Electrical Engineering Materials(3160923)

Teaching and Examination Scheme

Teaching Scheme			Credits	Examination Marks				Total Marks
				Theory Marks		Practical Marks		
L	T	P	C	ESE (E)	PA (M)	ESE (V)	PA (I)	
3	0	0	3	70	30	0	0	100

Syllabus

Sr. No.	Content	Total HRS	% Weightage
01	**Conductors** Classification: High conductivity, high resistivity materials, fundamental requirements of high conductivity materials and high resistivity materials, mobility of electron in metals, factors affecting conductivity and resistivity of electrical material, thermoelectric Effect: Seeback effect, Peltier effect, commonly used high conducting materials: copper, aluminum, bronze brass properties and characteristics, constantan, platinum and nichrome properties, characteristics and applications, material used for AC and DC machines	09	20
02	**Dielectric Materials and Insulators** Properties of gaseous, liquid and solid dielectric, dielectric as a field medium, electric conduction in gaseous, liquid and solid dielectric, breakdown in dielectric materials, mechanical and electrical properties of dielectric materials, effect of temperature on dielectric materials, polarization, loss angle and dielectric loss, petroleum based insulating oils, transformer oil, capacitor oils and its properties, classification of insulation (Solid) and application in AC and DC machines, solid electrical insulating materials, fibrous, paper boards, yarns, cloth tapes, sleeving wood, impregnation, plastics, filling and bounding materials, fibrous, film, mica, rubber, mica based materials, ceramic materials.	09	20

03	**Magnetic Materials** Basic terms, classification of magnetic material: diamagnetic, paramagnetic, ferromagnetic, anti- ferromagnetic and amorphous material, hysteresis loop, magnetic susceptibility. coercive force, curie temperature, magneto-striction, factors affecting permeability and hysteresis loss, common magnetic materials: soft and hard magnetic materials, electric steel, sheet steel, cold rolled grain-oriented silicon steel, hot rolled grain-oriented silicon steel.	08	20
04	**Semi-Conductors and Superconductors** General concepts, energy bands, types of semiconductors: intrinsic Semi-conductors, extrinsic Semi-conductors, compound semiconductor, amorphous semiconductor, hall effect, drift, mobility, diffusion in Semiconductors, semi-conductors and their applications. **Superconductors:** Superconductivity, properties of superconductors, critical field, Meissner effect, type-I and type-II Superconductors.	08	20
05	**Special purpose materials** Nickel iron alloys, high frequency materials, permanent magnet materials, feebly magnetic materials, ageing of a permanent magnet, effect of impurities, Losses in Magnetic materials, Refractory Materials, Structural Materials, Radioactive Materials, Galvanization and Impregnation of materials.	08	20

Text Books:

1. Electrical Engineering Materials: A.J. Dekker, PHI Publication.
2. An Introduction to Electrical Engineering Materials: C. S. Indulkar and S. Thiruvengadam, S. Chand & Co., India.

Reference Books:

1. Material Science for Electrical & Electronics Engineers: Ian P. Hones, Oxford University Press.
2. Electrical Properties of Materials: L. Solymar and D. Walsh, Oxford University Press-New Delhi.
3. A Course in Electrical Engineering Materials: T K Basak, New Age Science Publications.
4. A Course in Electrical Engineering Materials: R K Rajput, Laxmi Publications.
5. A Course in Electrical Engineering Materials: S. P. Seth and P. V. Gupta, Dhanpat Rai & Sons.
6. Electrical and Electronic Engineering Materials: S.K. Bhattacharya, Khanna Publishers, New Delhi.
7. Electrical Engineering Materials: T.T.T.I Chennai, Tata MacGraw Hill.

Ch. 3 **Magnetic Materials**

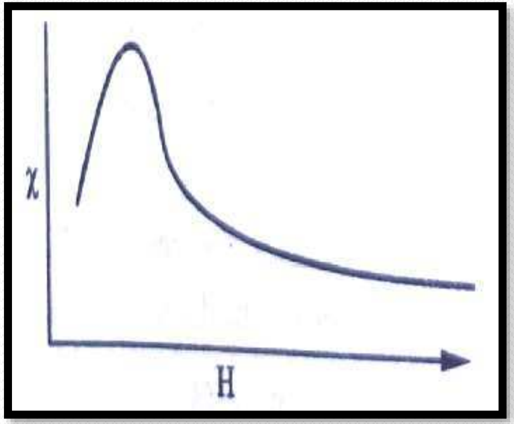
Introduction

- Materials in which a state of magnetisation can be induced are called magnetic materials. When magnetised, such materials create a magnetic field in the surrounding space.
- Magnetic Moment is a measure of the strength of a magnet. The **magnetic moment** is a determination of its tendency to get arranged through a **magnetic** field. As we all know, a **magnet** has two poles, i.e., North and South.
- **Magnetic moment** can be defined as: The **magnetic** strength and orientation of a **magnet** or other object that produces a **magnetic** field. It is the product of strength of one of the poles and the distance between the two poles of a magnet.
- All the molecules of a material contain electrons orbiting around the nucleus. These orbits are therefore equivalent to circulating currents and so develop an m.m.f. Depending on whether any unneutralised orbit exists or not, specimens can be said to be magnetised or unmagnetised. The readiness of a material to accept magnetism is expressed by its permeability.

