23

Magnetic Effects of Current

Magnetic Force

If a charged particle having charge q enters a magnetic field B with a velocity v, it experiences a force $\vec{F} = q\,(\vec{v} \times \vec{B})$

Note that this principle is used in Television Receivers to deflect electrons. The SI unit of magnetic field is Wbm^{-2} or Tesla (T). The CGS unit is Gauss = Maxwell/cm^2

$\quad$ 1 Gauss = $10^{-4}T$

$\quad$ If both electric and magnetic fields are present, the net force acting on the moving charged particle is given by Lorentz force

$$\vec{F} = q\vec{E} + q\,(\vec{v} \times \vec{B})$$

$\quad$ This method is employed in J.J. Thomson's experiment to find e/m.

$\quad$ If velocity of the charged particle is always perpendicular to the magnetic field then it will describe a circle of radius R such that

$$R = \frac{mv}{qB}$$ as the force is radial. The force helps to

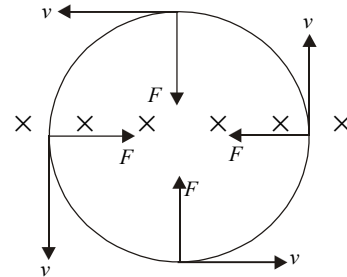change the direction only and does no work. [See Fig. 23.1]

Fig. 23.1 Principle of cyclotron illustration

$\quad$ Time period of revolution $T = \dfrac{2\pi R}{v} = \dfrac{2\pi m}{qB}$

and cyclotron frequency $f_{\mathrm{C}} = \dfrac{1}{T} = \dfrac{qB}{2\pi m}$

$\quad$ If the charged particle enters obliquely into a magnetic field B, the velocity can be resolved into two perpendicular components: one along the field and other perpendicular to the field. The perpendicular component describes a circle and parallel component causes linear motion. As a result the charged particle describes helix. See Fig. 23.2 (a) and (b).
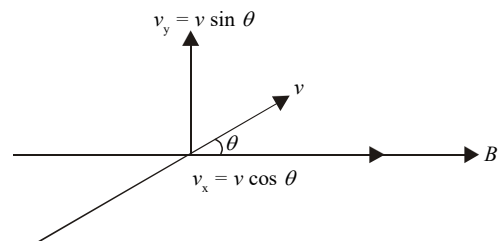

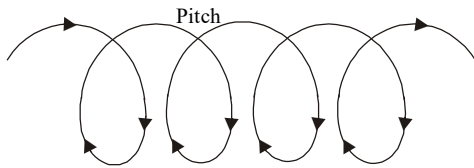**Fig. 23.2 (a)** Oblique projection of a charged particle

Fig. 23.2 (b)　　**Helix**

Pitch of helix　The linear or horizontal distance moved in one complete rotation is called pitch of the helix.

Pitch of the helix $= v_X . \, T = v_X \left(\dfrac{2\pi m}{qB} \right)$

Magnetic force due to a current-carrying conductor when placed in a uniform magnetic field B is

$\overrightarrow{dF} = I \, \overrightarrow{dl} \times \vec{B}$

The direction of magnetic force is given by Fleming's Left hand rule.

Note $\vec{F} = I \vec{l} \times \vec{B}$ if the conductor is straight.

Otherwise $\vec{F} = \int I \left(\overrightarrow{dl} \times \vec{B} \right)$

Torque acting on a current-carrying loop when placed in a uniform magnetic field is $\tau = nI \left(\vec{A} \times \vec{B} \right)$

where n is number of turns in the coil or loop and area vector A is perpendicular to the surface. For a rectangular coil

$A = lb$

and for a circular coil

$A = \pi r^2$. We can also write

$\tau = nI \left(\vec{A} \times \vec{B} \right) = \overrightarrow{M} \times \vec{B}$ where $\overrightarrow{M} = nI \vec{A}$ is magnetic dipole moment.

Note that the coil will be in stable equilibrium if $\theta = 0$ and coil will be in unstable equilibrium if $\theta = 180°$. Torque is maximum if $\theta = 90°$.

If the magnetic field is non uniform then coil will experience torque as well as linear motion.

Biot Savart Law　The magnetic field produced due to a current-carrying element of length dl at any point P is given

by $\overrightarrow{dB} = \mu_0 \dfrac{I \overrightarrow{dl} \times \vec{r}}{4\pi r^3}$ (See Fig. 23.3)
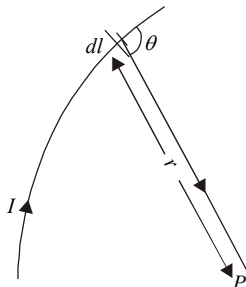

Fig. 23.3　　**Biot savart law**

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or　$|dB| = \dfrac{\mu_0 I dl \sin \theta}{4\pi r^2}$

where μ_0 is permeability of free space and $\mu_0 = 4\pi \times 10^{-7}$ Wb (A–m)$^{-1}$ or Henry m^{-1}.

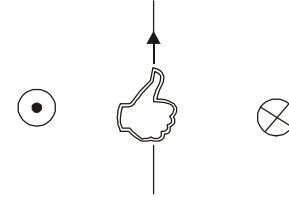The direction of magnetic field is given by Right hand thumb rule as illustrated in Fig. 23.4
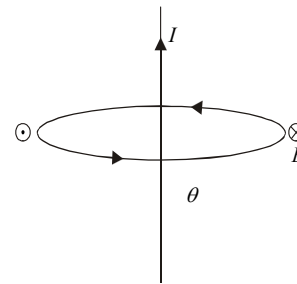

Fig. 23.4 (a)

Fig. 23.4 (b)　　**Illustration of direction of magnetic field**

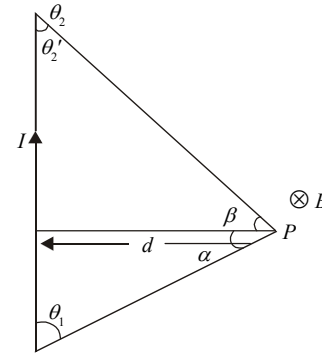**Magnetic field strength due to straight current-carrying conductor at a point P**

Fig. 23.5　　**Magnetic field due to finite straight conductor**

From Fig. 23.5 magnetic field strength at P is

$B = \dfrac{\mu_0 I}{4\pi d} (\cos \theta_1 - \cos \theta_2)$

$= \dfrac{\mu_0 I}{4\pi d} (\cos \theta_1 + \cos \theta_2')$

$= \dfrac{\mu_0 I}{4\pi d} (\sin \alpha + \sin \beta)$

The direction of magnetic field is given by Right hand thumb rule. From Fig. 23.4(a), it is clear that magnetic field at P is perpendicular inwards the plane of paper and magnetic field at S is perpendicular outwards the plane of paper.

Magnetic field strength at point P on a perpendicular bisector is

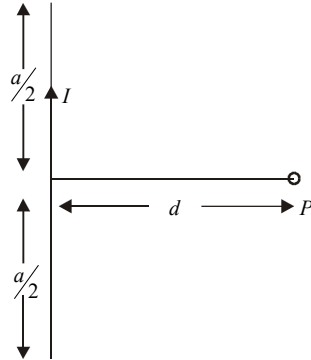$$B = \frac{\mu_0 Ia}{2\pi d\sqrt{a^2 + 4d^2}}$$

Magnetic field strength at point p due to a long current-carrying conductor is $B = \dfrac{\mu_0 I}{2\pi d}$

Magnetic field strength at the center of a circular loop carrying current I

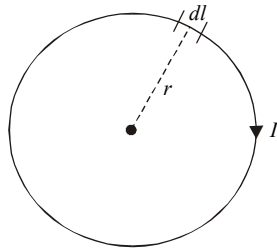$$B = \frac{\mu_0 I}{2r}$$

Fig. 23.7   **Magnetic field due to a circular loop at its centre**

The direction of magnetic field is perpendicular inwards the plane of loop if the current is clockwise and perpendicular outwards if the current is anti-clockwise.

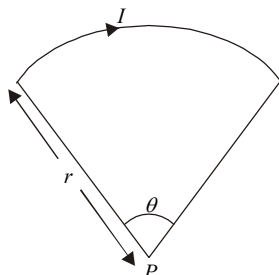**Magnetic field strength due to a circular arc of radius r at the centre**

Fig. 23.8   **Magnetic field due to a circular arc**

See Fig. 23.8 and take θ in radian.

$$B = \frac{\mu_0 I}{2r}\left(\frac{\theta}{2\pi}\right)$$

Thus for a semicircular loop

$$B = \frac{\mu_0 I}{4r} \quad \text{as } \theta = \pi$$

Magnetic field strength at any point on axial line of circular ring carrying current I
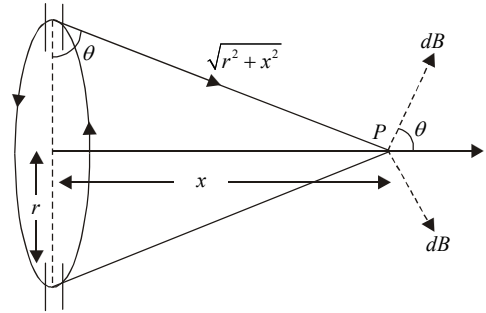
Fig. 23.9   **Magnetic field due to a circular loop at any point**

$$B = \frac{\mu_0 Ir^2}{2\left(r^2 + x^2\right)^{3/2}}$$

where r is radius of the circular loop.

The direction of magnetic field is same as for circular coils.

Special cases   Magnetic field at a very large distance from the centre i.e. $x \gg r$

$$B = \frac{\mu_0 Ir^2}{2x^3} = \frac{\mu_0 I\left(\pi r^2\right)}{2\pi x^3} = \frac{2\mu_0 M}{4\pi x^3}$$

That is, coil behaves as a magnetic dipole.

At the centre of the loop $x = 0$; $B = \dfrac{\mu_0 I}{2r}$

Ampere's Circuital law

$$\oint B.dl = \mu_0 I$$

See Fig. 23.10.

Fig. 23.10   **Ampere circuital law illustration**

If I_1 and I_3 are taken as positive and I_2 as negative then

$$I = I_1 + I_3 - I_2 \text{ and then}$$

$$\oint B.dl = \mu_0(I_1 + I_3 - I_2)$$

Note that any current outside the loop is not included in the right hand side in the current.

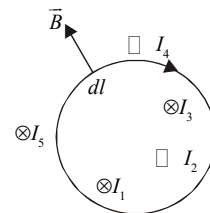Note that $\oint B \,.dl = \mu_0 I$ can be applied even to a long conductor.

Magnetic field due to a long solenoid at the axis of the solenoid

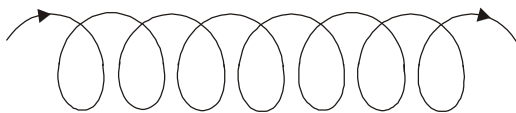$B = n\mu_0 I$ where n is number of turns per unit length

Fig. 23.11   **Solenoid**

Magnetic field outside the coil is zero.

Magnetic field at any point P in the solenoid as shown in Fig. 23.12 is

$$B_P = \frac{1}{2}\mu_0 nI[\cos\theta_1 - \cos\theta_2]$$

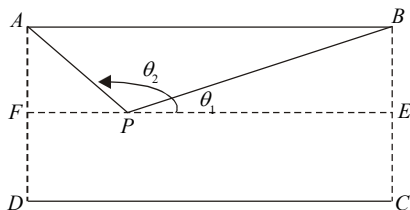At point F or E $B = \frac{1}{2}\mu_0 nI$ [see Fig. 23.12]

Fig. 23.12   **Magnetic field inside the solenoid at any point**
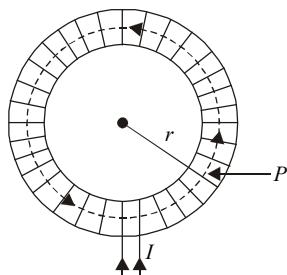
Magnetic field at any point P (acting tangentially) on a toroid

Fig. 23.13   **Toroid**

From Fig. 23.13 $B = \dfrac{\mu_0 NI}{2\pi r}$

where N is total number of turns.

Magnetic force between two long, parallel current-carrying conductors

If d is the separation between two long current-carrying conductors carrying currents I_1 and I_2 as shown in Fig. 23.14
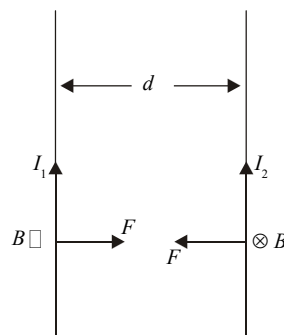
Fig. 23.14   **Force between two long current-carrying conductors**

Then $\dfrac{dF}{dl} = \dfrac{\mu_0 I_1 I_2}{2\pi d}$

Note that the force is attractive if the conductors carry current in the same direction. Force will be repulsive if they carry current in opposite directions.

Magnetic field due to a moving charge at any point P distant r from the charge.

$$B = \frac{\mu_0 qv\sin\theta}{4\pi r^2} \text{ or } \vec{B} = \frac{\mu_0 q(\vec{v}\times\vec{r})}{4\pi r^3}$$

Magnetic force between moving charges: If two charges q_1 and q_2 are moving with v_1 and v_2 parallel to each other at a separation r then

$$F_{mag} = \frac{\mu_0 q_1 q_2 v_1 v_2}{4\pi r^2}$$

Even the like charges moving in the same direction will repel as $F_{elect} > F_{mag}$
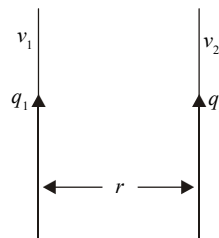
Fig. 23.15   **Magnetic force between moving charges**

Since electric force is repulsive and magnetic force is attractive, the net force is repulsive. Note the force will be attractive only if charges are unlike.

SHORT CUTS AND POINTS TO NOTE

1. Cyclotron is normally used to accelerate positively charged particles though it can accelerate negatively charged particles except electrons. Electrons are accelerated using betatron.

2. The principle of mass spectrometer (to measure mass of atoms/molecules) is same as that of cyclotron.

Here $\dfrac{m_1}{m_2} = \dfrac{r_1}{r_2}$ assuming they were monovalent/ divalent/ trivalent ions and enter the magnetic field with same velocity. Note that discovery of isotopes was made using mass spectrometer.

3. $\vec{F} = q\,(\vec{v} \times \vec{B})$

or $d\vec{F} = i\,(\vec{dl} \times \vec{B})$ represent Ampere's force.

4.   Magnetic flux $= \int B.ds$ is scalar

5.   A cylindrical coil or a circular coil carrying current behaves like a bar magnet. A clockwise current generates S-pole and an anti-clockwise current will generate N-pole.

Fig. 23.16   **Direction of magnetic field illustration**

6.   Magnetic field lines make closed loop. Unlike electric field, lines representing monopole cannot exist.
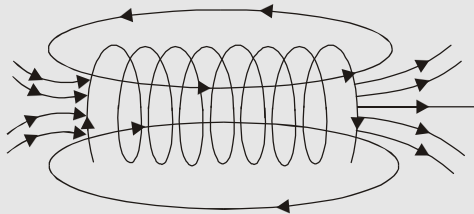
Fig. 23.17

7.   When current passes through a spring it shrinks as all the rings in it carry current in the same direction and are attracted towards one another.

8.   Momentum of a charged particle in a cyclotron

$p = Bqr = \sqrt{2(KE)m}$ where KE is kinetic energy of the particle.

9.   In cyclotron when KE and magnetic fields for two charged particles are equal then,
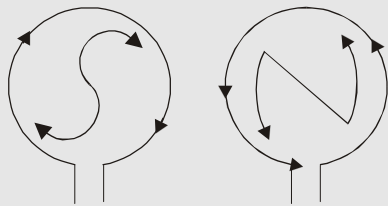
$$\dfrac{r_1}{r_2} = \dfrac{q_2}{q_1}\sqrt{\dfrac{m_1}{m_2}}$$

If only magnetic field is same for the two charged particles then $\dfrac{r_2}{r_1} = \dfrac{q_2}{q_1}\sqrt{\dfrac{m_1\,(KE_1)}{m_2\,(KE_2)}}$

where KE_1 and KE_2 are kinetic energies for the two particles respectively.

