Can Room-Temperature Superconductors Save the World?

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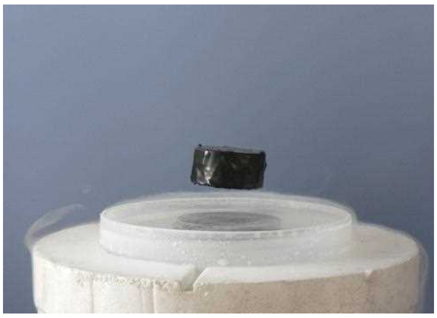
One of the major challenges facing our society is global warming. According to IPCC Fifth Assessment Report (2014), the global average temperature rose by 0.85 °C over the period 1880 to 2012, and the IPCC is now 95 % certain that humans are the main cause of current global warming. There are a variety of gases that contribute to global warming. Among them, carbon dioxide is the one that has the greatest impact on global warming. One of the major contributors to carbon dioxide emissions is power generation. In Japan, it accounts for 40 % of the whole carbon dioxide emissions. To reduce carbon dioxide emissions, it is necessary to use electricity efficiently. However, the enemy of efficient use of electricity is electrical resistance. When electricity flows through a conductor, some of it is wasted as heat, which is severe in transmission losses from power plants. The electricity produced at power plants is delivered to our homes through many transformer substations and power lines. However, in the process of transmission, as much as 3.4% of the electricity consumed in Japan (equivalent to seven thermal power plants) is lost due to voltage conversion at substations and resistance in transmission lines.

To reduce energy loss, one of the promising materials is a superconductor. A superconductor is a substance that conducts electricity without resistance when it becomes colder than a certain temperature. Superconducting materials are used in familiar applications such as MRI, which captures and visualizes the inside of the human body, and linear motor cars. If we use superconducting wires with zero electrical resistance for transmission lines from power plants, we can transport electricity without energy loss. However, we need to cool the material to a very low temperature to use superconductivity. To achieve low temperatures, it is necessary to use liquid helium or liquid nitrogen. Since we need a lot of electricity to liquefy helium and nitrogen, the advantages of using superconducting wires are canceled out. Therefore, the emergence of materials that exhibit room temperature superconductivity is strongly desired. If materials that exhibit superconductivity at room temperature can be created, it will be possible to use electricity much more efficiently than before by replacing various items with superconducting materials. On the other hand, it is not easy to develop materials that exhibit room-temperature superconductivity. Now I would like to introduce the history of superconductors and the research toward room-temperature superconductivity.

The history of superconductivity research began in 1908 when the Dutch physicist Kamerlingh Onnes succeeded in liquefying helium. He used liquid helium to measure the electrical resistance of metals at low temperatures. In 1911, he measured the electrical resistance of mercury while lowering the temperature and found that the electrical resistance suddenly dropped to zero at 4.2 K (-268.95°C). Later, it was discovered that the electrical resistance of metals such as tin and lead dropped sharply below a certain temperature inherent to them, and these materials were named superconductors.



In 1933, other peculiar properties of superconductors were discovered by German physicists Meissner and Ochsenfeld. By carefully measuring the distribution of the magnetic field when a weak magnetic field is applied to a superconductor, they discovered that the magnetic field inside a superconductor is always zero, regardless of its history. This phenomenon is called the Meissner-Ochsenfeld effect. It was later found that the effect was intrinsic and could explain the zero electrical resistance.

Along with the experimental findings, theoretical research was also conducted. In metals, electric current is caused by the flow of electrons, subatomic particles that carry an electric charge. In 1957, an epoch-making theory is submitted by American physicists Bardeen, Cooper, and Schrieffer. In their theory, two electrons make a pair and explained the Meissner-Ochsenfeld effect. The theory is called the BCS theory after them. In BCS theory, the sample needs to be cooled to a very low temperature for the electrons to form pairs. Therefore, it was considered difficult to realize high-temperature superconductivity

However, this situation changed in 1986 with the discovery of a new type of superconductor by Bednorz and Müller. They found that copper oxides containing lanthanum exhibit superconductivity at higher temperatures than ever before. After their discovery, various copper oxide superconductors were found and some of them exhibit superconductivity at the temperature of liquid nitrogen, which is cheaper than liquid helium.

Currently, the superconductivity exhibited by hydrides (compounds with hydrogen) under extremely high pressure is attracting much attention after the discovery of superconductivity at above 200 K (-73.15 ℃) [2]. Let's introduce a unit called GPa (gigapascal) to represent very high pressure: 1 GPa is about 9870 times the atmospheric pressure! In 2015, Drozdov et.al. measured the conductivity of hydrides at the pressure of 155 GPa and found superconductivity at 203K (-70.15 ℃) [3]. In 2020, it was reported by Snider et. al. that another hydride exhibits superconductivity at 267 GPa and 287.7 K (14.55 ℃) [4], which is a room-temperature. Although it is necessary to achieve superconductivity at room-pressure for practical use, these discoveries were important steps to room-temperature and room-pressure superconductivity.

There are still many barriers to the practical use of room temperature superconductors in electric wires. First, there is a need to achieve room temperature superconductivity at room pressure. Secondly, they need to be easy to process and inexpensive. Finally, the wire must be durable and withstand years of use. Considering these conditions, it will take many years before the electric wire network in the city is replaced by superconductors. However, as we have seen, research on superconductors is progressing steadily. I hope you will keep an eye out for news about superconductors.

References

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