For most of the materials, magnetic permeability is equal to that of free space μ_o and is constant; but for magnetic materials, the permeability equals μ_o times the relative permeability which is denoted by μr. the relative permeability varies with the degree of magnetisation of the material and may have a value as high as 2500.

$$\chi = \mu_r - 1$$

Where χ is a dimensionless quantity defines as the magnetic susceptibility of the medium.The magnetic susceptibility depends on the nature of the magnetic material and on its state (temperature, etc.). The susceptibility of a material may change on cold working. For example, if copper is cold worked, the susceptibility may change from negative to a positive value, and again on annealing after cold work, the susceptibility may become negative again.



- How do Magnets Work? : https://www.youtube.com/watch?v=MRqQQGO7Xe8

- The susceptibility may be determined by measuring the force exerted on a magnetic material when it is placed in a magnetic field, the susceptibility of a ferromagnetic substance is very strongly dependent on the field strength. Fig. shows curve of Susceptibility versus Field strength (Feromagnetic materials)

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 categories Diamagnetic Materials

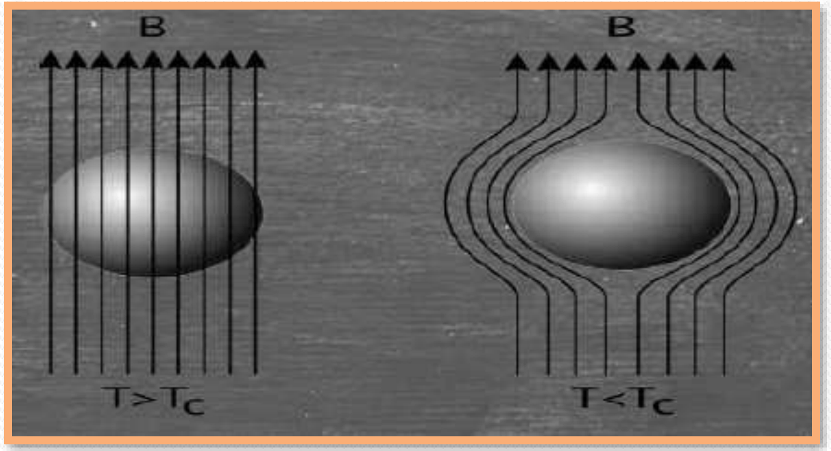
- Diamagnetic Materials
- Paramagnetic Materials
- Ferromagnetic Materials
- Antiferromagnetic Materials
- Ferrimagnetic Materials

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.

- Atoms have no magnetic moment when there is no applied field.
- Under the influence of an applied field (*H*), produces a magnetization (*M*) *in the* opposite direction to that of the applied field.
- They are repelled by the applied magnetic field.
- Antiparallel alignment of the atomic magnetic moment. This accounts for the weak and negative magnetic susceptibility.
- In a diamagnetic material the value of Susceptibility is independent of temperature.
- The permanent dipoles are absent in Diamagnetic materials.



General Properties of Diamagnetic Materials

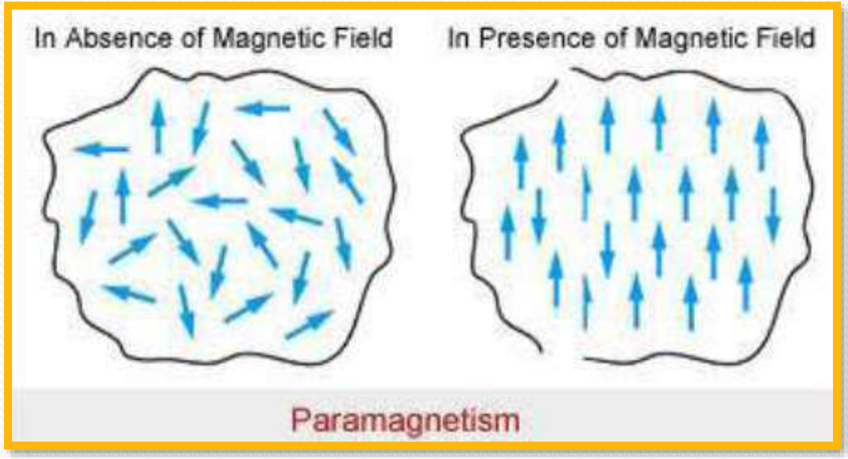
- Diamagnetic Materials experiences a repelling force when brought near the pole of a strong magnet.
- The magnetic susceptibility χ of these materials is always negative.
- The relative permeability μ_r is always less than one.
- In the absence of external magnetic field ,The net magnetic dipole moment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

