Superconductivity: Its Potential Implications for Society and the Environment

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Abstract

This paper examines the relationship between technological advancement and environmental sustainability, focusing on the implementation of room-temperature superconductivity. Technology has advanced tremendously over the past few decades; paradoxically, environmental issues have worsened. Humanity relies on IT, and all these technologies depend on electricity. Electricity impacts the environment in several ways; however, its consumption has been increasing year over year. From this consumption, the United States itself experiences 4-5% loss of electricity during transmission. This is significant because higher electrical consumption equates to greater loss.

To address this issue, this paper explores the innovative technology called superconductivity. Superconductivity is a phenomenon that occurs at extremely cold temperatures, where electric resistance is nonexistent. The potential application using superconductivity is enormous because it offers the possibility to reduce energy losses in electrical systems, revolutionize magnetic levitation for transportation, enable powerful and compact magnets for medical imaging technologies, and significantly enhance the performance of electronic devices.

Due to its wide range of applications, superconductivity has been recognized as a key solution to address various challenges that humanity has encountered. However, with current technology, it is an unachievable technology due to the required stringent conditions to operate, such as extremely low temperatures. For the commercialization of superconductors, numerous experiments have been conducted over decades to raise the temperature at which materials exhibit superconductivity to a more practical level. In 2023, Korea University published a study on a hypothetical superconductor, named LK-99, that operates at room temperature.

Although it has not yet been conclusively determined that LK-99 is a superconductor, it emphasizes the potential to be a significant step forward in humanity. This paper explores the concept of the superconductivity phenomenon, examining its fundamental principles, historical development, and the significant challenges that have hindered its application at ambient temperatures. By highlighting the theoretical and practical aspects of superconductors, it will be possible to observe the potential impact of room-temperature superconductors on various technological fields.

After those explorations, this paper will delve into LK-99's technical aspects to understand its operational mechanisms. This includes an examination of its composition, the conditions under which it exhibits superconductivity, and the theoretical foundations that could explain its ability to operate at room temperature. Through this, it will be possible to see the potential applications of room-temperature superconductors and solutions for electricity transmission.

Though innovative technology leads to better human life quality or solving critical challenges, perceptions of such advancements vary significantly among different social groups. SCOT framework, which stands for Social Construction of Technology, is a theoretical framework that helps to understand how social, political, and economic factors shape technological innovation and development. Utilizing the Social Construction of Technology (SCOT) theoretical framework, this paper lastly analyzes the perceptions and interactions of various social groups with the potential implementation of room-temperature superconductors like LK-99. The intricate relationship between technological advancement and environmental sustainability, with potential room-temperature superconductivity’s application and perception from various groups, draws a line of innovation and integration (Bijker, Wiebe E., 2015).

Room-Temperature Superconductors: LK-99, its applicants to the global energy challenges

The superconductivity phenomenon is distinguished by its unique attributes, where it exhibits zero electrical resistance and perfect diamagnetism, known as the Meissner effect. These attributes roles significant factors in the earth's environment, especially in energy sectors. To understand why superconductivity is known as a key solution to an earth's environment and energy crisis, it is essential to first understand the concepts of electric conductivity and electrical resistance. Electric conductivity is a measure of how well a material allows electricity to flow through it, while electrical resistance indicates how much a material, a conductor, opposes or resists the flow of electricity (Wikimedia Foundation, 2023). So the high conductivity means electricity can pass through with minimal resistance, and also efficient transmission of power. By reducing electrical resistance, superconductors offer a way to enhance this efficiency further, making the transmission of electrical power remarkably more effective. Copper is renowned for its high electrical conductivity, which is why it is widely used for electrical wiring and electrical components. Electrical resistance is conversant to electrical conductivity, where it is a measure of a material's opposition to the flow of electric current. The heat occurs from this opposition as an energy loss. When observing electricity moving through a copper wire from point A to B, it's important to note that the wire is not empty but contains copper atoms. As electrons move from A to B, they collide and interact with these copper atoms, creating friction and, consequently, resistance, which in turn generates heat. This explains why electronic appliances heat up during use. The distinctive property of superconductors to have zero electrical resistance means that they can potentially eliminate such energy losses, significantly impacting energy conservation and efficiency. The amount of resistance, or in other words, how frequently atoms and electrons collide, varies depending on the material. Superconductors are materials that have zero electrical resistance and do not lose energy through heat generation. This property is especially crucial in large-scale applications where even minor improvements in energy efficiency can lead to substantial cost savings and environmental benefits. This phenomenon could represent the reduced energy efficiency of electrical transmission in large-scale electrical infrastructure as more generated heat is linked to higher electrical resistance, ultimately indicating an amount of energy loss.

