Properties of Solids.

Some of the properties of solids which are useful in electronic and magnetic devices such as, transistor, computers, and telephones etc., are summarizedbelow:

(1) Electrical properties: Solids are classified into following classes depending on the extent of conducting nature.

(i) Conductors: The solids which allow the electric current to pass through them are called conductors. These are further of two types; Metallic conductors and electrolytic conductors. In the metallic conductors the current is carries by the mobile electrons without any chemical change occurring in the matter. In the electrolytic conductor like NaCl, KCl, etc., the current is carried only in molten state or in aqueous solution. This is because of the movement of free ions. The electrical conductivity of these solids is high in the range $10^4 - 10^6\, ohm^{-1} cm^{-1}$. Their conductance decrease with increase in temperature.

(ii) Insulators: The solids which do not allow the current to pass through them are called insulators. e.g., rubber, wood and plastic etc. the electrical conductivity of these solids is very low i.e., $10^{-12} - 10^{-22}\, ohm^{-1} cm^{-1}$.

(iii) Semiconductors: The solids whose electrical conductivity lies between those of conductors and insulators are called semiconductors. The conductivity of these solid is due to the presence of impurities. E.g. Silicon and Germanium. Their conductance increase with increase in temperature. The electrical conductivity of these solids is increased by adding impurity. This is called Doping. When silicon is doped with P (or as, group 15 elements), we get n-type semiconductor. This is because P has five valence electrons. It forms 4 covalent bonds with silicon and the fifth electron remains free and is loosely bound. This give rise to n-type semiconductor because current is carried by electrons when silicon is doped with Ga (or in in/Al, group 13 elements) we get p-type semiconductors.

Conductivity of the solids may be due to the movement of electrons, holes or ions.

Due to presence of vacancies and other defects, solids show slight conductivity which increases with temperature.

Metals show electronic conductivity.

The conductivity of semiconductors and insulators is mainly governed by impurities and defects.

Metal oxides and sulphide have metallic to insulator behavior at different temperatures.

Conductivity

Insulator like	Insulator – to –metal	Metal like
FeO, Fe_2O_3	Ti_2O_3	TiO
MnO, MnO_2	V_2O_3	VO
Cr_2O_3	VO_2	CrO2
CoO		ReO3
NiO		
CuO		
V2O5		

(2) Superconductivity: When any material loses its resistance for electric current, then it is called superconductor, Kammerlingh Onnes (1913) observed this phenomenon at 4K in mercury. The materials offering no resistance to the flow of current at very low temperature (2-5 K) are called superconducting materials and phenomenon is called superconductivity. e.g., Nb_3 Ge alloy (Before 1986), $La_{1.25}Ba_{0.15}CuO_4$ (1986), $YBa_2Cu_3O_7$ (1987) – super conductive at a temperature up to 92 K.

Applications

(a) Electronics, (b) Building super magnets,

(c) Aviation transportation, (d) Power transmission

“The temperature at which a material enters the superconducting state is called the superconducting transition temperature, (T_c)”. Superconductivity was also observed in lead (Pb) at 7.2 K and in tin (Sn) at 3.7K. The phenomenon of superconductivity has also been observed in other materials such as polymers and organic crystals. Examples are

(SN) x, polythiazyl, the subscript x indicates a large number of variable size.

(TMTSF)2PF6, where TMTSF is tetra methyl tetra selena fulvalene.

(3) Magnetic properties: Based on the behavior of substances when placed in the magnetic field, there are classified into five classes.

Magnetic properties of solids

Properties	Description	Alignment of Magnetic Dipoles	Examples	Applications
Diamagnetic ↑↓ ↑↓ ↑↓	Feebly repelled by the magnetic fields. Non-metallic elements (excepts O2, S) inert gases and species with paired electrons are diamagnetic	All paired electrons	TiO2, V2O5, NaCl, C6H6 (benzene)	Insulator
Paramagnetic ↑↓ ↑ ↑	Attracted by the magnetic field due to the presence of permanent magnetic dipoles (unpaired electrons). In magnetic field, these tend to orient themselves parallel to the direction of the field and thus, produce magnetism in the substances.	At least one unpaired electron	$O_2, Cu^{2+}, Fe^{3+}, TiO,$ Ti_2O_3, VO, VO_2, CuO	Electronic appliances
Ferromagnetic ↑ ↑ ↑ ↑ ↑	Permanent magnetism even in the absence of magnetic field, Above a temperature called Curie temperature, there is no ferromagnetism.	Dipoles are aligned in the same direction	Fe, Ni, Co, CrO2	CrO2 is used in audio and video tapes
Antiferromagnetic ↑ ↓ ↑ ↓ ↑ ↓	This arises when the dipole alignment is zero due to equal and opposite alignment.		MnO, MnO2, Mn2O, FeO, Fe2O3; NiO, Cr2O3, CoO, Co3O4,	–
↑ ↓ ↓ ↓ ↑ ↓	This arises when there is net dipole moment		Fe3O4, ferrites	–

(4) Dielectric properties: When a non-conducting material is placed in an electrical field, the electrons and the nuclei in the atom or molecule of that material are pulled in the opposite directions, and negative and positive charges are separated and dipoles are generated, in an electric field:

(i) These dipoles may align themselves in the same direction, so that there is net dipole moment in the crystal.

(ii) These dipoles may align themselves in such a manner that the net dipole moment in the crystal is zero.

Based on these facts, dielectric properties of crystals are summarized in table:

Dielectric properties of solids

Property	Description	Alignment of electric dipoles	Examples	Applications
Piezoelectricity ↑ ↑ ↑ ↑ ↑ ↑ ↓ ↑ ↓ ↑ ↓	When polar crystal is subjected to a mechanical stress, electricity is produced a case of piezoelectricity. Reversely if electric field is applied mechanical stress developed. Piezoelectric crystal acts as a mechanical electrical transducer. Piezoelectric crystals with permanent dipoles are said to have Ferro electricity Piezoelectric crystals with zero dipole are said to have antiferroelectricity	–	Quartz, Rochelle salt BaTiO3, KH2PO4, PbZrO3	Record players, capacitors, transistors, computer etc.
Pyroelectricity	Small electric current is produced due to heating of some of polar crystals – a case of pyroelectricity	–		Infrared detectors

Important Tips

Doping: Addition of small amount of foreign impurity in the host crystal is termed as doping. It increases the electrical conductivity.

Ferromagnetic property decreases from iron to nickel $(Fe > Co > Ni)$ because of decrease in the number of unpaired electrons.

Electrical conductivity of semiconductors and electrolytic conductors increases with increase in temperature, whereas electrical conductivity of super conductors and metallic conductors decreases with increase in temperature.