Chapter 5: Magnetism and Matter

Exercises — Exercises

Q1 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} J. What is the magnitude of magnetic moment of the magnet?

SOLUTION

Given: angle $\theta = 30°$, $B = 0.25$ T, torque $\tau = 4.5 \times 10^{-2}$ N·m

The torque on a magnetic dipole in a uniform field is:
$\tau = mB \sin\theta$

Solving for m:
$m = \tau / (B \sin\theta)$
$m = (4.5 \times 10^{-2}) / (0.25 \times \sin 30°)$
$m = (4.5 \times 10^{-2}) / (0.25 \times 0.5)$
$m = (4.5 \times 10^{-2}) / 0.125$
$m = 0.36$ J T^{-1}

Answer: Magnetic moment $m = 0.36$ J T^{-1}

Q2 A short bar magnet of magnetic moment $m = 0.32$ J T^{-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 (a) stable, and (b) unstable equilibrium? What is the potential energy of the magnet in each case?

SOLUTION

Given: $m = 0.32$ J T^{-1}, $B = 0.15$ T
Magnetic potential energy: $U = -m \cdot B = -mB \cos\theta$

(a) Stable equilibrium:
Stable equilibrium occurs when potential energy is minimum, i.e., at $\theta = 0°$, when the magnetic moment m is parallel to (aligned with) the field B.
$U_{stable} = -mB \cos 0° = -mB = -(0.32)(0.15) = -4.8 \times 10^{-2}$ J

(b) Unstable equilibrium:
Unstable equilibrium occurs when potential energy is maximum, i.e., at $\theta = 180°$, when m is anti-parallel to B.
$U_{unstable} = -mB \cos 180° = +mB = +(0.32)(0.15) = +4.8 \times 10^{-2}$ J

Answer: (a) Stable: m parallel to B (θ = 0°), U = -4.8 × 10^{-2} J; (b) Unstable: m anti-parallel to B (θ = 180°), U = +4.8 × 10^{-2} J

Q3 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 the solenoid acts like a bar magnet. What is its associated magnetic moment?

SOLUTION

Given: N = 800 turns, A = 2.5 × 10^{-4} m^2, I = 3.0 A

A current-carrying solenoid acts like a bar magnet in the following sense:
Its magnetic field pattern — with field lines emerging from one face (north pole) and entering the other (south pole) — is identical to that of a bar magnet. At large distances, the axial field of both obeys the same formula B = (μ0/4π)(2m/r^3). Cutting the solenoid in half yields two smaller solenoids, just as cutting a bar magnet yields two smaller magnets. The magnetic moment of the solenoid equals that of an equivalent bar magnet.

The magnetic moment of a current loop (or solenoid) is:
m = NIA
m = 800 × 3.0 × 2.5 × 10^{-4}
m = 0.60 J T^{-1}

Answer: The solenoid acts like a bar magnet because their field patterns and far-field formulas are identical. Magnetic moment m = 0.60 J T^{-1}

Q4 If the solenoid in Exercise 5.3 is free to turn about the vertical direction and a uniform horizontal magnetic field of 0.25 T is applied, what is the magnitude of torque on the solenoid when its axis makes an angle of 30° with the direction of applied field?

SOLUTION

Given: From Exercise 5.3, magnetic moment m = 0.60 J T^{-1}
Applied field B = 0.25 T, angle θ = 30°

Note: The textbook labels this as Exercise 5.5 but the solenoid data (N=800, A=2.5×10^{-4} m^2, I=3.0 A) corresponds to Exercise 5.3.

Torque on a magnetic dipole in a uniform field:
τ = mB sinθ

$\tau = 0.60 \times 0.25 \times \sin 30°$

$\tau = 0.60 \times 0.25 \times 0.5$

$\tau = 7.5 \times 10^{-2}$ N·m

Answer: Torque $\tau = 7.5 \times 10^{-2}$ N·m

Q5 A bar magnet of magnetic moment 1.5 J T^{-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, (ii) opposite to the field direction? (b) What is the torque on the magnet in cases (i) and (ii)?

