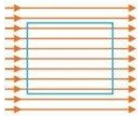
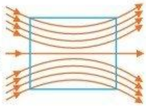
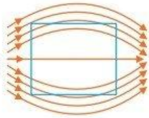
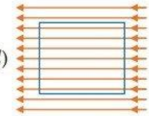
Magnetism and Matter

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. **The material which is not suitable for making a permanent magnet is** [*CBSE 2020 (55/2/2)*]
   (*a*) Steel (*b*) Ticonal
   (*c*) Lead (*d*) Alnico
2. **A magnetic needle is kept in a uniform magnetic field. It experiences**
   (*a*) a force and a torque (*b*) a force but not a torque
   (*c*) a torque but not a force (*d*) neither a torque nor a force
3. **A magnetic needle is kept in a non-uniform magnetic field. It experiences**
   (*a*) a force and a torque (*b*) a force but not a torque
   (c) a torque but not a force (*d*) neither a force nor a torque
4. **A bar magnet of magnetic moment $\vec{m}$ is placed in a uniform magnetic field of induction $\vec{B}$. The torque exerted on it is**
   (*a*) $\vec{m} \cdot \vec{B}$ (*b*) $-\vec{m} \cdot \vec{B}$ (*c*) $\vec{m} \times \vec{B}$ (*d*) $-\vec{m} \times \vec{B}$

5. **A uniform magnetic field exists in space in the plane of paper and is initially directed from left to right. When a bar of soft iron is placed in the field parallel to it, the lines of force passing through it will be represented by**

(*a*) 
(*b*) 
(*c*) 
(*d*) 

6. **Points A and B are situated perpendicular to the axis of a 2 cm long bar magnet at large distances x and $3x$ from its centre on opposite sides. The ratio of the magnetic fields at A and B will be approximately equal to**

(*a*) 1: 9 (*b*) 2: 9 (*c*) 27: 1 (*d*) 9: 1

7. **A paramagnetic sample shows a net magnetisation of 8 Am^{-1} when placed in an external magnetic field of 0.6 T at a temperature of 4 K. When the same sample is placed in an external magnetic field of 0.2 T at a temperature of 16 K, the magnetisation will be [NCERT Exemplar]**

(*a*) $\frac{32}{3}$ Am^{-1} (*b*) $\frac{2}{3}$ Am^{-1} (*c*) 6 Am^{-1} (*d*) 2.4 Am^{-1}

8. **A long solenoid has 1000 turns per metre and carries a current of 1 A. It has a soft iron core of $\mu_r = 1000$. The core is heated beyond the Curie temperature, T_c, then** [*NCERT Exemplar*]

(*a*) the *H* field in the solenoid is (nearly) unchanged but the *B* field decreases drastically.
(*b*) the *H* and *B* fields in the solenoid are nearly unchanged.
(*c*) the magnetisation in the core reverses direction.
(*d*) the magnetisation in the core diminishes by a factor of about 10^8.

9. **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

10. **A magnet of magnetic moment *m* is cut into two equal parts. The two parts are placed perpendicular to each other so that their north poles touch each other. The resultant magnetic moment is:**

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

11. **The meniscus of a liquid contained in one of the limbs of a narrow U-tube is placed between the pole-pieces of an electromagnet with the meniscus in a line with the field. When the electromagnet is switched on, the liquid is seen to rise in the limb. This indicates that the liquid is**

(*a*) ferromagnetic (*b*) paramagnetic
(*c*) diamagnetic (*d*) non-magnetic

12. **Electro-magnets are made of soft iron because soft iron has**

(*a*) small susceptibility and small retentivity (*b*) large susceptibility and small retentivity
(*c*) large permeability and large retentivity (*d*) small permeability and large retentivity.

13. **In a permanent magnet at room temperature** [*NCERT Exemplar*]

(*a*) magnetic moment of each molecule is zero.
(*b*) the individual molecules have non-zero magnetic moment which are all perfectly aligned.
(*c*) domains are partially aligned.
(*d*) domains are all perfectly aligned.

14. **If a magnetic substance is kept in a magnetic field, then which of the following substances is thrown out?**

(*a*) Paramagnetic (*b*) Ferromagnetic
(*c*) Diamegnetic (*d*) Antiferromagnetic

15. **Above Curie temperature, a** *[CBSE 2020 (55/2/1)]*
   (*a*) ferromagnetic material becomes diamagnetic.
   (*b*) ferromagnetic material becomes paramagnetic.
   (*c*) paramagnetic material becomes ferromagnetic.
   (*d*) paramagnetic material becomes diamagnetic.

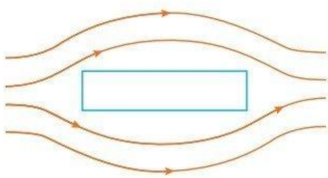
16. **In the hysteresis cycle, the value of H needed to make the intensity of magnetisation zero is called**
   (*a*) retentivity
   (*b*) coercive force
   (*c*) Lorentz force
   (*d*) none of the above

17. **Susceptibility is positive for**
   (*a*) paramagnetic substances
   (*b*) ferromagnetic substances
   (*c*) non-magnetic substances
   (*d*) diamagnetic substances

18. **A bar magnet has magnetic dipole moment $\vec{M}$. Its initial position is parallel to the direction of uniform magnetic field $\vec{B}$. In this position the magnitudes of torque and force acting on it respectively are** *[CBSE 2022 (55/2/4), Term-1]*
   (*a*) 0 and MB
   (*b*) MB and MB
   (*c*) 0 and 0
   (*d*) $|\vec{M} \times \vec{B}|$ and 0

19. **A diamagnetic substance is brought near the north or south pole of a bar magnet. It will be** *[CBSE 2023 (55/1/1)]*
   (*a*) repelled by both the poles.
   (*b*) attracted by both the poles.
   (*c*) repelled by the north pole and attracted by the south pole.
   (*d*) attracted by the north pole and repelled by the south pole.