10.   No magnetic field occurs on a point P on the current carrying conductor or an any point S or R which lie on the extended part of the conductor as shown in Fig. 23.18
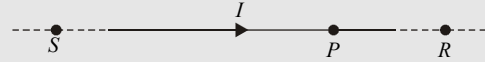
Fig. 23.18

i.e. $B_S = B_P = B_R = 0$

11.   Magnetic field intensity at the centre of a loop made with a uniform cross-section wire and uniform density is zero irrespective of its shape provided current enters from a point and leaves from another point on the conductor as shown in Fig. 23.19.
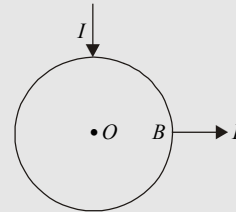
Fig. 23.19

12.   If magnetic field and electric field are perpendicular to each other and a charged particle enters perpendicular to both electric and magnetic fields, if charged particle goes undeviated then,

$$E = Bv \text{ or } v = \dfrac{E}{B}$$

13.   Magnetic field intensity in a thick current-carrying conductor at any point $x < r$ (inside the conductor) as illustrated in Fig. 23.20

Fig. 23.20 (a)

Fig. 23.20 (b)

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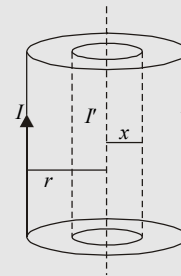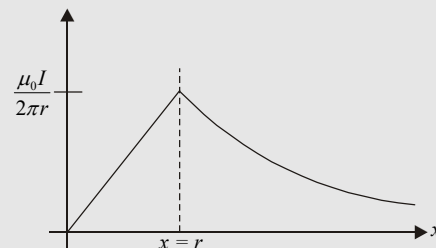
$$B_{inside} = \frac{\mu_0 I x}{2\pi r^2} \qquad \text{for } x < r$$

$$B_{surface} = \frac{\mu_0 I}{2\pi r} \qquad \text{for } x = r$$

$$B_{outside} = \frac{\mu_0 I}{2\pi x} \qquad \text{for } x > r$$

14. While finding magnetic force on the curved part of a conductor use displacement as length and then $F = IlB$ is valid where l is displacement between the extreme points of a curved part. For instance in Fig. 23.21 the force due to curved part is $2\,IRB$ as $l = 2R$ is displacement.
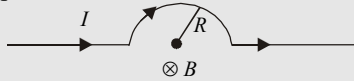
Fig. 23.21

15. Under the action of magnetic field alone, speed or KE of the charged particle remains unchanged.

16. Cyclotron principle can be used to detect leak in high vacuum system. For this purpose He^+ ions are used. A very small magnetic field is required which makes the leak detector a compact device.

17. Magnetic dipole moment $M = IA$. While finding torque on a coil carrying current due to a dipole if the (angle) is given between area vector $\vec{A}$ and magnetic field B (Area vector is normal to the plane of the surface of coil) then $\tau = IAB \sin\theta$. If angle between plane of the coil and magnetic field is known then $\tau = IAB \cos\theta$.

18. Potential energy $U = \int \tau . d\theta = -IAB \cos\theta = -\vec{M}.\vec{B}$.

19. Note that in parallel conductors carrying current you have $\dfrac{dF}{dl} = \dfrac{\mu_0 I_1 I_2}{2\pi d}$.

To find force, multiply with the length or integrate appropriately.

If the case is as shown in Fig. 23.22 (b) where the magnetic field varies at every point, assume an element. Find force on the element and then integrate.
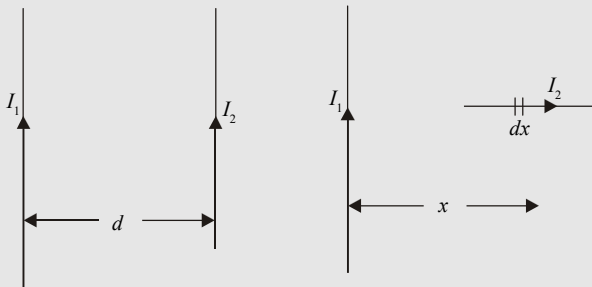
Fig. 23.22

20. $\vec{F} = q(\vec{v} \times \vec{B})$,

   $d\vec{F} = I(dl \times B)$

   For a straight conductor $F = Il \times B$ integrate otherwise.

21. $\oint E.dl = 0$ because force is conservative but $\oint B.dl \neq 0$. Rather $\oint B.dl = \mu_0 I$ as $B.dl$ is not related to work. Moreover, the current is enclosed in the loop.

22. A moving charge produces both electric and magnetic field $\vec{B} = \dfrac{\mu_0 q \vec{v} \times \vec{r}}{4\pi r^3}$

   A stationary charge produces only electric field.

23. The magnetic field due to a short solenoid is illustrated in Fig. 23.23.
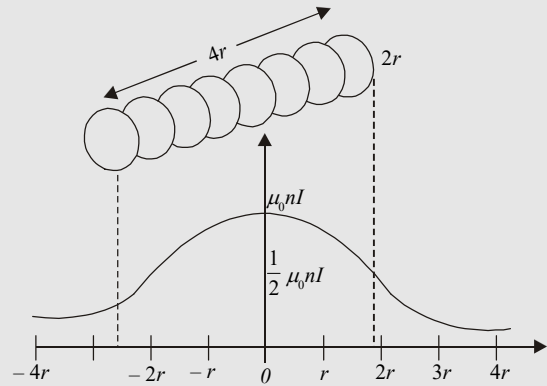
Fig. 23.23

Note that magnetic field is nearly half the value at the centre. r is radius of the coil.

24.
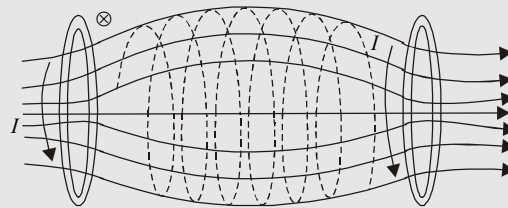
Fig. 23.24

Fig. 23.24 illustrates the method of retaining ionised gas particles having temperature $\sim 10^6$ K which would vaporise any material container. Such a system is termed as magnetic bottle.

25. SNOW rule can be applied if a current carrying conductor is placed over compass needle.

CAUTION

1. Considering physical length of the conductor to be taken as

$$F = \int idl \times B$$

$\Rightarrow$ Shortest distance between the end points be taken as the length.

2. Considering magnetic field exists on a (thin) current-carrying conductor or on its extended part.

$\Rightarrow$ Magnetic field does not exist on the conductor or on its extended part. Thus magnetic field at A, P and X is zero.
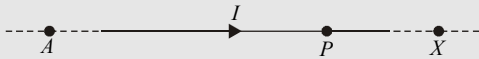
Fig. 23.25 ABC

3. Considering $\oint B.dl = 0$ on the lines of $\oint E.dl = 0$

$\Rightarrow$ Note that $\oint E.dl = 0$ because it represents work done in conservative force. $\oint B.dl$ does not define work and hence $\oint B.dl = \mu_0 I$

4. Confusing work is done by magnetic force.

$\Rightarrow$ Magnetic force only changes direction. Work done is zero. Hence speed and KE do not change.

5. Considering magnetic field to be zero only along the axis of a hollow cylindrical conductor carrying current.

$\Rightarrow$ Magnetic field is zero at all points inside a current-carrying hollow cylindrical conductor. However, magnetic field is zero along the axis of a solid cylindrical conductor carrying current.

$\therefore$ B_{inside} (Solid cylinder)

$$= \frac{\mu_0 I x}{2\pi r^2}$$

6. While finding direction of force with moving charged particle and applying Fleming's left hand rule.

$\Rightarrow$ We can apply Fleming's left hand rule if we take into account the appropriate direction of current a $+ve$ or a $-ve$ charge will form during motion. Conventional current direction be taken.

7. Not considering perpendicular distance due to straight conductor while finding magnetic field. For example as in Fig. 23.26 taking perpendicular distance r for AB.
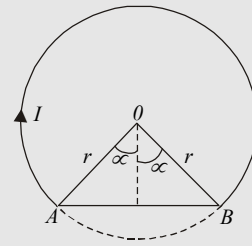
Fig. 23.26

$\Rightarrow$ Take perpendicular distance $r\cos\alpha$ if 2α is the angle made by AB at the centre.

8. Considering no force will act on current-carrying conductors placed transverse to a long current-carrying conductor as shown in Fig. 23.27.
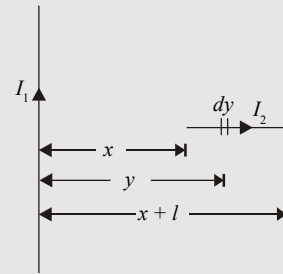
Fig. 23.27

$\Rightarrow$ In such a case magnetic field at every point will vary, therefore take an element dy at a distance y

then $\quad F = \dfrac{\mu_0 I_1 I_2}{2\pi} \displaystyle\int_x^{x+l} \dfrac{dy}{y} = \dfrac{\mu_0 I_1 I_2}{2\pi} \log_e \dfrac{x+l}{x}$

9. Considering magnetic moment M shall depend upon the shape of the current-carrying conductor.

$\Rightarrow$ Magnetic moment $M = IA$ or nIA is independent of the shape of the conductor if their areas are equal and number of turns are also equal.

10. Considering that if plane of a coil is parallel to the magnetic field the net force acting on the coil is zero.

$\Rightarrow$ If the magnetic field is uniform the statement is correct. If magnetic field is not uniform then both torque and a net force are present.

11. Considering magnetic field is zero at the centre of a loop if current enters from a point and leaves at the other.

Fig. 23.28

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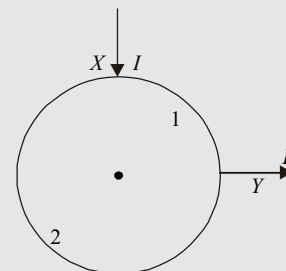
⇒ This statement is true if the loop is made with a single wire of same material of uniform cross-section and uniform density. If however joining parts $X1Y$ and $X2Y$ are of different materials or one of them is thinner than the other (though they are of the same material), then magnetic field is non-zero at the centre.

12. Considering $B = \dfrac{\mu_0 I r^2}{2\left(r^2 + x^2\right)^{3/2}}$ can be applied any-

where inside the coil.

⇒ $B = \dfrac{\mu_0 I r^2}{2\left(r^2 + x^2\right)^{3/2}}$

$= \dfrac{2\mu_0 M}{4\pi\left(r^2 + x^2\right)^{3/2}}$

can be applied along the axis only.

SOLVED PROBLEMS

1. A magnetic needle is kept in a non-uniform magnetic field. It experiences

   (a) neither a force nor a torque
   (b) a torque but not a force
   (c) a force but not a torque
   (d) a force and a torque.

   [AIEEE 2005]

   Solution (d)

2. A charged particle of mass m and charge q travels on a circular path of radius r that is perpendicular to the magnetic field B. The time taken by the particle to complete one revolution is

   (a) $\dfrac{2\pi q^2 B}{m}$ (b) $\dfrac{2\pi mq}{B}$

   (c) $\dfrac{2\pi m}{qB}$ (d) $\dfrac{2\pi qB}{m}$

   Solution (c)

3. Two concentric coils each of radius 2π cm are placed at right angles to each other. 3A and 4A are the currents flowing in them respectively. Find magnetic induction in Wb/m² at the centre of the coils.

   [AIEEE 2005]

   (a) 10^{-5} (b) 12×10^{-5}
   (c) 7×10^{-5} (d) 5×10^{-5}

   Solution (d) $B = \dfrac{\mu_0 I}{2r}$. Since the two coils are perpendicular, so are the magnetic inductions.

   ∴ $B_{net} = \sqrt{B_1^2 + B_2^2} = \dfrac{\mu_0}{2r}\sqrt{I_1^2 + I_2^2}$

   $= \dfrac{4\pi \times 10^{-7}}{2\left(2\pi \times 10^{-2}\right)}\sqrt{3^2 + 4^2} = 5 \times 10^{-5}$ Wb/m²

4. Two thin long, parallel wires separated by a distance d carry a current i each in the same direction. They will

   (a) repel each other with a force $\dfrac{\mu_0 i^2}{2\pi d}$

   (b) attract each other with a force $\dfrac{\mu_0 i^2}{2\pi d}$

   (c) repel each other with a force $\dfrac{\mu_0 i^2}{2\pi d^2}$

   (d) attract each other with a force $\dfrac{\mu_0 i^2}{2\pi d^2}$

   [AIEEE 2005]

   Solution (b) $\dfrac{dF}{dl} = \dfrac{\mu_0 I_1 I_2}{2\pi d} = \dfrac{\mu_0 i^2}{2\pi d}$

   Since currents are in same direction they attract each other.

5. A uniform electric field and a uniform magnetic field are acting along the same direction in a certain region. If an electron is projected along the direction of the fields with a certain velocity then

   (a) its velocity will increase
   (b) its velocity will decrease
   (c) it will turn towards left of its motion
   (d) it will turn towards right of its motion

   [AIEEE 2005]

   Solution (b) Since $F = q\left[\vec{E} + (\vec{v} \times \vec{B})\right]$

   $F_{mag} = q(\vec{v} \times \vec{B}) = 0$ as $\vec{v}$ and $\vec{B}$ are parallel

   Since electron is moving along the field, force qE is repulsive and hence it will slow down.

6. The Fig. 23.29 shows an infinitely long current-carrying wire out of the plane of paper (shown by ⊙). A current carrying loop ABCD is placed as shown. The loop
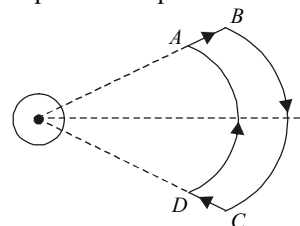

   Fig. 23.29

   (a) experiences no net force
   (b) experiences no torque

(c) turns clockwise as seen by an observer at $\odot$ position

(d) turns anticlockwise as seen by an observer at $\odot$ position

[IIT 2006]

Solution (a), (c) Magnetic force due to AB and CD is zero ($\because \theta = 0°$ or $180°$). Magnetic force on BC is upward and on DA is downward. These two forces will tilt loop in clockwise direction when seen from $\odot$ position.

7. A very long straight wire carries a current I. At the instant when a charge $+Q$ at point P has velocity $\vec{v}$, as shown in Fig 23.30, the force on charge is

[CBSE 2005]

(a) along oy (b) opposite to oy

(c) along ox (d) opposite to ox
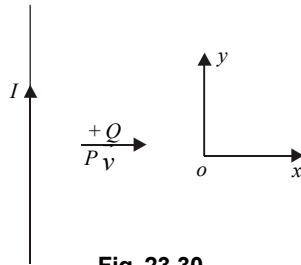
Fig. 23.30

Solution (a) The magnetic field at P is inwards due to a straight long conductor. Fleming's left hand rule gives the direction along oy.

8. An electron moves in a circular orbit with a uniform speed v. It produces a magnetic field B at the centre of the circle. The radius of the circle is proportional to

(a) $\sqrt{\dfrac{B}{v}}$ (b) $\dfrac{B}{v}$

(c) $\sqrt{\dfrac{v}{B}}$ (d) $\dfrac{v}{B}$

[CBSE 2005]

Solution (d) $r = \dfrac{mv}{qB}$ as $\dfrac{m}{q}$ is constant $\therefore r \alpha \dfrac{v}{B}$

9. A circular loop of wire 4 cm in radius carries a current of 80 A. Find the energy density at the centre of the loop.

(a) $\pi J/m^3$ (b) $2\pi J/m^3$

(c) $0.1\pi Jm^3$ (d) $0.2\pi Jm^{-3}$

Solution (d) $B = \dfrac{\mu_0 i}{2r}$ and energy density $u = \dfrac{B^2}{2\mu_0}$

$$= \dfrac{\mu_0^2 i^2}{4r^2 (2\mu_0)} = \dfrac{\mu_0 i^2}{8r^2}$$

$$u = \dfrac{4\pi \times 10^{-7} \times (80)^2}{8(4\times 10^{-2})^2} = \dfrac{4\pi \times 8 \times .8}{8 \times 16}$$

$$= 0.2\pi = 0.628\, Jm^{-3}$$

10. The adjacent Figure shows lines of a field. It cannot represent
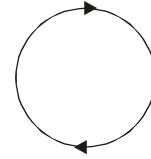
Fig. 23.31

(a) an electrostatic field   (b) an induced electric field

(c) a gravitational field   (d) a magnetostatic field

[IIT 2006]

Solution (a), (c) Electrostatic and gravitational field do not complete the loop.

