CLASS XII – PHYSICS (042)
STEP-BY-STEP SOLUTIONS AND MARKING SCHEME

Chapter 5: Magnetism and Matter – Practice Paper (35 Marks)

Answer key – Section A

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

Marks are shown in square brackets. Equivalent correct methods are acceptable. Take $\mu_0/4\pi = 10^{-7}$ T m A^{-1}.

SECTION A

Q.1 (c)

Magnetic field lines form closed loops: every line that leaves the surface at the north-pole side re-enters it (through the magnet). By Gauss's law for magnetism the net flux through any closed surface is zero, whatever its size. **[1]**

Q.2 (a)

U = −mB cos θ. For P (θ = 0°) U = −mB is the minimum and the needle is in stable equilibrium; for T (θ = 180°) U = +mB is the maximum and the equilibrium is unstable. **[1]**

Q.3 (b)

τ = mB sin θ = 0.25 × 0.4 × sin 30° = 0.25 × 0.4 × 0.5 = 0.05 N m. **[1]**

Q.4 (d)

X: χ small and negative, diamagnetic. Y: χ small and positive, paramagnetic. Z: χ large and positive, ferromagnetic. **[1]**

Q.5 (b)

Complete expulsion of the field means B = 0 inside the material (perfect diamagnetism, Meissner effect): $B = \mu_0(1 + \chi)H = 0$, so $\chi = -1$ and $\mu_r = 1 + \chi = 0$. **[1]**

Q.6 (c)

On the equatorial line of P the field of P is opposite to m_P ($B = -\mu_0 m_P/4\pi r^3$), i.e. downward. m_Q is downward, so it is parallel to the field. Parallel alignment is the minimum of potential energy: stable equilibrium. **[1]**

Q.7 (b)

In an external field the domains oriented along B_0 grow in size while the others shrink (the domain walls move), and domain moments also turn towards B_0. The other options are false; each domain has about 10^{11} atoms already and atoms keep their moments. **[1]**

Q.8 (d)

A is false: a bar magnet cut in two gives two smaller bar magnets, each with a north and a south pole; monopoles cannot be isolated. R is true. **[1]**

Q.9 (a)

Both true. The forces on the two poles are equal and opposite, so the net force is zero, but being along different lines they form a couple (τ = m × B). R explains A. **[1]**

SECTION B

Q.10

τ = mB sin θ = 0.6 × 0.2 × sin 60° = 0.12 × 0.866 ≈ 0.10 N m. **[1]**

U = −mB cos θ = −0.6 × 0.2 × cos 60° = −0.12 × 0.5 = −0.06 J. **[1]**

Q.11

Diagram (i) cannot represent a magnetic field: the lines diverge from a point like those of a positive point charge. Magnetic field lines are closed loops with no source or sink, so the net flux through a closed surface around that point would be non-zero, which violates Gauss's law for magnetism. **[1]**

Diagram (ii) cannot represent a magnetic field either: field lines never intersect, because at the point of intersection the field would have two directions. **[1]**

Q.12 (A)

At P (axis): $B = (\mu_0/4\pi)(2m/r^3) = 10^{-7} \times (2 \times 0.8)/(0.2)^3 = 10^{-7} \times 1.6/(8 \times 10^{-3}) = 2 \times 10^{-5}$ T, along the direction of m (S to N, towards P). **[1]**

At Q (equator): $B = (\mu_0/4\pi)(m/r^3) = 10^{-7} \times 0.8/(8 \times 10^{-3}) = 1 \times 10^{-5}$ T, directed opposite to m (N to S, parallel to the axis). **[1]**

Q.12 (B)

The moment of the solenoid $m = NIA$, so $I = m/NA = 0.4/(200 \times 5 \times 10^{-4}) = 0.4/0.1 = 4$ A. **[1]**

Axial field: $B = (\mu_0/4\pi)(2m/r^3) = 10^{-7} \times 0.8/(0.25)^3 = 10^{-7} \times 0.8/0.015625 = 5.12 \times 10^{-6}$ T $\approx$ 5.1 μT, along m. **[1]**

Q.13

The graph is a straight line through the origin; at $H = 5000$ A m^{-1}, $M = 10 \times 10^{-2} = 0.10$ A m^{-1}. $\chi = M/H = 0.10/5000 = 2 \times 10^{-5}$. **[1]**

$\mu_r = 1 + \chi = 1.00002$. χ is small and positive, so the material is paramagnetic. **[1]**

SECTION C

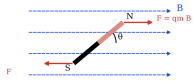
Q.14

Take x along the axis of M_1 (towards P) and y along the moment of M_2. P is on the axis of M_1: $B_1 = (\mu_0/4\pi)(2m/r^3) = 10^{-7} \times 5/10^{-3} = 5 \times 10^{-4}$ T, along +x (the direction of m_1). **[1]**

P is on the equatorial line of M_2: $B_2 = (\mu_0/4\pi)(m/r^3) = 10^{-7} \times 2.5/10^{-3} = 2.5 \times 10^{-4}$ T, opposite to m_2, i.e. along −y. The two fields are perpendicular. **[1]**

$B = \sqrt{(B_1^2 + B_2^2)} = 10^{-4} \times \sqrt{(25 + 6.25)} \approx 5.6 \times 10^{-4}$ T. $\tan\varphi = B_2/B_1 = 0.5$, so $\varphi \approx 26.6°$ from the line joining P to M_1 (the x-axis), on the −y side. **[1]**

Q.15 (A)

