MAGNETISM AND MATTER

IMPORTANT FORMULAE

1. **Magnetic dipole moment,** $m = q_m \times 2l$
2. **Magnetic dipole moment of a current loop,** $m = NIA$
3. **Magnetic field due to a short magnetic dipole**

   (*i*) At axis $\quad B_{axis} = \dfrac{\mu_0}{4\pi}\dfrac{2M}{r^3}$

   (*ii*) At equatorial, $\quad B_{eqt.} = \dfrac{\mu_0}{4\pi}\dfrac{M}{r^3}$
4. **Elements of earth's magnetic field**

   $$\left.\begin{array}{ll}\text{Horizontal component} & H = B_e \cos\theta \\ \text{Vertical component} & V = B_e \sin\theta\end{array}\right\} \text{ where } \theta = \text{angle of dip.}$$

   $\Rightarrow \tan\theta = \dfrac{V}{H}$ and $\quad B_e = \sqrt{H^2 + V^2}$
5. **Magnetic moment of an orbital electron**

   $$\mu_l = \frac{evr}{2} = \frac{e}{2m}L$$
6. **Orbital magnetic dipole moment of an electron in *n*th orbital,**

   $$\mu_l = \frac{evr}{2} = \frac{e}{2m_e}l = n\left(\frac{eh}{4\pi m_e}\right)$$
7. **Magnetic susceptibility** $\chi_m = \dfrac{M}{H}$

MULTIPLE CHOICE QUESTIONS

Choose and write the correct option in the following questions.

1. **Magnetism in substances is caused by**
   (*a*) orbital motion of electrons only
   (*b*) spin motion of electrons only
   (*c*) due to spin and orbital motions of electrons both
   (*d*) hidden magnets
2. **A toroid of *n* turns, mean radius *R* and cross-sectional radius *a* carries current *I*. It is placed on a horizontal table taken as *X-Y* plane. Its magnetic moment $\vec{m}$** *[NCERT Exemplar]*
   (*a*) is non-zero and points in the *Z*-direction by symmetry.
   (*b*) points along the axis of the toroid ($\vec{m} = m\phi$).
   (*c*) is zero, otherwise there would be a field falling as $\dfrac{1}{r^3}$ at large distances outside the toroid.
   (*d*) is pointing radially outwards.

3. The magnetic field of Earth can be modelled by that of a point dipole placed at the centre of the Earth. The dipole axis makes an angle of 11.3° with the axis of Earth. At Mumbai, declination is nearly zero. Then, **[*NCERT Exemplar*]**

(*a*) the declination varies between 11.3° W to 11.3° E.

(*b*) the least declination is 0°.

(*c*) the plane defined by dipole axis and Earth axis passes through Greenwich.

(*d*) declination averaged over Earth must be always negative.

4. In a plane perpendicular to the magnetic meridian, the dip needle will be

(*a*) vertical

(*b*) horizontal

(*c*) inclined equal to the angle of dip at that place

(*d*) pointing in any direction

5. If the horizontal and vertical components of earth's magnetic field are equal at a certain place, the angle of dip is

(*a*) 90° (*b*) 60° (*c*) 45° (*d*) 0°

6. Magnetism in a substance is due to

(*a*) orbital motion of electrons only (*b*) spin motion of electrons only

(*c*) both orbital and spin motion of electrons (*d*) none of the above cause magnetism

7. A stationary magnet does not interact with

(*a*) magnet (*b*) stationary charge

(*c*) iron rod (*d*) moving charge

8. A bar magnet AB with magnetic moment *M* is cut into two equal parts perpendicular to its axis. One part is kept over the other so that end B is exactly over A. What will be the magnetic moment of the combination so formed?

(*a*) $\frac{M}{4}$ (*b*) $\frac{3M}{4}$ (*c*) M (*d*) Zero

9. SI unit of magnetic pole strength is

(*a*) ampere-meter (*b*) $\frac{\text{ampere}}{\text{meter}^2}$ (*c*) $\frac{\text{ampere}}{\text{meter}}$ (*d*) $\frac{\text{volt}}{\text{meter}}$

10. The SI unit of magnetic permeability μ_0 is

(*a*) $WA^{-1}m^{-1}$ (*b*) $NA^{-1}m^{-1}$

(*c*) NA^{-2} (*d*) Both $WA^{-1}m^{-1}$ and NA^{-2}

11. The unit of magnetic permeability of vacuum is ________ .

(*a*) NA^2 (*b*) T (*c*) NA^{-1} (*d*) NA^{-2}

12. A bar magnet of magnetic length 2*l* has pole strength *p* and magnetic moment *m*. Then *m* is equal to

(*a*) *pl* directed from north pole to south pole

(*b*) *pl* directed from south pole to north pole

(*c*) 2*pl* directed from north pole to south pole

(*d*) 2*pl* directed from south pole to north pole

13. The major contribution of magnetism in substances is due to

(*a*) orbital motion of electrons

(*b*) spin motion of electrons

(*c*) equally due to orbital and spin motions of electrons

(*d*) hidden magnets.