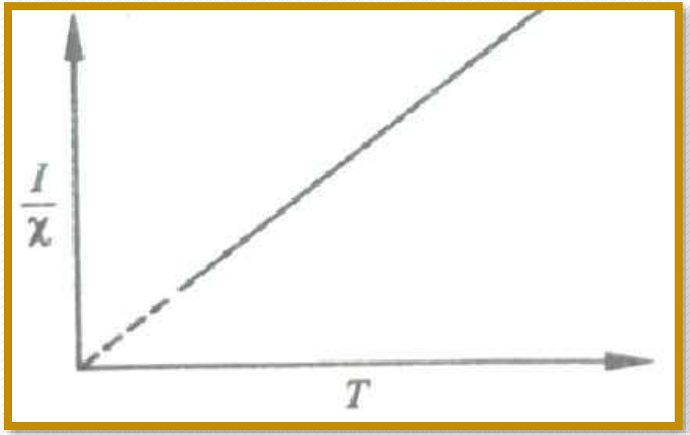
Material	$\chi = \mu_r - 1$	Material	$\chi = \mu_r - 1$
Al_2O_3	-0.5×10^{-5}	Cu	-0.9×10^{-5}
$BaCl_2$	-2.0×10^{-5}	Au	-3.6×10^{-5}
NaCl	-1.2×10^{-5}	Ge	-0.8×10^{-5}
Diamond	-2.1×10^{-5}	Si	-0.3×10^{-5}
Graphite	-12×10^{-5}	Se	-1.7×10^{-5}

Susceptibility of some Diamagnetic material at room temperature

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.





Curie law for paramagnetic material

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.
• The relationship between paramagnetic susceptibility and magnetic moment of an atom is given by

$$\chi = m^2/3KT$$

Where m is the magnetic moment, K is the Boltzmann's constant and T is the absolute temperature.

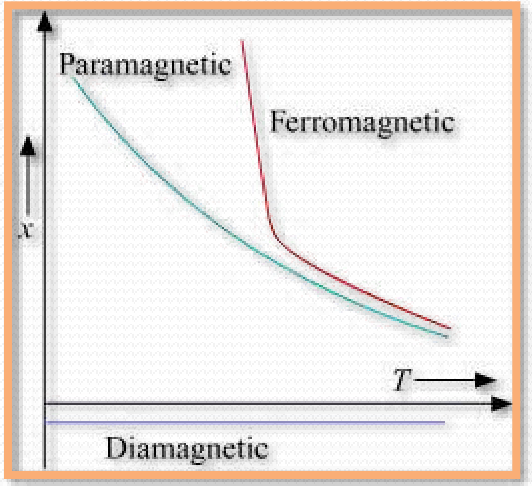
The paramagnetic susceptibility varies inversely with the absolute temperature for ordinary fields

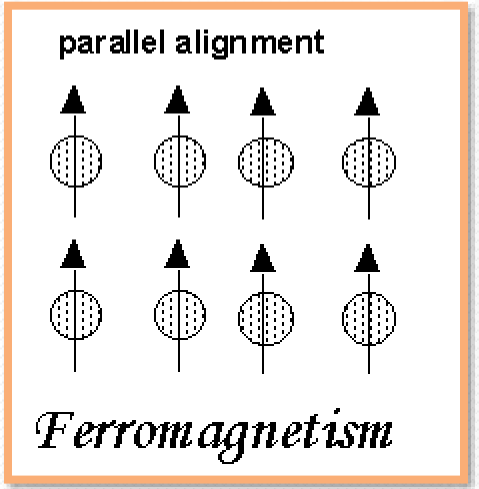
$$\chi = C/T$$

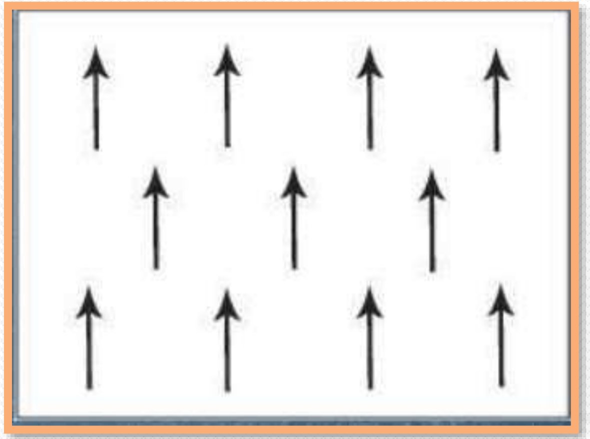
•Examples:-Platinum,Aluminium,Copper sulphate etc.

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.

