

Q1.

In a stretched string the frequency of the wave DOES NOT depends on:

- A) Amplitude of the wave
- B) Wavelength of the wave
- C) Velocity of the wave
- D) Tension in the string
- E) Linear mass density of the string.

Solution:

$$f = \frac{v}{\lambda}; \quad v = \sqrt{\frac{\tau}{\mu}}$$

Ans A.

Sec# Wave - I - The speed of a Traveling Wave

Q2.

A stretched string of mass 2.6 g and length 2.0 m, carries a sinusoidal wave with displacement $y(x, t) = 0.1 \sin(50\pi t + 2\pi x)$, where x and y are in meters and t in seconds. The Average power transmitted in the string is:

- A) 4.0 W
- B) 1.0 W
- C) 0.0 W
- D) 5.6 W
- E) 2.8 W

Solution:

$$v = \frac{\omega}{k} = \frac{50\pi}{2\pi} = 25 \text{ m/s}$$

$$\mu = \frac{m}{l} = \frac{2.6 \times 10^{-3}}{2.0} = 1.3 \times 10^{-3} \text{ kg/m}$$

$$P = \frac{1}{2} \mu v \omega^2 y_m^2 = 0.5 \times 1.3 \times 10^{-3} \times 25 \times (50\pi)^2 \times (0.1)^2 = 4 \text{ W}$$

Sec# Wave - I - Energy and Power of a Traveling String Wave

Q3.

A sound source and a reflecting surface move directly towards each other. Relative to the air, the speed of the source is 29.90 m/s, the speed of the surface is 65.80 m/s and the speed of sound is 329.0 m/s. The frequency of the sound of the source is 1200 Hz. What is the frequency of the reflected sound waves detected at the source?

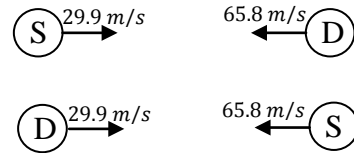
- A) 2160 Hz
- B) 1584 Hz

- C) 7500 Hz
- D) 2560 Hz
- E) 7100 Hz

Solution:

$$f' = f \frac{v + v_D}{v - v_s} = 1200 \frac{394.8}{299.1} = 1583.9 \text{ Hz}$$

$$f'' = f' \frac{v + v_o}{v - v_s} = 1583.95 \frac{358.9}{263.2} = 2159.9 \text{ Hz} \approx 2160 \text{ Hz}$$



Sec# Wave - II - The Doppler Effect
Grade# 45

Q4.

At 20 °C, a brass cube has an edge length of 10 cm. What is the increase in the cube's total surface area when it is heated from 20°C to 75°C? $\alpha_{\text{brass}} = 19 \times 10^{-6} /\text{K}$

- A) 1.3 cm²
- B) 2.5 cm²
- C) 0.51 cm²
- D) 3.1 cm²
- E) 13 cm²

Solution:

$$\Delta A = 2 \alpha A_i \Delta T \times 6$$

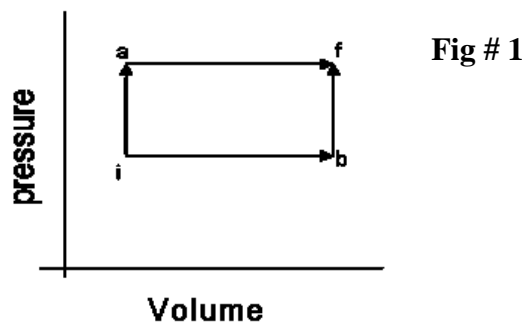
$$\Delta A = 6 \times 2 \times 19 \times 10^{-6} \times (10)^2 \times (75 - 20) = 1.254 \text{ cm}^2$$

Sec# Temperature, Heat, and the First Law of Thermodynamics - Thermal Expansion

Q5.

When a system is taken from state i to state f along path iaf, as in in Figure 1, 60 cal of heat is absorbed by the system and 25 cal of work is done by the system. Along path ibf, 36 cal of heat is absorbed by the system. The work done along the path ibf is:

- A) + 1.0 cal
- B) - 1.0 cal
- C) + 35 cal
- D) - 35 cal
- E) 0.0 cal



Solution:

$$\Delta E_{int} = Q - W ; \Delta E_{iaf} = \Delta E_{ibf}$$

$$Q_{iaf} - W_{iaf} = Q_{ibf} - W_{ibf}$$

$$60 - 25 = 36 - W_{ibf}$$

$$W_{ibf} = 1 \text{ cal}$$

Sec# Temperature, Heat, and the First Law of Thermodynamics - The First Law of Thermodynamics

Q6.

Five moles of nitrogen are in a 5.0-liter container at a pressure of 5.0×10^6 Pa. Find the average translational kinetic energy of a molecule.

