Magnetism

Magnet and magnetism

1. Magnetism is caused by moving charges or current loops.
2. A bar magnet consists of two equal and opposite magnetic poles separated by a distance. So a magnet is called as magnetic dipole. The magnetic moment of a bar magnet M = m x 2*l*, where m is the pole strength (SI unit Amp–m) and 2*l* is the separation between the poles. Magnetic moment is a vector quantity (SI unit Amp–m^2), having direction along the axial line of magnet from south to north.
3. The magnetic length of a magnet is the shortest distance between two poles of a magnet.
4. The magnetic length of a bar magnet is always less than actual (geometric) length because poles are little inward from faces.
5. A magnet when suspended freely aligns itself along geographical north-south line such that the north pole of the magnet is towards the north of the earth. So it has directive property,
6. Unlike poles attract and like poles repel. Repulsion is the sure test for distinguishing between a magnet and a piece of iron.
7. Magnetic poles exist in pairs, i.e., an isolated magnetic pole does not exist. However a no pole magnet (eg. Toroid) and three pole magnet is possible.
8. A freely suspended current carrying solenoid behaves just like a bar magnet.

Magnetic lines of force

1. The magnetic lines of force are the curves such that the tangent drawn on it at any point indicates the direction of magnetic field (not the direction of force on a charge particle).
2. The magnetic lines of force form closed curves, emerging from the North Pole and entering the South Pole. Inside a bar magnet these lines are from south to north.
3. Like electric lines of force, magnetic lines also never cross each other.
4. The intensity of magnetic field at any point in the field is defined as the number of lines of force passing per unit area normal to the area.

Other points concerning a magnet

1. When a magnet or a current carrying coil is placed in a uniform magnetic field $\vec{B}$, then the torque or couple acting on the magnet or coil is given by, τ = MB sin θ, where M is magnetic moment of the magnet and θ is the angle between $\vec{M}$ and $\vec{B}$. In vector form $\vec{\tau} = \vec{M} \times \vec{B}$.
2. The work done in deflecting the magnet from position θ_1 to θ_2 is given by : W = - MB(cos θ_2 - cos θ_1)
3. If the two magnets of moments $\vec{M_1}$ and $\vec{M_2}$ are arranged such that their axes are inclined making an angle θ, the magnetic moment $\vec{M}$ of the system is given by $\vec{M} = \vec{M_1} + \vec{M_2}$ or $\vec{M} = \sqrt{M_1^2 + M_2^2 + 2M_1M_2\cos\theta}$.
4. The magnetic induction on the axial line (Tan A or end on position) of a bar magnet is given by: $B_{axial} = \frac{\mu_0}{4\pi}\frac{2Md}{(d^2 - l^2)^2}$, where B = magnetic induction, *d* = distance between the centre of the magnet and the given point on the axial line, 2*l* = length of the magnet and *M* = magnetic moment of the magnet.

   For a short dipole, $B_{axial} = \frac{\mu_0}{4\pi}\frac{2M}{d^3}$, where 'd' is the distance between center of magnet and point.

Properties of magnetic materials

1. Magnetising force or intensity of magnetising field (H): It is defined as the force experienced by a unit north pole placed at a point in the field. In SI system, the unit of H is amp-tums/metre.

The direction of $\vec{H}$ is the same as the direction of $\vec{B}$ and is related as $\vec{B}$ $\vec{H}$, where is called the magnetic permeability.

