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Pnictide high-temperature superconductors

by Kevin Kienitz

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In 2008 researchers in Japan published a report detailing their discovery of a new class of high-temperature superconductors¹. These new superconductors, referred to as *pnictides*, are being created from a parent compound consisting of an iron arsenide core surrounded by a rare-earth metal oxide (LaOFeAs)¹⁻³. Though copper based superconductors continue to operate closer to ideal temperatures (room temperature) this new class is the first that has been found to operate as closely. Therefore researchers are hoping that this class of superconductors may finally provide answers for how high-temperature superconductors work.

Superconductors are substances that will conduct electricity without resistance below a certain temperature, referred to as the transition temperature (T_c). This superconducting property was first discovered by the Dutch physicist Heike Kamerlingh in 1911. While cooling elemental mercury with liquid helium to about 4 kelvins he noticed that its resistance suddenly disappeared. In 1933 Walther Meissner and Robert Ochsenfeld discovered that superconductors will repel a magnetic field. This property of superconductors would eventually become very useful for practical applications.

The first widely accepted theory of how superconductors worked was proposed in 1957 by researchers John Bardeen, Leon Cooper, and John Schrieffer. This theory became known as *BCS theory* in homage to those who created it. Though this theory was successful at explaining superconductivity at low temperatures, it failed at providing an adequate answer for superconductivity at high temperatures (above 30 kelvins). A big leap in superconductors occurred during the 1980's when copper-based versions were discovered. Whereas earlier superconductors had transition temperatures below 30 kelvins, these new copper-based versions quickly reached transition temperatures approaching 100 kelvins by the end of the decade. This was a significant discovery as it marked the first time a superconductor had been discovered with transition temperatures above 77 kelvins, the boiling point of liquid nitrogen. This was an important discovery because liquid nitrogen is a common coolant.

Throughout the 1990's and early 2000's, researchers continued to experiment with superconductors. Transition temperatures above 100 kelvins in the copper-based superconductors were achieved and new superconducting materials were discovered. In 2008 the new class of superconductors utilizing a rare-earth metal iron arsenide (LaO_{1-x}Fe_xAs) parent compound was discovered by researchers in Japan with initial transition temperatures measured at about 26 kelvins¹. Shortly after this discovery researchers were able to increase the temperature to nearly 43 kelvins². This has been a significant discovery because this new class is the first non-copper based version to superconduct at temperatures in excess of 50 kelvins³. As a result, researchers are hoping that through further research they will gain more insight on improving copper-based superconductors. In addition, researchers are hoping that this discovery will lead to an improved theory that explains how high temperature superconductors function.

Though superconductivity has been known of and studied for the last century, little is known about how it works. BCS theory proposes that superconductivity works through the pairing of electrons, known as *Cooper pairs*. Within the superconductor there is a lattice structure composed of positive cations. A free electron will interact with this lattice creating an area of concentrated positive charge referred to as an *electron-phonon interaction*. An additional electron becomes attracted to this

interaction creating the Cooper pair. BCS theory says that this electron pair is more stable than each electron would be individually. As a result, the electron pair is less affected by the vibrational energy of the lattice allowing it to travel with lower resistance. The Cooper pair will remain stable if the energy required to keep the electrons paired is less than the vibrational energy of the lattice trying to break them apart. This theory explains why superconductors generally require such low temperatures. As a superconductive material is cooled the vibrational energy of the lattice becomes less vigorous allowing the electron pair to move through the structure unimpeded. However, as successful as this theory is at explaining superconductivity at very low temperatures, it fails to provide an accurate explanation for the occurrence of superconductivity at higher temperatures. This is where researchers hope that this new class of iron arsenide superconductors will be of most benefit.

Due to the uncertainty of how high temperature superconductors work, the discovery of this new class of pnictide superconductors is significant. The bridge from level 1 superconductivity to level 2 superconductivity occurs at about 30-40 kelvins. The pnictide superconductors operate precisely across this range of transition temperatures. Therefore researchers hope that by studying these iron arsenide superconductors a more complete theory of superconductivity will be formed. A new theory that explains high temperature superconductors combined with BCS theory would allow scientists to make more accurate predictions. This could lead to the development of the holy grail of superconductors, those which operate at room temperature. This would be a significant achievement, opening the door to a new wide range of potential applications.

Though superconductors are not understood in their entirety, it has not stopped the commercialization of the technology. In the 1970's superconductor technology was applied to the transportation industry. Due to the strong repulsion of magnetic fields by superconductors, special trains were built that levitated over traditional railroad track. These trains gain the benefit of not having to overcome the friction involved with a wheel in contact with a rail or the friction of bearings. As a result they are able to reach speeds much higher than traditional trains.

Another application that is currently being tested is the use of superconductors for the transmission of electricity to cities from generating plants. Due to long distances that electrical current must travel to arrive at homes and businesses a significant amount of energy is lost to resistance in the wires. A superconducting wire with virtually no resistance reclaims much of this lost energy, increasing efficiency. Industries hope that by implementing this technology on a wide scale it will help to minimize the increasing demand for energy in future years.

Other areas that superconductor technology finds use include particle acceleration, electric generators, and electric motors. Particle accelerators such as those at Fermi National Laboratory and CERN use superconducting magnets to accelerate particles to near the speed of light in order to conduct basic research. The energy industry is deploying superconducting electric generators, which can store large amounts of energy for use during main system failures.

Due to their high efficiency, superconducting motors are being developed for use as propulsion systems in large naval vessels. Superconductor technology and research is still in its infancy however it is already proving to be useful in wide range of applications. As new superconducting materials are discovered, such as the new iron arsenide class, researchers will hopefully continue to make progress in developing an over-arching theory to describe their behavior. This will likely lead to new advancements which will increase their practical uses and help to offset the increasing demands for energy.

References

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