20. **The magnetic field lines near a substance are as shown in the figure. The substance is** *[CBSE 2023 (55/4/1)]*



   (*a*) Copper
   (*b*) *Iron*
   (*c*) Sodium
   (*d*) Aluminium

Answers

1. (*c*)	**2.** (*c*)	**3.** (*a*)	**4.** (*c*)	**5.** (*b*)	**6.** (*c*)	**7.** (*b*)
8. (*a*), (*d*)	**9.** (*a*)	**10.** (*b*)	**11.** (*b*)	**12.** (*b*)	**13.** (*c*)	**14.** (*c*)
15. (*b*)	**16.** (*b*)	**17.** (*a*), (*b*)	**18.** (*c*)	**19.** (*a*)	**20.** (*a*)	

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*) : The susceptibility of a diamagnetic substance is independent of temperature.
   Reason (*R*) : Every atom of a diamagnetic substance is characterised by electron pairs of opposite spin; so with change of temperature, the motion of electrons are affected by same amount in opposite directions.
2. **Assertion** (*A*) : Magnetic susceptibility is a pure number.
   Reason (*R*) : The value of magnetic susceptibility for vacuum is one. [*AIIMS 2009*]
3. **Assertion** (*A*) : Soft iron is used a transformer core.
   Reason (*R*) : Soft iron has a narrow hysteresis loop.
4. **Assertion** (*A*) : Susceptibility is defined as the ratio of intensity of magnetisation I to magnetic intensity H.
   Reason (*R*) : Greater the value of susceptibility, smaller the value of intensity of magnetisation I. [*AIIMS 2018*]
5. **Assertion** (*A*) : For making permanent magnets, steel is preferred over soft iron.
   Reason (*R*) : As retentivity of steel is smaller.
6. **Assertion** (*A*) : When radius of a current carrying loop is doubled, its magnetic moment becomes four times.
   Reason (*R*) : The magnetic moment of a current carrying loop is directly proportional to the area of the loop. [*CBSE 2022 (55/2/4), Term-1*]
7. **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.
8. **Assertion** (*A*) : The ferromagnetic substances do not obey Curie's law.
   Reason (*R*) : At Curie point a ferromagnetic substance start behaving as a paramagnetic substance.
9. **Assertion** (*A*) : When a bar of copper is placed in an external magnetic field, the field lines get concentrated inside the bar.
   Reason (*R*) : Copper is a paramagnetic substance. [*CBSE 2023 (55/1/1)*]
10. **Assertion** (*A*) : Diamagnetic substances exhibit magnetism.
    Reason (*R*) : Diamagnetic materials do not have permanent magnetic dipole moment. [*CBSE 2023 (55/1/1)*]

Answers

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

Case-based/Passage-based Questions

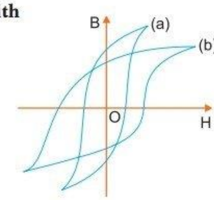
Read the paragraph given below and answer the questions that follow:

Ferromagnetism: In the absence of an external magnetic field, some of the electrons in a ferromagnetic material have their magnetic dipole moments aligned by mean of a quantum physical interaction called exchange coupling, producing regions (domains) within the material with strong magnetic dipole moments. An external field $\vec{B}_{ext}$ can align the magnetic dipole moment of those regions, producing a strong net magnetic dipole moment for the material as a whole, in the direction of $\vec{B}_{ext}$ · This net magnetic dipole moment can partially persist when field $\vec{B}_{ext}$ is removed. If $\vec{B}_{ext}$ is nonuniform, the ferromagnetic material is attracted to region of greater magnetic field. These properties are called *ferromagnetism*. Exchange coupling disappears when a sample's temperature exceeds its Curie temperature, and then the sample has only paramagnetism.

(i) Susceptibility is positive and small for

(a) paramagnetic substances
(b) ferromagnetic substances
(c) non-magnetic substances
(d) diamagnetic substances

(ii) The B—H curves (a) and (b) shown in the figure are associated with



(a) a diamagnetic and a paramagnetic substance respectively
(b) a paramagnetic and a ferromagnetic substance respectively
(c) soft iron and steel respectively
(d) steel and soft iron respectively

(iii) If bar magnet of pole strength m and magnetic moment M is cut equally in five parts parallel to its axis and again four equal parts perpendicular to its axis then the pole strength and magnetic moments of each piece are, respectively,

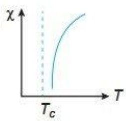
(a) $\frac{m}{20}, \frac{m}{20}$
(b) $\frac{m}{4}, \frac{M}{20}$
(c) $\frac{m}{5}, \frac{M}{20}$
(d) $\frac{m}{5}, \frac{M}{4}$

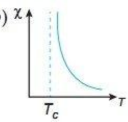
(iv) If the magnetizing field on a ferromagnetic material is increased, its permeability

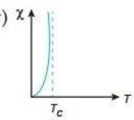
(a) is decreased
(b) is increased
(c) is unaffected
(d) may be increased or decreased

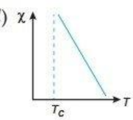
OR

The variation of magnetic susceptibility with the temperature of a ferromagnetic material can be plotted as

(a)


(b)


(c)


(d)


Explanations

(i) (a) χ is positive and small for paramagnetic materials.

(ii) (c) The retentivity of soft iron is greater than steel while coercivity of soft iron is less than steel. Hence area of (B–H) loop for soft iron is smaller than that of steel.

(iii) (c) Magnetic moment, $M = m \times 2L$ where, m = pole strength.

When it cuts in to 5 equal parts parallel to its axis, then $m' = \frac{m}{5}$.

Again, when it cuts in to 4 equal parts perpendicular to its axis. So, $2L' = \frac{2L}{4}$

Now, $M' = m' \times 2L' = \frac{m}{5} \times \frac{2L}{4} = \frac{M}{20}$

(iv) (a) We know, $\mu = \frac{B}{H} \Rightarrow \mu \propto \frac{1}{H}$

Permeability of a ferromagnetic material decreases with the increase in magnetising field intensity H.

OR

(b) χ of a ferromagnetic material decreases with the increase in temperature and above Curie temperature T_C, it becomes paramagnetic. Hence,

According to Curie law, $\chi \propto \frac{1}{T}$

CONCEPTUAL QUESTIONS

Q. 1. Which of the following substances are diamagnetic?

Bi, Al, Na, Cu, Ca and Ni *[CBSE Delhi 2013]*

Ans. Diamagnetic substances are (*i*) Bi (*ii*) Cu.

