Superconductivity: A Centenary Celebration

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Abstract:

Superconductivity was empirically discovered 100 years ago. This paper describes briefly the history and developments in critical temperature of different superconductors. Many efforts have been put on research and development so as to raise critical temperature. Different superconducting materials both conventional and unconventional have been discovered. The phenomenon of superconductivity is widely applicable in different fields of S&T so as to ease human life and activities. High - temperature superconductors have taken central stage as a dream material after long research and development. Hitherto, superconductors have proven to be highly varied in composition but elusive and mysterious.

Keywords: *Centenary of superconductor, chronological development of T_c, conventional and unconventional superconductors, high temperature superconductors, insufficiency of BCS theory.*

1. Introduction

One hundred years ago on April 8, 1911, physicist Heike Kamerlingh Onnes and his co-workers at cryogenic laboratory of Leiden University, the Netherland, were the first to observe the phenomenon of superconductivity. When a superconducting material is cooled to a fairly low temperature, this phenomenon can be observed to some materials. Suddenly an electric current can then flow with no resistance through the material. This is the phenomenon; the normal conductor exhibits sudden drop in resistance at a particular low temperature, known as superconductivity. The temperature at which an abrupt decrease in resistance takes place is called critical temperature (T_c).

H K Onnes (Sep 21, 1853 – Feb 21, 1926), Discoverer of Superconductivity.

In the experiment performed by K Onnes, frozen mercury wire, contained in seven U-shaped capillaries in series, electrical resistance suddenly seemed to vanish at 4.16 K. A flow of electron without friction takes place in this state. The ratio of resistance between the normal conducting and the superconducting state has been tested to exceed 10^{14}, it is at least as large as between a usual insulator and copper as the best normal conducting material. The phenomenon of superconductivity has not lost its fascination ever since its discovery.

When we consider the process whereby water is changed into ice at its freezing point, the state of water and the state of ice are recognized as different phases. The change between two phases is called a phase transition, and in a similar way, the superconducting phenomenon is also a kind of phase transition. The superconducting temperatures above T_c is in its normal conducting state and has electrical resistance. Here, the electron system does not have order. In contrast, by cooling the specimen to temperatures below T_c it enters into the superconducting state, and a certain order in the electron system arises.

The first superconducting material mercury exhibited a dramatic drop in resistance at its critical temperature from 0.03 Ω to 3 ×10^{-6} Ω within a temperature range of 0.01K. Following this discovery, a number of superconducting elements were discovered; including lead, aluminum and several alloys those superconduct at very low temperature. They are known as conventional superconductors. The microscopic mechanism of superconductivity in this class of superconductors can be explained by BCS theory. The electrical conductivity is due to cooper pairs

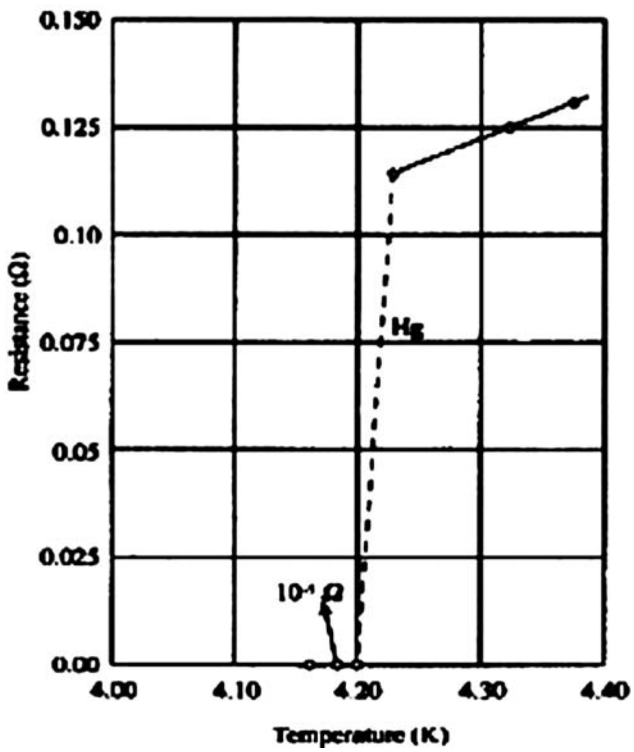

Fig 1. *Illustration of Kamerlingh Onnes' discovery of superconductivity and vanishing of the electrical resistivity (in 1911)*

