Superconductors: Wave of the Future?

Imagine riding in a magnetically levitated (maglev) passenger train that zooms along the rails at record speeds or using computers that are light-years faster than computers currently in use. Science fiction? Think again. Superconductors are at the heart of these and other inventions that are currently being used or tested for future use in the United States, Canada, and other nations.

As we navigate a course to the 21st century, many researchers are convinced that superconductors are a major technology of the future. U.S. and Canadian researchers are spending large sums of money to explore the applications of this technology, which many believe will revolutionize the way we live while possibly saving the electrical industry billions of dollars.

Definition and History

What superconductors are and how they arrived on technology's doorstep tells us a lot about the implications of superconductors in our future.

Superconductivity is the disappearance of all resistance to the flow of electricity in a material. A superconductor is a material that loses all resistance to the flow of electrical current once the material has been cooled to a certain temperature known as the transition temperature or critical temperature.

When Dutch physicist Heike Kamerlingh Onnes liquefied helium gas in 1911, he stumbled upon the existence of superconductors in mercury, which he cooled to -269° Celsius. He observed how electrical resistance began to lessen and that mercury lost all resistance at 4.15 Kelvin. Onnes' research led to the discovery of Type I superconductors that included lead, aluminum, tin, titanium, tungsten and zinc. (See Table A. for comparisons to temperature scales.)

In the years following Onnes' breakthrough discovery, researchers could not find substances that would superconduct at temperatures more than a few tenths of degrees above absolute zero. But the promise of cheap, efficient, less resistant power transmission was only one of the reasons that they were so relentless in their drive to find superconductors that operated at temperatures above the frigid bottom of the temperature scale.

In 1933, Walther Hans Meissner and Robert Oschsefeld discovered that when Type I superconductors are lowered below their critical temperature, all interior magnetic fields are gone. The expulsion of all magnetic fields from the interior to the exterior of the superconductor is called the Meissner effect. One such example is when a magnet is repelled by a superconductor. During the 1950s and 1960s, researchers looked for superconductors with higher critical temperatures. A cluster of superconductors was found that possessed the element Niobium. Intermetallic superconductors, which are known as Type II superconductors, contain more than one element. In 1957, John Bardeen, Leon Cooper and John Robert Schrieffer explained why superconductivity loses all resistance—an explanation known as the "BCS theory." The BCS theory states that single electrons do not carry an electric current, but paired electrons (known as Cooper pairs) do. Two negative electrons are attracted to each other because they flow more freely through the lattice structure of the superconductor due to the very low temperatures that reduce the vibrations of the lattice. The Cooper pairs are thus enabled to flow unhindered through the lattice with no resistance to the current.