14. A sensitive magnetic instrument can be shielded very effectively from outside fields by placing it inside a box of

(*a*) teak wood (*b*) plastic material
(*c*) soft iron of high permeability (*d*) a metal of high conductivity

15. Earth's magnetic field inside a closed iron-box, as compared to that outside is

(*a*) more (*b*) less
(*c*) same (*d*) zero

16. The line on the earth's surface joining the points where the field is horizontal is called

(*a*) magnetic meridian (*b*) magnetic axis
(*c*) magnetic line (*d*) magnetic equator

17. The angle between the magnetic meridian and the geographical meridian is known as

(*a*) magnetic dip (*b*) magnetic declination
(*c*) magnetic moment (*d*) magnetic field strength

18. Earth's magnetic field always has a horizontal component except at

(*a*) equator (*b*) magnetic pole
(*c*) at latitude 60° (*d*) at latitude 30°

19. Two bar magnets of same geometry with magnetic moments M and $2M$ are first placed in such a way that their similar poles are on the same side, then its period of oscillation is T_1. Now the polarity of one of the magnets is reversed, then the time period of oscillations is T_2 then,

(*a*) $T_1 < T_2$ (*b*) $T_1 > T_2$ (*c*) $T_1 = T_2$ (*d*) $T_2 = \infty$

20. The time-period of a freely-suspended magnet is independent of

(*a*) length of the magnet
(*b*) moment of inertia of the magnet
(*c*) horizontal component of earth's magnetic field
(*d*) length of the suspension

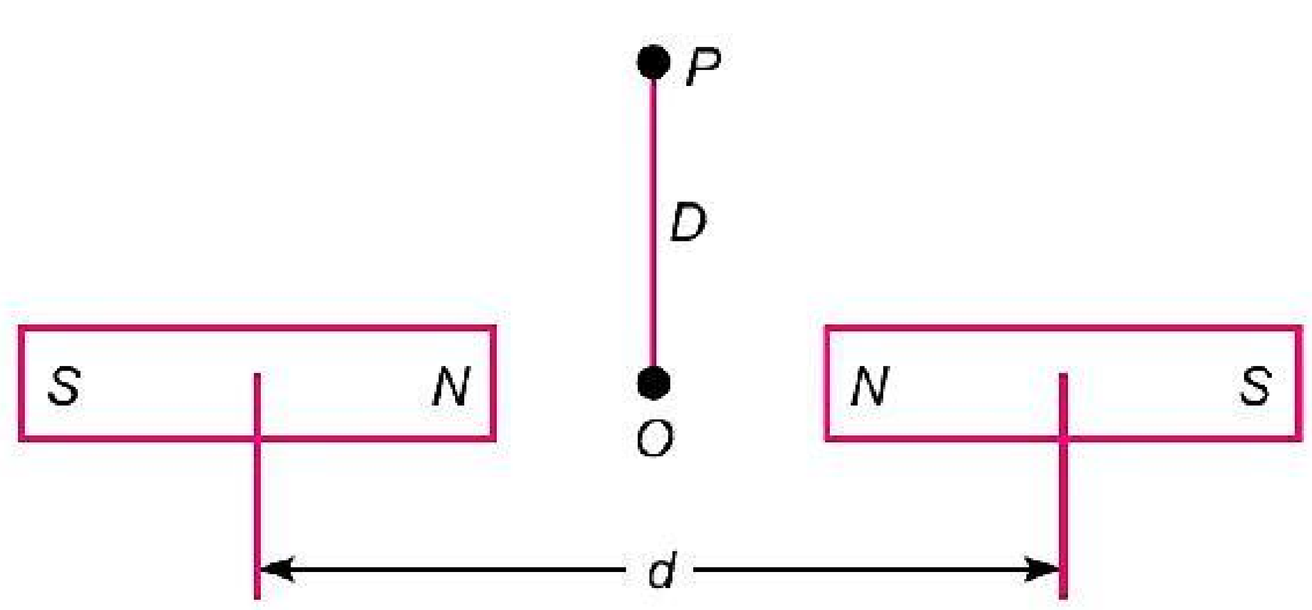
21. At a certain place a magnet makes 30 oscillations/min. At another place where the magnetic field is double, its time period will be

