Electronic Properties and Band Theory

*INTRODUCTION

* Metals have long ben known to man for their ability to conduct electricity, following the discovery of semiconductors and transistors in 1948 by Bardeen, Schockley and Brattain.
* The main difference between metals, semiconductors and insulators is in the magnitude of their conductivity.
* Metals conduct electricity very easily, $\sigma \approx 10^4$ to 10^6 ohm^{-1} cm^{-1}, insulators very poorly, or not at all, $\sigma \leq 10^{-15}$ ohm^{-1} cm^{-1} and semiconductors lies in between, $\sigma \approx 10^{-5}$ to 10^3 ohm^{-1} cm^{-1}.
* The boundaries between the three stes of values are somewhat arbitrary and a certain amount of overlap occurs.

* The conductivity of most semiconductors/insulators increases rapidly with increasing temperature, whereas that of metals shows a slight but gradual decrease.
* The conductivity, C, is given by the equation

$$C = neu$$

where n is the number, e is the charge and u is the mobility of the charge carriers.

Different behaviour of metals, semiconductors and insulators

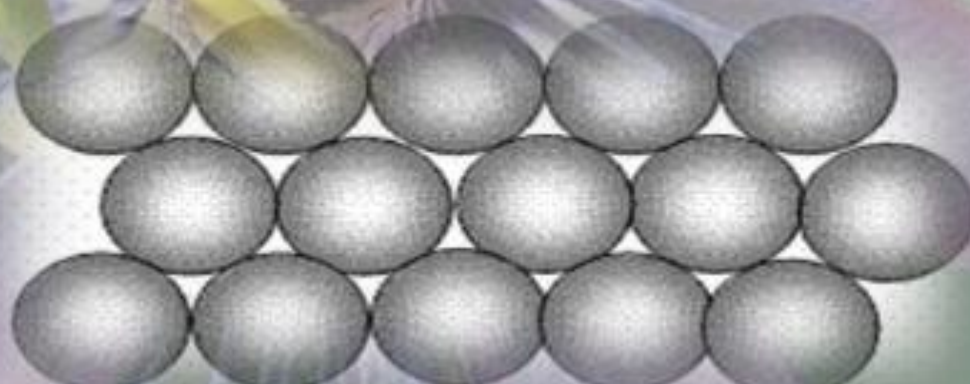
a.) For metals, n is large and essentially remains unchanged with temperature. The only variable in C is u and since u decreases slightly with temperature, C also decreases.

b.) For semiconductors and insulators, n usually increases exponentially with temperature. The effect of this dramatic increase in n outweighs the effect of the small decrease in u. Hence, C increases rapidly with temperature.

ELECTRONIC STRUCTURE OF SOLIDS- BAND THEORY

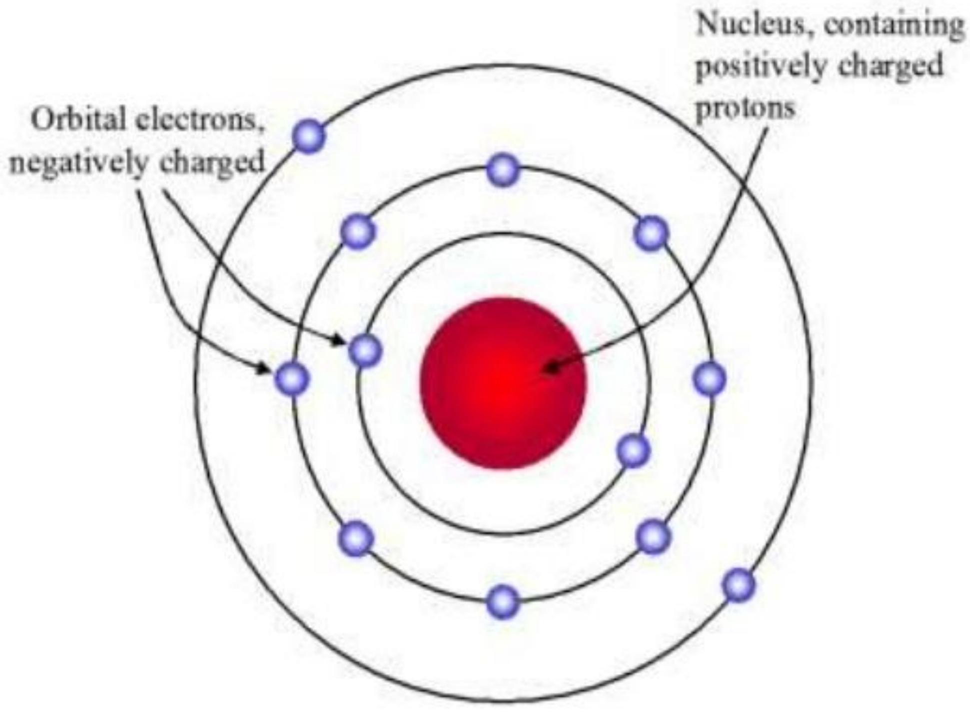
In solids , the atoms are arranged in a systematic space lattice and each atom is influenced by neighbouring atoms.

The closeness of atoms results in the intermixing of electrons of neighbourring atoms.