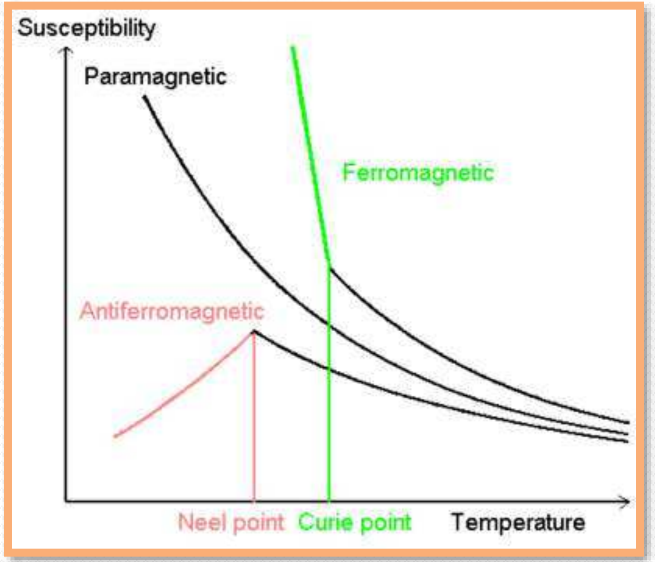


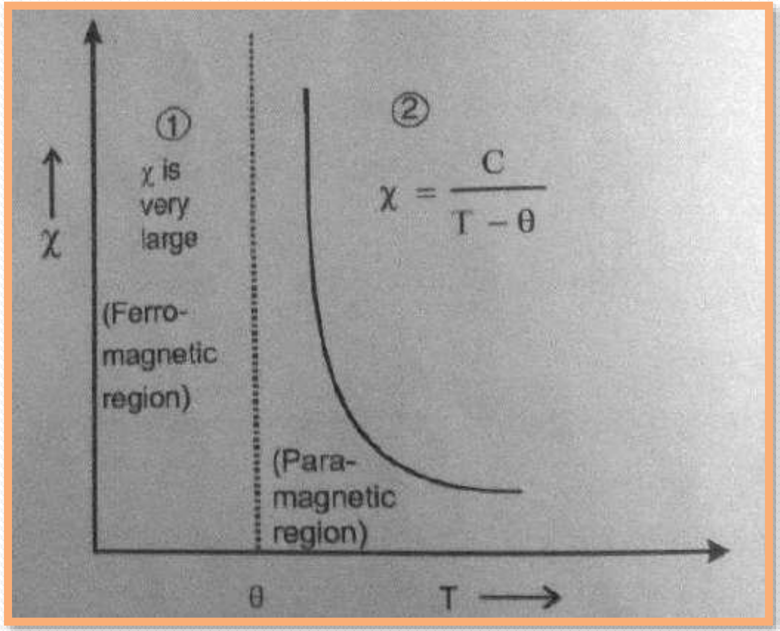




General Properties of ferromagnetic materials

- 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.

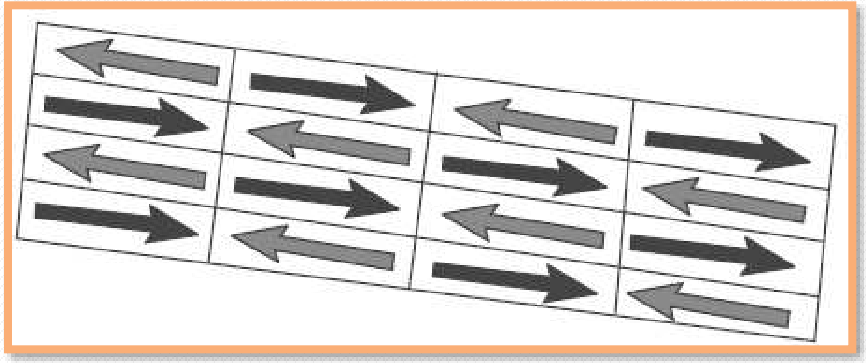




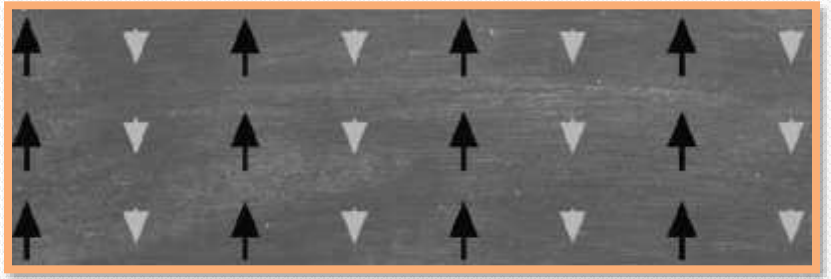
Variation Of susceptibility with temperature in a ferromagnetic material

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.