11. An α–particle enters at the middle as shown in Fig. 23.32 with 10^5 ms^{-1}. In which direction will it bend?
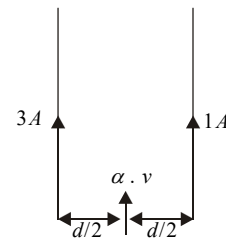
Fig. 23.32

(a) Towards 1 A wire   (b) Towards 4 A wire

(c) Upwards the plane of wires

(d) Downwards the plane of wires

Solution (b)

12. A particle having mass m and charge q is released from the origin in a region in which electric field and magnetic fields are given by $B = -B_0 \hat{j}$ and $E = E_0 \hat{k}$. Find the speed of the particle as a function of its z coordinate.

(a) $\sqrt{\dfrac{qEz}{m}}$ (b) $\sqrt{\dfrac{2(qvB + qE)z}{m}}$

(c) $\sqrt{\dfrac{(-qvB + qE)2z}{m}}$ (d) $\sqrt{\dfrac{2qEz}{m}}$

Solution (d) $v^2 = 2az$ $a = \dfrac{qE}{m}$ or $v = \sqrt{\dfrac{2qEz}{m}}$

13. An electron has a speed $\sqrt{2} \times 10^6$ ms^{-1} at A as shown in Fig. 23.33. Find the direction and magnitude of magnetic field so that electron reaches B following a semicircular path.

(a) 1.6×10^{-4}T $\otimes$ (b) 1.6×10^{-4} T $\square$

(c) 3.6×10^{-4}T $\otimes$ (d) none of these

Fig. 23.33

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Solution (a) $r = 5 \text{cm} = \dfrac{mv}{qB}$

or $\quad B = \dfrac{mv}{er} = \dfrac{9 \times 10^{-31} \times \sqrt{2} \times 10^6}{1.6 \times 10^{-19} \times 5 \times 10^{-2}} = \dfrac{9\sqrt{2} \times 10^{-4}}{8}$

$= 1.6 \times 10^{-4} \, T$ direction perpendicular inwards the plane of paper.

14. An electron in the beam of a TV picture tube is accelerated by a potential difference 2 kV. Then it passes through a transverse magnetic field to produce a circular arc of radius 0.18m. Find the magnetic field.

(a) 6.38×10^{-4} T   (b) 7.68×10^{-4} T

(c) 8.38×10^{-4} T   (d) 8.98×10^{-4} T

Solution (c) $r = \dfrac{mv}{qB}$

or $\quad B = \dfrac{mv}{er} = \dfrac{\sqrt{2eVm}}{er} = \sqrt{\dfrac{2Vm}{er^2}}$

or $\quad B = \sqrt{\dfrac{2 \times 10^3 \times 2 \times 9 \times 10^{-31}}{1.6 \times 10^{-19} \times 10^{-4}}} = \sqrt{\dfrac{10^{-5}}{.4 \times 36}}$

$\quad = \sqrt{\dfrac{10^{-5}}{14.4}} = 8.38 \times 10^{-4} \text{T}$

15. Fig. 23.34 shows a thin 50 cm long rod resting on two metallic supports in a uniform magnetic field of 0.45 T. Find the maximum voltage which can be applied without breaking the circuit. Mass of the rod is 750 g. Take $g = 10 \text{ ms}^{-2}$

(a) 83.3 V   (b) 8.33 V

(c) 833 V   (d) 0.833 V
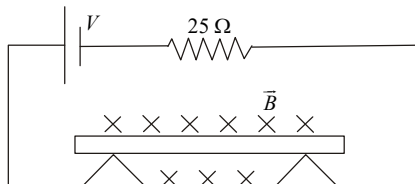
Fig. 23.34

Solution (c) $mg = IlB$ or $mg = \dfrac{V}{R} lB$

or $\quad V = \dfrac{mgR}{lB} = \dfrac{3 \times 10 \times 25}{4 \times .5 \times .45} = 833 \; V$

16. A wire along x-axis carries a current 3.5 A. Find the force on a 1 cm section of the wire exerted by

$B = 0.74 \text{ T } \hat{j} - 0.36 \text{ T } \hat{k}$

(a) $2.59 \hat{k} + 1.26 \hat{j}$ (b) $1.26 \hat{k} - 2.59 \hat{j}$

(c) $-2.59 \hat{k} - 1.26 \hat{j}$ (d) $-1.26 \hat{k} + 2.59 \hat{j}$

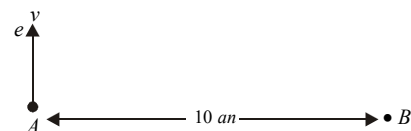**Solution** (a) $F = I(\vec{l} \times \vec{B})$

$= 3.5 [10^{-2} \hat{i} \times (.74 \hat{j} - 0.36 \hat{k})]$

$= (2.59 \hat{k} + 1.26 \hat{j}) \times 10^{-2}$

17. An electron and a $^{7}_{3}Li$ nucleus enter a magnetic field with same velocity. Find the ratio of number of revolutions per second of the two.

(a) 2.44×10^3 (b) 4.24×10^3

(c) 3.24×10^3 (d) 5.42×10^3

Solution (b) $f = \dfrac{qB}{2\pi m}$

$\therefore \quad = \dfrac{f_e}{f_{Li}} = \dfrac{e/m_e}{3e/m_{Li}} = \dfrac{m_{Li}}{3m_e} = \dfrac{7 \times 1.6 \times 10^{-27}}{3 \times 9 \times 10^{-31}}$

$\quad = \dfrac{11.2}{27} \times 10^4 = 4.24 \times 10^3$

18. A thin uniform rod of negligible mass and length l is attached to the floor by a hinge P. The other end is connected to a spring of force constant k. Rod is in a uniform magnetic field B pointing inwards the plane of paper. A current I is passed through the rod. Find the torque acting on the rod due to magnetic force when the rod makes an angle $53°$ as shown in Fig. 23.35.
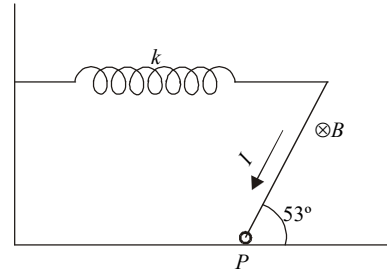
Fig. 23.35

(a) Il^2B (b) $\dfrac{Il^2}{2} B$

(c) $\dfrac{3Il^2 B}{5}$ (c) $\dfrac{4}{5} Il^2 B$

Solution (b) $F = kx = IlB$

$\tau = \int d\tau = \int IlB dl = \dfrac{Il^2 B}{2}$

19. Two long parallel wires are hung by 4 cm long cords from a common axis. The wires have a mass 0.0125 kg/m and carry equal currents in opposite direction. Find the current in each wire if the cords hang at $6°$ with the vertical as shown in Fig. 23.36 (a).
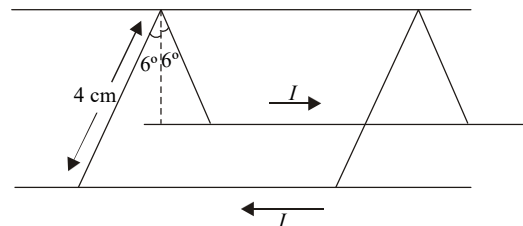
Fig. 23.36 (a)

(a) 11.2 A   (b) 22.3 A

(c) 717 A   (d) 71.7 A

Solution (b) $\dfrac{dF}{dl} \, rep = \dfrac{\mu_0 I^2}{2\pi(2d)} = T\sin 6°$

$\dfrac{mg}{4} = T\cos 6°$ $\tan 6° = \dfrac{\mu_0 I^2}{4\pi dmg}$

$I = \sqrt{\dfrac{\tan 6°\left(4\pi 4\sin 6°\right)mg \times 10^{-2}}{\mu_0}}$

$= \sqrt{\dfrac{(.1)^2 \times 4\pi \times 4 \times .0125 \times 10 \times 10^{-2}}{4\pi \times 10^{-7}}} = 22.3 \text{ A}$
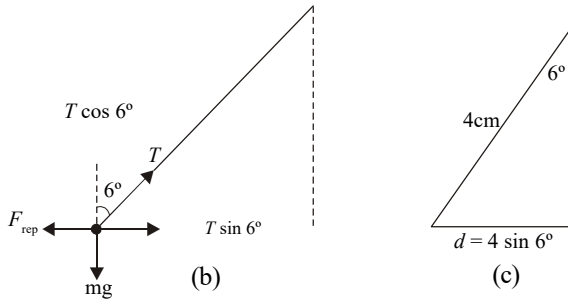
Fig. 23.36

$\tan 6° = \sin 6° = \dfrac{6 \times \pi}{180} = .1$

20. An infinitely long wire carries a current i (see Fig. 23.37). Find magnetic field at p.
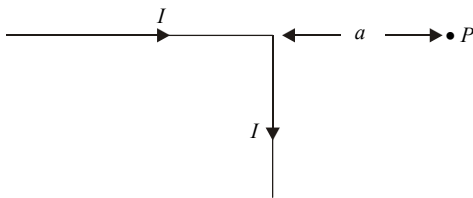
Fig. 23.37

(a) $\dfrac{\mu_0 I}{2\pi a}$ (b) $\dfrac{\sqrt{2}\mu_0 I}{4\pi a}$

(c) $\dfrac{\mu_0 I}{4\pi a}$ (d) $\dfrac{\mu_0 I}{4\sqrt{2}\pi a}$

Solution (c) $B = B_1 + B_2 = 0 + \dfrac{\mu_0 i}{4\pi a}[\sin 90 + \sin 0]$

$= \dfrac{\mu_0 I}{4\pi a}$

21. A wire bent as shown in Fig. 23.38 carries a current I. Find the magnetic field at P.
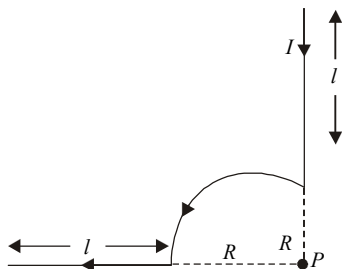
Fig. 23.38

(a) $\dfrac{\mu_0 I}{4R}$ (b) $\dfrac{3\mu_0 I}{2R}$

(c) $\dfrac{7\mu_0 I}{8R}$ (d) $\dfrac{\mu_0 I}{8R}$

Solution (d) $B = B_1 + B_2 + B_3 = 0 + \dfrac{\mu_0 I}{2R}\left(\dfrac{\pi/2}{2\pi}\right) + 0$

$= \dfrac{\mu_0 I}{8R}$

22. A wire bent as shown in Fig. 23.39 is oriented along yz plane. Find the magnetic field at and P_1.

(a) $\dfrac{\mu_0 I}{4a}$, $\dfrac{\mu_0 I}{2\pi x}$ (b) $\dfrac{\mu_0 I}{4a}$, $\dfrac{\mu_0 Ia}{2\pi\left(x^2 + a^2\right)}$

(c) $\dfrac{\mu_0 I}{4a}$, $\dfrac{\mu_0 Ia}{2\pi a\sqrt{x^2 + a^2}}$ (d) none of these
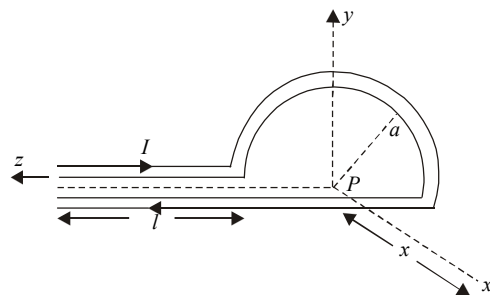
Fig. 23.39

Solution (c) $B_P = \dfrac{\mu_0 I}{4a}$ along $-x$

$Bp_1 = \dfrac{\mu_0 I(2a)}{2\pi x\sqrt{4a^2 + 4x^2}}$ along y

[use magnetic field at perpendicular bisector]

$= \dfrac{\mu_0 Ia}{2\pi x\sqrt{a^2 + x^2}}$ along y

[only contribution is from straight wire $-a$ to $+a$ along z axis]

23. A square loop of side a is placed at a distance a away from a long wire carrying a current I_1. If the loop carries a current I_2 as shown in Fig. 23.40 (a) then the nature of the force and its amount is

(a) $\dfrac{\mu_0 I_1 I_2}{2\pi a}$, attractive   (b) $\dfrac{\mu_0 I_1 I_2}{4\pi}$, attractive

(c) $\dfrac{\mu_0 I_1 I_2}{4\pi}$, repulsive   (d) $\dfrac{\mu_0 I_1 I_2}{4\pi a}$, repulsive

(a)
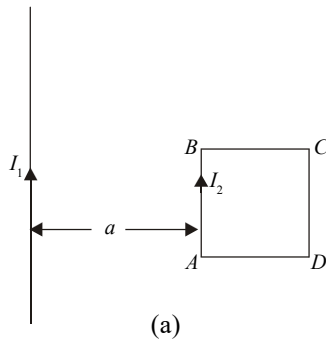
Fig. 23.40

[AFMC 1998, CEE Delhi 1997, 2000]

Solution (b) F_2 and F_1 cancel one another. F_1 is attractive F_3 is repulsive. But $F_1 > F_3$

∴ Force is attractive

(b)
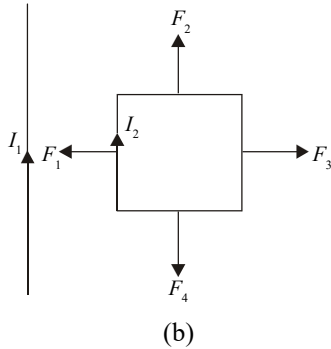
Fig. 23.40 (b)

$$F_1 = \frac{\mu_0 I_1 I_2}{2\pi a} \ (a), F_3 = \frac{\mu_0 I_1 I_2}{4\pi a} \ (a)$$

$$F_{net} = F_1 - F_3 = \frac{\mu_0 I_1 I_2}{4\pi}$$

24. Fig. 23.41 shows a circular wire of radius r carrying a current i. The force of compression on the wire is
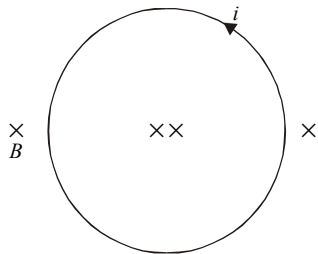
Fig. 23.41

(a) $2iaB$ (b) iaB

(c) $2\pi iaB$ (d) none of these

Solution (b) $dF = idIB$

$$F = \int idI \ \ B = iaB$$

25. A square coil of edge l having n turns carries a current i. It is placed on a smooth horizontal plate A magnetic field B parallel to one edge is applied. The total mass of the coil is M. The minimum value of B for which the coil will tip over is
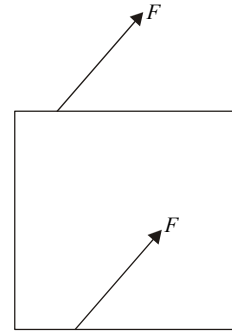
Fig. 23.42

(a) $\dfrac{Mg}{lin}$ (b) $\dfrac{Mg}{2lin}$

(c) $\dfrac{2Mg}{lin}$ (d) none of these

Solution (b) $F = lin \ B + lin \ B$

$$Mg = 2 \ lin \ B \text{ or } B = \frac{Mg}{2lin}.$$

26. A particle of mass M and charge Q moving with a velocity $\vec{v}$ describes a circular path of radius R when subjected to a uniform transverse magnetic field of induction B. The work done by the field when the particle completes one full circle is

(a) zero   (b) $BQ2\pi R$

(c) $BQv(2\pi R)$ (d) $\left(\dfrac{Mv^2}{R}\right)(2\pi R)$

[AIEEE 2003]

Solution (a) As displacement is zero.

27. A particle of charge $q = 16 \times 10^{-18}$ C moving with 10 ms^{-1} along x-axis enters a magnetic field of induction B along the y-axis and an electric field 10^4 Vm^{-1} along negative z-direction. If the particle continues to move along x-axis then the strength of magnetic field is

(a) 10^5 Wbm^{-2} (b) 10^{16} Wbm^{-2}

(c) 10^{-3} Wbm^{-2} (d) 10^3 Wbm^{-2}

[AIEEE 2003]

Solution (d) $v = \dfrac{E}{B} \Rightarrow \dfrac{10^4}{B} = 10$ ∴ $B = 10^3$ Wbm^{-2}

28. A conducting loop carrying a current I is placed in a uniform magnetic field pointing into the plane as shown in Fig. 23.43. The loop will have tendency to
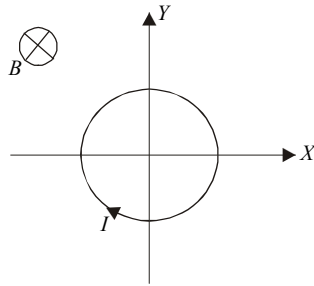
Fig. 23.43

(a) contract   (b) expand

(c) move towards positive x-axis

(d) move towards negative x-axis

[IIT Screening 2003]

Solution   (b) Using Fleming left hand rule you find that the force is acting outwards.