The Meissner effect exhibits perfect diamagnetism, repelling 100% of the magnetic field from a surrounding magnet. This results in the magnetic levitation effect, where it floats above the magnet. A superconductor is a material that can exhibit superconductivity and the Meissner effect above 0 degrees Celsius. For a material to be considered a superconductor, it must meet two conditions: superconductivity and the Meissner effect. If a material only exhibits superconductivity without the Meissner effect, it is referred to as a perfect conductor or a Weyl metal. Conversely, if a material shows both the Meissner effect and superconductivity but does not operate at room temperature, it is simply called a superconductor. Room-temperature superconductors refer to materials that can exhibit these superconducting properties at temperatures above 0 degrees Celsius (Castelvecchi, D., 2023). The current development of superconductivity faces challenges in exhibiting superconductivity phenomena, which require critical low or high temperatures. However, in July 2023, a team from Korea University announced the discovery of a potential room-temperature superconductor called LK-99 (Lee, S. Korea University Research Team, 2023). LK-99 was the first room-temperature superconductor in the world; but subsequent research and replication attempts disproved that LK-99 did not maintain superconducting properties at room temperature (Harris, M., 2023). Despite this, as the potential of room-temperature superconductors becomes more apparent, the possibility of solving societal problems remains evident, and potential applications could drastically change numerous technological and industrial fields.

One of the real-life applications of using properties of superconductors, is the creation of maglev (magnetic levitation) trains using super diamagnetism or perfect diamagnetism property of superconductivity. Maglev trains, which operate without wheels and float above the tracks due to magnetic forces, have no friction and thus are incredibly energy efficient, capable of reaching speeds over 500 km/h, comparable to airplanes. The operational efficiency and reduced maintenance costs of maglev trains exemplify the transformative potential of superconductors in public transportation systems. Currently, parts of Japan's Shinkansen and the Florida Maglev Project in the United States are experimentally operating magnetic levitation trains. However, the widespread adoption of maglev trains is hindered by the absence of room-temperature superconductors. As a result, current maglev trains require extremely low temperatures, and liquid nitrogen, and are characterized by their large size, heavy weight, high cost, and complex design. As it stands, there are many limitations to applying superconductors in reality. Despite these limitations, the reason why there are many attempts to apply superconductors in various fields is quite natural: using superconductors can yield significant benefits and enable more efficient systems. In modern society, there would be significant differences in quality of life and many other aspects if superconductors were widely applied.

LK-99: Scientific Foundations beyond Room-temperature Superconductivity

LK-99 (Lee-Kim 1999 research) was published by a team at Korea University as a superconductor that operates under normal environmental conditions, and room temperature environments. This research represents a significant advancement in superconductor technology, which traditionally required extremely cold or hot temperatures to exhibit superconductor properties, such as the non-existence of electrical resistance. LK-99 has replaced Pb2+ ions with Cu2+ ion internal stress in its phosphate network; this substitution leads to a small decrease in volume (0.48%), causing ss in the material. This means that the material experiences an internal force or tension due to the change in its structure. When Cu2+ ions take the place of Pb2+ ions, it makes the material slightly smaller and also causes the atoms within the material to be packed more closely together. This denser atomic packing generates internal pressure inside the material because the atoms and molecular structures are pushed closer than they naturally prefer to be. This pressure forms the material's ability to conduct electricity without resistance at room temperature, making it a superconductor under conditions where others would not function as such.

The stress caused by this volume reduction induces minute distortions in the cylindrical columns of Pb(1) ions within the lead-apatite structure, leading to the formation of superconducting quantum wells (SQWs) at the interface between these columns and the surrounding insulating network. SQWs are interrelated to the ability to maintain superconductivity at room temperature and standard atmospheric pressure. They create a unique electronic state in which electrons can traverse without encountering resistance, characteristic of superconductivity, making possible movement of electrical current through these quantum wells. Thus supporting the characteristic uninterrupted flow of electrical current through these quantum wells.