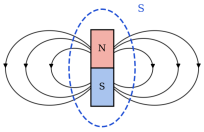


On a dipole of moment m making angle θ with B the torque is $\tau = mB \sin\theta$ (the forces on the two poles form a couple). The torque tends to reduce θ. **[1]**

Work done by an external torque to rotate it from θ_0 to θ: $W = \int \tau\, d\theta = \int mB \sin\theta\, d\theta = -mB\cos\theta$ + constant. Choosing U = 0 at θ = 90° makes the constant zero: $U = -mB\cos\theta = -\mathbf{m}\cdot\mathbf{B}$. **[1]**

Minimum U = −mB at θ = 0° (m parallel to B): stable equilibrium. Maximum U = +mB at θ = 180° (m antiparallel to B): unstable equilibrium. **[1]**

Q.15 (B)



Gauss's law for magnetism: the net magnetic flux through any closed surface is zero: $\Sigma\, \mathbf{B}\cdot\Delta\mathbf{S} = 0$. **[1]**

Electrostatics: $\Sigma\, \mathbf{E}\cdot\Delta\mathbf{S} = q/\varepsilon_0$, which can be non-zero because isolated charges (sources and sinks of **E**) exist. For magnetism the lines are continuous closed loops, so as many lines enter a closed surface as leave it, because isolated magnetic poles (monopoles) do not exist; the simplest magnetic element is a dipole or a current loop. **[1]**

If a monopole of magnetic charge q_m existed, the law would become $\Sigma \mathbf{B}\cdot\Delta\mathbf{S} = \mu_0 q_m$ (the analogue of Gauss's law for electrostatics). **[1]**

Q.16

(a) Lines expelled from the rod, field inside reduced: **diamagnetic**; $-1 \le \chi < 0$ (small and negative); in a non-uniform field it moves from the stronger to the weaker field region (it is repelled). **[1]**

(b) Lines slightly concentrated inside the rod: **paramagnetic**; $0 < \chi < \varepsilon$ (small and positive); it moves from the weaker to the stronger field region (weakly attracted). **[1]**

(c) Lines strongly concentrated inside the rod: **ferromagnetic**; $\chi >> 1$ (large and positive); it is strongly attracted and moves from the weaker to the stronger field region. **[1]**

SECTION D

Q.17 (Case study)

(i) **(b)** $H = nI = 800 \times 2.5 = 2000$ A m^{-1} (it depends only on the current, not on the core). **[1]**

(ii) **(c)** $\mu_r = 1 + \chi$, so $\chi = 400 - 1 = 399$. **[1]**

(iii) **(a)** $B = \mu_0\mu_r H = 4\pi \times 10^{-7} \times 400 \times 2000 \approx 1.0$ T. **[1]**

(iv) **(b)** $M = \chi H = 399 \times 2000 \approx 8.0 \times 10^5$ A m^{-1}. **[1]**

OR (iv) (d) $B = \mu_r\mu_0 nI = \mu_0 n(I + I_m)$, so $I + I_m = \mu_r I = 400 \times 2.5 = 1000$ A and $I_m = (\mu_r - 1)I = 399 \times 2.5 \approx 1000$ A. **[1]**

SECTION E

Q.18 (A)

Domains: each atom of a ferromagnet has a magnetic moment, and neighbouring atoms interact so as to align spontaneously over a region (domain, about 1 mm, about 10^{11} atoms). Each domain is magnetised, but the directions differ from domain to domain, so the bulk magnetisation is zero. **[1]**

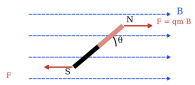
In an external field B_0 the domains orient themselves along B_0 and those along B_0 grow in size, finally forming one giant domain: strong magnetisation and concentrated field lines. On removal of the field, the magnetisation persists in hard ferromagnets (alnico, lodestone; used for permanent magnets) and disappears in soft ones (soft iron). **[1]**

On heating to a high enough temperature the domain structure disintegrates gradually and the ferromagnet becomes paramagnetic. **[1]**

Numerical: $\chi = \mu_r - 1 = 2 \times 10^{-4}$, so $M = \chi H = 2 \times 10^{-4} \times 4 \times 10^3 = 0.8$ A m^{-1}. **[1]**

$B = \mu_0\mu_r H = 4\pi \times 10^{-7} \times 1.0002 \times 4 \times 10^3 \approx 5.03 \times 10^{-3}$ T. **[1]**

Q.18 (B)



Let the poles be $\pm q_m$ a distance 2l apart, $m = q_m(2l)$. In the field B the forces on the poles are equal, opposite and parallel to B: $F = q_m B$. They form a couple and the net force is zero. **[1]**

Arm of the couple = $2l \sin\theta$, so $\tau = q_m B \times 2l \sin\theta = mB \sin\theta$, i.e. $\boldsymbol{\tau} = \mathbf{m} \times \mathbf{B}$. **[1]**

Work done against the torque from $\theta_0 = 90°$ (taking U = 0 there) to θ: $U = \int mB \sin\theta\, d\theta = -mB \cos\theta = -\mathbf{m}\cdot\mathbf{B}$. **[1]**

Numerical: (i) $W = U(90°) - U(0°) = 0 - (-mB) = mB = 0.4 \times 0.5 = 0.2$ J. (ii) $W = U(180°) - U(0°) = mB - (-mB) = 2mB = 0.4$ J. **[1]**

Torque at 90°: $\tau = mB \sin 90° = 0.4 \times 0.5 = 0.2$ N m (the maximum value). **[1]**

— End of Solutions —