There are two kinds of superconductors type I and type II. Type I superconductors are characterized by perfect diamagnetism i.e. material completely expel magnetic flux until they become completely normal. The screening current flowing in the surface layer produces a magnetization which cancels the applied magnetic field in the interior of the superconductor. The strength of the applied magnetic field required to completely destroy the state of perfect diamagnetism in the interior of type–I superconducting material is called the thermodynamic critical field H_C. Superconducting materials of type II for which the magnetization varies with the applied field with two critical fields designated as H_{C1} and H_{C2}, the lower critical field and upper critical field respectively. The magnetic field is completely expelled only up to the field H_{C1}. After H_{C1}, the flux begins to penetrate the specimen and the penetration increases until H_{C2} is reached. At Hc_2 the magnetization vanishes and the specimen becomes a normal conductor

The conventional superconducting materials are elements and alloys with low value of T_c whereas unconventional materials, generally oxides, exhibit high value of T_c. Among the conventional superconductors MgB_2, discovered in 2001, has the highest transition temperature 39 K. The scientific efforts in superconductivity were rewarded by six Nobel Prizes so far. Studying the behavior of the electrical resistance of metals at low temperatures was interesting from both a practical and a theoretical point of view. The discovery of superconductivity may have been accidental, but nonetheless the experiment was part of a carefully considered research.

The paper is organized as follows. First I review the history of discovery of superconductivity materials with their transition temperature in subsequent order of year of discovery, in brief. Nobel laureate in superconductivity with year of discovery, awarding year and contributions are to mention. Second, I review the different types of superconducting materials with their chemical composition and T_c. Third; I mention the world largest construction, where research is impossible without any idea of superconducting phenomena and employment of superconducting materials. Then after I argue that BCS theory, though it is fundamental microscopic theory for conventional superconductors, now is insufficient to explain superconducting phenomena for unconventional superconductors which are commonly known as High Temperature Superconductor (HTSC). Application of superconductors is another unavoidable part of discussion, which is also a part of this paper, in brief. In the mean time, I mention how the 100th anniversary of the exciting discovery of superconductivity is being to celebrate and commemorate worldwide.

2. The history of discovery of superconductivity

The history of superconductivity has been full of surprises and that superconductivity is a stimulating and continuing problem of physics. The historical review of discovery of superconductivity in the past 100 years can be chronologically summed in the following fashion.

The mysterious phenomenon of superconductivity was discovered after the liquefaction of helium by H K Onnes, in the mercury sample but he could not explain why electrons below the critical temperature T_c, were not interfering with the atom of the mercury. It remained mysterious and unexplained for long time about half a century. He was awarded the Nobel Prize in 1913 for his empirical discovery. He continued research until 1924. In successive years from 1928 to 1930, three important new superconductors were identified, they were tantalum(T_c of 4.4 K), thorium (T_c of 1.4 K) and niobium (T_c of 9.2 K).

The next major discovery occurred in 1933. German researcher Walter Meisssner discovered that a superconducting material excludes a magnetic field. This phenomenon supports as strong diamagnetism and is today referred to as the Meissner effect. The Meissner effect is so strong that a magnet can actually be levitated over a superconductive material. The magnetic flux through the material is expelled completely.

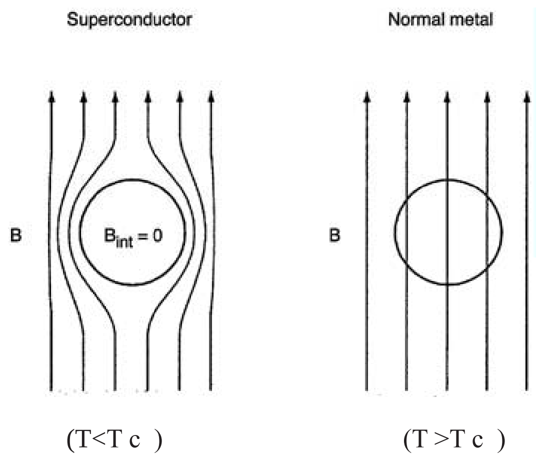

Fig. 2. *Meissner effect in superconductors: If a superconductor is in an external magnetic field below T_C, the magnetic flux B is abruptly expelled, as an indication of diamagnetic property.*

