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1	85.48	91.67	96.01	92.22	92.78	93.06	86.02	92.62	93.61	93.01	88.89	91.40	348	1	196	1544
10	81.39	85.42	88.48	85.83	86.94	83.92	78.49	86.88	86.11	82.80	81.06	84.99	324	8	185	2043
100	70.76	79.79	78.68	76.39	77.50	69.84	68.61	83.33	74.72	72.85	71.72	74.93	323	13	178	2395
500	62.17	72.08	69.36	66.67	68.61	60.32	54.57	77.32	64.44	61.02	59.34	65.08	313	25	160	3542
1000	57.87	68.13	64.46	61.67	63.33	56.75	49.46	72.95	58.59	55.65	53.28	60.22	310	27	154	4137
2000	52.97	62.50	58.33	55.56	57.22	49.21	43.55	67.48	53.06	50.00	46.46	54.21	302	46	145	5005
3000	49.69	59.17	54.41	51.94	53.61	45.44	42.74	63.38	49.17	46.77	42.42	50.79	297	66	135	6180
4000	47.03	56.67	51.72	49.17	51.11	42.66	37.90	60.38	46.39	44.09	39.39	47.86	296	70	131	6750
5000	44.99	54.38	49.51	47.22	48.89	40.48	36.02	57.65	43.89	41.94	37.12	45.64	286	94	126	7516
6000	43.35	52.17	47.55	45.56	47.22	38.69	34.41	55.45	41.94	40.32	35.10	43.85	266	201	121	8494
7000	41.92	51.04	45.83	43.89	45.56	37.10	33.33	53.55	40.28	38.71	33.59	42.25	254	299	109	10848
8000	40.49	49.79	43.38	42.50	44.44	35.91	31.99	51.63	38.61	37.63	32.32	40.79	245	395	102	12874
9000	39.47	48.54	43.14	41.11	43.06	34.52	30.91	50.27	37.22	36.29	30.81	39.58	239	471	100	13215
10000	38.85	47.71	41.91	40.00	41.94	33.33	29.84	48.90	36.11	35.22	29.80	38.51	231	600	85	18547
QUAL%	38.85	47.71	34.55	33.88	35.00	23.81	20.16	22.50	25.00	25.00	17.42	29.44	212	1006	79	21157

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Chapter 8

Electromagnetism

Remember

Before beginning this chapter, you should be able to:

- Learn the important terms such as a magnet, magnetic field, modern theory of magnetism
- Classify various magnetic substances
- Learn about the different elements of earth's magnetic field, magnetic field produced by bar magnet in the earth's magnetic field in different orientations
- Understand the concept in electromagnetism and different instruments using magnetic effect of electric current

KEY IDEAS

After completing this chapter, you should be able to:

- Learn the important properties of magnets, magnetic field and field lines, Ewing's Molecular Theory, inverse square law of magnetism, magnetic induction, modern electron theory, classification of magnetic materials, and terrestrial magnetism
- Study Oersted's Experiment, rules that help to find the direction of magnetic field
- Find magnetic field due to a long straight and circular current carrying wires, solenoid and application of Fleming's left-hand rule
- Understand Faraday's experiments and laws of electro magnetic induction including Lenz's Law and Fleming's right-hand rule
- Study about electric generator, RMS voltage and peak voltage, self and mutual induction, transformer, eddy currents, etc.

INTRODUCTION

In 1820, Hans Christian Oersted discovered that current carrying conductor produces a magnetic field around it. Later Micheal Faraday showed that current can be induced in a conducting coil, when there is relative motion between the coil and a magnet. Thus, electric current has magnetic effect and changing magnetic fields can induce electricity. Together, their study forms a very important branch of physics called electromagnetism. Large scale generation of electricity worldwide and most of the devices which work on it are based on the principles of electromagnetism.

In the previous chapter, you studied electricity. Before we begin the study of electromagnetism, let us understand some important aspects of magnetism.

MAGNETISM

Since ancient times it was known that ferrous oxide (Fe_3O_4) had the ability to attract substances like iron, nickel, etc. Substances having this ability are called magnets. Fe_3O_4 is called natural magnet as it is naturally occurring while those substances in which this ability is artificially imparted are called artificial magnets.

The substances which are attracted towards a magnet and can become magnets are called magnetic substances. Example: iron, nickel, cobalt. etc.

The substances which are not attracted towards a magnet and cannot be magnetized are called non-magnetic substances. Example: wood, paper, plastic. etc.

Important Properties of Magnets

1. **Property of attraction:** Magnets attract small pieces of materials like iron, nickel, and cobalt. The property of a magnet to attract small pieces of iron seems to be concentrated in small regions at the ends of the magnet. These regions are called magnetic poles.
2. **Property of direction:** A freely suspended magnet always aligns itself in the North-South direction. The pole which points towards geographic north is called North pole of the magnet and the pole which points towards geographic south is called South pole of the magnet.
3. Like-poles of magnets repel each other and unlike-poles attract each other, just as like-charges repel and unlike-charges attract. Since a magnet can attract small pieces of iron and also the opposite pole of another magnet, property of attraction is not a sure test to find whether a given piece is a magnet or not. Repulsion is a sure test to confirm whether a given piece is a magnet or not.
4. **Property of induction:** A magnet can induce magnetism in substances like soft iron, cobalt, nickel, etc.
5. Breaking a magnet successively into smaller pieces would still produce tiny magnets each with a north pole and south pole. The above phenomena is observed till we reach molecular stage.
6. Magnetic poles always exist in opposite pairs.

Magnetic Field and Field Lines

The area surrounding magnet, in which its effect can be felt, is called a magnetic field of the magnet.

Place a bar magnet on a cardboard. Randomly sprinkle iron filings on the cardboard and tap it lightly. The iron filling arrange themselves in a particular pattern.

Draw lines along these patterns. These lines form continuous, closed curves between the poles of the magnet. Place a magnetic needle near the north pole of bar magnet and mark the north pole end of needle. Now place the needle with its S-pole at this mark and mark the new position of its N-pole. It is found that the needle always traces a path formed by above mentioned curved lines. These lines are called magnetic lines of force. Thus, a magnetic field can be represented by lines of force.

Magnetic lines of force are those lines in a magnetic field along which an imaginary free isolated north pole moves.

1. Lines of force are continuous lines.
2. Outside a bar magnet, the lines of force are directed away from North pole and towards the South pole.
3. Inside a bar magnet, the lines are directed from South pole to the North pole.
4. Lines of force do not intersect.
5. The magnetic field is strong at places where the lines of force are crowded and weak where the lines of force are far apart.
6. The direction of magnetic field at a point is tangential to the line of force at that point.

EWING'S MOLECULAR THEORY OF MAGNETISM

If we break a magnet into two parts, each part becomes a magnet with a north pole at one end and a south pole at the other end. If we break it further, we observe the same behaviour. This will continue even if we break the magnet to its molecular level.

Each molecule of a magnetic substance is an independent magnet irrespective of whether the substance is magnetized or not, these tiny magnets are called molecular magnets.

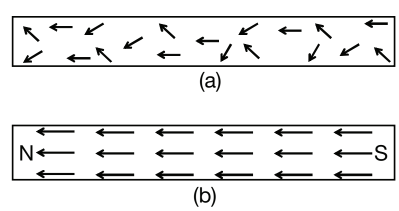


FIGURE 8.1 (a) An unmagnetized state, (b) A magnetized state

In an unmagnetized state [Fig 8.1 (a)], the molecular magnets are arranged in random manner. Therefore, the net magnetic effect is zero.

In the magnetized state [Fig. 8.1 (b)], these molecular magnets are arranged in an order. All the south poles are aligned in one direction and the north poles in the other direction. Therefore, a strong magnetic field is created.

In general, perfect alignment of all the molecular magnets in the entire magnet is difficult to obtain. When this condition is obtained, it is called the point of saturation and magnetizing the magnet further cannot increase the strength of the magnet. These postulates are known as Ewing's molecular theory named after the scientist who proposed them.

However, Ewing's molecular theory could not explain why the individual molecules of a magnetic substance like iron behave as tiny magnets. Also it failed to explain, why molecules of non-magnetic substances, like brass, do not behave like magnets. The theory could not explain the fact that substances like bismuth, copper are repelled by strong magnets.

INVERSE SQUARE LAW OF MAGNETISM

The ability of the pole of a magnet to attract or repel another magnetic pole is called its **pole strength**. It is denoted by 'm'. Its SI unit is ampere-metre.

Consider two hypothetical isolated magnetic poles of pole strengths m_1 and m_2 separated by a distance 'r'.

According to inverse square law of magnetism, given by Coulomb, the force of attraction or repulsion between two magnetic poles is directly proportional to the product of their pole strengths and inversely proportional to the square of the distance between them and acts along the line joining the poles.

Mathematically,

$$F \propto m_1 \times m_2$$

$$\text{and } F \propto \frac{1}{r^2},$$

$$\text{or, } F = K\frac{m_1 m_2}{r^2}$$

where K is the constant of proportionality. Its value depends on the magnetic properties of the medium surrounding the magnetic poles and the system of units used.

If we choose SI units, and if vacuum or air is the medium surrounding the poles, then the value of K is denoted by to be $\left(\frac{\mu_0}{4\pi}\right)$.

$$\therefore\ F = \left(\frac{\mu_0}{4\pi}\right)\frac{m_1 m_2}{r^2} \tag{8.1}$$

where μ_0 is called permeability of vaccum or air.

The value of μ_0 is $4\pi \times 10^{-7}$ henry metre^{-1}.

If any medium other than vacuum or air surrounds the poles, then

$$F_1 = \frac{\mu}{4\pi} \times \frac{m_1 m_2}{r^2} \tag{8.2}$$

where 'μ' is absolute magnetic permeability of the medium.

Some Important Terms

Magnetic Permeability

Magnetic permeability (μ) of a medium is defined as its ability to allow the magnetic lines of force to pass through it or to allow itself to be influenced by magnetic field.

On dividing equation (8.2) by equation (8.1), we have

$$— \quad — = \mu_r \Rightarrow \mu = \mu_0 \mu_r$$

where μ_r is called **relative permeability** and it is defined as the ratio of magnetic force in a medium to the magnetic force in vacuum.

μ_r being a ratio has no units. For air or vacuum, $\mu_r = 1$.

Unit Pole Strength

The unit magnetic pole is defined as that pole which repels an identical pole at 1 metre distance with a force of 10^{-7} N.

By taking $\mu_0 = 4\pi \times 10^{-7}$ henry metre^{-1}, $r = 1$ m and $m_1 = m_2 = 1(A\text{–}m)$, we have

$$F = \frac{\mu_0}{4\pi} \times \frac{m_1 m_2}{r^2}$$

$$= \frac{\mu_0}{4\pi} \times \frac{1 \times 1}{1^2} = \frac{4\pi \times 10^{-7}}{4\pi} = 10^{-7}\,\text{N}$$

Magnetic Flux Density 'B'

The space around the magnet where the influence of the magnet can be felt is called **magnetic field**. Let us imagine this field as constituted by magnetic lines of force. The total number of lines passing through the given area is called **magnetic flux 'ϕ'**. The unit of magnetic flux in S.I system is weber (Wb). If a magnetic substance exits in this field, then the lines of force pass through it. These lines of force are called magnetic induction lines as these lines induce magnetism in the magnetic substance.

Magnetic flux per unit area is called magnetic flux density or magnetic induction.

i.e.,
$$B = \frac{\phi}{A}$$

Magnetic induction can also be defined as the force experienced by a unit north pole kept in a magnetic field.

We know that the force experienced by two poles m_1 and m_2 is given by,

$$F = \frac{\mu_0}{4\pi} \frac{m_1 m_2}{d^2}$$

Let m_1 be the pole strength of unit N pole.

$$\therefore\ m_1 = 1\ A - m$$

Let $m_2 = m$

$$\therefore\ F = \frac{\mu_0}{4\pi}\frac{m}{r^2}$$

By definition magnetic induction at a point in a magnetic field is the force experienced by a unit north pole placed at that point.

$$\therefore B = \frac{\mu_0}{4\pi}\frac{m}{r^2}$$

The SI unit of flux density is Wb m^{-2} or tesla (T). The CGS unit of flux density is gauss (G).

$$1\ \text{T} = 10^4\ \text{G}$$

Its other unit is N $A^{-1}m^{-1}$. The force experienced by a north pole of pole strength 'm', kept in a magnetic field of induction 'B', is given by,

$$F = mB.\ \text{or}\ B = \frac{F}{m}$$

Intensity of Magnetic Field (H)

The intensity of magnetic field refers to the strength of a magnetic field at a point in C.G.S. units.

We know that

$$F = K\frac{m_1 m_2}{r^2}$$

where $K = \dfrac{1}{\mu}$ and μ is the permeability of free space which is equal to 1 in C.G.S system.

In the above equation, if m_1 is unit north pole and $m_2 = m$, then

$$F = \frac{m}{r^2}$$

This force is called intensity of magnetic field (H)

$$\therefore H = \frac{m}{r^2}$$

Thus, intensity of magnetic field can be defined as the force acting on unit north pole independent of the medium.

In S.I. system,

$$H = \frac{m}{4\pi r^2}$$

Since $K = \dfrac{1}{4\pi}$ in S.I system, the S.I. unit of H is ampere metre^{-1} (A m^{-1}).

In C.G.S. system, its unit is oersted.

Both H and B represent strength of magnetic field at a point, the difference being that H is independent of the medium. H and B are related as follows:

$$B = \mu_o H$$

Magnetic Moment 'M'

The magnetic moment of a bar magnet is given by the product of its length and pole strength. Let us take the length of the magnet as '$2l$' and magnetic pole strength of the magnet as 'm'. Then the magnetic moment of the magnet is given by,

$$M = (2l) \times m$$

S.I. unit of magnetic moment is ampere – metre^2(A m^2)

Magnetic Field Induction of a Bar Magnet on the Axial Line of the Magnet

The line joining the north pole and south pole of a magnet is called the axial line. The magnetic induction 'B' of a short bar magnet on the axial line is given by,

$$B = \left(\frac{\mu_0}{4\pi}\right)\frac{2M}{d^3}$$

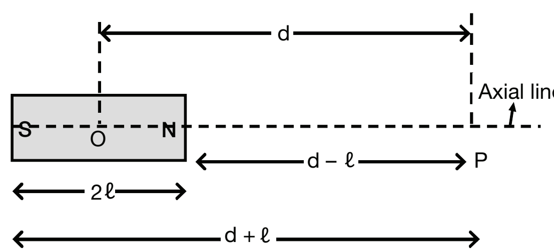


FIGURE 8.2 Diagram to show magnetic field induction of a bar magnet on the Axial Line of the Magnet

Where μ_o is the permeability of free space, M is the magnetic moment of the magnet and 'd' is the distance of the point 'P' from the centre of the magnet. The direction of B is along the axis, parallel to $\overrightarrow{SN}$ vector.

Magnetic Field Induction of a Magnet on the Equatorial Line of the Magnet

A line perpendicular to the axis and passing through the midpoint of the magnet is called the equatorial line. The magnetic induction 'B' of a short bar magnet on the equatorial line is given by

$$\mathrm{B} = \left(\frac{\mu_0}{4\pi}\right) \cdot \frac{M}{d^3} \; N\,A^{-1} – m^{-1},$$

where μ_o is the permeability of free space, M is the magnetic moment of the given magnet and 'd' is the distance of the point 'P' on the equatorialline from the magnet.

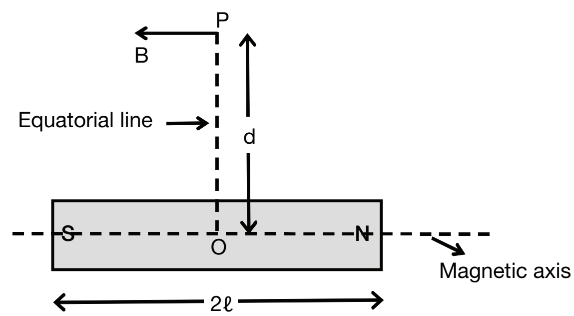


FIGURE 8.3 Diagram to show magnetic field induction of a magnet on the equatorial line of the magnet

The direction of B is parallel to the axis of the magnet and is in the $\overrightarrow{NS}$ direction.