29. In a square loop made with a wire of uniform cross-section current I enters from point A and leaves from point B. The magnetic field strength B at the centre of the square is
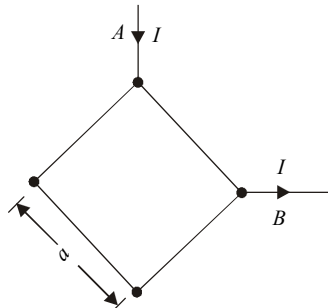
Fig. 23.44

(a) zero   (b) $\dfrac{\mu_0 I 2\sqrt{2}}{4\pi a}$

(c) $\dfrac{4\sqrt{2}\mu_0 I}{4\pi a}$ (d) $\dfrac{2\sqrt{2}\mu_0 I}{4a}$

Solution   (a) See shortcut (3).

30. In the Fig. 23.45 shown below each battery has emf = 5 V. Then the magnetic field at P is
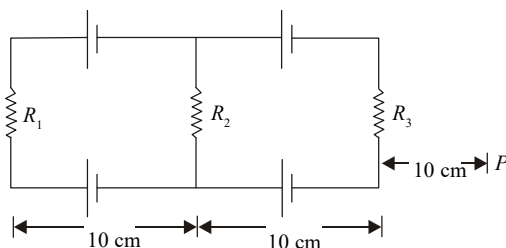
Fig. 23.45

(a) zero   (b) $\dfrac{10\mu_0}{R_1\left(4\pi\right)\left(.2\right)}$

(c) $\dfrac{20\mu_0}{\left(R_1+R_2\right)\left(.8\pi\right)}$ (d) none of these

Solution   (a) Because current in the loop is zero.

31. The magnetic field strength at O due to current I in the Fig. 23.46 is
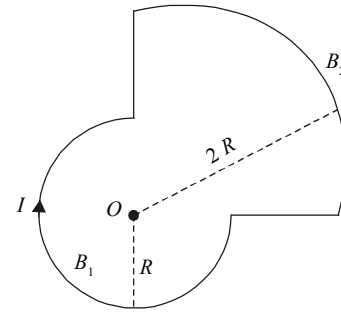
Fig. 23.46

(a) $\dfrac{7\mu_0 I}{16R}$ (b) $\dfrac{15\mu_0 I}{16R}$

(c) $\dfrac{11\mu_0 I}{32R}$ (d) $\dfrac{13\mu_0 I}{32R}$

Solution   (a) $B = B_1 + B_2 = \dfrac{\mu_0 I}{2R}\left(\dfrac{3}{4}\right) + \dfrac{\mu_0 I}{4R}\left(\dfrac{1}{4}\right) = \dfrac{7\mu_0 I}{16R}$

32. Two long wires carrying current are kept crossed (not joined at O). The locus where magnetic field is zero is
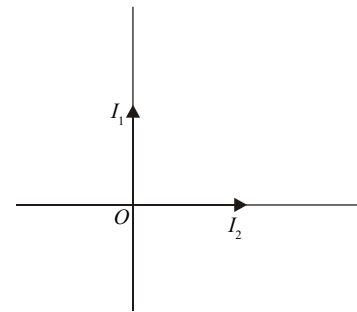
Fig. 23.47 (a)

(a) $I_1 = \dfrac{x}{y}\,I_2$ (b) $I_1 = \dfrac{y}{x}\,I_2$

(c) $I_1 = I_2$ (d) $I_1 = -I_2$

Solution   (a) Magnetic field could be zero in 1st or 3rd quadrant.

$$\dfrac{\mu_0 I_1}{2\pi x} = \dfrac{\mu_0 I_2}{2\pi y}$$

or $I_1 = \dfrac{x}{y}\,I_2.$
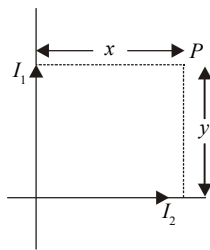
Fig. 23.47 (b)

33. A long solenoid has magnetic field strength of 3.14×10^{-2} T inside it when a current of 5A passes through it. The number of turns in 1 m of the solenoid is

(a) 1000   (b) 3000

(c) 5000   (d) 10000

Solution   (c) $n = \dfrac{B}{\mu_0 I} = \dfrac{3.14 \times 10^{-2}}{4\pi \times 10^{-7} \times 5} = \dfrac{10^5}{20} = 5000.$

34. A particle of mass m and charge q is projected into a region having a perpendicular magnetic field B. Find the angle of deviation as it comes out of the magnetic field if the width d of the region is very slightly less than $\dfrac{mv}{2qB}$

(a) 30°   (b) 60°

(c) 90°   (d) 45°

Solution   (a) $\dfrac{mv \sin\theta}{qB} = \dfrac{mv}{2qB}$

i.e. $\sin\theta = \dfrac{1}{2}$ or $\theta = 30°$

35. Two metal strips each of length l as shown are kept b apart and connected to a battery of emf ε through a resistance R. A wire of mass m lies on it. Metal strips are smooth but floor has coeff of friction μ. Find how far the wire will land after leaving the metal strips after the switch is made ON in Fig. 23.48.
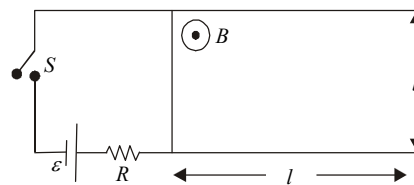
Fig. 23.48

(a) $\dfrac{\varepsilon b^2 B}{\mu R g m}$ (b) $\dfrac{\varepsilon l^2 B}{\mu R m g}$

(c) $\dfrac{\varepsilon l b B}{\mu R m g}$ (d) none of these

Solution   (c) $I = \dfrac{\varepsilon}{R}$ $F = Ilb$ and $a = \dfrac{IlB}{m} = \dfrac{\varepsilon lB}{Rm}$

$V^2 = 2al = 2\mu g x$ if x is the distance moved on floor

or $x = \dfrac{\varepsilon b Bl}{\mu R m g}$

TYPICAL PROBLEMS

36. A thin disc (or dielectric) having radius r and charge q distributed uniformly over the disc is rotated n rotations per second about its axis. Find the magnetic field at the centre of the disc.

(a) $\dfrac{\mu_0 q n}{a}$ (b) $\dfrac{\mu_0 q n}{2a}$

(c) $\dfrac{\mu_0 q n}{4a}$ (d) $\dfrac{3\mu_0 q n}{4a}$

Solution   (a) Surface charge density $\sigma = \dfrac{q}{\pi a^2}$

Charge on the hypothetical ring $= \dfrac{q}{\pi a^2} 2\pi x \, dx$

$dI = \dfrac{q}{T} = \dfrac{q}{1/n} = nq$
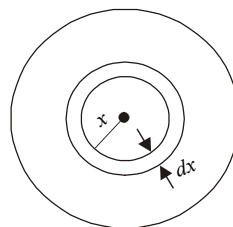
Fig. 23.49

Magnetic field due to the element

$dB = \dfrac{\mu_0 dI}{2x} = \dfrac{\mu_0 2x \, dx \, qn}{a^2 (2x)} = \dfrac{\mu_0 q n \, dx}{a^2}$

$B = \int dB = \dfrac{\mu_0 q n}{a^2} \int_0^a dx = \dfrac{\mu_0 q n}{a^2} [x]_0^a = \dfrac{\mu_0 q n}{a}$

37. Find the magnetic field intensity due to a thin wire carrying current I in the Fig. 23.50 (a)
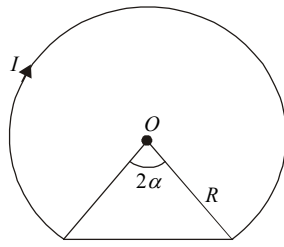
Fig. 23.50 (a)

(a) $\dfrac{\mu_0 i}{2\pi R} (\pi - \alpha + \tan\alpha)$ (b) $\dfrac{\mu_0 i}{2\pi R} (\pi - \alpha)$

(c) $\dfrac{\mu_0 i}{2\pi R} (\pi + \alpha)$ (d) $\dfrac{\mu_0}{2\pi R} (\pi + \alpha - \tan\alpha)$

Solution   (a) $B_{\text{arc}} = \dfrac{\mu_0 I}{4\pi R} (2\pi - 2\alpha)$,

$$B_{\text{line}} = \dfrac{\mu_0 I (\sin\alpha + \sin\alpha)}{4\pi R \cos\alpha}$$

$d = R \cos \alpha$
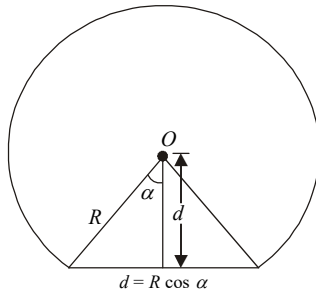
Fig. 23.50 (b)

$$B_{\text{net}} = \dfrac{\mu_0 I}{2\pi R} (\pi - \alpha + \tan\alpha).$$

38. Electrons emitted with negligible speed from an electron gun are accelerated through a potential difference V_0 along the x-axis. These electrons emerge from a narrow hole into a uniform magnetic field of strength B directed along x-axis, Some electrons emerging at slightly divergent angles as shown in the Fig. 23.51. These paraxial electrons are refocused on the x-axis at a distance
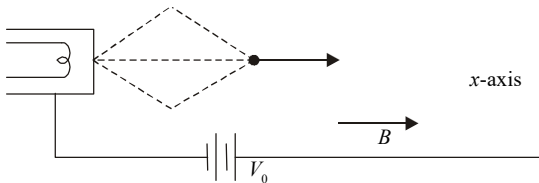
Fig. 23.51

(a) $\sqrt{\dfrac{8\pi^2 mV}{eB^2}}$ (b) $\sqrt{\dfrac{2\pi^2 mV}{eB}}$

(c) $\sqrt{\dfrac{4\pi^2 mV}{eB^2}}$ (d) $\sqrt{\dfrac{2\pi^2 mV}{eB^2}}$

Solution   (a) $KE = \dfrac{1}{2}mv^2 \neq eV$

or $mv = \sqrt{2emV}$

The electron will be refocussed after travelling a distance = pitch of helix pitch

$$= \dfrac{2\pi mV}{qB} = \sqrt{\dfrac{4\pi^2 \times 2emV}{e^2 B^2}} = \sqrt{\dfrac{8\pi^2 mV}{eB^2}}$$

39. A uniform current of density J flows inside an infinite plate of thickness $2d$ parallel to its surface. Find the magnetic induction induced by this current as a function of distance x from the median plane of the plate. The magnetic permeability is assumed unity both inside and outside the plate.

Solution   We assume that the current flows perpendicular to the plane of the paper.
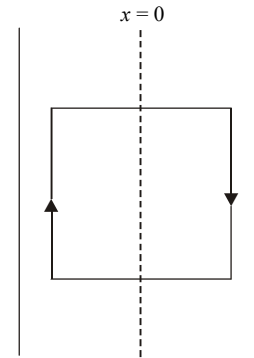
Fig. 23.52

$2Bdl = \mu_0(2xdl)J$

or $B = \mu_0 xJ$ for $|x| \leq d$

Outside $2Bdl = \mu_0 2ddlJ$

or $B = \mu_0 dj |x| \geq d$.

40. Consider a solid sphere of radius R and mass m having charge Q distributed uniformly over its volume. The sphere is rotated about a diameter with the angular speed ω. Show that the magnetic moment M and the angular momentum L of sphere are related as

$$M = \dfrac{Q}{2m} L.$$

Solution   The magnetic moment acts along the axis of rotation. Consider a volume element dV. It contains a

charge $\dfrac{Q}{\dfrac{4}{3}\pi R^3}$ dV and current constituted by the

element is
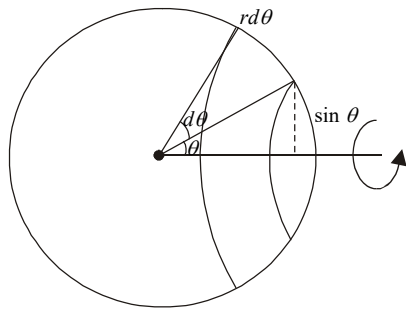
Fig. 23.53

$$I = \frac{3Q}{4\pi R^3} \, dV \, \frac{\omega}{2\pi} \text{ and magnetic moment}$$

$$dM = I\mu \, r^2 \sin^2 \theta = \frac{3Q}{4\pi R^3} \, dV \, \frac{\omega}{2\pi} \, \pi r^2 \sin^2 \theta$$

$$M = \int_0^\pi \int_0^R \frac{3Q}{4\pi R^3} \, (2\pi r^2 \sin \theta \, d\theta \, dr) \left(\frac{\omega}{2} r^2 \sin^2 \theta \right)$$

$$= \frac{3Q}{2R^3} \times \frac{\omega}{2} \times \frac{R^5}{5} \times \frac{4}{3} = \frac{QR^2\omega}{5}$$

$$\because \qquad L = \frac{2}{5} \, mR^2 \, \omega$$

$$\therefore \qquad R^2\omega = \frac{L}{2m} \text{ . Hence } M = \frac{QL}{2m}$$

41. Inside a long straight cylindrical wire, there is a long round cylindrical cavity whose axis is parallel to the axis of the wire and displaced from the latter by a distance l. A direct current density J flows along the wire. Find the magnetic induction inside the cavity. What will be the magnetic induction at $l = 0$?
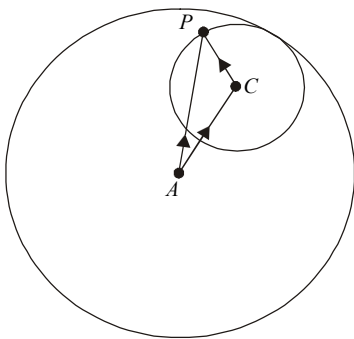
Fig. 23.54

Solution Assume that uniform current flows in the cavity superposed on actual current.

$$\vec{B} = \frac{\mu_0}{2} \, \vec{J} \times (AP - PC) = \frac{\mu_0}{2} \, \vec{J} \times l$$

if $l = 0, B = 0$.

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42. The length of conductor ab carrying current l_2 is l. Find the force acting on it due to a long current carrying conductor as shown in Fig. 23.55 (a). The mid-point of wire ab is distance x apart from long wire.
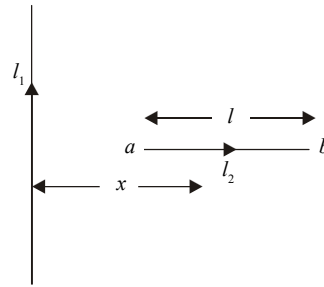
Fig. 23.55 (a)

Solution Consider a small element dy at a distance y from the long conductor. Force on this element

Fig. 23.55 (b)

$$dF = \frac{\mu_0 I dy}{2\pi y}$$
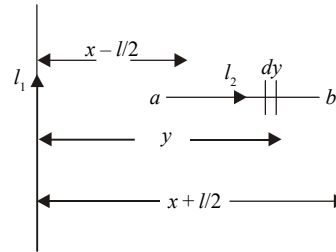
$$F = \frac{\mu_0 I}{2\pi} \int_{x-l/2}^{x+l/2} \frac{dy}{y} = \frac{\mu_0 I}{2\pi} \log_e \frac{x+l/2}{x-l/2}.$$

43. Find the magnetic field intensity at a point O. Assume linear parts to be long and the curved part has the radius R.
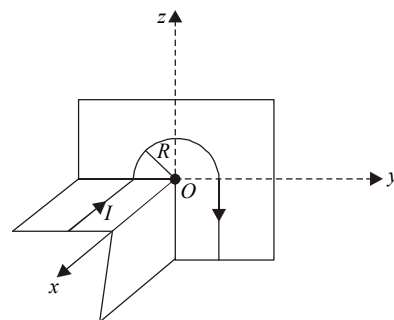
Fig. 23.56

Solution $B_1 = \frac{\mu_0 I}{4\pi R}$ along $-z$-axis due to horizontal part

$$B_2 = \frac{\mu_0 I}{4R} \text{ along } -x\text{-axis due to semicircular part}$$

$B_3 = \dfrac{\mu_0 I}{4\pi R}$ along $-x$-axis due to the vertical part

$B = B_1 + B_2 + B_3$

$= \dfrac{\mu_0 I\left(-\hat{k}\right)}{4\pi R} + \dfrac{\mu_0 I\left(-\hat{i}\right)}{4R} + \dfrac{\mu_0 I\left(-\hat{i}\right)}{4\pi R}$.