In subsequent decades, other superconducting metals, alloys and compounds were discovered. In 1941, niobium-nitride was found to be at 16 K and in 1953 Vanadium-Silicon displayed superconductive properties at 17.5 K. The study of superconducting phenomena in various materials at low temperature was continued. In 1953, the material NbN-NbC at Bell laboratories raised T_c to 17.86 K. At the same year, at the University of Chicago V_3Si showed T_c of 17 K. Another superconducting material Nb_3Sn would be added the following year at Bell laboratory, with a further increase in T_c at 18 K. In 1970, the highest temperature reached for Nb_3Ge. An alloy of niobium (Nb) with 47 weight percentage, titanium, was also discovered. It is widely used in magnets for Magnetic Resonance Imaging (MRI) in hospitals.

In 1957, three prominent scientists John Barden, Leon Cooper and Rober Schrieffer published a theory, popularly known as BCS theory, which explained superconductivity as quantum mechanical effect of coupled electrons. When we cool the specimen the normal state transforms itself into a different type of fluid, a quantum fluid of highly correlated pairs of electrons. Below T_c conduction electrons of a given momentum and spin get weakly coupled with another electrons of exactly the opposite momentum and spin. These pairs of electrons are called cooper pairs. In total they have spin zero and have many attributes of bosons. The effective unit of charge is '2e' rather than 'e' as in ordinary state, where 'e' is considered basic unit of charge. The glue is provided by the elastic waves of the lattice, called phonons.

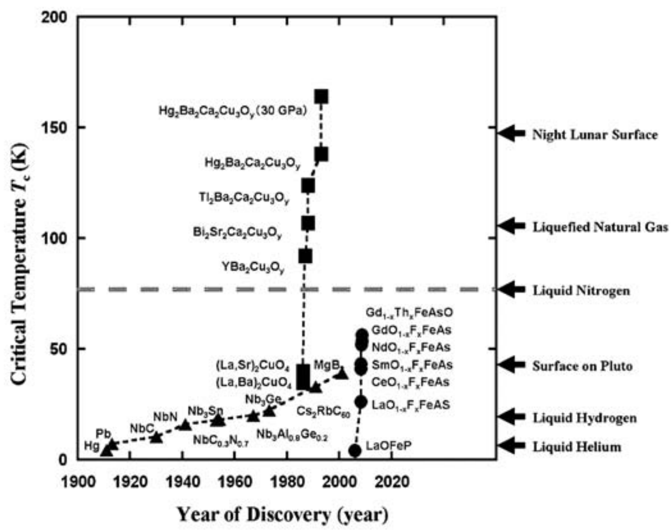

Figure 3. *The evolution of the critical temperature T_c superconductors. The series of high - T_c cuprate superconductors were first discovered in 1986. Iron arsenide superconductors, which are other candidates for high -T_c superconductors, were discovered in 2008*

Figure 3 represents various values of $T_{c,}$ for different materials representing subsequent remarkable temperature during the course of raising of critical temperature. Different steps of temperature as liquid helium (~5 K), liquid nitrogen (77K), night lunar surface temperature (~160K) and so on have been considered as a reference value.

The BCS theory explains the attractive force between electrons through the medium. If one electron in the crystal attracts neighboring positive ions, a nearby second electron will be pulled in by these positive charges. This means that an attractive interaction throughout the medium is generated between electrons and all such paired electrons form a condensate that moves as a single entity and overcomes the Coulombic interaction (fig 4). This theory successfully explained why certain materials were superconducting and others were not. They received the Nobel Prize for BCS theory in 1972.