(*a*) 4 second (*b*) 2 second (*c*) 0.5 second (*d*) $\sqrt{2}$ second

22. The period of oscillation of a bar magnet in a vibration magnetometer is 2 second. The period of oscillation of a bar magnet whose magnetic moment is 4 times that of first magnet is

(*a*) 4 second (*b*) 1 second (*c*) 2 second (*d*) 0.5 second

23. Two identical bar magnets are fixed with their centers at a distance 'd' apart. A stationary charge $+Q$ is placed at P in between the gap of the two magnets at a distance D from the centre O as shown in fig. The force on charge $+Q$ is



(*a*) directed along $\overrightarrow{OP}$
(*b*) directed along $\overrightarrow{PO}$
(*c*) directed perpendicular to the plane of the paper
(*d*) zero

24. A current 'i' ampere flows through an infinitely long straight thin walled tube, then the magnetic induction at any point inside the tube is

(*a*) infinite (*b*) zero (*c*) $\frac{\mu_0}{4\pi}\frac{2i}{r}$ (*d*) $\frac{2i}{r}$

25. The length of a magnet is large compared to its width and breadth. The time period of its oscillations in a vibration magnetometer is 2 s. The magnet is cut along the length into three equal parts and then placed on each other with their like poles together. The time period of this combination will be

(*a*) 2 s (*b*) $\frac{2}{3}$s (*c*) $2\sqrt{3}$ s (*d*) $\frac{2}{\sqrt{3}}$s

26. The magnetic induction and the intensity of magnetic field inside an iron pole of an electromagnet are 1 Wb m^{-2} and 150 Am^{-1} respectively. The relative permeability of iron must be

(*a*) $\frac{10^6}{4\pi}$ (*b*) $\frac{10^6}{6\pi}$ (*c*) $\frac{10^5}{4\pi}$ (*d*) $\frac{10^5}{6\pi}$

27. A vibration magnetometer consists of two identical bar magnets placed one over the other such that they are perpendicular and bisect each other. The time period of oscillator in a horizontal magnetic field is $(2)^{5/4}$ seconds. If one of the magnet is removed and the other magnet oscillate in the same field, then the time period will be:

(*a*) $2^{1/4}$ s (*b*) $2^{1/2}$ s (*c*) 2 s (*d*) $2^{5/4}$ s

28. In an experiment with vibration magnetometer the value of $\frac{4\pi^2 I}{T^2}$ for a short bar magnet is observed as 36×10^{-4}. In the experiment with deflection magnetometer with the same magnet, the value of $\left(\frac{4\pi d^3}{2\mu_0}\right)$ tan θ is observed as $\frac{10^8}{36}$. The magnetic moment of the magnet used is:

(*a*) 50 A – m^2 (*b*) 100 A – m^2

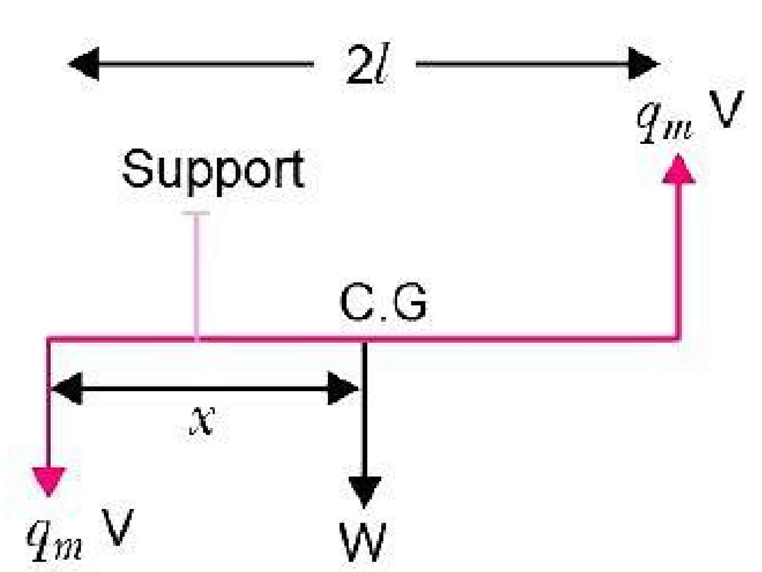
(*c*) 200 A – m^2 (*d*) 1000 A – m^2

29. A bar magnet has a magnetic moment equal to 5×10^{-5} weber-metre. It is suspended in a magnetic field which has a magnetic induction $B = 8\pi \times 10^{-4}$ T. The magnet vibrates with a period equal to 15 seconds. The moment of inertia of the magnet is

(*a*) 7.35×10^{-7} kgm^2 (*b*) 7.26×10^{-7} kgm^2

(*c*) 7.22×10^{-7} kgm^2 (*d*) 7.16×10^{-7} kgm^2

30. A magnetic needle of weight W has a magnetic moment m. If the needle is to be maintained horizontal in northern hemisphere, where should the point of support lie relative to its centre of gravity. [Vertical component of earth's magnetic field is V and horizontal component of earth's magnetic field is H.]