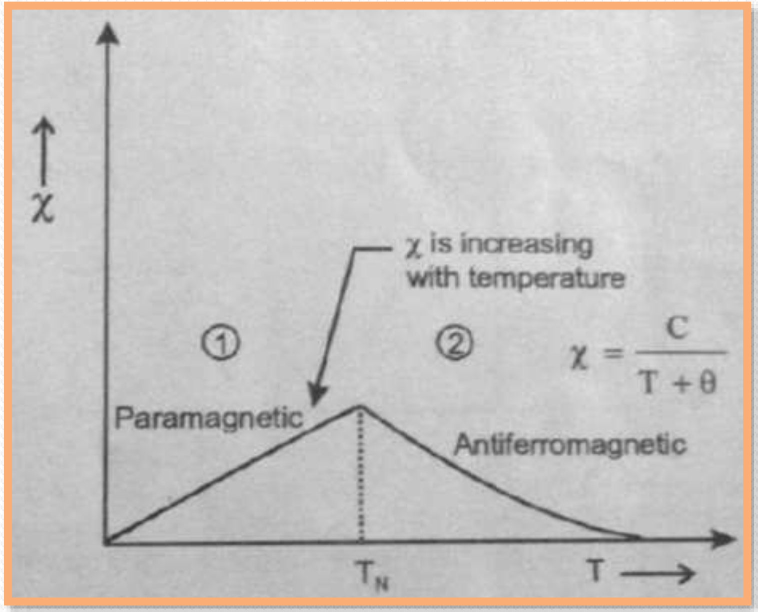


The Alignment of Electrons in Anti-Ferromagnetic Materials



General properties of Antiferromagnetic materials

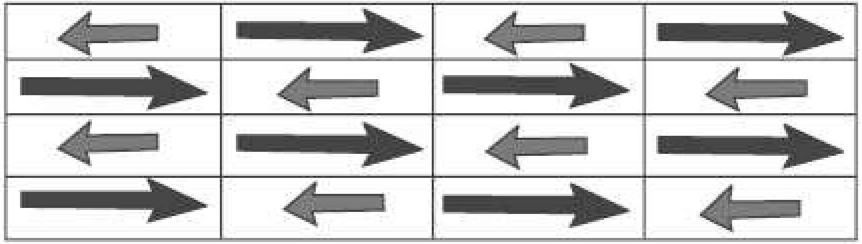
- Like ferromagnetic materials antiferromagnetic materials also possess dipole moment due to spin of the electron.
- The opposite alignment of adjacent dipoles due to an exchange interaction.
- The susceptibility is very small and is +ve.



Variation of the susceptibility with temperature in antiferromagnetic material

Ferrimagnetic Material

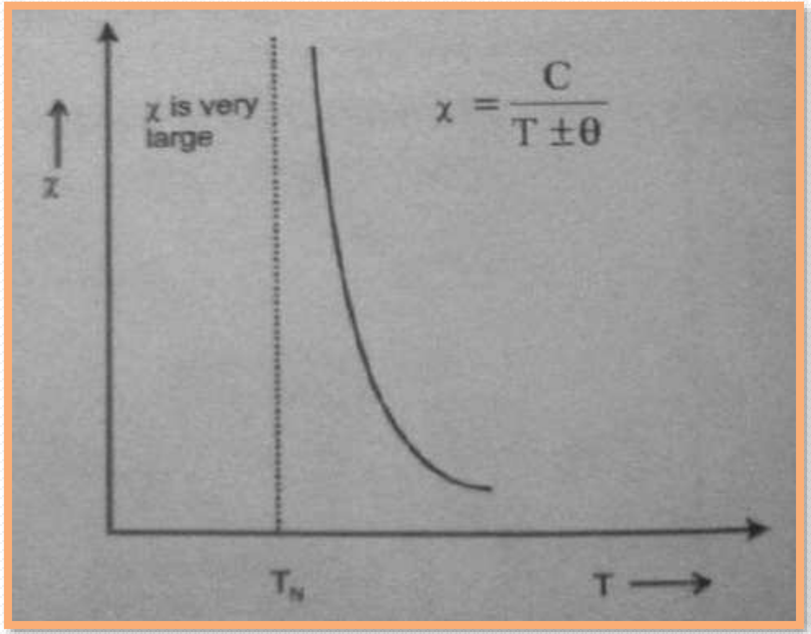
- Ferrimagnetism is a phenomenon in which the magnetic interaction between any two dipoles align anti-parallel to each other.
- But since the magnitude of dipoles are not equal.
- The cancellation of magnetic moments become incomplete resulting in a net magnetization in the material.



The Alignment of Electrons in Ferrimagnetic Materials

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.



Variation of susceptibility with temperature in ferrimagnetic materials

Amorphous material

- An amorphous solid is that in which the constituent particles do not possess a regular three-dimensional arrangement.
- Amorphous solids, lacking the three-dimensional long-range order of a crystalline material, possess a more random arrangement of molecules, exhibit short-range order over a few molecular dimensions, and have physical properties quite different from those of their corresponding crystalline states.
- Amorphous solid resemble liquids in that they do not have an ordered structure, an orderly arrangement of atoms or ions in a three-dimensional structure. These solids do not have a sharp melting point and the solid to liquid transformation occurs over a range of temperatures. The physical properties exhibited by amorphous solids are generally isotropic as the properties do not depend on the direction of measurement and show the same magnitude in different directions.
- Examples of amorphous solids are glasses, ceramics, gels, polymers etc.

General Properties of Amorphous Solids

- Lack of long-range order

Amorphous Solid does not have a long-range order of arrangement of their constituent particles. However, they may possess small regions of orderly arrangement. These crystalline parts of an otherwise amorphous solid are known as crystallites.

