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Superconductivity

Superconductivity is the term for the condition of a material in which the material exhibits no electrical resistance. This means that if you ran an electrical current through a superconductor, the current would stay there forever. This has incredibly promising implications, as most materials which carry a current do show resistance. Obviously, if a superconductor is used in place of a normal wire in a circuit, it will be more efficient, as the energy which would normally be lost due to resistance in normal material is conserved. However, demonstrating zero resistance is not the only feature of a superconductive material. Something that is said to be superconductive also removes itself of all magnetic fields passing through it as it transitions into a superconductor. Superconductivity as we know it right now is possible only in certain materials and only below certain temperatures. The temperature required to reach superconductivity for one material might be different from the temperature needed for another material, and this point is called the critical temperature. The critical temperature for each material is unique, which gave rise to the hope in a material whose critical temperature is much higher than normal; that is, a material which could, at commonly attainable temperatures, be superconductive.

Superconductivity was discovered in 1911 by a Dutch physicist named Heike Kamerlingh Onnes. Onnes was already experimenting with very low temperatures. Just 3 years prior, in 1908, he successfully condensed helium into liquid form. Unfortunately, exact history of the experiment is dubious; Onnes was known for messy handwriting, and the journal which is believed to correspond to the time period in which he did the experiment has entries which are dated inconsistently or not at all. However, it is widely accepted that Onnes first discovered superconductivity in mercury. When he was testing its conductivity at increasingly low temperatures, he noticed that it went to zero at 4.2 K. The comparative change in resistance from very close to zero to exactly zero happened quite abruptly. This implies that the state of superconductivity is not simply the extension of a linear function; something else happens at the critical temperature to warrant so abrupt a change in resistance. Onnes reasoned that superconductivity, therefore, is not simply an extrapolated point at which the resistance becomes zero, but is almost like a new phase of matter, which does not have electrical resistance.

Although superconductivity was discovered in 1911, a working model to describe why it occurs was not developed until 1957 by John Bardeen, Leon Cooper and John Schreiffer. Their model explains the behavior of superconductors by introducing Cooper pairs, or pairs of electrons that are attracted to each other by having different spins. This model, called the BCS Theory of Superconductivity, says that when the energy of the oscillating atoms in an element or compound is less than the energy required to break up a Cooper pair of electrons, then all electrons in an element or compound are Cooper pairs. Cooper pairs encounter no electrical resistance, as they are composed of two electrons following each other, not scattering about by repelling each other. Thus, when all electrons in an element or compound are in Cooper pairs, there is no electrical resistance.

The implications in everyday life of superconductivity are exciting. Due to the nature of the subject, although it was first discovered in mercury at 4.1 K, it has now been observed in much higher temperatures in specific compounds. Some compounds have been able to achieve superconductivity at temperatures as high as 125 K. A compound which is superconductive at room temperature would be able to be used in household wires which would be extremely efficient. If a superconductor which is available at outside temperatures is discovered or synthesized, replacing power lines with it would result in large amounts of power being saved every day. The benefits of saving so much energy are too obvious and multifaceted to go into detail. However, it can be said that making the switch would take an enormous amount of effort; so much so that it might not be worth it immediately after such a compound is discovered.

When Onnes first discovered superconductivity, he was extremely excited, then saddened slightly by the fact that a superconductive material displays no magnetism. In fact, a superconductor acts as a perfect diamagnet; this is one facet of the Meissner effect, more formally known as the Meissner-Ochsenfeld effect. Onnes was disappointed by this because if a superconductor could be magnetic, they could be used in generators to produce a virtually infinite amount of energy. Of course, diamagnetism has other implications which might be useful. For example, when a magnet is placed near a diamagnet, the two repel each other. This is easily demonstratable with a superconductive plate and a small magnet. The small magnet will levitate above the superconductive plate. The most obvious utilization of the Meissner Effect is probably transportation. A magnetic train over a superconductive track would be lifted into the air with no need for a current in the track.

Another part of the Meissner Effect, which is what separates it from strict diamagnetism, is that fact that a superconductor will actively repel all magnetic fields inside it. While a perfect diamagnet, which is what would be expected in a perfect conductor like a superconductor, would be expected to keep a magnetic field through the process of transitioning into a superconductor, this is not what happens. When a material is given a magnetic current and then transitioned into a superconductor, the superconductor actively expels the current inside of it. The Meissner effect was discovered by Walther Meissner and Robert Ochsenfeld in 1933.

One of the main reasons superconductivity is so exciting is the nature of the critical temperature. The critical temperature is the temperature, unique for each material, at which the material becomes superconductive. The fact that the change occurs so abruptly is one thing; however, more exciting is the fact that not only different elements, but different compounds have all unique critical temperatures. The first superconductor discovered was mercury at 4.1 K in 1911. However, in 1986, Georg Bednorz and Alex Muller found that lanthanum-barium-copper oxide becomes superconductive at 30 K; a temperature much higher than ever recorded. This inspired a new wave of scientists attempting to find a superconductor at even higher temperatures. The implications of a room temperature superconductor are, as previously mentioned, obvious and multifaceted. Therefore, the enthusiastic search for such a superconductor is well warranted. The highest temperature superconductor ever discovered is thallium-barium-copper oxide at 125 K. The fact that one so high is possible only adds to the excitement that even higher temperature superconductors are right around the corner.

As you can see, superconductivity is a highly promising field of physics which not only provides an interesting opportunity for research, but also has already benefited certain areas of science and society in general. It seems like all that is necessary to find a room-temperature superconductor is a lot of research, and that such a superconductor would be extremely helpful to society. The superconductor's Meissner effect not only provides a really cool levitation effect in the classroom, but also promises a realistic opportunity for hovering trains on superconductive tracks. So many cool applications for an aspect of science which was only discovered one hundred years ago guarantees significant improvements to science in general in the very near future.