2. Intensity of magnetisation (I): When a magnetic material is placed in a magnetic field, it is magnetised and it acquires a magnetic dipole moment M. The intensity of magnetisation is defined as the magnetic dipole moment per unit volume, i.e., $I \; \frac{M}{V} \; \frac{2ml}{A(2l)} \; \frac{m}{A}$, where A is the area of cross-section of the material. So intensity of magnetisation may also be defined as pole strength per unit area of cross-section. Intensity of magnetisation is also expressed in amp/metre.
3. Magnetic susceptibility ( ): Magnetic susceptibility indicates the ease with which a substance can be magnetised. It is defined as the ratio of the intensity of magnetisation (I) to the magnetising field (H) in which the material is placed, i.e., $= (I/H)$. It has no units (dimensionless).
4. Magnetic permeability ( ): The permeability is defined as the ratio of magnetic induction (B) to the magnetising force (H), i.e., = (B/H).
5. Magnetic induction or flux density (B): The flux density is the total number of lines of force per unit area due to the flux density $\vec{B_o}$ in vacuum produced by that magnetising field and flux density $\vec{B_m}$ due to magnetisation of the material. Thus $\vec{B}$ $\vec{B_o}$ $\vec{B_m}$

Diamagnetic materials

1. Materials which are repelled by magnets are known as diamagnetic materials. Examples: bismuth, zinc, copper, silver, gold, diamond, NaCl, water, nitrogen, hydrogen, etc.
2. These materials get magnetised in a direction opposite to that of the magnetic field.
3. A diamagnetic rod suspended in a uniform magnetic field becomes perpendicular to the direction of the field.
4. In a non-uniform magnetic field, they move from regions of higher concentration to regions of lower concentration.
5. Relative permeability ($_r$)of these materials is less than one but positive.
6. Magnetic susceptibility ($_m$) of these materials is negative and small. It is independent of temperature.

Paramagnetic materials

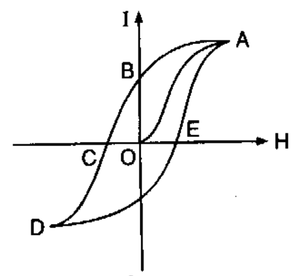
1. Materials which are feebly attracted by magnets are known as paramagnetic materials. Examples are aluminium, sodium, platinum, manganese, $CuCl_2$, $FeCl_3$, oxygen, etc.
2. These materials get magnetised in the direction of the magnetic field.
3. A paramagnetic rod suspended in a uniform magnetic field becomes parallel to the direction of the field.
4. In a non-uniform magnetic field, they move towards region of higher field.
5. Relative permeability ($_r$) of these materials is just greater than one and positive.
6. Magnetic susceptibility ($_m$) is small and positive (10^{-1} to 10^{-3}).
7. The magnetic susceptibility is inversely proportional to absolute temperature. This is called Curie law, = (C/T), where C is called Curie's constant and T is absolute temperature.

Ferromagnetic materials

1. Substances which are strongly attracted by magnets are known as ferromagnetic substances. Examples: iron, nickel, cobalt, etc.
2. A ferromagnetic rod, when suspended in uniform magnetic field, aligns itself along the direction of field.
3. In a non-uniform magnetic field, a these material move towards regions of higher magnetic field.
4. The relative permeability ($_r$) of these materials is very large (10^2 to 10^6).
5. The magnetic susceptibility ($_m$) of these materials is positive and very high (10^2 to 10^6).

6. The magnetic susceptibility decreases with increasing magnetising field.
7. Magnetic susceptibility is very high and constant upto a certain temperature above which it varies with temperature according to the equation: $\frac{K}{T \quad T_C}$ where K and T_C are constants. The constant T_C is called Curie temp. C*urie temperature is the temp. above which a ferromagnetic material becomes a paramagnetic material*.
8. Ferromagnetism is due to the existence of magnetic domains.
9. Ferromagnetic materials exhibit a phenomenon called hysteresis.