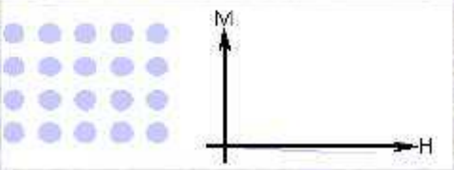
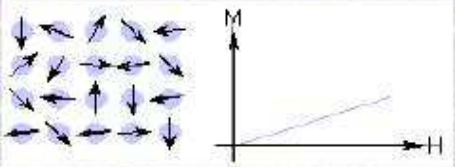
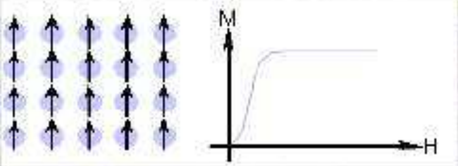
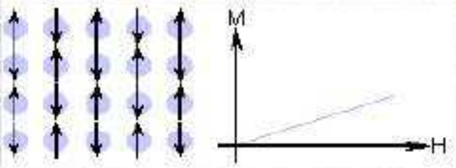
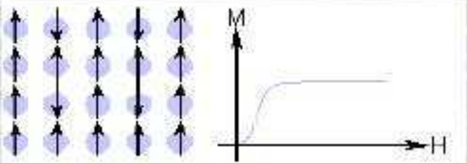
- No sharp melting point

An amorphous solid does not have a sharp melting point but melts over a range of temperatures. For example, glass on heating first softens and then melts over a temperature range. Glass, therefore, can be moulded or blown into various shapes.

- Conversion into crystalline form

Amorphous solid, when heated and then cooled slowly by annealing, becomes crystalline at some temperature. That is why glass objects of ancient time look milky because of some crystallization having taken place.

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

Thank you

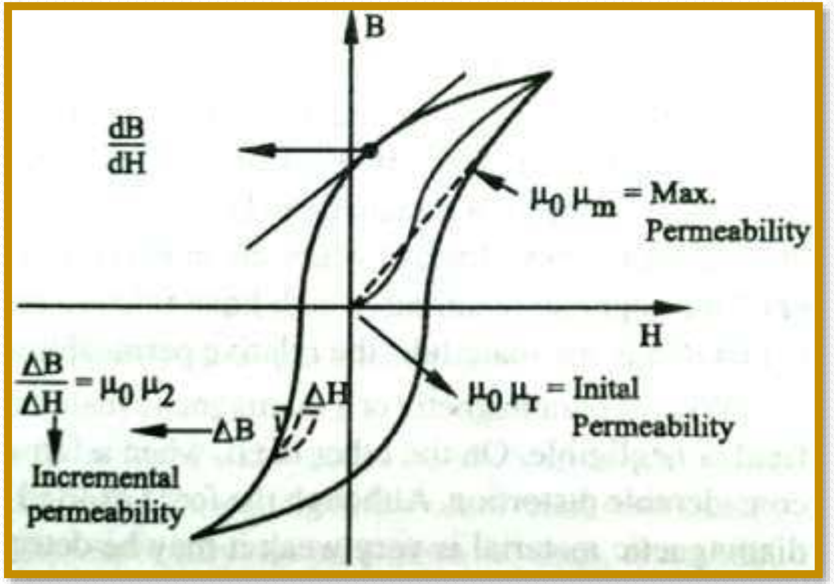
Extra Slides

Magnetic quantity	Symbol	Definition	Units	Comment
Magnetic field; magnetic induction	**B**	$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$	T = tesla = webers m^{-2}	Produced by moving charges or currents and acts on moving charges or currents.
Magnetic flux	Φ	$\Delta\Phi = B_{normal}\Delta A$	Wb = weber	$\Delta\Phi$ is flux through ΔA and B_{normal} is normal to ΔA. Total flux through any closed surface is zero.
Magnetic dipole moment	μ_m	$\mu_m = I A$	A m^2	Experiences a torque in **B** and a net force in a nonuniform **B**.
Bohr magneton	β	$\beta = e\hbar/2m_e$.	A m^2 or J T^{-1}	Magnetic moment due to the spin of the electron. $\beta = 9.27\times10^{-24}$ A m^2
Magnetization vector	**M**	Magnetic moment per unit volume	A m^{-1}	Net magnetic moment in a material per unit volume
Magnetizing field; Magnetic field intensity	**H**	$\mathbf{H} = \mathbf{B}/\mu_o - \mathbf{M}$	A m^{-1}	**H** is due to external conduction currents only and is the cause of **B** in a material.
Magnetic susceptibility	χ_m	$\mathbf{M} = \chi_m \mathbf{H}$	None	Relates the magnetization of a material to the magnetizing field **H**.
Absolute permeability	μ_o	$c = [\varepsilon_o\mu_o]^{-1/2}$	H m^{-1} = Wb m^{-1} A^{-1}	A fundamental constant in magnetism. In free space $\mu_o = B/H$.
Relative permeability	μ_r	$\mu_r = B / (\mu_o H)$.	None	
Magnetic permeability	μ	$\mu = \mu_o \mu_r$	H m^{-1}	Not to be confused with magnetic moment.
Inductance	L	$L = \Phi_{Total} / I$	H (henries)	Total flux threaded per unit current.
Magnetostatic energy density	E_{vol}	$dE_{vol} = H\,dB$	J m^{-3}	dE_{vol} is the energy required per unit volume in changing B by dB.

