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Lab Report in Physics

Demonstration of Meissner Effect and Levitation of Yttrium Barium Copper Oxide

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Abstract: As a hot topic in recent physics, superconductors have attracted the attention of countless people. We demonstrate the feasibility of conducting experiments on superconductors under extremely crude conditions and perform several experiments and produce data. We used YBCO superconductors and liquid nitrogen to conduct related experiments. In conclusion, in the case of insufficient experimental conditions, the superconductor can still be partially suspended, which is sufficient to demonstrate the Meissner Effect, and exhibits various properties of the superconductor at the critical temperature.

Keywords: Superconductors; Meissner effect; Levitation

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1. Introduction

Superconductivity is one of the most interesting physical phenomena, which could bring the world to a new era if we understand fully. Superconductor is a material that has zero resistance under certain temperature. This report mainly describes the demonstration of the Meissner effect and levitation of Yttrium Barium Copper Oxide.

The superconductors can be categorized into two groups based on their critical temperature: high-temperature superconductors and low-temperature superconductors. High-temperature superconductors usually refer to superconductors whose critical temperature is higher than the temperature of liquid nitrogen (greater than 77K), and low-temperature superconductors usually refer to superconductors whose critical temperature is lower than that of liquid nitrogen (less than 77K).

2. Background, Analysis Methods, Materials, Research Process, and Data Collection

2.1. Introduction and Background of Superconductors

The superconductors can be categorized into two groups based on their critical temperature: high-temperature superconductors and low-temperature superconductors. High-temperature superconductors usually refer to superconductors whose critical temperature is higher than the temperature of liquid nitrogen (greater than 77K), and low-temperature superconductors usually refer to superconductors whose critical temperature is lower than that of liquid nitrogen (less than 77K).

Superconductors originated in 1911. When Dutch scientists were studying liquid nitrogen to cool mercury, they lowered the temperature of mercury to about 4.2K. Scientists found that the resistance of mercury completely disappeared at this time. The temperature of 4.2K is called the critical temperature, and superconductors can be divided into high-temperature superconducting materials and low-temperature superconducting materials based on this temperature.

In 1973, there was a major discovery in the field of superconductors - niobium-germanium alloys. Its critical superconducting temperature is 23.2K, a temperature record that has remained unbroken for 13 years.

In 1986, the IBM Research Center in Zurich, Switzerland reported a superconductor with a critical temperature of 35K. Since then, the development of superconductors has been very rapid, and superconductors with high critical temperatures have been continuously discovered. Superconductors with a superconducting critical temperature of 40K were discovered in the same year.

Around 1990, yttrium barium copper oxide series superconductors came out. This series of superconductors was also selected in this research.

2.1. Superconductor selection

Typically, superconductors exhibit zero electrical resistance only at extremely low temperatures. This means that the critical temperature of the superconductor and the corresponding cooling medium need to be considered when conducting experiments related to superconductors. This experiment was carried out at home. There are other materials and methods for cooling substances that are much closer to 0 K than using liquid nitrogen. For instance, liquid helium is often used as the cooling substance for professional experiments. Currently, very few cooling media are available on the market. Also, due to the unavoidable deficiency about homemade experiments, a high-temperature superconductor must be selected.

The author chose yttrium barium copper oxide superconductors and made two purchases during this phase. The superconductor purchased for the first time burst when placed in liquid nitrogen, so subsequent experiments could not be carried out. Subsequently, the author contacted the largest superconductor manufacturer in China and purchased a circular superconductor. According to the information provided by the manufacturer, the superconductor will exhibit superconductivity if cooled by liquid nitrogen at the temperature of 93K.

