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Honors Intro to Engineering

ENG 1901

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Superconductivity

In a world as dependent on electricity as this one, the ability to carry that energy efficiently is crucial. Some applications require near perfect conductivity. For these, superconductors are used to transfer energy. Superconductors are materials which have zero electrical resistance. These make for very efficient wires. Superconductors also have other properties which have interesting implications. Superconductors are an advancing technology which will one day allow great technological feats to occur once developed enough.

Superconductors were first discovered on April 8, 1911, by Heike Kamerlingh Onnes. Using liquid helium to cool mercury, he tested the electrical resistance of mercury at low temperatures. He discovered that at 4.2 Kelvin, the solid mercury completely lost all resistance. The next important discovery, the discovery of the Meissner Effect, took place in 1933. Walther Meissner and Robert Ochsenfeld noticed that weak magnetic fields are repulsed by superconductors. In 1957, Bardeen, Cooper and Schrieffer proposed the BCS theory, which details the entire microscopic theory of superconductivity. Since this time, most advancements have been in the discovery of new superconductors, further proof and refinement to the BCS theory, and superconductors with high temperature critical points.

Superconductors are different than normal conductors in their sudden change to zero resistance; while the resistance of any conductor decreases as its temperature nears absolute zero, a normal conductor will always have some amount of resistance. Superconductors, once reaching a certain temperature, exhibit no resistance whatsoever. In addition, their change to no resistance is abrupt. Once they reach their critical temperature, they drop immediately from whatever their resistance was before to zero resistance. The critical temperature of a superconductor depends on what its elemental makeup consists of; some require extremely low, near absolute zero temperatures, while others gain superconductivity at slightly below 100 Kelvin.

Another interesting property superconductors have is the Meissner Effect. Due to a lack of free electrons because of the complete conductivity of a superconductor, superconducting materials repel any sufficiently weak magnetic field. This effect limits the use of superconductors somewhat. Since there is no resistance, a superconductor should be an excellent choice for a material to use in the production of generators, because generators convert physical energy into electrical energy using coils. Because of the Meissner Effect, coils made of superconducting material do not gain the opposite current they are presented with; instead, they simply repel the current. This prevents electricity generation from happening in the conventional manner. If the superconductor encounters a strong enough magnetic field, it will lose its superconductivity.

In addition to the magnetic field repulsion demonstrated by superconductors exhibiting the Meissner Effect, they also have one other magnetic characteristic: the London moment. The London moment occurs when a superconductor is being rotated around a spin point. The superconductor will generate a magnetic field which is perfectly aligned with the spin axis. This effect makes superconductors great electromagnets, because the direction of the field is so precise.

Another characteristic of superconductors which benefits superconductor electromagnets is the preservation of current. Since there is no resistance, a closed superconductive loop will not lose current. This can continue for a very long time, and under the right conditions, such a loop could last for longer than the expected life of the universe without losing the current. In real life applications, this is not the case due to factors which cause some loss of current. However, the current is maintained enough that a superconductor electromagnet can be run for months on little to no power input by short circuiting the superconducting coils. This results in current remaining in the loop, and allows for ultra-efficient superconductor electromagnets to be run in a very power efficient manner.

One other characteristic which superconductors exhibit which could have useful commercial implications is known as the Josephson Effect. The Josephson Effect is the tendency for superconductors to be able to pass current without losing resistance across a thin isolator. This allows for a very fast, very small switch. These switches, known as Josephson junctions, are used in quantum devices, one of the most common being the SQUID. SQUID stands for Superconducting Quantum Interference Device. These devices are some of the most sensitive magnetometers known to man. These Josephson junctions always offer an exact ratio between frequency and voltage, and are used in order to define the SI volt.

Once superconductors become more commercially feasible, they will be able to revolutionize most modern electronics. Easy and cheap Josephson junctions could allow for quantum computing, an advancement which would enable computers to continue growing exponentially faster for much longer than the current estimates predict. The Meissner Effect could enable easy and reliable levitation. A breakthrough in this field could revolutionize transportation, allowing for levitating bullet trains moving at hundreds of miles per hour, as well as other levitating devices. The zero resistance nature of superconductors would allow perfectly efficient wires to be created, which could increase the efficiency of the power grid immensely, reducing costs and cutting back on pollution. Efficient superconductor electromagnets could also lead to medical advancements, such as improved magnetic imaging, as well as more commercial applications, like magnetic refrigeration.

Several technical constraints prevent superconductors from being widely used. The primary constraint is the lack of a superconductor which maintains superconductivity at an easily and cheaply accessible temperature. There have been no superconductors found yet which are able to exhibit their superconductivity above approximately 90 Kelvin. In order to be commercially feasible, a compound would need to be discovered that exhibits superconductivity at a temperature at or above 273.15 Kelvin, the freezing point of water. Another constraint is the limited workability of current high-temperature superconductors; most of the highest operating superconductors are brittle ceramics, which are inflexible and cannot easily be molded into useful shapes.

Since the critical point of a superconductor is based on its molecular makeup, it is possible that we will one day see room temperature superconductors. When this occurs and the superconductor can be produced inexpensively, the consumer market will reap the benefits. However, until that time, superconductors are used heavily in scientific research. Particle accelerators, such as CERN’s Large Hadron Collider, use superconducting wires in order to guarantee maximum efficiency. Superconductor electromagnets also have a place in science, in a variety of fields from directing the beam direction is particle accelerators to MRI machines. Superconductor electromagnets are the strongest type of electromagnets, and are used whenever precision and strength are needed in an application which requires small size and energy efficiency. Superconductors are a fascinating topic which, when the science has developed enough, could revolutionize the world as we know it in nearly every way.

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