44. Find the force acting on the conductor carrying current.
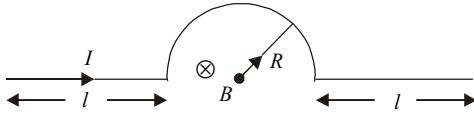
Fig. 23.57 (a)

(a) $\mu_0 I (2l + \mu R)B$ (b) $\mu_0 I(2l + R)B$

(c) $\mu_0 I(2l + 2R)B$ (d) none of these

Solution   (c) $F_{net} = F + F + \int_0^{90} 2IF_1 \cos\theta$

$= IlB + IlB + \int_0^{90} 2l\ R\ d\theta\cos\theta$

$= 2IlB + 2IRB$

Short cut $F_{net} = F + F + IB$ (displacement length of curved part) $= IlB + IlB + IB(2R) = 2IlB + 2IRB$.
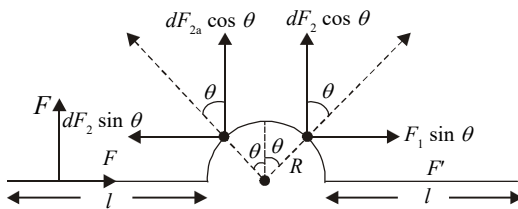
Fig. 23.57 (b)

45. Find the magnetic field strength B of an infinite plane carrying a current of linear density J (same at all points).

[Olympaid 1994]

Solution
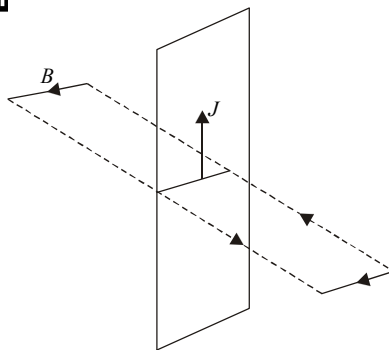
Fig. 23.58

$\oint B \cdot dl = \mu_0 J(l)\ B\ (2l) = \mu_0 Jl$ or $B = \dfrac{\mu_0 J}{2}$.

The magnetic field intensity is horizorntal and parallel to the plane.

46. Two parallel long conductors carrying current I_1 and I_2 are shown in Fig. 23.59. Assuming magnetic field to be positive pointing for up the plane of paper and $I_1 = I_2$, which of the following graphs best represents the conditions?

(a)

(b)

(c)

(d) none of these
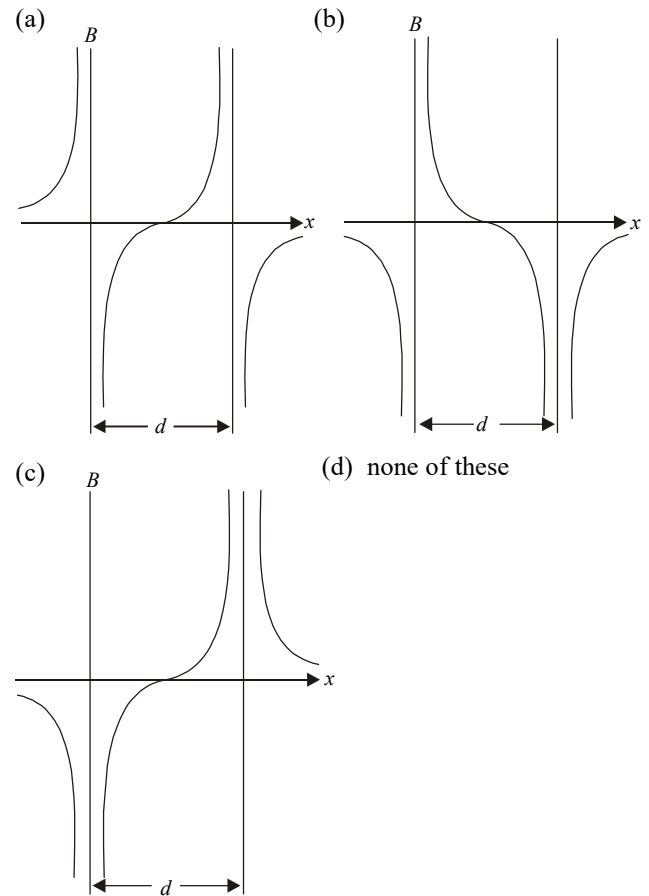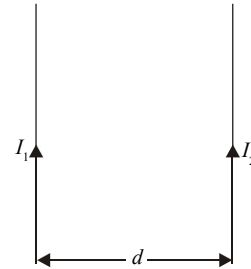
Fig. 23.59

[IIT Screening 2001]

Solution   (a) Use $B = \dfrac{\mu_0 I}{4\pi d}$ and keep direction in mind.

47. A long straight solid cylinder oriented with its axis along z carries a current whose density j is given by
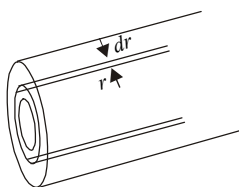
Fig. 23.60

$$\vec{j} = \frac{2I_0}{\pi a^2}\left[l - \left(\frac{r}{a}\right)^2\right]\hat{k} \text{ for } r \le a$$

$$= 0 \text{ for } r > a$$

a being radius of the cylinder.

Find the magnetic field in the region $r < a$

Solution $\oint B \cdot dl = \mu_0 I_{enclosed}$

$$= \mu_0 \int_0^r \left(\frac{2I_0}{ra^2}\right)\left[I - \frac{r^2}{a^2}\right]2\pi r dr$$

$$B(2\pi r) = \frac{\mu_0 I_0}{a^2}r^2\left[2 - \frac{r^2}{a^2}\right]$$

$$\text{or } B = \frac{\mu_0 I_0 r}{2\pi a^2}\left[2 - \frac{r^2}{a^2}\right]$$

48. A coil having N turns is wound tightly in the form of a spiral with inner and outer radii a and b respectively. When current I passes through the coil, the magnetic field at the centre is

(a) $\dfrac{N\mu_0 I}{2(b-a)}\log_e\dfrac{b}{a}$

(b) $\dfrac{N\mu_0 I}{2(b-a)}\log_e\dfrac{b+a}{b-a}$

(c) $\dfrac{2N\mu_0 I}{(b+a)}\log_e\dfrac{b}{a}$

(d) none of these
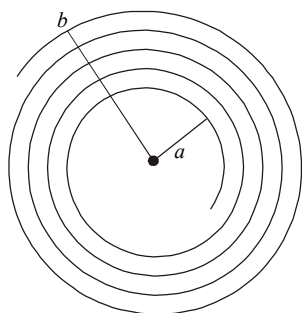
Fig. 23.61

Solution (a) Magnetic induction due to a circular current-carrying loop at x is $dB = \dfrac{\mu_0 i}{2x}(dN)$

Total magnetic field at the centre (due to all loops)

$$B = \int\frac{\mu_0 i}{2x}dN$$

$$= \int_a^6 \frac{\mu_0 i}{2x}\frac{N}{(b-a)}dx$$

$$= \frac{\mu_0 iN}{2(b-a)}\log_e\frac{b}{a}$$

PASSAGE 1

Read the following passage and answer the questions given at the end.

Thomson assumed that each positive ion had a charge equal in magnitude to that of the electron because each was an atom that had lost one electron. He could then identify particular values of q/m with particular ions. Positive particles move more slowly than electrons and have lower values of q/m because they are much more massive. The largest q/m for positive particles is that for the lightest element hydrogen. From the value q/m it was found that the mass of the hydrogen ion or proton is 1836.13 ± 0.01 times the mass of an electron. Electrons contribute only a small amount of the mass of material objects.

The most striking result of these experiments was that certain chemically pure gases have more than one value of q/m. Most notable was the case of neon, which has atomic mass $20.2 \text{ g} - \text{mol}^{-1}$,. Thomson obtained two values of q/m, corresponding to 20 and 22 $\text{g} - \text{mol}^{-1}$, and after trying and discarding various explanations he concluded that there must be two kinds of neon atoms with different mass.

Soon afterward Aston, a student of Thomson, succeeded in actually separating these two atomic species. Aston permitted the gas to diffuse repeatedly through a porous plug between two containers.

1. Using specific charge Thomson could find isotopes. Name another method with which isotopes could be separated.

   (a) Mass spectrometer   (b) Millikan's method

   (c) Superconductivity transition

   (d) Mossbaur effect.

2. A student found e/m using Thomson method for electron. His value was 1/3 rd of the original. He claimed to commit no mistake.

   (a)   Instead of electron he used quark.

   (b)   He took some mysterious particle.

   (c)   The electron was moving with relativistic speed.

   (d)   He just lied.

3. A proton is moving with 10^4 ms^{-1} in a transverse direction to the magnetic field of 0.2 T undeviated. It is due to

(a) an electric field of $2kVm^{-1}$ along the magnetic field

(b) an electric field of $2\ kVm^{-1}$ along the direction of motion

(c) $2\ kVm^{-1}$ electric field acting in the third perpendicular direction

(d) none of these.

Solution 1. (a)

Solution 2. (c)

Solution 3. (c) $E = vB = 10^4\,(.2) = 2$ kvm^{-1}

PASSAGE 2

Read the following passage and answer the questions given at the end.

Millikan and his co-workers measured the charges of thousands of drops and found that, within the limits of their experimental error, every drop had a charge equal to some small integer multiple of a basic charge e. That is, drops were observed with charges of e, $2e$, $3e$, etc, but never with such values as $0.76\ e$ or $2.49\ e$. The evidence is conclusive that electric charge is not something that can be divided indefinitely, but that it exists in nature only in units of magnitude e. When a drop is observed with charge e, we conclude it has acquired one extra electron; if its charge is $2e$, it has two extra electrons, and so on.

1. A drop of oil of mass 2 ng is kept stationary in between two plates kept 2 cm apart. A potential difference is 2 kV is applied. The number of electrons it gained is.

   (a) 16 (b) 160

   (c) 4 (d) 1600

   (e) none of these

2. An oil drop of mass 0.2 ng has lost 100 electrons. The density of oil is 0.8 g/cc. Find the electrostatic pressure it has.

   (a) 4.42×10^{-8} Pa (b) 4.42×10^{-10} Pa

   (c) 4.42×10^{-6} Pa (d) 4.42×10^{-4} Pa

3. Which process ionises the oil drops in Millikan's experiment?

   (a) Friction (b) Photo electric effect

   (c) Thermionic emission (d) Secondary emission

4. The quarks have fractional electronic charge $e/3$ and $2e/3$. Then why is such a fractional electronic charge not reflected on the oil drop?

   (a) Quarks cannot be gained or lost.

   (b) Only electrons can be gained or lost.

   (c) To lose quark, energy in MeV is required

   (d) Single quark is unstable.

Solution 1. (d) $2 \times 10^{-9} \times 10^{-3} \times 9.8 = (ne)\,\dfrac{V}{d}$

or $ne = \dfrac{2 \times 10^{-12} \times 2 \times 10^{-2} \times 9.8}{2000}$

$n \times 1.6 \times 10^{-19} = 19.6 \times 10^{-17}$

$n = 1600$

Solution 2. (a) $r = \left(\dfrac{m}{\dfrac{4}{3}\pi 9}\right)^{1/3} = \left(\dfrac{10^{-9} \times .2}{8 \times \dfrac{4}{3} \times \pi}\right)^{1/3}$

$= \dfrac{10^{-3}}{2.6}$ cm $= \dfrac{10^{-5}}{2.6}$ m.

$P = \dfrac{1}{2}\,\varepsilon_0\,E^2$

$= \dfrac{1}{2} \times 8.85 \times 10^{-12}\,\dfrac{10^{-19} \times 100 \times 9 \times 10^9 \times 2.6^2}{\left(10^{-5}\right)^2}$

$= 4.42 \times 10^{-12} \times 1440 \times 6.89$

$= 4.42 \times 10^{-8}$ Pa

Solution 3. (a,b)

Solution 4. (c,d)

PASSAGE 3

Read the following passage and answer the questions given at the end.

Consider a toroidal solenoid with rectangular cross-section as shown in Fig. 23.62. While finding the expression for magnetic field in toroid, we considered that magnetic field remains same in the whole cross-section. In actual practice we know that it varies with distance. Use Ampere's law and consider a solenoid (toroidal) having N turns uniformly spaced with air inside. The inner radius is a and outer radius is b. Its height is h.
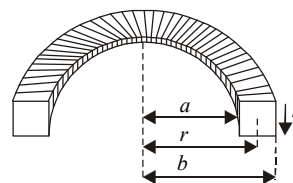
Fig. 23.62

1. The magnetic flux through the cross-section of the toroidal solenoid is

   (a) $\dfrac{\mu_0 Nih}{2\pi}$ (b) $\dfrac{\mu_0 Nih(b-a)}{2\pi r}$

   (c) $\dfrac{\mu_0 Nih}{2\pi}\log_e\dfrac{b}{a}$ (d) $\dfrac{\mu_0 N^2 ih}{2\pi}\log_e\dfrac{a}{b}$

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2. The self inductance of the toroidal solenoid described in the passage is

(a) $\dfrac{\mu_0 N^2 h}{2\pi}$ (b) $\dfrac{\mu_0 N^2 h}{2\pi} \log_e \dfrac{b}{a}$

(c) $\dfrac{\mu_0 N h}{2\pi} \log_e \dfrac{b}{a}$ (d) $\dfrac{\mu_0 N^2 h}{2\pi} \log_e \dfrac{a}{b}$

Solution 1. (c) Consider a small section of height h and width dr of the total toroidal cross-section.
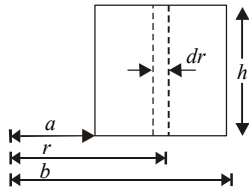
Fig. 23.63

$$\oint B \cdot dl = N\mu_0 i$$

$$B = \dfrac{\mu_0 i N}{2\pi r}$$

magnetic flux $d\phi = BdA$ through cross-section hdr of a turn

$$\phi_{perturn} = \int d\phi = B \int dA$$

$$= \dfrac{\mu_0 i N h}{2\pi} \int_a^b \dfrac{dr}{r} = \dfrac{\mu_0 i N h}{2\pi} \log_e \dfrac{b}{a}$$

Solution 2. (b) ϕ_{total} = Number of turns $\times \phi_{perturn}$

$$= \dfrac{\mu_0 N^2 h I}{2\pi} \log_e \dfrac{b}{a}$$

using $\varepsilon = -\dfrac{d\phi}{dt} = -L \dfrac{dI}{dt}$

or $L = \dfrac{\mu_0 N^2 h}{2\pi} \log_e \dfrac{b}{a}$

PASSAGE 4

Read the following passage and answer the questions given at the end.

In the circuit shown, no charge is initially given to the capacitor. At $t = 0$, the switch S is closed

Fig. 23.64

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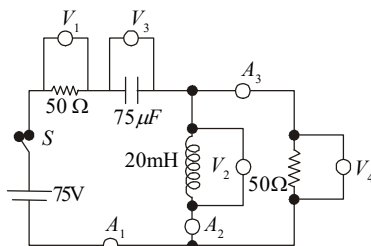
1. When the switch is just closed
  (a) V_1 reads 75 V and all others read zero
  (b) V_1 reads 25 V and V_4 reads 50 V while all others read zero.
  (c) all meters read zero.
  (d) V_3 reads 75 V and all others read zero

2. After the switch has been closed for a sufficiently long time
  (a) V_1 reads 25 V and V_4 reads 50V
  (b) V_3 reads 75 V and all others read zero.
  (c) V_1 reads 75 V and all others read zero.
  (d) none of the above.

3. The time constant of charging of the capacitor is
  (a) 3.75 ms (b) 11.25 ms
  (c) 1.5 ms (d) none of these

4. The maximum charge on the capacitor at any instant is
  (a) $5.625 \, \mu C$ (b) $5.625 \times 10^{-4} \, C$
  (c) $5.625 \times 10^{-5} \, C$ (d) $5.625 \, mc$

Solution 1. (c) Charging of capacitor is q
  $= q_0 (1 - e^{-t/RC})$
or $V = V_0 (1 - e^{-t/RC})$

Solution 2. (b) Capacitor is fully charged and capacitor does not allow DC current to flow except during transients.