Classification of Magnetic Materials

Magnetic material for which a linear relationship between M and H exists are divided into classes depending upon the sign of χ .Materials which have a negative value of χ of the order of 10^{-4} to 10^{-6} are called diamagnetic and those which have a positive value of χ of about the same order of magnitude are called paramagnetic. The materials in which the resultant magnetization is one to several orders of magnitude greater than $\mu_0 H$ are called ferromagnetic.

The figure shows a number of permeabilities.



Another classification of magnetic materials is based on the presence or absence of permanent magnetic dipoles. Materials which lack permanent magnetic dipoles are called diamagnetic. If permanent magnetic dipoles are present in the atoms of a material, it may be paramagnetic, ferromagnetic, antiferromagnetic or ferromagnetic depending on the interaction between the individual dipoles. If the interaction between the atomic permanent dipole moments is zero or negligible and the individual dipole moments are oriented at random as shown in fig 3(a), the material will be paramagnetic.

Paramagnetic, ferromagnetic, anti-ferromagnetic and ferrimagnetic arrangement of spins

If the dipoles tend to line up in parallel, as shown in fig 3(b), the material will be ferromagnetic. When neighbouring moments are aligned in antiparallel as in fig 3(c), the phenomenon is called as antiferromagnetism. When the order of the magnetic moments is as shown as in fig 3(d), the phenomenon is known as ferrimagnetism. The molecular moments in ferromagnetic materials will have the values in between the values for ferromagnetic and antiferromagnetic materials.

The magnetic properties of materials are characterised by their relative permeabilities. Based on this, magnetic materials can be divided into 3 categories viz. 1) ferromagnetic materials, the relative permeabilities of which are much greater than unity and are dependent on the field strengths 2) paramagnetic materials, which have relative permeabilities slightly greater than unity 3) diamagnetic materials, the relative permeabilities of which are slightly less than unity

When a paramagnetic or a diamagnetic material is placed in a magnetic field, the distortion of the field is negligible. On the other hand, when a ferromagnetic material is placed on the field,there is a considerable distortion. Diamagnetism is a universal property of all materials. The diamagnetic properties, however are weaker than the paramagnetic ones and still weaker than the ferromagnetic properties. The peculiarities of ferromagnetic behaviour are due to a very specific property, viz. the formation within the ferromagnetic material of vast regions or domains within which the magnetic moments of a large number of atoms are arranged parallel to on another giving magnetic saturation in each domain.

Diamagnetism

In a diamagnetic material the atoms have no magnetic moment when there is no applied field. Under the influence of an applied field (H), *the spinning electrons rotate around the* nucleus and this rotation creates a current loop and produces a magnetization (M) *in the* opposite direction to that of the applied field. In other words, when placed in a magnetic field, an extra torque is applied to the electron, resulting in an antiparallel alignment of the atomic magnetic moment. This accounts for the weak and negative magnetic susceptibility. All materials have a diamagnetic effect, but often the diamagnetic effect is masked by the larger paramagnetic or ferromagnetic term. In a diamagnetic material the value of susceptibility is independent of temperature.

Material	$\chi = \mu_r - 1$	Material	$\chi = \mu_r - 1$
Al_2O_3	-0.5×10^{-5}	Cu	-0.9×10^{-5}
$BaCl_2$	-2.0×10^{-5}	Au	-3.6×10^{-5}
NaCl	-1.2×10^{-5}	Ge	-0.8×10^{-5}
Diamond	-2.1×10^{-5}	Si	-0.3×10^{-5}
Graphite	-12×10^{-5}	Se	-1.7×10^{-5}

Susceptibility of some Diamagnetic material at room temperature

Paramagnetism

Paramagnetism refers to a property of certain materials that are weakly attracted to magnetic fields. When exposed to an external magnetic field, internal induced magnetic fields form in these materials that are ordered in the same direction as the applied field. Once the applied field is removed, the materials lose their magnetism as thermal motion randomizes the electron spin orientations.

Materials that display paramagnetism are called paramagnetic. Some compounds and most chemical elements are paramagnetic under certain circumstances. However, true paramagnets display magnetic susceptibility according to the Curie or Curie-Weiss laws and exhibit paramagnetism over a wide temperature range. Examples of paramagnets include the coordination complex myoglobin, transition metal complexes, iron oxide (FeO), and oxygen (O_2). Titanium and aluminum are metallic elements that are paramagnetic.