ORIGIN OF MAGNETISM–MODERN ELECTRON THEORY

One of the major drawbacks of Ewing's theory is that it fails to explain why molecules of magnetic substances like iron behave like tiny magnets while those of non-magnetic substances like wood do not. The modern electron theory offers an explanation to this. A molecule consists of two or more atoms. Each atom consists of electrons which revolve around the nucleus in orbits and rotate or spin about an axis. Since electrons carry negative charge, the orbital and spin motion of electrons give rise to electric current which produces a magnetic field.

For substances like iron, the net magnetic moment due to a molecule is not zero hence they are magnetic in nature. The net magnetic moment due to a molecule is zero in wood hence it is non-magnetic.

Magnetic Properties

1. **Intensity of magnetisation 'I':** It is the magnetic moment acquired per unit volume when a substance is placed in a magnetic field. Its unit is A m^{-1}.
2. **Magnetic susceptibility 'χ':** It is the measure of capability of a medium to get magnetized. Susceptibility of a substance is defined as the ratio of intensity of magnetization 'I' to the intensity of applied magnetic field 'H'. Soft iron has high susceptibility.

$$\chi = \frac{1}{H}\frac{(Am^{-1})}{(Am^{-1})}$$

Magnetic susceptibility is a constant for a given substance. Since it is a pure ratio, it has no unit.

3. **Retentivity:** It is a property of magnetic material by virtue of which it retains the magnetic property even after removal of the applied magnetic field. Steel has high retentivity. Due to this reason, steel is used for making permanent magnets.

Classification of Magnetic Materials

Based on the magnetic properties, all materials can be classified as:

1. Diamagnetic substances
2. Paramagnetic substances
3. Ferromagnetic substances

Diamagnetic Substances

The resultant magnetic moment of an atom in a substance depends on the orientation of electron orbits and the axes about which electrons spin.

The substances in which the net magnetic moment of any atom in them is zero are called diamagnetic substances.

1. A diamagnetic substance is feebly repelled by a powerful magnet.
2. When suspended in a non-uniform magnetic field, it settles at right angles to the direction of the field.
3. Its relative permeability (μ_r) is approximately equal to or less than 1 ($\mu_r \leq 1$).
4. Magnetic susceptibility is negative very small, e.g., for bismuth, $x = -0.000015$

Example: air, water, copper, bismuth, etc.

PARAMAGNETIC SUBSTANCES

Those substances in which the orientation of electron orbits and axes of their spins are such that the net magnetic moment of any atom is not zero, are called paramagnetic substances. Those atoms which have unpaired electrons acquire resultant magnetic moment.

1. Paramagnetic substances are feebly attracted by a strong magnet.
2. When placed in a non-uniform external magnetic field, it aligns itself with the direction of the field and moves from weaker to stronger region of the field.
3. Its relative permeability is slightly greater than 1 (μ r > 1).
4. Its magnetic susceptibility (χ) is small and positive, e.g., for platinum, its value is 0.0001
5. Example: aluminium, platinum, chromium

Ferromagnetic Substances

Like paramagnetic substances, the atoms of these elements have resultant magnetic moment. But unlike paramagnetic substances, they achieve high degree of magnetic alignment due to a special effect called 'exchange coupling'.

The elements Fe, Co, Ni, Gd and Dy are examples of ferromagnetic substances.

Ferromagnetic substances are those in which the resultant magnetic moments of individual atoms align themselves parallel to each other due to a special effect which leads to spontaneous magnetisation.

1. They are strongly attracted by magnets.
2. They align in the direction of the applied field.
3. Their relative permeability is very high ($\mu_r >> 1$).
4. Magnetic susceptibility (χ) is very high and positive. Therefore, they can be easily magnetised and made into magnets.

DOMAIN THEORY

Domain theory explains the properties of ferromagnetic substances. According to domain theory, a large number of small local regions are formed in ferromagnetic substances, called **domains**. Within each domain, the magnetic dipoles of all the atoms align themselves parallel to each other giving rise to magnetism. The direction of magnetisation in each domain is different from that in the other domains as indicated by arrows in the Fig. 8.4.

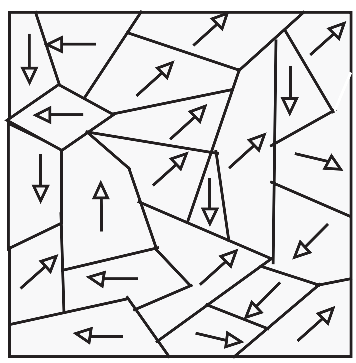


FIGURE 8.4 Different domain showing direction of magnetization by arrows

In the diagram, boundary lines indicate different domains and arrows indicate direction of magnetisation of respective domains. In the absence of applied magnetic field, the arrow of each domain point along different directions. As a result, the net magnetisation of the specimen as a whole is zero. This explains why an iron rod is not a magnet by itself.

When a ferromagnetic specimen is magnetised the domains expand and all arrows align parallel to each other in one direction. In an ideal magnet, there is a single domain with all the arrows pointing in one direction. This way the specimen becomes a magnet. Ferromagnetic substances exhibit retentivity because on demagnetising them, the original domains are not formed immediately, so that a certain amount of magnetisation is still retained.

Terrestrial Magnetism

Our earth behaves like a magnet. This is proved by the fact that a freely suspended bar magnet or a compass needle always come to rest in north–south direction. It is as if a huge bar magnet is buried at the centre of the earth with its south pole at the geographic north and vice versa. The axis of the earth's magnet makes an angle of about 17° with the geographic axis.

It is supposed that electric currents in the molten outer core rich in iron give rise to the earth's magnetism. The study of the earth's magnetism and its various elements constitutes terrestrial magnetism.

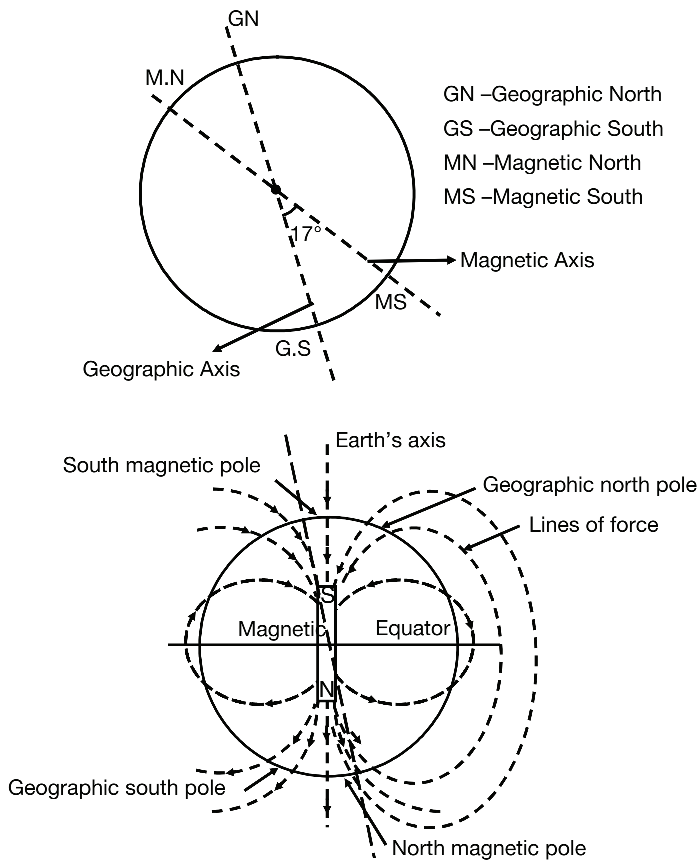


FIGURE 8.5 Terrestrial magnetism

Elements of Earth's Magnetism

1. **Angle of dip or inclination:** A magnetic needle suspended at its centre of gravity and free to rotate in vertical and horizontal planes comes to the rest in the direction of the earth's magnetic field. The angle made by the axis of magnetic needle with the horizontal is called angle of dip or inclination.

   The angle of dip is maximum at the magnetic poles and its value is 90°. At magnetic equator of the earth, its value is zero.

2. **Angle of declination:** The vertical plane passing through a place and containing geographic north and south poles is called geographic meridian.

   The vertical plane passing through a place and containing the earth's magnetic north and south pole is called magnetic meridian.

   The angle between geographic and magnetic meridian at a place is called angle of declination.

Mapping Neutral Points

The magnetic field due to a bar magnet consists of number of lines of force which emerge from its north pole and enter the south pole. At the same time the effect of the horizontal component (B_H) of the earth's magnetic field is also felt at a given place. The magnetic field induction (B) due to the bar magnet is large near it and decreases with the distance, whereas B_H remains constant in magnitude and direction at a given place. Thus, within the magnetic field of a bar magnet, the lines of force represent the net effect of B and B_H. There are some points within the magnetic field where B and B_H are equal in magnitude and opposite in direction and cancel each other. These points where the resultant magnetic field is zero are called as 'neutral points'. The location of neutral points also depend on the orientation of the bar magnet.

1. **North pole of the bar magnet facing the geographical north of the earth:** At the geographical north pole lies the magnetic south pole of the earth and vice versa. The earth's magnetic lines of force are thus directed from geographical south to north. Hence the horizontal component (BH) of the earth's magnetic field neutralizes the magnetic field induction (B) of the bar magnet at two diametrically opposite points lying on the equatorial line of the bar magnet.

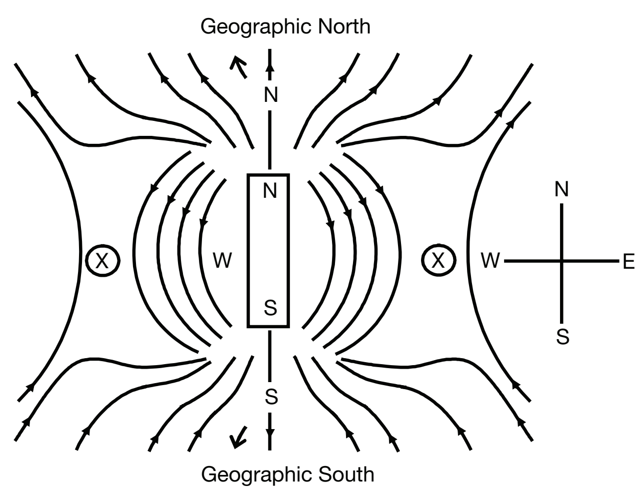


FIGURE 8.6 Magnetic field around a bar magnet whose N-pole is facing the geographical north of the earth

These points are the neutral points when N-pole of the bar magnet points towards geographic north. If a compass needle is placed at any of these points, it points in any random direction.

2. **South pole of the bar magnet facing geographical north pole of the earth:** In this orientation, the south pole of the bar magnet faces the magnetic south pole of the earth.

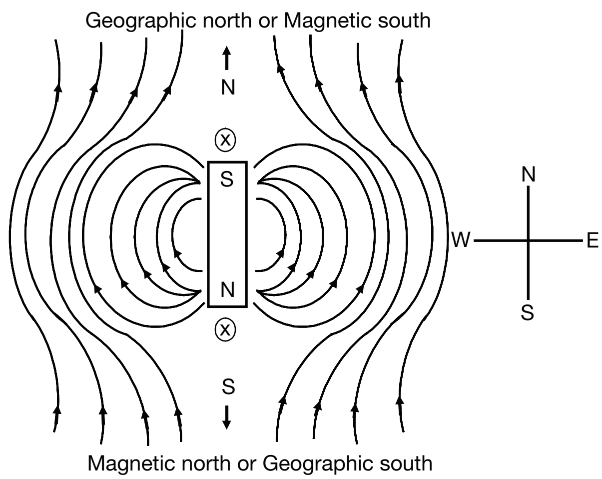


FIGURE 8.7 Magnetic field around a bar magnet whose S-pole is facing the geographical north of the earth

Along the axial line of the bar-magnet, the lines of force due to the magnetic fields of the earth and bar magnet are oppositely directed. Hence at two particular points along the axial line, one nearer to the south pole and the other closer to the north pole of the bar magnets, the B_H nullifies the B. These two points represent the neutral points.

Calculation of Magnetic Moment M of a Bar Magnet

At the neutral points, the magnetic field intensity due to a bar magnet equals horizontal component of earth's magnetic field (B_H). Knowing B_H at a given place (which is 0.39×10^{-4} T in Andhra Pradesh) and distance 'd' of neutral point, we can determine M.

Case I:

When neutral points lie on equatorial line,

$$B = \frac{\mu_0}{4\pi} \times \frac{M}{d^3} \text{ w}$$

Substituting $$B_H = 0.39 \times 10^{-4} \text{ T}, \ \frac{\mu_0}{4\pi} = 10^{-7}$$

Simplifying,

we get $$M = 390d^3 \text{ A m}^2.$$

Knowing the length of the magnet, we can find m.

The value of m can be calculated as

$$m = \frac{M}{2I} = \frac{390d^3}{2I} \text{ Am}$$

Case II:

When neutral points are on axial line,

$$B = B_H = \frac{\mu_0}{4\pi}\frac{2M}{d^3}$$

Substituting the values of B_H and $\mu_0/4\pi$, we get

$$\frac{2M}{d^3} = 390,$$

and we get

$M = 195d^3$ A m^2

Knowing the value of d, the value of m can be calculated.

If we know the length of the bar magnet, we can find its pole strength m as

$$m = \frac{M}{2l} = \frac{195d^3}{2l} \text{ A m}$$

OERSTED EXPERIMENT

Oersted was the first to put forth the direct relation between electricity and magnetism. He conducted several experiments to determine the magnetic effect of a current carrying wire. The following describes the Oersted experiment conducted to establish that a current carrying wire acts as a magnet.

A long straight wire is connected to an external battery and an electric current is passed through it. When a magnetic needle is placed below the wire such that the wire is parallel to the axis of the magnetic needle and the current flows in the south to north direction, a deflection in the needle is observed. It is observed that the north pole of the needle is deflected westwards and as the magnitude of current is increased, the deflection increases till the north pole of the needle turns towards exact west. It is also observed that if instead of placing the magnetic needle below the wire, if it was placed above the wire, the north pole of the magnetic needle is deflected eastwards. From this experiment, Oersted concluded the following facts.

1. Any current carrying wire produces a magnetic field around it, as it can deflect a magnetic needle placed near it.
2. The intensity of the magnetic field is proportional to the magnitude of the current passing through the wire.
3. The magnetic field setup acts at right angles to the direction of the flow of current.
4. The direction of the magnetic field depends upon the direction of the flow of current.

The direction of the magnetic field produced due to a current carrying wire may be determined using any one of the following rules.

AMPERE'S SWIMMING RULE

Imagine a man swimming along the conductor in the direction of current, facing a magnetic compass kept near and below the conductor. Then the north pole of the needle will be deflected towards his left hand.

AMPERE'S RIGHT-HAND THUMB RULE

Imagine you are holding the current carrying wire with your right hand, with the thumb pointing the direction of current. Then the direction of fingers encircling the wire show the direction of magnetic field.

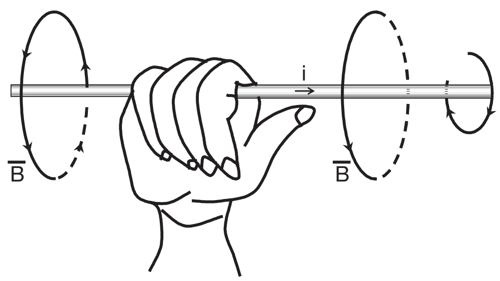


FIGURE 8.8 Ampere's right-hand thumb rule

MAXWELL'S CORK SCREW RULE

Imagine a right handed cork screw held by your hand. Rotate the screw's head such that its tip advances in the direction of the current. Then the direction in which the head rotates gives the direction of the magnetic field.

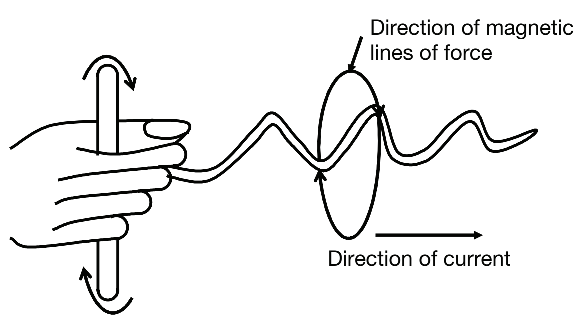


FIGURE 8.9 Maxwell's Cork Screw Rule

Magnetic Field Due to Current

I. **Magnetic field due to a long straight current carrying wire:** The following experiment helps us study the magnetic field around a long straight current carrying wire.

