Chapter 4: Moving Charges and Magnetism

Exercises — Exercises

Q1 A circular coil of wire consisting of 100 turns, each of radius 8.0 cm carries a current of 0.40 A. What is the magnitude of the magnetic field B at the centre of the coil?

SOLUTION

Given: N = 100 turns, R = 8.0 cm = 0.08 m, I = 0.40 A

Formula for magnetic field at the centre of a circular coil:

$B = \mu_o NI / (2R)$

$B = (4\pi \times 10^{-7} \times 100 \times 0.40) / (2 \times 0.08)$

$B = (4\pi \times 10^{-7} \times 40) / 0.16$

$B = (160\pi \times 10^{-7}) / 0.16$

$B = 1000\pi \times 10^{-7}$ T

$B = \pi \times 10^{-4}$ T $\approx 3.14 \times 10^{-4}$ T

Answer: $B \approx 3.14 \times 10^{-4}$ T ($= \pi \times 10^{-4}$ T)

Q2 A long straight wire carries a current of 35 A. What is the magnitude of the field B at a point 20 cm from the wire?

SOLUTION

Given: I = 35 A, r = 20 cm = 0.20 m

For a long straight wire, by Ampere's circuital law:

$B = \mu_o I / (2\pi r)$

$B = (4\pi \times 10^{-7} \times 35) / (2\pi \times 0.20)$

$B = (4 \times 10^{-7} \times 35) / (2 \times 0.20)$

$B = (140 \times 10^{-7}) / 0.40$

$B = 350 \times 10^{-7}$ T

$B = 3.5 \times 10^{-5}$ T

Answer: $B = 3.5 \times 10^{-5}$ T

Q3 A long straight wire in the horizontal plane carries a current of 50 A in north to south direction. Give the magnitude and direction of B at a point 2.5 m east of the wire.

SOLUTION

Given: I = 50 A (flowing north to south = southward), r = 2.5 m (point to the east)
Magnitude:
$B = \mu_0 I / (2\pi r) = (4\pi \times 10^{-7} \times 50) / (2\pi \times 2.5)$
$B = (4 \times 10^{-7} \times 50) / (2 \times 2.5) = 200 \times 10^{-7} / 5$
$B = 4.0 \times 10^{-6}$ T

Direction using right-hand rule:
Set up coordinates: x = east, y = north, z = upward.
Current direction: south (−y). Point is to the east (+x) of the wire.
B ∝ (current direction) × (radial direction from wire to point)
$= (-\hat{y}) \times (+\hat{x}) = -(\hat{y} \times \hat{x}) = -(-\hat{z}) = +\hat{z}$
B is directed vertically upward at the east point.

Physical check: wrap right hand around wire with thumb pointing south; at the east side, fingers point upward. Confirmed.

Answer: $B = 4.0 \times 10^{-6}$ T, directed vertically upward

---

Q4 A horizontal overhead power line carries a current of 90 A in east to west direction. What is the magnitude and direction of the magnetic field due to the current 1.5 m below the line?

SOLUTION

Given: I = 90 A (east to west = −x direction), distance below = 1.5 m
Magnitude:
$B = \mu_0 I / (2\pi r) = (4\pi \times 10^{-7} \times 90) / (2\pi \times 1.5)$
$B = (4 \times 10^{-7} \times 90) / (2 \times 1.5) = 360 \times 10^{-7} / 3$
$B = 1.2 \times 10^{-5}$ T

Direction using right-hand rule:
Coordinates: x = east, y = north, z = up.
Current: west (−x̂). Point is directly below the wire: r from wire to point = −ẑ.
B direction ∝ $(-\hat{x}) \times (-\hat{z}) = \hat{x} \times \hat{z} = -(\hat{z} \times \hat{x}) = -\hat{y}$
B is directed toward geographic south.

Physical check: thumb pointing west, fingers at the point below the wire curl

southward. Confirmed.