(*a*) $\frac{mV}{W}$ (*b*) $\frac{mW}{H}$

(*c*) $\frac{mH}{W}$ (*d*) $\frac{m\sqrt{V^2 + H^2}}{W}$

Answers

1. (*c*)	**2.** (*c*)	**3.** (*a*)	**4.** (*a*)	**5.** (*c*)	**6.** (*c*)	**7.** (*b*)	**8.** (*d*)
9. (*a*)	**10.** (*d*)	**11.** (*d*)	**12.** (*d*)	**13.** (*b*)	**14.** (*c*)	**15.** (*d*)	**16.** (*d*)
17. (*b*)	**18.** (*b*)	**19.** (*a*)	**20.** (*d*)	**21.** (*d*)	**22.** (*b*)	**23.** (*d*)	**24.** (*b*)
25. (*b*)	**26.** (*d*)	**27.** (*c*)	**28.** (*b*)	**29.** (*d*)	**30.** (*a*)		

CASE-BASED QUESTIONS

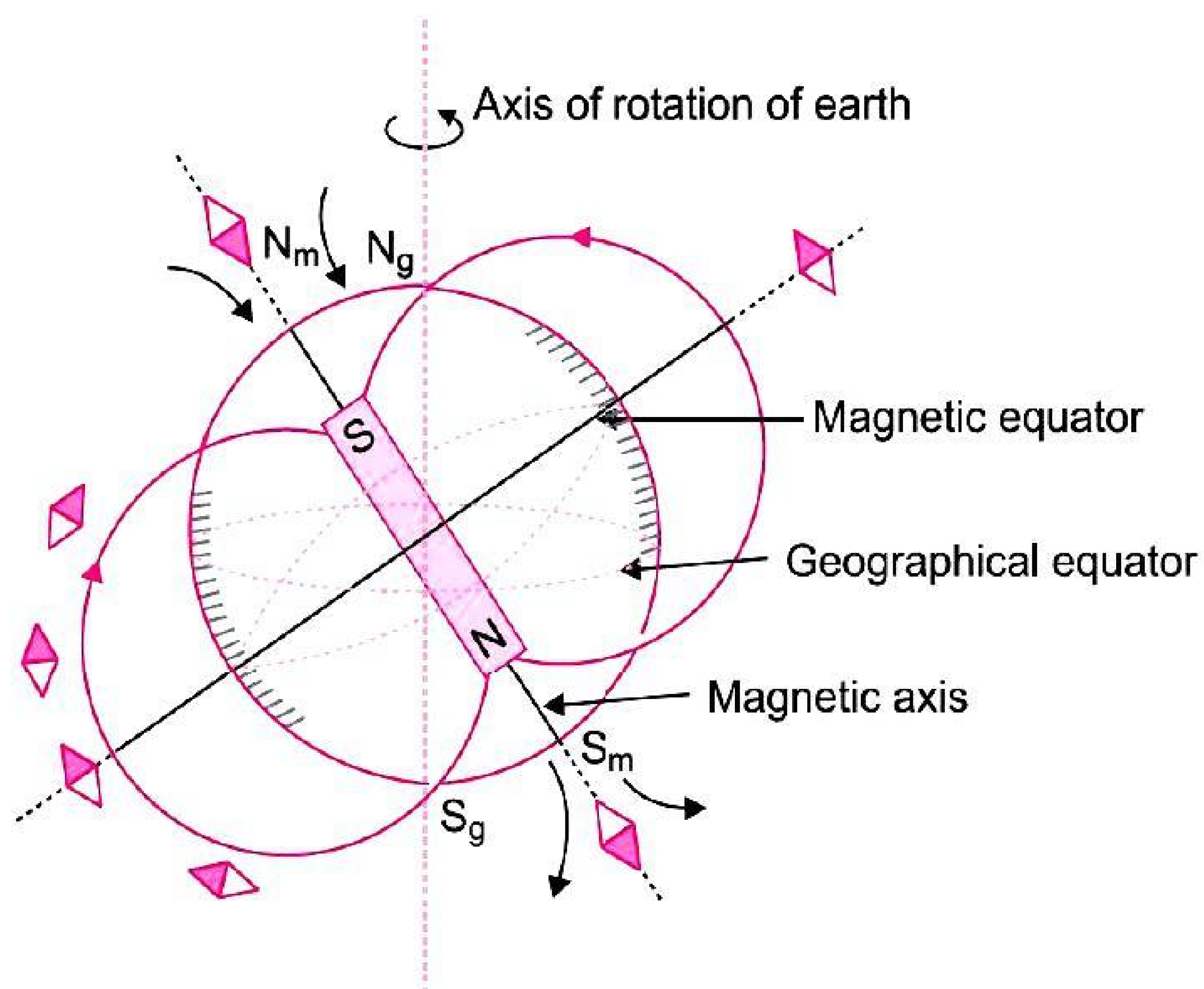
Attempt any 4 sub-parts from each question. Each question carries 1 mark.