Q. 2. What are permanent magnets? Give one example. *[CBSE Delhi 2013]*

Ans. Substances that retain their attractive property for a long period of time at room temperature are called permanent magnets.

Examples: Those pieces which are made up of steel, Alnico, cobalt and Ticonal.

Q. 3. Mention two characteristics of a material that can be used for making permanent magnets. *[CBSE Delhi 2010]*

Ans. For making permanent magnet, the material must have high **retentivity** and high **coercivity** (*e.g.*, steel).

Q. 4. Why is the core of an electromagnet made of ferromagnetic materials? *[CBSE Delhi 2010]*

Ans. Ferromagnetic material has a high permeability. So on passing current through windings it gains sufficient magnetism immediately.

Q. 5. The permeability of a magnetic material is 0.9983. Name the type of magnetic materials it represents. *[CBSE Delhi 2011]*

Ans. μ is <1 and > 0, so magnetic material is diamagnetic.

Q. 6. A short bar magnet placed with its axis at 30° with a uniform external magnetic field of 0.25 T experiences a torque of magnitude equal to 4.5×10^{-2} N–m. What is the magnitude of magnetic moment of the magnet? *[NCERT]*

Ans. Given, $B = 0.25$ T, $\tau = 4.5 \times 10^{-2}$ N-m, $\theta = 30°$

We have $\tau = mB \sin\theta$

$$\Rightarrow \text{Magnetic moment, } m = \frac{\tau}{B\sin\theta} = \frac{4.5\times10^{-2}}{0.25\times\sin 30°} = \frac{4.5\times10^{-2}}{0.25\times0.5} = \mathbf{0.36\ A\text{–}m^2}$$

Q. 7. In what way is the behaviour of a diamagnetic material different from that of a paramagnetic, when kept in an external magnetic field? *[CBSE Central 2016]*

Ans. A diamagnetic specimen would move towards the weaker region of the field while a paramagnetic specimen would move towards the stronger region.

Q. 8. The magnetic susceptibility of magnesium at 300 K is 1.2×10^5. At what temperature will its magnetic susceptibility become 1.44×10^5? *[CBSE 2019 (55/2/1)]*

Ans. From Curie law,

$$X_m \propto \frac{1}{T} \qquad \text{½}$$

Now, $$T_2 = \frac{\chi_{m_1}}{\chi_{m_2}} \times T_1 \qquad \text{½}$$

$$\therefore\ T_2 = \frac{1.2\times10^5}{1.44\times10^5}\times300 = \mathbf{250\ K}$$

[CBSE Marking Scheme 2019 (55/2/1)]

Q. 9. The magnetic susceptibility χ of a given material is – 0.5. Identify the magnetic material. *[CBSE 2019 (55/2/1)]*

Ans. The susceptibility of material is – 0.5, which is negative. Hence, material is diamagnetic substance.

Q. 10. Write one important property of a paramagnetic material. *[CBSE 2019 (55/5/1)]*

Ans. Any one property of paramagnetic materials. (e.g.)

(*i*) It attracts field lines, weakly.

(*ii*) It moves from weaker towards stronger field. or any other property.) **1**

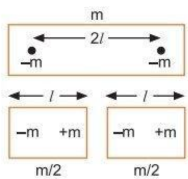
[CBSE Marking Scheme 2019 (55/5/1)]

Q. 11. Do the diamagnetic substances have resultant magnetic moment in an atom in the absence of external magnetic field? *[CBSE 2019 (55/5/1)]*

Ans. No, diamagnetic substances have no resultant magnetic moment in the absence of external magnetic field.

Q. 12. How does the (*i*) pole strength and (*ii*) magnetic moment of each part of a bar magnet change if it is cut into two equal pieces transverse to length?

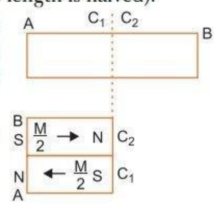
Ans. When a bar magnet of magnetic moment $(\vec{M} = m2\vec{l})$ is cut into two equal pieces transverse to its length,



(*i*) the pole strength remains unchanged (since pole strength depends on number of atoms in cross-sectional area).

(*ii*) the magnetic moment is reduced to half (since $M \propto$ length and here length is halved).

Q. 13. A hypothetical bar magnet (*AB*) is cut into two equal parts. One part is now kept over the other, so that the pole C_2 is above C_1. If *M* is the magnetic moment of the original magnet, what would be the magnetic moment of the combination, so formed?



Ans. The magnetic moment of each half bar magnet is $\frac{M}{2}$ but oppositely directed, so net magnetic moment of combination $= \frac{M}{2} - \frac{M}{2} = 0$ (zero).

Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. Write any two points of difference between a diamagnetic and a paramagnetic substance. *[CBSE 2023 (55/3/1)]*

Ans.

Diamagnetic Substance	Paramagnetic
(*i*) They are feebly reppeled by magnets	(*i*) They are feebly attracted by magnet
(*ii*) Susceptibility is independent of temperature.	(*ii*) Susceptibility varies inversely with temperature. *i.e.,* $X_m \propto \frac{1}{T}$
(*iii*) $-1 \le \chi < 0$ and $0 \le \mu_r < 1$	(*iii*) $0 < \chi < \varepsilon$ and $1 \le \mu_r < (1 + \varepsilon)$

[any two]

Q. 2. The susceptibility of a magnetic material is -2.6×10^{-5}. Identify the type of magnetic material and state its two properties. [*CBSE Delhi 2012*]

Ans. The magnetic material having negative susceptibility is diamagnetic in nature.

Properties:

(*i*) This material has + ve but low relative permeability.

(*ii*) They have the tendency to move from stronger to weaker part of the external magnetic field.

Q. 3. (*a*) Closely wound solenoid of 800 turns and area of cross-section 2.5×10^{-4} m^2 carries a current of 3.0 A. Explain the sense in which solenoid acts like a bar magnet. What is the associated magnetic moment?

