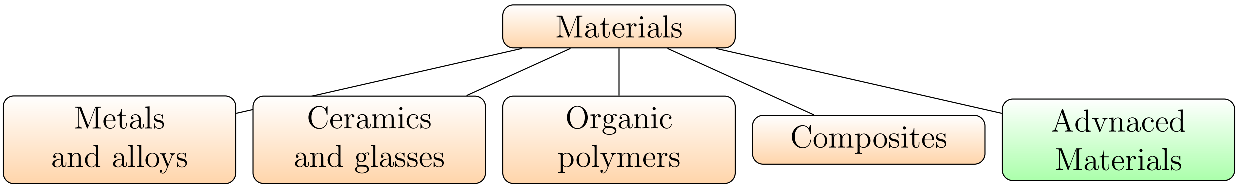
1 Introduction

Materials science is primarily concerned with the search for basic knowledge about the internal structure, properties, and processing of materials. Materials engineering is mainly concerned with the use of fundamental and applied knowledge of materials so that the materials can be converted into products needed or desired by society. Strictly speaking, materials science involves investigating the relationships that exist between the structures and properties of materials (i.e., why materials have their properties). In contrast, materials engineering involves, on the basis of these structure–property correlations, designing or engineering the structure of a material to produce a predetermined set of properties. In the currently understood sense of the term, materials refer only to solid materials, even though it is possible to quote a number of examples of liquid and gaseous materials.

1.1 Classification of Materials



Solid materials have been conveniently grouped into three basic categories: ***metals, ceramics (compounds between metallic and nonmetallic elements), and polymers (compounds composed of carbon, hydrogen, and other nonmetallic elements)*** , a scheme based primarily on chemical makeup and atomic structure. Most materials fall into one distinct grouping or another. In addition, there are the **composites** that are engineered combinations of two or more different materials. *Metals are good electric conductors; ceramics and polymers are electric insulators.*

Most of our tools are made of metals because they are strong, hard, and do not break readily under high stress. Let us observe how most metallic objects are fabricated: many consist of sheets or bars of metal that have been bent, stamped, or forged into their final shapes; they have also been cut, sawed, or drilled and can be fabricated to high precision. No metal is transparent. Light of all wavelengths is absorbed and reflected by metals. Metals are used as mirrors.

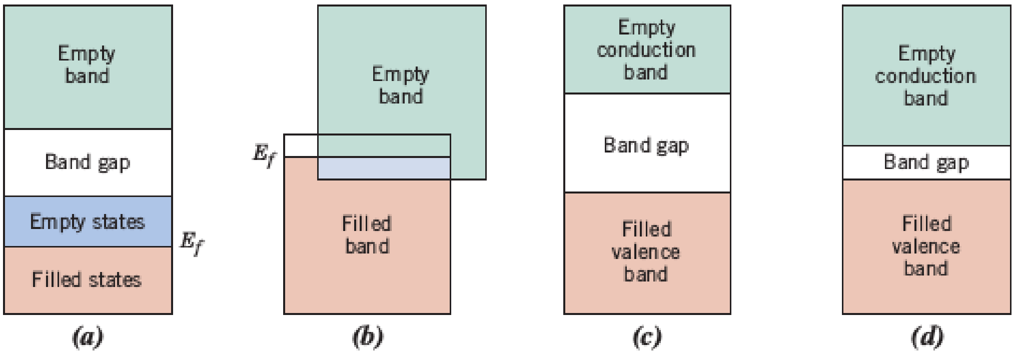
Ceramics are very strong but brittle. A knife does not scratch a porcelain plate: porcelain is harder than steel but it will break when dropped to the floor. Ceramics remain strong at very high temperatures: ceramic bricks line the inside of furnaces and form the crucibles used in melting metals. These materials can only be machined by abrasion with diamond.

The plastic (polymer) is much softer than a metal or a ceramic; we can bend it, but it will not keep the new shape the way a metal does. Most plastics cannot be used at high temperatures; they soften or liquefy at temperatures not much higher than that of boiling water. Plastics can be transparent, translucent, or colored as well.

Many ceramics are transparent and some are are translucent, which means that light passes through them but is scattered by internal defects; some ceramics are colored; they are transparent to some wavelengths of light but not to others.