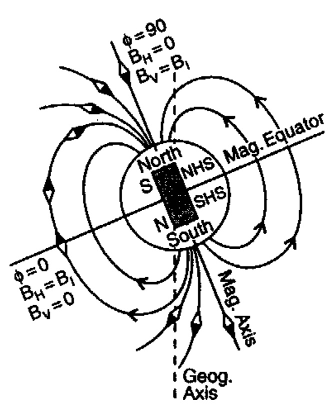
Hysteresis loop

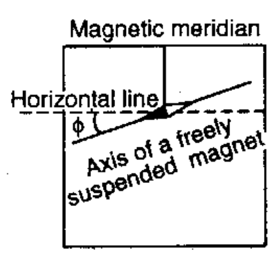


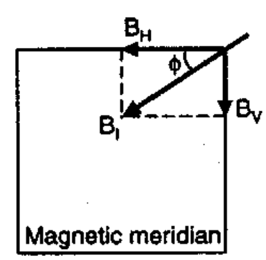
1. Hysteresis loop or cycle is a plot of intensity of magnetisation (I) against magnetising field (H) over closed loop ABCDEA.
2. Curve OA indicates the variation of I with H till the saturation point A is reached.
3. Curve AB indicates the variation of I as H is decreased to zero.
4. Curve BCD indicates the variation of I as H is increased in reverse direction.
5. Curve DE indicates the variation of I as H is decreased to zero but in reverse direction.
6. Curve EA indicates the variation of I as H is increased in the original direction.
7. It can be seen that when H is zero, the value of I does not become zero, but has a value of OB. This lagging of I behind H is called hysteresis.
8. Retentivity: The residual magnetism present inside the specimen even when the external magnetising force is made zero is called retentivity, or, retentivity is the capacity of the material to retain its magnetism when the magnetising force is removed. The intercept OB is a measure of retentivity.
9. Coercivity: Coercivity is the capacity of the material to retain its magnetism inspite of any demagnetising process. The intercept OC is a measure of coercivity.
10. The area of the hysteresis loop is a measure of work done or energy dissipation or hysteresis loop.
11. For soft iron: Coercivity is less, retentivity is more, hysteresis loss is less, susceptibility is more and permeability is more. For steel: Coercivity is more, retentivity is less, hysteresis loss is more, susceptibility is less and permeability is less.
12. Hysteresis loop is useful in selection of material for different purposes. Soft iron is used in transformers, moving coil galvanometers, electromagnets, etc., while steel is used for permanent magnets.

Earth's magnetic field

1. Magnetic axis is the line joining North magnetic and South magnetic poles of earth.
2. South magnetic of earth is towards North geographic and North magnetic of earth is towards South geographic
3. Magnetic meridian is a vertical plane passing through magnetic axis.







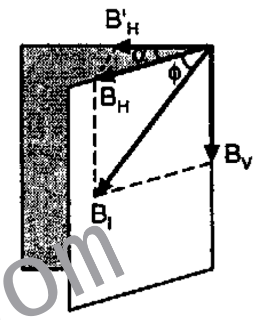
4. On the magnetic meridian plane, the magnetic induction vector of the earth at any point is inclined to the horizontal at an angle called the magnetic dip at that place, such that $\vec{B}$ = total magnetic induction of the earth

at that point, B_v (vertical component of $\vec{B}$ in the magnetic meridian plane) = B sin , And B_H (horizontal component of $\vec{B}$ in the magnetic meridian plane) = B cos and hence $\frac{B_V}{B_H}$ tan

Declination

1. Declination is the angle between magnetic meridian and geographical meridian at a given place.
2. The value of declination at equator is 17° which varies from place to place.
3. The lines joining the places of equal declination are called isogonic lines.
4. The lines joining the places of zero declination are called agonic lines.

Dip or Inclination ( )



1. The angle made by the earth's magnetic field with the horizontal at a place is called dip or inclination at that place. This angle in magnetic meridian is called *true dip* at that place.
2. Dip circle is the instrument used to measure the dip.
3. It varies between 0° and 90°. At the magnetic equator it is zero and 90° at poles.
4. The lines joining the places of equal dip are called isoclinic lines.
5. The lines joining the places of zero dip are called aclinic lines.
6. In a vertical plane at an angle to the magnetic meridian, $B'_H = B_H$ Cos . and $B'_v = B_v$ so angle of dip in a vertical plane making an angle with magnetic meridian,

   tan $\frac{B_V}{B_H}$ $\frac{B_V}{B_H \cos}$ $\frac{\tan}{\cos}$

7. From above it is clear that: In a vertical plane other than magnetic meridian, angle of dip is always more than in magnetic meridian.
8. For a plane perpendicular to magnetic meridian = 90°, and so '= 90° i.e., in a plane perpendicular to magnetic meridian 'dip needle' will become vertical.
9. If at a given place $_1$ and $_2$ are angles of dip in two arbitrary vertical planes which are perpendicular to each other, the true angle of dip is given by $\cot^2 = \cot^2{}_1 + \cot^2{}_2$
10. Angle of dip at a place is related to its magnetic latitude , through the relation tan = 2 tan

