CHAPTER 1:
A Little Bit of History

1.1. The Discovery of the Phenomenon of Superconductivity. Meissner-Ochsenfeld Effect. Silsbee Effect. Existingtheories

Kamerlingh Onnes discovered the phenomenon of superconductivity at Leiden Laboratory, Holland, in 1991 [1]. While studying the dependence of Hg resistance on temperature, he found out that when the material is cooled down to the temperature of about 4 K the resistance drops abruptly to zero. This phenomenon was called superconductivity. Soon after that other elements with similar properties were discovered. **Figure 1.1** demonstrates the scheme of measurement of superconductor resistance.

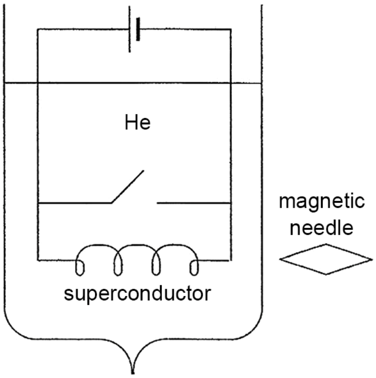

Figure 1.1. The magnetic needle detects a supercurrent-induced magnetic field.

A superconductor is immersed in liquid helium. Initially, a weak current is supplied from a battery. Then temperature is reduced. When temperature falls below a certain value, the superconductor circuit is shorted. The current in the superconductor circuit can be sustained infinitely long. A magnetic needle provided as a detector indicates the magnetic field produced by the current in the solenoid.

Figure 1.2 shows the dependence of resistivity ρ on temperature T in a superconductor. Temperature T_c is called critical temperature. This means that we cannot measure the resistance of the superconductor at $T < T_c$. At the same time we cannot say that the resistivity ρ is equal to zero. The superconductor has a property that makes it impossible to measure the resistivity.

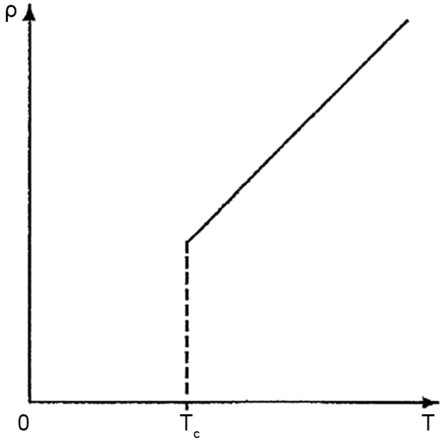

Figure 1.2. The dependence of the resistivity on temperature.

Soon it was discovered that superconductivity disappears when a test piece is placed in a relatively weak magnetic field. This phenomenon was discovered by Meissner and Ochsenfeld [2]. Value H_m of the magnetic field strength in which superconductivity is disrupted is called a critical field. The temperature dependence of the critical field is described by the following empirical formula:

$$H_m(T) = H_m(0)\left[1-(T/T_c)^2\right], \tag{1.1}$$

where $H_m(0)$ is a critical field produced at absolute zero of temperature $T = 0$. Dependence (1.1) is shown in **Figure 1.3**. Plane (H, T) represents a phase diagram of the superconductive state. Substance in the superconductive state S is shown below the curve (1.1) and this substance in the normal state N is above the curve. The superconductor that demonstrates such states is called the type-I superconductor. Superconductivity is disrupted when the current in the substance exceeds a certain critical value (The Silsbee effect).

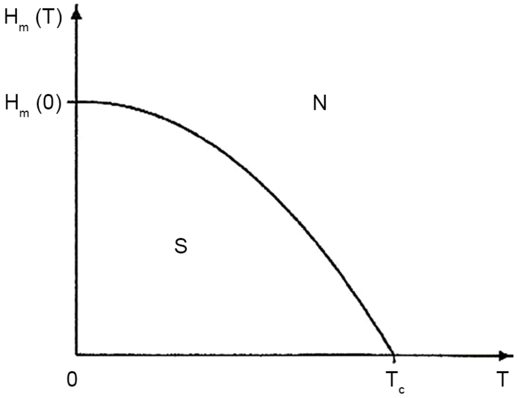

Figure 1.3. Phase diagram of the type-I superconductive state at coordinates (H, T).