1.2 Metals

Metals are familiar objects with a characteristic appearance; they are capable of changing their shape permanently, and have good thermal and electrical conductivity.



The various possible electron band structures in solids at 0 K. (a) The electron band structure found in metals such as copper, in which there are available electron states above and adjacent to filled states, in the same band. (b) The electron band structure of metals such as magnesium, in which there is an overlap of filled and empty outer bands. (c) The electron band structure characteristic of insulators; the filled valence band is separated from the empty conduction band by a relatively large band gap (¿2 eV). (d) The electron band structure found in the semiconductors, which is the same as for insulators except that the band gap is relatively narrow (¡ 2 eV).

Metals and alloys are commonly divided into two classes: ferrous metals and alloys that contain a large percentage of iron such as the steels and cast irons and nonferrous metals and alloys that do not contain iron or contain only a relatively small amount of iron. Examples of nonferrous metals are aluminum, copper, zinc, titanium, and nickel. The distinction between ferrous and nonferrous alloys is made because of the significantly higher usage and production of steels and cast irons when compared to other alloys.

An alloy is a combination of more than one metal. Metals are composed of one or more metallic elements (e.g., iron, aluminum, copper, titanium, gold, nickel), and often also non-metallic elements (e.g., carbon, nitrogen, oxygen) in relatively small amounts. Atoms in metals and their alloys are arranged in a very orderly manner. and are relatively dense in comparison to the ceramics and polymers . With regard to mechanical characteristics, these materials are relatively stiff and strong, yet are ductile (i.e., capable of large amounts of deformation without fracture), and are resistant to fracture, which accounts for their widespread use in structural applications. Metallic materials have large numbers of nonlocalized electrons - that is, these electrons are not bound to particular atoms. Many properties of metals are directly attributable to these electrons. For example, metals are extremely good conductors of electricity and heat, and are not transparent to visible light; a polished metal surface has a lustrous appearance. In addition, some of the metals (i.e., Fe, Co, and Ni) have desirable magnetic properties.

1.3 Ceramics

Ceramics include natural stones; clays and porcelains; electric insulators; abrasives; glass; and cement. These materials are hard and brittle; they do not conduct electricity and are often transparent. These properties are the consequences of a filled valence band. The chemical bond is covalent for elemental solids and ionic or mixed covalent-ionic for compounds. The nature of the chemical bond controls the crystal structure of the materials. These bonds are generally stronger than in metals and give the solid a high melting temperature that prevents casting from a melt. Ceramics cannot be machined the way metals are. Ceramic pieces are fabricated by forming a paste, consisting of the ceramic powder and water, into a near-final shape and solidifying it by firing. Firing causes sintering of the ceramic particles through diffusion of atoms or molecules. Glass is an amorphous silicon oxide with additions of sodium, magnesium, or boron. These additions form positive ions that neutralize the oxygen atoms and allow a disordered structure. Glass does not have a melting point but increases its viscosity, upon cooling, to values so high that the glass cannot be deformed at room temperature. The fabrication of glass objects makes use of its high viscosity. Cement is a ceramic that hardens by a chemical reaction with water. Hardening increases with time and reaches its final value in more than a year.

Ceramics and glasses are nonmetallic inorganic substances, which are brittle and have good thermal and electrical insulating properties. Ceramics are compounds between metallic and nonmetallic elements; they are most frequently oxides, nitrides, and carbides. For example, common ceramic materials include aluminum oxide (or alumina, Al_2O_3), silicon dioxide (or silica, SiO_2), silicon carbide (SiC), silicon nitride (Si_3N_4), and, in addition, what some refer to as the traditional ceramics-those composed of clay minerals (e.g., porcelain), as well as cement and glass. With regard to mechanical behavior, ceramic materials are relatively stiff and strong-stiffnesses and strengths are comparable to those of the metals. In addition, they are typically very hard. Historically, ceramics have exhibited extreme brittleness (lack of ductility) and are highly susceptible to fracture. However, newer ceramics are being engineered to have improved resistance to fracture; these materials are used for cookware, cutlery, and even automobile engine parts. Furthermore, ceramic materials are typically insulative to the passage of heat and electricity (i.e., have low electrical conductivities) and are more resistant to high temperatures and harsh environments than are metals and polymers. With regard to optical characteristics, ceramics may be transparent, translucent, or opaque, and some of the oxide ceramics (e.g., Fe_3O_4) exhibit magnetic behavior.

