Preface

Superconductivity has fascinated physicists and engineers for over a century and continues to do so. New superconductors with ever-increasing transition temperatures and in very unconventional systems continue to be discovered. Theorists keep struggling hard to find an acceptable theory of superconductivity in cuprates and many new superconductors discovered recently. Such is the nature of these mysterious materials. Yet, the exploitation of these materials for building magnets producing intense field or magnets of large size for fusion reactors and particle accelerators has been going on at a fast pace. A large workforce of young researchers working in areas of superconductivity has thus grown over the decades. Books have also been published by distinguished professors and scientists at regular intervals on different topics of superconductivity to cater to this growing community.

During the last 40 years of my involvement with superconducting materials and magnets I have, however, always felt the need for a self-sufficient and concise volume which can impart all the background knowledge to young researchers who want to take a plunge into projects on magnet applications. Often, one has to search for different books for different topics. In the present book I have tried to cover most topics on superconductivity beginning from the basic phenomenon to conductor production to magnet development for a variety of applications such as high field production, accelerators, fusion reactors, NMR, MRI, SHGMS and SMES. The contents of the book are largely based on the numerous lectures that I had been delivering to young scholars preparing for their master/doctorate degrees in India and abroad. It was during the period 2002–2009 that I gave a very large number of lectures on superconductivity to the Laurea students at INFN Labratori Nazionali di Legnaro, Padova University, which I visited almost every year on the invitation of Prof. Enzo Palmieri. The material for these lectures had been collected over the years from many books, journals, my own work and lectures from international schools on various topics of superconductivity and magnets.

Since superconductivity is a low temperature phenomenon, for the sake of completeness, I have started with an introduction in Chap. 1, why do we need low temperature, how to produce such low temperatures, how to liquefy gases, and how ultimately Kamerlingh Onnes succeeded in liquefying helium and discovered the phenomenon of superconductivity. This, I believe, will be entertaining to any beginner.

Chapter 2 is about the phenomenon and the physical properties of this class of materials. Important topics like the Meissner effect, two-fluid model, critical magnetic field, penetration depth, concept of coherence length, energy gap, positive surface energy and flux quantization have been discussed. The chapter ends with the description of dc and ac Josephson effect and the SQUID used for mapping the feeble magnetic field in the human brain. Chapter 3 introduces Abrikosov's concept of negative surface energy leading to strange superconductivity in alloys and compounds called type II superconductors. Only type II superconductors can carry very large current in presence of high magnetic field when suitably doped with defects or impurities.

When the superconductivity community was reeling under the despondency of getting nowhere beyond T_c = 23 K (for Nb_3Ge), Bednorz and Muller discovered superconductivity at T_c = 35 K in 1986–1987 in La_2CuO_4, an insulator, when doped with Sr or Ba. What we witnessed next was unprecedented. Superconductivity was found in curates one after another starting with YBaCuO (T_c = 93 K) to BiSrCaCuO (T_c = 110 K) to TlCaBaCuO (T_c = 125 K) and to HgCaBaCu (T_c = 135 K). The entire saga offered vast opportunities for experimentalists and technocrats but left the theorists completely bewildered. This and much more about the discoveries of superconductivity in MgB_2 (T_c = 39 K) and several iron-based compounds (T_c = 50–60 K) have been discussed in Chap. 4.

Chapter 5 is a brief review of theories of conventional and high T_c cuprates such as Londons' theory, the Ginzberg-Landau theory, the BCS theory, Resonance Valence Bond (RVB) theory and the Spin Fluctuation (SF) theory. No attempt has been made to give rigorous mathematical treatment. Chapter 6 discusses the unprecedented improvement in current-field behaviour of conventional superconductors, Nb–Ti, Nb_3Sn, V_3Ga and Nb_3Al through ingenious techniques. At the end, I report very high J_c in REBCO coated wires which have turned out to be far superior to Nb_3Sn when used below 64 K.

Chapter 7 explains how to build laboratory magnets using Nb–Ti and Nb_3Sn conductors starting from the design concept to winding, impregnation, quench protection to the operation of the magnet. Specific examples for the fabrication of 7 T Nb–Ti magnet, 11 T Nb–Ti/Nb_3Sn magnet and a warm bore 6 T Cryofree magnet have been taken up for discussion. All important high field LTS/HTS magnets generating intense magnetic field peaking at 32 T at NHMFL (FSU) have been discussed. Chapter 8 is on the magnets for accelerators. A short description of all superconducting accelerators built so far, namely Tevatron, HERA, SSC, RHIC and LHC has been given in the chapter. The magnet system of the most powerful collider, LHC, finds prominence. All futuristic dipole designs too have been described. Futuristic International Linear Collider (ILC) has been included in this chapter. Important superconducting cyclotron beginning with K-500, K-1200 and K-2500 cyclotrons have been discussed with special reference to magnet design and specifications.

Chapter 9 is on the magnets for fusion reactors. All superconducting fusion machines, based on tokamak concept, starting with the Soviet (Russian) tokamak T-7, Tore Supra (now WEST), JT-60SA, EAST, KSTAR, SST-1 and finally the largest machine, called ITER have been discussed. Exception has however been made for two machines, viz TFTR at PPPL, Princeton and JET at Culham (UK) which are not superconducting, nevertheless, both had contributed enormously to fusion science leading to the final design of the ITER. Two futuristic fusion machines, W7-X (Wendelstein 7-X) Stellerator and IGNITOR, have also been included. The last Chap. 10 is on magnet applications to systems widely used for analytical and diagnostic purposes like NMR and MRI. Other very promising applications, HGMS and SMES have been described.

One unique feature of the book is that each chapter starts with a background introduction to the application discussed in the chapter so that the reader does not have to search for supporting literature. I hope the researchers will enjoy reading the book A to Z.

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