Take a cardboard and fix a white paper over it. Make a small hole at its centre. Clamp this cardboard, to a stand in a horizontal position. Sprinkle some iron filings over it. Pass an insulated copper wire through the small hole at the centre of the cardboard and perpendicular to it.

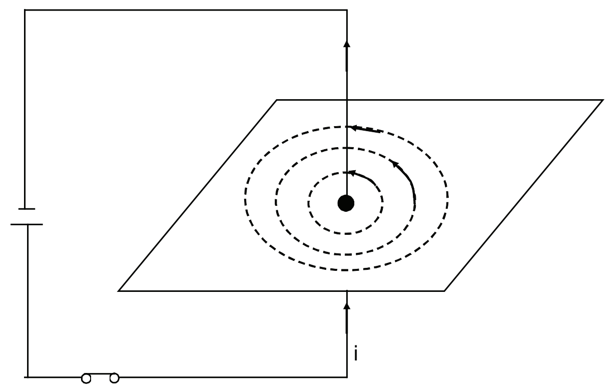


FIGURE 8.10 Magnetic field due to a long straight current carrying wire

A battery, a switch and a variable resistance are connected in series to the wire and when the circuit is closed, a current (i) flows through the wire. The iron filings on the cardboard form concentric circles around the wire showing that a current carrying conductor sets up a magnetic field around the conductor. The direction of the magnetic field at any point is in the plane of the paper and is always tangential to the circle passing through that point.

Observations	Conclusions
If the magnitude of the current in the wire is increased, then the number of concentric circles increases (i.e., the number of magnetic lines of forces increases).	The magnetic field induction $(\vec{B})$ is directly proportional to the current flowing through the wire. $\Rightarrow B \propto i$
If a magnetic needle is brought near the conductor, the deflection in the needle is more and when it is moved away, the deflection decreases.	As the distance from the wire increases, magnetic field $(\vec{B})$ decreases. The magnetic induction (B) at a point is inversely proportional to the distance of the point from the wire. Hence, $B \propto \frac{1}{r}$

From these conclusions, we have

$$B \propto i \text{ and } B \propto \frac{1}{r}$$

$$\therefore \qquad B \propto \frac{1}{r} \Rightarrow B = \frac{Ki}{r}$$

Where K is the constant of proportionality and may experimentally be verified to be equal to $\frac{\mu_0}{2\pi}$

(in S.I system), where μ_0 is called the permeability constant of free space or vacuum, whose value is given as

$$\mu_0 = 4\pi \times 10^{-7} \text{ T m A} \because 1.26 \times 10^{-6} \text{ T m A}^{-1}$$

Hence,
$$B = \frac{\mu_0 i}{2\pi r}$$

EXAMPLE

The Fig. 8.11 shows two long parallel wires carrying currents i_1 and i_2 in opposite directions. What is the magnitude and direction of the resultant magnetic field at the point P?

SOLUTION

The magnetic field B_1 at P due to i_1 is given as,

$$B_1 = \frac{\mu_0 i_1}{2\pi r_i} = \frac{\mu 0}{2\pi} \times \frac{15A}{0.05\text{m}} = \frac{150\mu_0}{\pi} T$$

The magnetic field B_2 at P due to i_2 is given as

$$B_2 = \frac{\mu_0 i_2}{2\pi r_2} = \frac{\mu_0}{2\pi} \times \frac{30A}{0.1m} = \frac{150\mu_0}{\pi} T$$

By the Right-hand thumb rule, we find that both $B1$ and $B2$ are in the same direction at P. Thus, the resultant magnetic field at P is

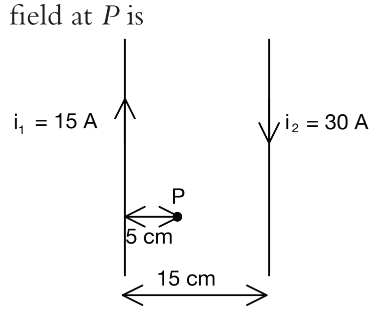


FIGURE 8.11 Two parallel long long wires carrying current

$$B = B_1 + B_2 = \frac{150\mu_0}{\pi} + \frac{150\mu_0}{\pi}$$

$$= \frac{300 \times 4\pi \times 10^{-7}}{\pi} = 1200 \times 10^{-7} \text{ T}$$

$$= 1.2 \times 10^{-4} \text{ T}$$

The direction of B is perpendicular to the plane of the conductors.

2. Magnetic field due to a circular current carrying wire: Let us now study the magnetic field due to a circular current carrying conductor. Take a copper wire, bend it in the form of a circular coil. Connect this coil to a battery with a rheostat and a switch in series. Pass this copper wire over two holes of a cardboard covered with a white paper. Sprinkle iron filings on the cardboard.

It is observed that iron filings arrange themselves in concentric circles as shown in the figure below.

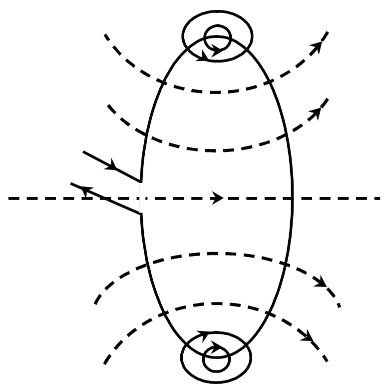


FIGURE 8.12 Magnetic field lines due to a circular current carrying conductor

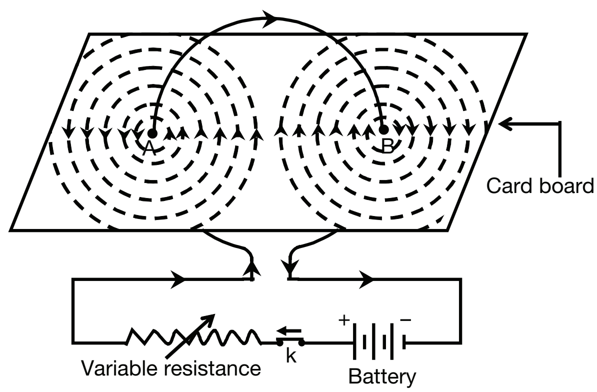


FIGURE 8.13 Magnetic field due to a circular current carrying wire

Observations	Conclusions
An increase in the magnitude of the current in the coil increases the number of magnetic lines of force.	Magnetic field induction is directly proportional to the current flowing in the wire.
It is observed that a magnetic compass shows more deflection if the circular coil is bent into a circle of less radius compared to a coil bent into a circle of larger radius.	As the radius of circular coil increases, the magnetic induction decreases. It' means, $B \propto \dfrac{1}{R}$

Near the conductor, the field is circular and the direction of the field is given by right hand thumb rule. As we move away from the wire towards the centre of the coil, the radius curvature of magnetic lines increases, i.e., they become straighter and almost parallel to each other. At the centre of the coil, the magnetic line of force is perpendicular to the plane of the coil.

The magnitude of the magnetic field at the centre of the circular current carrying wire is found to be:

1. directly proportional to the strength of the current passing through the wire.
2. inversely proportional to the radius of the circular coil.

∴ If B is the magnetic field at the centre, then

$$B \propto i$$

$$B \propto \frac{1}{r}$$

$$\therefore \qquad B = K\frac{i}{r},$$

Where K is the proportionality constant and is equal to $\frac{\mu_0}{2}$ (in S.I. system)

$$\therefore\ B = \frac{\mu_0}{2}$$

Where μ_0 as defined earlier is the permeability constant of vacuum and is equal to $4\pi \times 10^{-7}$ T m A^{-1}.

If there are 'n' turns in the circular coil, then each turn will contribute to the magnetic field at the centre. So the total magnetic field at the centre due to 'n' turns will be equal to $\frac{n\mu_0 i}{2r}$

Electromagnetism

Properties of Magnetic Lines of Force Around a Circular Coil

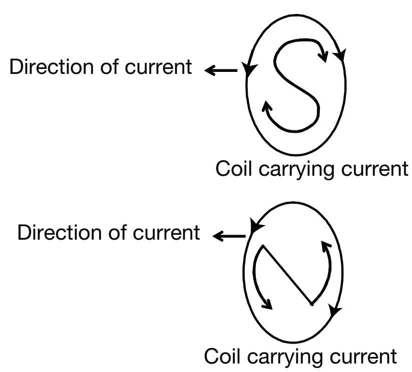


FIGURE 8.14 Sign conventions for magnetic field around a circular coil

1. At the points where current enters or leaves coil is like a straight wire. Hence, the lines of force around these points are almost circular.
2. The lines of force inside coil are in same direction.
3. Magnetic field near the centre of coil is uniform as the lines of force are parallel to each other.
4. At the centre, the plane of magnetic field is perpendicular to the coil. The magnetic field strength increases with the increase in current.
5. Looking at a face of coil, if current is flowing in clockwise direction, the face develops south polarity. If it is in anti clockwise direction, the face develops north polarity.

EXAMPLE

Find the magnetic induction field B at a distance of 10 cm from a long straight conductor carrying a current of 10 A.

SOLUTION

The magnetic induction field near a straight conductor is given by,

$$B = \frac{\mu_0 i}{2\pi r} \tag{1}$$

In the given problem,

$R = 10$ cm $= 0.1$ m, $i = 10$ A, $\mu_0 = 4\pi \times 10^{-7}$ H m^{-1}

Substituting above values in equation (1),

$$B = \frac{4\pi \times 10^{-7} \times 10}{2\pi \times 0.1}$$

$$= 2 \times 10^{-7} \times 10 \times 10$$

$$= 20 \times 10^{-6} \text{ T}$$

$$= 20 \ \mu\text{T}.$$

EXAMPLE

Find the ratio of the magnetic fields, at distances 5 cm and 50 cm from a long straight current carrying conductor.

SOLUTION

Let the fields be B_1 and B_2 at distances 5 cm and 50 cm, respectively. As current remains same, we can write

$$B \propto \frac{1}{r}$$

$$\Rightarrow \frac{B_1}{B_2} = \frac{r_2}{r_1} \tag{1}$$

Substituting the value of r_1 and r_2 in equation (1), we get

$$\frac{B_1}{B_2} = \frac{50}{5} = 10$$

$\therefore$ The ratio of fields is 10 : 1.

EXAMPLE

A circular coil of radius π cm and 100 turns is carrying a current of 10 A. Find the magnitude of the magnetic induction field at the centre of the coil.

SOLUTION

The induction field at the centre of the coil is given by,

$$B = \frac{n\mu_0 i}{2r} \qquad (1)$$

In the problem, the values given are, $r = \pi$ cm $= \pi \times 10^{-2}$ m, $n = 100$, $i = 10$ A

$$B = ?$$

Substituting the above values in equation (1), we get

$$B = \frac{100 \times 4\pi \times 10^{-7} \times 10}{2 \times \pi \times 10^{-2}} = 2 \times 10^{-2}\ \text{T} = 0.02\ \text{T}$$

3. **Magnetic field due to a solenoid carrying current:** An insulated copper coil wound around some cylindrical cardboard or some other core such that its length is greater than its diameter is called a solenoid or a helix.

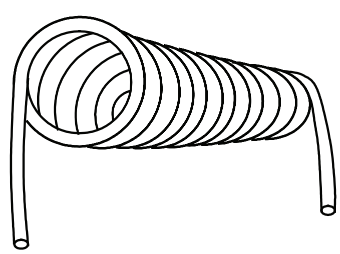


FIGURE 8.15 A Helix of Solenoid

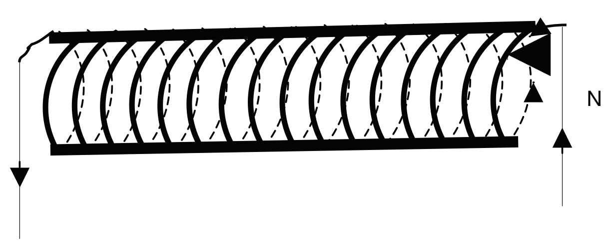


FIGURE 8.16 An insulated copper coil wound around a solenoid

When an electric current flows in the solenoid then each turn of the coil behaves like an independent magnet. All these magnets are arranged in order and therefore the total magnetic strength of the solenoid depends upon the number of turns. Thus, the solenoid acts like a bar magnet.

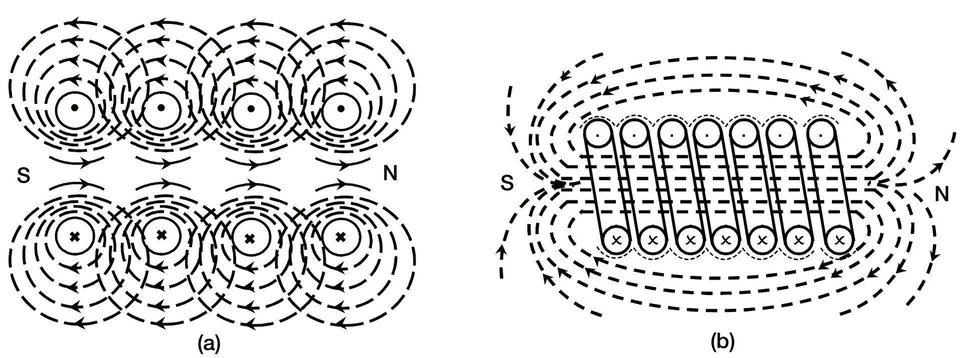


FIGURE 8.17 (a) Magnetic field inside a solenoid, (b) Magnetic field lines around a solenoid

The end in which current flows in an anticlockwise direction becomes a North Pole and the other end where the current flows in clockwise direction, becomes a South pole.

Properties of a Solenoid

1. The magnetic field due to solenoid is directly proportional to the number of turns per unit length of the solenoid.
2. The magnetic field due to the solenoid is directly proportional to the current passing through the solenoid.
3. The field depends upon the nature of material on which the coil is wound.
4. If an iron core is kept inside the solenoid, the field becomes stronger.
5. Laminated soft iron core increases the intensity of the magnetic field inside a solenoid.
6. The magnetic lines of force within the solenoid are almost parallel to each other and to the axis of solenoid.

Force on a Current Carrying Conductor Kept in a Magnetic Field

It is observed that when a current carrying conductor is kept in a magnetic field, it experiences a force.

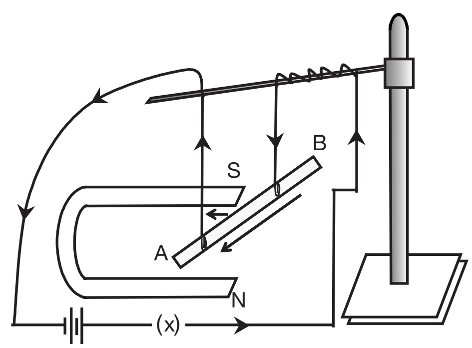


FIGURE 8.18 A current carrying rod, AB experiences a force perpendicular to the length and the magnetic field

Explanation

The lines of force representing the magnetic field between the poles of a horseshoe magnet would be straight and parallel to each other as shown in Fig. 8.19 (a) below.

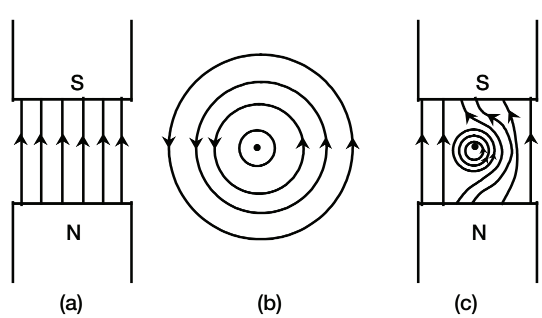


FIGURE 8.19 (a) Parallel magnetic field lines between the poles of a horseshoe magnet, (b) The magnetic field lines around a current carrying conductor, (c) Magnetic field lines when circular current carrying conductor is placed berbetween poles of permanent magnet

The magnetic field lines around a current carrying conductor would be as shown in Fig. 8.19 (b). When this conductor is placed between the poles of the permanent magnet, the two fields would superimpose and there would be a tendency for the lines to crowd on the right side. These lines acting like stretched elastic strings would tend to straighten themselves, and thus push the conductor towards the left. If the current in the conductor is reversed, the effect would be opposite.