1.4 Polymers

Polymers, namely plastics, rubbers, and resins, are light, relatively soft materials that can easily be formed into films, sheets, bottles, or complex shapes. Most polymers are organic materials, consisting mostly of carbon and hydrogen. Thermoplastic polymers consist of very long molecules (chains) that are bound to each other by weak secondary bonds. The materials are amorphous or partly crystalline: they do not have a definite melting point; when they are cooled from the liquid state, their viscosity increases until they are solid. This property allows one to blow the material like glass and form thin films or bottles. Partial crystallization increases the strength of the material. Thermosets solidify by a chemical reaction that creates primary bonds between the chains. They tend to be more solid and stable to higher temperatures. Rubbers (elastomers) are polymers with a distinct molecular structure; their response to stresses is viscoelastic (sluggish), a property that is used in the design of tires.

Organic polymers are relatively inert and light, and generally have a high degree of plasticity. Polymers include the familiar plastic and rubber materials. Many of them are organic compounds that are chemically based on carbon, hydrogen, and other nonmetallic elements (i.e., O, N, and Si). Furthermore, they have very large molecular structures, often chainlike in nature, that often have a backbone of carbon atoms. Some common and familiar polymers are polyethylene (PE), nylon, poly(vinyl chloride) (PVC), polycarbonate (PC), polystyrene (PS), and silicone rubber. These materials typically have low densities, whereas their mechanical characteristics are generally dissimilar to those of the metallic and ceramic materials—they are not as stiff or strong as these other material types. However, on the basis of their low densities, many times their stiffnesses and strengths on a per-mass basis are comparable to those of the metals and ceramics. In addition, many of the polymers are extremely ductile and pliable (i.e., plastic), which means they are easily formed into complex shapes. In general, they are relatively inert chemically and unreactive in a large number of environments. Furthermore, they have low electrical conductivities and are nonmagnetic. One major drawback to the polymers is their tendency to soften and/or decompose at modest temperatures, which, in some instances, limits their use.

1.5 Composites

A composite is a physical mixture of two or more materials. By combining the advantages of different material classes, a composite achieves properties that could not be obtained from any of its constituents alone. The best known composite is fiberglass, which consists of glass fibers embedded in a polymer matrix. Higher performance is obtained from carbon or graphite fibers in an epoxy matrix. Metal matrix composites contain ceramic particles distributed in a metal matrix. Ceramic matrix composites are reinforced with metal or ceramic fibers to increase fracture toughness. Reinforced and prestressed concrete are composites that combine the hardness of ceramics and the tensile strength of metal. Wood is a natural composite. The strength of these materials is dictated by the layout of the reinforcing phase.

A composite is composed of two (or more) individual materials that come from the categories previously discussed—metals, ceramics, and polymers. The design goal of a composite is to achieve a combination of properties that is not displayed by any single material and also to incorporate the best characteristics of each of the component materials. A large number of composite types are represented by different combinations of metals, ceramics, and polymers. Furthermore, some naturally occurring materials are composites - for example, wood and bone. However, most of those we consider in our discussions are synthetic (or human-made) composites. One of the most common and familiar composites is fiberglass, in which small glass fibers are embedded within a polymeric material (normally an epoxy or polyester). The glass fibers are relatively strong and stiff (but also brittle), whereas the polymer is more flexible. Thus, fiberglass is relatively stiff, strong, and flexible. In addition, it has a low density. Another technologically important material is the carbon fiber-reinforced polymer (CFRP) composite-carbon fibers that are embedded within a polymer. These materials are stiffer and stronger than glass fiber-reinforced materials but more expensive. CFRP composites are used in some aircraft and aerospace applications, as well as in high-tech sporting equipment (e.g., bicycles, golf clubs, tennis rackets, skis/ snowboards) and recently in automobile bumpers.