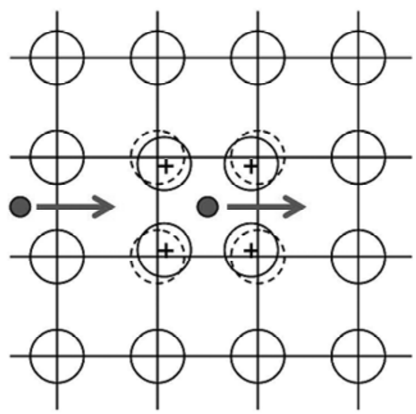

Figure 4. *The generation of attractive force between electrons in a crystal. The second electron moving in the crystal is attracted by the positive charge of the crystal ions which is produced by Coulomb interaction with the first electron passing there. Thus, two electrons interact with each other through the medium.*

The search for new high temperature superconducting materials was continued. Another significant discovery came in 1962 when B D Josephson, a graduate student at Cambridge University, predicted that electrical current would flow between two superconducting materials-even when they are separated by a non-superconductor or insulators. His predictions own him a share of the 1973 Nobel Prize in Physics. In the same year Ivar Giaever independently demonstrated the Josephson's prediction, which also won him the Nobel Prize in 1973. What Josephson predicted about is tunneling of electrons pair, known today as the Josephson effect.

Thus in the long run of about half a century (six decades) in the field of science and research, superconductivity was discovered experimentally, and successful theories were developed to explain the new baffling phenomena. The table gives the list of Nobel Laureates and their contribution in superconductivity.

Table 1: Nobel Prize in physics for contribution to superconductors

year	Scientists	Contribution
1913	H K Onnes	Properties of material at low temperature
1972	J Bardeen, L Cooper and R Schrieffer	Microscopic (BCS) theory of Superconductor
1973	I Giaever and B Joshephson	Tunnelling effect in Superconductor
1986	J G Bednorz nd K A Muller	Discovery of the copper oxide based high temperature superconductor
1991	P de Gennes	Studies on complex systems including superconductivity
2003	V L Ginzburg and A A Arbrikosov	For pioneering contribution to the theory of superconductors

In 1986 a truly breakthrough discovery was made by Alex Muller and George Bednorz at the IBM Research Laboratory in Zurich, Switzerland. They developed a ceramic-barium-copper oxide crystal ($Ba_xLa_xCuO_4$) that displayed superconductivity at 30 K, the work for which they received Nobel Prize in 1987. In January, 1987 a research team substituted Yttrium for Lanthanum in the compound and achieved a transition temperature of 92 K. Additional discoveries have since been made by substituting bismuth, lead, thallium, mercury and strontium in the base Peroviskite ceramic that was discovered by Muller and Bednorz. An unbelievable T_c of 132 K was maintained by mercuric-cuprate composed of mercury, barium, calcium, copper and oxygen.

Nobel Prize of the year 1991 was awarded to Frenchman Pierre-Gilles de Gennes. He described mathematically how magnetic dipoles, long molecules or molecule chains can under certain conditions form ordered states, and what happens when they pass from an ordered to a disordered state. Such changes of order occur when, for example, a heated magnet changes from a state in which all the small atomic magnets are lined up in parallel to a disordered state in which the magnets are randomly oriented. The transition from disorder to order always occurs at a well-defined temperature and can sometimes also take place in jumps. There is a phase transition at a critical temperature, which in the case of ferro-magnets is termed the Curie temperature.

Nobel Prize in Physics in 2003 awarded to three physicists Alexei A. Abrikosov , Vitaly L. Ginzburg and Anthony J. Leggett who have made decisive contributions concerning two phenomena in quantum physics: superconductivity and superfluidity. Superconducting material is used, for example, in magnetic resonance imaging for medical examinations and particle accelerators in physics. Knowledge about superfluid liquids can give us deeper insight into the ways in which matter behaves in its lowest and most ordered state.

However, the 100-year history of superconductivity can also be divided into following different period according to the achievement of the subsequent period. The beginning of the superconductivity has been considered from the first historic discovery of K Onnes though cryogenic activities had begun earlier.

i) the era of science and discovery(1911-1961)
ii) the era of technology and innovation(1962-1970)
iii) the era of entrepreneurship (1971-1981)
iv) the era of product of profits(1982-1990)
v) the era of new materials and applications(1991-2003)
vi) the era of industry consolidation(2004-2011)

3) Superconducting materials

Following the discovery of superconductivity, during the span of 100 years, a number of superconducting elements, alloys, oxides and several other kinds were discovered. Superconductors can be divided into several classes according to transition temperature T_c, structure and nature of their superconducting properties. They can be classified as conventional superconductors, chevrel phase superconductors, organic superconductors, heavy fermions, copper oxide based high T_c superconductors, non-copper oxide based superconductors and quaternary carbide compounds are the different kinds, all exhibit superconducting phenomena.