The force acting on the current carrying conductor depends upon the following factors:

1. The force on the conductor is directly proportional to the current in the wire.

$$F \propto i \tag{8.3}$$

2. The force on the conductor is directly proportional to the strength of the magnetic field.

$$F \propto B. \tag{8.4}$$

3. The force on the conductor is proportional to the length of the conductor.

$$F \propto \ell \tag{8.5}$$

From (8.3), (8.4) and (8.5), we have $F \propto Bi\ell$

$\Rightarrow F = kBi\ell$, where 'k' is the constant of proportionality.

4. Let the force on a conductor of length 1m, carrying 1 current of 1A and placed in magnetic field of induction 1 T be 1N, then

$$1\ N = K \times \frac{1N}{Am} \times 1\ A \times 1\ \text{m}$$

$$\therefore K = 1$$

$$\therefore F = Bil$$

The equation is applicable only when the current carrying conductor is placed at a right angle to the direction of the magnetic field B.

To find the direction of the force acting on the current carrying conductor, **Fleming's Left Hand Rule** is used which states as follows:

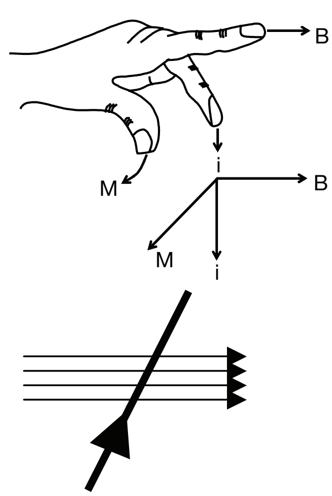


FIGURE 8.20 Fleming's Left-hand Rule

Stretch the forefinger, middle finger and thumb of your left hand in three mutually perpendicular directions. Now, if the forefinger points the direction of magnetic field (B) and the middle finger points in the direction of current (i), then the thumb will point in the direction of motion of the conductor (M), i.e., the force acting on it.

If the magnetic field is not perpendicular to the current carrying wire, then the magnitude of force is given by, $F = Bi\ell\sin\theta$, where θ is the angle which the current carrying wire makes with the direction of the magnetic field.

MOVING COIL GALVANOMETER (SUSPENSION TYPE)

Principle

A current carrying coil kept in a magnetic field experiences a couple which is proportional to the current. It is used to detect and find the direction of the flow of current. Voltmeter and ammeter are modified forms of a galvanometer.

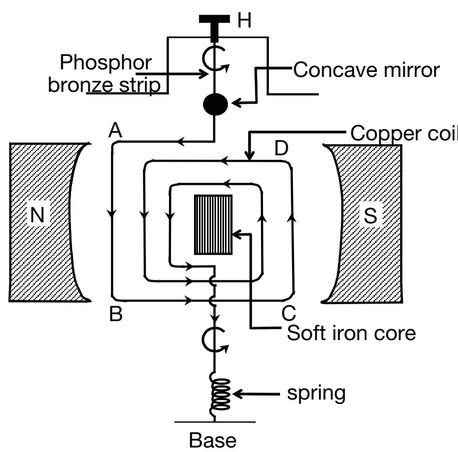


FIGURE 8.21 Moving coil galvanometer

Construction

A moving coil galvanometer consists of a rectangular coil of thin, insulated copper wire suspended between the poles of a strong horseshoe magnet NS by means of a strip of phosphor bronze. It is attached to a torsion head 'H'. There is a small mirror attached to the phosphor bronze strip. This is to observe the deflection produced by the coil, when a current is passed through it. Current enters through the torsion head 'H' and leaves through the spring at the phosphor bronze bottom.

The magnet is made concave in shape so that its magnetic field is always parallel to the plane of the coil when the coil rotates and the magnitude of the magnetic field is the same at every point of time. This type of magnetic field is called radial magnetic field. Furthermore, soft iron core is kept suspended within the coil to increase the magnetic field.

Working

The current carrying coil ABCD is kept in a magnetic field such that the direction of the current and the field are perpendicular to each other. The direction of the current in the arms AB and CD are equal and opposite, therefore, both of them experience equal and opposite forces, forming a couple. Which tries to rotate the coil. This is called the deflecting couple. The direction of the rotation of the coil is given by Fleming's left hand rule.

As the coil rotates, the suspension wire and the loose spring of phosphor bronze get twisted, thus opposing the rotation of the coil. This gives rise to an opposing couple called restoring couple. As the phosphor bronze wire is highly tensile, it does not break when the spring and wire are twisted.

When the moment of force produced by the deflecting couple is equal to the moment of force due to restoring couple, the coil comes to rest, at a new position.

The angle through which the coil has rotated can be measured by lamp and scale arrangement. It is found that the tangent of the angle of deflection is directly proportional to the strength of the current.

$$\tan\theta \propto i.$$

$$\therefore \qquad i = k\tan\theta,$$

where k is a constant and its value depends on

1. The number of turns in the coil,
2. The area of cross section of the coil and
3. The strength of the magnetic field

The value of k is given by the manufacturers of galvanometers and knowing the deflection, we can calculate the current. Most often, using the given k the scale is directly calibrated in terms of current for a given galvanometer.

DC motor

A motor is a device which converts electrical energy into mechanical energy.

Principle: It works on the principle that a current carrying coil experiences a couple when placed in a magnetic field, which sets it into continuous rotations.

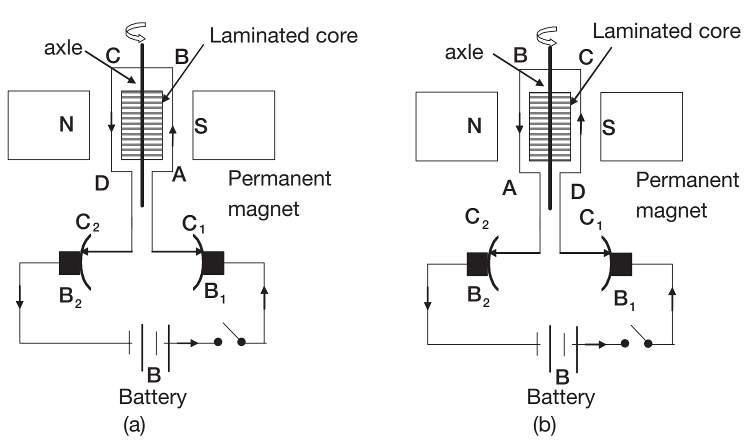


FIGURE 8.22 (a) Clockwise rotation of a motor by passing current, (b) Commutator reverses the current in DC motor.

The main parts of a motor are:

1. Permanent magnet N, S
2. Armature coil A, B, C, D
3. Commutator C_1, C_2
4. Brushes B_1, B_2
5. Battery B

The permanent magnet produces the necessary magnetic field. Its poles are made concave in shape so as to give radial field. In big motors, in order to have strong magnetic field, electromagnets are used.

Armature coil consists of a large number of insulated copper coils wound on a laminated soft iron core. The function of the coil is to set up magnetic field when a current is passed through it. The core is laminated to avoid any eddy current loss, and to provide strong magnetic field when current flows through the coil.

Commutator

The ends of the wire are connected to the two split rings C_1 and C_2 of the commutator. The function of the commutator is to change the direction of the current after half a rotation of the coil.

Brushes

The function of the two brushes B_1 and B_2 is to give electrical connection from the battery wire to the rotating coil, i.e., between the stationary parts and the moving parts of the electric circuit.

Battery

The function of the battery is to give the motor the necessary electrical energy.

Working of the Motor

The current from the positive terminal of the battery passes through the brush B_1, split ring C_1, and the armature coil ABCD returns via split ring C_2, brush B_2, to the negative terminal of the battery. The coil is placed in such a way that the magnetic field created by it is perpendicular to field due to magnets.

The current carrying coil is kept in the magnetic field of the permanent magnet. Therefore it will experience a torque.

As per Fleming's left hand rule, the arm AB of the coil experiences a force perpendicular to the plane of the paper and into the paper. The arm CD experiences a force perpendicular to the plane of paper and outwards (opposite to that of end AB) as shown in Fig. 8.22(a). These two forces constitute a couple and the motor rotates in *clockwise direction*.

When the coil turns through 90°, the magnetic field due to the coil and the field due to the permanent magnet become parallel to each other. Therefore rotation should stop as there will not be any couple when the two fields are parallel. But due to the inertia of motion, it continues to rotate and it turns through 180°.

Now the commutator reverses the direction of the current which flows along DCBA. (as shown in Fig. 8.22(b). The arm CD of the wire experiences a force perpendicular to the plane of the paper and into the paper, and the arm AB experiences a force perpendicular to the plane of the paper and outwards (opposite to that of end AB). Thus, the motor rotates continuously in one direction.

The revolutions per minute of a motor coil depends on the following:

1. The number of the turns of the coil
2. The area of the coil
3. The magnitude of the current
4. The strength of the magnetic field.

Electromagnetic Induction

We have seen that when current flows through a conductor, it produces a magnetic field. Micheal Faraday, through series of experiments, showed that current can be induced in a coil if it is moved in a magnetic field or if magnet is moved relative to coil. Due to the relative motion between them, the magnetic flux (ϕ_0) linked with the coil, i.e., the number of lines of force passing normally through it, changes. This sets up an emf at the end of which causes current to flow. Faraday found that the current flows as long as there is continuous change in the magnetic flux passing through the conducting coil. Thus, even if both the coil and magnet are stationary, current can still be induced in coil, if the magnetic field is changed continuously which is possible by using electromagnets. This phenomenon of inducing current by changing the magnetic field associated with an electric circuit containing no source is called electromagnetic induction.

Faraday's Experiments

When a magnet is moved towards a coil with its north pole facing the coil as shown in the Fig. 8.23, Faraday observed a deflection in the galvanometer. The amount of deflection is found to be more if the speed of magnet is more.

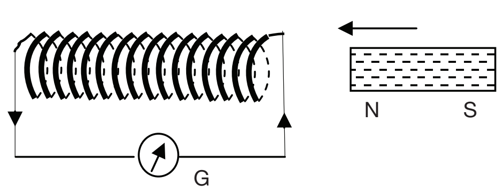


FIGURE 8.23 A magnet moved towards a coil with its north pole facing the coil

When the magnet is moved away from the coil, then it produces a deflection in the opposite direction as compared to the case, when the magnet is moved towards the coil.

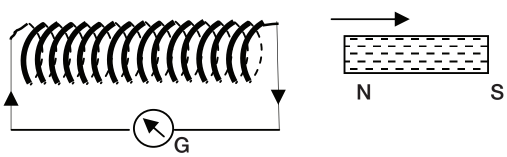


FIGURE 8.24 A magnet moved away from the coil

When the magnet is moved towards the coil with its south pole pointing towards the coil, then it produced a deflection in the opposite direction as compared to the case, when the north pole was pointing towards the coil.

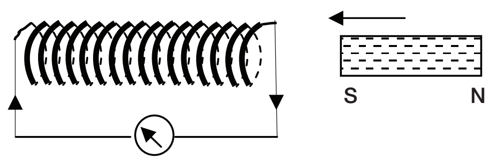


FIGURE 8.25 A magnet moved towards the coil with its south pole pointing towards the coil

Once again, if the magnet is moved away from the coil with the south pole pointing towards the coil, then it produces deflection in the opposite direction as compared to the case when the magnet is moved towards the coil.

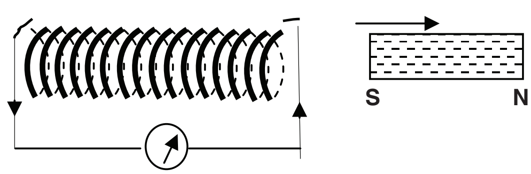


FIGURE 8.26 A magnet moved away from the coil with the south pole pointing towards the coil

Similar observations were made when the coil was moved towards or away from a stationary magnet. The deflections in the galvanometer were governed by the orientation of the magnet and the direction of the motion of the coil.

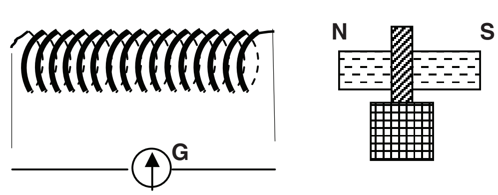


FIGURE 8.27 The coil moved towards or away from a stationary magnet.

Now, if we fix both the magnet and the coil such that there is no relative motion, then no deflection is observed in the galvanometer.

On the basis of the observations made in his experiments, Faraday formulated the following laws.

There are only two laws of EM induction, due to Faraday.

FARADAY'S LAWS OF ELECTROMAGNETIC INDUCTION

1. Whenever the magnetic flux linking a coil changes, then an emf is induced in the coil.
2. The magnitude of the induced emf is directly proportional to the rate of the change of flux.

From the above observations, we can conclude that if there is a *relative motion between the magnet and the coil,* an emf is induced in the coil.

1. This emf lasts so long as there is a relative motion between the magnet and the coil.
2. If there is no relative motion, no emf is induced.
3. The magnitude of emf depends upon the relative speed.
4. The magnitude of emf depends upon the number of turns in the coil.

Following the above conclusions, Faraday formulated the law for induced emf in a coil as, the induced emf in a coil is equal to the negative rate of the change of magnetic flux linked with the coil.

Thus, $$E = -N\frac{d\varphi}{dt}$$

The observations of Faraday's experiments on electromagnetic induction and his laws can also be studied by replacing the permanent magnet with an electromagnet.

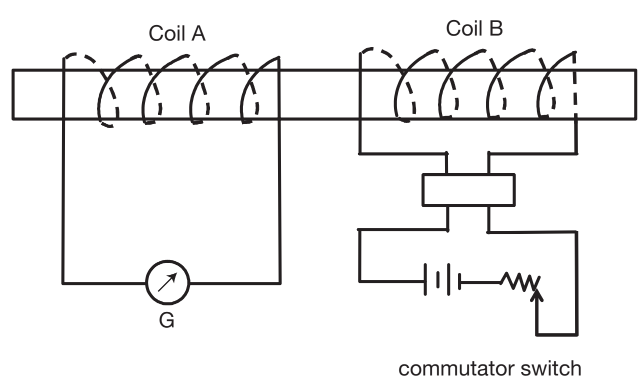


FIGURE 8.28 Faraday's Experiment

Wind two coils on a soft iron core separated by some distance, connecting the ends of coil A to a galvanometer and the ends of B to a battery through a rheostat (to vary the current) and a commutator switch (to reverse the current). It is observed that the needle of the galvanometer instantly deflects to one side and returns to zero quickly whenever the key is closed. When the key is opened, thus disconnecting the coil from the battery, a greater deflection is observed is the galvanometer, but in the opposite directions.

Repeating the experiment after reversing the direction of current in coil B, similar observations are recorded.

LENZ'S LAW

According to Lenz's law, the direction of induced current is such that it opposes the very cause that produces it.

Consider a bar magnet moving towards a coil with its north pole facing the coil. Due to (Fig. 8.23) movement of the magnet, current is induced in anti-clockwise direction in the coil when it is viewed from magnet. The face pointing towards the magnet becomes north pole and opposes its movement. When magnet is pulled away such that its north-pole leaves the coil, (Fig. 8.24) current is induced in clockwise direction giving the face of the coil pointing towards magnet a south polarity. Thus, the movement of magnet which is responsible for induced current, is always opposed by the current itself.

Let $d\phi_B$ be the change in the magnetic flux in a short interval of time dt. The induced emf (E), according to Faraday's law is given by,

$$E = \frac{d\varphi_B}{dt} \tag{8.6}$$

According to Lenz's law, the induced emf is such that it opposes the cause producing it. Hence equation (8.6) on application of Lenz's law becomes

$$E = \frac{d\varphi_B}{dt} \tag{8.7}$$

If the coil contains N turns, equation (8.7) becomes

$$E = -N\frac{d\varphi_B}{dt}$$

Fleming's Right-hand Rule

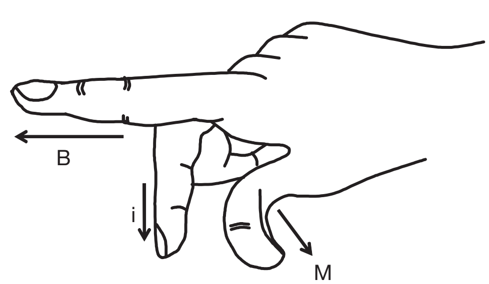


FIGURE 8.29 Fleming's Right-hand Rule

To determine the direction of induced current in a conductor, when it is moved across a magnetic field, Fleming proposed the 'Right-hand rule'.