Figure 1. Picture of the selected superconductors

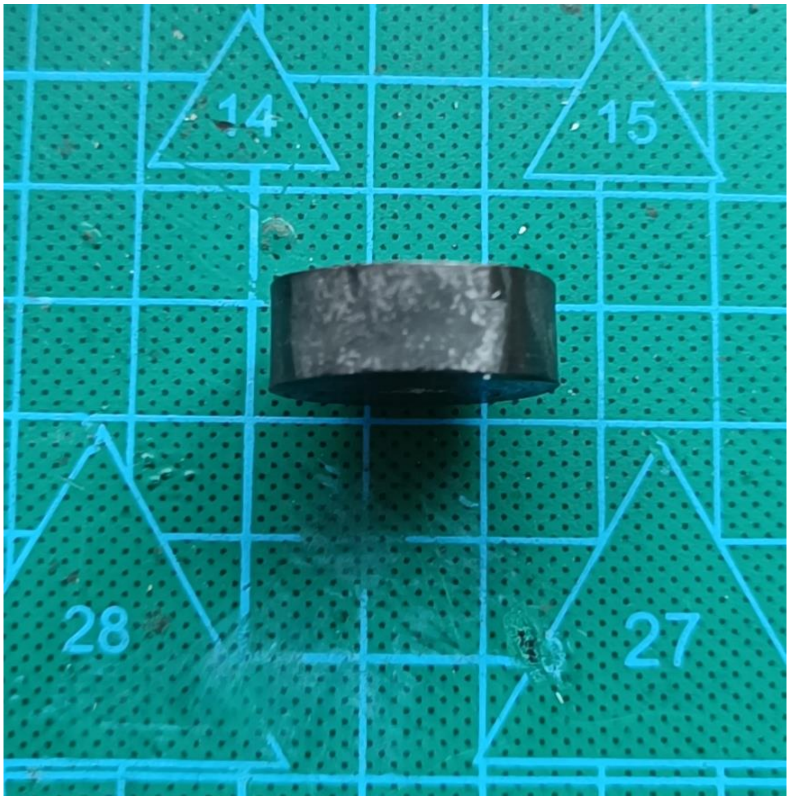

Figure 2. Picture of the selected superconductors

2.2. Liquid Nitrogen Preparation

Liquid nitrogen is a controlled substance in China, and the author obtained two liters of liquid nitrogen through various contacts. The storage of liquid nitrogen requires the use of special low-temperature-resistant containers. The container for storing liquid nitrogen must use a special cover, which can allow the normal discharge of liquid nitrogen during the vaporization process to ensure equal pressure inside and outside the container.

Figure 3. Picture of the Liquid Nitrogen Container

Figure 4. Picture of the Liquid Nitrogen Container

2.3. Experiment and Demonstration

The levitation of superconductors requires extreme cold and strong external magnetism. Currently, neodymium magnets that are available in the market are the best choice. The entire mechanism consists of three parts: the square base, the magnets, and the cooled superconductor. The magnet is attached to the square base, with like poles are pointing together. The square base is a carbon-rich metal sheet that are approximately 25cm × 25cm. The main reason of having a metal sheet as the base is that the magnets can be directly attached to the base with the strong magnetic force between the sheets and magnets. In addition to this, the magnetic force between the magnets and the base is significantly greater than the repelling force between the two adjacent magnets. In this way, the flexibility and mobility of the magnets is presented.

2.3.1 Steps and Observations

After the above preparations were completed, the YBCO superconductor was immersed in liquid nitrogen for 10 minutes, quickly taken out and placed on the magnet prepared in advance. After finding the balance point through repeated exploration, the YBCO superconductor is levitated on the magnet. After being gently pushed, and the superconductor moves smoothly on the linearly arranged magnets.

Resistance measurement, the authors measured the resistance of the superconductor using a digital multimeter. As the cooling time increases, the temperature of the superconductor decreases, and at about 95K, the multimeter shows a resistance of 0.

