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5. MAGNETISM AND MATTER

PGT Physics-Practice Set

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SUMMARY

1. The science of magnetism is old. It has been known since ancient times that magnetic materials tend to point in the north-south direction; like magnetic poles repel and unlike ones attract; and cutting a bar magnet in two leads to two smaller magnets. Magnetic poles cannot be isolated.

2. When a bar magnet of dipole moment $\vec{m}$ is placed in a uniform magnetic field $\vec{B}$,

(a) the force on it is zero,

(b) the torque on it is $\vec{m}\times\vec{B}$,

(c) its potential energy is $-\vec{m}\cdot\vec{B}$, where we choose the zero of energy at the orientation when $\vec{m}$ is perpendicular to $\vec{B}$.

3. Consider a bar magnet of size l and magnetic moment $\vec{m}$, at a distance r from its mid-point, where $r >> l$, the magnetic field $\vec{B}$ due to this bar is,

$$\vec{B} = \frac{\mu_0 \vec{m}}{2\pi r^3} \text{ [along axis]}$$

$$= -\frac{\mu_0 \vec{m}}{4\pi r^3} \text{ [along equator]}$$

4. Gauss's law for magnetism states that the net magnetic flux through any closed surface is zero

$$\phi_B = \sum_{\substack{all\, area \\ elements\, \Delta S}} \vec{B}.\Delta\vec{S} = 0$$

5. The earth's magnetic field resembles that of a (hypothetical) magnetic dipole located at the centre of the earth. The pole near the geographic north pole of the earth is called the north magnetic pole. Similarly, the pole near the geographic south pole is called the south magnetic pole. This dipole is aligned making a small angle with the rotation axis of the earth. The magnitude of the field on the earth's surface $\approx 4\times10^{-5}T$.

6. Three quantities are needed to specify the magnetic field of the earth on its surface – the horizontal component, the magnetic declination, and the magnetic dip. These are known as the elements of the earth's magnetic field.

7. Consider a material placed in an external magnetic field $\vec{B}_0$. The magnetic intensity is defined as,

$$\vec{H} = \frac{\vec{B}_0}{\mu_0}$$

The magnetisation $\vec{M}$ of the material is its dipole moment per unit volume. The magnetic field $\vec{B}$ in the material is, $\vec{B} = \mu_0\left(\vec{H} + \vec{M}\right)$

8. For a linear material $\vec{M} = \chi\vec{H}$. So that $\vec{B} = \mu\vec{H}$ and χ is called the magnetic susceptibility of the material. The three quantities, χ, the relative magnetic permeability μ_r, and the magnetic permeability μ are related as follows:

$$\mu = \mu_0\mu_r, \quad \mu_r = 1 + \chi$$

9. Magnetic materials are broadly classified as: diamagnetic, paramagnetic, and ferromagnetic. For diamagnetic materials χ is negative and small and for paramagnetic materials it is positive and small. Ferromagnetic materials have large χ and are characterised by non-linear relation between $\vec{B}$ and $\vec{H}$. They show the property of hysteresis.

10. Substances, which at room temperature, retain their ferromagnetic property for a long period of time are called permanent magnets.