i) Conventional superconductors

Conventional superconductors are essentially pure metals and alloys such as Pb, Al, Ru and Nb_3Ge. The T_c of this group was less than 23 K until the discovery of MgB_2 in 2001 with a T_c of 39 K. With few exceptions, most elemental superconductors are type- I while alloys and other complex superconducting materials belong to type-II. The microscopic mechanism of superconductivity in this class of superconductors can be explained by BCS theory. The charge carrier one pair of electrons is known as cooper pairs. The distance between electrons in a cooper pair (coherence length), in such material, is from 400A^o to 10^{4}A^o.

ii) Chevrel phase superconductors

These types of superconductors were discovered in 1971, have general chemical formula $M_xMo_6X_8$, where M stands for a metal or a rare-earth element, and X is a chalcogen, such as S, Se or Te. Generally they have high critical fields, which make them an attractive alternative for high field applications for example; $PbMo_6S_8$ has a T_c of about 14.6 K and upper critical field of 60 Tesla.

iii) Organic superconductors

Superconductivity in low dimensional organic materials was first suggested by Little in 1965. Theoretically, it has been shown that a very high T_c may be possible in low dimensional system. Carbon, being perhaps the most important element for life , has not played a big role in superconductivity for long time. The organic superconductors $(TMTSF)_2PF_6$, with T_c 1.2 K was first discovered in late 1970s (TMTSF- tetramethyltetra-Selenofulvalen). In addition to these organic compounds, the discovery of Carbon-60 (C_{60}) also known as buckminsterfullerene has led to the discovery of new subclass of organic superconductors. Fullerence (C_{60}, C_{70},….) attracted much attention since their discovery in 1985. It is the form of carbon molecule that is neither graphite nor diamond. They consists spherical, ellipsoid or cylindrical arrangement of carbon atom. The compound itself is a very poor conductor but by doping this compound with electron donors such as alkaline metals, which provides the conduction electrons, superconductivity can be included. For example, K_3C_{60} has a T_c of 19 K.

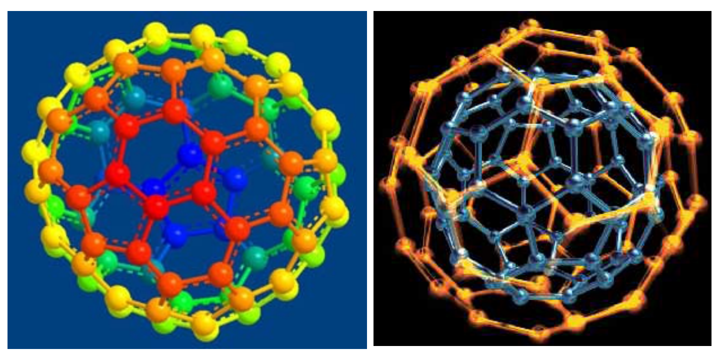

Fig 5. *The superconducting fullerence (C_{60}) They are examples of unconventional superconductors.*

iv) Heavy fermions superconductors

These materials, above room temperature, consist of disordered f-electron magnetic moments. Some of the examples of these kinds are $CeCu_2Si_2$, URu_2Si_2, UBe_{13} and $CeAl_3$. The electronic properties of these materials are quite similar to normal metals. One of the interesting features of heavy fermions materials is that antiferromagnetism and superconductivity can co-exists under certain conditions.

Table 2: Classes of superconducting materials and their T_c

Classes of materials	Examples	T_c(K)
Metals and alloys	Al, Pb, Nb_3Sn , NbTi, MgB_2	≤ 39
Organic Superconductors	K_3C_{60}, $[BEDT\text{-}TIF]_2X$	< 42
Heavy Fermion	$CeCu_2Si_2$	< 1
Borocarbide & boronitride	$LuNi_2B_2C$	< 23
Oxide base (Bi, Ti, Sr)	$Ba_{0.63}K_{0.37}BiO_3$, $SrTiO_{3-d}$	< 30
Copper oxide base	YBCO,BSCCO,HBCCO	≤ 164
Iron-arsenide	RFeAsOF	≤ 50

v) Non-copper oxide superconductors

These superconductors have generally low T_c s and were discovered as early as 1960s. Some of the examples are $SrTiO_{3-x}$, $BaPb_{1-x}Bi_xO_3$. The superconductors in these kinds of materials are not well understood.