(*b*) If the solenoid is free to turn about the vertical direction in an external uniform horizontal magnetic field at 0.25 T, what is the magnitude of the torque on the solenoid when its axis makes an angle of 30° with the direction of the external field. [*NCERT*]

Ans. (*a*) If solenoid is suspended freely, it stays in N-S direction. The polarity of solenoid depends on the sense of flow of current. If to an observer looking towards an end of a solenoid, the current appears anticlockwise, the end of solenoid will be N-pole and other end will be S-pole.

Magnetic moment, $m = NIA = 800 \times 3.0 \times 2.5 \times 10^{-4} = \mathbf{0.60\ A\text{-}m^2}$

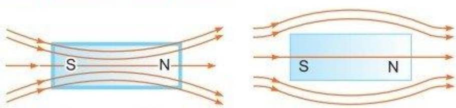
(*b*) Torque on solenoid $\tau = mB \sin \theta$

$= 0.60 \times 0.25 \sin 30°$

$= 0.60 \times 0.25 \times 0.5 = \mathbf{7.5 \times 10^{-2}\ N\text{–}m}$

Q. 4. Two identical bars, one of paramagnetic material and other of diamagnetic material are kept in a uniform external magnetic field parallel to it. Draw diagrammatically the modifications in the magnetic field pattern in each case. [*CBSE 2020 (55/3/1)*]

Ans.



Paramagnetic substance (i)

Diamagnetic substance (ii)

- A paramagnetic material tends to move from weaker field to stronger field regions of the magnetic field. So, the number of lines of magnetic field increases when passing through it.
- A diamagnetic material tends to move from stronger field to weaker field region of the magnetic field. So, the number of lines of magnetic field passing through it decreases.

Q. 5. Write two properties of a material suitable for making (*a*) a permanent magnet, and (*b*) an electromagnet. [*CBSE (AI) 2017*]

Ans.

6. Making a permanent magnet
Usually steel is used for making the
permanent magnet. Because the material [illegible]
since require high retentivity
high coercivity
intensive magnetism
For making electromagnets:
Soft Iron core is mainly used for making an
electromagnet because of the following properties:
high permeability
less area of the covered hysteresis loop
in order to minimise the energy loss

High retentivity
Low coercivity
Hence the relative permeability of the material should be very high in order to permit more magnetic field lines to pass through them

[*Topper's Answer 2017*]

Q. 6. What is the basic difference between the atom and molecule of a diamagnetic and a paramagnetic material? Why are elements with even atomic number more likely to be diamagnetic?

Ans. Atoms/molecules of a diamagnetic substance contain even number of electrons and these electrons form the pairs of opposite spin; while the atoms/molecules of a paramagnetic substance have excess of electrons spinning in the same direction.

The elements with even atomic number Z has even number of electrons in its atoms/molecules, so they are more likely to form electrons pairs of opposite spin and hence more likely to be diamagnetic.

Q. 7. A small magnetised needle *P* is placed at the origin of *x–y* plane with its magnetic moment pointing along the *y*-axis. Another identical magnetised needle *Q* is placed in two positions, on by one. [*CBSE 2023 (55/4/1)*]

***Case 1* : at (*a*, 0) with its magnetic moment pointing along *x*-axis.**

***Case 2* : at (*a*, 0) with its magnetic moment pointing along *y*-axis.**

(*a*) In which case is the potential energy of *P* and *Q* minimum?

(*b*) In which case is *P* and *Q* not in equilibrium?

Justify your answers.

Ans. (*a*) Since $P.E = U = -MB\cos\theta$

Case 1: $\theta = 90° \Rightarrow U = 0$

Case 2: $\theta = 0° \Rightarrow U = -MB$

Hence, *P.E* is minimum in case 2.

(*b*) Since $\tau = MB\sin\theta$

Case 1: $\theta = 90° \Rightarrow \tau = MB$

Case 2: $\theta = 0° \Rightarrow \tau = 0$

Hence, *P* and *Q* are not in equilibrium in case 1. In this case, *Q* is at normal bisector of *P*.

Short Answer Questions

Each of the following questions are of 3 marks.

Q. 1. (*i*) Mention two properties of soft iron due to which it is preferred for making an electromagnet.

(*ii*) State Gauss's law in magnetism. How is it different from Gauss's law in electrostatics and why? [*CBSE South 2016*]

Ans. (*i*) Low coercivity and high permeability

(*ii*) **Gauss's Law in magnetism:** The net magnetic flux through any closed surface is zero.

$$\oint B.ds = 0$$

Gauss's Law in electrostatics: The net electric flux through any closed surface is $\frac{1}{\varepsilon_0}$ times the net charge enclosed by the surface.

$$\oint E.ds = \frac{q}{\varepsilon_0}$$

The difference between the Gauss's law of magnetism and that for electrostatic is a reflection of the fact that magnetic monopole do not exist *i.e.*, magnetic poles always exist in pairs.

Q. 2. A bar magnet of magnetic moment 1.5 JT^{-1} lies aligned with the direction of a uniform magnetic field of 0.22 T.

(*a*) What is the amount of work required by an external torque to turn the magnet so as to align its magnetic moment

(*i*) normal to the field direction? and (*ii*) opposite to the field direction?

(*b*) What is the torque on the magnet in cases (*i*) and (*ii*)? [*NCERT*]

Ans. (*a*) Work done in aligning a magnet from orientation θ_1 to θ_2 is given by

$$W = U_2 - U_1 = -mB\cos\theta_2 - (-mB\cos\theta_1)$$
$$= -mB(\cos\theta_2 - \cos\theta_1)$$

(*i*) Here $\theta_1 = 0°, \theta_2 = 90°$

$\therefore \quad W = mB(\cos 0° - \cos 90°) = mB(1-0) = mB$

$= 1.5 \times 0.22 = \mathbf{0.33\ J}$

(*ii*) Here $\theta_1 = 0°, \theta_2 = 180°$

$\therefore \quad W = mB(\cos 0° - \cos 180°) = 2mB$

$= 2 \times 1.5 \times 0.22 = \mathbf{0.66\ J}$

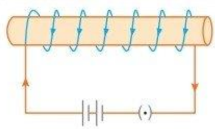
(*b*) Torque $\tau = mB\sin\theta$

In (*i*) $\theta = 90°, \tau = mB\sin 90° = mB = 1.5 \times 0.22 =$ **0.33 N-m**

This torque tends to align the magnet along the direction of field direction.