Horizontal component (B_H)

1. The component of the total induction of the earth's magnetic field (B) along the horizontal direction is called the horizontal component.
2. The horizontal component can be measured with the help of a deflection magnetometer or vibration magnetometer.
3. If is the dip, i.e., the angle between total magnetic induction of the earth's magnetic field B and horizontal component B_H then horizontal component B_H = B cos , vertical component B_V = B sin ,

   And B = $\sqrt{B_H^2 \quad B_V^2}$ and tan = (B_V/B_H)

4. B_H is zero at magnetic poles and maximum (equal to B) at the magnetic equator.
5. The lines joining the places of equal horizontal component are called isodynamic lines.

Torque on a current carrying loop suspended freely in a magnetic field

1. When a loop is suspended freely in a magnetic field and a current is passed through it then resultant force on the loop is zero but the resultant torque is not zero.
2. If during the rotation of the loop, the normal to the plane of the loop makes an angle with the direction of uniform magnetic field B, then torque acting on the loop is given by; = *IAB* sin , where A = *lb* = area of the loop.

3. If the loop is replaced by a coil consisting of N turns, then = *NIAB* sin

4. In vector form, $\vec{}$ $\vec{M}$ $\vec{B}$, where M NIA magnetic diopole moment of the current carrying coil.

Moving coil galvanometer

1. It is used for the measurement of current. It is based on the principle that when a current carrying conductor is placed in the magnetic field it experiences a force whose direction is given by Fleming's left hand rule.

2. The current *I* is directly proportional to deflection *I* or *I* = K ,

3. K is a constant of the galvanometer and is known as galvanometer constant and K = c/NAB, where c = elastic torsional constant of the suspension wire, N = number of turns in the coil A = area of the coil and B = magnetic induction of radial magnetic field.

4. The current sensitivity, .S_i = /I =1/K = NBA/c and voltage sensitivity S_v = /V = /IR = S_i/R.

   For higher sensitivity:

   (a) Area of the moving coil should be large. In practice length of the coil is increased as increase in breadth tends to decrease B.

   (b) Number of turns in the coil should be increased but this is done up to a certain limit as increase in number of turns leads to increase in the resistance of the galvanometer.

   (c) Magnetic induction B should be made large. For this, laminated ferro-cobalt steel permanent magnet is used.

   (d) Torsional torque per unit twist c should be made small. As c = (r^4/2l), where r is the radius and *l* is the length of suspension wire. Hence, length is made large and radius made small to ensure decrease in c. The suspension wire is made of phosphor bronze, since it is a good conductor and is highly elastic and shows little elastic after effect.

5. In dead beat galvanometer, the frame on which the coil is wound is metallic. Due to strong induced current, the coil is not allowed to oscillate due to eddy current.

Ammeter

1. An ammeter is used to measure the current in a circuit. It is connected in series with the circuit to avoid division of current, but when placed in series with the circuit, it increases the resistance and decreases the current being measured by it. Hence it measures the current less than actual.

2. An ideal ammeter has a zero resistance.

3. The resistance of a milliammeter is more than that of an ammeter.

4. To convert a galvanometer which gives full scale deflection for a current I_g, in an ammeter to read a current *I*, the value of the shunt required is given by: $S \quad \frac{I_g G}{I \quad I_g}$, where G = galvanometer resistance.

Voltmeter

1. Voltmeter is used to measure potential difference across any element of the circuit. A voltmeter is connected in parallel with the element to avoid division of voltage, but when placed in parallel with the element it shares current from the element and decreases the potential difference across the element before measuring it. Hence it measures the potential difference less than actual.

