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Super Conductivity and Its Application

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ABSTRACT

Superconductivity is one of nature's most exotic phenomenon; the complete loss of electrical resistance in certain materials when they are cooled to a low temperature. The loss-free circulation of superconducting currents also underlies key technological applications. For instance, intense magnetic fields are generated by coils of superconducting wires for medical magnetic resonance imaging. Only when cooled close to absolute zero of temperature (−273°C) do such metals and alloys become superconducting.

A revolution took place 20 years ago when entirely new families of superconductors based on ceramic oxides were discovered. These work at much higher temperatures. The current high-temperature superconductor HgBa2Ca2Cu3O8 is the record holder. It operates at temperatures as high as 164 K (−109°C). The crystal structure (on the front cover) of this complex oxide allows the electrical current to travel easily along certain crystal planes, which leads to superconductivity at these remarkably high temperatures.

1. BASIC RESEARCH CHALLENGES FOR APPLICATIONS

In the decade following the discovery of high-temperature superconductors (HTSs) in 1986, extensive international research led to the fabrication of HTS materials with a range of critical transition temperatures (Tc's) above the boiling point of liquid nitrogen, as well as to broad phenomenological understanding of their properties. These materials have been pursued for a variety of technologies, but the strongest driver has been the electric power utility sector. Electric power transmission through HTS power cables offers the chance to reclaim some of the power lost in the grid, while also increasing capacity by several times. Use of HTS conductors could also improve high-current devices, especially in terms of efficiency, capacity, and reliability. By the mid-1990s, despite many formidable technical problems, researchers had begun to realize viable first-generation (1G) HTS conductor technologies based on Bi2Sr2Ca2Cu3O14 (BSCCO), which make available conductors that are suitable for engineering demonstration projects and for first-level applications in real power systems. Second-generation (2G) HTS conductors based on YBa2Cu3O7 (YBCO) are currently poised to replace BSCCO, which will
dramatically improve performance while also lowering costs.

2. BASIC RESEARCH CHALLENGES FOR SUPERCONDUCTIVITY THEORY

The discovery of high-temperature superconductivity in the cuprates represents a grand challenge for theory to explain. Significant progress has been made, and a number of principles common to many of the suggested theories of these materials have emerged. Nevertheless, an accepted theory of high-Tc superconductivity still eludes us; it will likely result in a Nobel Prize if and when such a theory is developed. Here, rather than survey the large body of proposed theories, we discuss a number of the common questions and themes that are central to theories of superconductivity and superconductors.

3. THE SUPERCONDUCTING STATE: A COHERENT STATE OF PAIRED ELECTRONS

The concepts of pairing and coherence (see sidebar, "Basics of Superconductivity: BCS Theory") are the theory's foundation, and their relevance to astro-, condensed-matter, nuclear, and high-energy physics demonstrates the utility of BCS theory with regard to vastly different systems. Here we first discuss the concept of a coherent electronic state in a metal. The basic observation is that in the superconducting state, all mobile electrons (carriers of charge) participate in the same ordered state and move in a highly coordinated fashion, just as soldiers march together in a parade (see Figure 15). This is in stark contrast to the lack of such order in the electronic states of a normal metal. The unusual properties of a superconducting material are direct consequences of this so-called long-range order. As it turns out, impurities causing resistance will not be able to disrupt the long-range order of the electrons, unless the current flow exceeds a critical (sample- and material-dependent) magnitude.

4. PURSUE DIRECTED SEARCH AND DISCOVERY OF NEW SUPERCONDUCTORS

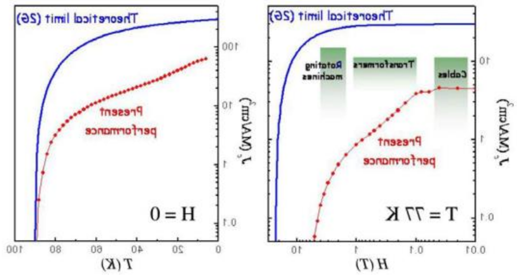
The search for new superconducting compounds is the very heart of scientific research on superconductivity. The discovery of new compounds has driven the field from its beginning 100 years ago, with landmark discoveries enabling new science and new technologies. Recent experimental and theoretical advances clearly demonstrate that there is a huge potential for discovering new materials that can have significant impact.

5)CONTROL STRUCTURE AND PROPERTIES OF SUPERCONDUCTORS DOWN TO THE ATOMIC SCALE

Refinement of materials properties has been essential to countless advances in science and technology. The growth of highly perfect crystals of many representative compounds in bulk and film form is vital to the basic understanding of superconductivity in existing complex, strongly correlated materials. Understanding and attaining the performance limits of these materials will require exquisite control through advanced synthesis in order to make them either very pure or controllably defective on many length scales, down to the atomic. The interfaces that result either accidentally or deliberately play an essential role in how charge and spin move on these scales.

6)MAXIMIZE CURRENT-CARRYING ABILITY OF SUPERCONDUCTORS WITH SCALABLE FABRICATION TECHNIQUES

The utility of practical superconducting electric-power conductors depends on both their performance and their cost. Maximal performance is governed by the fundamental limits of the material and by our ability to exploit these limits. Raising the performance ceiling reduces the cost and/or increases electrical capacity; however, ultimate cost reductions must exploit performance limits within inexpensive manufacturing processes.



7)SUPERCONDUCTIVITY AND SUPERCONDUCTORS

An understanding of the pairing of electrons and their coalescence into a state of matter that conducts electricity without loss not only constitutes the conceptual underpinning of superconducting technology but is also fundamental to materials physics. Building predictive theories based on this knowledge of underlying pairing mechanisms provides a path for fully identifying and realizing the remarkable possibilities of the superconducting state and its technological impacts

8)ENABLING MATERIALS FOR SUPERCONDUCTOR UTILIZATION

Current superconductors offer the potential to provide five times greater power capacity in secure underground cable systems, as well as energy-efficient generation and use. Fully integrated power systems, in which superconductors are the key technology, will utilize numerous other low-temperature materials. To achieve the maximum potential, breakthroughs are needed not only in terms of better superconductors but also with respect to related magnetic, dielectric, and insulating materials. The full implementation of this vision will require advances beyond those achievable with present-day conductors, low-temperature materials, and cryogenic systems.

CONCLUSION

We depend on the electricity grid to supply clean, abundant power for a growing urban population and its personal, industrial, and commercial needs. The demand for electricity is expected to grow by 50% in the United States and 100% globally by 2030. Urban and suburban grid capacity is limited by saturated overhead access lines and underground cables, and by the cost and permitting restrictions associated with new power corridor construction. Reliability is compromised by voltage fluctuations outside acceptable windows, intentional rolling blackouts and brownouts during peak demand, and local power failures that cause economic loss and can cascade to regional proportions. The North American blackout of 2003 and subsequent blackouts in London, Scandinavia, and Italy demonstrate the ever-increasing risk of widespread outages caused by cascading failures.

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