Stretch the forefinger, middle finger and thumb of your right hand in three mutually perpendicular directions, such that the forefinger points the direction of magnetic field(B), the thumb indicates the direction of motion(M), then the middle finger represents the direction of induced current (i) in the conductor.

Moving Coil Microphone

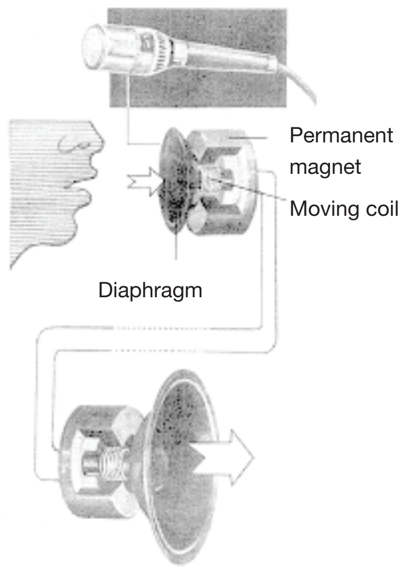


FIGURE 8.30 Microphone and loudspeaker

It is a device which converts sound energy into electric energy. It works on the principle of electromagnetic induction.

It consists of a diaphragm, a moving coil and a permanent magnet. The coil is kept in the magnetic field. As a person speaks into microphone, diaphragm is set into vibrations. The moving coil connected to it begins to vibrate accordingly. It being under magnetic field, a electric current is induced in it whose variations represent the vibrations of original sound. This electrical signal is amplified and then fed to a loud speaker.

Loud Speaker

It converts electric energy into sound energy. It consists of a permanent magnet, moving coil and a diaphragm in the form of paper cone as shown in the Fig. 8.30.

The electrical signal corresponding to the variations of original sound from the microphone is fed to the coil placed between the poles of permanent magnet. The coil begins to vibrate and sets the paper cone into vibrations. The air around the loudspeaker vibrates reproducing the original sound more loudly.

ELECTRIC GENERATOR

An electric generator is a device which converts mechanical energy into electrical energy. When a coil is rotated in a magnetic field, an emf is induced in it. The mechanical energy required to rotate the coil is converted into an electrical energy. Hence, an electric generator converts mechanical energy into electrical energy.

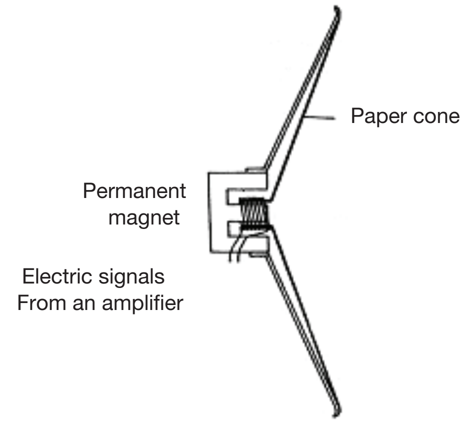


FIGURE 8.31 Parts of a loud speaker

There are two types of generators—Alternating Current (AC) generator and Direct Current (DC) generator. In the former, the current changes direction after every half-rotation. In the latter, the current is unidirectional throughout.

The Alternating Current Generator

The main parts of an AC generator are the horseshoe magnet, armature (coil), slip rings and carbon brushes.

Construction

The construction of an electric generator is similar to that of an electric motor. An AC generator consists of a rectangular coil ABCD known as armature. This armature is rotated rapidly between the poles of a permanent horseshoe magnet. The ends of the rectangular coil A and D are connected to two circular metal pieces called slip rings A_1 and A_2. The slip rings rotate along with the coil. The two pieces of carbon brushes B_1 and B_2 are kept in contact with the slip rings. The carbon brushes are capable of tapping the current produced in the rotating coil.

Working

1. Assume that the rectangular coil ABCD is in horizontal position initially [See Fig. 8.32 (1)].
2. Let the rectangular coil ABCD be rotated from 0° to 90°, such that during its rotation, the side AB of the coil moves downwards and the side CD of the coil upwards. Hence the flux linked decreases, but the rate of change in the flux increases from zero to maximum. Hence, emf induced increases from zero to maximum, (according to Faraday's laws of electromagnetic induction). The current flows in the direction ABCD according to Lenz's Law.
3. On further rotation from 90° to 180°, the side AB of the coil starts moving upwards while the side CD of the coil moves down. Hence, flux linked increases from zero to maximum. But the rate of change in flux decreases from maximum to zero. The emf induced in the coil decreases from maximum to zero. The current continues to flow in the direction ABCD, but the magnitude of the current decreases.

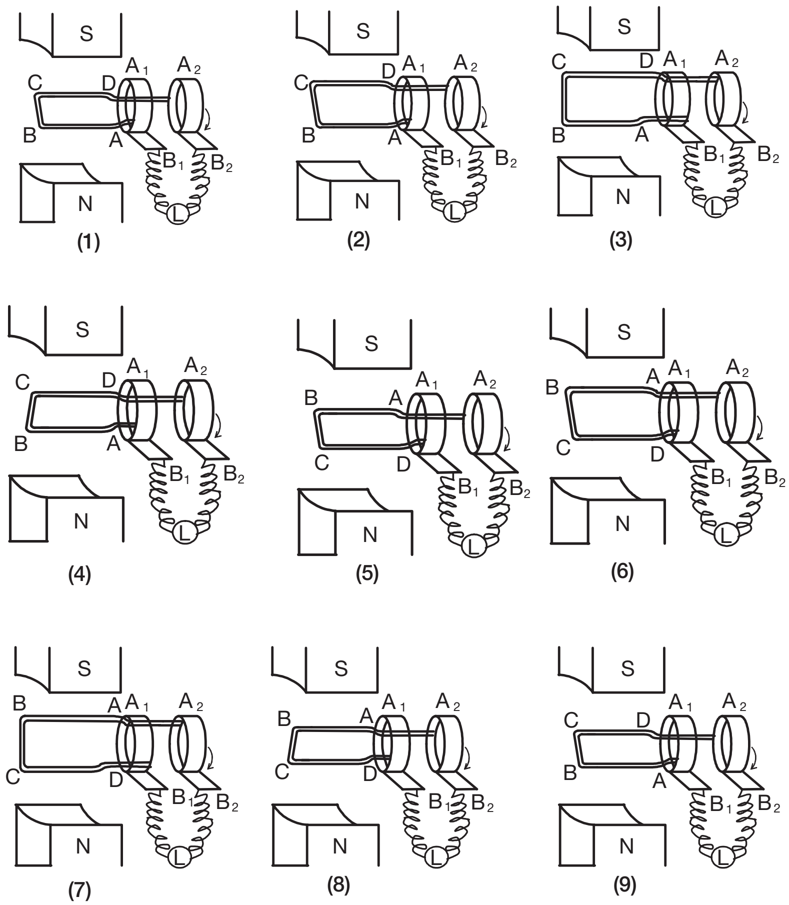


FIGURE 8.32 Working of an AC Generator in various steps showing positions of coil.

4. On further rotation of the coil from 180° to 270°, the side AB of the coil which is now once again horizontal moves upwards while the side CD of the coil moves downwards. The flux linked by the coil decreases from maximum to zero. But the rate of change in flux increases from zero to maximum in the opposite direction. Hence the emf induced is maximum, but in opposite direction, and the current starts flowing in the direction DCBA, with the magnitude increasing, in accordance with the Lenz's Law.

5. On further rotation of coil from 270° to 360°, the side AB of the coil moves downwards while the side CD of the coil moves upwards. The flux linked by the coil increases from zero to maximum and the rate of change in flux decreases from maxiumum to zero in opposite direction. Therefore, the emf induced also decreases from maximum to zero in opposite direction, with decreasing current continuing to flow in the direction DCBA.

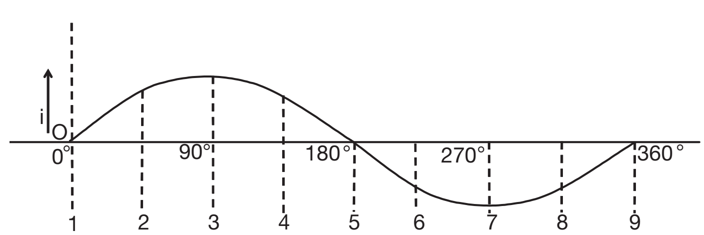


FIGURE 8.33 The variation in the current produced for various positions of the coil

In the above, the direction of induced current at any instant can be found using Fleming's right hand rule or Lenz's Law. For one complete rotation of the coil, i.e., from 0° to 360°, the coil produces an alternating voltage (AC). The variation in the current produced for various positions of the coil is shown in the graph.

Alternating Current (AC) Dynamo

Principle

When a conducting coil in a closed circuit in a constant uniform magnetic field rotates, the magnetic flux passing through it changes continuously producing an induced emf or current in the circuit.

Construction

It consists of four major parts.

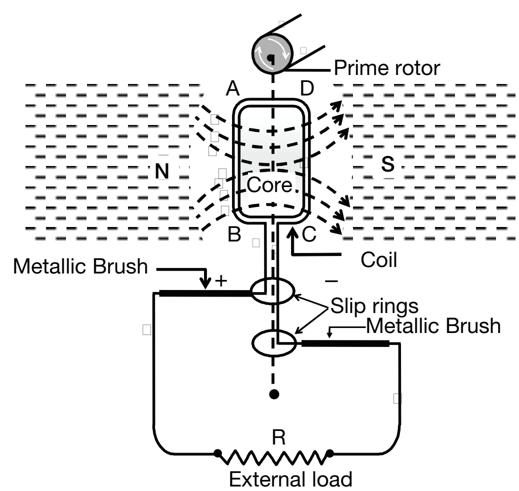


FIGURE 8.34 An Alternating Current (AC) Dynamo

1. **Armature:** It consists of insulated copper coil wound over a rectangular frame and soft iron core which a laminated. In the Fig. 8.34, ABCD represents armature.
2. **Slip rings:** S_1 and S_2 are two metallic rings connected to the ends of the rectangular coil. They rotate along with the coil about the same axis.
3. **Carbon brushes:** B_1 and B_2 are two carbon brushes used as electrical contact between moving parts (S_1 and S_2) and stationary part (load R).
4. **Permanent magnet:** N-S is powerful horse shoe magnet having concave cylindrical poles. It produces a uniform radial magnetic field.

Working

As the amature ABCD is rotated between the poles of magnet, the magnetic flux linked with it changes continuously resulting in generation of induced emf which causes current to flow through the coil and load resistance R. As the position of amature coil changes due to its rotation, the magnitude of induced current also changes as shown in following diagram.

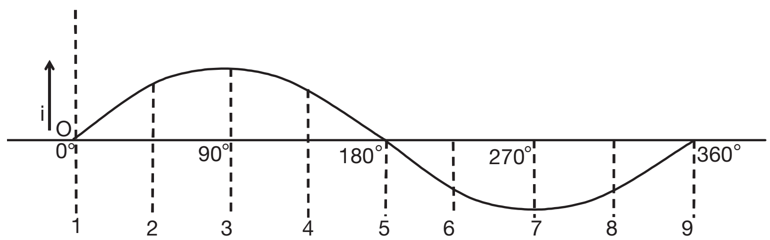


FIGURE 8.35 Graph of the magnitude of induced current

In its initial position where angle of rotation is zero, the plane of the coil is perpendicular to the magnetic lines of force or magnetic flux (ϕ_B). Maximum number of lines of force pass through coil but the induced current is zero as coil is stationary. Let the coil be rotated in counter clockwise direction such that arm AB goes down and CD comes up. As the coil rotates by 90° $\pi/2$, its plane becomes parallel to lines of forces. The magnetic flux linked with it is zero but the change in magnetic flux ($d\phi_B$) with respect to original position is maximum. Hence, maximum induced current flows. The direction of this current can be found by applying fleming's right hand rule. As the arm AB moves in downward direction and lines of force are from right to left, current flows from B to A in the arm AB. Arm CD has moved in upward direction, hence current through it flows in opposite direction, i.e., from D to C. Through the load R, it flows from B_1 to B_2. As the coil rotates further by 90°, it again becomes perpendicular to magnetic flux with AB below CD. The magnetic flux passing through the coil is same as in initial position. Hence the change $d\phi_B$ is zero causing the induced current to decrease from maximum to zero in the same direction. From this position as the coil rotates by 90°, AB moves up and CD down such that its plane is parallel to magnetic flux. As the change in the flux ($d\phi_B$) is maximum with respect to 'O' the induced current increases from zero to maximum in opposite direction which can be verified by applying flemings right hand rule. Now the current flows from A to B, in AB, C to D in CD and B_2 to B_1 in R. As the coils comes back to its original position by rotating more by 90°, current decreases from maximum to zero in the same direction. This cycle is repeated as coil continues its rotational motion.

It can be seen that during 1st half of rotation, i.e., from 0 to π, current flows from B_1 to B_2 in R, while during 2nd half from π to 2π, it flows from B_2 to B_1. Thus, current changes its direction after regular intervals of time. Hence alternating current is generated. This reversal in current direction is brought about by slip rings S_1 and S_2 which alternately connect the two ends of coil to B_1 and B_2.

The magnitude of induced current can be increased by increasing:

1. The number of turns in coil.
2. The area of cross section of coil.
3. The intensity of magnetic field.
4. The speed of rotation of coil.

RMS Voltage and Peak Voltage

In this type of a generator, we observe that the induced voltage across the output terminals alternates between $+V_0$ and $-V_0$ as shown in the Fig. 8.35. The alternation from $+V_0$ to $-V_0$ and again back to $+V_0$ (or $-V_0$ to $+V_0$ to $-V_0$) is referred to as one cycle, and if the frequency is n Hz, it implies that n cycles are completed in one second. The voltage V_0 is called peak value.

If the terminals of this generator are connected across a resistor, the current flowing through the circuit would also alternate at the same frequency and is referred to as alternating current. Thus, such a source of electrical energy is referred to as AC source or Ac supply. The symbol for an AC source is. $\textcircled{\sim}$

If a heater coil is connected to an AC supply of peak voltage V_0, the heater coil gets continuously heated even though the direction of current alternates. It is found that the heating effect produced by such a source would be the same as that caused by a constant voltage source such as a cell of terminal p.d. equal to $V_0/\sqrt{2}$. It can be shown that this value is the square root of the mean of the squares of the instantaneous voltages across the terminals of the AC supply. Hence, it is called the Root Mean Square (RMS) value.

$$\therefore \qquad V_{\text{RMS}} = \frac{V_0}{\sqrt{2}} \text{ and } I_{\text{RMS}} = \frac{I_0}{\sqrt{2}}$$

EXAMPLE

Find the RMS value of +4, +2, 0, –2 and –4.

SOLUTION

Let $x_1 = 4$, $x_2 = +2$, $x_3 = 0$, $x_4 = -2$ and $x_5 = -4$.

Then, $x_1^2 = x_5^2 = 16$

$x_2^2 = x_4^2 = 4$

$x_3^2 = 0$

$\therefore\ x_1^2 + x_2^2 + x_3^2 + x_4^2 + x_5^2 = 16 + 4 + 0 + 4 + 16 = 40$

Mean of the squares $= \frac{40}{5} = 8$

Square root of the mean $= \sqrt{8} = 2\sqrt{2}$

$\therefore$ The RMS value of the given numbers $= 2\sqrt{2}$

EXAMPLE

If an AC supply is rated as 220 V, find the peak voltage.