- A) 1.2×10^{-20} J
- B) 3.1×10^{-20} J
- C) 5.3×10^{-20} J
- D) 7.3×10^{-20} J
- E) 0.32×10^{-20} J

Solution:

$$K_{avg} = \frac{3}{2} k_B T = \frac{3}{2} k_B \frac{PV}{nR}$$
$$= \frac{3}{2} \times \frac{1.38 \times 10^{-23} \times 5 \times 10^6 \times 5 \times 10^{-3}}{5 \times 8.31} = 1.2 \times 10^{-20} \text{ J}$$

Sec# The kinetic Theory of Gases - Translational Kinetic Energy

Q7.

A refrigerator converts 5.0 kg of water at 0°C into ice at 0°C in 30 min. What is the coefficient of performance of the refrigerator if its power input is 300 W?

- A) 3.1
- B) 2.4
- C) 1.3
- D) 5.3
- E) 9.0

Solution:

$$K = \frac{Q_L}{W} = \frac{Q_L/t}{P} = \frac{mL_f/t}{P} = \frac{5 \times 333 \times 10^3}{1800 \times 300} = 3.08 \approx 3.1 \quad [Q_L = mL_f]$$

Sec# Entropy and the Second Law of Thermodynamics - Entropy in the Real World:
Refrigerators

Q8.

Two charges $q_1 = 20 \text{ C}$ and $q_2 = -5.0 \text{ C}$ are placed at point $(0.0 \text{ m}, 0.0 \text{ m})$ and $(5.0 \text{ m}, 0)$ respectively. Where a 10 C charge should be placed on the x-axis so that the net force on it is zero?

- A) 10 m
- B) 15 m
- C) 3.0 m
- D) 1.0 m
- E) 20 m

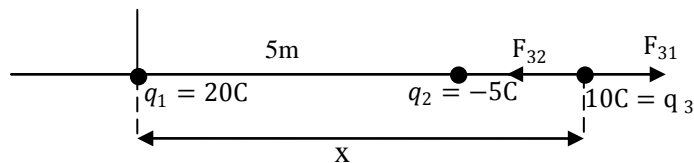
Solution:

$$F_{32} = F_{31}$$

$$\frac{kq_1q_3}{x^2} = \frac{kq_2q_3}{(x-5)^2}$$

$$\frac{20}{x^2} = \frac{5}{(x-5)^2}$$

$$4(x-5)^2 = x^2 \Rightarrow 2(x-5) = x \Rightarrow x = 10 \text{ m}$$



Sec# Electric Charge - Coulomb's Law

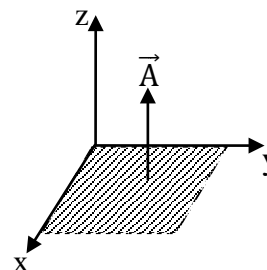
Q9.

For the electric field $\vec{E} = (12\hat{i} + 24\hat{j}) \text{ N/C}$, what is the electric flux through a 1.0 m^2 portion of the xy-plane?

- A) $0.0 \text{ N}\cdot\text{m}^2/\text{C}$
- B) $12 \text{ N}\cdot\text{m}^2/\text{C}$
- C) $24 \text{ N}\cdot\text{m}^2/\text{C}$
- D) $36 \text{ N}\cdot\text{m}^2/\text{C}$
- E) $40 \text{ N}\cdot\text{m}^2/\text{C}$

Solution:

$$\phi = \vec{E} \cdot \vec{A} = (12\hat{i} + 24\hat{j}) \cdot 1\hat{k} = 0$$



Sec# Gauss's law - Flux of an Electric Field

Q10.

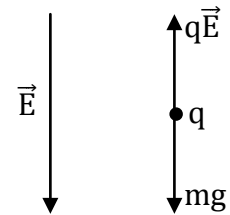
A charged particle with a mass of 2.0×10^{-4} kg is moving vertically down with acceleration 2.0 m/s^2 under the action of gravity and a downward electric field of 300 N/C . The charge on the particle is:

- A) $-5.2 \mu\text{C}$
- B) $+5.2 \mu\text{C}$
- C) $-1.3 \mu\text{C}$
- D) $+1.3 \mu\text{C}$
- E) $-7.8 \mu\text{C}$

Solution:

$$mg - qE = ma$$

$$q = \frac{m(g - a)}{E} = \frac{2 \times 10^{-4} \times (9.8 - 2)}{300} = 5.2 \times 10^{-6} \text{ C}$$



The charge should be negative because \vec{F}_E is opposite of \vec{E}

Sec# Electric fields - A point Charge in an Electric Field

Q11.

A charged solid conducting sphere has a radius $R = 20.0 \text{ cm}$ and a potential of 400 V . The electric potential at point 10.0 cm from the center of the sphere is:

- A) 400 V
- B) 200 V
- C) 0.00 V
- D) 500 V
- E) 100 V

Ans.