❑ Energy Band Structure of Solids Conductor, Semiconductor and Insulator

- In isolated atoms the electrons are arranged in energy levels.



❑ Energy Band in Solid

The following are the important energy band in solids:

- ➢ Valence band
- ➢ Conduction band
- ➢ Forbidden energy gap or Forbidden band

❖ Valence band

The band of energy occupied by the valence electrons is called valence band. The electrons in the outermost orbit of an atom are known as valence electrons. This band may be completely or partially filled.

Electron can be move from one valence band to the conduction band by the application of external energy.

❖ Conduction band

The band of energy occupied by the conduction electrons is called conduction band. This is the uppermost band and all electrons in the conduction band are free electrons.

The conduction band is empty for insulator and partially filled for conductors.

❖ Forbidden Energy Gap or Forbidden band

The gap between the valance band and conduction band on energy level diagram known as **forbidden band or energy gap**.

Electron are never found in the gap. Electrons may jump from back and forth from the bottom of valance band to the top of the conduction band. But they never come to rest in the forbidden band.

Conductors

There is no forbidden gap and the conduction band and valence band are overlapping each other between and hence electrons are free to move about. Examples are Ag, Cu, Fe, Al, Pb ….

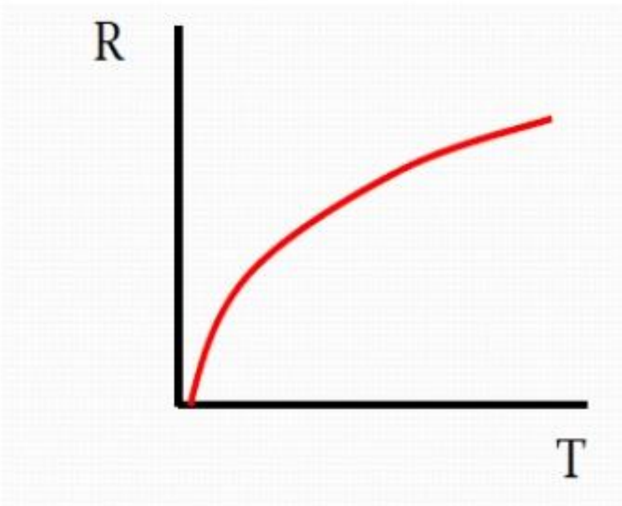
- Conductor are highly electrical conductivity.
- So, in general electrical resistivity of conductor is very low and it is of the order of 10^{-6} Ω cm.
- Due to the absence of the forbidden gap, there is no structure for holes.
- The total current in conductor is simply a flow of electrons.
- For conductors, the energy gap is of the order of 0.01 eV.

Semiconductors

Semiconductors are materials whose electrical resistivity lies between insulator and conductor. Examples are silicon (Si), germanium (Ge) ....

- The resistivity of semiconductors lie between $10^{-4}\ \Omega$ cm to $10^{3}\ \Omega$ cm at room temperature.
- At low temperature, the valence band is all most full and conduction band is almost empty. The forbidden gap is very small equal to 1 eV.
- Semiconductor behaves like an insulator at low temperature. The most commonly used semiconductor is silicon and its band gap is 1.21 eV and germanium band gap is 0.785 eV.

When a conductor is heated its resistance increases; The atoms vibrate more and the electrons find it more difficult to move through the conductor but, in a semiconductor the resistance decreases with an increase in temperature. Electrons can be excited up to the conduction band and Conductivity increases.