SOLUTION

Given: m = 1.5 J T^{-1}, B = 0.22 T
Initial orientation: $\theta_i = 0°$ (m aligned with B)
Potential energy $U = -mB\cos\theta$

Initial potential energy: $U_i = -mB \cos 0° = -1.5 \times 0.22 = -0.33$ J

(a)(i) Turn to $\theta_f = 90°$ (normal to field):
$U_f = -mB \cos 90° = 0$ J
Work = $U_f - U_i = 0 - (-0.33) = +0.33$ J

(a)(ii) Turn to $\theta_f = 180°$ (opposite to field):
$U_f = -mB \cos 180° = +mB = +1.5 \times 0.22 = +0.33$ J
Work = $U_f - U_i = 0.33 - (-0.33) = +0.66$ J

(b)(i) Torque at $\theta = 90°$:
$\tau = mB \sin 90° = 1.5 \times 0.22 \times 1 = 0.33$ N·m

(b)(ii) Torque at $\theta = 180°$:
$\tau = mB \sin 180° = 1.5 \times 0.22 \times 0 = 0$ N·m

Answer: (a)(i) W = 0.33 J; (a)(ii) W = 0.66 J; (b)(i) $\tau = 0.33$ N·m; (b)(ii) $\tau = 0$ N·m

Q6 A closely wound solenoid of 2000 turns and area of cross-section 1.6×10^{-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 is the force and torque on the solenoid if a uniform horizontal magnetic field of 7.5×10^{-2} T is set up at an angle of 30° with the axis of the solenoid?

SOLUTION

Given: N = 2000 turns, $A = 1.6 \times 10^{-4}$ m^2, I = 4.0 A, $B = 7.5 \times 10^{-2}$ T, $\theta = 30°$

(a) Magnetic moment:
$m = NIA = 2000 \times 4.0 \times 1.6 \times 10^{-4}$
$m = 1.28$ A·m^2

(b) Force and torque in a uniform field:
Force: A magnetic dipole in a uniform magnetic field experiences zero net force (the forces on its two poles cancel).
$F = 0$

Torque: $\tau = mB \sin\theta$
Here $\theta = 30°$ is the angle between the solenoid axis (direction of m) and B.
$\tau = 1.28 \times 7.5 \times 10^{-2} \times \sin 30°$
$\tau = 1.28 \times 7.5 \times 10^{-2} \times 0.5$
$\tau = 4.8 \times 10^{-2}$ N·m

Answer: (a) m = 1.28 A·m^2; (b) Force = 0, Torque = 4.8×10^{-2} N·m

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Q7 A short bar magnet has a magnetic moment of 0.48 J T^{-1}. Give the direction and magnitude of the magnetic field produced by the magnet at a distance of 10 cm from the centre of the magnet on (a) the axis, (b) the equatorial lines (normal bisector) of the magnet.

SOLUTION

Given: m = 0.48 J T^{-1}, r = 10 cm = 0.10 m
Constant used: $\mu_0/4\pi = 10^{-7}$ T m A^{-1}

(a) Axial field (along the axis of the magnet):
$B_A = (\mu_0/4\pi) \times (2m / r^3)$
$B_A = 10^{-7} \times (2 \times 0.48) / (0.10)^3$
$B_A = 10^{-7} \times 0.96 / 10^{-3}$
$B_A = 10^{-7} \times 960$
$B_A = 9.6 \times 10^{-5}$ T = 0.96 G

Direction: along the axis of the magnet, pointing from south to north (i.e., in the direction of the magnetic moment m).

(b) Equatorial field (along the normal bisector):

$B_E = (\mu_0/4\pi) \times (m / r^3)$

$B_E = 10^{-7} \times 0.48 / (0.10)^3$

$B_E = 10^{-7} \times 0.48 / 10^{-3}$

$B_E = 10^{-7} \times 480$

$B_E = 4.8 \times 10^{-5}$ T = 0.48 G

Direction: along the equatorial line, pointing opposite to the magnetic moment m (i.e., from north to south outside the magnet, directed anti-parallel to m).

Answer: (a) $B_A = 0.96 \times 10^{-4}$ T (along axis, direction of m); (b) $B_E = 0.48 \times 10^{-4}$ T (along equator, opposite to m)