A. $(V = \frac{kQ}{R} \text{ everywhere inside and on the surface})$

Sec# Electric Potential - Potential of a Charged Isolated Conductor

Q12.

An electron is accelerated from a speed of $5.00 \times 10^6 \text{ m/s}$ to $8.00 \times 10^6 \text{ m/s}$. Calculate the potential through which the electron has to pass to gain this acceleration?

- A) 111 V
- B) 157 V
- C) 201 V
- D) 57.7 V
- E) 296 V

Solution:

$$\Delta U + \Delta K = 0$$

$$q\Delta V = -\Delta K = -\frac{\frac{1}{2}m(v_f^2 - v_i^2)}{q}$$

$$= -\frac{9.1 \times 10^{-31} \times [(8 \times 10^6)^2 - (5 \times 10^6)^2]}{2 \times (-1.6 \times 10^{-19})}$$

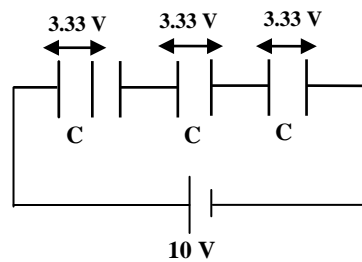
$$\Delta V = 110.9 \text{ V}$$

Sec# Electric Potential - Electric Potential Energy of a System of Point Charges

Q13.

Three capacitors each with capacitance C are connected to a 10 V battery as shown in Figure 2. If the magnitude of the charge on one of the plates of the first capacitor is $2.0 \mu\text{C}$, its capacitance C is:

Fig # 2



- A) $6.0 \times 10^{-7} \text{ F}$
- B) $2.0 \times 10^{-7} \text{ F}$
- C) $3.0 \times 10^{-7} \text{ F}$
- D) $6.0 \times 10^{-4} \text{ F}$
- E) $3.0 \times 10^{-4} \text{ F}$

Solution:

$$V = 3.33 \text{ V on each capacitor}$$

$$Q = CV \Rightarrow C = \frac{Q}{V} = \frac{2 \times 10^{-6}(\text{C})}{3.33 (\text{V})} = 6 \times 10^{-7} \text{ F}$$

Sec# Capacitance - Capacitors in Parallel and in Series

Q14.

An electric field exerts a torque on a dipole ONLY IF:

- A) the field is not parallel to the dipole moment
- B) the field is parallel to the dipole moment

- C) the field is perpendicular to the dipole moment
- D) the field is not perpendicular to the dipole moment
- E) the field is uniform

Ans

A. ($\vec{\tau} = \vec{p} \times \vec{E}$; $\tau = PE \sin\theta$)

Sec# Electric fields - A Dipole in an Electric Field

Q15.

A copper wire of length 150 m carries a current with a uniform current density of 2.8×10^7 A/m². The resistivity of copper is 1.7×10^{-8} Ω-m. The applied voltage across this wire is:

- A) 71 V
- B) 43 V
- C) 52 V
- D) 15 V
- E) 93 V

Solution:

$$V = iR = J\cancel{A}\rho\frac{L}{\cancel{A}} = J\rho L$$
$$= 2.8 \times 10^7 \times 1.7 \times 10^{-8} \times 150 = 71.4 \text{ V}$$

Sec# Current and Resistance - Current density

Q16.

A student kept his 60.0 W, 120 V study lamp turned on from 6:00 PM until 6:00 AM on a night. How many coulombs of charge went through the lamp?

- A) 2.16×10^4
- B) 3.60×10^3
- C) 7.20×10^4
- D) 1.80×10^3
- E) 1.50×10^2

Solution:

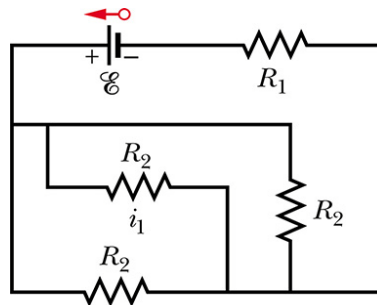
$$P = iV \Rightarrow i = \frac{P}{V} = \frac{q}{t}$$
$$\Rightarrow q = \frac{Pt}{V} = \frac{60 \times 43200}{120} = 21600 \text{ Coulombs}$$

Sec# Current and Resistance - Power in Electric Circuits

Q17.

Consider the circuit shown in Figure 3. The resistances $R_1 = 10 \Omega$, $R_2 = 20 \Omega$ and the ideal battery has emf $\epsilon = 12 \text{ V}$. What are the magnitude and direction (left or right) of the current i_1 ?

