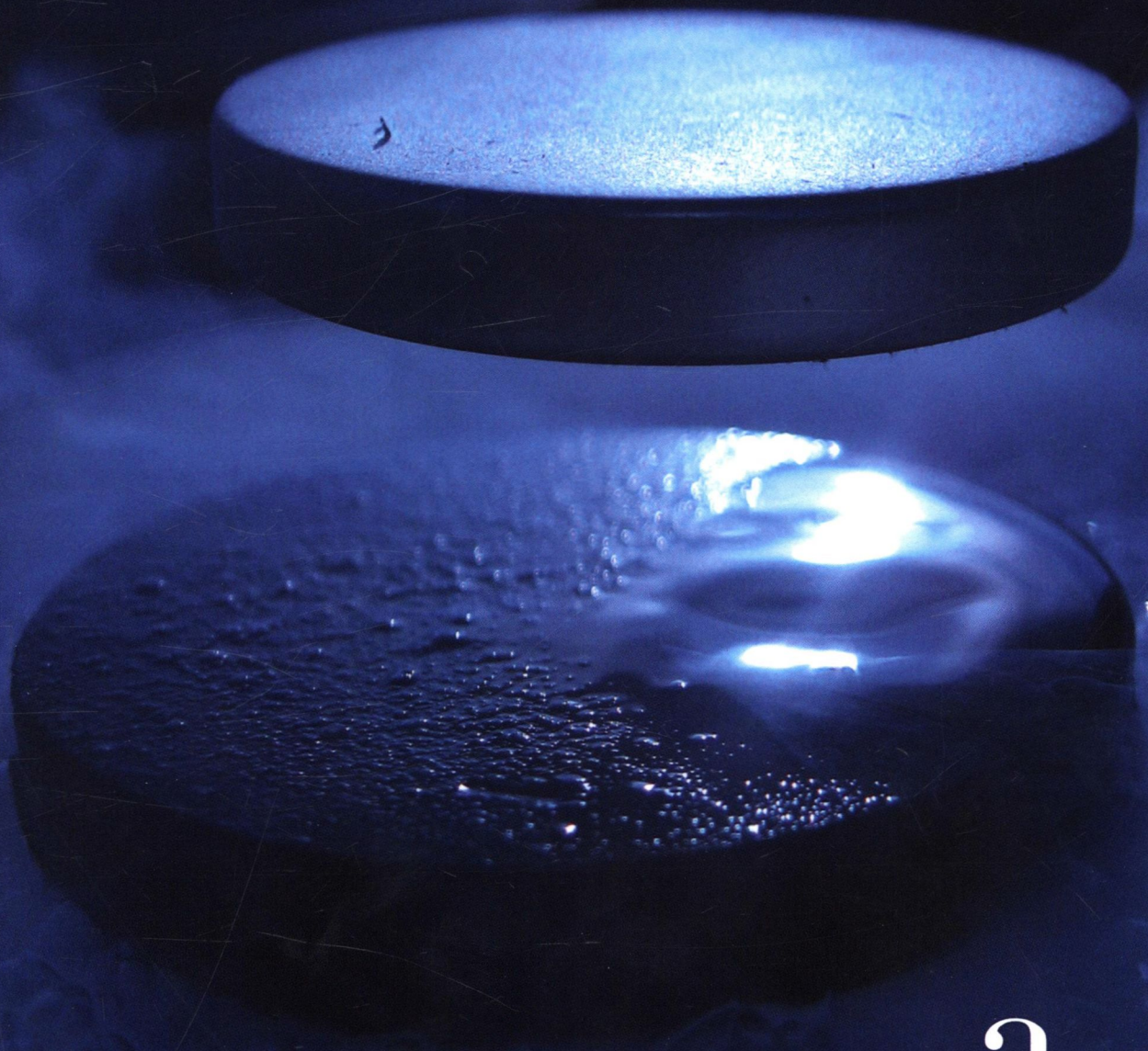


Superconductors: New Developments

Olga Moreira, Ph.D.