Solution 3. (a) Capacitor charge through 50 Ω resistor as coil acts like short circuit.

Solution 4. (d) $Q = V_0 C = 75 \times 75 \, \mu C = 5.625 \, mc$

PASSAGE 5

Read the following passage and answer the questions given at the end.

A brilliant student of physics class developed a magnetic balance to weigh objects. The mass m to be measured is hung from the centre of the bar. Bar is kept in a uniform magnetic field of 1.5 T directed into the plane of Fig. 23.65. Battery voltage can be adjusted to vary the current in the circuit. The horizontal bar shown is 60 cm long and is made of extremely light weight material. It is connected to the battery via a 5 Ω resistance. There is no tension in the supporting wires. The magnetic force only supports the hanging weight.
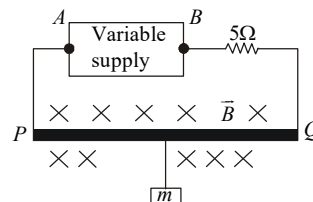
Fig. 23.65

1. Which point of battery terminal is positive?

   (a) A (b) B

   (c) either of A or B (d) cannot be found

2. If $V = 150\ V$, what is the maximum mass m?

   (a) 1.3 kg   (b) 1.8 kg

   (c) 2.2 kg   (d) 2.7 kg

Solution **1.** (a) Current should enter bar from P so that magnetic force is upwards.

Solution **2.** (d) $ilB = mg$ or $\dfrac{V}{5}\ lB = mg$

or $m = \dfrac{150 \times .6 \times 1.5}{5 \times 10} = 2.7\ \text{kg}$

PASSAGE 6

Read the following passage and answer the questions given at the end.

A chemist faced a problem of separating isotopes of chlorine. His friend who was studying physics suggested him to use magnetic field $\vec{B}$, a velocity selector and a photographic plate as illustrated in Fig. 23.65. Allow slightly charged particles (ionised) to enter the magnetic field with a selected (predetermined) velocity, then higher mass will make a larger radius and smaller mass will make a smaller radius.
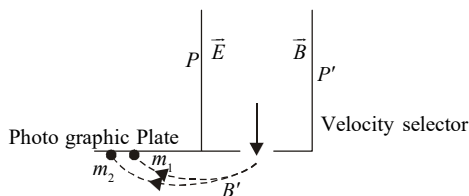
Fig. 23.65

1. What is velocity selector mentioned in the passage?

   (a) Electric and magnetic field crossed to each other and electric field parallel to motion of the particles and $E = vB$

   (b) Electric and magnetic field crossed to each other and magnetic field parallel to motion of the particle and $v = B/E$

   (c) Magnetic field, electric field and velocity mutually perpendicular so that $v = \dfrac{E}{B}$

   (d) Magnetic field, electric field and velocity mutually perpendicular so that $v = \dfrac{B}{E}$

2. What is the separation $m_1 m_2$? Given $v = 10^5\ \text{ms}^{-1}$, $\vec{B} = 2T$

   (a) 1 cm   (b) 2 cm

   (c) 0.5 cm   (d) none

Solution **1.** (c)

Solution **2.** (b) $\dfrac{R_1}{R_2} = \dfrac{m_1}{m_2}$

$= \dfrac{35}{37}$; $R_1 = \dfrac{m_1 v}{qB}$

$= \dfrac{35 \times 1.6 \times 10^{-27} \times 10^5}{1.6 \times 10^{-19} \times .2}$

$= 17.5\ \text{cm}$

$R_2 = 18.5\ \text{cm}$

$m_1 m_2 = 2\,(R_2 - R_1) = 2\ \text{cm}$

QUESTIONS FOR PRACTICE

1. If a charged particle kept at rest experiences an electromagnetic force

   (a) the electric field must not be zero

   (b) the magnetic field must not be zero

   (c) the electric field may or may not be zero

   (d) the magnetic field may or may not be zero

2. If a charged particle projected in a gravity-free room deflects,

   (a) there must be an electric field

   (b) there must be a magnetic field

   (c) both fields cannot be zero

   (d) both fields can be non-zero.

3. A charged particle moves in a gravity-free space without change in velocity. Which of the following is/are possible?

   (a) $E = 0, B = 0$ (b) $E = 0, B \neq 0$

   (c) $E \neq 0, B = 0$ (d) $E \neq 0, B \neq 0$.

4. A charged particle moves along a circle under the action of possible constant electric and magnetic fields. Which of the following are possible?

   (a) $E = 0, B = 0$ (b) $E = 0, B \neq 0$

   (c) $E \neq 0, B = 0$ (d) $E \neq 0, B \neq 0$.

5. A charged particle goes undeflected in a region containing electric and magnetic fields. It is possible that

(a) $\vec{E} \parallel \vec{B}$, $\vec{v} \parallel \vec{E}$ (b) $\vec{E}$ is not parallel to $\vec{B}$

(c) $\vec{v} \parallel \vec{B}$ but $\vec{E}$ is not parallel to $\vec{B}$

(d) $\vec{E} \parallel \vec{B}$ but $\vec{v}$ is not parallel to $\vec{E}$

6. If a charged particle goes unaccelerated in a region containing electric and magnetic fields,

(a) $\vec{E}$ must be perpendicular to $\vec{B}$

(b) $\vec{v}$ must be perpendicular to $\vec{E}$

(c) $\vec{v}$ must be perpendicular $\vec{B}$

(d) E must be equal to vB.

7. Two ions have equal masses but one is singly-ionised and the other is doubly-ionised. They are projected from the same place in a uniform magnetic field with the same velocity perpendicular to the field.

(a) Both ions will go along circles of equal radii.

(b) The circle described by the singly-ionised charge will have a radius double that of the other circle.

(c) The two circles do not touch each other.

(d) The two circles touch each other.

8. An electron is moving along the positive X-axis. You want to apply a magnetic field for a short time so that the electron may reverse its direction and move parallel to the negative X-axis. This can be done by applying the magnetic field along

(a) Y-axis   (b) Z-axis

(c) Y-axis only   (d) Z-axis only.

9. Let $\vec{E}$ and $\vec{B}$ denote electric and magnetic fields in a frame S and $\vec{E}'$ and $\vec{B}'$ in another frame S' moving with respect to S at a velocity $\vec{v}$. Two of the following equations are wrong. Identify them.

(a) $B_y' = B_y + \dfrac{vE_2}{c^2}$ (b) $E_y' = E_y - \dfrac{vB_2}{c^2}$

(c) $B_y' = B_y + vE_2$ (d) $E_y' = E_y + vB_2$.

10. The magnetic field at the origin due to a current element $i\,\vec{dl}$ placed at a position $\vec{r}$ is

(a) $\dfrac{\mu_0 i}{4\pi}\dfrac{\vec{dl} \times \vec{r}}{r^3}$ (b) $\dfrac{\mu_0 i}{4\pi}\dfrac{\vec{r} \times \vec{dl}}{r^3}$

(c) $-\dfrac{\mu_0 i}{4\pi}\dfrac{\vec{r} \times \vec{dl}}{r^3}$ (d) $-\dfrac{\mu_0 i}{4\pi}\dfrac{\vec{dl} \times \vec{r}}{r^3}$

11. A long straight wire carries a current along the Z-axis. One can find two points in the X-Y plane such that.

(a) the magnetic fields are equal

(b) the direction of the magnetic fields are the same

(c) the magnitude of the magnetic fields are equal

(d) the field at one point is opposite to that at the other point

12. Consider three quantities $x = E/B$, $Y = \sqrt{1/\mu_0 \varepsilon_0}$ and $Z = \dfrac{1}{CR}$. Here, l is the length of a wire, C is a capacitance and R is a resistance. All other symbols have standard meanings.

(a) x, y have the same dimensions.

(b) y, z have the same dimensions.

(c) z, x have the same dimensions.

(d) The field at one point is opposite to that at the other point.

13. A hollow tube is carrying an electric current along its length distributed uniformly over its surface. The magnetic field

(a) increases linearly from the axis to the surface

(b) is constant inside the tube

(c) is zero at the axis

(d) is zero just outside the tube

14. A steady electric current is flowing through a cylindrical conductor.

(a) The electric field at the axis of the conductor is zero.

(b) The magnetic field at the axis of the conductor is zero.

(c) The electric field in the vicinity of the conductor is zero.

(d) The magnetic field in the vicinity of the conductor is zero.

15. A long straight wire of radius R carries a current distributed uniformly over its cross-section. The magnitude of the magnetic field is

(a) maximum at the axis of the wire

(b) minimum at the axis of the wire

(c) maximum at the surface of the wire

(d) minimum at the surface of the wire

16. In a coaxial, straight cable, the central conductor and the outer conductor carry equal currents in opposite directions. The magnetic field is zero

(a) outside the cable

(b) inside the inner conductor

(c) inside the outer conductor

(d) in between the two conductors

17.
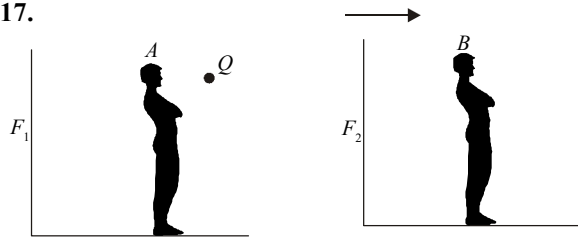
Fig. 23.66

An observer A and a charge Q are fixed in a stationary frame F_1. An observer B is fixed in a frame F_2, which is moving with respect to F_1.

(a)   Both A and B will observe electric fields.

(b)   Both A and B will observe magnetic fields.

(c)   Neither A nor B will observe magnetic fields.

(d) B will observe a magnetic field, but A will not.

18. A long straight wire carries a current along the x-axis. Consider the points $A(0, 1, 0)$, $B(0, 1, 1)$, $C(1, 0, 1)$ and $D(1, 1, 1)$. Which of the following pairs of points will have magnetic fields of the same magnitude?

(a) A and B (b) A and C

(c) B and C (d) B and D

19. In the previous question, if the current is i and the magnetic field at D has magnitude B,

(a) $B = \dfrac{\mu_0 i}{2\sqrt{2}\pi}$ (b) $B = \dfrac{\mu_0 i}{2\sqrt{3}\pi}$

(c) B is parallel to the z-axis

(d) B makes an angle of 45^0 with the xy plane

20. A straight conductor carries a current. Assume that all free electrons in the conductor move with the same drift velocity v. A and B are two observers on a straight line XY parallel to the conductor. A is stationary. B moves along XY with a velocity v in the direction of the free electrons.

(a) A and B observe the same magnetic field.

(b) A observes a magnetic field, B does not.

(c) A and B observe magnetic fields of the same magnitude but opposite directions.

(d) A and B do not observe any electric field.

21.
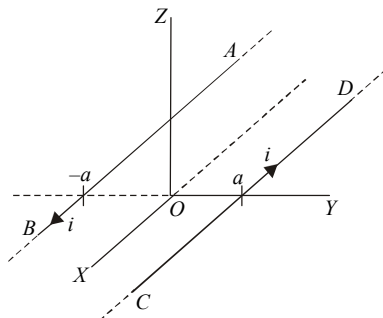
Fig. 23.67

Two long parallel wires, AB and CD, carry equal currents in opposite directions. They lie in the xy plane, parallel to the x-axis, and pass through the points $(0, -a, 0)$ and $(0, a, 0)$ respectively. The resultant magnetic field is

(a)   zero on the x-axis

(b)   maximum on the x-axis

(c)   directed along the z-axis at the origin, but not at other points on the z-axis

(d)   directed along the z-axis at all points on the z-axis

22.
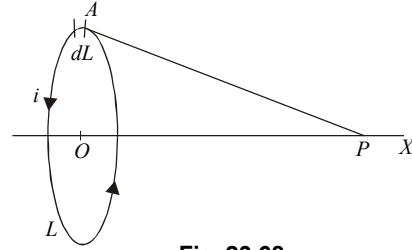
Fig. 23.68

L is circular loop carrying a current. P is a point on its axis OX. dl is an element of length on the loop at a point A on it. The magnetic field at P

(a)   due to L is directed along OX

(b)   due to dl is directed along OX

(c)   due to dl is perpendicular to OX

(d)   due to dl is perpendicular to AP

23. A straight conductor carries a current along the z-axis. Consider the points $A(a, 0, 0)$, $B(0, -a, 0)$, $C(-a, 0, 0)$ and $D(0, a, 0)$.

(a)   All four points have magnetic fields of the same magnitude.

(b)   All four points have magnetic fields in different directions.

(c)   The magnetic fields at A and C are in opposite directions.

(d)   The magnetic fields at A and B are mutually perpendicular.

24.

Fig. 23.69
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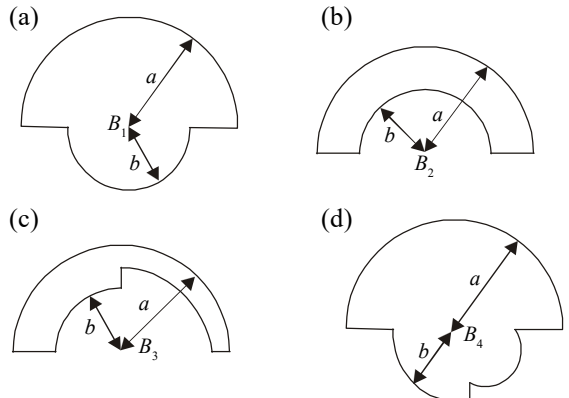
In the loops shown, all curved sections are either semicircles or quarter circles. All the loops carry the same current. The magnetic fields at the centres have magnitudes B_1, B_2, B_3 and B_4.

(a) B_4 is maximum   (b) B_3 is minimum

(c) $B_4 > B_1 > B_2 > B_3$ (d) $B_1 > B_4 > B_3 > B_2$

25. L is a circular ring made of a uniform wire. Current enters and leaves the ring through straight conductors which, if produced, would have passed through the centre C of the ring. The magnetic field at C
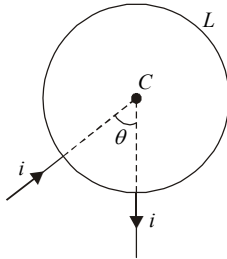
Fig. 23.70

(a) due to the straight conductors is zero

(b) due to the loop is zero

(c) due to the loop is proportional to θ

(d) due to the loop is proportional to $(\pi - \theta)$

26. A fiat circular coil, carrying a current, has a magnetic moment μ.

(a) μ has only magnitude; it does not have direction.

(b) The direction of μ is along the normal to the plane of the coil.

(c) The direction of μ depends on the direction of the current flow.

(d) The direction of μ does not change if the current in the coil is reversed.

27.
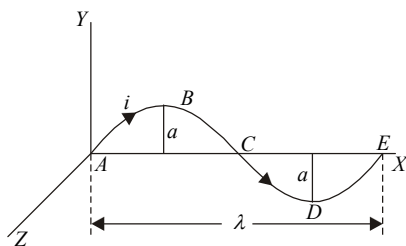
Fig. 23.71

A conductor ABCDEF, shaped as shown, carries a current i. It is placed in the xy plane with the ends A and E on the x-axis. A uniform magnetic field of magnitude B exists in the region. The force acting on it will be

(a) zero, if B is in the x-direction

(b) λBi in the z-direction, if B is in the y-direction

(c) λBi in the negative y-direction, if B is in the z-direction

(d) $2aBi$, if B is in the x-direction

28. A long straight conductor, carrying a current i, is bent to form an almost complete circular loop of radius r as shown. The magnetic field at the centre of the loop
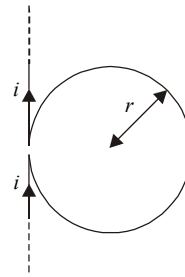
Fig. 23.72

(a) is directed into the paper

(b) is directed out of the paper

(c) has magnitude $\dfrac{\mu_0 i}{2r}\left(1 - \dfrac{1}{\pi}\right)$

(d) has magnitude $\dfrac{\mu_0 i}{2r}\left(1 + \dfrac{1}{\pi}\right)$

29. A conductor AB carries a current i in a magnetic field $\vec{B}$. If $\overrightarrow{AB} = \vec{r}$ and the force on the conductor is $\vec{F}$

(a) $\vec{F}$ does not depend on the shape of AB

(b) $\vec{F} = i(\vec{r} \times \vec{B})$

(c) $\vec{F} = i(\vec{B} \times \vec{r})$

(d) $|\vec{F}| = i(\vec{r} \cdot \vec{B})$

30. A long, straight, hollow conductor (tube) carrying a current has two sections A and C of unequal cross-sections joined by a conical section B. 1, 2 and 3 are points on a line parallel to the axis of the conductor. The magnetic fields at 1, 2 and 3 have magnitudes B_1, B_2 and B_3.
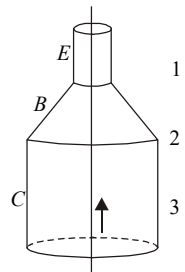
Fig. 23.73

(a) $B_1 = B_2 = B_3$ (b) $B_1 = B_2 \neq B_3$

(c) $B_1 < B_2 < B_3$

(d) B_2 cannot be found unless the dimensions of the section B are known.