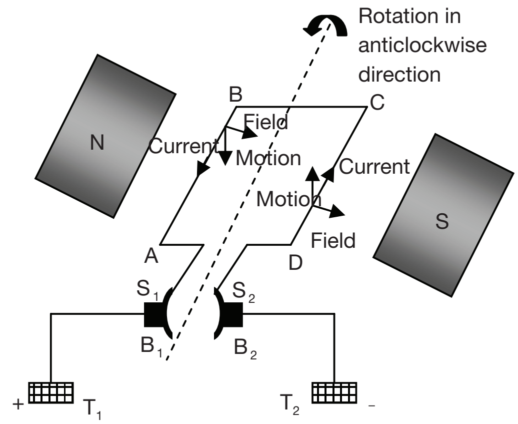


FIGURE 8.36 DC Generator

SOLUTION

The rating of an AC supply refers to its RMS value

Thus, $V_{RMS} = 220$ V

i.e., $\frac{V_0}{\sqrt{2}} = 220$ V

$\therefore \quad V_0 = 220\sqrt{2}$ V

Therefore, the peak voltage is $220\sqrt{2}\text{V} \simeq 311\text{V}$.

The Direct Current Generator

When the current flows continuously in one direction, the current is referred to as direct current. To obtain such a DC current, the AC generator is modified by replacing the slip rings with a commutator (half-slip rings or split rings) S_1S_2.

Working

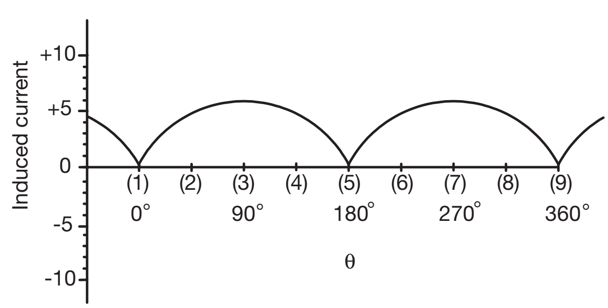


FIGURE 8.37 Graph of direct current

Let the generator coil ABCD be initially in the horizontal position. Let the coil be rotated in an anticlockwise direction as shown in the Fig. 8.37, side AB downwards and side CD upwards. According to Fleming's right-hand rule, the induced current flows in the direction BA in the side AB and in the direction DC in the side CD. Thus, induced current flows in the direction DCBA during the first half of rotation.

After half rotation, arms AB and CD interchange their positions. When the coils interchange their positions, the commutator split rings S_1 and S_2 automatically change their contact with the carbon brushes. Due to this, the current flowing in the load remains in one direction. Thus, the brush B_1 remains always positive and the brush B_2 remains always negative. Thus, the current would always be flowing out from the terminal T_1.

Inductance of a Coil

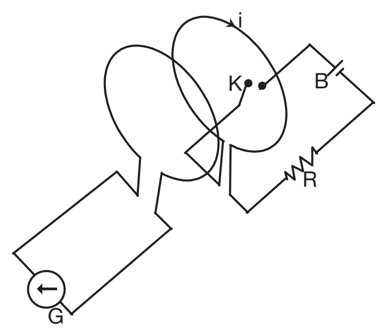


FIGURE 8.38 Circuit diagram to show a coil and a magnet induces an emf in the coil

The relative motion of a coil and a magnet induces an emf in the coil. This emf is referred to as dynamically induced emf, an since the emf is induced due to the actual motion of either the magnet or coil. If a change in the current in one coil induces an emf in another coil (due to changing magnetic field linked with each other), then the emf induced in the second coil is referred to as statically induced emf.

Inductance is the property of a coil to induce emf in the same coil or another coil placed near it due to the changes in the current in the coil.

Self-Induction

Every current carrying coil produces a magnetic field which is linked to the same coil. When the current in the coil changes, the magnetic flux produced also changes and is linked to the coil itself. According to Faraday's law of induction, this change in magnetic field produces an induced emf which opposes the change.

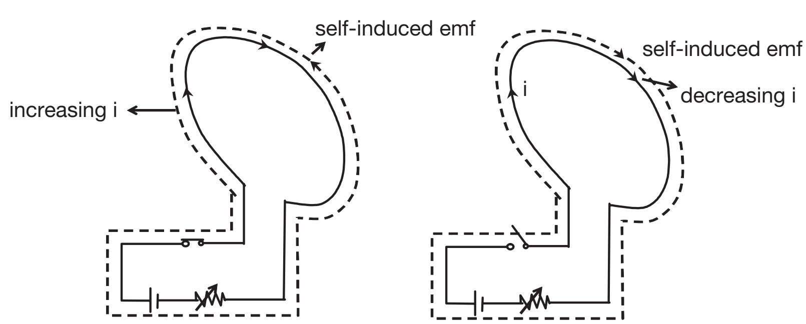


FIGURE 8.39 Self-induction in current carrying coils

This phenomenon in which an induced emf is produced in a coil due to a change in the current in the same coil is called self-induction, and the induced emf is generally referred to as self-induced emf.

The induced emf is equal to the rate of change of flux.

$$E = -\frac{d\varphi}{dt}$$

The negative sign indicates the induced emf opposes the applied emf.

But $$\frac{d\varphi}{dt} \propto \frac{di}{dt} \text{ and so } \frac{d\varphi}{dt} = L\frac{di}{dt}$$

$\therefore E = -L\dfrac{di}{dt}$ where 'L' is the constant of proportionality and is called self-inductance of the coil.

$$L = \frac{-E}{\left({}^{di}\!/\!{}_{dt}\right)}$$

The self inductance 'L' of a coil is numerically equal to the ratio of the induced emf to the rate of change of current in the coil.

Mutual Induction

The phenomenon, due to which a change in current in one coil induces an emf in another coil held close to it, is called 'mutual induction'.

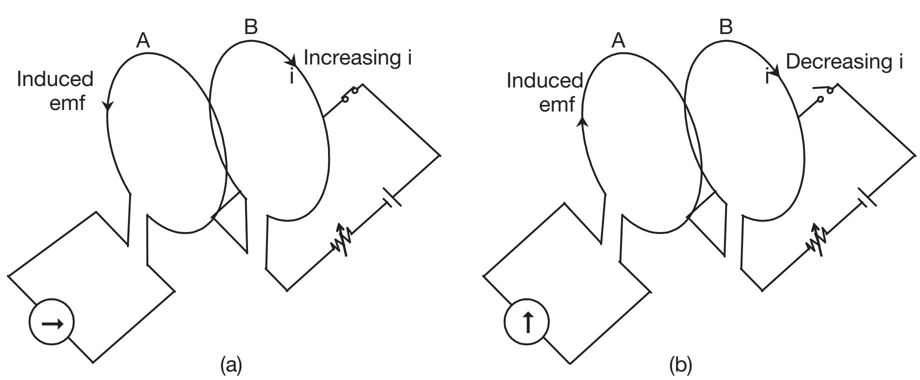


FIGURE 8.40 (a) Induced emf in coil A on increasing current in coil B, (b) Induced emf in coil A on decreasing current in coil B

Here, the current is changing in coil 'B'. Therefore the flux associated with the coil B is changing. If we place one more coil 'A' near it, the changing magnetic field in coil 'B' will produce an emf in the second coil 'A'. This phenomenon is known as mutual induction.

$$E_A \propto -\frac{di_B}{dt}$$

$$E_A = -M_{AB}\frac{di_B}{dt}$$

Here, the constant of proportionality 'M' is called the 'mutual inductance'.

The negative sign indicates that the induced emf opposes the change producing it. The mutual inductance of a coil is numerically equal to the ratio of the induced emf in the coil to the rate of change of current in the another coil, placed near it.

$$M_{AB} = -\frac{E_A}{di_B/dt}$$

The unit of inductance (self-inductance and mutual inductance) is Henry (H) and 1 H = 1 V s A^{-1} (volt second per ampere).

Transformer

It is a static electrical device used to step-up a low voltage to a high voltage or to step-down a high voltage into a low voltage and is used on AC circuits. Transformer works on the principle of mutual induction. The main parts of a transformer are:

1. A soft iron laminated core
2. A primary coil
3. A secondary coil

Core

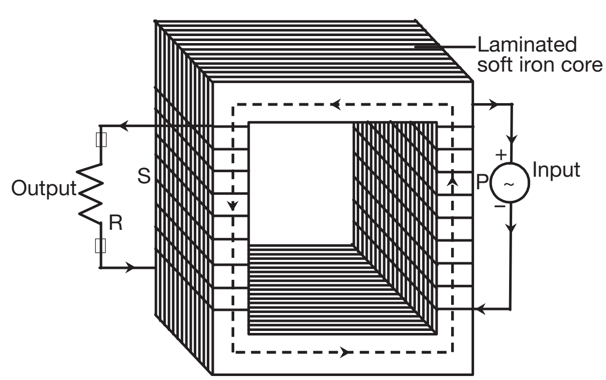


FIGURE 8.41 The core of a transformer

The core is made up of a rectangular frame made up of silicon steel. Each sheet is insulated from the neighbouring sheet by varnishing it.

1. It is made up of soft iron to increase the magnetic permeability.
2. It is made up of laminations to avoid eddy current loss.

Primary Coil

The input of the alternating voltage is connected to this coil. Since the voltage changes with respect to time, changing magnetic flux is introduced by this coil. This changing flux is coupled to the secondary coil through the core.

Secondary Coil

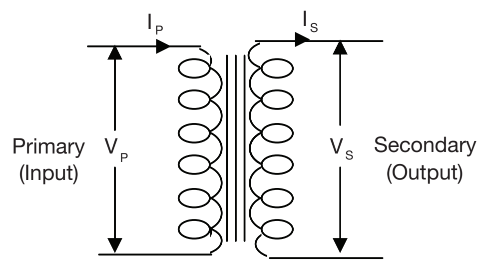


FIGURE 8.42 Secondary coil

The output from the transformer is taken from this coil. The changing flux due to changing voltage in the primary coil is coupled to the secondary coil. This will produce an alternating voltage.

The symbolic representation of a transformer in electric circuits is as shown below.

Step-Up Transformer

A step-up transformer steps the primary (incoming) voltage up to a higher value. If the number of turns of the secondary coil is more than the number of turns of the primary coil, it is called a step-up transformer. In this case, the secondary voltage will be more than the primary voltage. The secondary current is less than the primary current.

Step-Down Transformer

A step-down transformer steps the primary voltage down to a lower value. If the number of turns of the secondary coil is less than that of the primary coil, it is called a step-down transformer. In this case, the secondary voltage will be less than the primary voltage. The secondary current is more than the primary current in a step-down transformer.

Working

If an AC voltage V_1 is applied to the primary coil of N_1 turns, an alternating current flows in the primary coil and produces a changing magnetic flux. This magnetic flux is linked to the N_2 turns of the secondary coil, thereby, an emf is induced in the secondary coil. Let it be V_2.

According to Faraday's law of induction,

$$E = -\mathrm{N}\frac{d\varphi_B}{dt}$$

i.e., emf per turn, $E_{\text{tum}} = \frac{E}{N} = -\frac{d\varphi_B}{dt} = \text{constant}$

Thus, emf per turn is the same for both primary and secondary coils.

$$\therefore \frac{V_1}{N_1} = \frac{V_2}{N_2}$$

Thus, the relation between the number of turns and the voltage in a transformer is given by,

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} \tag{8.8}$$

Since in an ideal transformer, there is no loss of power,

power in the primary = power in the secondary coils. If I_1 and I_2 are the currents in the primary and secondary coils, respectively,

$$P = V_1 I_1 = V_2 I_2$$

$$\frac{V_1}{V_2} = \frac{I_2}{I_1} \tag{8.9}$$

From. (8.8) and (8.9),

$$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$$

$$V_2 = V_1 \frac{N_2}{N_1} \text{ (transformation of voltage)}$$

$$I_2 = I_1 \frac{N_1}{N_2} \text{ (current transformation)}$$

$\therefore N_2 > N_1 \Rightarrow$ step-up transformer

$\therefore N_2 < N_1 \Rightarrow$ step-down transformer.

EXAMPLE

In a transformer, the ratio of the number of turns of a primary to a secondary coil is 2 : 5. If the current through the primary coil is 10 A and input power is 300 W, find the current and voltage in the secondary coil.

SOLUTION

The turn-ratio and currents are related as

$$\frac{N_1}{N_2} = \frac{I_2}{I_1} \tag{1}$$

In the problem, values given are $\frac{N_1}{N_2} = \frac{2}{5}$, $I_1 = 10$ A

Substituting the above values in (1) and solving for I_2, we get

$$\frac{2}{5} = \frac{I_2}{10}$$

$$\Rightarrow I_1 = \frac{2}{5} \times 10 \Rightarrow I_2 = 4 \text{ A}$$

In an ideal transformer, the input and the output powers are equal. Therefore, we can write

$$V_1 I_1 = V_2 I_2 \qquad (2)$$

But the input power is given as 300 W. Substituting this in equation (2), we get

$$V_2 I_2 = 300$$

Substituting $I_2 = 4$ A in the above equation, we get

$$V_2 \times 4 = 300 \;\Rightarrow V_2 = \frac{300}{4}$$

$$\Rightarrow V_2 = 75 \; V.$$

Energy Loss in Transformers

1. Due to the finite resistance of the primary and secondary coils, there will be a power loss in the primary and secondary coils due to heat energy developed in them. This is known as copper loss or heat loss.

   Copper loss = I^2R
2. A part of the energy is wasted on account of the magnetic flux in the soft iron core. This is known as magnetic loss or hysteris loss.
3. A part of energy is wasted on account of the eddy current. This is known as eddy current loss. This is minimized by using laminated core.
4. Loss due to flux leakage.

Uses of a Transformer

1. At the generating station, a transformer is used to step-up the voltage before transmitting it for long distances to avoid losses. At the receiving end, it is used to step-down to the required level to supply to the domestic users. It is used to change the voltage to required level.
2. In a radio, TV, X-ray tube, etc., either the step-up or step-down transformers are used.
3. In stabilizers, step-up–cum–step-down transformers are used to control the fluctuations in voltage.

Eddy Currents

Induced currents produced in a solid core piece of metal placed in changing magnetic field is called an eddy current. It has advantages and disadvantages.

Let us see why eddy currents are undesirable. The eddy currents produced heat up the metallic solid core. The heating of core by eddy currents is undesirable because

1. it results in the loss of useful energy.
2. it increases the risk of the breakdown of the insulation of the winding.

Eddy currents can be eliminated by the following methods.

1. The solid metal is cut in such a manner so as to increase the path for the eddy current. Hence the resistance increases and eddy current reduces.
2. Eddy currents can be reduced by using a laminated core. Instead of using a solid core, if we use thin sheets packed together and insulated between two layers, the resistance increases and the eddy current is reduced. This is the reason why the coil of a transformer is wound on a laminated core and not on the solid core.

Uses of Eddy Current

We can make use of the eddy current for some useful purpose. Eddy currents produce heat in metals. Hence, metals can be melted using the eddy current. This is the principle in induction melting and heating furnaces.

TEST YOUR CONCEPTS

Very Short Answer Type Questions

1. State the expression for magnetic induction field on axial and equatorial line. Give its direction.
2. Define retentivity.
3. What is meant by an electromagnetic induction?
4. State Fleming's right hand rule.
5. Define a neutral point. Give the location of neutral points when the North Pole of a bar magnet faces geographic north and geographic south.
6. Give the relation between V, N and I with respect to the primary and secondary coils of a transformer.
7. State Lenz's law.
8. Explain the principle of an electric generator.
9. Define: (1) magnetic field (2) magnetic lines of force
10. Define intensity of magnetisation, magnetic susceptibility and retentivity. Give their SI units.
11. Which observation made in Oersted's experiment with a current carrying conductor concludes that the magnetic induction is proportional to the strength of the current in the conductor?
12. What is the difference between an AC dynamo and a DC dynamo?
13. What is magnetic saturation?
14. Define dia, para and ferromagnetic substances. Give examples.
15. Why the magnetic lines of force away from a straight conductor carrying current are elliptical?
16. Define: (a) inductance (b) selfinduction (c) mutual induction
17. Define the pole strength of a magnet. What is its S.I. unit?
18. What is a domain in ferromagnetic substances?
19. What type of magnetic field is observed at the centre of a circular coil carrying current?
20. Give the principle of a transformer. State the types of transformers.
21. What is meant by electromagnetism?
22. Why is Ewing's theory called molecular theory of magnetism?
23. What is meant by a solenoid?
24. Why do magnetic lines of force pass through iron more freely than through air?
25. According to Ewing's molecular theory, why is steel used to make permanent magnets?
26. Which rule is used to find the force on a current carrying wire placed in a magnetic field?
27. Mention the energy conversions taking place in a loud speaker and a microphone.
28. Define magnetic induction field B. Intensity of magnetic field (H) and state their units.
29. What happens to the length of a iron bar when it is magnetised?
30. State the principle of a moving coil galvanometer.