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Materials can be classified in terms of how well they conduct electricity. Metals such as copper and gold are good conductors of electricity while many plastics and rubbers tend to be poor conductors of electricity and are classified as insulators. Semiconductors behave similarly to insulators, but they can be induced to conduct electricity by adding impurities such as the ones used in transistors and computer chips. In 1911, Onnes discovered superconductors, materials that, at critical temperatures, are able to conduct electricity with no resistance. He was the first person to liquefy helium at temperatures as low as 4.2 kelvin (K). During his experiments, he found that the mercury sample was slowly cooled below the boiling point of liquid helium (4.2K), and its resistance suddenly disappeared. Initially, he thought this phenomenon was an experimental artefact thus he repeated the experiments attempting to remove this artefact. All the attempts seemed to have failed until his assistant, who was responsible for controlling the temperature in the cryostat, nodded off and he the temperature began to rise, the resistance in the mercury then reappeared. Onnes finally realized the "experimental artefact" was actually a real state of the mercury when cooled below a certain critical temperature. In 1933, Meissner and Ochsenfeld discovered a related phenomenon, what has become known as the Meissner effect, which shows that below the critical temperature the conductivity of a superconducting material is infinite and all magnetic field lines are expelled. This expulsion of magnetic fields from a superconductor is responsible for the incredible ability of superconductors to levitate above magnets. The Meissner effect is at the basis of magnetic levitation trains (Maglev trains) which have been proved to be an efficient and alternative solution for conventional trains. Indeed, the Japanese Maglev train holds the land speed record (for a railed vehicle) of 581 km/h. In 1956, Glover and Tinkham exposed for the first time superconductors to infrared radiation and showed the carriers in a superconductor behave as if they had an energy gap. Since superconductors are much closer to metals than to insulators, such energy gap was unexpected. In order to explain the properties that had been observed in superconductors up until that time, including this latter phenomenon, Bardeen, Cooper, and Schrieffer (BCS) developed theory which introduced the idea of a Cooper pair state. The BCS theory paved the way for the discovery of the first superconducting compounds and devices. In the 1960s, the Niobium-titanium (NbTi) superconductor was discovered, providing the first material for the manufacture of superconducting magnets. The first superconducting tunnel junction (a Josephson junction) was also discovered during this decade, providing the means to fabricate a variety of unique electronic devices. The first applications of superconducting magnets were the MRI scans and particle accelerators. MRI scans have revolutionized medical diagnostics, allowing the detection of tumors, examination of neurological functions, and reveal disorders in joints, muscles, the heart, and the blood vessels. Large particle accelerators have allowed physicists to study the dynamics and structure of matter, space, and time by colliding opposing beams of high-energy protons inside a tunnel of several kilometers of circumference lying underground. At a smaller scale, Josephson effect also has a wide range of applications, including high-sensitivity detectors of electromagnetic radiation, magnetometers, high-speed digital circuit elements, and quantum computing circuits. For instance, the superconducting quantum interference device (SQUID) is used as an ultra-sensitive probe of magnetic fields, such as those produced by electrical activity in the brain or the heart. High-speed digital circuits promised to revolutionize the information technology, thus, IBM began to invest millions of dollars in the Bell Labs project to build a Josephson computer. However, because the computer needed to be refrigerated for the junctions to work, this increased the cost, the project was abandoned. In 1986, Bednorz and Müller discovered an oxide material with superconducting properties at a temperature of 30K, this awarded them the Nobel Prize in Physics 1987. One year later, in 1987, Chu discovered Yttrium barium copper oxide (YBCO) which became a superconductor at just 90K. This discovery was a major breakthrough because, at 90K, the liquid nitrogen (a common industrial refrigerant) can be used to cool down the system instead of liquid helium. New compounds steadily started to appear, in 1988 bismuth-containing copper oxide superconductors brought the transition temperature up to 110K and the thallium-containing copper oxides pushed it further up to 120K a month later. In 1993, mercury-containing copper oxide compounds were found to be superconducting up to about 135K at ambient pressure. In the 1970s, various teams were determined to create organic superconductors but the first breakthrough was only achieved in 1980 by Klaus Bechgaard who prepared a series of compounds (known as Bechgaard salts) which involve a molecule called tetramethyltetraselenafulvalene (TMTSF). A large number of organic superconductors with transition temperatures up to about 12K have been discovered after that. These organic superconductors were mainly generated by chemical doping. The more added dopants, the higher the transition temperature but at higher doping levels the transition temperature will eventually decrease again. The highest transition temperatures achieved for these types of superconductors was reached by finding 'optimal dopings', which required the researcher to make a lot of compounds. In 1985, Kroto et al. succeeded in creating the first fullerene molecule, C₆₀. New superconductors then started to appear. For instance, the combination of potassium with C₆₀, resulted in the superconductor compound K₃C₆₀. By making different substitutions, it became possible to increase transition temperature up to 38K in the compound Cs₃C₆₀. Although magnesium diboride (MgB₂) was first synthesized in 1953, its superconducting properties were only discovered in 2001, when Akimitsu had been trying to isolate a complicated compound from an impurity phase that seemed to be superconducting. He succeeded in isolating the impurity and found it to be MgB₂ at a transition temperature of 39K. It is possible to cool down MgB₂ without needing to use liquid helium. Furthermore, MgB₂ powder can be compressed with silver metal or stainless steel into a wire and because of the low cost of its constituent elements, it is an attractive superconductor for a variety of applications. In 2008, an iron-based family of high-temperature superconductors was discovered by Hosono et al. They found lanthanum oxygen fluorine iron arsenide, an oxypnictide that superconducts below 26 K. Replacing the lanthanum with samarium increases the transition temperature to 55 K. New superconductors and applications are being discovered every year at higher transition temperatures. In this book, we include some of the most recent developments in the field of superconductivity. It includes the following reviews, discoveries and applications.