There are two magnetic fields in the superconductor. One magnetic field is created by the supercurrent and another external field is induced from other sources. The compass needle shown in **Figure 1.3** responds to the supercurrent-induced field. Let's denote such strength of field by parameter $H^{(s)}$ and name this field the superconductor self-generated magnetic field. We shall denote the strength of other magnetic fields by parameter $H^{(exter)}$. This is an external magnetic field. Let the strength of the external magnetic field on the surface of the superconductor be equal to $H^{(exter)} = H_o$. The Meissner-Ochsen-feld effect can be expressed by the following inequality. Superconductivity is generated in metal when its temperature T drops down below the critical temperature T_c:

$$T < T_c, \tag{1.2}$$

where the strength of the external magnetic field at the surface of the superconductor is less than that of the critical field:

$$H_o < H_m(T). \tag{1.3}$$

In other cases the superconductor will show ordinary metal properties.

There are superconductors of type II, for which the phase diagram has the form shown in **Figure 1.4**. The state of the superconductor, which lies between the normal state N and superconducting state S is called mixed.

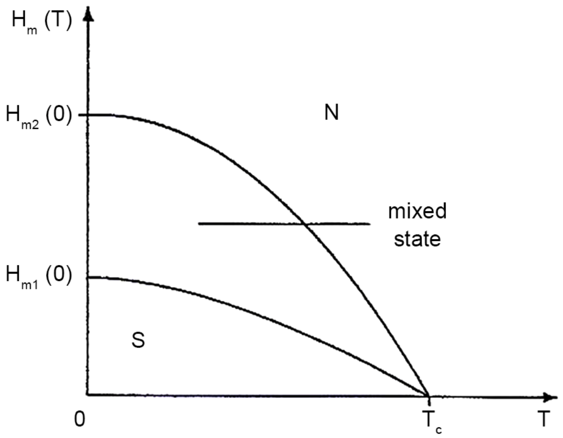

Figure 1.4. Phase diagram of the superconducting state of type II.

The next important step was finding out the existence of an energy gap. Experimental dependence of the gap width $\Delta = \Delta(T)$ on temperature is shown in **Figure 1.5**.

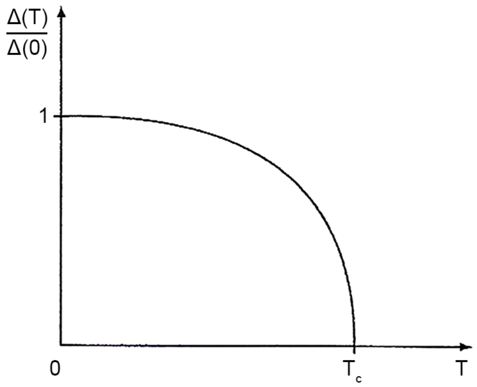

Figure 1.5. The width of the energy gap.

The dependence of the heat capacity of the superconducting and normal states, which corresponds to the width of the energy gap $\Delta = \Delta(T)$, is shown in **Figure 1.6**.

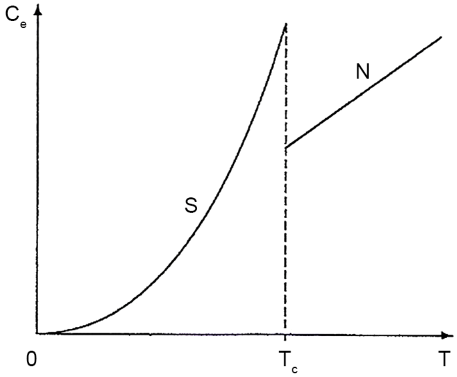

Figure 1.6. The heat capacity of the super-conducting and normal states.

In 1950 superconductivity has received its theoretical explanation on the phenomenological level in the Ginzburg-Landau theory [3] and in 1957 on the microscopic level in the Bardeen-Cooper-Schrieffer theory [4]. The latter theory was based on a preposition as described in electronical second quantization theory.