Short Answer Type Questions

31. Compare the properties of
    (a) diamagnetic (b) paramagnetic
    (c) ferromagnetic substances
32. Explain how will you calculate magnetic moment (M) of a bar magnet using neutral points.
33. Explain domain theory.
34. Give the properties of a solenoid.
35. Calculate magnetic field induction B due to a long straight conductor carrying a current of 5 A at a perpendicular distance of 10 cm from it.
36. Write a note on important magnetic properties.
37. Give various characteristics of magnetic lines of force.
38. Describe Ewing molecular theory.
39. Calculate magnetic field induction 'B' at the centre of a circular coil having 500 turns, radius π cm and carrying a 5 A of current.
40. Explain Oersted's experiment.
41. Explain why isolated magnetic poles do not exist.
42. What is modern electron theory?

43. Explain Faraday's experiment using a magnet and a coil and state Faraday's laws of electromagnetism

44. Explain magnetic induction 'B' and intensity of magnetizing field.

45. Distinguish between absolute and relative permeability of a medium.

Essay Type Questions

46. Describe a moving coil galvanometer.

47. Explain in detail:
 (a) Electric motor (b) AC generator
 (c) DC generator (d) Transformer

48. Write a note on terrestrial magnetism.

49. Write a note on:
 (1) self-inductance (2) mutual inductance

50. How do you locate the neutral points when
 (1) the North Pole of a bar magnet faces geographical north and
 (2) when the south pole of bar magnet faces geographical north?

CONCEPT APPLICATION

Level 1

Direction for questions 1 to 7:
State whether the following statements are true or false.

1. In a DC electric motor, a pair of split rings is used as commutator.

2. According to Ewing's molecular theory, every molecule of a given substance is a magnet by itself.

3. A transformer is an electrical device that works on the principle of self-induction.

4. Outside the magnet, the magnetic lines of forces pass from north pole to the south pole and inside the magnet, they pass from south to the north pole.

5. Lenz's law is used to find out the magnitude of the induced emf.

6. Relative permeability and absolute permeability have the same units.

7. The angle between geographic and magnetic meridian is called angle of dip.

Direction for questions 8 to 14:
Fill in the blanks.

8. The phenomenon of production of back emf in a coil due to flow of varying current through it is called _____.

9. The unit of self-inductance in SI system is _____.

10. The point where resultant magnetic field strength is zero is called _________.

11. Fleming's left-hand rule is used to find the direction of _______ acting on the current carrying conductor placed in a/an _______ field.

12. ________ is the measure of the ability of a given magnetic pole to attract or repel another magnetic pole.

13. The product of pole strength of a magnet and its magnetic length is called its ___________.

14. An emf is induced in a coil when ___________ linked with it changes.

Direction for question 15:
Match the entries in Column A with appropriate ones from Column B.

15.

	Column A			Column B
A.	μ	( )	a.	Faraday's law of electromagnetic induction
B.	Diamagnetic substance	( )	b.	Magnetic equator
C.	H	( )	c.	$\mu_0\mu_r$
D.	Angle of dip = 0	( )	d.	Deflection of coil directly proportional to the current flowing through the coil
E.	Tan $\theta \propto I$	( )	e.	$\dfrac{B}{\mu_0}$
F.	$E = -N\dfrac{d\varphi}{dt}$	( )	f.	Thick copper wire in the secondary winding.
G.	Moving coil galvanometer	( )	g.	force on a current carrying conductor placed perpendicular to field.
H.	Step down transformer	( )	h.	Tangent galvanometer
I.	$F = Bi\ell$	( )	i.	Susceptibility is very small and negative.
J.	Solenoid	( )	j.	Uniform magnetic field.

Direction for questions 16 to 40:
For each of the questions, four choices have been provided. Select the correct alternative.

16. A transformer
(a) converts AC to DC
(b) converts DC to AC
(c) increases or decreases (step up or step down) AC voltage
(d) increases or decreases (step up or step down) DC voltage.

17. In an AC generator, maximum number of lines of force pass through the coil when the angle between the plane of coil and lines of force is ________.
(a) 0° (b) 60°
(c) 30° (d) 90°

18. Magnetic induction field due to a short bar magnet on its equatorial line at a certain distance is B. Its value at the same distance on the axial line is ______.
(a) $2B$ (b) $\dfrac{B}{2}$
(c) $3B$ (d) $\dfrac{B}{3}$

19. Magnetic field inside the solenoid is________.
(a) radial (b) uniform
(c) Both (a) and (b) (d) circular

20. A step down transformer steps up __________ and steps down _________.
(a) current, voltage (b) voltage, current
(c) power, energy (d) voltage, power

21. The power of a DC motor can be increased by
(a) increasing the area of the cross section of the coil.
(b) increasing the current flowing through the coil.
(c) laminating the soft iron core.
(d) All of the above

22. Keeping the distance between two magnetic poles constant, if the two poles are connected by an iron rod, the force between the two poles ______.
(a) increases (b) decreases
(c) remains same (d) None of these

23. In a suspension type of moving coil galvanometer, the couple developed in the suspension wire and the loose spring is called a________.
(a) deflecting couple (b) restoring couple
(c) twisting couple (d) None of these

24. The right hand thumb rule is used to find
(a) force on a charged particle passing through the magnetic field.
(b) force on a current carrying conductor placed in a magnetic field.

PRACTICE QUESTIONS

(c) direction of induced current.

(d) direction of B around a current carrying straight conductor.

25. Looking from one side towards the face of a coil, the current in it flows in clockwise direction. On looking from the opposite side towards the second face of the coil, the current flows in

(a) anti-clockwise direction and this face represents the south pole.

(b) clockwise direction and this face represents the north pole.

(c) anticlockwise direction and this face represents the north pole.

(d) clockwise direction and this face represents the south pole.

26. The relative permeability of a paramagnetic substance is ______.

(a) much more than one

(b) slightly more than one

(c) less than one but greater than zero

(d) zero.

27. Ferromagnetic substances achieve a high degree of magnetic alignment due to the effect known as _____.

(a) pole swapping (b) exchange coupling

(c) magnetic poling (d) None of these

28. An AC generator can be converted into DC generator by replacing ______.

(a) armature with coil

(b) concave magnets with horse shoe magnet

(c) slip rings with split rings

(d) All of the above

29. Magnetic permeability is the ratio of

(a) magnetic induction to susceptibility.

(b) magnetic induction to magnetizing field.

(c) magnetizing field to magnetic induction.

(d) magnetizing field to susceptibility.

30. When a piece of iron is placed in a changing magnetic field, it gets heated due to flow of ______.

(a) Eddy current (b) Faraday's current

(c) Fleming's current (d) None of the above

31. The magnetic induction field B around a current carrying straight conductor is

(a) perpendicular to the current.

(b) parallel to the current.

(c) opposite to the direction of flow of current.

(d) None of the above.

32. ________ is used to make permanent magnets.

(a) Soft iron (b) Steel

(c) Nichrome (d) Copper

33. A transformer works with

(a) AC voltages only.

(b) DC voltages only.

(c) Both (a) and (b).

(d) None of these

34. Eddy currents are produced in a metallic conductor when

(a) the magnetic flux linked with it changes.

(b) it is placed in a changing magnetic field.

(c) it is placed in a magnetic field.

(d) Both (a) and (b).

35. The self or mutual induction takes place when magnetic flux through a coil _______.

(a) remains steady (b) decreases

(c) increases (d) Both (b) and (c).

36. Which of the following statements is incorrect? In the process of electromagnetic induction, the magnitude of the induced emf depends on _______.

(a) the number of turns of the coil.

(b) the magnetic flux linked with the coil.

(c) the rate of change of magnetic flux linked with the coil.

(d) area of the coil.

37. Write the following steps in a sequential order to find the current and voltage in the secondary coil. The ratio of the number of turns of a primary to a secondary coil, current through the primary coil and input power are given.

(a) Let the given data be taken as $\frac{N_1}{N_2}$ (turn-ratio), i_1, (input current) and P (input power).

(b) Substitute the given values of $\frac{N_1}{N_2}$ and i_1, in the above formula and get the value of i_2.

(c) Write the relation between turn-ratio and the currents as $\frac{N_1}{N_2} = \frac{i_2}{i_1}$, where i_2 is the current in the secondary coil.

(d) Write the relation between input power and output power in terms of V_1, i_1, V_2, i_2, i.e., $V_1 i_1 = V_2 i_2 = P$, where V_1 and V_2 are the voltage in the primary and secondary coils, respectively.

(e) Substitute the values of i_2 and P in the above relation to get the value of V_2.

(a) a d b c e (b) b c a d e
(c) a c b d e (d) d b c a e

38. Write in the sequential order the following steps of an experiment to show that a current carrying conductor sets up a magnetic field around it.

(a) Pass the insulated copper wire through the small hole at the centre of the cardboard and perpendicular to it.

(b) Paste a white paper on a rectangular cardboard and make a small hole at its centre.

(c) Connect this wire to a battery, a switch and a variable resistor in series.

(d) Clamp this cardboard to a stand in a horizontal position and sprinkle some iron filings over it.

(e) Now, when the circuit is closed, the iron filings on the cardboard form concentric circles around the wire.

(a) b d a c e (b) b a c e d
(c) a d b e c (d) e d a b c

39. Write the following steps of an experiment (in a sequential order), to establish that a circular current carrying wire creates a magnetic field around it.

(a) Sprinkle iron filings on the cardboard and switch on the circuit.

(b) Make two holes on a piece of cardboard covered with white paper. Pass this copper wire through the two holes of a cardboard .

(c) Take a copper wire and bend it in the form of a circle.

(d) Now connect the ends of the copper coil to a battery with a rheostat and a switch in series.

(e) You observe that the iron filings arrange themselves in concentric circles.

(a) a c b d e (b) c b d a e
(c) c a d b e (d) b c d a e

40. Two long parallel wires A and B separated by a distance d, carry currents i_1 and i_2 respectively in the same direction. Write the following steps in a sequential order to find the magnitude of the resultant magnetic field at a point 'P', which is between the wires and is at a distance 'x' from the wire A. (All the physical quantities are measured in SI units)

(a) Note the given values of i_1, i_2, d and x .

(b) Write the formula to find the magnetic field due to a long straight current carrying wire, i.e. $B = \frac{\mu_o i}{2\pi r}$.

(c) Find the directions of the magnetic field at 'P' due to two wires A and B, using right hand thumb rule.

(d) Determine the magnetic field at P due to wire A, using $B_1 = \frac{\mu_o i_1}{2\pi x}$.

(e) If the directions of magnetic field are same, then the resultant magnitude is equal to the sum of B_1 and B_2.

(f) Determine the magnetic field B_2 due to wire B at point P, ie. $B_2 = \frac{\mu_o i_2}{2\pi(d-x)}$.

(g) If the directions of magnetic fields are opposite to each other, then the resultant magnitude is equal to the difference of B_1 and B_2.

(a) d f c e g b a (b) c d f e g b a
(c) a c b d f e g (d) a b d f c e g

Level 2

41. When a short magnet is placed with its south pole pointing the geographic north of the earth, the neutral point is at a distance 10 cm. At what distance the neutral point will be formed, when the magnet is rotated through 180^0?

$$\left[\text{Take } \frac{1}{3\sqrt{2}} = 0.88(\text{app})\right]$$

PRACTICE QUESTIONS

42. Calculate the magnetic force per unit length on a conductor carrying a current of 10 A and making an angle of 30° with the direction of a uniform magnetic field of 0.3 T.

43. In a moving coil galvanometer, why do we not use a magnet with flat poles? Explain.

44. A circular coil of area 1.5 m^2 is placed normal to a uniform magnetic field of induction 2 Wb m^{-2}. The field is increased uniformly to 4 Wb m^{-2} in 20 s. Calculate the induced emf.

45. At a given point in a magnetic field, is it possible to have different magnetic induction fields? At two different points in a magnetic field, is it possible to have same magnetic induction field? Explain.

46. Why does a solenoid contract when a current passes through it?

47. The current through the coil of inductance 0.15 H increases at a rate of 10 A s^{-1}. Find the induced emf across the coil.

48. Two identical circular coils are placed in the same plane side by side such that they do not touch each other. An increasing current is in the same plane and passed through one of the coils in the clockwise direction. Do the two coils attract or repel each other? Explain.

49. A bar magnet of magnetic moment M is cut into 'n' parts along the axial line and 'm' parts perpendicular to the axial line. Find the magnetic moment of each piece.

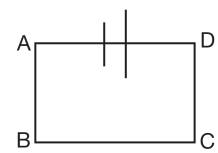
50. Two infinitely long wires P and Q carry currents of 2 A and 8 A, respectively, in the same direction. Find at what distance from P the resultant induction field is zero, if they are kept parallel to each other at a distance of 10 cm.

51. How will you light a bulb rated 100 W, 120 V using 240 V AC supply?

52. A magnetized rod of moment M and length 'L' is bent in the form of an arc of a circle of radius r. If the arc length is $\frac{1}{4}$ th the circumference of the circle, then find the magnetic moment of the arc, in terms of M.

53. Explain why two magnetic field lines can never intersect.

54. A cell is connected across AD of a square loop ABCD, made of a conductor of uniform area of cross section, as shown in the figure. Find the ratio of magnetic-fields at the centre produced by



(a) sides AB and CD and

(b) sides AD and BC.

55. A bar magnet of magnetic moment M is cut into 'p' parts along the axial line and 'q' parts perpendicular to the axial line. Find the magnetic moment of each piece.

56. An experimentist placed two magnetic poles separated by 10 cm (in air), one having double the strength as the other and found that both repel each other with a force of 8×10^{-3} N. Calculate the pole strength of each pole.

57. If m is the pole strength, A is the area of cross section and I is the intensity of magnetization of a given magnet, prove that $I = \frac{M}{A}$.

58. Randheer's father gave him a short bar magnet of length 5 cm and asked him to find its pole strength. He also gave him information that the earth's horizontal component of magnetic intensity is 50 μT at the given place. Experimentally Randheer found that the bar magnet produces a neutral point 15 cm away from its centre on the equatorial line and calculated its pole strength. Find the answer.

59. In a science fair, a student performed an activity with a magnet. First, he placed the magnet with its south pole pointing towards the geographic north of the earth and rotated the magnet by an angle of 180°, then calculated how the angle made by the line joining the neutral points had rotated. Find the angle.

Level 3

60. Lenz's law is in accordance with the law of conservation of energy. Explain.

61. The dipole moment of a semicircular magnet is 28 A m^2. It is straightened to form a bar magnet, which is then cut along its axial line to give two magnets. Find the magnetic induction at a point on the equatorial line 0.2 m away from the centre of one of the magnets. If the point is along the axis same distance away from the centre of the magnet, then find the magnetic induction.

62. Explain why a current carrying conductor experiences a force when placed in a magnetic field but not when placed in an electric field.

63. Two magnetic poles of strengths 'm_1' and 'm_2' when placed in air at a distance of 'd' from each other, a force 'F' acts between them. If the pole strength of the poles is doubled, the distance between them is trebbled and the poles are placed in some other medium, the force between them reduces by 25%. Find the relative magnetic permeability of the medium.

64. A bar magnet is suspended in a uniform magnetic field. Find the ratio of the torques when it makes an angle of 30° and 60°, respectively, with the field.

Direction for questions 65 to 69:
Select the correct alternatives from the given choices.

65. Calculate magnetic field induction B due to a straight conductor carrying current 5 A at a perpendicular distance of 10 cm from it.

66. Calculate the magnetic field induction 'B' at the centre of a circular coil having 500 turns, radius π cm and carrying 5 A of current.

67. When a coil of 100 turns and resistance 0.5 Ω is moved towards a stationary magnet, the magnetic flux linked with the coil changes from 5×10^{-2} weber to 0.15 weber. Find the charge flowing through the coil during its motion.