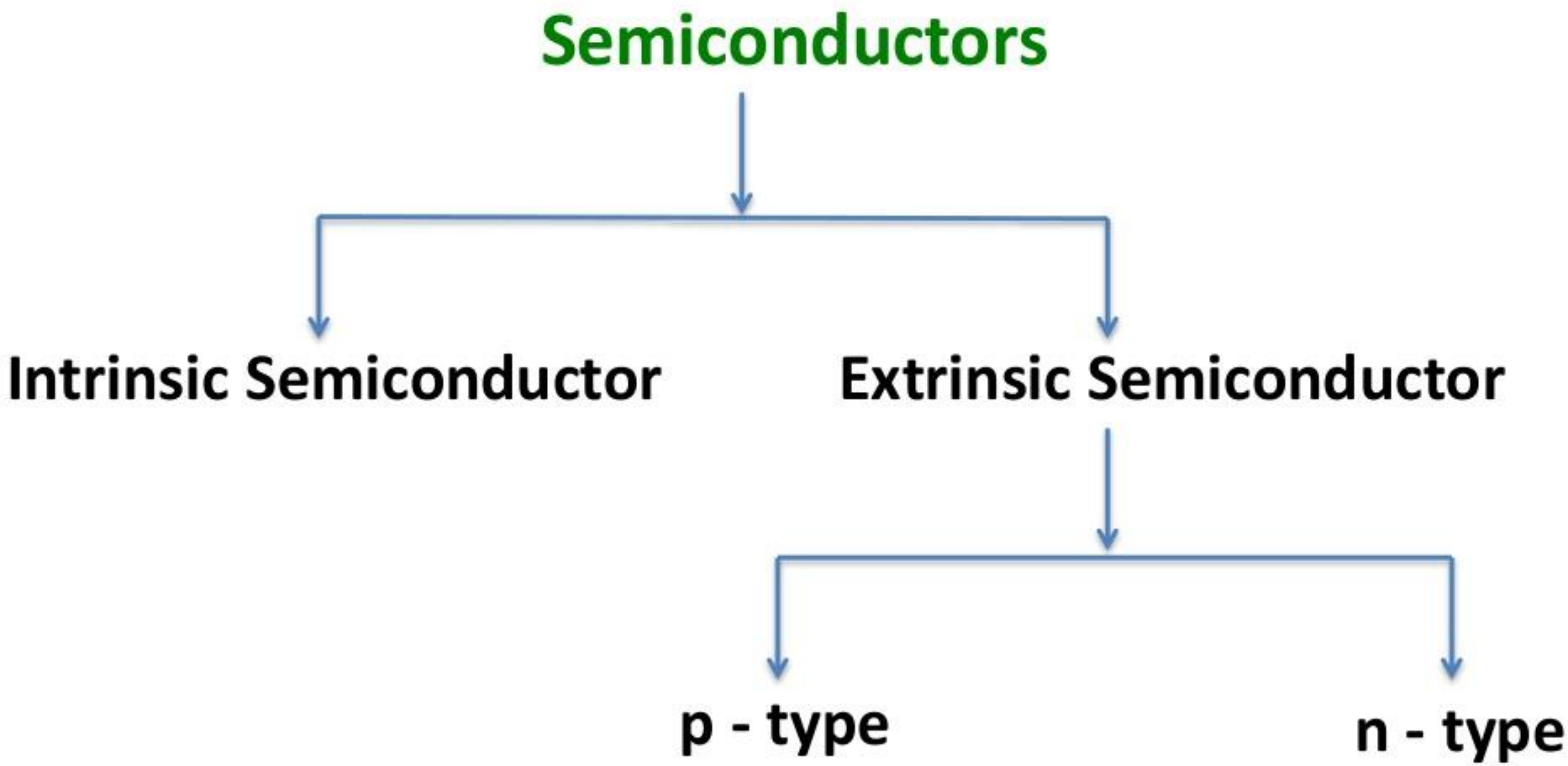


Insulators

In insulator, the valence band is full but the conduction band is totally empty. So, free electrons from conduction band is not available.

- In insulator the energy gap between the valence and conduction band is very large and its approximately equal to 5 eV or more.
- Hence electrons cannot jump from valence band to the conduction band. So, a very high energy is required to push the electrons to the conduction band.
- The electrical conductivity is extremely small.
- The resistivity of insulator lie between 10^3 to 10^{17} Ωm, at the room temperature
- Examples are plastics, paper .....

❑ Types of semiconductors



❖ Intrinsic Semiconductor

- The intrinsic semiconductor are pure semiconductor materials.
- These semiconductors posses poor conductivity.
- The elemental and compound semiconductor can be intrinsic type.
- The energy gap in semiconductor is very small.
- So even at the room temperature, some of electrons from valance band can jump to the conduction band by thermal energy.
- The jump of electron in conduction band adds one conduction electron in conduction band and creates a hole in the valence band. The process is called as “generation of an electron–hole pair”.
- In pure semiconductor the no. of electrons in conduction band and holes in holes in valence bands are equal.

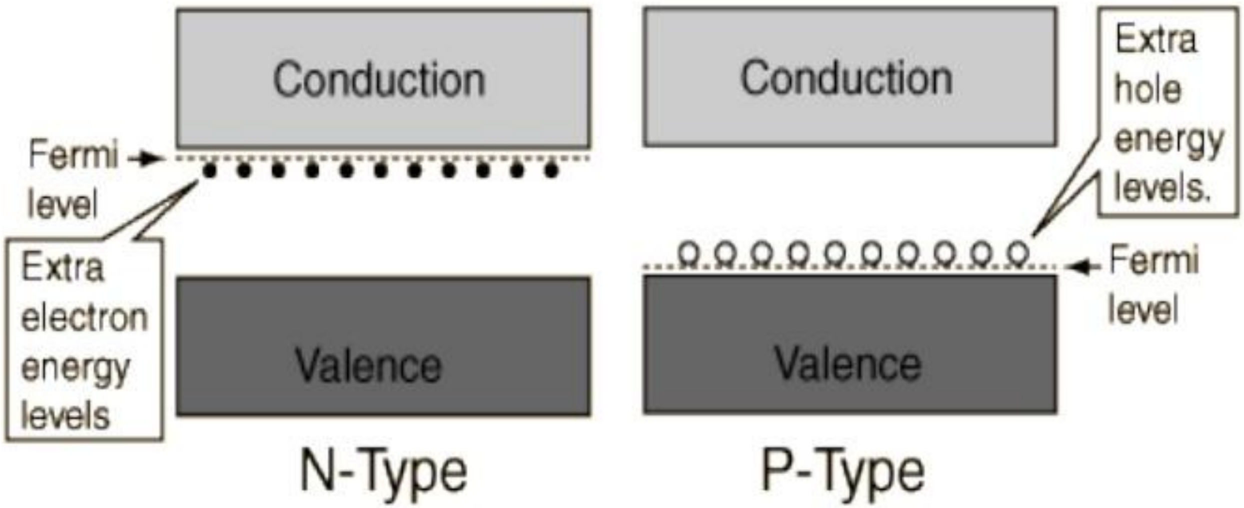
❖ Extrinsic Semiconductor

- Extrinsic semiconductor is an impure semiconductor formed from an intrinsic semiconductor by adding a small quantity of impurity atoms called dopants.
- The process of adding impurities to the semiconductor crystal is known as doping.
- This added impurity is very small of the order of one atom per million atoms of pure semiconductor.
- Depending upon the type of impurity added the extrinsic semiconductors are classified as:

  (1) p – type semiconductor

  (2) n – type semiconductor

The application of band theory to n-type and p-type semiconductors shows that extra levels have been added by the impurities.