31. Current flows through a straight cylindrical conductor of radius r. The current is distributed uniformly over its cross-section. The magnetic field at a distance x from the axis of the conductor has magnitude B.

(a) $B = 0$ at the axis   (b) $B = x$ for $0 \le x \le r$.

(c) $B \propto \dfrac{1}{x}$ for $x > r$.

(d) B is maximum for $x = r$.

32. A semicircular wire of radius r, carrying a current i, is placed in a magnetic field of magnitude B. The force acting on it

(a) can never be zero

(b) can have the maximum magnitude $2Bir$

(c) can have the maximum magnitude $Bi\mu r$

(d) can have the maximum magnitude Bir

33. Two long, thin, parallel conductors seperated by a distance carry currents i_1 and i_2. The force per unit length on one of them is F. Then

(a) $F \propto (i_1 i_2)$ (b) $F \propto (i_1 i_2)^2$

(c) $F \propto \dfrac{1}{d^2}$ (d) $F \propto \dfrac{1}{d}$

34. A current-carrying ring is placed in a magnetic field. The direction of the field is perpendicular to the plane of the ring.

(a) There is no net force on the ring.

(b) The ring will tend to expand.

(c) The ring will tend to contract.

(d) Either (b) or (c) depending on the directions of the current in the ring and the magnetic field.

35.
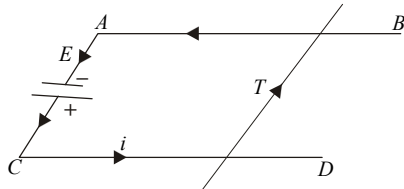
Fig. 23.74

AB and CD are smooth, parallel, horizontal rails on which a conductor T can slide. A cell, E, drives current i through the rails and T.

(a) The current in the rails will set up a magnetic field over T.

(b) T will experience a force to the right.

(c) T will experience a force to the left.

(d) T will not experience any force.

36. Two long, thin, parallel conductors, separated by a distance d carry currents i_1 and i_2. The force acting on unit length of any one conductor is F.

(a) F is attractive, if i_1 and i_2 flow in the same directions.

(b) F is attractive, if i_1 and i_2 flow in opposite directions.

(c) F is the same for both conductors.

(d) F is different for the two conductors.

37. AB and CD are smooth parallel rails seperated by l and inclined at angle θ with the horizontal. If B is normal to the plane of the rails then force on conductor EF placed on the rails is

(a) $Bil = \text{mg} \tan \theta$

(b) $Bil = \text{mg} \sin \theta$

(c) $Bil = \text{mg} \cos \theta$

(d) equilibrium cannot be reached

38.
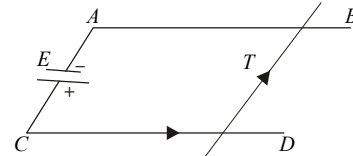
Fig. 23.75

AB and CD are smooth parallel horizontal rails on which a conductor T can slide. A cell of emf E drives a current i through the rails. Then

(a) the force on T is proportional to i

(b) the force on T is proportional to i^2

(c) if the direction of i is reversed in the circuit by reversing E, the force on T will reverse in direction

(d) if the direction of i is reversed in the circuit by reversing E, the force on T will remain in the same direction

39. A conducting gas is in the form of a long cylinder. Current flows through the gas along the length of the cylinder. The current is distributed uniformly across the cross-section of the gas. Disregard thermal and electrostatic forces among the gas molecules. Due to the magnetic fields set up inside the gas and the forces which they exert on the moving ions, the gas will tend to

(a) expand   (b) contract

(c) expand and contract alternately

(d) none of the above

40.
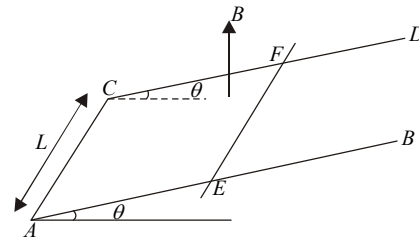
Fig. 23.76

AB and CD are smooth parallel rails, separated by a distance l, and inclined to the horizontal at an angle θ. A uniform magnetic field of magnitude B, directed vertically upwards, exists in the region. EF is a conductor of mass m, carrying a current i. For EF to be in equilibrium,

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(a) *i* must flow from *E* to *F*

(b) $Bil = mg \tan \theta$

(c) $Bil = mg \sin \theta$

(d) $Bil = mg$

41. A current *i* is flowing in a conductor as shown in the figure. The magnetic induction at point *O* will be
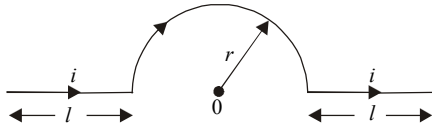
Fig. 23.77

(a) zero   (b) $\mu_0 i/r$

(c) $2\mu_0 i/r$ (d) $\mu_0 i/4r$

42. The magnetic lines of force due to straight current carrying conductor are

(a) circular lines   (b) straight lines

(c) concentric lines   (d) elliptical lines

43. The magnetic field generated along the axis of a solenoid is proportional to

(a) its length

(b) square of current flowing in it

(c) number of turns per unit length in it

(d) reciprocal of its radius

44. The phenomenon of production of magnetic field on passing an electric current in a straight conducting wire is based on the law of

(a) Faraday   (b) Coulomb

(c) Ampere   (d) Oersted

45. Current *i* is flowing in a long straight conducting wire. The magnetic induction at a distance r from it is 0.4 Tesla, then its value at double the distance will be

(a) 1.6 Tesla   (b) 0.8 Tesla

(c) 0.2 Tesla   (d) 0.1 Tesla

46. On passing electric current in two long straight conductors in mutually opposite directions, the magnetic force acting between them will be

(a) attractive   (b) repulsive

(c) both attractive and repulsive

(d) neither attractive nor repulsive

47. Current *i* is flowing in a circular coil of radius *a*, then magnetic induction at centre is *B*. If the current is doubled then magnetic induction will be

(a) $2B$ (b) *B*

(c) $4B$ (d) $2\sqrt{2}$

48. The magnetic induction due to a current *i* passed in a straight conductor at a distance *d* from it is proportional to

(a) $\dfrac{1}{d}$ (b) $\dfrac{1}{d^2}$

(c) *d*   (d) d^2

49. Current *i* is flowing in each of the two similar coaxial circular coils in the same direction. If the loops are moved towards each other, the following phenomenon will happen

(a) current in each loop will decrease

(b) current in each loop will increase

(c) current in each loop will remain same

(d) current in one loop will increase and that in another loop will decrease

50. The magnetic field on the axis of a current-carrying circular coil of radius *a* at a distance $2a$ from its centre will be

(a) $\mu_0 i/2$ (b) $\mu_0 i/10\sqrt{5}a$

(c) $\mu_0 i/4a$ (d) $\mu_0 i$

51. The correct curve between the magnetic field *B* due to a long straight current-carrying conductor and distance *r* from it will be
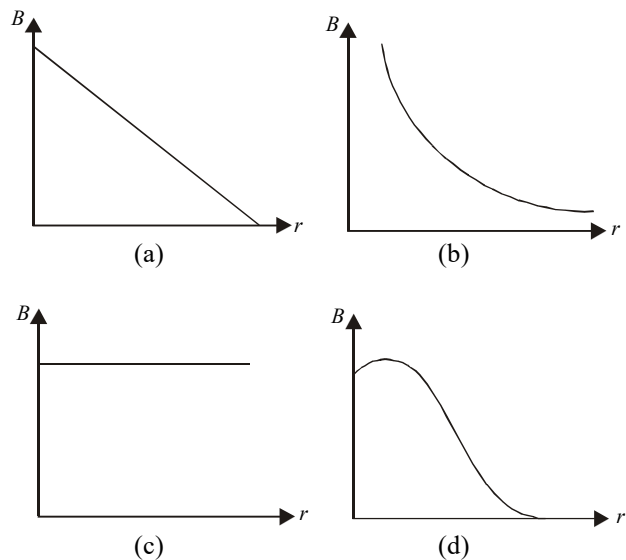
Fig. 23.78

52. The magnetic induction due to circular current-carrying conductor of radius *a*, at its centre is *Bc*. The magnetic induction on its axis at a distance *a* from its centre is *Ba*. The value of *Bc* : *Ba* will be

(a) $\sqrt{2}:2$ (b) $1:2\sqrt{2}$

(c) $2\sqrt{2}:1$ (d) $2:\sqrt{2}$

53. A 0.5 m long straight wire in which a current of 3.2 *A* is flowing is kept at right angle to a uniform magnetic field of 2.0 Tesla. The force acting on the wire will be

(a) $2\,N$ (b) $2.4\,N$

(c) $1.2\,N$ (d) 3

54. The radius of each coil of a Helmholtz galvanometer is 0.1 m and number of turns in each is 25. When a current is passed in it then the deflection of magnetic needle observed as 45°. If the horizontal component of earth's magnetic field is 0.314×10^{-4} Tesla then the value of current will be

(a) $0.14\,A$ (b) $0.28\,A$

(c) $0.42\,A$ (d) $0.07\,A$

55. An electron is revolving in a circular path of radius 2.0×10^{-10} m with a uniform speed of 3×10^6 m/s. The magnetic induction at the centre of the circular path will be

(a) 0.6 Tesla   (b) 1.2 Tesla

(c) 0.12 Tesla   (d) zero

56. Two parallel straight conductors, in which current is flowing in the same direction, attract each other. The cause of it is

(a) magnetic force between the two

(b) electric force between the two

(c) potential difference between the two

(d) mutual induction between the two

57. A rectangular loop, carrying current i, is lying near a long straight conductor PQ as shown in the figure in such away that the wire is parallel to one of the sides of the loop and is in the plane of the loop. If constant current I is passed in the wire then the loop will
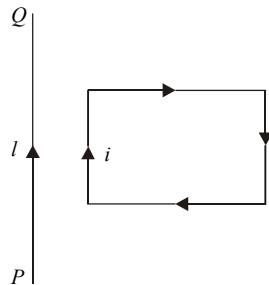
Fig. 23.79

(a) move towards the wire

(b) move away from the wire

(c) remain stationary

(d) rotate about an axis parallel to the wire

58. The distance between two thin long straight parallel conducing wires is b. On passing the same current i in them, the force per unit length between them will be

(a) $\dfrac{\mu_0 i}{2\pi b}$ (b) $\dfrac{\mu_0 i^2}{2\pi}$

(c) $\dfrac{\mu_0 i^2}{2\pi b}$ (d) zero

59. The wall of a straight tube of infinite length is thin. On passing current i through it, the value of magnetic induction inside the tube will be

(a) $\dfrac{2i}{r}$ (b) $\dfrac{2i\mu_0}{r}$

(c) $\dfrac{2r}{i}$ (d) Zero

60. A proton and an electron, with same momenta, enter a magnetic field in a direction at right angles to the lines of force. If the radii of their circular paths arc rp and re respectively then the value of rp:re will be

(a) $1:1$ (b) $1:2$

(c) $2:1$ (d) $4:1$

61. A magnetic needle placed in a non-uniform magnetic field experiences

(a) only force   (b) force and torque

(c) only torque

(d) neither force nor torque,

62. A current i is flowing in a specific wire. It is turned into a circular coil of one turn. Then it is turned to make a coil of two turns and smaller radius. Now the magnetic induction at the centre for same current will be

(a) half of its previous value

(b) one fourth of its previous value

(c) four times of its previous value

(d) zero

63. Uniform electric and magnetic fields are directed along X-direction. An electron is projected in X-direction with a velocity v, then

(a) magnitude of velocity of electron will increase

(b) magnitude of velocity of electron will decrease

(c) electron will turn towards right

(d) electron will turn towards left

64. The force between two parallel conductors, each of length 50 m and distant 20 cm apart, is 1 newton. If the current in one conductor is double that in another one, then their values will respectively be

(a) $100\,A$ and $200\,A$ (b) $50\,A$ and $400\,A$

(c) $10\,A$ and $30\,A$ (d) $5\,A$ and $25\,A$

65. The magnetic induction due to a straight current-carrying conductor of infinite length at a distance d from it will be

(a) $\dfrac{\mu_0 i}{2d}$ (b) $\dfrac{\mu_0 i}{2\pi d}$

(c) zero   (d) $\dfrac{\mu_0 i}{4\pi d}$

66. On applying a uniform magnetic field on a current-carrying coil the coil rotates in such a way that its plane

    (a) becomes perpendicular to magnetic field

    (b) becomes parallel to magnetic field

    (c) makes an angle of 45° with the magnetic field

    (d) makes any angle with the magnetic field

67. Which of the following quantities is not affected by a magnetic field?

    (a) Stationary charge

    (b) Moving charge

    (c) Change in magnetic flux

    (d) Current flowing in a conductor

68. The magnetic field inside a solenoid is

    (a) infinite   (b) zero

    (c) uniform   (d) non-uniform

69. A current of 10 A is flowing in a wire of length 1.5 m. When it is placed in a uniform magnetic field of 2 Tesla then a force of 15 N acts on it. The angle between the magnetic field and the direction of current flow will be

    (a) 30°   (b) 45°

    (c) 60°   (d) 90°

70. A wire is lying parallel to a square coil. Same current is flowing in same direction in both of them. The magnetic induction at any point P inside the coil will be

Fig. 23.80

    (a) zero
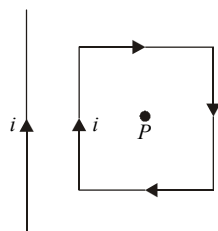
    (b) more than that produced by only coil

    (c) less than that produced by only coil

    (d) equal to that produced by only coil.

71. If the currents in two straight current-carrying conductors, disatant d apart, are i_1 and i_2 respectively in the same direction then they will

    (a) rotate about a central axis

    (b) attract each other

    (c) repel each other

    (d) neither attract nor repel each other

72. The correct curve between the magnetic induction (B) along the axis of a long solenoid due to current flow i in it and distance x from one end is
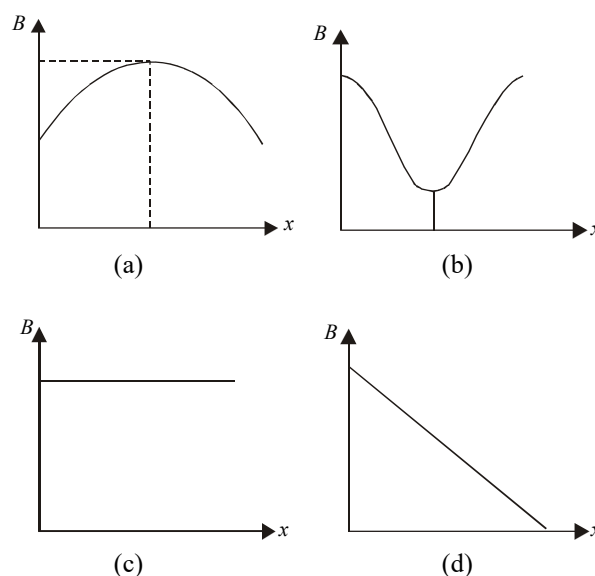
Fig. 23.81

73. Gauss is the unit of

    (a) B (b) H

    (c) M (d) 1

74. The correct expression for Lorentz force is

    (a) $q[\vec{E} + (\vec{B} \times \vec{V})]$ (b) $q[\vec{E} + (\vec{V} \times \vec{B})]$

    (c) $q(\vec{V} \times \vec{B})$ (d) $q\vec{E}$

75. The correct relation between B and M for a small current-carrying coil is

    (a) $B = \dfrac{\mu_0 M}{2x^3}$ (b) $B = \dfrac{\mu_0 M}{x^3}$

    (c) $B = \dfrac{\mu_0 M}{\pi x^3}$ (d) $B = \dfrac{\mu_0 M}{2\pi x^3}$

76. A proton, a deutron and an a-particle are moving with same momentum in a uniform magnetic field. The ratio of magnetic forces acting on them will be

    (a) $1 : 1 : 2$ (b) $1 : 2 : 3$

    (c) $2 : 1 : 1$ (d) $1 : 1 : 1$

77. An a- particle, a deutron and a proton are moving with same momentum in a uniform magnetic field. The ratio of their speeds will be

    (a) $1 : 2 : 4$ (b) $4 : 2 : 1$

    (c) $1 : 1 : 1$ (d) $2 : 2 : 4$

78. The value of B, at the point of inflexion in B-x curve is

    (a) maximum   (b) positive

    (c) constant   (d) negative

79. The resultant force on the current loop $PQRS$ due to a long current-carrying conductor will be, if the current flow in the loop is clockwise,
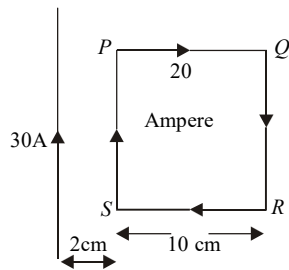
Fig. 23.82

(a) zero

(b) $0.36 \times 10^{-3} N$

(c) $1.8 \times 10^{-3} N$

(d) $0.5 \times 10^{-3} N$

80. A small linear segment of an electric circuit is lying on x-axis extending from $x = -a/2$ to $x = a/2$ and a current i is flowing in it. The magnetic induction due to the segment at a point $x = a$ will be

(a) $\propto a$

(b) Zero

(c) $\propto a^2$

(d) $\alpha \dfrac{1}{a}$

81. The rays, which remain undeflected in a magnetic field, are

(a) $\propto$-rays

(b) β-rays

(c) γ-rays

(d) positive rays.