1. EARTH'S MAGNETISM:

A magnetic field exists everywhere around the earth and earth behaves as if a powerful magnet is placed at the centre of earth in such a way that its north pole is towards south of earth and south pole is towards north of earth.

A freely suspended magnetic needle always stays along north-south direction. The north pole of needle is towards north of earth and south pole is towards south of earth.

When magnetic lines of magnet are drawn, neutral points are obtained. Neutral points are those points where net magnetic field is zero. The existence of these points indicates that earth has its own magnetic field and at these points the magnetic field of magnet is cancelled by earth's magnetic field.



At the magnetic north pole of earth, the north pole of magnetic needle points towards the north; while at the south pole of earth, the south pole of magnetic needle points towards the south. From this it is concluded that the south and north poles of frictitious magnetic dipole deep inside the earth must be in northern and southern hemispheres respectively. The line joining the two places where the needle becomes perfectly horizontal is called the magnetic equator. The magnetic equator intersects the geographical equator at longitudes 6° W and 174° E respectively. It is found that the angle between magnetic axis and the axis of earth's rotation is nearly 11.3°. The observations taken at different times show that the positions of earth's magnetic poles changes gradually.

(*i*) The line on the earth's surface joining the points where the field is horizontal is called

(*a*) magnetic meridian
(*b*) magnetic axis
(*c*) magnetic line
(*d*) magnetic equator

(*ii*) The magnetic field of earth can be modelled by that of a point dipole placed at the centre of the earth. The dipole axis makes an angle of 11.3° with the axis of earth. At Mumbai, declination is nearly zero. Then,

(*a*) the declination varies between 11.3° W to 11.3° E

(*b*) the least declination is 0°

(*c*) the plane defined by dipole axis and earth axis passes through Greenwich

(*d*) declination averaged over earth must be always negative

(*iii*) In a plane perpendicular to the magnetic meridian, the dip needle will be

(*a*) vertical

(*b*) horizontal

(*c*) inclined equal to the angle of dip at that place

(*d*) pointing in any direction

(*iv*) If the horizontal and vertical components of earth's magnetic field are equal at a certain place, the angle of dip is

(*a*) 90°
(*b*) 60°
(*c*) 45°
(*d*) 0°

(*v*) Earth's magnetic field always has a horizontal component except at

(*a*) equator
(*b*) magnetic pole
(*c*) at latitude 60°
(*d*) at latitude 30°

Answers

1. (*i*) (*d*); The line on the earth's surface joining the points where the field is horizontal is magnetic equator.

(*ii*) (*a*); The axis of dipole makes an angle of 11.3° with the axis of the earth and the declination varies between 11.3° W to 11.3° E depending upon the point of observation.

(*iii*) (*a*); In a plane perpendicular to the magnetic meridian, the dip needle will be vertical.

(*iv*) (*c*); Here, $B_H = B_V$

$$\tan\delta = \frac{B_V}{B_H} = 1$$

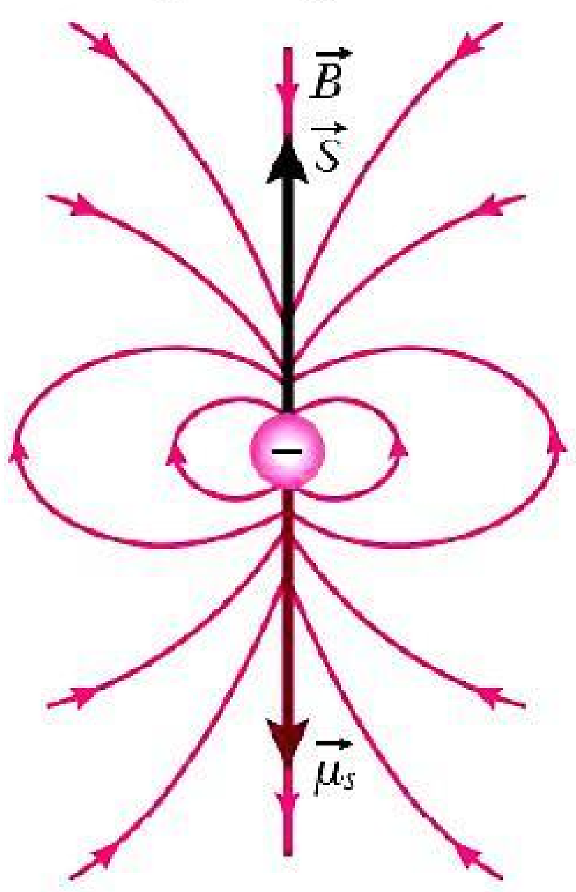
$$\therefore \quad \delta = 45°$$

(*v*) (*b*); At magnetic poles, the horizontal component of Earth's Magnetic field is zero.