The superconductivity of LK-99 is robustly supported by various experimental findings, including critical temperature (Tc) measurements, observations of zero resistivity, assessments of critical current (Ic) and critical magnetic field (Hc), and the evident demonstration of the Meissner effect. These findings are further substantiated by detailed analytical methods such as

X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), Electron Paramagnetic Resonance Spectroscopy (EPR), and measurements of the material's heat capacity and magnetic properties. The analyses from XRD and XPS provide insights into the structural changes and the stress implications of substituting Cu2+ for Pb2+, which validate the SQWs' formation. EPR measurements indicate the existence of SQWs by showcasing two-dimensional electron gas behavior, a characteristic indicative of quantum wells and a direct testament to the superconducting state facilitated by the internal structure of LK-99.

Below is the statement in the research that talks about why does LK-99 exhibit superconductivity at room temperature and ambient pressure (Lee, S. Korea University Research Team, 2023). This statement explains that the reason LK-99 exhibits superconductivity at room temperature and ambient pressure is due to the unique structural characteristics of its composition. Specifically, the replacement of Pb(2)2+ ions with Cu2+ ions creates stress within the material, which is not alleviated because of the specific structural arrangement of LK-99. This stress is effectively transferred to the interface of the cylindrical columns within the material. At these interfaces, the Pb(1) atoms are confined to a structurally limited space, fully experiencing the stress and strain from the Cu2+ ions. Consequently, this stress induces sufficient distortion to generate superconducting quantum wells (SQWs) at the interface, enabling superconductivity to occur under normal conditions without any need for relaxation. This delicate balance of internal forces and the resultant structural adaptations underscore the material's novel properties and its potential in practical applications.

> 'This is because the stress generated by the Cu2+ replacement of Pb(2)2+ ion was not relieved due to the structural uniqueness of LK-99 and at the same time was appropriately transferred to the interface of the cylindrical column. In other words, the Pb(1) atoms in the cylindrical column interface of LK-99 occupy a structurally limited space. These atoms are entirely affected by the stress and strain generated by Cu2+ ions. Therefore, SQWs can be generated

> in the interface by an appropriate amount of distortion(57) at room temperature and ambient pressure without a relaxation.'

STS Theory: SCOT Framework

Science is a field of discovery that provides solutions to the challenges faced by humanity. The discovery of superconductivity theory has led to the recent breakthrough of room-temperature superconductors. Despite the facts concerning LK-99, the development and commercialization of room-temperature superconductors will bring significant benefits to humanity. These benefits include solving energy problems and offering transformative solutions to many of society's energy challenges.

Society is highly reliant on electricity, and in the US alone, approximately $20 billion of electricity is lost annually during transmission, according to Chen (2018). This loss occurs because of the use of copper wires, which lose 4-5% of electricity as heat during transmission due to resistance. Integrating the properties of superconductivity in this energy sector, with no electrical resistance, ensures the efficiency of transferring electricity is 100%, thus maximizing energy efficiency. Simply put, the US itself can save $20 billion from just electricity transmission. This will require replacing traditional copper wires with room-temperature superconductor wires. The economic impact of such a transformation would be significant, but also the environment since the thickness of superconductor cables is said to be about one-third that of copper cables. This means they are lighter and can make more efficient use of underground space.

Just integrating room-temperature superconductors into electricity wires involves various key stakeholders, including countries/governments, energy companies, customers, and environmentalists. Using the Social Construction of Technology (SCOT) framework, this section aims to examine the interrelationship between society and technology (Bijker, Wiebe E., 2015).

This examination will differentiate each society's needs and explore how this technology can be applied within society.

Superconductors can be applied in all areas of electrical energy, including generation, transmission, electrical resistance, and power equipment. Room-temperature superconductors could also advance the battery sector. Batteries based on room-temperature superconductors could allow for rapid charging and discharging. The size of the battery itself can be reduced, improving spatial efficiency and, since there is no heat generation due to resistance, the lifespan of the battery is extended. This is particularly beneficial in the era of electric vehicles, contributing significantly to the development of electric vehicles and the solution of environmental issues. Electricity car companies can advocate a reduction in their carbon footprint and lower operational costs, which companies, environmentalists, and consumers can meet their needs.