vi) Quarternary borocarbide superconductor compounds

These classes of superconductors (T_c ~ 23 K) may be regarded as a layered system similar to that of copper oxide based high temperature superconductors. Superconductivity in this type of compound was discovered in 1994. The compound such as Ln-i-B (where Ln is a Lanthanides such as Y) is one of the examples of the compound discovered is $LnNi_2B_2C$.

vii) Iron Arsenide superconductors

These kind of superconducting materials possess very high upper critical field. One of the compounds of this type, La-As-O-F has transition temperature near 26 K. Many more derivative materials exhibiting T_c above 50 K. The Superconducting mechanism in these materials also is of great interest.

viii) Copper oxide – based high temper superconductors

Bednorz and Müller in 1986 discovered copper oxide based high temperature superconductors. This type of superconductors is perhaps the most popular and most studied of all. Some of the mercury-oxide superconductors exhibiting T_c of 134 K under normal pressure and reaching 164K under high pressure. Probably it is the highest known T_c, so far. Copper oxide HTSC materials have short coherent length (3-20 A°) and hence much stronger Coulomb repulsion (F α $1/r^2$) . Some of the HTSC cuprate oxide superconductors are La-Ba-Cu-O, Y-Ba-Cu-O, Bi-Sr-Ca-Cu-O, Hg-Ba-Ca-Cu-O and so on.

ix) Thallium based cuprates

Another interesting field of superconducting material is Thallium based HTSC. The superconducting property was first discovered in TlBiSrCaCuO and TlBaCaCuO system. The superconducting temperature of $TlSr_2CaCu_2O$ is about 80 K, Some other such compounds show superconducting temperature up to 110 K.

4) The largest superconducting construction of the century

The Large Hadron Collider (LHC), the particle accelerator at CERN, Geneva is the largest and probably the most complex scientific instrument ever built. LHC lies in a tunnel of 27 kilometer in circumference and 127 meter beneath in the boarder of Switzerland and France near Geneva. It was built by European Organization for Nuclear Research (CERN) with a budgeting of 9 billion US dollar. It is a particle accelerator designed to collide counter-circulating proton beams. It relies heavily on superconductivity. Superconductivity plays a key role because the accelerator is based on the reliable operation of almost 10 000 superconducting magnets cooled by 130 tonnes of helium at 1.9 K and 4.2 K and containing a total stored magnetic energy of about 15 000 MJ. The very good design and manufacture of the 1200 tonnes of top quality superconducting cable have been employed. The huge construction aims to clarify about unsolved mystery of Higgs bosons known as god particles. They are hypothetical massive particles, queries for origin of mass. This huge construction has been employing cryogenic cooling technique with superconducting phenomena.

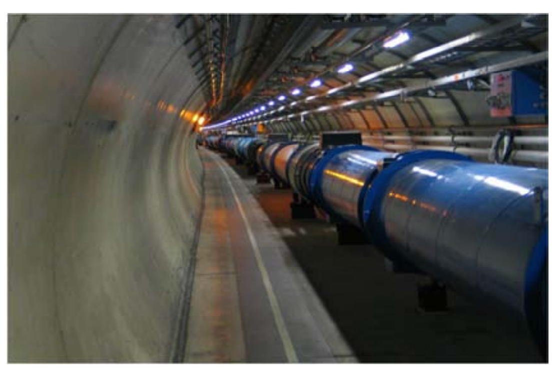

Fig 6 . *The superconducting magnets in the LHC tunnel*

5) Superconductivity centennial events worldwide

In year 2011, the worldwide superconductivity community will celebrate the 100th anniversary of the discovery of superconductivity by Heike Kamerling Onnes and his collaborators. This discovery was made on April 8, 1911. As can be expected, many special events of different kind are being organized; some are already announced and scheduled and other still in the works. Major events and Regional events have been planned in different countries Australia, France, United Kingdom, United States, Switzerland, Russia and so on. Some of the international journals in Physics have published/publishing special issue devoted to superconductivity. Many conferences/societies/meeting/workshop will commemorate the 100th anniversary of the discovery of superconductivity worldwide.