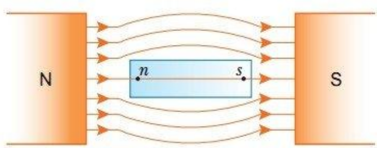
In (*ii*) $\theta = 180°, \tau = mB\sin 180° = \mathbf{0}$

Q. 3. Draw the magnetic field lines for a current carrying solenoid when a rod made of (*a*) copper, (*b*) aluminium and (*c*) iron are inserted within the solenoid as shown.

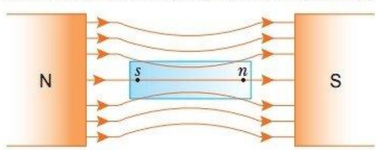


[*CBSE Sample Paper 2018*]

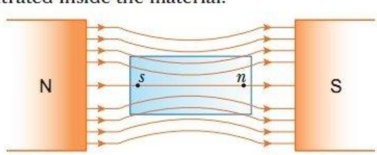
Ans. (*a*) When a bar of diamagnetic material (copper) is placed in an external magnetic field, the field lines are repelled or expelled and the field inside the material is reduced.



(*b*) When a bar of paramagnetic material (Aluminium) is placed in an external field, the field lines gets concentrated inside the material and the field inside is enhanced.



(*c*) When a ferromagnetic material (Iron) is placed in an internal magnetic field, the field lines are highly concentrated inside the material.



Q. 4. In what way is Gauss's law in magnetism different from that used in electrostatics? Explain briefly. The Earth's magnetic field at the equator is approximately 0.4 G. Estimate the Earth's magnetic dipole moment. Given: Radius of the Earth = 6400 km. **[*CBSE Patna 2015*]**

Ans. As we know that

Isolated positive or negative charge exists freely. So, Gauss's law states that $\oint \vec{E} \cdot d\vec{S} = \frac{1}{\varepsilon_0}[q]$

Isolated magnetic poles do not exist. So, Gauss's law states that

$$\oint \vec{B} \cdot \vec{dS} = 0$$

Magnetic field intensity at the equator is

$$B = \frac{\mu_0}{4\pi} \cdot \frac{m}{R^3} = 10^{-7} \frac{m}{R^3}$$

$$\therefore \quad m = 10^7 \cdot BR^3$$

$$= 10^7 \times 0.4 \times 10^{-4} \times (6400 \times 10^3)^3$$

$$= \mathbf{1.05 \times 10^{23}\ Am^2}$$

Q. 5. A bar magnet of magnetic moment 6 J/T is aligned at 60° with a uniform external magnetic field of 0·44 T. Calculate (*a*) the work done in turning the magnet to align its magnetic moment (*i*) normal to the magnetic field, (*ii*) opposite to the magnetic field, and (*b*) the torque on the magnet in the final orientation in case (*ii*). **[*CBSE Examination Paper 2018*]**

Ans. (*a*) Work done = $mB(\cos\theta_1 - \cos\theta_2)$

(*i*) $\theta_1 = 60°, \theta_2 = 90°$

$\therefore$ Work done = $mB(\cos 60° - \cos 90°)$

$$= mB\left(\frac{1}{2} - 0\right) = \frac{1}{2}mB$$

$$= \frac{1}{2} \times 6 \times 0.44\ \text{J} = \mathbf{1.32\ J}$$

(*ii*) $\theta_1 = 60°, \theta_2 = 180°$

$\therefore$ Work done = $mB(\cos 60° - \cos 180°)$

$$= mB\left(\frac{1}{2} - (-1)\right) = \frac{3}{2}mB$$

$$= \frac{3}{2} \times 6 \times 0.44\ \text{J} = \mathbf{3.96\ J}$$

(*b*) Torque = $|\vec{m} \times \vec{B}| = mB\sin\theta$

For $\theta = 180°$ and B = 0.44 T we have

Torque = $6 \times 0.44 \sin 180° = \mathbf{0}$

Q. 6. (*a*) An iron ring of relative permeability μ_r has windings of insulated copper wire of *n* turns per metre. When the current in the windings is *I*, find the expression for the magnetic field in the ring.

(*b*) The susceptibility of a magnetic material is 0.9853. Identify the type of magnetic material. Draw the modification of the field pattern on keeping a piece of this material in a uniform magnetic field. **[*CBSE Examination Paper 2019*]**

Ans. (*a*) From Ampere's circuital law, we have,

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 \mu_r I_{enclosed} \qquad ...(i)$$

For the field inside the ring, we can write

$$\oint \vec{B} \cdot \vec{dl} = \oint Bdl = B.2\pi r \quad (r = \text{radius of the ring})$$

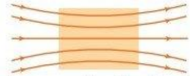
Also, $I_{enclosed} = (2\pi rn)I$

$\therefore \quad B.2\pi r = \mu_0 \mu_r.(n.2\pi r)I$ [Using equation (*i*)]

$\therefore B = \mu_0 \mu_r.nI$

(b) The material is paramagnetic.

The field pattern gets modified as shown in the figure alongside.



Q. 7. (a) Show that the time period (T) of oscillations of a freely suspended magnetic dipole of magnetic moment (m) in a uniform magnetic field (B) is given by $T = 2\pi\sqrt{\frac{I}{mB}}$, where I is a moment of inertia of the magnetic dipole.