Fig # 3

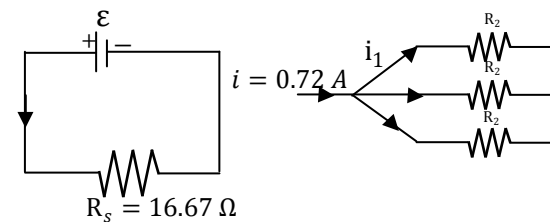
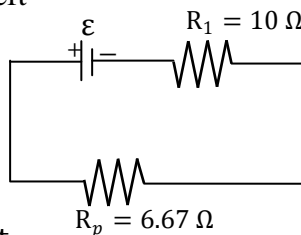


- A) 0.24 A to the right
- B) 0.24 A to the left
- C) 0.48 A to the right
- D) 0.48 A to the left
- E) 0.12 A to the left

Solution:

$$i = 0.72 \text{ A}$$

$$i_1 = \frac{0.72}{3} = 0.24 \text{ A to the right}$$

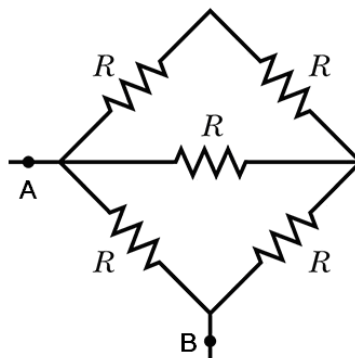


Sec# Circuits - Potential Difference Between Two Points

Q18.

Consider the five 10Ω resistors connected as shown in Figure 4. Find the equivalent resistance (in Ohms) between the points A and B.

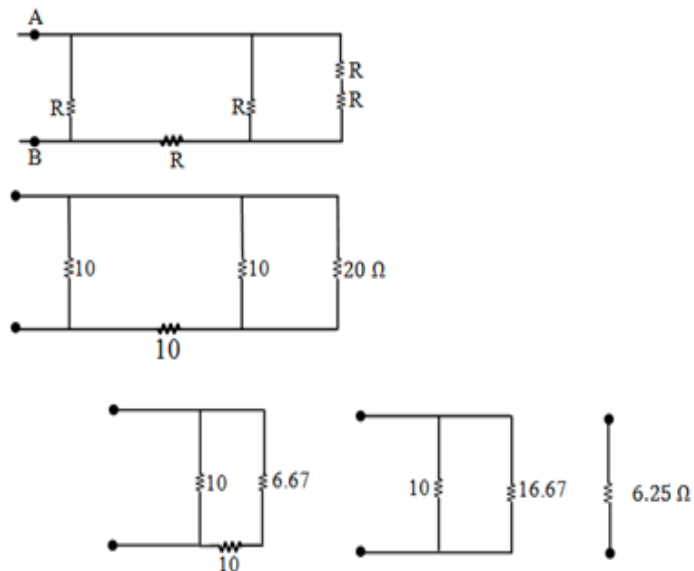
Fig # 4



- A) 6.3
- B) 5.2
- C) 10
- D) 9.5
- E) 2.0

Solution:

Figure 4 ⇒



Ans. A

Sec# Circuits - Multiloop Circuits

Q19.

A capacitor in a series RC circuit is charged to 60% of its maximum value in 1.0 s. The time constant of the circuit is:

- A) 1.1 s
- B) 5.9 s
- C) 0.72 s
- D) 2.0 s
- E) 3.5 s

Solution:

$$q = q_0 \left(1 - e^{-\frac{t}{\tau}}\right)$$

$$t = 1 \text{ s} \Rightarrow 0.6 q_0 = q_0 \left(1 - e^{-\frac{1}{\tau}}\right)$$

$$e^{-\frac{1}{\tau}} = 0.4 \Rightarrow t = 1.09 \text{ s}$$

Sec# Circuits - RC Circuits

Q20.

Initially a single resistor R_1 is connected to a battery. Then another resistor R_2 (different from R_1) is added in parallel. Which one of the following is ALWAYS TRUE?

- A) The current through R_1 now is the same as that before R_2 is added.
- B) The current through R_1 now is less than that before R_2 is added.
- C) The current through R_1 now is more than that before R_2 is added.
- D) The total current through R_1 and R_2 is the same as that through R_1 before R_2 is added.
- E) The total current through R_1 and R_2 is twice as that through R_1 before R_2 is added.

Ans.

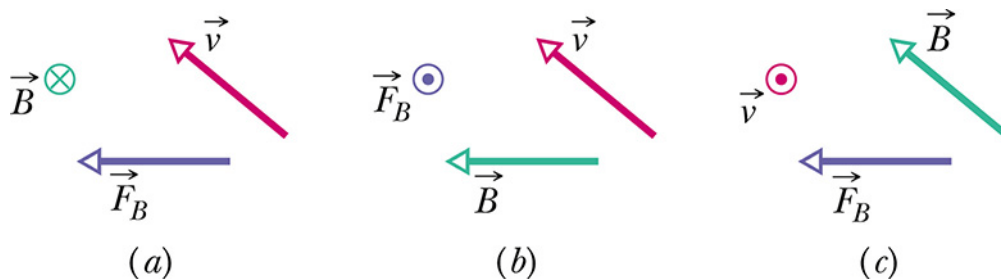
A.

