Zero Energy Loss Electrical Conduction:

Empowering Life with High-Temperature Superconductivity

Univ. of Tokyo, Dep. of Phys. Ryotaro Suda

Introduction

Have you ever found physics classes to be less interesting compared to other subjects? While chemistry and biology classes often involve exciting experiments that create impressive reactions, physics classes tend to focus on abstract concepts. A zero-gram spring, a pendulum swinging back and forth without any purpose, or the physical laws of motion in hypothetical and abstract spaces, which are purely theoretical and abstract. Some students may even think that physics is so basic study and not practically useful, like "Physical laws? They may be necessary for calculations but is theoretical physics truly important?".

However, in reality, physics has greatly contributed and has the potential to contribute significantly to the social development of humanity, both experimentally and theoretically. For example, even something as basic as the electronic circuits in the smartphones and computers that we use every day are built on the foundations of physics law, precisely electronics. The cars that drive on the roads and the airplanes that fly in the sky would not have been possible without the principles of physics. Furthermore, physics still holds the potential to significantly transform human society in the future. And that possibility is built on basic abstract science again. I will write about one such possibility: high-temperature superconductivity.

What is superconductivity?

What is superconductivity? It is a phenomenon in which a material loses all electrical resistance when it is cooled to a very low temperature. This means that electricity can flow through a superconductor with zero loss of energy. Also, when a magnet is placed under a superconductor, it has the strange property of floating. Superconductivity was first discovered in 1911 by Dutch physicist Heike Kamerlingh Onnes. [1] Physicists of the time were exploring the physics of low temperatures, and there was a race to reach low temperatures. They knew that resistance generally decreased as the sample cooled, but they did not know what would happen when the temperature reached extreme lows near absolute zero. To answer this question, Onnes developed a cooler using helium to explore the behavior of materials at low temperatures. At first, he did not expect that the resistance would suddenly drop while cooling. But he found that it lost all resistance when it was cooled to 4K (-269 degrees Celsius). By exploring the physics of low temperatures, physicists have made unexpected discoveries of superconductivity. And this discovery was a major breakthrough in physics. It opened up a new way to the development of many new technologies.

One of the most important and believed applications of superconductivity is in the development of high-speed trains. Using a Superconductor, we can make magnets with no-loss energy, thus can be used to create powerful magnetic fields that levitate trains above the track. This allows trains to travel at speeds of up to 500 kilometers per hour. And superconductivity is currently utilized in medical devices Superconducting magnets are being used in MRI machines to create detailed images of the human body. In addition, superconducting magnets are expected to be extremely useful for plasma confinement in nuclear fusion reactors. This reactor can be used to establish fusion power generation, expected to make a significant contribution to resource issues. Imagine a world where we can generate electricity without relying on fossil fuels and transport energy without resistance, a utopia we can only dream of! Superconductivity holds great potential in various applications.

The Role of Basic Science in the Search for High-Temperature Superconductors

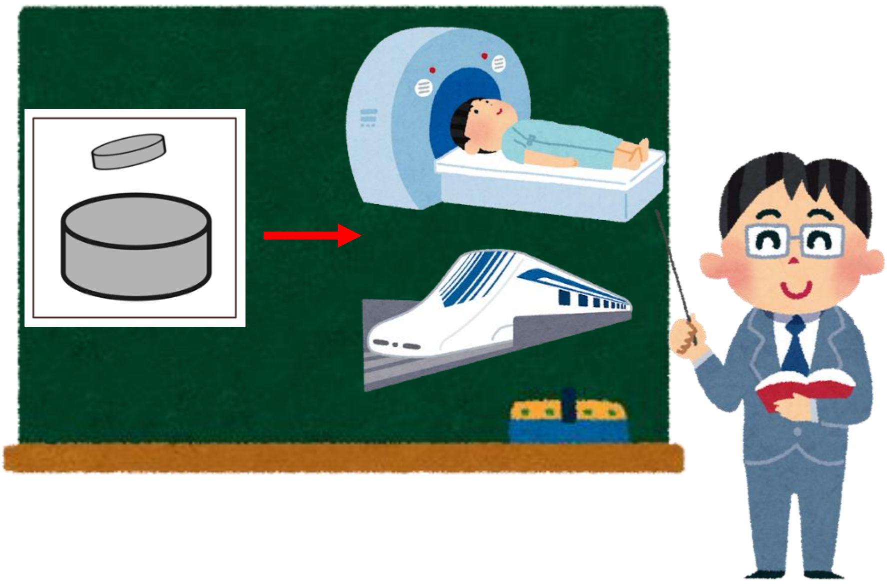
However, there was a problem with superconductivity. It only works at very low temperatures, around -270 degrees Celsius. Naturally, we want to find superconducting materials that can operate at high temperatures. Then what should we do? This point is where basic science, or physics comes into play. We need to understand why superconductivity occurs!