(b) Identify the following magnetic materials:

(i) A material having susceptibility $(\chi_m) = -0.00015$

(ii) A material having susceptibility $(\chi_m) = 10^{-5}$ [*CBSE 2019 (55/3/1)*]

Ans. (a) Let us consider a uniform magnetic field $\vec{B}$ exists in the region, in which a magnet of dipole moment $\vec{m}$ is placed. The dipole is making small angle θ with the magnetic field. The torque acts on the magnet is given by

$$\vec{\tau} = -mB\sin\theta \qquad \text{(Restoring torque)}$$

$$= -mB\theta \qquad (\because \theta \text{ in small})$$

Also the torque on dipole try to restore its initial position *i.e.*, along the direction of magnetic field. (I = moment of inertia)

In equilibrium

$$I\frac{d^2\theta}{dt^2} = -mB\sin\theta$$

Negative sign implies that restoring torque is in opposition to deflecting torque.

$$\frac{d^2\theta}{dt^2} = \frac{-mB}{I}\theta$$

Comparing with equation of angular SHM

$$\frac{d^2\theta}{dt^2} = -\omega^2\theta$$

We have

$$\omega^2 = \frac{mB}{I} \Rightarrow \omega = \sqrt{\frac{mB}{I}}$$

$$\Rightarrow \qquad \frac{2\pi}{T} = \sqrt{\frac{mB}{I}} \Rightarrow \frac{T}{2\pi} = \sqrt{\frac{I}{mB}}$$

$$T = 2\pi\sqrt{\frac{I}{mB}}$$

(b) (i) Diamagnetic substance. (ii) Paramagnetic substance.

Q. 8. Write three points of differences between para-, dia- and ferro- magnetic materials, giving one example for each. [*CBSE 2019 (55/1/1)*]

Ans.

	Diamagnetic	Paramagnetic	Ferromagnetic	
1.	$-1 \le \chi \langle 0$	$-0 < \chi \langle \varepsilon$	$\chi \rangle\rangle 1$	½
2.	$0 \le \mu_r \langle 1$	$1 \le \mu_r \langle (1+\varepsilon)$	$\mu_r \rangle\rangle 1$	½
3.	$\mu \langle \mu_0$	$\mu \rangle\rangle \mu_0$	$\mu \rangle\rangle \mu_0$	½

Where ε is any positive constant.

[**Note:** Give full credit of this part if student write any other three correct difference]

Examples (Any one example of each type)

Diamagnetic materials: Bi, Cu, Pb, Si, water, NaCI, Nitrogen (at STP) ½

Paramagnetic materials: Al, Na, Ca, Oxygen (at STP), Copper chloride ½

Ferromagnetic materials: Fe, Ni, Co, AlniCo ½

[*CBSE Marking Scheme 2019 (55/1/1)*]

Q. 9. **(a) State Gauss's law for magnetism. Explain its significance.** [*CBSE 2019 (55/1/1)*]

(b) Write the four important properties of the magnetic field lines due to a bar magnet.

Ans. (*a*) Gauss's law for magnetism states that "The total flux of the magnetic field, through any closed surface, is always zero. ½

Alternatively,

$\Rightarrow \oint \vec{B}.\vec{d}s = 0$

This law implies that magnetic monopoles do not exist" / magnetic field lines form closed loops ½

[Note: Award this 1 mark if the student just attempts it]

(*b*) Four properties of magnetic field lines

(*i*) Magnetic field lines always form continuous closed loops. ½

(*ii*) The tangent to the magnetic field line at a given point represents the direction of the net magnetic field at that point. ½

(*iii*) The larger is the number of field lines crossing per unit area, the stronger is the magnitude of the magnetic field. ½

(*iv*) Magnetic field lines do not intersect. ½

[*CBSE Marking Scheme 2019 (55/1/1)*]

Long Answer Questions

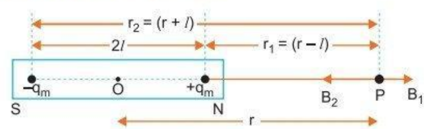
Each of the following questions are of 5 marks.

Q. 1. **Derive an expression for magnetic field intensity due to a magnetic dipole of a bar magnet at a point on its axial line.**

Ans. Consider a magnetic dipole (or a bar magnet) *SN* of length $2l$ having south pole at *S* and north pole at *N*. The strength of south and north poles are $-q_m$ and $+q_m$ respectively.

Magnetic moment of magnetic dipole $m = q_m 2l$, its direction is from *S* to *N*.

Consider a point *P* on the axis of magnetic dipole at a distance *r* from mid point *O* of dipole.



The distance of point *P* from *N*-pole,

$r_1 = (r - l)$

The distance of point *P* from *S*-pole, $r_2 = (r + l)$

Let B_1 and B_2 be the magnetic field intensities at point *P* due to north and south poles respectively. The directions of magnetic field due to north pole is away from *N*-pole and due to south pole is towards the *S*-pole. Therefore,

$$B_1 = \frac{\mu_0}{4\pi}\frac{q_m}{(r-l)^2} \text{ from } N \text{ to } P \text{ and } B_2 = \frac{\mu_0}{4\pi}\frac{q_m}{(r+l)^2} \text{ from } P \text{ to } S$$

Clearly, the directions of magnetic field strengths $\vec{B}_1$ and $\vec{B}_2$ are along the same line but opposite to each other and $B_1 > B_2$.

Therefore, the resultant magnetic field intensity due to bar magnet has magnitude equal to the difference of B_1 and B_2 and direction from *N* to *P*.

$$i.e., \quad B = B_1 - B_2 = \frac{\mu_0}{4\pi}\frac{q_m}{(r-l)^2} - \frac{\mu_0}{4\pi}\frac{q_m}{(r+l)^2}$$

$$= \frac{\mu_0}{4\pi}q_m\left[\frac{1}{(r-l)^2} - \frac{1}{(r+l)^2}\right] = \frac{\mu_0}{4\pi}q_m\left[\frac{(r+l)^2-(r-l)^2}{(r^2-l^2)^2}\right]$$

$$= \frac{\mu_0}{4\pi} q_m \left[\frac{4rl}{(r^2 - l^2)^2} \right] = \frac{\mu_0}{4\pi} \frac{2(q_m 2l)r}{(r^2 - l^2)^2}$$

But $q_m\, 2l = m$ (magnetic dipole moment)

$$\therefore \quad B = \frac{\mu_0}{4\pi} \frac{2m.r}{(r^2 - l^2)^2} \qquad \ldots(i)$$

If the bar magnet is very short and point P is far away from the magnet, the $r >> l$, therefore, equation (*i*) takes the form

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

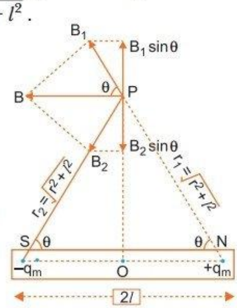
or

$$B = \frac{\mu_0}{4\pi} \frac{2m}{r^3}$$

This is the expression for magnetic field intensity at axial position due to a short bar magnet.