2. An ideal voltmeter has an infinite resistance so that it may not change the current in the element.

3. The resistance of a millivoltmeter is less than that of a voltmeter.

4. If I_g represents the current for full scale deflection of the galvanometer, then the potential difference that can be measured V_g across the terminals of the galvanometer for full scale deflection is given by; $V_g = I_g G$

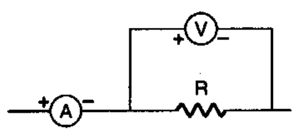
5. When a high resistance R is connected in series with a galvanometer of resistance G, it becomes a voltmeter. The potential difference V across the terminals of the series combination of R and G is given by: $V = I_g(R+G)$ So,

$\frac{V}{V_g}\ \ \frac{R\ \ G}{G}$, Here, (V/V_g) is called the voltage multiplying power of the series resistor and is denoted by: n = (V/V_g). So $n\ \ \frac{R\ \ G}{G}$ or $R\ \ G(n\ \ 1)$

6. If the total resistance of this series combination which is effectively a voltmeter is denoted by R_V, then $R_V = R + G = G(n - l) + G = nG$

Magnetism Assignment

1. In a moving coil galvanometer, we use a radial magnetic field so that the galvanometer scale is:
   (a) logarithmic (b) exponential
   (c) linear (d) none of these
2. A candidate connects a moving coil voltmeter V and a moving coil ammeter A and a resistor R as shown. If the voltmeter reads 20 volt and the ammeter reads 4 ampere, then R is:



   (a) equal to 5 ohm
   (b) greater than 5 ohm
   (c) less than 5 ohm
   (d) greater or less than 5 ohm depending upon its material
3. In a moving coil galvanometer the deflection of the coil is related to the electric current I by the relation:
   (a) I tan (b) I
   (c) I ^{2} (d) I
4. If 2% of the main current is to be passed through a galvanometer of resistance G, the resistance of shunt required is:
   (a) G/49 (b) 49G
   (c) G/50 (d) 50G
5. A voltmeter has a resistance of G ohm and range V volt. The value of resistance used in series to convert it into voltmeter of range nV volt is:
   (a) nG (b) (n-l)G (c) G/n (d) G/(n -1)
6. Which of the following is likely to have the largest resistance?
   (a) A galvanometer
   (b) An ammeter
   (c) A milliammeter
   (d) A voltmeter
7. A galvanometer has a resistance of 3663 ohm. A shunt S is connected across it such that (1/34) of the total current passes through the galvanometer. Then the value of the shunt is;
   (a) 3663 ohm (b) 111 ohm
   (c) 107.7 ohm (d) 3555.3 ohm
8. A soft iron cylinder is used in a moving coil galvanometer because without it in galvanometer:
   (a) magnetic field will not be radial and strong
   (b) magnetic field will be radial but weak
   (c) magnetic field will be radial and' strong
   (d) magnetic field will not be radial and weak
9. What is the relation between voltage sensitivity S_v and current sensitivity S_i of a moving coil galvanometer? Given that the resistance of the galvanometer is G:
   (a) $S_v = GS_i$ (b) $S_v = S_i/G$
   (c) $S_vS_i = G$ (d) none of these
10. A bar magnet of magnetic moment 80 units is cut into two halves of equal length; the magnetic moment of each half will be:
    (a) 80 units (b) 40 units
    (c) 60 units (d) 20 units
11. A steel wire of length L has a magnetic moment M. It is then bent into a semi-circular arc; the new magnetic moment will be:
    (a) M (b) 2M/
    (c) M/L (d) ML
12. Two identical magnets each of moment M are kept at an angle of 60°, such that like poles are touching each other. The magnetic moment of the combination will be:
    (a) M (b) 2M (c) M 2 (d) M 3
13. Magnetic field produced by electrons in atoms and molecules is due to their:
    (a) spin motion only
    (b) orbital motion only
    (c) spin and orbital motion both
    (d) neither spin nor orbital motion
14. For a paramagnetic material, the dependence of the magnetic susceptibility on the absolute temperature T is given by:
    (a) T (b) constant x T
    (c) 1/T (d) = constant
15. Points A and B are situated along the extended axis of a 2 cm long bar magnet at distances x and 2x cm respectively from the pole nearer to the points. The ratio of the magnetic fields at A and B will be:
    (a) 4 : 1 exactly
    (b) 4 : 1 approximately