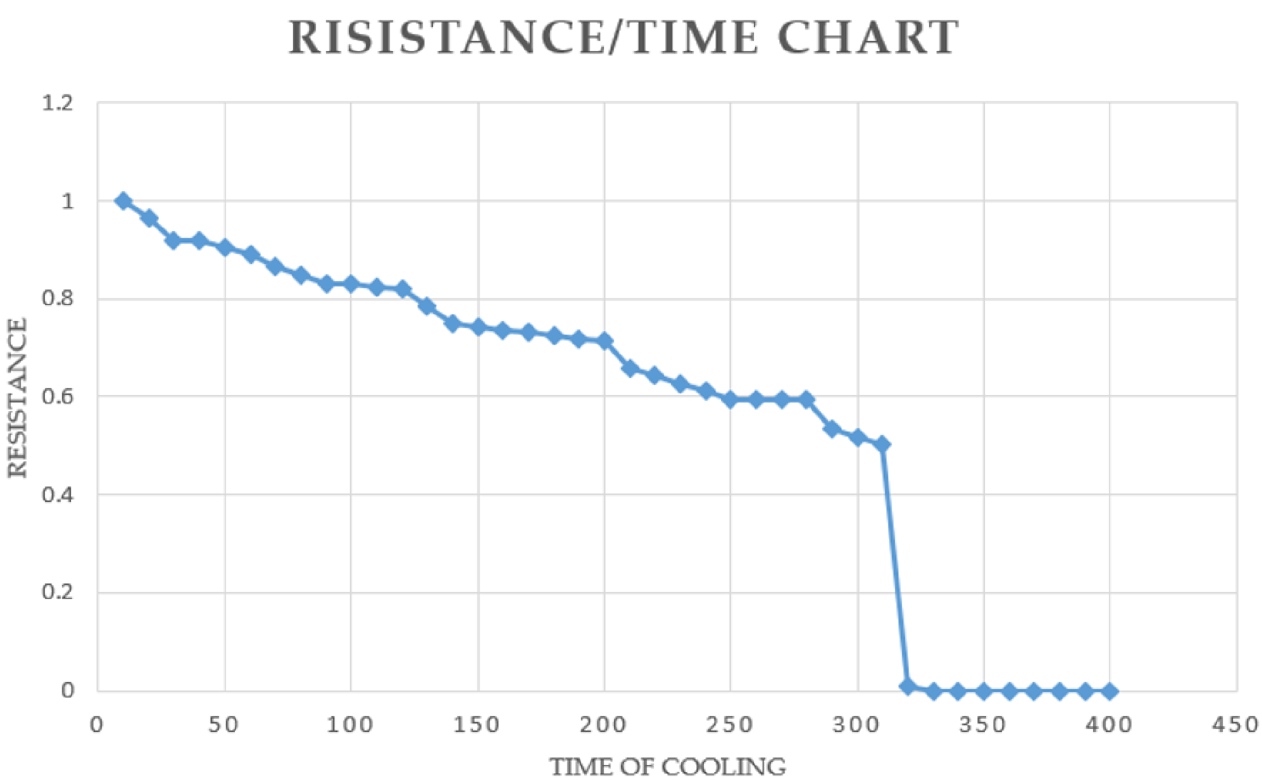

Figure 5. Resistance vs. Cooling Time

2.3.2 Meissner Effect

When the experimental YBCO superconductor enters the superconducting state under the cooling of liquid nitrogen, it will repel the magnetic field, which is called the Meissner effect. This effect was discovered in 1933 by Walther Meissner and his postdoc Robert Ochsenfeld in magnetic field distribution measurements of tin and lead cooled to a superconducting state (hence it was also called the Meissner-Ochsenfeld effect). When a magnet is brought close to a superconductor, the sum of the magnetic flux inside the superconductor becomes zero. This is because of the generation of superconducting current. Superconducting currents are induced when a magnet is close to a superconductor. The superconducting current will generate a magnetic field in the superconductor that is equal in magnitude and opposite to the external magnetic field, and the two magnetic fields cancel each other out, resulting in a constant zero magnetic induction in the superconductor. Therefore, the material in the superconducting state has no magnetic flux near the magnet.

When the authors placed a superconducting material on a magnet, the superconductor could be suspended above the magnet as long as the magnet's magnetic field strength did not exceed a certain limit. This is because the Meissner effect distorts the magnetic field, creating an upward force. But the magnets used in this experiment did not have the ability to generate enough magnetic flux to levitate the superconductor.

3. Discussion and Synthesis

Since the author conducts experiments in his personal capacity, this series of experiments all face huge shortcomings in funding and availability of resources. The author contacted various parties to coordinate the experimental resources, but the experimental equipment and methods used are not completely professional. The YBCO sample was discovered to transition to a superconducting state when cooled by liquid nitrogen, and the levitation demonstration was effective, but the author was unable to acquire accurate quantitative measurements.

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