Q. 2. Derive an expression for magnetic field intensity due to a magnetic dipole of a bar magnet at a point lies on its equatorial line.

Ans. Consider a point P on equatorial position (or broad side on position) of short bar magnet of length $2l$, having north pole (N) and south pole (S) of strength $+q_m$ and $-q_m$ respectively. The distance of point P from the mid point (O) of magnet is r. Let B_1 and B_2 be the magnetic field intensities due to north and south poles respectively. $NP = SP = \sqrt{r^2 + l^2}$.



$$\vec{B}_1 = \frac{\mu_0}{4\pi} \frac{q_m}{r^2 + l^2} \text{ along } N \text{ to } P$$

$$\vec{B}_2 = \frac{\mu_0}{4\pi} \frac{q_m}{r^2 + l^2} \text{ along } P \text{ to } S$$

Clearly, magnitudes of $\vec{B}_1$ and $\vec{B}_2$ are equal

i.e., $\quad |\vec{B}_1| = |\vec{B}_2| \quad$ or $\quad B_1 = B_2$

To find the resultant of $\vec{B}_1$ and $\vec{B}_2$, we resolve them along and perpendicular to magnetic axis SN. Components of $\vec{B}_1$ along and perpendicular to magnetic axis are $B_1 \cos\theta$ and $B_2 \sin\theta$ respectively. Components of $\vec{B}_2$ along and perpendicular to magnetic axis are $B_2 \cos\theta$ and $B_2 \sin\theta$ respectively. Clearly, components of $\vec{B}_1$ and $\vec{B}_2$ perpendicular to axis SN. $B_1 \sin\theta$ and $B_2 \sin\theta$ are equal in magnitude and opposite in direction and hence, cancel each other; while the components of $\vec{B}_1$ and $\vec{B}_2$ along the axis are in the same direction and hence, add up to give to resultant magnetic field parallel to the direction $\overrightarrow{NS}$.

$\therefore$ Resultant magnetic field intensity at P.

$$B = B_1 \cos\theta + B_2 \cos\theta$$

But $\quad B_1 = B_2 = \frac{\mu_0}{4\pi} \frac{q_m}{r^2 + l^2}$ and $\cos\theta = \frac{ON}{PN} = \frac{l}{\sqrt{r^2 + l^2}} = \frac{l}{(r^2 + l^2)^{1/2}}$

$$\therefore \quad B = 2B_1 \cos\theta = 2 \times \frac{\mu_0}{4\pi} \frac{q_m}{(r^2 + l^2)} \times \frac{l}{(r^2 + l^2)^{1/2}} = \frac{\mu_0}{4\pi} \frac{2q_m l}{(r^2 + l^2)^{3/2}}$$

But $q_m.2l = m$, magnetic moment of magnet

$$\therefore \quad B = \frac{\mu_0}{4\pi} \frac{m}{(r^2 + l^2)^{3/2}} \qquad \ldots(i)$$

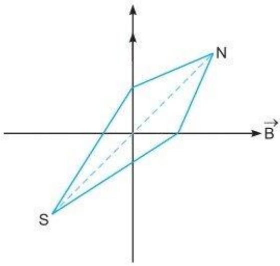
If the magnet is very short and point P is far away, we have $l << r$; so l^2 may be neglected as compared to r^2 and so equation (*i*) takes the form

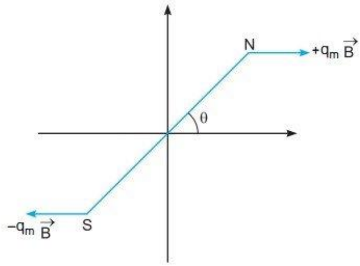
$$B = \frac{\mu_0}{4\pi} \frac{m}{r^3}$$

This is expression for magnetic field intensity at equatorial position of the magnet.

Q. 3. A small compass needle of magnetic moment 'm' is free to turn about an axis perpendicular to the direction of uniform magnetic field 'B'. The moment of inertia of the needle about the axis is 'I'. The needle is slightly disturbed from its stable position and then released. Prove that it executes simple harmonic motion. Hence deduce the expression for its time period.

Ans. If magnetic compass of dipole moment $\vec{m}$ is placed at angle θ in uniform magnetic field, and released it experiences a restoring torque.





Restoring torque, $\vec{\tau} = -$ magnetic force × perpendicular distance

$= -q_m B \cdot (2a \sin\theta)$,

$\tau = -mB.\sin\theta$, where q_m = pole strength, $m = q_m.2a$ (magnetic moment)

Negative sign shows that restoring torque acts in the opposite direction to that of defecting torque.

In equilibrium, the equation of motion,

$$\Rightarrow \quad I\frac{d^2\theta}{dt^2} = -mB\theta \qquad \text{(For small angle } \sin\theta \approx \theta\text{)}$$

$$\Rightarrow \quad \frac{d^2\theta}{dt^2} = -\frac{mB}{I}\theta \Rightarrow \frac{d^2\theta}{dt^2} = -\left(\frac{mB}{I}\right)\theta$$

Since $\frac{d^2\theta}{dt^2} \propto \theta \Rightarrow \frac{d^2\theta}{dt^2} = -\omega^2\theta$

It represents the simple harmonic motion with angular frequency

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

Questions for Practice

1. **Choose and write the correct option in the following questions.**

(*i*) If a diamagnetic substance is brought near the north or the south pole of a bar magnet, it is

(*a*) repelled by the north pole and attracted by the south pole

(*b*) attracted by the north pole and repelled by the south pole

(*c*) attracted by both the poles

(*d*) repelled by both the poles

(*ii*) A bar magnet having a magnetic moment of 2×10^4 J T^{-1} is free to rotate in a horizontal plane. A horizontal magnetic field $B = 6 \times 10^{-4}$ T exists in the space. The work done in taking the magnet slowly from a direction parallel to the field to a direction 60° from the field is

(*a*) 12 J (*b*) 6 J

(*c*) 2 J (*d*) 0.6 J

(*iii*) Above Curie's temperature ferromagnetic substances becomes

(*a*) paramagnetic (*b*) diamagnetic

(*c*) superconductor (*d*) no change

(*iv*) There are four light-weight-rod samples, *A*, *B*, *C*, and *D* separately suspended by threads. A bar magnet is slowly brought near each sample and the following observation are noted

(*i*) *A* is feebly repelled (*ii*) *B* is feebly attracted

(*iii*) *C* is strongly attracted (*iv*) *D* remains unaffected

Which one of the following is true?