Answer: B = 1.2 × 10^{-5} T, directed toward geographic south

---

Q5 What is the magnitude of magnetic force per unit length on a wire carrying a current of 8 A and making an angle of 30° with the direction of a uniform magnetic field of 0.15 T?

SOLUTION

Given: I = 8 A, θ = 30°, B = 0.15 T

The force on a current-carrying wire in a magnetic field: F = BIL sinθ

Force per unit length: f = F/L = BI sinθ

f = 0.15 × 8 × sin 30°

f = 0.15 × 8 × 0.5

f = 0.60 N/m

Answer: f = 0.60 N m^{-1}

Q6 A 3.0 cm wire carrying a current of 10 A is placed inside a solenoid perpendicular to its axis. The magnetic field inside the solenoid is given to be 0.27 T. What is the magnetic force on the wire?

SOLUTION

Given: l = 3.0 cm = 0.030 m, I = 10 A, B = 0.27 T

The wire is perpendicular to the solenoid axis, and B is along the solenoid axis, so the wire is perpendicular to B (θ = 90°).

F = BIl sinθ = 0.27 × 10 × 0.030 × sin 90°

F = 0.27 × 10 × 0.030 × 1

F = 8.1 × 10^{-2} N

Answer: F = 8.1 × 10^{-2} N

Q7 Two long and parallel straight wires A and B carrying currents of 8.0 A and 5.0 A in the same direction are separated by a distance of 4.0 cm. Estimate the force on a 10 cm section of wire A.

SOLUTION

Given: $I_A = 8.0$ A, $I_B = 5.0$ A, $d = 4.0$ cm $= 0.04$ m, $L = 10$ cm $= 0.10$ m

The force per unit length between two parallel wires:

$f = \mu_0 I_A I_B / (2\pi d)$

Force on length L of wire A due to wire B:

$F = \mu_0 I_A I_B L / (2\pi d)$

$F = (4\pi \times 10^{-7} \times 8.0 \times 5.0 \times 0.10) / (2\pi \times 0.04)$

$F = (4 \times 10^{-7} \times 8.0 \times 5.0 \times 0.10) / (2 \times 0.04)$

$F = (4 \times 10^{-7} \times 4.0) / 0.08$

$F = 16 \times 10^{-7} / 0.08$

$F = 2.0 \times 10^{-5}$ N

Since the currents are in the same direction, the force is attractive (wire A is attracted toward B).

Answer: $F = 2.0 \times 10^{-5}$ N (attractive)

Q8 A closely wound solenoid 80 cm long has 5 layers of windings of 400 turns each. The diameter of the solenoid is 1.8 cm. If the current carried is 8.0 A, estimate the magnitude of B inside the solenoid near its centre.

SOLUTION

Given: length $l = 80$ cm $= 0.80$ m, 5 layers × 400 turns/layer = 2000 total turns

Diameter = 1.8 cm (given for reference), $I = 8.0$ A

Number of turns per unit length: $n = 2000 / 0.80 = 2500$ turns/m

Since $l >>$ diameter (0.80 m $>>$ 0.018 m), use the ideal solenoid formula:

$B = \mu_0 n I$

$B = 4\pi \times 10^{-7} \times 2500 \times 8.0$

$B = 4\pi \times 2.0 \times 10^{-3}$

$B = 8\pi \times 10^{-3}$ T

$B = 2.51 \times 10^{-2}$ T

Answer: $B \approx 2.51 \times 10^{-2}$ T

Q9 A square coil of side 10 cm consists of 20 turns and carries a current of 12 A. The coil is suspended vertically and the normal to the plane of the coil makes an angle of 30° with the direction of a uniform horizontal magnetic field of magnitude 0.80 T. What is the magnitude of torque experienced by the coil?