Olga Moreira obtained her Ph.D. in Astrophysics from the University of Liege (Belgium) in 2010, her BSc. in Physics and Applied Mathematics from the University of Porto (Portugal). Her post-graduate travels and international collaborations with the European Space Agency (ESA) and European Southern Observatory (ESO) led to great personal and professional growth as a scientist. Currently, she is working as an independent researcher, technical writer, and editor in the fields of Mathematics, Physics, Astronomy and Astrophysics.

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About the Editor

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Preface

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Indeed, the Japanese Maglev train holds the land speed record (for a railed vehicle) of 581 km/h. In 1956, Glover and Tinkham exposed for the first time superconductors to infrared radiation and showed the carriers in a superconductor behave as if they had an energy gap. Since superconductors are much closer to metals than to insulators, such energy gap was unexpected. In order to explain the properties that had been observed in superconductors up until that time, including this latter phenomenon, Bardeen, Cooper, and Schrieffer (BCS) developed theory which introduced the idea of a Cooper pair state. The BCS theory paved the way for the discovery of the first superconducting compounds and devices. In the 1960s, the Niobium-titanium (NbTi) superconductor was discovered, providing the first material for the manufacture of superconducting magnets. The first superconducting tunnel junction (a Josephson junction) was also discovered during this decade, providing the means to fabricate a variety of unique electronic devices. The first applications of superconducting magnets were the MRI scans and particle accelerators. MRI scans have revolutionized medical diagnostics, allowing the detection of tumors, examination of neurological functions, and reveal disorders in joints, muscles, the heart, and the blood vessels. Large particle accelerators have allowed physicists to study the dynamics and structure of matter, space, and time by colliding opposing beams of high-energy protons inside a tunnel of several kilometers of circumference lying underground. At a smaller scale, Josephson effect also has a wide range of applications, including high-sensitivity detectors of electromagnetic radiation, magnetometers, high-speed digital circuit elements, and quantum computing circuits. For instance, the superconducting quantum interference device (SQUID) is used as ultra-sensitive probe of magnetic fields, such as those produced by electrical activity in the brain or the heart. High-speed digital circuits promised to revolutionize the information technology, thus, IBM began to invest millions of dollars in the Bell Labs project to build a Josephson computer. However, because the computer needed to be refrigerated for the junctions to work, this increased the cost, the project was abandoned. In 1986, Bednorz and Müller discovered an oxide material with superconducting properties at a temperature of 30K, this awarded them the Nobel Prize in Physics 1987. One year later, in 1987, Chu discovered Yttrium barium copper oxide (YBCO) which became a superconductor at just 90K. This discovery was a major breakthrough because, at 90K, the liquid nitrogen (a common industrial refrigerant) can be used to cool down the system instead of liquid helium. 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Furthermore, MgB₂ powder can be compressed with silver metal or stainless steel into a wire and because of the low cost of its constituent elements, it is an attractive superconductor for a

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