(c) 8 : 1 exactly
(d) 8 : 1 approximately

16. At the magnetic poles of the earth, a dip needle will be:
    (a) bent slightly vertical
    (b) vertical
    (c) horizontal
    (d) inclined at 45° to the horizontal
17. An iron rod of cross-sectional area 4 cm^2 is placed with its length parallel to a magnetic field of intensity 1600 amp/m. The flux through the rod is 4 x 10^{-4} weber. What is the permeability of the material of the rod? (In weber/amp-m)
    (a) 0.625 (b) 6.25
    (c) 0.625 x 10^{-3} (d) None of these
18. Find the angle through which a magnet is to be rotated from rest position when it is suspended in a magnetic field so that it experiences half of the maximum torque:
    (a) 60° (b) 30° (c) 45° (d) 90°
19. A magnet is parallel to a uniform magnetic field. If it is rotated by 60°, the work done is 0.8 J. How much work is done in moving it 30° further?
    (a) 0.8 x 10^7 ergs (b) 0.4 J
    (c) 8 J (d) 0.8 ergs
20. The temperature at and above which a ferromagnetic material becomes paramagnetic is called:
    (a) critical temperature
    (b) inversion temperature
    (c) Curie temperature
    (d) Debye temperature
21. The magnetic moment of a diamagnetic atom is:
    (a) zero (b) ∞
    (c) - ∞ (d) another value
22. A magnetic needle is kept in a non-uniform magnetic field. It experiences:
    (a) a force and a torque
    (b) a force but not a torque
    (c) a torque but not a force
    (d) neither a torque nor a force
23. If a magnet is suspended at an angle of 30° to the magnetic meridian, the dip needle makes an angle of 45° with the horizontal. The real dip is:
    (a) $\tan^{-1}(\sqrt{3}/2)$ (b) $\tan^{-1}(\sqrt{3})$
    (c) $\tan^{-1}(\sqrt{3/2})$ (d) $\tan^{-1}(2\sqrt{3})$
24. At a certain place, the angle of dip is 30° and the horizontal component of earth's magnetic field is 0.50 oersted. The earth's total magnetic field is:
    (a) $\sqrt{3}$ (b) 1 (c) $1/\sqrt{3}$ (d) 1/2
25. If a magnet is suspended at an angle 30° to the magnetic meridian, the dip needle makes an angle of 60° with the horizontal. The true value of dip is:
    (a) $\tan^{-1}(2/3)$ (b) $\tan^{-1}(3/2)$
    (c) $\tan^{-1}(3)$ (d) $\tan^{-1}(2)$
26. A magnet of magnetic moment $50\hat{i}$ A m^2 is placed along the x-axis in a magnetic field $\hat{B}$ $(0.5\hat{i}\ \ 3.0\hat{j})$ tesla. The torque acting on the magnet is:
    (a) 175 $\hat{k}$ Nm (b) 75 $\hat{i}$ Nm
    (c) 150 $\hat{k}$ Nm (d) $25\sqrt{37}\ \hat{k}$ Nm
27. A circular loop carrying a current is replaced by an equivalent magnetic dipole A point on the axis of the loop is:
    (a) an end-on position
    (b) a broad-side-on position
    (c) both
    (d) neither

ANSWERS

1c ,2b ,3b ,4a ,5b ,6d ,7b ,8a ,9b ,10b ,11b ,12d ,13c ,14c ,15d ,16b ,17c ,18b ,19a ,20c ,21a ,22a ,23a ,24c ,25b ,26c ,27a