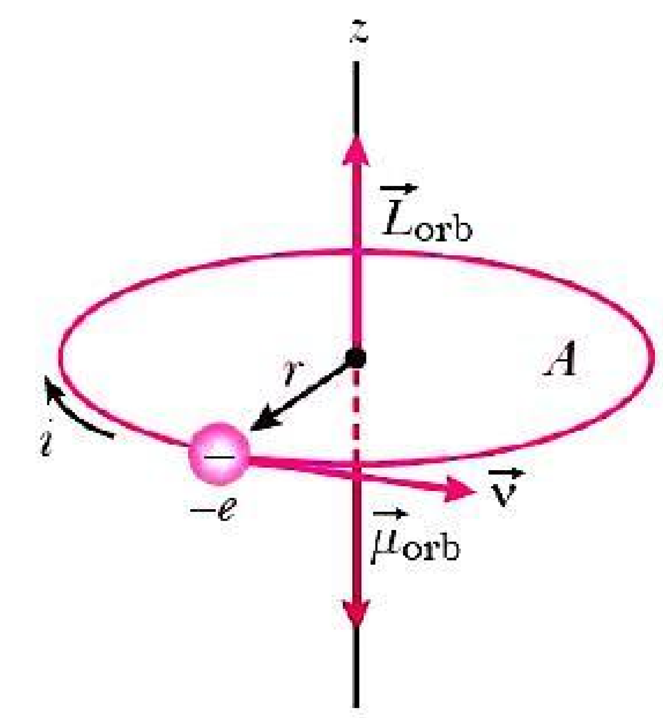
2. ATOMIC MODEL OF MAGNETISM:

Every matter is formed of atoms. According to atomic model of magnetism, each atom is a complete magnetic dipole. Each atom, consist of a positively charged small nucleus at the centre and electrons revolve around the nucleus in definite orbits. The motion of the electrons around the nucleus is identical to that of earth around the sun. The electrons revolve around the nucleus in a definite orbit and the motion is called orbital motion. The electron spins about its own axis and the motion is called spin motion. This spin motion may be clockwise or anticlockwise.

Electron spinning on its axis



Electron orbiting around the nucleus



The magnetic moment is produced due to both orbital motion and spin motion. However, most of the magnetic moment is produced due to spin motion and very small contribution due to orbital motion.

(*i*) The orbital magnetic moment due to orbital motion of electron is

(*a*) evr (*b*) $\frac{1}{2}evr$ (*c*) $\frac{1}{4}evr$ (*d*) none of these

(*ii*) An atom is a current loop. It is assumed that the magnetism of atom is caused by revolving electron due to its

(*a*) orbital motion (*b*) spin motion
(*c*) both (*a*) and (*b*) (*d*) none of these

(*iii*) The major part of magnetism is caused by

(*a*) spin motion (*b*) orbital motion
(*c*) both (*a*) and (*b*) (*d*) none of these

(*iv*) An electron moving in a circular orbit of radius *r* makes *n* rotations per second. The magnetic field produced at the centre is

(*a*) $\frac{\mu_0 n^2 e^2}{r}$ (*b*) $\frac{\mu_0 n^2 e}{r}$ (*c*) $\frac{\mu_0 ne}{2\pi r}$ (*d*) $\frac{\mu_0 ne}{2r}$

(*v*) The primary origin(s) of magnetism is

(*a*) atomic currents (*b*) Pauli exclusion principle
(*c*) intrinsic spin of electron (*d*) both (*a*) and (*c*)

Answers

2. (*i*) (*b*); $I = \frac{e}{T} = \frac{e}{\frac{2\pi r}{v}} = \frac{ev}{2\pi r}$

Area of current loop, $A = \pi r^2$

$$\mu_l = IA = \frac{ev}{2\pi r}.\pi r^2$$

$$\mu_l = \frac{evr}{2}$$

(*ii*) (*c*); When electron revolve around the nucleus, the magnetism is caused by both angular momentum due to spin motion and linear momentum due to orbital motion.

(*iii*) (*a*); The major part of magnetism is caused by angular momentum of electron *i.e.*, spin motion of electron.