H.No. 40-D, G.F., Jia Sarai, Near IIT, Hauz Khas, New Delhi-16
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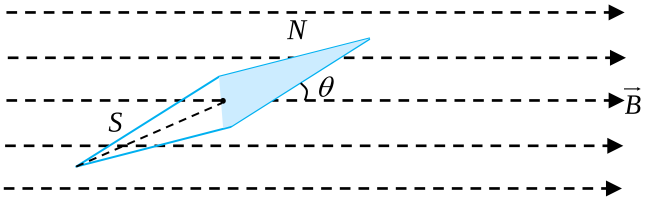
Physical Quantity	Symbol	Nature	Dimensions	Units	Remarks
Permeability of free space	μ_0	Scalar	$\left[MLT^{-2}A^{-2}\right]$	$T\,mA^{-1}$	$\mu_0/4\pi = 10^{-7}$
Magnetic field, Magnetic induction, Magnetic flux density	$\vec{B}$	Vector	$\left[MT^{-2}A^{-1}\right]$	T (tesla)	$10^4 G$ (gauss) = 1 T
Magnetic moment	$\vec{m}$	Vector	$\left[L^{-2}A\right]$	$A\,m^2$	
Magnetic flux	ϕ_B	Scalar	$\left[ML^2T^{-2}A^{-1}\right]$	W (weber)	$W = T\,m^2$
Magnetisation	$\vec{M}$	Vector	$\left[L^{-1}A\right]$	$A\,m^{-1}$	$\frac{\text{Magnetic moment}}{\text{Volume}}$
Magnetic intensity Magnetic field strength	$\vec{H}$	Vector	$\left[L^{-1}A\right]$	$A\,m^{-1}$	$\vec{B} = \mu_0\left(\vec{H} + \vec{M}\right)$
Magnetic susceptibility	χ	Scalar	-	-	$\vec{M} = \chi\vec{H}$
Relative magnetic permeability	μ_r	Scalar	-	-	$\vec{B} = \mu_0\mu_r\vec{H}$
Magnetic permeability	μ	Scalar	$\left[MLT^{-2}A^{-2}\right]$	$T\,m\,A^{-1}$ $N\,A^{-2}$	$\mu = \mu_0\mu_r$ $\vec{B} = \mu\vec{H}$

Question 1:

In figure shown below, the magnetic needle has magnetic moment $6.7\times10^{-2}\,Am^2$ and moment of inertia $I=7.5\times10^{-6}\,kgm^2$. It performs 10 complete oscillations in $6.70\,s$. What is the magnitude of the magnetic field?



Question 2:

A short bar magnet placed with its axis at 30^0 degrees with a uniform external magnetic field of $0.25T$ experiences a torque of magnitude equal to $4.5\times10^{-2}\,J$. What is the magnitude of magnetic moment of the magnet?

Question 3:

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

Question 4:

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

(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, (ii) opposite to the filed direction?

(b) What is the torque on the magnet in cases (i) and (ii)?

Question 5:

A closely wound solenoid of 800 turns and area of cross section $2.5\times10^{-4}\,m^2$ carries a current of $3.0\,A$. It is free to turn about the vertical direction and a uniform horizontal magnetic field of $0.25T$ is applied, what is the magnitude of torque on the solenoid when its axis makes an angle of 30^0 degrees with the direction of applied field?

Question 6:

A short bar magnet placed with its axis at 30^0 with an external field of $800G$ experiences a torque of $0.016\,Nm$. (a) What is the magnetic moment of the magnet? (b) What is the work done in moving it from its most stable to most unstable position? (c) The bar magnet is replaced by a solenoid of cross-sectional area $2\times10^{-4}\,m^2$ and 1000 turns, but of the same magnetic moment. Determine the current flowing through the solenoid.

Question 7:

A circular coil of 16 turns and radius $10\,cm$ carrying a current of $0.75\,A$ rests with its plane normal to an external field of magnitude $5.0\times10^{-2}T$. The coil is free to turn about an axis in its plane perpendicular to the field direction. When the coil is turned slightly and released, it oscillates about its stable equilibrium with a frequency of $2.0s^{-1}$. What is the moment of inertia of the coil about its axis of rotation?

Question 8:

(a) What happens if a bar magnet is cut into two pieces: (i) transverse to its length, (ii) along its length?

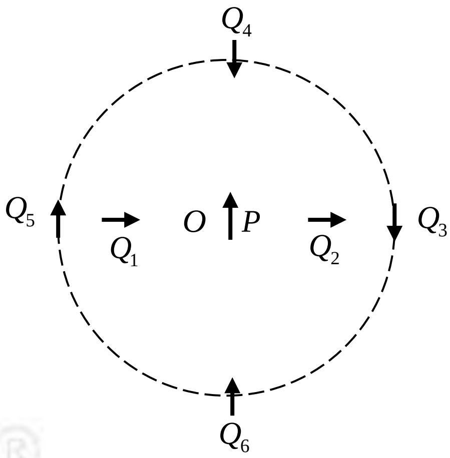
(b) A magnetised needle in a uniform magnetic field experiences a torque but no net force. An iron nail near a bar magnet, however, experiences a force of attraction in addition to a torque. Why?

