Superconductivity and the Meissner Effect

**1. Introduction**

On July 10, 1908 liquid helium was produced for the first time, allowing for experiments to be done on the ultra-low temperature scale. On April 8, 1911 Heike Kamerlingh Onnes set out to measure the resistivity of mercury at cryogenic temperatures. He discovered that at about 4.2 K the resistance fell abruptly to 0. This was the first observation of the phenomenon dubbed superconductivity. Since its inception, superconductivity has been proven to be one of the most important discoveries of the 20th century. Although it is not completely understood, there are numerous theories with experimental backing that offer an explanation for the mechanisms behind the phenomenon. This paper will briefly explain the Bardeen-Cooper-Schrieffer (BCS) theory of superconductivity, however the main focus of this paper is to offer an overview of the Meissner Effect.

**2. BCS Theory**

The BCS theory of superconductivity is the most widely accepted explanation for conventional superconductors which awarded the three physicist who wrote it the Nobel Prize in 1972. The theory goes something like this: Electrons flow freely in a metal when an electric field is applied. When these travelling electrons encounter impurities in the metal they collide and produce heat. This is what is known as electrical resistance. When a superconducting material (which doesn’t have to be a metal) is cooled down below its transition temperature Tc, it experiences a sudden phase change where its electrical resistance drops down to exactly zero. The electrons in the solid interact with phonons which cause neighboring electrons to pair up. The two electrons, both with spin ½, create a composite particle with spin 0. This integer spin particle acts like a boson which condenses into a superfluid. Just like how a traditional superfluid can flow with no viscosity, Cooper Pairs can flow in a superconductor with no resistance.

**3. Meissner Effect**

Superconductivity is defined by two properties; the first is exactly zero electrical resistance, the second is the expulsion of magnetic flux lines. This second property, called the Meissner Effect, is perhaps the most confusing of the two.

3.1 Classical Diamagnetism and the Meissner Effect

In the classical theory of electricity and magnetism, magnet fields cannot do work on the system. Meaning, magnetscannot add energy to the system. In diamagnetic systems, an opposite magnetic field is induced, and energy is added to the system. Because of this, it is often claimed that there is no explanation of classical magnetism. However, the Darwin Hamiltonian given by

Where Be is the external magnetic field and Bi is the internal magnetic field due to tRhe moving charged particles. This gives rise to a magnetic energy term and can therefore model diamagnetism. This is in disagreement with the previously accepted Bohr-van Leeuwen theorem, which states that the Hamiltonian of interacting charged particles does not depend on the external vector potential. Additional evidence

Why is it important that we can explain diamagnetism classically, and how is this relevant to the Meissner Effect?