Sec# Circuits - Multiloop Circuits

Q21.

Figure 5 shows three situations in which an electron moves at velocity \vec{v} through a uniform magnetic field \vec{B} and experiences a magnetic force \vec{F}_B . Determine which situation(s) are physically reasonable for the orientations of the vectors.

Fig# 5



- A) None of them
- B) Only (b)
- C) Only (a)
- D) Both (a) and (b)
- E) All of them

Ans.

A. ($\vec{F} = q$ (negative charge) ($\vec{v} \times \vec{B}$))

Sec# Magnetic Fields - The Definition B

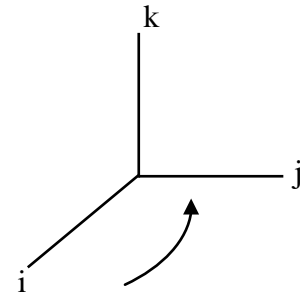
Q22.

An electron travels through a uniform magnetic field $\vec{B} = -2.50\hat{i}$ mT and electric field $\vec{E} = 4.00\hat{k}$ V/m. At one instant the velocity of the electron is $\vec{v} = 2000\hat{j}$ m/s. At that instant and in unit vector notation, what is the net force (in Newton) acting on the electron?

- A) $-1.44 \times 10^{-18} \hat{k}$
- B) $+1.44 \times 10^{-18} \hat{k}$
- C) $-3.00 \times 10^{-15} \hat{j}$
- D) $+3.00 \times 10^{-15} \hat{j}$
- E) zero

Solution:

$$\begin{aligned} \vec{F} &= q(\vec{E} + \vec{v} \times \vec{B}) \\ &= -1.6 \times 10^{-19} (4\hat{k} + 2.5 \times 10^{-3} \times 2000\hat{k}) \\ &= -1.6 \times 10^{-19} \times 9\hat{k} = 1.44 \times 10^{-18} \hat{k} \text{ N} \end{aligned}$$



Sec# Magnetic Fields - Crossed Fields: Discovery of the Electron

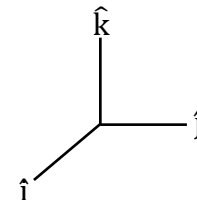
Q23.

A 50 cm long wire carries a 0.50 A current along the positive x-axis through a magnetic field $\vec{B} = (6.0\hat{j} + 8.0\hat{k})$ mT. What is the magnitude of the magnetic force on the wire?

- A) 2.5 mN
- B) 2.0 mN
- C) 1.5 mN
- D) 1.0 mN
- E) 3.5 mN

Solution:

$$\begin{aligned} \vec{F} &= i(\vec{L} \times \vec{B}) \\ &= 0.5 \times (0.5\hat{i} \times [6\hat{j} + 8\hat{k}] \times 10^{-3}) \\ &= 0.5 \times (3\hat{k} - 4\hat{j} \times 10^{-3}) = (1.5\hat{k} - 2\hat{j}) \times 10^{-3} \text{ N} \\ |\vec{F}| &= 2.5 \times 10^{-3} \text{ N} \end{aligned}$$

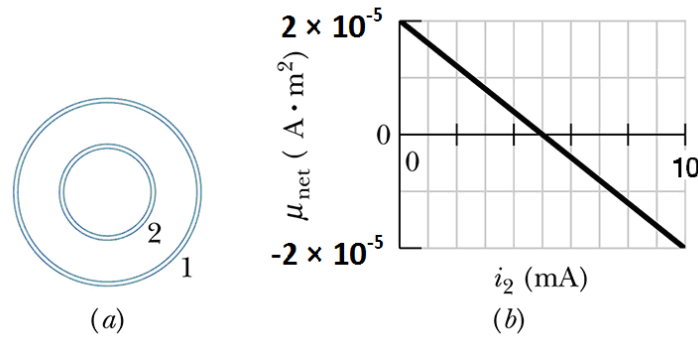


Sec# Magnetic Fields - Magnetic Force on a Current-Carrying Wire

Q24.

Figure 6a shows two concentric coils, lying in the same plane, carry currents in opposite directions. The current in the larger coil 1 is fixed. Current i_2 in coil 2 can be varied. Figure 6b gives the net magnetic moment of the two-coil system as a function of i_2 . If the current in coil 2 is then reversed, what is the magnitude of the net magnetic moment (in $\text{A}\cdot\text{m}^2$) of the two-coil system when $i_2 = 8.0 \text{ mA}$?