6) Question on the validity of BCS theory of superconductivity

The microscopic theory put forward by Bardeen Cooper and Schrieffer (BCS) in 1957 provides the better quantum explanation of superconductivity and accounts very well for all properties exhibited by the superconductors. This theory involves the electron interaction through phonons as mediators. The fundamental postulates of BCS theory is that the superconductivity occurs when an attractive interaction between two electrons, by means of phonon exchange, dominates the usual repulsive interaction. Two such electrons which interact attractively in the phonon field are called Cooper pairs. This theory received the Nobel Prize in 1972. The theory explained superconductivity at temperatures close to absolute zero for elements, metals and simple alloys. However, at higher temperatures and with different superconductor systems, the BCS theory has subsequently become inadequate to fully explain how superconductivity occurs.

BCS theory accepted to be the correct theory of conventional superconductivity by Physicists, by the world at large. There are, however, an increasing number of evidences that strongly suggest the possibility that BCS theory may be fundamentally flawed. An ever-growing number of superconductors are being classified as unconventional, not described by the conventional BCS theory and requiring a different physical mechanism. It has been claimed that BCS theory is unable to explain the Meissner effect, the most fundamental property of superconductors. There are several other phenomena in superconductors such as Tao effect, de Heer effect, Chapnik's rule remained unexplained. BCS theory has proven unable to predict any new superconducting compounds.

Since 1970 at least ten distinct materials or families of materials have been discovered that exhibit superconductivity for which there is a consensus that they can not be described by electron-phonon BCS theory. High T_c cuprates, heavy fermion materials, organics, strontium-ruthenate, fullerence, borocarbides, bismuthates, iron arsenide compounds and ferromagnetic superconductors, these all classes of materials exhibits deviations from conventional BCS behaviour. It is similar to the theories in the past as Ptolemy's theory of planetary motion negated by Copernicus theory, theory of fixed continents with land bridges negated by Wegener's theory of continental drift.

7) Applications of superconductors

The applications of superconductivity are as old as the beginning of superconductivity itself. A large number of possible practical applications of the phenomenon have not been achieved on account to the limit to the T_c value. Because of low T_c, the maintenance of superconductivity through refrigeration requires a very high cost. Since room temperature superconductivity has not been found yet, the application of high temperature superconductivity are restricted to temperature around that of liquid nitrogen. Some of the prominent applications can be summarized in the following fashion.

i) Superconducting magnets

Type II superconductors such as niobium-tin and niobium-titanium are used to make the coil windings for superconducting magnets. The first successful superconducting magnet that used type II superconductor was built in 1954 by George Yntema of the University of Illinois, produced a field of 0.7 Tesla.

Most high energy accelerators now use superconducting magnets. The proton accelerator at Fermilab uses 774 superconditing magnets in a ring of circumference 6.2 km. To make magnet wire, niobium-titanium is formed into filaments finer than human hair (~10^{-6} m) and embedded in a matrix of solid copper. The fine filaments are advantageous since current flows only within a skin-depth of the surface of a superconductor.

High energy physics opens up a wide field of applications for magnets made of metallic superconductors. In this high magnetic and electric field particles are accelerated to several GeV (1GeV=10^9eV). Many gigantic d c magnets have been built for elementary particle detectors as well as beam guidance magnets outside the accelerator ring and have been operated for years in many laboratories worldwide. Superconducting magnets of 100 GeV at Fermilab in USA and Hera accelerator at DESY, Hamburg which have 1000 and 630 dipole and quadrupole magnets, respectively installed in their 6 km ring.

ii) Superconductors in NMR imaging

Superconducting magnets find application in a magnetic resonance imaging (MRI) of the human body. MRI requires extremely uniform field across the subject and extreme stability over time. An MRI corresponds to taking an electronic census of the body's hydrogen contents. Hydrogen atoms act like tiny magnets in the cell. Hydrogen turns out to be a very useful monitor of the body's health. Since two-third of water consists of hydrogen atoms, water rich tissues as well as hydrogen rich organic materials respond strongly to MRI probes. MRI has emerged as a key medical diagnostic tool and superconductivity has played an important enabling role in its development.

iii) Magnetic levitation vehicles(maglev)