(*iv*) (*d*); B at centre $= \frac{\mu_0 I}{2r}$

Here, $I = ne$

So, $B = \frac{\mu_0 ne}{2r}$

(*v*) (*d*); The primary origin of magnetism depends on atomic current and intrinsic spin of electron.

ASSERTION-REASON QUESTIONS

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(a) Both A and R are true and R is the correct explanation of A.

(b) Both A and R are true but R is not the correct explanation of A.

(c) A is true but R is false.

(d) A is false and R is also false.

1. Assertion (A) : If a compass needle be kept at magnetic north pole of Earth, the compass needle may stay in any direction.

Reason (R) : Dip needle will stay vertical at the north pole of Earth.

2. Assertion (A) : Earth's magnetic field does not affect the working of a moving coil galvanometer.

Reason (R) : Earth's magnetic field is very weak.

3. Assertion (A) : Gauss's theorem is not applicable in magnetism.

Reason (R) : Magnetic monopoles do not exist.

4. Assertion (A) : The magnetic poles of a magnet can never be separated.

Reason (R) : Every atom of a magnetic substance is a complete dipole.

5. Assertion (A) : The poles of a magnet cannot be separated by breaking into two pieces.

Reason (R) : The magnetic moment will be reduced to half when a magnet is broken into two equal pieces.

6. Assertion (A) : The magnetic moment (μ) of an electron revolving around the nucleus decreases with increasing principal quantum number (n). ***[AIIMS 2015]***

Reason (R) : Magnetic moment of the revolving electron, $\mu \propto n$.

7. Assertion (A) : When radius of a circular loop carrying current is doubled, its magnetic moment becomes four times. ***[AIIMS 2018]***

Reason (R) : Magnetic moment depends on area of the loop.

8. Assertion (A) : The magnetic poles of earth do not coincide with the geographic poles. ***[AIIMS 2010]***

Reason (R) : The discrepancy between the orientation of a compass and true north-south direction is known as magnetic declination.

9. Assertion (A) : Magnetic susceptibility is a pure number. ***[AIIMS 2009]***

Reason (R) : The value of magnetic susceptibility for vacuum is one.

10. Assertion (A) : Susceptibility is defined as the ratio of intensity of magnetisation I to magnetic intensity H. ***[AIIMS 2018]***

Reason (R) : Greater the value of susceptibility, smaller the value of intensity of magnetisation I.

Answers

1. (*b*) **2.** (*a*) **3.** (*a*) **4.** (*a*) **5.** (*b*) **6.** (*d*) **7.** (*a*) **8.** (*a*)
9. (*c*) **10.** (*c*)

HINTS/SOLUTIONS OF SELECTED MCQs

1. (*c*) Magnetism in substance is caused by spin and orbital motion of electrons.

2. (*c*) In toroid, the magnetic field is only confined inside the body of toroid in the form of concentric magnetic lines of force and these is no magnetic field outside the body. This is because the loop encloses no current. Thus, the magnetic moment is zero, otherwise, r as large distance outside the toroid, $m \propto \frac{1}{r^3}$.

3. (*a*) For the earth's magnetism, the magnetic field lines of the earth resemble that of a hypothetical magnetic dipole located at the centre of the earth. The axis of the dipole does not coincide with the axis of rotation of the earth but it is presently litted by 11.3° with respect to the later. Hence, the declination varies between 11.3° W to 11.3°E.

4. (*a*) The angle of dip would change of needle to placed in the geometric meridian. The vertical component would remain the same but the horizontal component would change. Hence, dip needle would remain vertical in a plane perpendicular to the magnetic meridian.

5. (*c*) $\tan = \frac{B_v}{B_H} = 1 \quad \Rightarrow \delta = 45°$

8. (*d*) $\vec{M} = \left(\frac{1}{2}\vec{M}\right) + \left(-\frac{1}{2}\vec{M}\right) = 0$

12. (*d*) $m = p \times 2l = 2pl$ (S to N)

19. (*a*) $T = 2\pi\sqrt{\frac{I}{MB}}$, *i.e.*, $T \propto \frac{1}{\sqrt{M}}$

21. (*d*) $T = 2\pi\sqrt{\frac{I}{MB_H}}$

$$\frac{T_1}{T_2} = \sqrt{\frac{(B_H)_2}{(B_H)_1}}$$

$n = 30$ oscillation/min $= \frac{1}{2}$ oscillation/sec

$$\therefore \frac{\mu}{4\pi}\cdot\frac{m^2}{r^2} = 50 \text{ gm} - \text{wt}$$

$$\therefore T_2 = 2\sqrt{\frac{B_H}{2B_H}} = \sqrt{2} \text{ sec}$$

22. (*b*) $\frac{T_1}{T_2} = \sqrt{\frac{M_2}{M_1}} = \sqrt{\frac{4M}{M}} = 2 \quad \Rightarrow \frac{2}{T_2} = 2 \Rightarrow T_2 = 1 \text{ sec}$

23. (*d*) Force on a stationery charge in magnetic field is zero.