Fig# 6



- A) 5.2×10^{-5}
- B) 3.2×10^{-5}
- C) 1.2×10^{-5}
- D) 2.0×10^{-5}
- E) 4.8×10^{-5}

Solution:

$$i_2 = 0; \mu_1 = 2 \times 10^{-5} \text{A}\cdot\text{m}^2$$

$$\mu_{\text{net}} = 0; \mu_2 - \mu_1 = 0$$

$$|\mu_2| = |\mu_1|$$

$$5A_2 = 2 \times 10^{-5} \text{A}\cdot\text{m}^2 \Rightarrow A_2 = \frac{2}{5} \times 10^{-5} \text{A}\cdot\text{m}^2$$

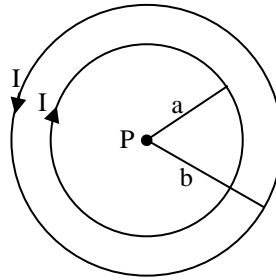
$$\mu_{\text{net}} = 8A_2 + \mu_1 = 8 \times \frac{2}{5} \times 10^{-5} + 2 \times 10^{-5} = 5.2 \times 10^{-5} \text{A}\cdot\text{m}^2$$

Sec# Magnetic Fields - The Magnetic Dipole Moment

Q25.

Consider two concentric circular loops of radii $a = 2.0 \text{ cm}$ and $b = 4.5 \text{ cm}$ carrying the same current $I = 5.0 \text{ A}$ as shown in Figure 7. What is the magnitude of the net magnetic field at the center P?

Fig# 7



- A) 87 μ T, into the paper
- B) 87 μ T, out of the paper
- C) 0.23 mT, out of the paper
- D) 0.23 mT, into the paper
- E) 23 μ T, into the paper

Solution:

$$B = \frac{\mu_0 i}{2R}$$

$$B_{\text{net}} = \frac{\mu_0 i}{2a} + \frac{\mu_0 i}{2b}$$

$$= \frac{\mu_0 i}{2} \left(\frac{1}{b} - \frac{1}{a} \right) = \frac{4\pi \times 10^{-7} \times 5}{2} \left(\frac{1}{4.5 \times 10^{-2}} - \frac{1}{2 \times 10^{-2}} \right)$$

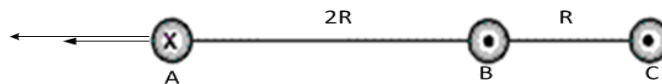
$$= -87.3 \times 10^{-6} \text{ T (into the paper)}$$

Sec# Magnetic Fields Due to Currents - Calculating the Magnetic Field Due to a Current

Q26.

Figure 8 shows a cross section of three parallel wires each carrying a current of 24 A. The currents in wires B and C are out of the paper, while that in wire A is into the paper. If the distance $R = 5.0$ mm, what is the magnitude of the net magnetic force on a 4.0-m length of wire A?

Fig#8



- A) 77 mN
- B) 15 mN
- C) 59 mN
- D) 12 mN
- E) 32 mN

Solution:

$$F = \frac{\mu_0 i^2 L}{2\pi(2R)} + \frac{\mu_0 i^2 L}{2\pi(3R)} = \frac{5\mu_0 i^2 L}{2\pi(6R)}$$
$$= \frac{5 \times 4\pi \times 10^{-7} \times (24)^2 \times 4}{4\pi \times 5 \times 10^{-3} \times 3} = 0.0768 \text{ N} \approx 76.8 \text{ mN}$$

Sec# Magnetic Fields Due to Currents - Force Between Two Parallel Currents

Q27.

A long straight wire of diameter 2.0 mm carries a current of 25 A. What is the magnitude of the magnetic field 0.50 mm from the axis of the wire?

- A) 2.5 mT
- B) 10 mT
- C) 0.63 mT
- D) 0.01 mT
- E) 5.0 mT

Solution:

$$B = \frac{\mu_0 i}{2\pi R^2} r = \frac{4\pi \times 10^{-7} \times 25 \times 0.5 \times 10^{-3}}{4\pi \times (1 \times 10^{-3})^2} = 2.5 \times 10^{-3} \text{ T}$$

Sec# Magnetic Fields Due to Currents - Ampere's Law

Q28.

A solenoid is designed to produce a magnetic field of 0.0250 T at its center. It has 1.20 cm radius and 30.0 cm length and the solenoid wire can carry a maximum current of 9.947 A. The total length of the wire required to make the solenoid is:

- A) 45.2 m
- B) 63.4 m
- C) 71.3 m
- D) 23.1 m
- E) 33.0 m

Solution:

$$B = \mu_0 \frac{N}{L} i \Rightarrow N = \frac{BL}{\mu_0 i} = \frac{0.025 \times 0.3}{4\pi \times 10^{-7} \times 9.947} = 600$$

$$N2\pi r = l = 600 \times 2 \times \pi \times 1.2 \times 10^{-2} = 45.2 \text{ m}$$

Sec# Magnetic Fields Due to Currents - Ampere's Law

Q29.