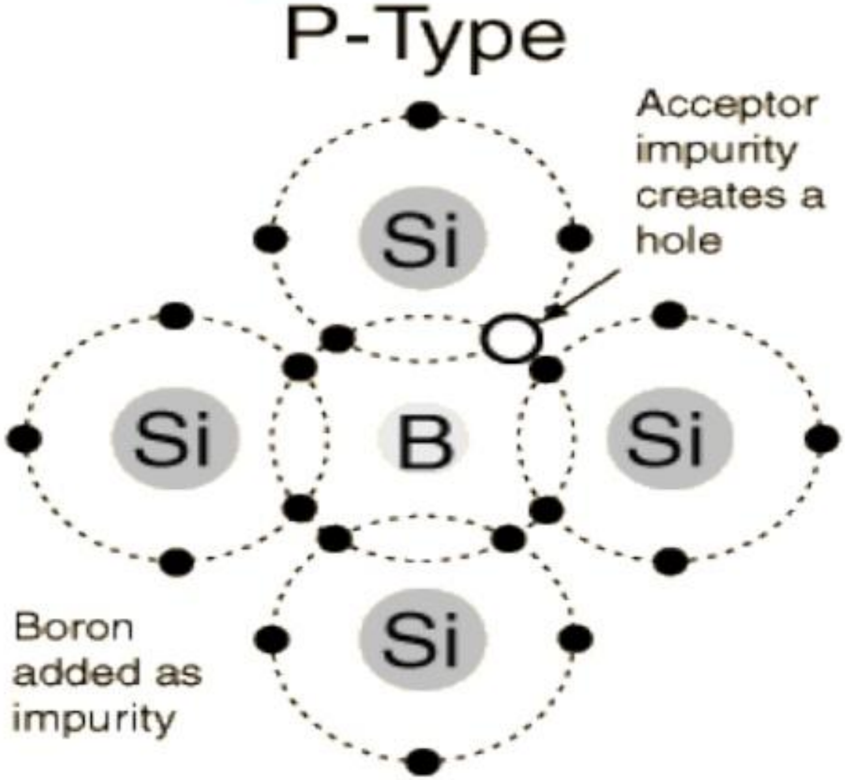


In n-type material there are electron energy levels near the top of the band gap so that they can be easily excited into the conduction band.

In p-type material, extra holes in the band gap allow excitation of valence band electrons, leaving mobile holes in the valence band.

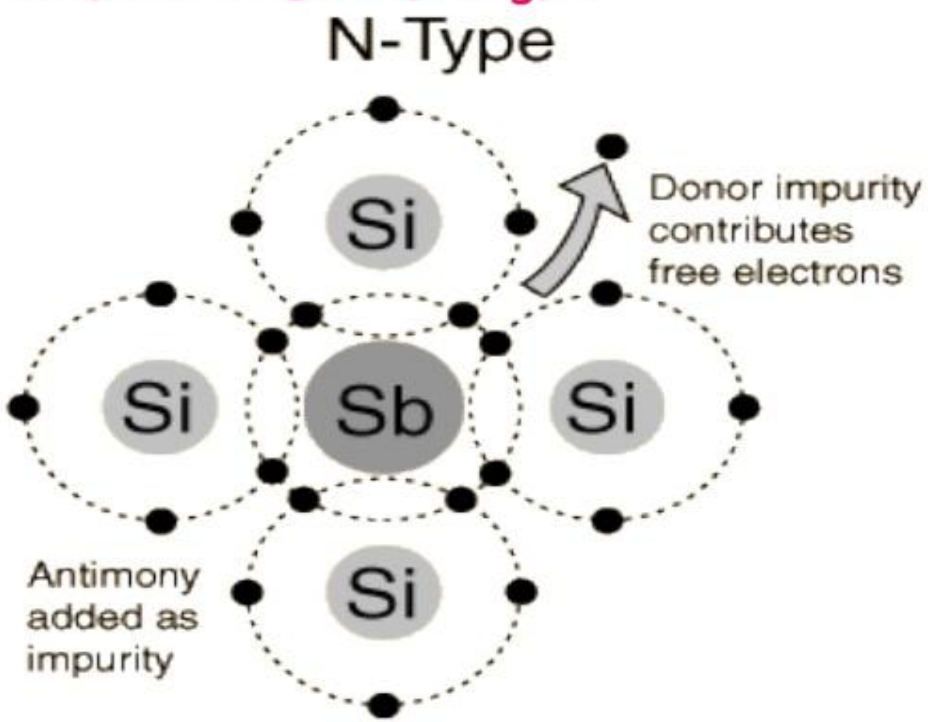
p – type semiconductor

The addition of trivalent impurities such as boron, aluminum or gallium to an intrinsic semiconductor creates deficiencies of valence electrons,called "holes". It is typical to use B_2H_6 diborane gas to diffuse boron into the silicon material.



n – type semiconductor

The addition of pentavalent impurities such as antimony, arsenic or phosphorous contributes free electrons, greatly increasing the conductivity of the intrinsic semiconductor. Phosphorous may be added by diffusion of phosphine gas (PH_3).