Magnetic levitation using superconducting magnet was first suggested in 1963 by Powell, soon after the discovery of type –II superconductors with their implications for carrying large currents. It is not practical to lay down superconducting rails, it is possible to construct a superconducting system onboard a train to repel conventional rails below it. Two different kinds of maglev are in the phase of development, attractive levitation force (Electromagnetic suspension) or repulsive forces (electrodynamics levitation). Beginning in the 1970s, research in Germany explored both systems, but more recently only electromagnetic systems are in use. In Japan, both systems were tried and electrodynamics system was preferred. The German Tran-rapid TR-07 is designed to carry 200 passengers at maximum speed of 500 km/hr. The levitation height is 8mm and power consumption is estimated to be 43 MW at 400 km/hr.

iv) Generators and motors with superconducting windings

Coils with iron cores are employed to generate the necessary magnetic fields in conventional motors and generators. This limits the practical maximum field strength that can be obtained from a machine of given volume. Superconducting magnets allow the generations of very much higher magnetic fields. This means superconducting machines can be made much smaller for the same output. The cryoscopic complication must naturally be taken into account in every estimate of economy. The low electrical losses lead to marked gain in efficiency, especially for higher power gains. Efforts are being made worldwide, to create large superconducting synchronous generators for use in power plants. In comparison with conventional generators, the volume and weight are reduced with efficiency up to 99.5%.

v) Superconducting transformers and power transmission cables

Advances in low-loss a.c. superconductors with submicron filaments in a resistive CuNi matrix have given rise to increased interest in the superconducting transformer. The high voltage and low voltage windings are cooled in a bath of liquid coolant. The advantages of superconducting transformer are in high efficiency, substantial decrease in the weight and hysteresis losses and high current densities.

The energy consumption of mankind will continue to increase in future. As the amount of power consumption increases so does the problem of power transmission. Naturally a conductor with no ohmic resistance offers a new and attractive possibility of power transmission at high voltage/current and for longer distance. Superconducting transmission cables can provide two to five times the current transmission capability of a conventional cable with the same cable diameter.

vi) Electronic applications of superconductivity

Superconducting electronics have become an indispensable part of human applications. Superconducting electronic circuits are used where very low noise, very high sensibility minimal losses, short switching times and stability of voltage calibrations are crucial e.g. communication, high precision and high frequency electronics magnetic fields measurements, super fast computers and so on. Potentiality of several superconductor electronics devices have already been established using conventional LTSCS. Helium-cooled SQUID(Superconducting Quantum interference Devices) is most sensitive detector, firmly established in many laboratories. Rapid advancement in the synthesis of thin HTSC thin films and artificial grain boundary HTSC Josephson junctions have excited considerable interest in the development of electronic devices e.g. SQUID, microwave and digital devices, Since the discovery of HTSC curprates, that operate as high as 77 K.

Superconducting digital electronics is another promising field and offers the possibility of high speed operations at extremely low power. Presently, the developments of Rapid Single Flux Quantum (RSFQ) logic currents are the most exciting field in superconducting electronics. RSFQ has ultra-fast operating speed of several hundred GHz and very small power dissipation of the order of 10 nW(1 nW = 10^{-9} W). Several HTSC digital circuits have been fabricated e.g. RSFQ circuits consisting of dc SQF converter, comparators, voltage divider, sigma-delta modulator, sampler and many more.

Although some superconductor operates at temperature well above liquid nitrogen (77K), by everyday standers they still needed to be very cold. In order to achieve this, refrigeration, using cryoengineering at various levels of sophistication, compact economical refrigeration is very important for the wider adoption of cryoelectronics in industry.

8) Conclusion

The paper followed the development of superconductivity through the past century, from discovery to high temperature superconductors as well as its types. Paper it has been discussed about the indication of inadequacy of explanation of BCS theory of superconductivity in regards to unconventional superconductors. The major application of superconductivity in MRI have been discussed along with the latest application of superconducting magnets in LHC.

Twenty-five years have already been passed since the discovery of high temperature materials. The critical temperature of superconducting materials has been increasing gradually but still not approaching to room temperature. The theoretical basis of high temperature superconductivity is still uncertain. The renaissance of superconductivity could apply in future with radical breakthrough in a different and highly attractive fashion in various possible fields, like: nanotechnology, computer, communication, IT, entertainment, clean energy, transportation and many more. This shows the history of superconductivity has been full of surprises and is a stimulating and continuing problem of Physics.

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