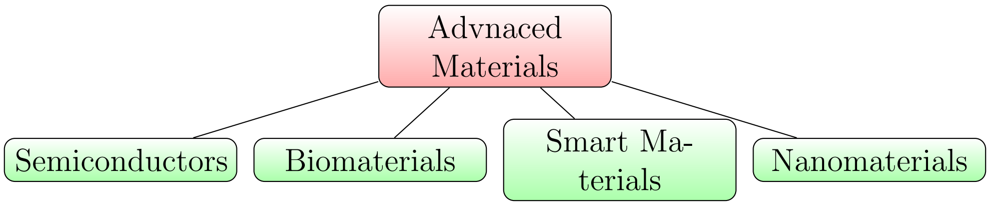
Steels, aluminium, copper, silver, gold, Brasses, bronzes, manganin, invar, Superalloys, Boron, rare earth magnetic alloys etc are the main members in *Metals and Alloys* class.

Plastics: PVC, PTFE, polyethylene, Fibres: terylene, nylon, cotton, Natural and synthetic rubbers, Leather etc are main *Organic Polymers.*

The important members in *Ceramics and Glasses* are MgO, CdS, Al_2O_3 , SiC, $BaTiO_3$, Silica, soda-lime-glass, concrete, cement, Ferrites and garnets, Ceramic superconductors

Metal-reinforced plastics are formed by combining the materials in metals and organic polymers. By combining materials in Ceramics and Glasses and Organic Polymers we get *Glass fibre-reinforced plastics* and Si, Ge, GaAs and Boride-reinforced steel are examples for combinations of Ceramics & Glasses and Metals & Alloys.

1.6 Advanced Materials



Another materials category is the advanced materials that are used in high-tech applications, including semiconductors (having electrical conductivities intermediate between those of conductors and insulators), biomaterials (which must be compatible with body tissues), smart materials (those that sense and respond to changes in their environments in predetermined manners), and nanomaterials (those that have structural features on the order of a nanometer, some of which may be designed on the atomic/molecular level).

1.6.1 Semiconductors

Semiconductors have electrical properties that are intermediate between those of electrical conductors (i.e., metals and metal alloys) and insulators (i.e., ceramics and polymers). Furthermore, the electrical characteristics of these materials are extremely sensitive to the presence of minute concentrations of impurity atoms, for which the concentrations may be controlled over very small spatial regions.

Semiconductors, like insulators, have a filled energy band, called the valence band, that is separated by a band gap from an empty energy band, which is called the conduction band. In semiconductors, the band gap is relatively small. The most useful property of semiconductors is that one is able to place electrons into the conduction band (making it an n-type semiconductor) or remove electrons from the valence band (to produce a p-type semiconductor) by the addition of impurities, thereby producing mobile charge carriers capable of electric conduction. By juxtaposing n-type and p-type semiconductor regions, one creates p-n junctions, which can act as electric rectifiers, transistors, light detectors, light-emitting diodes, and solid-state lasers.

Silicon is the material that forms the basis of all common integrated circuits. Other semiconductors of technical interest are III-V compounds, such as GaAs, GaP, and II-VI compounds such as ZnS or CdS.

Numerous electronic devices are based on the semiconductor p-n junction. These are commonly called solid-state devices. A number of these applications involve a single p-n junction; these are the diodes, namely the rectifier, the photodiode, the light-emitting diode (LED), the solar cell, and the semiconductor laser.

Transistors are triodes consisting of two p-n junctions. They exist as n-p-n or p-n-p structures. A constant potential is applied between the extreme electrodes, and a small variable potential applied to the middle electrode controls the amount of current flowing through the transistor. Bipolar transistors are used as power amplifiers, and field effect transistors serve as on-off switches in digital circuits.

The recent discovery of organic semiconductors presents an interesting development because these materials can be processed with the techniques of printing and polymer chemistry, which are much less expensive and energy-intensive than photolithography. Organic semiconductors include oligomers (i.e., large molecules) and polymers. Oligomers include anthracene, pentacene, and rubrene. Semiconducting polymers include polyacetylene, poly(p-phenylene vinylene), and others.

1.6.2 Biomaterials

The length and the quality of our lives are being extended and improved, in part, due to advancements in the ability to replace diseased and injured body parts. Replacement implants are constructed of biomaterials-nonviable (i.e., nonliving) materials that are implanted into the body, so that they function in a reliable, safe, and physiologically satisfactory manner, while interacting with living tissue. That is, biomaterials must be *biocompatible*-compatible with body tissues and fluids with which they are in contact over acceptable time periods. Biocompatible materials must neither elicit rejection or physiologically unacceptable responses nor release toxic substances. Consequently, some rather stringent constraints are imposed on materials in order for them to be biocompatible.