MAGNETIC PROPERTIES

Introduction

- **Magnetic Materials** are those materials in which a state of magnetization can be induced. In other words, The materials which can be magnetized are known as Magnetic Materials.

- **Magnetic Moment** is a measure of the strength of a magnet. It is the product of strength of one of the poles and the distance between the two poles of a magnet.

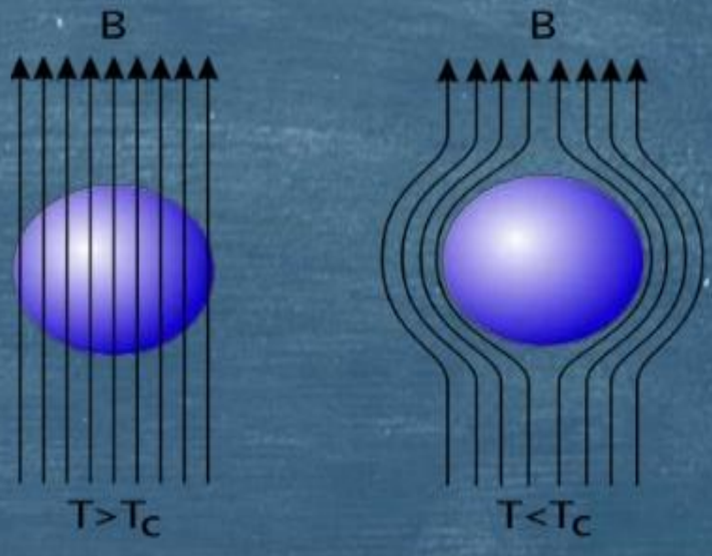
Classification Of Magnetic Material

- Magnetic materials are classified into different categories based on their magnetic parameters. And also on the basis of effect of temperature and magnetic field on the magnetic properties.
- So, all materials are classified broadly into the following three categories
  - Diamagnetic Materials
  - Paramagnetic Materials
  - Ferromagnetic Materials
  - Antiferromagnetic Materials
  - Ferrimagnetic Materials

These are having very close structure to ferromagnetic materials but posses different magnetic effect.

Diamagnetic Materials

- **Diamagnetic** materials create an induced magnetic field in a direction opposite to an externally applied magnetic field.
- They are repelled by the applied magnetic field.
- The permanent dipoles are absent in Diamagnetic materials

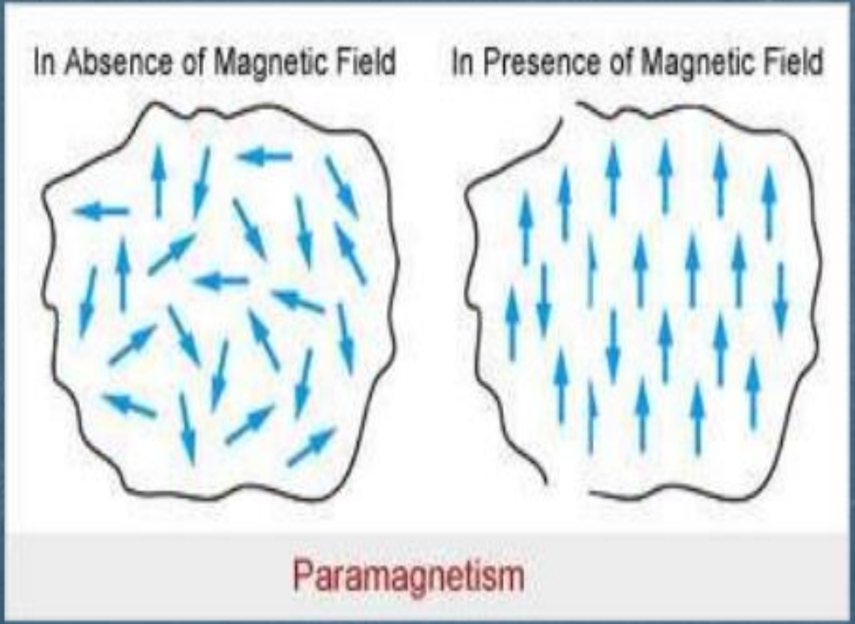


General Properties of Diamagnetic Materials

- Diamagnetic Materials experiences a repelling force when brought near the pole of a strong magnet.
- The magnetic susceptibility χ of these materials is always negative.
- The relative permeability μr is always less than one.
- In the absence of external magnetic field ,The net magnetic dipole moment over each atom or molecule of a diamagnetic material is zero. This is due to pairing of electrons.
- Examples:-Bismuth,Copper,Lead,Zinc etc.

Paramagnetic Material

- Paramagnetic materials exhibit magnetism when the external magnetic field is applied. Paramagnetic materials loose magnetization in the absence of an externally applied magnetic field. These materials are weakly attracted towards magnetic field.