(c) Must every magnetic configuration have a north pole and a south pole? What about the field due to a toroid?

(d) Two identical looking iron bars A and B are given, one of which is definitely known to be magnetised. (We do not know which one.) How would one ascertain whether or not both are magnetised? If only one is magnetised, how does one ascertain which one? [Use nothing else but the bars A and B.]

Question 9: What is the magnitude of the equatorial and axial fields due to a bar magnet of length $5.0\,cm$ at a distance of $50\,cm$ from its mid-point? The magnetic moment of the bar magnet is $0.40\,Am^2$.

Question 10: Figure shows a small magnetised needle P placed at a point O. The arrow shows the direction of its magnetic moment. The other arrows show different positions (and orientations of the magnetic moment) of another identical magnetized needle Q.



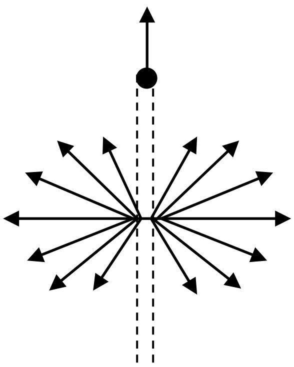
(a) In which configuration the system is not in equilibrium?

(b) In which configuration is the system in (i) stable, and (ii) unstable equilibrium?

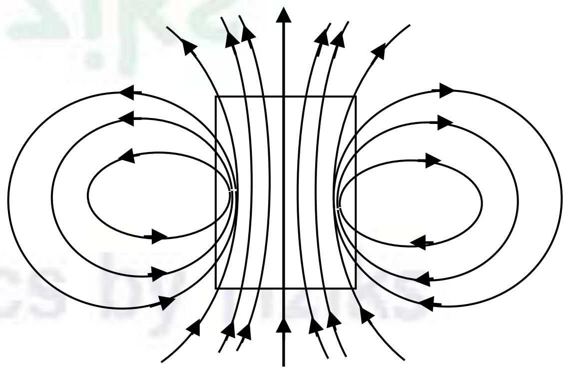
(c) Which configuration corresponds to the lowest potential energy among all the configurations shown?

Question 11:

Many of the diagrams given in below show magnetic field lines (thick lines in the figure) wrongly. Point out what is wrong with them. Some of them may describe electrostatic field lines correctly. Point out which ones.



(a)



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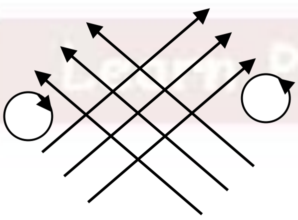
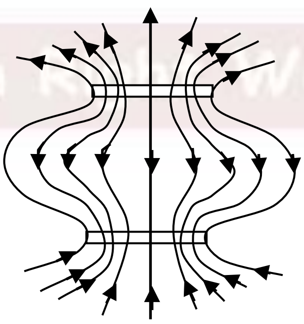


Empty space

(b)



(f)

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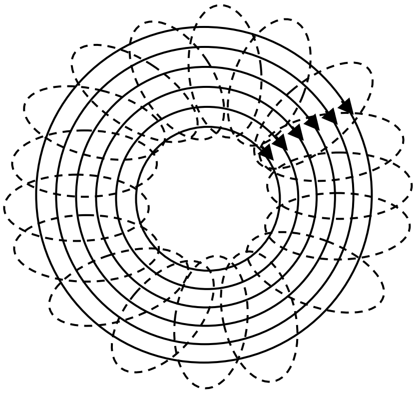
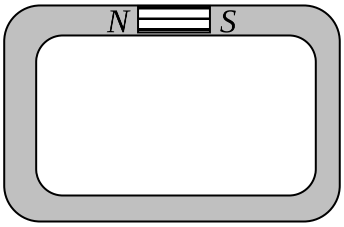
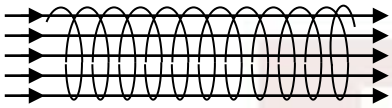


(c)



(g)



(d)

Question 12:

(a) Magnetic field lines show the direction (at every point) along which a small magnetized needle aligns (at the point). Do the magnetic field lines also represent the *lines of force* on a moving charged particle at every point?

