Class 12 Physics · Chapter 4: Moving Charges and Magnetism

Answer key and marking scheme · 20 marks · about 40 minutes · based on NCERT

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1. A proton goes round a circle in a uniform magnetic field. The work done on it by the magnetic force during half a revolution is [1]

(a) zero (b) $qvB \times \pi r$

(c) $qvB \times 2r$ (d) $\frac{1}{2}mv^2$

Answer: (a) The magnetic force is always perpendicular to the velocity, so it does no work along any part of the path; the speed and kinetic energy stay the same.

2. The tesla, the SI unit of magnetic field, is equivalent to [1]

(a) $N\ C^{-1}\ m\ s^{-1}$ (b) $N\ A\ m^{-1}$

(c) $N\ A^{-1}\ m^{-1}$ (d) $J\ A^{-1}$

Answer: (c) From $F = qvB$, $B = F/(qv)$, with unit $N\ s\ C^{-1}\ m^{-1}$. Since $1\ C\ s^{-1} = 1\ A$, this is $N\ A^{-1}\ m^{-1}$.

3. With ε_0 the permittivity and μ_0 the permeability of free space, and c the speed of light in vacuum, the product $\varepsilon_0\mu_0$ equals [1]

(a) $1/c$ (b) c^2

(c) $1/c^2$ (d) c

Answer: (c) $\varepsilon_0\mu_0 = (4\pi\varepsilon_0)(\mu_0/4\pi) = [1/(9 \times 10^9)] \times 10^{-7} = 1/(3 \times 10^8)^2 = 1/c^2$.

4. In a cyclotron the oscillator works at 12 MHz. The magnetic field needed for protons to go round in step with it is ($e = 1.6 \times 10^{-19}$ C, mass of proton $= 1.67 \times 10^{-27}$ kg) [1]

(a) 0.13 T (b) 0.79 T

(c) 1.6 T (d) 0.39 T

Answer: (b) $v_c = qB/2\pi m$, so $B = 2\pi m v_c/q = (2\pi \times 1.67 \times 10^{-27} \times 12 \times 10^6)/(1.6 \times 10^{-19}) = 0.79$ T. Leaving out 2π gives 0.13 T.

5. A short element of a wire carries a steady current. By the Biot–Savart law, its magnetic field is zero at a point that lies [1]

(a) on the line of the element itself (b) on the perpendicular bisector of the element

(c) at 45° to the element (d) anywhere at a large distance

Answer: (a) $|dB| = (\mu_0/4\pi)\, I\, dl \sin\theta/r^2$. On the line of the element $\theta = 0°$ or 180°, so $\sin\theta = 0$ and the field there is zero.

6. A straight conductor 40 cm long carrying 2.5 A is placed in a uniform magnetic field of 0.20 T. (a) What is the largest force it can experience, and how must it lie for this? (b) At what angle to the field must it lie for the force to be 0.10 N? [2]

(a) $F = IlB \sin\theta$ is largest at $\theta = 90°$: $F_{max} = 2.5 \times 0.40 \times 0.20 = 0.20$ N, with the conductor perpendicular to the field. (b) $\sin\theta = 0.10/0.20 = 0.5$, so $\theta = 30°$ (or 150°).

- $F_{max} = IlB = 0.20$ N, conductor perpendicular to B (1)
- $\sin\theta = 0.5$, $\theta = 30°$ (1)

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7. At a place the horizontal component of the earth's field is 3.5×10^{-5} T, pointing from south to north. A vertical wire carries 5.0 A upwards. Find the magnitude and direction of the force on each metre of the wire due to this component. [2]

$F/l = IB \sin 90° = 5.0 \times 3.5 \times 10^{-5} = 1.75 \times 10^{-4}$ N m^{-1}. With l upwards ($\hat{z}$) and B northwards ($\hat{y}$), l × B is along $\hat{z} \times \hat{y} = -\hat{x}$, that is, towards the west.

- $F/l = IB = 1.75 \times 10^{-4}$ N m^{-1} (1)
- direction from l × B: towards the west (1)

8. A small circular current loop hangs in a uniform magnetic field, free to turn. When is it in (a) stable equilibrium, (b) unstable equilibrium? Give the reason for each. [2]

The torque $\tau = m \times B$ is zero when m is parallel or anti-parallel to B. (a) m parallel to B: a small rotation produces a torque that turns it back, so the equilibrium is stable. (b) m anti-parallel to B: a small rotation produces a torque that turns it further away, so it is unstable.

- stable with m parallel to B, restoring torque on small rotation (1)
- unstable with m anti-parallel to B, torque increases the displacement (1)

9. Two long straight parallel wires A and B are 10 cm apart and carry 4.0 A and 6.0 A in the same direction. Using $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1}, find (a) the magnitude of the resultant field at the mid-point between them, (b) the point on the line joining them where the resultant field is zero. [3]

(a) Between the wires the two fields are opposite (right-hand rule). $B = (\mu_0/2\pi)(6.0 - 4.0)/0.050 = 2 \times 10^{-7} \times 40 = 8.0 \times 10^{-6}$ T, in the sense of B's field. (b) The fields cancel between the wires where $4.0/x = 6.0/(0.10 - x)$: $0.40 - 4.0x = 6.0x$, $x = 0.040$ m. The field is zero 4.0 cm from A (6.0 cm from B).

- fields opposite between the wires; uses $B = \mu_0 I/2\pi r$ with superposition (1)
- B at mid-point = 8.0×10^{-6} T (1)
- zero 4.0 cm from A (1)

10. A rectangular loop of sides a and b carries a current I in a uniform magnetic field B. The normal to the loop makes an angle θ with B, and the sides of length b are perpendicular to B. Show that the net force on the loop is zero and that the torque on it is IAB sin θ, where A = ab. [3]

The sides of length a lie in the plane containing B and the normal; the forces on them are equal, opposite and collinear, so they cancel. The sides of length b each feel F = IbB, equal and opposite, so the net force is zero. These two forces are not collinear: their lines are separated by a sin θ, so they form a couple of moment $\tau = IbB \times a \sin\theta = I(ab)B \sin\theta = IAB \sin\theta$. In vector form $\tau = m \times B$ with m = IA.

- forces on one pair of sides cancel and are collinear (1)
- IbB on the other pair: equal and opposite, net force zero (1)
- couple arm a sin θ, $\tau = IAB \sin\theta$ (1)

11. A galvanometer of resistance 30 Ω gives full-scale deflection for 4.0 mA. Find (a) the shunt that converts it into an ammeter of range 0 to 1.0 A, (b) the resistance of this ammeter, (c) the series resistance that converts it into a voltmeter of range 0 to 6.0 V. [3]

(a) The coil and the shunt are in parallel, so they share one potential difference, and the shunt carries $I - I_g$. With $V = IR$, $I_g \cdot R_G = (I - I_g) \cdot r_s$, so $r_s = (4.0 \times 10^{-3} \times 30)/(1.0 - 0.004) = 0.12$ Ω. (b) $R_G r_s/(R_G + r_s) = 30 \times 0.12/30.12 \approx 0.12$ Ω, close to r_s since $R_G \gg r_s$. (c) In series one current I_g flows through the coil and R, and their potential differences add: $V = I_g(R_G + R)$, so $R = V/I_g - R_G = 6.0/(4.0 \times 10^{-3}) - 30 = 1470$ Ω.

- shunt $r_s = 0.12$ Ω (1)
- ammeter resistance ≈ 0.12 Ω (1)
- series resistance 1470 Ω (1)