A 5-turn square coil (10 cm along a side, resistance = 4.0 Ω) is placed in a magnetic field that makes an angle of 30° with the plane of the coil. The magnitude of this field varies with time according to $B = 0.50t^2$, where t is measured in s and B in T. What is the induced current in the coil at t = 4.0 s?

- A) 25 mA
- B) 5.0 mA
- C) 13 mA
- D) 43 mA
- E) 50 mA

Solution:

$$\varepsilon = \frac{d\Phi}{dt} = NA \frac{dB}{dt} \cos \theta = Ri; \quad \frac{dB}{dt} = t$$

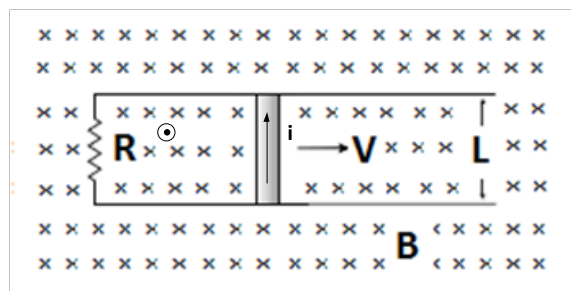
$$i = \frac{NA \frac{dB}{dt} \cos \theta}{R} = \frac{5 \times (0.1)^2 \times \cancel{4} \times \cos 60^\circ}{\cancel{4}} = 0.025 \text{ A}$$

Sec# Induction and Inductance - Faraday's Law of Induction

Q30.

A bar of length $L = 80 \text{ cm}$ moves with velocity \vec{V} on two frictionless rails, as shown in Figure 9, in a region where the magnetic field is uniform ($B = 0.30 \text{ T}$) and into the paper. If $\vec{V} = 50 \text{ cm/s}$ and $R = 60 \text{ m}\Omega$, what is the magnetic force on the moving bar?

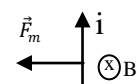
Fig# 9



- A) 0.48 N to the left
- B) 0.21 N to the right
- C) 0.32 N to the right
- D) 0.32 N to the left
- E) 0.48 N to the right

Solution:

$$F_m = iLB = \frac{\varepsilon}{R} LB = \frac{BLvLB}{R} = \frac{B^2 L^2 v}{R} = 0.48 \text{ N to the Left}$$