The relationship between paramagnetic susceptibility and magnetic moment of an atom is given by

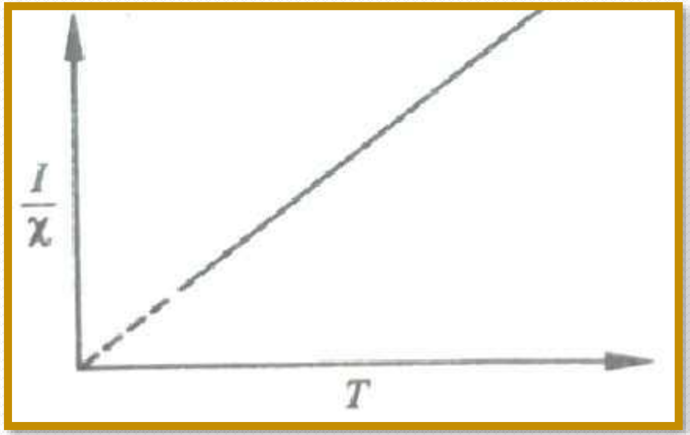
$\chi = m^2/3KT$

Where m is the magnetic moment, K is the Boltzmann's constant and T is the absolute temperature. In general, the magnitude of m is of the order of 1 Bohr Magneton.The paramagnetic susceptibility varies inversely with the absolute temperature for ordinary fields and temperatures

Or,

$\chi = C/T$

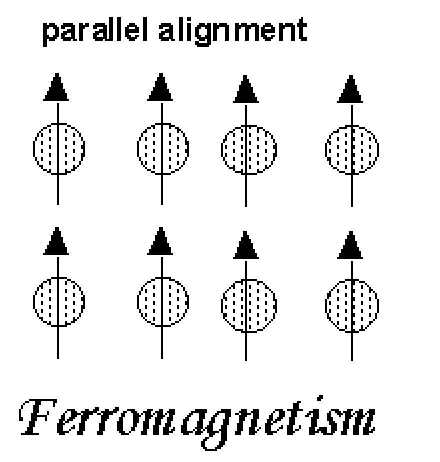
This law is known as the Curie Law of paramagnetism and the constant C is called the Curie constant.



Curie law for paramagnetic material

Ferromagnetism

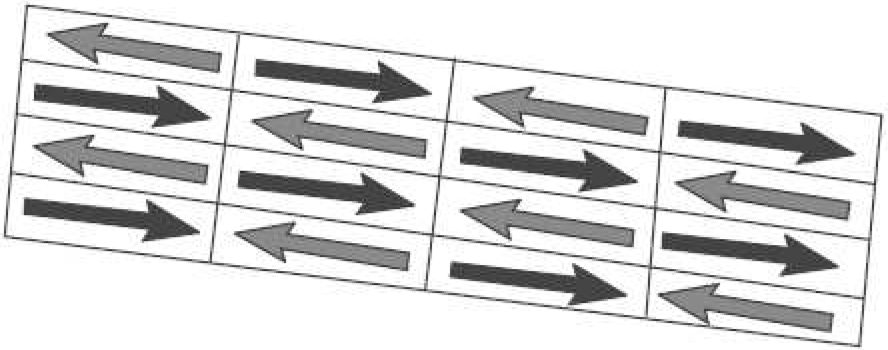
- Ferromagnetics are solids, generally crystalline in nature, which are magnetised independent of any external field.
- This can be explained in terms of the uncompensated electron spins. When the number of electrons spinning in clockwise and anticlockwise direction are unequal, then the magnetic moment is equal to magnetic field produced due to single spinning electron times the difference in number of electrons spinning in each direction.



- When the temperature exceeds the ferromagnetic Curie temperature or transition temperature TF, the susceptibility becomes independent of field strength and the behaviour of a ferromagnetic material becomes similar to that of a paramagnetic material.

Antiferromagnetism

Antiferromagnetic materials are similar to ferromagnetic materials, but the exchange interaction between neighboring atoms leads to the antiparallel alignment of the atomic magnetic moments. Therefore, the magnetic field cancels out, and the material appears to behave in the same way as a paramagnetic material. Like ferromagnetic materials these materials become paramagnetic above a transition temperature, known as the Néel temperature, T_N.

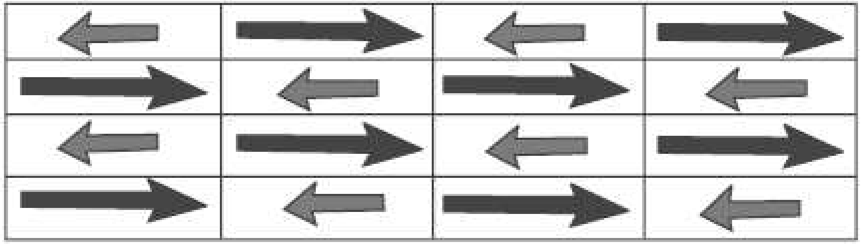


The Alignment of Electrons in Anti-Ferromagnetic Materials

Ferrimagnetism

Ferrimagnetism, type of permanent magnetism that occurs in solids in which the magnetic fields associated with individual atoms spontaneously align themselves, some parallel, or in the same direction (as in ferromagnetism), and others generally antiparallel, or paired off in opposite directions (as in antiferromagnetism). The magnetic behaviour of single crystals of ferrimagnetic materials may be attributed to the parallel alignment; the diluting effect of those atoms in the antiparallel arrangement keeps the magnetic strength of these materials generally less than that of purely ferromagnetic solids such as metallic iron.

The spontaneous alignment that produces ferrimagnetism is entirely disrupted above a temperature called the Curie point , characteristic of each ferrimagnetic material. When the temperature of the material is brought below the Curie point, ferrimagnetism revives.



The Alignment of Electrons in Ferrimagnetic Materials

The Magnetisation Curve