SOLUTION

Given: side a = 10 cm = 0.10 m, N = 20 turns, I = 12 A, B = 0.80 T, θ = 30°

Area of the square coil: $A = a^2 = (0.10)^2 = 0.010\ m^2$

Torque on a current loop in a magnetic field: $\tau = NIAB \sin\theta$

$\tau = 20 \times 12 \times 0.010 \times 0.80 \times \sin 30°$

$\tau = 20 \times 12 \times 0.010 \times 0.80 \times 0.5$

$\tau = 20 \times 12 \times 0.004$

$\tau = 0.96$ N m

Answer: $\tau = 0.96$ N m

Q10 Two moving coil meters, M1 and M2, have the following particulars:
R1 = 10 Ω, N1 = 30, A1 = 3.6×10^{-3} m², B1 = 0.25 T
R2 = 14 Ω, N2 = 42, A2 = 1.8×10^{-3} m², B2 = 0.50 T
(The spring constants are identical for the two meters.)
Determine the ratio of (a) current sensitivity and (b) voltage sensitivity of M2 and M1.

SOLUTION

Current sensitivity of a moving coil galvanometer: $\varphi/I = NAB/k$

(a) Ratio of current sensitivities (M2/M1):

CS = (N2 A2 B2) / (N1 A1 B1) [k cancels as both are identical]

CS = $(42 \times 1.8 \times 10^{-3} \times 0.50) / (30 \times 3.6 \times 10^{-3} \times 0.25)$

Numerator: $42 \times 1.8 \times 10^{-3} \times 0.50 = 37.8 \times 10^{-3}$

Denominator: $30 \times 3.6 \times 10^{-3} \times 0.25 = 27 \times 10^{-3}$

CS ratio = 37.8 / 27 = 1.4

(b) Voltage sensitivity = $\varphi/V = NAB/(kR)$

Ratio of voltage sensitivities (M2/M1):

VS = (N2 A2 B2 / R2) / (N1 A1 B1 / R1)

VS = $(37.8 \times 10^{-3} / 14) / (27 \times 10^{-3} / 10)$

VS = $(2.7 \times 10^{-3}) / (2.7 \times 10^{-3}) = 1.0$

The voltage sensitivity ratio is 1.0 because doubling N also doubles R

(proportional to wire length),
so the increase in current sensitivity is exactly cancelled in voltage sensitivity.

Answer: (a) Current sensitivity ratio (M2/M1) = 1.4; (b) Voltage sensitivity ratio (M2/M1) = 1.0

Q11 In a chamber, a uniform magnetic field of 6.5 G (1 G = 10^{-4} T) is maintained. An electron is shot into the field with a speed of 4.8 × 10^{6} m s^{-1} normal to the field. Explain why the path of the electron is a circle. Determine the radius of the circular orbit. (e = 1.6 × 10^{-19} C, m_e = 9.1 × 10^{-31} kg)

SOLUTION

Given: B = 6.5 G = 6.5 × 10^{-4} T, v = 4.8 × 10^{6} m/s (perpendicular to B),
e = 1.6 × 10^{-19} C, m_e = 9.1 × 10^{-31} kg

Why a circle: The magnetic force on the electron is F = ev × B.
Since v is perpendicular to B, the force has magnitude F = evB.
This force is always perpendicular to the velocity (it is a centripetal force),
so it changes the direction of v but not its magnitude.
The electron therefore moves in a circle in the plane perpendicular to B.
The magnetic force does no work, so the speed (and kinetic energy) remain constant.