(b) Magnetic field lines can be entirely confined within the core of a toroid, but not within a straight solenoid. Why?

(c) If magnetic monopoles existed, how would the Gauss's law of magnetism be modified?

(d) Does a bar magnet exert a torque on itself due to its own field?

Does one element of a current-carrying wire exert a force on another element of the *same wire*?

(e) Magnetic field arises due to charges in motion. Can a system have magnetic moments even though its net charge is zero?

Question 13:

The earth's magnetic field at the equator is approximately $0.4G$. Estimate the earth's dipole moment.

Question 14:

In the magnetic meridian of a certain place, the horizontal component of the earth's magnetic field is $0.26G$ and the dip angle is 60^0. What is the magnetic field of the earth at this location?

Question 15:

A magnetic needle free to rotate in a vertical plane parallel to the magnetic meridian has its north tip pointing down at 22^0 with the horizontal. The horizontal component of the earth's magnetic field at the place is known to be $0.35G$ Determine the magnitude of the earth's magnetic field at the place.

Question 16:

A long straight horizontal cable carries a current of $2.5A$ in the direction 10^0 south of west to 10^0 degrees north of east. The magnetic meridian of the place happens to be 10^0 west of the geographic meridian. The earth's magnetic field at the location is $0.33G$, and the angle of dip is zero. Locate the line of neutral points (ignore the thickness of the cable). (At neutral points. magnetic field due to a current-carrying cable is equal and opposite to the horizontal component of earth's magnetic field)

Question 17:

A telephone cable at a place has four long straight horizontal wires carrying a current of $1.0A$ in the same direction east to west. The earth's magnetic field at the place is $0.39G$, and the angle of dip is 35^0. The magnetic declination is nearly zero. What are the resultant magnetic fields at points $4.0cm$ below and above the cable?

Question 18:

A compass needle free to turn in a horizontal plane is placed at the center of circular coil of 30 turns and radius $12cm$. The coil is in a vertical plane making an angle of 45^0 with the magnetic meridian. When the current in the coil is $0.35A$, the needle points west to east.

(a) Determine the horizontal component of the earth's magnetic field at the location.

(b) The current in the coil is reversed, and the coil is rotated about its vertical axis by an angle of 90^0 in the anticlockwise sense looking from above. Predict the direction of the needle. Take the magnetic declination at the place to be zero.

Question 19:

A magnetic dipole is under the influence of two magnetic fields. The angle between the field directions is 60^0, and one of the fields has a magnitude of $1.2\times10^{-2}T$. If the dipole comes to stable equilibrium at an angle of 15^0 with this field, what is the magnitude of the other field?

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Question 20:

A solenoid has a core of a material with relative permeability 400. The windings of the solenoid are insulated from the core and carry a current of $2A$. If the number of turns is 1000 per meter, calculate (a) H, (b) M, (c) B and (d) the magnetizing current I_m.

Question 21:

A domain in ferromagnetic iron is in the form of a cube of side length $1\mu m$. Estimate the number of iron atoms in the domain and the maximum possible dipole moment and magnetization of the domain. The molecular mass of iron is $55g/\text{mole}$ and its density is $7.9\,g/cm^3$. Assume that each iron atom has a dipole moment of $9.27\times10^{-24}\,Am^2$.

Question 22:

A sample of paramagnetic salt contains 2.0×10^{24} atomic dipoles each of dipole moment $1.5\times10^{-23}\,JT^{-1}$. The sample is placed under a homogeneous magnetic field of $0.64T$. and cooled to a temperature of $4.2\,K$. The degree of magnetic saturation achieved is equal to 15%. What is the total dipole moment of the sample for a magnetic field of $0.98T$ and a temperature of $2.8\,K$? (Assume Curie's law)

Question 23:

A Rowland ring of mean radius $15\,cm$ and has 3500 turns of wire wound on a ferromagnetic core of relative permeability 800. What is the magnetic field B in the core for a magnetizing current of $1.2A$?