pairs mathematically for millions of electrons. Instead he opted to apply mathematics of the formation of one Cooper pair at a time. Schrieffer was then able to contribute through treating the problem statistically. He realized that the Cooper pairs seemed to all move in one group. An analogy to which he described: "Ice skaters who are linked arm in arm. If one was pushed then the rest would move along in the line"