Sec# Induction and Inductance - Induction and Energy Transfers

$v = \sqrt{\frac{\tau}{\mu}}, v = \lambda f, v = \sqrt{\frac{B}{\rho}}$ $S = S_m \cos(kx - \omega t)$ $I = \frac{\text{Power}}{\text{Area}}$ $y = y_m \sin(kx - \omega t - \phi)$ $P = \frac{1}{2} \mu \omega^2 y_m^2 v$ $\Delta P = \Delta P_m \sin(kx - \omega t)$ $\Delta P_m = \rho v \omega S_m$ $I = \frac{1}{2} \rho (\omega S_m)^2 v$ $\beta = 10 \log \frac{I}{I_0}, I_0 = 10^{-12} \text{ W/m}^2$ $f' = f \left(\frac{v \pm v_D}{v \mp v_s} \right)$ $y = \left(2y_m \cos \frac{\phi}{2} \right) \sin \left(kx - \omega t - \frac{\phi}{2} \right)$ $\Delta L = \frac{\lambda}{2\pi} \phi$ $\Delta L = n \frac{\lambda}{2} \quad n = 0, 1, 2, 3, \dots$ $\Delta L = m\lambda$ $\Delta L = \left(m + \frac{1}{2} \right) \lambda$ $f_n = \frac{nv}{2L}, \quad n = 1, 2, 3, \dots$ $f_n = \frac{nv}{4L}, \quad n = 1, 3, 5, \dots$ $y = 2y_m \sin(ktx) \cos(\quad)$ $\alpha = \frac{\Delta L}{L} \frac{1}{\Delta T}, PV = nRT = NkT$ $n = \frac{m}{M} = \frac{N}{N_A}, \beta = \frac{1}{v} \frac{\Delta v}{\Delta T}$ $Q = mL, \quad W = \int PdV,$ $P = \frac{2}{3} \frac{N}{V} \left(\frac{1}{2} m \bar{v}^2 \right), C_p - C_v = R$ $Q = mc \Delta T,$ $\Delta E_{\text{int}} = Q - W, \Delta E_{\text{int}} = nc_v \Delta T$	$v_{\text{rms}} = \sqrt{\frac{3RT}{M}}, \frac{1}{2} m \bar{v}^2 = \frac{3}{2} k_B T,$ $P_{\text{cond}} = \frac{Q}{t} = \kappa A \frac{T_H - T_C}{L}$ $Q = n c_p \Delta T, \quad Q = n c_v \Delta T$ $P V^\gamma = \text{constant}, \quad T V^{\gamma-1} = \text{constant}$ $T_F = \frac{9}{5} T_C + 32, \quad T_K = T_C + 273$ $W = Q_H - Q_L, \quad \varepsilon = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H}$ $\frac{Q_L}{Q_H} = \frac{T_L}{T_H}, K = \frac{Q_L}{W}, \Delta S = \int \frac{dQ_r}{T}$ $F = \frac{kq_1 q_2}{r^2}, \quad F = q_0 E, \quad \vec{\tau} = \vec{p} \times \vec{E}$ $\phi = \int_{\text{Surface}} \vec{E} \cdot d\vec{A}, \quad E = \frac{kq}{r^2}, U = \vec{p} \cdot \vec{E}$ $E = \frac{kQ}{R^3} r, \quad E = \frac{2k\lambda}{r}$ $\phi_c = \oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{in}}}{\varepsilon_0}$ $E = \frac{\sigma}{2\varepsilon_0}, \quad E = \frac{\sigma}{\varepsilon_0}, \quad V = \frac{kQ}{r}$ $\Delta V = V_B - V_A = - \int_A^B \vec{E} \cdot d\vec{s} = \frac{\Delta U}{q_0}$ $E_x = -\frac{\partial V}{\partial x}, E_y = -\frac{\partial V}{\partial y}, E_z = -\frac{\partial V}{\partial z}$ $U = \frac{kq_1 q_2}{r_{12}}, C = \frac{Q}{V}, C_0 = \frac{\varepsilon_0 A}{d}$ $C = 4\pi\varepsilon_0 \frac{ab}{b-a}, U = \frac{1}{2} CV^2$ $u = \frac{1}{2} \varepsilon_0 E^2, C = \kappa C_0,$ $E = \frac{E_0}{\kappa}, v = \frac{v_0}{\kappa}, I = \frac{dQ}{dt},$	$I = JA, R = \frac{V}{I} = \rho \frac{L}{A}$ $\rho = \rho_0 [1 + \alpha(T - T_0)], P = IV$ $q(t) = C\varepsilon [1 - e^{-t/RC}],$ $q(t) = q_0 e^{-t/RC}$ $\tau = N i A B \sin \theta, \quad \vec{\tau} = \vec{\mu} \times \vec{B}$ $\vec{F} = q(\vec{v} \times \vec{B}), \quad \vec{F} = i(\vec{L} \times \vec{B})$ $F_{\text{ba}} = \frac{\mu_0 I_a I_b}{2\pi d}, d\vec{B} = \frac{\mu_0 i d\vec{s} \times \vec{r}}{4\pi r^3}$ $\oint \vec{B} \cdot d\vec{s} = \mu_0 i_{\text{enc}}, U = -\vec{\mu} \cdot \vec{B}$ $B = \frac{\mu_0 i}{4\pi R} \phi, \quad B = \frac{\mu_0 i}{2\pi r}$ $B_s = \mu_0 n i, \phi_B = \int_{\text{Surface}} \vec{B} \cdot d\vec{A}$ $\varepsilon = -\frac{d\phi_B}{dt}, \quad \varepsilon = BLv$ <hr style="border-top: 1px dashed black;"/> $v = v_0 + at$ $x - x_0 = v_0 t + \frac{1}{2} at^2$ $v^2 = v_0^2 + 2a(x - x_0)$ $\varepsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N}\cdot\text{m}^2$ $k = 9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$ $q_e = -1.6 \times 10^{-19} \text{ C}$ $m_e = 9.11 \times 10^{-31} \text{ kg}$ $m_p = 1.67 \times 10^{-27} \text{ kg}$ $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$ $\mu_0 = 4\pi \times 10^{-7} \text{ Wb/A}\cdot\text{m}$ $k_B = 1.38 \times 10^{-23} \text{ J/K}$ $N_A = 6.02 \times 10^{23} \text{ molecules/mole}$ $1 \text{ atm} = 1.013 \times 10^5 \text{ N/m}^2$ $R = 8.31 \text{ J/mol}\cdot\text{K}$ $g = 9.8 \text{ m/s}^2, 1 \text{ cal} = 4.186 \text{ J},$ $1 \text{ L} = 10^{-3} \text{ m}^3$ for water: $c = 4180 \frac{\text{J}}{\text{kg}\cdot\text{K}}$ $L_F = 333 \frac{\text{kJ}}{\text{kg}}, \quad L_V = 2256 \frac{\text{kJ}}{\text{kg}}$
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