Example biomaterial applications include joint (e.g., hip, knee) and heart valve replacements, vascular (blood vessel) grafts, fracture-fixation devices, dental restorations, and generation of new organ tissues.

1.6.3 Smart Materials

Smart (or intelligent) materials are a group of new and state-of-the-art materials now being developed that will have a significant influence on many of our technologies. The adjective smart implies that these materials are able to sense changes in their environment and then respond to these changes in predetermined manners-traits that are also found in living organisms. In addition, this smart concept is being extended to rather sophisticated systems that consist of both smart and traditional materials. Components of a smart material (or system) include some type of sensor (which detects an input signal) and an actuator (which performs a responsive and adaptive function). Actuators may be called upon to change shape, position, natural frequency, or mechanical characteristics in response to changes in temperature, electric fields, and/or magnetic fields. Four types of materials are commonly used for actuators: shape-memory alloys, piezoelectric ceramics, magnetostrictive materials, and electrorheological/magnetorheological fluids. Shape-memory alloys are metals that, after having been deformed, revert to their original shape when temperature is changed (see the Materials of Importance box following Section 10.9). Piezoelectric ceramics expand and contract in response to an applied electric field (or voltage); conversely, they also generate an electric field when their dimensions are altered. The behavior of magnetostrictive materials is analogous to that of the piezoelectrics, except that they are responsive to magnetic fields. Also, electrorheological and magnetorheological fluids are liquids that experience dramatic changes in viscosity upon the application of electric and magnetic fields, respectively. Materials/devices employed as sensors include optical fibers, piezoelectric materials (including some polymers), and microelectromechanical systems.

1.6.4 Nanomaterials

Nanomaterials are characterized by a size smaller than 100 nm in one, two, or all three dimensions. Accordingly, they can be small particles, very thin fibers (nanotubes), stacks of very thin planes, or bulk materials with nanometer-size grains. These materials, which are currently the subject of much research, have unique properties that are a direct consequence of their small size. They are expected to provide revolutionary innovations, some of which have already been realized.

One new material class that has fascinating properties and tremendous technological promise is the nanomaterials, which may be any one of the four basic types-metals, ceramics, polymers, or composites. However, unlike these other materials, they are not distinguished on the basis of their chemistry but rather their size; the nano prefix denotes that the dimensions of these structural entities are on the order of a nanometer (10^{-9} m) - as a rule, less than 100 nanometers. Prior to the advent of nanomaterials, the general procedure scientists used to understand the chemistry and physics of materials was to begin by studying large and complex structures and then investigate the fundamental building blocks of these structures that are smaller and simpler. This approach is sometimes termed top-down science. However, with the development of scanning probe microscopes, which permit observation of individual atoms and molecules, it has become possible to design and build new structures from their atomic-level constituents, one atom or molecule at a time. This ability to arrange atoms carefully provides opportunities to develop mechanical, electrical, magnetic, and other properties that are not otherwise possible. We call this the bottom-up approach, and the study of the properties of these materials is termed nanotechnology. Some of the physical and chemical characteristics exhibited by matter may experience dramatic changes as particle size approaches atomic dimensions. For example, materials that are opaque in the macroscopic domain may become transparent on the nanoscale; some solids become liquids, chemically stable materials become combustible, and electrical insulators become conductors. Furthermore, properties may depend on size in this nanoscale domain. Some of these effects are quantum mechanical in origin, whereas others are related to surface phenomena-the proportion of atoms located on surface sites of a particle increases dramatically as its size decreases.

1.7 Magnetic Materials

Magnetic materials are used in electric motors, transformers, loudspeakers, cranes, data processing, and in households. Hard magnets must retain their magnetization even in stray magnetic fields, and soft magnets must change their magnetization with the lowest possible resistance. In this chapter we explore the different magnetic materials and the processing that endows them with the desired properties.

New and important applications based on the magnetic properties of materials have come into prominence in the last two decades, supplementing such traditional applications as in the making of an ordinary transformer core. Our understanding of the microstructural factors that influence the magnetic properties is now better than before. The control of microstructure for obtaining the desired magnetic properties is today almost as important as the control necessary for achieving the optimum mechanical properties.