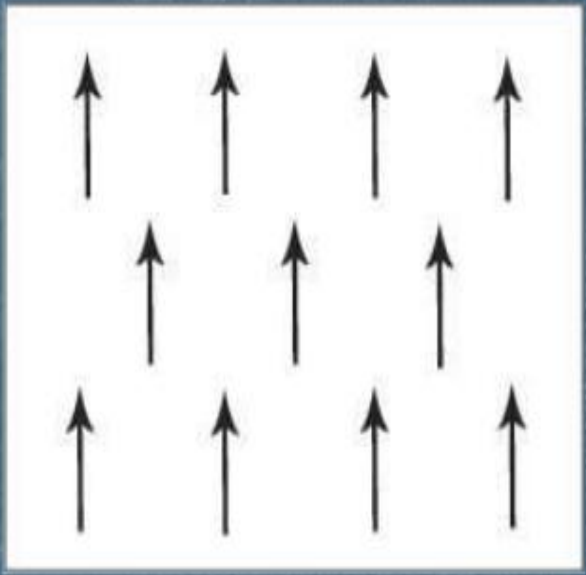


General Properties of Paramagnetic materials

- Paramagnetic materials experiences a feeble attractive force when brought near the pole of a magnet
- These materials possess some permanent dipole moment which arise due to some unpaired electrons.
- The magnetic susceptibility χ is small and +ve.
- Examples:-Platinum,Aluminium,Copper sulphate etc.

Ferromagnetic Material

- It is the phenomenon in which a material gets magnetized to a very large extent in the presence of an external field.
- The direction in which the material gets magnetized is the same as that of the external field.



General Properties of ferromagnetic materials

- Ferromagnetic materials experience a very strong attractive force when brought near the pole of a magnet.
- Permeability is very much greater than one.
- Susceptibility is +ve and high.
- Examples:-Fe,Co,Ni,MnAs etc.

Ferromagnetic Materials

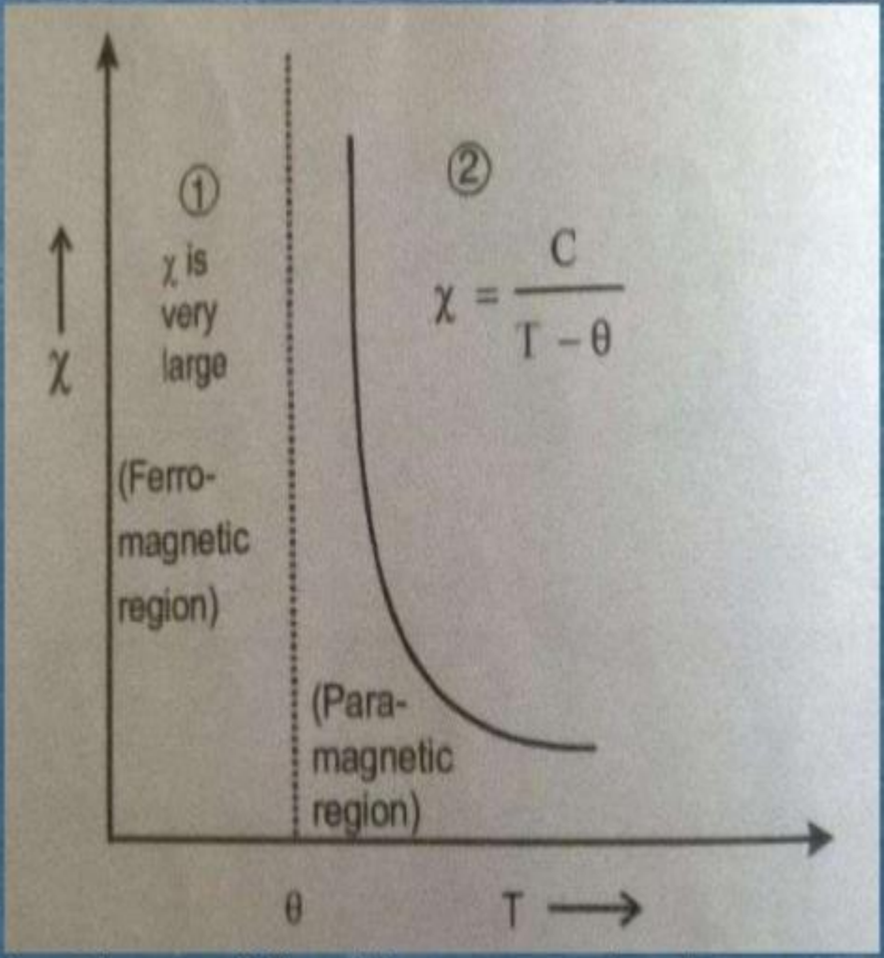
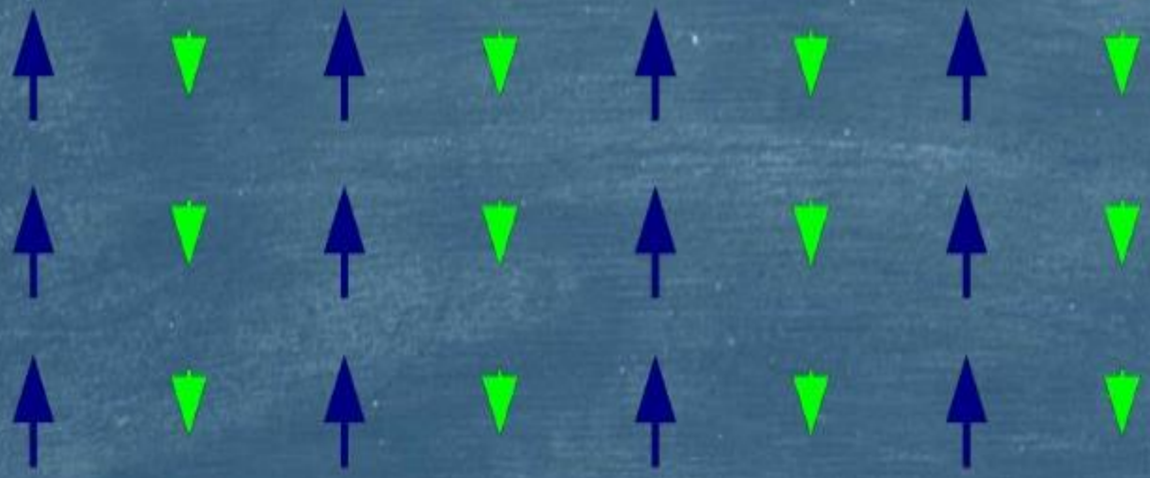