Radius of the circular orbit: equating centripetal force to magnetic force,
$m_e v^2 / r = evB$
=> $r = m_e v / (eB)$
$r = (9.1 \times 10^{-31} \times 4.8 \times 10^{6}) / (1.6 \times 10^{-19} \times 6.5 \times 10^{-4})$
Numerator: $9.1 \times 4.8 \times 10^{-31+6} = 43.68 \times 10^{-25}$ kg m/s
Denominator: $1.6 \times 6.5 \times 10^{-19-4} = 10.4 \times 10^{-23}$ C T
$r = 43.68 \times 10^{-25} / (10.4 \times 10^{-23})$
$r = (43.68 / 10.4) \times 10^{-25+23} = 4.2 \times 10^{-2}$ m
r ≈ 4.2 cm

Answer: r ≈ 4.2 × 10^{-2} m (= 4.2 cm)

Q12 In Exercise 4.11 obtain the frequency of revolution of the electron in its circular orbit. Does the answer depend on the speed of the electron? Explain.

SOLUTION

Using the data from Exercise 4.11: B = 6.5×10^{-4} T, e = 1.6×10^{-19} C, m_e = 9.1×10^{-31} kg

The cyclotron frequency (frequency of revolution in a magnetic field):
$\nu = eB / (2\pi m_e)$
$\nu = (1.6 \times 10^{-19} \times 6.5 \times 10^{-4}) / (2\pi \times 9.1 \times 10^{-31})$
Numerator: $1.6 \times 6.5 \times 10^{-23} = 10.4 \times 10^{-23}$
Denominator: $2\pi \times 9.1 \times 10^{-31} = 57.18 \times 10^{-31}$
$\nu = (10.4 \times 10^{-23}) / (57.18 \times 10^{-31})$
$\nu = 1.82 \times 10^{7}$ Hz ≈ 18.2 MHz

Does the answer depend on speed?
No. The cyclotron frequency $\nu = eB/(2\pi m)$ depends only on the charge-to-mass ratio
and the magnetic field strength — not on the speed.
Although a faster electron moves in a larger circle ($r = mv/eB$),
the larger circumference is covered in exactly the same time,
so the frequency and period remain unchanged.
This speed-independence is the principle exploited in the cyclotron.

Answer: $\nu = 1.82 \times 10^{7}$ Hz (≈ 18.2 MHz); the frequency does not depend on the speed of the electron.

Q13 (a) A circular coil of 30 turns and radius 8.0 cm carrying a current of 6.0 A is suspended vertically in a uniform horizontal magnetic field of magnitude 1.0 T. The field lines make an angle of 60° with the normal of the coil. Calculate the magnitude of the counter torque that must be applied to prevent the coil from turning.
(b) Would your answer change, if the circular coil in (a) were replaced by a planar coil of some irregular shape that encloses the same area? (All other particulars are also unaltered.)

SOLUTION

Part (a):
Given: N = 30 turns, R = 8.0 cm = 0.08 m, I = 6.0 A, B = 1.0 T
Angle between field lines and normal to coil: $\theta = 60°$

Area of the circular coil:
$A = \pi R^2 = \pi \times (0.08)^2 = \pi \times 6.4 \times 10^{-3} = 2.011 \times 10^{-2}\ m^2$

Torque on the coil:
$\tau = NIAB \sin\theta$
$\tau = 30 \times 6.0 \times 2.011 \times 10^{-2} \times 1.0 \times \sin 60°$
$\tau = 30 \times 6.0 \times 2.011 \times 10^{-2} \times (\sqrt{3}/2)$
$\tau = 30 \times 6.0 \times 2.011 \times 10^{-2} \times 0.866$
$\tau = 3.133\ N\ m$
$\tau \approx 3.13\ N\ m$

To prevent the coil from turning, an equal and opposite counter torque of 3.13 N m must be applied.

Part (b):
No, the answer does not change.
The torque on a planar current loop in a uniform magnetic field is $\tau = NIAB \sin\theta$.
This depends only on the area A enclosed by the loop, the current I, the number of turns N,
the magnetic field B, and the angle θ — not on the shape of the loop.
A planar irregular coil enclosing the same area as the circular coil will experience exactly the same torque (and require the same counter torque) when all other particulars are identical.

Answer: (a) Counter torque = 3.13 N m; (b) No change — torque depends on area, not shape of the loop.