Magnetic materials are necessary for many engineering designs, particularly in the area of electrical engineering. In general there are two main types: soft and hard magnetic materials. Soft magnetic materials are used for applications in which the material must be easily magnetized and demagnetized, such as cores for distribution power transformers, small electronic transformers, and stator and rotor materials for motors and generators. On the other hand, hard magnetic materials are used for applications requiring permanent magnets that do not demagnetize easily, such as the permanent magnets in loudspeakers, telephone receivers, synchronous and brushless motors, and automotive starting motors.

Certain metallic materials possess a permanent magnetic moment in the absence of an external field and manifest very large and permanent magnetizations. These are the characteristics of ferromagnetism, and they are displayed by the transition metals iron, cobalt, nickel, and some rare earth metals such as gadolinium. The metals iron, cobalt, and nickel are the only three elemental metals that, when magnetized at room temperature, can produce a strong magnetic field around themselves. They are said to be **ferromagnetic**.

A soft magnetic material is easily magnetized and demagnetized, whereas a hard magnetic material is difficult to magnetize and demagnetize. In the early days, soft and hard magnetic materials were physically soft and hard, respectively. Today, how- ever, the physical hardness of a magnetic material does not necessarily indicate that it is magnetically soft or hard.

Metallic glasses are a relatively new class of metallic-type materials whose dominant characteristic is a noncrystalline structure, unlike normal metal alloys, which have a crystalline structure. The atoms in normal metals and alloys when cooled from the liquid state arrange themselves into an orderly crystal lattice. Table 16.4 lists the atomic compositions of eight metallic glasses of engineering importance. These materials have important soft magnetic properties and consist essentially of various combinations of ferromagnetic Fe, Co, and Ni with the metalloids B and Si. Applications for these exceptionally soft magnetic materials include low-energy core-loss power trans- formers, magnetic sensors, and recording heads.

Diamagnetism is a very weak form of magnetism that is nonpermanent and persists only while an external field is being applied. It is induced by a change in the orbital motion of electrons due to an applied magnetic field. The magnitude of the induced magnetic moment is extremely small and in a direction opposite to that of the applied field. For some solid materials, each atom possesses a permanent dipole moment by virtue of incomplete cancellation of electron spin and/or orbital magnetic moments. In the absence of an external magnetic field, the orientations of these atomic magnetic moments are random, such that a piece of material possesses no net macroscopic magnetization. These atomic dipoles are free to rotate, and paramagnetism results when they preferentially align, by rotation, with an external field.

1.8 Insulators

Insulators are used for their ability to withstand high voltages without conducting any appreciable current. Porcelain insulators are used in overland power transmission lines; silicon oxide and hafnium oxide are the insulator materials of choice in integrated electronic circuits. Polymer insulators are used in electric cables and machinery. Insulators have a completely filled valence band that is separated from an empty energy band by a gap large enough to prevent the excitation of electrons either by thermal energy or the absorption of visible light. Consequently, they have no mobile charge carriers.

Insulators are group of solids which have an energy gap of 3 eV or more. The large magnitude of the energy gap in an ideal insulator precludes the possibility of electrons being excited from the valence band to the conduction band by thermal means, much less so by an externally applied electric field. Insulators are therefore very poor conductors of electricity. Insulators are known as **dielectrics**. Dielectric materials find extensive use in the electrical industry for insulation purposes and as capacitors. In a dielectric, the charge displacement increases with increasing field strength. Beyond a critical value of the field strength, there is an electric **breakdown** due to the physical deterioration of the material. The dielectric strength is defined as the breakdown voltage per unit thickness of the material.

Common electrical insulating materials such as polyethylene, bakelite, lucite, mica, PVC, rubber and porcelain fall in this category. The resistivity range for this category extends from 10^4 to beyond 10^{17} ohm m.

Electrical insulators such as polyethylene and polystyrene have very low electrical conductivities, about $10^{-14}(\Omega m)^{-1}$, which are about 10^{20} times less than those of the highly conductive metals.

Many types of ceramics are used for electrical insulators for low- and high-voltage electric currents. Ceramic materials also find application in various types of capacitors, especially where miniaturization is required. Other types of ceramics called piezoelectrics can convert weak pressure signals into electrical signals, and vice versa.

Ceramic materials have electrical and mechanical properties that make them especially suitable for many insulator applications in the electrical and electronic industries. The ionic and covalent bonding in ceramic materials restricts electron and ion mobility and thus makes these materials good electrical insulators.