Figure. Variation Of susceptibility with temperature in a ferromagnetic material

Antiferromagnetic Material

- It is refer to a phenomenon in which the magnetic interaction between any two dipoles align themselves anti-parallel to each other.
- Since all dipoles are of equal magnitude , the net magnetization is zero.



General properties of Antiferromagnetic materials

- Like ferromagnetic materials antiferromagnetic materials also possess dipole moment due to spin of the electron.
- The opposite alignment of adjacent dipoles due to an exchange interaction.
- The susceptibility is very small and is +ve.

Antiferromagnetic materials

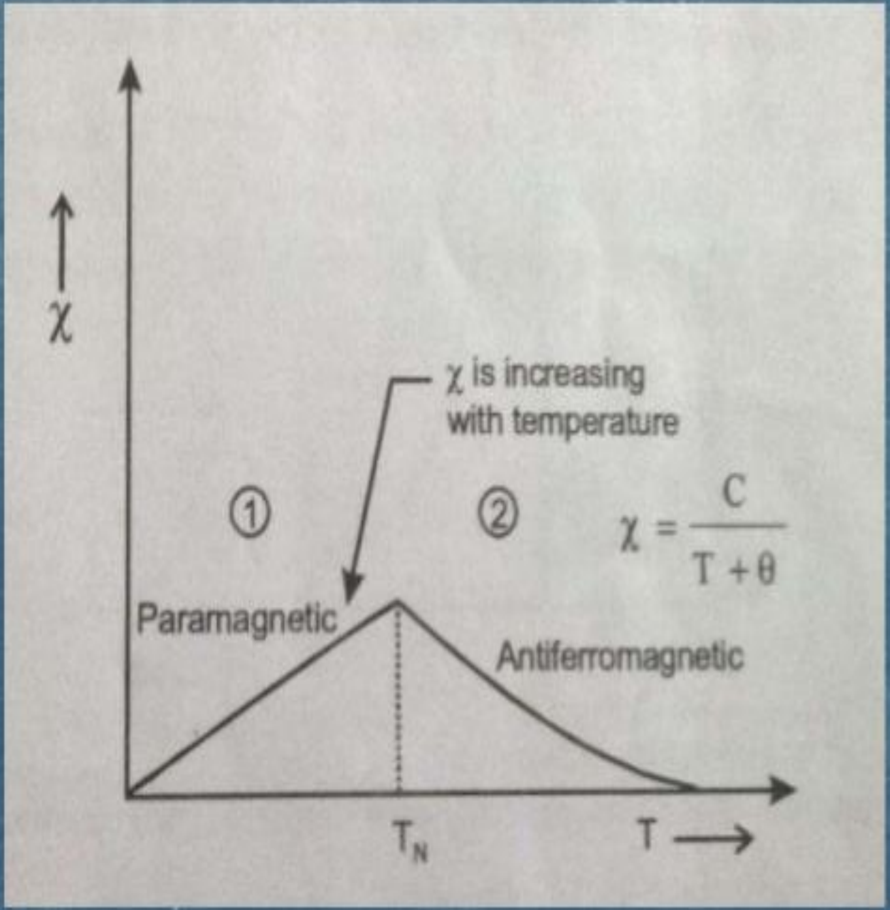


Figure. Variation of the susceptibility with temperature in antiferromagnetic material

Ferrimagnetic Material

- Ferrimagnetism is a phenomenon in which the magnetic interaction between any two dipoles align anti-parallel to each other.
- But since the magnitude of dipoles are not equal.
- The cancellation of magnetic moments become incomplete resulting in a net magnetization in the material.

General properties of Ferrimagnetic materials

- Ferrimagnetic materials possess magnetic dipoles moment due to the spin of the electron.
- A Ferrimagnetic material is composed of more state of different transition elements.
- The susceptibility is very Large and +ve.
- Examples:-Nickel,Ferrite and Ferrous ferrite.