In the first place, the discovery of superconductivity was surprising for scientists. Until then, it was believed in basic science that there is always resistance when an electric current flows and the resulting heat generation is unavoidable. Many scientists tried to find a theory that is underlying superconductivity. And the BCS theory was proposed in 1957 by John Bardeen, Leon Cooper, and Robert Schrieffer. [2] It explains superconductivity using the relationship between charge oscillations in the lattice of metal atoms, and electrons. This theory provided a fundamental explanation for superconductivity. And this theory provided clues for the search for high-temperature superconductors. According to this theory, a hypothesis was formulated by N.W.Ashcroft that high-temperature superconductivity could be achieved in metallic hydrogen.[3] Due to the extreme pressures required to achieve metallic hydrogen itself, which was expected to exhibit high-temperature superconductivity, researchers turned to the exploration of superconductors composed of hydrogen compounds as an alternative (Ashcroft claimed hydrogen compounds could exhibit superconductivity at lower pressures than metallic hydrogen. [4]).

In this pursuit, M.I. Eremets and his colleagues discovered in late 2014 that H_3S, obtained by subjecting hydrogen sulfide (H_2S) to pressures of 150 GPa (Equivalent to a 1.5 million times atmospheric pressure!), exhibits relatively high-temperature superconductivity at 203 K (-70 degrees Celsius) [5]. While this may still seem like a low temperature, it is a significant advancement considering that -196 degrees Celsius can be easily produced using liquid nitrogen, which is easy to produce industrially. Albeit with the drawback of requiring high pressures, (And apart from hydrogen compounds, high-temperature superconductors also exist in other materials. For example, the cuprate superconductors are well-known, but their theoretical explanation remains incomplete.) the predictions brought forth by the basic science of theoretical physics have led to the achievement of discovering superconductors at higher temperatures. This makes the utilization of superconductivity more realistic. The search for hydrogen compound superconductors continues to this day.

Conclusion

Thus, it is safe to say the practical applications and contributions of physics to society cannot be overlooked. Physics forms the foundation of many technological advancements that have shaped our modern world. Indeed, there is a possibility that in the not-so-distant future, room-temperature superconductors could be discovered, and at that time, the world would undergo significant changes.



[1] Kamerlingh Onnes, H. "On the sudden change in the rate at which the resistance of mercury disappears." Commun. Phys. Lab. Univ. Leiden, c 124 (1911).
[2] Bardeen, John, Leon N. Cooper, and

John Robert Schrieffer. "Theory of superconductivity." Phys. Rev.108.5 (1957): 1175.
[3] Ashcroft, Neil W. "Metallic hydrogen: A high-temperature superconductor?" *Physical Review Letters* 21.26 (1968): 1748.
[4] Ashcroft, N. W. "Hydrogen dominant metallic alloys: high temperature superconductors?" Physical Review Letters 92.18 (2004): 187002.
[5] Drozdov, A. P., et al. "Conventional superconductivity at 203 kelvin at high pressures in the sulfur hydride system." *Nature* 525.7567 (2015): 73-76.

I didn’t use any AI-tools except DeepL and Grammarly.

I use them for grammar proofreading

An Illust is made by me ,using いらすとや(https://www.irasutoya.com/), and

AutoDraw(https://www.autodraw.com)