68. A rectangular coil of area 100 cm^2 is placed normal to the magnetic field. If the magnetic field changes from 0.1 T to 0.2 T in 1 ms, find the induced emf in the coil.

69. In an experiment, a physics student named Rakesh took a magnet and a coil of resistance 10 Ω. He then performed an activity by moving the magnet towards the coil in such a way that the magnetic flux linked with the coil changes from 10 weber to 40 weber and he calculated the amount of charge that flowed through the coil during the motion. Find what his answer would be.

CONCEPT APPLICATION

Level 1

True or false

1. True **2.** False **3.** False **4.** True **6.** False **7.** False

Fill in the blanks

8. self-induction **9.** henry **10.** null point **11.** force, magnetic
12. pole strength **13.** Magnetic moment **14.** the magnetic flux

Match the following

15. A : c B : i C : e D : b E : h
F : a G : d H : f I : g J : j

Multiple Choices questions

16. (c) **17.** (d) **18.** (a) **19.** (b) **20.** (a) **21.** (d) **22.** (a) **23.** (b) **24.** (d) **25.** (c)
26. (b) **27.** (b) **28.** (c) **29.** (b) **30.** (a) **31.** (a) **32.** (b) **33.** (a) **34.** (d) **35.** (d)
36. (b) **37.** (c) **38.** (a) **39.** (b) **40.** (d)

Explanation for question 31 to 40:

31. The magnetic lines of force are concentric circles, with current carrying straight conductor at the centre and perpendicular to the plane of these concentric circles. The direction of the magnetic lines of force is clockwise or anticlockwise depending on the direction of flow of current. The direction of B is obtained by drawing tangent to the concentric circles at any point on it. It is seen that different points on the concentric circle gives different directions of B and B is always perpendicular to the direction of current.

32. The retentivity of steel is high. Hence, it is used to make permanent magnet.

33. The working of a transformer is based on mutual induction. The change in the current flowing through one coil changes the flux passing through it. When this change in flux is linked to the other coil, the flux through it also changes, thereby inducing an e.m.f. In AC, the current keeps on changing and so, a transformer works with AC only.

34. Eddy currents are produced in a solid piece of metal, when magnetic flux passing through it changes. When a metallic conductor is placed in a changing magnetic field, the magnetic flux passing through it changes and so eddy currents are produced.

Also when magnetic flux around it changes, the magnetic flux passing through it changes and so eddy currents are produced.

35. The self or mutual induction takes place when magnetic flux through the coil changes.

36. The magnitude of induced emf depends on the rate of change of magnetic flux and not on the magnetic flux linked with the coil. Also, it depends on the area of cross section and number of turns of the coil.

37. Let the given data be taken as $\dfrac{N_1}{N_2}$ (turn-ratio), i_1, (input current) and P (input power) (a). Write the relation between turn-ratio and the currents as $\dfrac{N_1}{N_2} = \dfrac{i_2}{i_1}$, where i_2 is the current in the secondary coil (c). Substitute the given values of $\dfrac{N_1}{N_2}$ and i_1, in the above formula and get the value of i_2 (b). Write the relation between input power and output power in terms of V_1, i_1, V_2, i_2 i.e $V_1\, i_1 = V_2\, i_2 = P$, where V_1 and V_0 are the voltages in the primary and secondary coils, respectively (d). Substitute the values of i_2 and P in the above relation to get the value of V_2 (e).

38. Paste a sheet of white paper on a rectangular cardboard and make a small hole at its centre (b). Clamp this cardboard to a stand in the horizontal position and sprinkle some iron filings over it (d). Pass the insulated copper wire through the small hole at the centre of the cardboard and perpendicular to it (a). Connect this wire to a battery, a switch and a variable resistance in series (c). Now, when the circuit is closed, the iron filings on the cardboard form concentric circles around the wire (e).

39. Take a copper wire and bend it in the form of a circle (c). Make two holes on a piece of cardboard covered with a sheet of white paper and pass the copper wire through the two holes of the cardboard covered with the sheet of white paper (b). Now connect the ends of the copper coil to a battery with a rheostat and a switch in series (d). Sprinkle iron filings on the cardboard and switch on the circuit (a). You observe that the iron filings arrange themselves in concentric circles (e).

40. Note the given values of i_1, i_2, d and x (a). Write the formula to find the magnetic field due to a long straight current carrying wire i.e B $= \frac{\mu_0 i_1}{2\pi x}$ (b). Determine the magnetic field at P due to wire A, using $B_1 = \frac{\mu_0 i}{2\pi r}$ Determine B_2 due to wire B ie, $B_2 = \frac{\mu_0 i_2}{2\pi(d-x)}$ (f). Find the directions of the magnetic field at 'P' due to two wires A and B, using right hand thumb rule (c). If the directions of magnetic fields are same, then the resultant magnitude is equal to the sum of B_1 and B_2 (e). If the directions of the two magnetic fields are opposite, then the resultant magnitude is equal to the difference of B_1 and B_2 (g).

Level 2

41. (i) When south pole faces the geographic north, the null point is formed on the axial line. At null point, the axial field and horizontal component of earth's magnetic field are equal.

$$B_H = B_{axial} = \frac{\mu_0}{4\pi} \times \frac{2M}{d_A^3} \quad (1)$$

Where d_A = 10 cm = 0.1 m.

When the magnetic is turned through 180°, the null point is formed on the equatorial line.

$$B_H = B_e = \frac{\mu_0}{4\pi} \times \frac{M}{d_e^3} \quad (2)$$

Equating (1) and (2), find d_e.

(ii) 8 cm

42. (i) Use $F = Bi\ell \sin\theta$.

Get the values of B, i and θ from the given data.

Find $\frac{F}{\ell}$.

(ii) 1.5 N m^{-1}

43. The magnet is made concave in shape so that its magnetic field is always perpendicular to the plane of the coil when it rotates.

44. (i) Get the values of area (A) and initial magnetic induction (B_i). Find magnetic induction (B_f) and time (t) from the given data.

Use $E = \frac{\Delta\varphi}{t}$ and $\varphi = BA$.

Find φ_{final}, $\varphi_{initial}$ and from them, find $\Delta\varphi$ as well.

(ii) 0.15 V

45. (i) Can two magnetic lines of force intersect at a point in a magnetic field?

(ii) Magnetic field can be uniform or non - uniform. In uniform magnetic field it is possible to have same magnetic induction field at two different points.

46. Analyse the type of magnetic poles formed on either sides of two adjacent rings of a solenoid. Are the poles formed like or unlike?

47. (i) The emf induced in the coil is given by,

$$E = -L\frac{di}{dt}$$

Where L is the self inductance of the coil.

(ii) 1.5 V

48. Recall the principles of mutual induction and Faraday's experiments.

49. (i) When the magnet is cut along axial line, its area of pole decreases. If the area of poles decreases 'n' times, pole strength also decreases 'n' times.

The magnetic moment of each piece is $\frac{M}{n}$

When each piece (obtained by cutting the magnet along the axial line) is divided into 'm' parts by cutting it perpendicular to the axial line, the length and the magnetic moment reduces to $\frac{1}{m}$ th the original value.

(ii) $\frac{M}{mn}$

50. (i) Use $B = \frac{\mu_0 i}{2r}$, for both the wires.

If the resultant field at a point is zero, then at the point B due to P it is equal in magnitude and opposite in direction to B due to Q.

(ii) 2 cm

51. Find the resistance of the bulb by using $P = \frac{V^2}{R}$

Use the resistance of the same value as resistance of the bulb and connect in series with the bulb, Another way is to connect a coil of suitable inductance in series with the bulb.

52. (i) The pole strength of the magnet (m) is

$$m = \frac{M}{L} \quad (1)$$

When the rod is bent in the form of arc, it subtends 90^0 at the centre.

If 'd' is the distance between the poles, then

$$d = \sqrt{r^2 + r^2}$$

$$d = r\sqrt{2} \quad (2)$$

where r is the radius of the arc.

The r is related to ℓ as

$$\ell = \pi r \quad (3)$$

Use (1), (2) and (3) and find the new magnetic moment (M_1)

M_1 = pole strength × distance between poles.

(ii) $\frac{2\sqrt{2}}{\pi} M$

53. Recall the definition of a magnetic field line.

Is it possible to have two directions for a given magnetic field at a given point in the field?

54. (i) Side AB and side CD carry equal currents. The distance of the centre from both the sides are equal. Therefore, fields produced by both sides are equal at the centre. Side AD and BC carry different currents. If R is the resistance of each side, then current through AD (I_D) is

$$I_D = \frac{3R}{4R} \times V \quad (1)$$

Where V is the terminal PD of the cell.

The current through BC is

$$I_{BC} = \frac{R}{4R} \times V \quad (2)$$

The ratio of currents gives the ratio of fields.

(ii) 1:1, 3:1

55. When a bar magnet is cut into 'p' parts along the axial line, its area becomes $(1/p)$th of the total area and the pole strength becomes $(1/p)$th of the pole strength. With decrease in pole strength, each part will have a magnetic moment (M/p). When the magnet is cut perpendicular to axial line the magnetic moment becomes(M/p). Thus, the magnetic moment of each part is (M/p)

56. Let the pole strengths be 'm_1' and 'm_2'. Let $m_1 = m$ and hence $m_2 = 2$ m

Distance between them, d = 10 cm = 0.1 m

Force of repulsion, $F = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{d^2} = \frac{10^{-7}(\text{m})(2\text{m})}{(0.1)^2}$

Given $F = 8 \times 10^{-3}$ N

$$\Rightarrow 8 \times 10^{-3} = \frac{10^{-7}(2m^2)}{0.01} \Rightarrow m = 20\text{Am}$$

Thus, the pole strengths are 20 A m and 40A m.

57. The intensity of magnetization is defined as magnetic dipole moment per unit volume.

$$I = \frac{M}{V}$$

Where M = dipole moment.

V = Volume of magnet

But $M = m \times 2$ l; $V = A \times 2$ l

Where 2 l − length of magnet.

A − area of cross section.

$$\therefore \quad \therefore I = \frac{m \times 2\ell}{A \times 2\ell}$$

$$I = \frac{m}{A}$$

58. Let B = magnetic induction due to the bar magnet.

$B = \frac{\mu_0}{4\pi}\frac{M}{d^3}$, on the equatorial line.

Where M = magnetic moment

D = distance of a point from the center of the magnet.

At neutral point, $B = B_H$, the horizontal component of the earth's magnetic field.

$\therefore$

$$\therefore B_H = \frac{\mu_0}{4\pi}\frac{M}{d^3}$$

$$m = (B_H d^3)\,\frac{4\pi}{\mu_0} \times \frac{1}{2\ell}$$

where 2 ℓ is length of the magnet.

$$m = \frac{10^7 \times (50\times10^{-6}) \times (0.15)^3}{5\times10^{-2}} = 33.75\text{Am}$$

59. When the South pole of a magnet points towards the North of the earth, neutral points are obtained on the axial line. Thus, the line joining neutral points is along the axis of the magnet. When the poles are reversed the neutral points are obtained along its equatorial line. Then the line joining the neutral points is the perpendicular bisector of the magnet. Thus, the line rotates by 90°.

Level 3

60. (i) What happens if the emf is induced in such a way that it support the relative change in magnetic field associated with the coil?

(ii) Work done by the external agent to bring the change in magnetic flux is converted into electrical energy.

61. (i) What is the expression for a magnetic moment of a semicircular magnet?

When the semicircular magnet is straightened, relate the distance between the two poles in the two cases to find the new length of the magnet.

Does the pole strength of the magnet change on straightening?

How does the pole strength change when the straight magnet is cut axially?

What is the magnetic moment of the newly formed (straightened) magnet?

Use $B_{\text{axial}} = \frac{\mu_0}{4\pi}\frac{2M}{d^3}$ and $B_{\text{equatorial}} \frac{\mu_0}{4\pi}\frac{M}{d^3}$

(ii) B equatorial = 0.0275 mT

B axial = 0.550 mT

62. How a current carrying conductor behaves? Like a magnet or like a charged body.

63. (i) Use $F = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{d^2}$, in both the cases.

Relate the quantities 'm_1', 'm_2', 'd' and 'F' in the second case with that in the first case using the given data. Then relate μ of the medium with μ_0 and find the value of μ_r of the medium.

(ii) 3

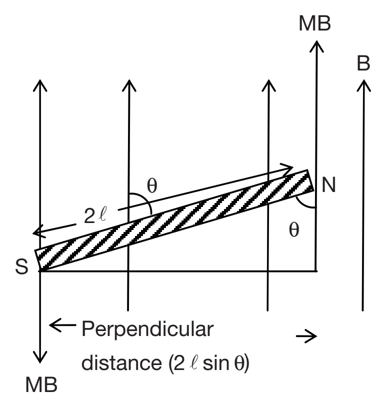
64. (i) The force on the poles of the bar magnet is mB. If the angle made by the bar magnet with the field is θ, then the perpendicular distance between the forces is $2\ell\sin\theta$ where '2ℓ' is the magnetic length, as shown in the figure below. The torque is given by,

Torque = force X perpendicular distance.

Torque = $mB \times 2\ell \sin\theta$

$\Rightarrow$ Torque $\propto \sin\theta$

(ii) $1 : \sqrt{3}$



65. Given $i = 5$ A

$r = 10$ cm $= 0.1$ m

$$B = \frac{\mu_o i}{2\pi r} = \frac{4\pi \times 10^{-7} \times 5}{2\pi \times 0.1}$$

$$B = 10^{-5} T = 10 \times 10^{-6} T = 10 \mu T$$

66. Given $i = 5$ A

$r = \pi$ cm $= \pi \times 10^{-2}$ m

$n = 500$ turns

$$B = \frac{n\mu_0 i}{2r} = \frac{500 \times 4\pi \times 10^{-7} \times 5}{2 \times \pi \times 10^{-2}}$$

$= 5 \times 10^{-2}$ T $= 0.05$T

67. The magnitude of induced emf is given by,

$$E = N\frac{d\varphi}{dt}$$

But $E = iR$

$$iR = N\frac{d\varphi}{dt}$$

Substitute $i = \frac{dq}{dt}$

$$\frac{dq}{dt} \times R = N\frac{d\phi}{dt} \Rightarrow dqR = Nd\phi$$

$$dq = \frac{Nd\phi}{R}$$

Substitute N = 100, $d\phi = 0.15 - 0.05$

$= 0.1$ weber, R $= 0.5\Omega$

$$dq = \frac{100 \times 0.1}{0.5} = 20\text{C}$$

68. The magnetic flux passing normal through the coil is given by,

$$\phi = B \times A$$

Where A is the area of the coil.

The change in flux, $\Delta\phi$ is

$$\Delta\phi = \Delta B \times A$$

Substitute $\Delta B = 0.2 - 0.1 = 0.1$T

And $A = 100$ cm^2 10^{-4} m^2

$\therefore \Delta\phi = 0.1 \times 10^{-4} = 10^{-3}$ weber.

The rate of change of magnetic flux is induced emf

i.e., $$\frac{\Delta\phi}{dt} = E$$

Substituting $\Delta\phi = 10^{-3}$ weber and

$\Delta t = 1$ ms $= 10^{-3}$s

$$E = \frac{10^{-3}}{10^{-3}} = 1\text{ volt.}$$

69. $$E = \frac{d\phi}{dt} = iR \Rightarrow i = \frac{E}{R} = \frac{d\phi}{dt},$$

$dq = idt$

Here, $q = idt = \frac{d\phi}{R}$

Given $d\phi = 40$ Wb $- 10$ Wb $= 30$ Wb and R $= 10\Omega$

$$\therefore \quad dq = \frac{30}{10} = 3\text{C}$$

Hence a charge of 3 C flows through the coil, during the motion of the magnet.

HINTS AND EXPLANATION

WHY MODULUS JUNIOR COLLEGE ?

Best IITJEE Faculty : Team led by an Alumni of IIT Delhi,**MODULUS** has expert faculty to provide IITJEE coaching, mentoring and counselling to the students to reach their goal.

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"I listen - I forget,
I read -I remember,
I do - I understand"

following this saying, measures like asking students to teach some subtopic will be taken.

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For 7th Class Students
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8th
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REFINE ONE YEAR

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