24. (*b*) Magnetic induction inside a hollow current tube is always zero.

25. (*b*) $T = 2\pi\sqrt{\frac{I}{mH}}, T' = 2\pi\sqrt{\frac{I/9}{mH}} \Rightarrow \frac{T'}{T} = \frac{1}{3}$

$$\Rightarrow T' = \frac{T}{3} = \frac{2}{3} \text{ s}$$

26. (*d*) $\mu = \frac{B}{H}$

$$\Rightarrow \mu_r = \frac{B}{\mu_0 H} = \frac{1}{4\pi \times 10^{-7} \times 150} = \frac{10^5}{6\pi}$$

27. (*c*) When magnets are perpendicular, magnetic moment,

$$m_r = \sqrt{m^2 + m^2} = \sqrt{2}\, m$$

$$\therefore \quad T = 2\pi\sqrt{\frac{2I}{m\sqrt{2}H}} = 2\pi\sqrt{\frac{2I}{\sqrt{2}mH}},$$

I = M.I. of each magnet

When one magnet is removed, then

$$T' = 2\pi\sqrt{\frac{I}{mH}}$$

$$\therefore \quad \frac{T'}{T} = \frac{1}{2^{1/4}} = T' = \frac{T}{2^{1/4}} = 2\text{ s}$$

28. (*b*) In vibration magnetometer,

$$T = 2\pi\sqrt{\frac{I}{mH}} \quad \Rightarrow \quad mH = 4\pi^2\frac{I}{T^2} \quad \ldots(1)$$

In deflection magnetometer,

$$H\tan\theta = \frac{\mu_0}{4\pi}\frac{2m}{d^3} \quad \Rightarrow \quad \frac{m}{H} = \frac{4\pi d^3}{2\mu_0}\tan\theta \quad \ldots(2)$$

Multiply (1) and (2),

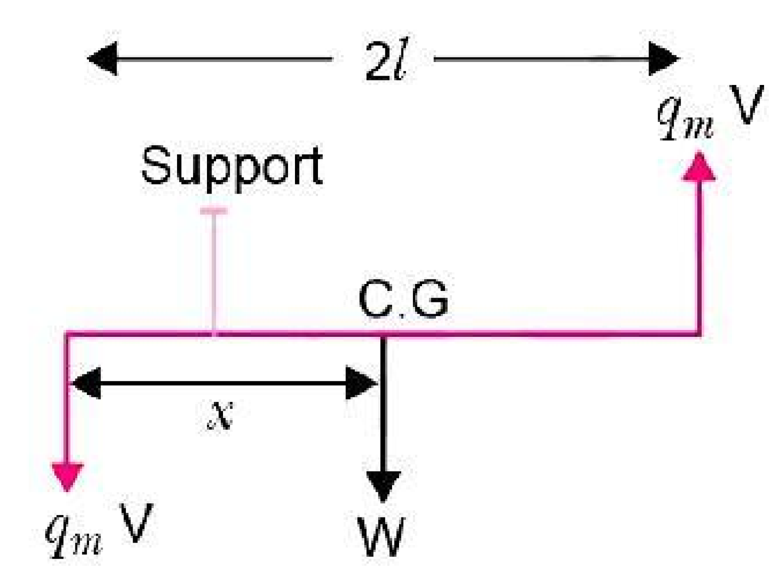
$$m^2 = \left(4\pi^2\frac{I}{T^2}\right)\cdot\left(\frac{4\pi d^3}{2\mu_0}\tan\theta\right) = 36\times10^{-4}\times\frac{10^8}{36} = 10^4 \Rightarrow m = 100\text{ A-m}^2$$

29. (*d*) Here, $m = 5\times10^{-5}$ Wb–m, $B = 8\pi\times10^{-4}$ T, $T = 15$ s

$$T = 2\pi\frac{\sqrt{I}}{mB} \quad \Rightarrow \quad I = \frac{T^2 mB}{4\pi^2}$$

$$= \frac{(15)^2\times5\times10^{-5}\times8\pi\times10^{-4}}{4\pi^2} = 7.16\times10^{-7}\text{ kgm}^2$$

30. (*a*)



$$W\,.\,x = q_m V\times2l \quad \Rightarrow \quad Wx = mV$$

$$\Rightarrow \quad x = \frac{mV}{W}$$