Most corporations’ model in the 21st century is sustainable business. Within the scope of sustainability, the adoption of room-temperature superconductors aligns perfectly with the goals of reducing energy waste, enhancing efficiency, and minimizing environmental impact. And so, the way energy/electricity companies perceive room-temperature superconductors would be similar to how environmentalists view them in terms of sustainability, and how consumers consider them from an economic perspective.

Environmentalists view room-temperature superconductors as a revolutionary technology, and would likely attribute superconductivity as a vital solution to climate change, as it will play a significant role in reducing energy wastage and our carbon footprint. A decrease in wasted energy means that there is a more optimal use of natural energy sources which could lessen environmental degradation. The superconductors’ properties would align environmentalists with maximizing the use of renewable energy sources and minimizing the ecological footprint of energy production and consumption. This stance is also informed by the broader implications of such technologies on climate change– would expect environmentalists' support for room-temperature superconductors also reflects their interest in long-term sustainable practices. An environmentalist would undoubtedly be in support of such effects if there are no particularly negative outcomes to the environment.

Meanwhile, consumers, ever-conscious of their monthly expenses, might perceive superconductivity as a means to reduce their energy bills due to the promise of efficient electricity transmission, which leads to higher quality products while also decreasing their costs. Consumers can also expect an improvement in quality of life, as technology development is inevitable following the discovery of room-temperature superconductors, and also saving their monthly budgets.

Government interest in room-temperature superconductivity primarily centers on ensuring equitable access and national security enhancements. In order for everyone to benefit from this technology, there would have to be global cooperation between governments to make this available to the general public. This also allows the government to use this product within militaristic developments as it could prove very useful in the implementation of tools that the military directly utilizes (U.S. Code, n.d.). However, as with any emerging technology, the government must process specific policies and regulations to discourage any malicious intent with the products that are being created utilizing superconductivity. Energy storage systems (ESS) and uninterruptible power supplies (UPS) will also see advancements. They can provide high-capacity backup power quickly and safely in the event of a blackout—whether it's due to a problem at a power plant or another emergency—in critical facilities such as military bases, data centers, and cities. These technological advancements ultimately enable governments to provide their citizens with a better quality of life and a sense of stability. Connected to this, citizens/consumers can also expect to lead more satisfying lives and possibly see an increase in GDP.

Each of these stakeholders interacts with and influences the room temperature superconductor based on their unique perceptions, needs, and expectations; shaping its development and societal acceptance. The SCOT framework provides a lens through which we can understand not only the immediate benefits of room-temperature superconductors but also the broader implications for sustainable development. This section shows how the emergence of a technology can have different impacts on various stakeholders.

Conclusion

In the realm of technological advancements, room-temperature superconductivity may offer various solutions to problems that the world has faced. Especially in the energy paradigms, this technology is considered a vital step to achieving a new era of energy efficiency that can address both economic and environmental challenges. Contrasting these benefits, the results of LK-99 refutation led modern society to recognize it as a mirage or illusion. However, I personally think it is too early to validate the consensus of LK-99 disproof with limited test cases and research. According to the research of other scholars, it appears that the Meissner effect is not observed in LK-99. Although becoming a superconductor requires meeting two properties, the emergence of LK-99 and the advancement of technology could play a different role in solving the environmental issues humanity currently faces.

Although this paper mentioned the current facts about room-temperature superconductors and it is yet inapplicable, the application of the SCOT framework amplifies the understanding of the broader implications of such technological development. For a fair perspective and to deliver the facts, this paper has mentioned that the facts of LK-99 remain as disproven. However, the publication of the technology opened another possibility and provided an opportunity to view the technology of room temperature superconductors positively through the perceptions of other stakeholders using the SCOT framework. While time is the only key to revealing the truth about LK-99, the essence of this paper emphasizes the potential and applications of this technology.

In conclusion, while the initial findings related to LK-99 may be contested, it addresses a broader consideration for future technologies capable of solutions to energy and environmental issues. Humanity must find solutions to these persistent challenges for a better quality of human life, and to ensure the long-term sustainability of our planet. The potential of room-temperature superconductivity, as a concept, extends beyond the confines of current technological limitations, offering a vision of what could be possible with continued innovation.

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