1.9 Superconducting Materials

The electrical resistivity of a normal metal such as copper decreases steadily as the temperature is decreased and reaches a low residual value near 0 K. In contrast, the electrical resistivity of pure mercury as the temperature decreases drops suddenly at 4.2 K to an immeasurably small value. This phenomenon is called superconductivity, and the material that shows this behavior is called a superconduc- tive material. About 26 metals are superconductive as are hundreds of alloys and compounds.

The temperature below which a material's electrical resistivity approaches zero is called the **critical temperature** T_c . Above this temperature, the material is called normal, and below T_c it is said to be superconducting or superconductive. Besides temperature, the superconducting state also depends on many other variables, the most important of which are the magnetic field B and current density J. Thus, for a material to be superconducting, the material's critical temperature, magnetic field, and current density must not be exceeded, and for each superconducting material there exists a critical surface in T, B, J space.

Niobium, Nb (9.15 K), Vanadium, V (5.30 K), Tantalum, Ta (4.48 K), Titanium, Ti (0.39 K), Tin (3.72 K) etc are some metals which becomes superconductors below the temperatures mentioned in the brackets. Some intermetallic and ceramic compound superconductors have critical temperatures of tens of Kelvin.

If a sufficiently strong magnetic field is applied to a superconductor at any temperature below its critical temperature , the superconductor will return to the normal state. The applied magnetic field necessary to restore normal electrical conductivity in the superconductor is called the **critical field** H_c.

Most commonly used superconductors are niobium-zirconium (Nb-Zr) and niobium-titanium (Nb-Ti) alloys and the niobium-tin intermetallic compound Nb_3Sn. Recently, a family of ceramic materials that are normally electrically insulative have been found to be superconductors with inordinately high critical temperatures.

The phenomenon of superconductivity has many important practical implications. Superconducting magnets capable of generating high fields with low power consumption are being used in scientific test and research equipment. In addition, they are also used for magnetic resonance imaging (MRI) in the medical field as a diagnostic tool. Abnormalities in body tissues and organs can be detected on the basis of the production of cross-sectional images. Chemical analysis of body tissues is also possible using magnetic resonance spectroscopy (MRS). Numerous other potential applications of superconduct- ing materials also exist. Some of the areas being explored include (1) electrical power transmission through superconducting materials—power losses would be extremely low, and the equipment would operate at low voltage levels; (2) magnets for high-energy par- ticle accelerators; (3) higher-speed switching and signal transmission for computers; and (4) high-speed magnetically levitated trains, for which the levitation results from magnetic field repulsion. The chief deterrent to the widespread application of these superconducting materials is the difficulty in attaining and maintaining extremely low temperatures. It can be hoped that this problem will be overcome with the development of the new generation of superconductors with reasonably high critical temperatures.

On the basis of magnetic response, superconducting materials may be divided into two classifications, type I and type II. Type I materials, while in the superconducting state, are completely diamagnetic—that is, all of an applied magnetic field is excluded from the body of material, a phenomenon known as the Meissner effect. Type II superconductors are completely diamagnetic at low applied fields, and field exclusion is total. However, the transition from the superconducting state to the normal state is gradual and occurs between lower critical and upper critical fields. Type II superconductors are preferred over type I for most practical applications by virtue of their higher critical temperatures and critical magnetic fields.

The superconducting effect has been explained in the Bardeen-Cooper-Schreiffer (BCS) theory as a three-way interaction between two electrons and a phonon.

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Questions

1. What is materials science ?
2. Classify materials according to their structure
3. Classify materials according to their function
4. Write a short note on metals
5. Write a short note on alloys
6. What are ceramics ? What are their general properties ?
7. What is meant by super conductivity ?
8. Sate why plastic is light weight
9. What are polymers ? Give examples
10. What are magnetic materials ? What is ferro-magnetism ?
11. What are composites ? Give examples for applications of composites
12. What are nanomaterials ? Explain their importance
13. Write a short note on smart materials ?
14. Taking aircraft as an examples, discuss any five types of materials used in it
15. Discuss the electrical conductivity of metals, ceramics and semiconductors
16. What are semiconductors ? Why are they called so ?
17. Give examples for super alloys

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