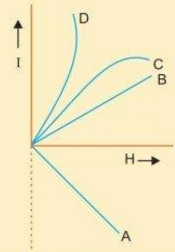
(*a*) *A* is of non-magnetic material

(*b*) *B* is of a paramagnetic material

(*c*) *C* is of a diamagnetic material

(*d*) *D* is of a ferromagnetic material

(*v*) The most appropriate *I-H* curve for a paramagnetic substance shown in figure is



(*a*) *A* (*b*) *B*

(*c*) *C* (*d*) *D*

2. ***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.***

(*i*) **Assertion (*A*) :** Diamagnetic materials can exhibit magnetism.

Reason (*R*) : Diamagnetic materials have permanent magnetic dipole moment.

(*ii*) **Assertion (*A*) :** The poles of a bar magnet cannot be separated.

Reason (*R*) : Magnetic monopoles do not exist. *[CBSE 2022 (55/2/4), Term–1]*

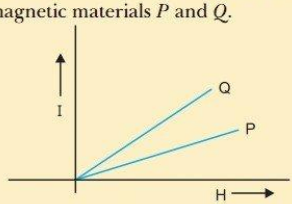
3. Define magnetic length of a barmagnet. Also find the ratio of magnetic length and geometrical length of bar magnet.

4. The susceptibility of a magnetic material is 1.9×10^{-5}. Name the type of magnetic materials it represents.

5. Depict the behaviour of magnetic field lines in the presence of a diamagnetic material.

6. The susceptibility of a magnetic materials is -4.2×10^{-6}. Name the type of magnetic materials it represents. *[CBSE 2011]*

7. The given graph shows the variation of intensity of magnetisation *I* with strength of applied magnetic field *H* for two magnetic materials *P* and *Q*.



(*i*) Identify the materials *P* and *Q*.

(*ii*) For material *P*, plot the variation of intensity of magnetisation with temperature. Justify your answer.

8. The relative magnetic permeability of a magnetic material is 800. Identify the nature of magnetic material and state its two properties.

9. From molecular view point, discuss the temperature dependence of susceptibility for diamagnetism, paramagnetism and ferromagnetism.

10. A short bar magnet of magnetic moment $m = 0.32\ JT^{-1}$ is placed in a uniform magnetic field of 0.15 T. If the bar is free to rotate in the plane of the field, which orientation would correspond to its (*i*) stable and (*ii*) unstable equilibrium? What is the potential energy of the magnet in each case? *[NCERT]*

11. A short bar magnet has a magnetic moment of $0.48\ JT^{-1}$. Give the magnitude and direction of the magnetic field produced by the magnet at a distance of 10 cm from the centre of magnet on (*a*) the axis, (*b*) equatorial lines (normal bisector) of the magnet. *[NCERT]*

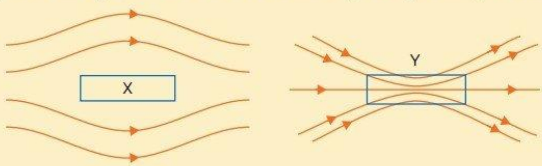
12. Explain the following:

(*i*) Why do magnetic field lines form continuous closed loops?

(*ii*) Why are the field lines repelled (expelled) when a diamagnetic material is placed in an external uniform magnetic field? *[CBSE (F) 2011]*

13. A uniform conducting wire of length $12a$ and resistance R is wound up as a current carrying coil in the shape of (*i*) an equilateral triangle of side a; (*ii*) a square of sides a and, (*iii*) a regular hexagon of sides a. The coil is connected to a voltage source V_0. Find the magnetic moment of the coils in each case.

14. A uniform magnetic field gets modified as shown below when two specimens X and Y are placed in it. Identify whether specimens X and Y are diamagnetic, paramagnetic or ferromagnetic.



15. A closely wound solenoid of 2000 turns and area of cross-section $1.6 \times 10^{-4}\ m^2$, carrying a current of 4.0 A is suspended through its centre allowing it to turn in a horizontal plane.

(*a*) What is the magnetic moment associated with the solenoid?

(*b*) What are the force and torque on the solenoid if a uniform magnetic field of 7.5×10^{-2} T is set up at an angle of 30° with the axis of the solenoid? *[NCERT]*

16. (*a*) Draw the magnetic field lines due to a circular loop of area A carrying current I. Show that it acts as a bar magnet of magnetic moment $\vec{m} = \overrightarrow{IA}$.

(*b*) Derive the expression for the magnetic field due to a solenoid of length '$2l$', radius 'a' having 'n' number of turns per unit length and carrying a steady current 'I' at a point on the axial line, distant 'r' from the centre of the solenoid. How does this expression compare with the axial magnetic field due to a bar magnet of magnetic moment 'm'?

Answers

1. (*i*) (*d*) (*ii*) (*b*) (*iii*) (*a*) (*iv*) (*b*) (*v*) (*b*)

2. (*i*) (*c*) (*ii*) (*a*)

10. (*i*) -4.8×10^{-2} J (*ii*) $+4.8 \times 10^{-2}$ J **11.** (*a*) 0.96 G (*b*) 0.48 G

13. (*i*) $\sqrt{3}\,a^2I$ (*ii*) $3a^2I$ (*iii*) $3\sqrt{3}\,a^2I$ **15.** (*a*) 1.28 Am^2 (*b*) Zero, 4.8×10^{-2} Nm.