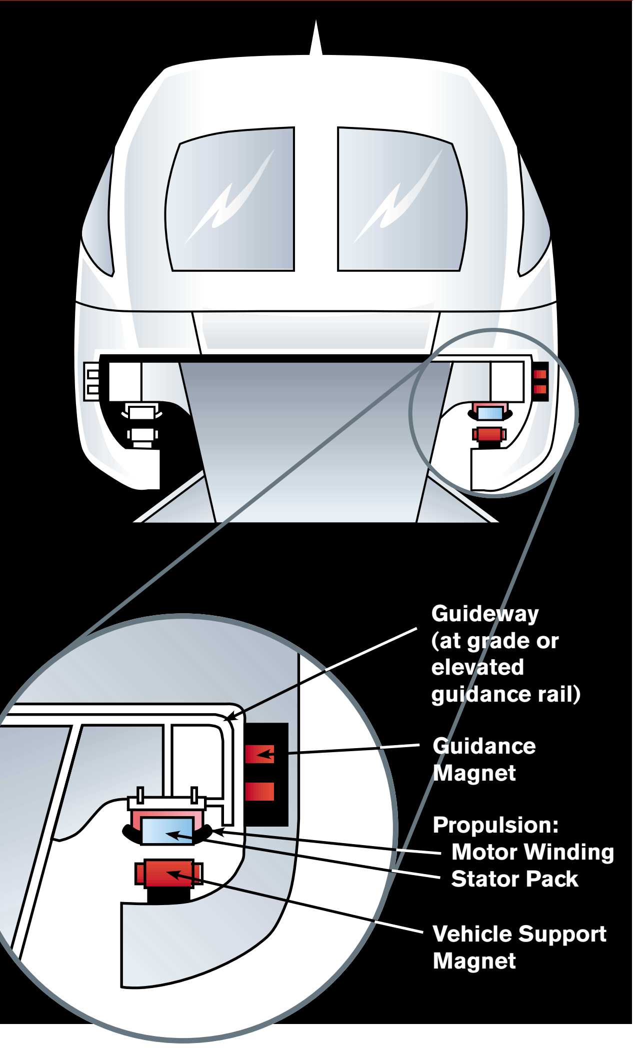
Dramatic Breakthroughs

Technology was rewarded in the spring of 1986 when Swiss researchers Johannes Georg Bednorz and Karl Alexander Muller at IBM Research Laboratories in Zurich, Switzerland, discovered than an oxide superconductor (consisting of barium, copper, lanthanum and oxygen) had a critical temperature of 35 Kelvin. In December 1986, Professors B. Mitrovic, F.P. Koffyberg and F.S. Razavi, working feverishly at the Brock University Physics Laboratory in Ontario, Canada, proved that a compound substance of barium, lanthanum, copper and oxygen becomes a superconductor at 80 Kelvin. Research on superconductors was advanced even further the following year when researcher Ching-Wu "Paul"

TABLE A. COMPARISONS OF TEMPERATURE SCALES

H2O boils	373.16 Kelvin	100° Celsius	212° Fahrenheit
H2O freezes	273.16 Kelvin	0° Celsius	32° Fahrenheit

DIAGRAM OF MAGLEV TECHNOLOGY



Chu and his collaborators at the University of Houston reported a material that becomes superconductive between 90 and 100 Kelvin. The compound comprised oxygen, barium, copper, and yttrium, code-named the "1-2-3 superconductor" for its relative atomic proportions of yttrium, barium and copper. The discovery of high-temperature superconductors (HTS) continues to spur the interest in superconducting technology. HTS allow liquid nitrogen to be used as a refrigerant in place of the liquid helium that must be used with low-temperature superconductors. The years since saw the birth of superconductors with critical temperatures that exceeded 120 Kelvin.

Applications

The emergence of high-temperature superconductors has spawned a race to take the technology out of the laboratories and into the commercial arena. Japan, for instance, tested a magnetically levitated (maglev) train in April that was clocked at 343 mph during a test run. Unlike conventional trains, maglev trains use magnets that lift them slightly off the rail, eliminating speed-reducing friction with the tracks. Maglev train pilot projects are currently under development in North America. A federal study has concluded that superconductivity could be a $15 billion business by the year 2000. The U.S. Department of Energy (DOE) is spending much of its research budget on the applications of high-temperature superconductors. Earlier this year, DOE announced the selection of six energy-saving projects representing a five-year total of more than $47 million of superconductor technology development.

The importance of superconductors will be measured in how well we apply them to our ever-expanding technology. One of the first applications of superconductivity to electronics successfully employed the Josephson effect, which takes place when superconducting electron pairs pass through an insulating barrier separating the two superconducting metals through a process known as tunneling. The tunneling current flows without any voltage across the junction— known as the Josephson junction—between the two superconductors. The Josephson junction, named for researcher Brian David Josephson of Cambridge University, is a superfast switch used in many computers. It consists of a thin layer of insulating material sandwiched between layers of superconducting material and can be made to switch from one mode to another. When these junctions are incorporated in superconducting circuits, their electrical characteristics are also affected by magnetic flux. Josephson junctions are the basis for many superconducting devices that depend on this unique electrical characteristic. They require little power to operate, thus creating less heat.

One of the successful applications of the superconductor is the magnetic resonance imaging (MRI), a medical diagnostic technique that produces images of the inside of the body. MRI use magnetic fields and radio waves to see through bones and produce images of blood vessels, cerebrospinal fluid, bone marrow, muscles, and ligaments. MRI does not produce harmful rays from radiation, unlike X-Rays or CAT scans. They require a strong, uniform, and controllable magnetic field in a space or area sufficient to accommodate the body of the subject.

Another application is the superconducting quantum interference device (SQUID), which detects magnetic fields because of changes in magnetic flux or the flow rate of energy or particles across a given surface. Physicists have used SQUIDs to search for gravitational waves, while geologists have employed them to find oil and deposits. Archeologists used the ultra-sensitive SQUID to successfully unearth the ruins of the Cleopatra Palace during excavations in Egypt in the fall of 1996.

Magnetoencephalography represents another successful application of the superconductor. This involves mapping the electric distribution in the brain using an array of SQUID magnetometers.

Stepping into the Future

Superconductors used in transmission cables that carry electricity without the loss of energy would allow more electricity to be transferred. Generators with superconducting wire will be lighter and get more power from fuel. Superconducting magnetic energy storage (SMES) stores electricity for long periods of time in superconductive coils with resulting savings.

As researchers around the globe continue to exploit the far-reaching applications of high-temperature superconductors, the current horizons of the electrical industry will be expanded to dimensions that far exceed our current boundaries. The result could be billions of dollars saved and a high-tech society that will make life easier for us all.