Ferrimagnetic materials

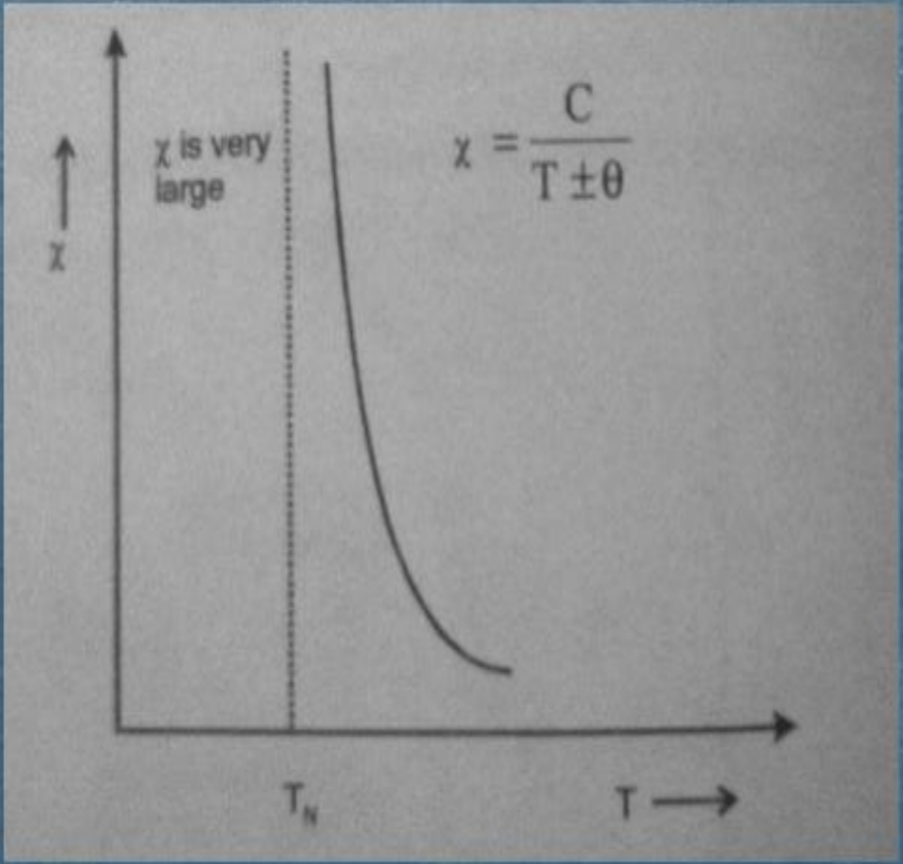
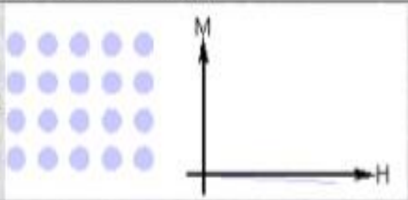
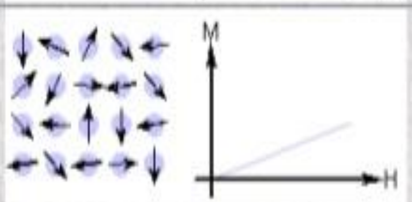
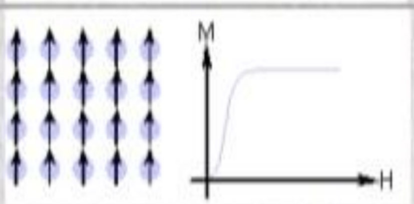
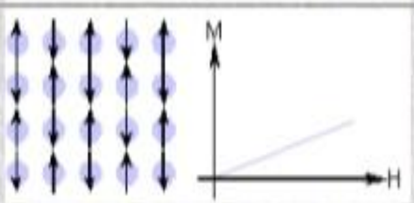
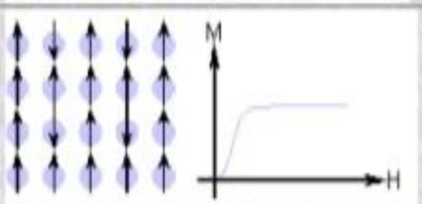


Figure. Variation of susceptibility with temperature in ferrimagnetic materials

Overview

Type of Magnetism	*Susceptibility*	*Atomic / Magnetic Behaviour*		*Example / Susceptibility*	
Diamagnetism	Small & negative.	Atoms have no magnetic moment		Au Cu	-2.74×10^{-6} -0.77×10^{-6}
Paramagnetism	Small & positive.	Atoms have randomly oriented magnetic moments		β-Sn Pt Mn	0.19×10^{-6} 21.04×10^{-6} 66.10×10^{-6}
Ferromagnetism	Large & positive, function of applied field, microstructure dependent.	Atoms have parallel aligned magnetic moments		Fe	~100,000
Antiferromagnetism	Small & positive.	Atoms have mixed parallel and anti-parallel aligned magnetic moments		Cr	3.6×10^{-6}
Ferrimagnetism	Large & positive, function of applied field, microstructure dependent	Atoms have anti-parallel aligned magnetic moments		Ba ferrite	~3

THANKS