82. A current i is flowing in a straight conductor of length L. The magnetic induction at a point distant from its centre will be

(a) $\dfrac{4\mu_0 i}{\sqrt{5}\pi L}$

(b) $\dfrac{\mu_0 i}{\sqrt{2}L}$

(c) $\dfrac{\mu_0 i}{2\pi L}$

(d) zero

83. A current-carrying circular coil of magnetic moment M is situated in a magnetic field B. The work done in deflecting it from an angle 0^0 to θ^0 will be

(a) MB

(b) $MB(1 - \cos\theta)$

(c) $-MB$

(d) $MB(1 - \sin\theta)$

84. Same current i is flowing in two straight parallel conducting wires situated a distance d apart. The magnetic induction at the centre between two wires will be

(a) zero

(b) $\dfrac{\mu_0 i}{d}$

(c) $\dfrac{4\mu_0 i}{d}$

(d) $\dfrac{\mu_0 i}{2d}$

85. A uniform magnetic field B and a uniform electric field E act in a common region. An electron is entering this region of space. The correct arrangement for it to escape undeviated is
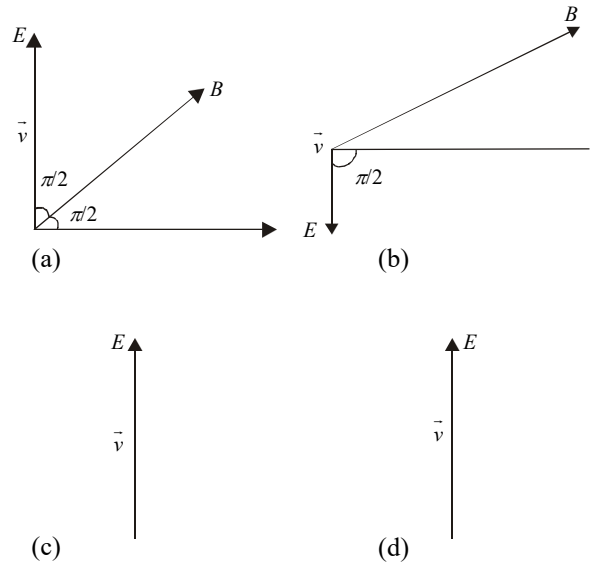
Fig. 23.83

86. A current of 30 amp is flowing in a conductor as shown in the figure. The magnetic induction at point O will be
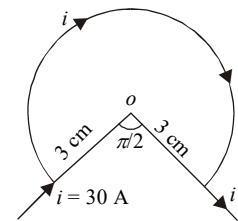
Fig. 23.84

(a) 1.5 Tesla

(b) 4.71×10^{-4} Tesla

(c) zero

(d) 0.15 Tesla

87. A current is flowing in a hexagonal coil of side a. The magnetic induction at the centre of the coil will be
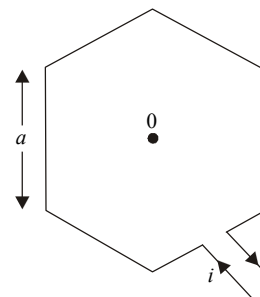
Fig. 23.85

(a) $\dfrac{3\sqrt{3}\mu_0 i}{\pi a}$

(b) $\dfrac{\mu_0 i}{3\sqrt{3}\pi a}$

(c) $\dfrac{\mu_0 i}{\sqrt{3}\pi a}$

(d) $\dfrac{\sqrt{3}\mu_0 i}{\pi a}$

88. A current i is flowing in an octagonal coil of side a. The magnetic induction at the centre of the coil will be
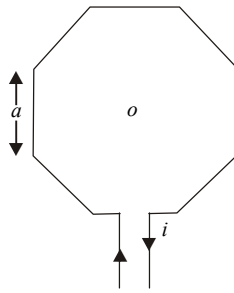
Fig. 23.86

(a) $\dfrac{5\mu_0 i}{4\pi a}$ (b) $\dfrac{5\sqrt{2}\mu_0 i}{\pi a}$

(c) $\dfrac{\mu_0 i}{\sqrt{5}\pi a}$ (d) $\dfrac{\sqrt{5}\mu_0 i}{2\pi a}$

89. Two similar coils of radius R and number of turns N are lying concentrically with their planes at right angles to each other. The currents flowing in them are I and $I\sqrt{3}$ respectively. Then the resultant magnetic induction at the centre will be (in Wb/m^2).

(a) $\dfrac{\mu_0 NI}{2R}$ (b) $\dfrac{\mu_0 NI}{R}$

(c) $\sqrt{3}\mu_0 \dfrac{NI}{2R}$ (d) $\sqrt{5}\dfrac{\mu_0 NI}{2R}$

90. A current of $10^{-3} A$ is flowing in a resistance of $1000\,\Omega$. To measure potential difference accurately, a voltmeter should be used whose resistance is

(a) $0\,\Omega$ (b) $500\,\Omega$

(c) $1000\,\Omega$ (d) $\gg 1000\,\Omega$

91. A galvanometer with resistance $100\,\Omega$ gives full scale deflection with a current of $10\ mA$. The value of shunt, in order to convert it into an ammeter of 10 ampere range, will be

(a) $-10\,\Omega$ (b) $1\,\Omega$

(c) $0.1\,\Omega$ (d) $0.01\,\Omega$

92. An ammeter gives full scale deflection with a current of 1 amp. It is converted into an ammeter of range 10 amp. The ratio of the resistance of ammeter to the shunt resistance used will be

(a) $1:9$ (b) $1:10$

(c) $1:11$ (d) $9:1$

93. The value of shunt resistance, in order to pass 10% of the main current in the galvanometer of resistance 99 Ω, will be

(a) $9.9\,\Omega$ (b) $10\,\Omega$

(c) $11\,\Omega$ (d) $9\,\Omega$

94. A galvanometer with resistance $5\,\Omega$ can read upto 5 m A. If this instrument is to be used to read upto 100

volt, then the value of resistance to be used in its series will be

(a) $19.9995\,\Omega$ (b) $199.995\,\Omega$

(c) $1999.95\,\Omega$ (d) $19995\,\Omega$

95. An ammeter of resistance $0.2\,\Omega$ and range $10\ mA$ is to be used to read potential difference upto 1 volt. It will have to be connected to

(a) 99.8 W resistance in series

(b) 99.8 W resistance in parallel

(c) 0.1 W resistance in parallel

(d) 0.1 W resistance in series

96. The proper resistance to be connected in series with a voltmeter, in order to increase its range 10 times, will be

(a)   nine times the resistance of voltmeter

(b)   ten times the resistance of voltmeter

(c)   eleven times the resistance of voltmeter

(d)   one-tenth the resistance of voltmeter

97. The resistance required to be connected in parallel to an ammeter in order to increase its range 10 times, will be

(a)   one-tenth the resistance of ammeter

(b)   nine times the resistance of ammeter

(c)   ten times the resistance of ammeter

(d)   one-ninth the resistance of ammeter

98. A galvanometer of resistance $50l$ W gives full scale deflection with a current of $0.5\ mA$. The value of resistance to be connected in series with it, in order to convert it into a voltmeter of range 10 volt, will be

(a) $1,995\,\Omega$ (b) $2,000\,\Omega$

(c) $19,950\,\Omega$ (d) $20,000\,\Omega$

99. If only 1% of main current is to be passed through a galvanometer of resistance G, then the value of shunt resistance will be

(a) $\dfrac{G}{50}$ (b) $\dfrac{G}{49}$

(c) $\dfrac{G}{99}$ (d) $99\,G$

**100.** A current of 10^{-7} ampere produces 50 division deflection in a galvanometer. Then its figure of merit will be

(a) 10^{-4} amp/div (b) 10^{-8} amp/div

(c) 10^{-10} amp/div (d) 2×10^{-9} amp/div

101. A voltmeter of $1000\,\Omega$ can read potential difference of 1.5 volt. What resistance will have to be connected in series with it, in order to measure potential difference upto 6 volt with the help of this voltmeter?

(a) $3000\,\Omega$ (b) $500\,\Omega$

(c) $1,000\,\Omega$ (d) $10,000\,\Omega$

102. The figures of merit of two galvanometers, whose resistances are $100\,\Omega$ and $20\,\Omega$ respectively, are 1×10^{-8} amp/div and 2×10^{-5} amp/div respectively. The galvanometer, whose voltage sensitivity is more, is

(a) nothing can be predicted   (b) second

(c) both   (d) first.

103. A resistance of $900\,\Omega$ is connected in series with a galvanometer of resistance $100\,\Omega$. A potential difference of 1 volt produces 300 division deflection in the galvanometer. The value of figure of merit will be

(a) 10^{-2} A/div   (b) 10^{-3} A/div

(c) 10^{-4} A/div   (d) 10^{-5} A/div

104. A proton, a deutron and an α-particle are accelerated through the same potential difference and then they enter a uniform normal magnetic field. If the radius of circular path of proton is 8 cm then the radius of circular path of deutron will be

(a) 11.31 cm   (b) 22 cm

(c) 5 cm   (d) 2.5 cm

105. A proton and an α-particle enter a uniform magnetic field at right angles to it with same velocity. The time period of α particle as compared to that of proton, will be

(a) four times   (b) two times

(c) half   (d) one-fourth

106. A charged particle with charge q is moving in a uniform magnetic field. If this particle makes any angle with the magnetic field then its path will be

(a) circular   (b) straight line

(c) helical   (d) parabolic

107. A proton is moving with a velocity of 3×10^7 m/s in the direction of a uniform magnetic field of 0.5 Tesla. The force acting on proton is

(a) $2\,N$ (b) $4\,N$

(c) $6\,N$ (d) zero

108. The work done by a normal magnetic field in revolving a charged particle q in a circular path will be

(a) zero   (b) $MB\,(1-\cos\theta)$

(c) MB (d) $-MB$

109. An electron is moving vertically downwards at any place. The direction of magnetic force acting on it due to horizontal component of earth's magnetic field will be

(a) towards east   (b) towards west

(c) towards north   (d) towards south

110. A positive charge is moving towards an observer. The direction of magnetic induction will be

(a) clockwise   (b) anti-clockwise

(c) towards right   (d) towards left

111. Two parallel wires P and Q carry electric currents of 10 A and 2 A respectively in mutually opposite directions. The distance between the wires is 10 cm. If the wire P is of infinite length and wire Q is 2 m long, then the force acting Q will be

(a) $4\times10^{-5}\,N$ (b) $8\times10^{-5}\,N$

(c) $4\times10^5\,N$ (d) $0\,N$

112. A proton with kinetic energy $8\,eV$ is moving in a uniform magnetic field. The kinetic energy of a deutron moving in the same path in the same magnetic field will be

(a) $2\,eV$ (b) $4\,eV$

(c) $6\,eV$ (d) $8\,eV$

113. Two wires carry currents of $100\,A$ and $200\,A$ respectively and they repel each other with a force of 0.4 N/m. The distance between them will be

(a) 1 m   (b) 1 cm

(c) 50 cm   (d) 25 cm

114. A current of $2\,A$ is flowing in a wire of length 50 cm. If this wire is lying in a uniform magnetic field of 5×10^{-4} N/A—m making an angle of $60°$ with the field, then the force acting on the wire will be

(a) $4.33\times10^{-4}\,N$ (b) $4\,N$

(c) 4 dyne   (d) Zero

115. In the following figure, three paths of a particle crossing a nucleus N are shown. The correct path is
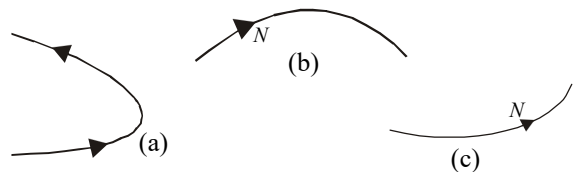
Fig. 23.87

(a) a and c (b) a and b

(c) a, b, and c (d) only a

116. The ratio of magnetic force (Fm) and electric force (Fe) acting on a moving charge is

(a) $\left(\dfrac{V}{C}\right)^2$ (b) $\left(\dfrac{C}{V}\right)^2$

(c) $\dfrac{V}{C}$ (d) $\dfrac{C}{V}$

117. A charge of 0.04 coulomb is moving in a magnetic field of 0.02 Tesla with a velocity 10m/s in a direction making an angle $30°$ with the direction of field. The force acting on it will be

(a) $4 \times 10^{-3} N$ (b) $2 \times 10^{-3} N$

(c) zero   (d) $8 \times 10^{-3} N$

118. An electron is moving in a perpendicular magnetic field of strength 4×10^{-3} Tesla with a velocity of 4×10^{7} m/s. The radius of electron path will be

(a) 0.056 m   (b) 0.056 m

(c) 56 m   (d) 5.6 m

119. The magnetic moment of an electron with orbital angular momentum J will be

(a) $\dfrac{e\vec{J}}{m}$ (b) $\dfrac{e\vec{J}}{2m}$

(c) $\dfrac{2m}{e\vec{J}}$ (d) zero

120. The correct statement about magnetic moment is:

(a) It is a vector quantity.   (b) Its unit is amp-m^2.

(c) Its dimensions are AL^2.   (d) All of the above.

121. The use of Helmholtz coils is to produce

(a) uniform magnetic field

(b) non-uniform magnetic field

(c) varying magnetic field

(d) zero magnetic field.

122. The magnetic induction due to a straight current-carrying conductor of infinite length at a distance r from it proportional to

(a) i^{-1} (b) i

(c) i^{-2} (d) i^2

123. If a load is suspended from a spring and a direct current is passed through it then the spring gets

(a) stretched

(b) compressed

(c) sometimes stretched and sometimes compressed

(d) neither stretched nor compressed

124. The correct expression for Ampere's law is

(a) $\oint B.dl = \Sigma i$ (b) $\oint B.dl = \dfrac{1}{\Sigma i}$

(c) $\oint B.dl = \mu_0 \Sigma i$ (d) $\oint B.dl = \dfrac{\Sigma i}{\mu_0}$

125. The magnitude of magnetic induction for a current-carrying toroid of uniform cross-section is

(a) uniform over the whole cross-section

(b) maximum on the outer edge

(c) maximum on the inner edge

(d) maximum at the centre of cross-section

126. If a positively charged particle is moving as shown in the figure, then it will get deflected due to magnetic field towards
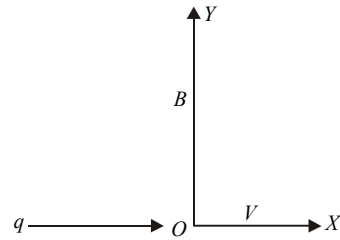
Fig. 23.88

(a) $+ x$ direction   (b) $+ y$ direction

(b) $- x$ direction   (d) $+ z$ direction

127. A current-carrying loop lying in a magnetic field behaves like a

(a) magnetic dipole   (b) magnetic pole

(b) magnetic material   (d) non-magnetic material

128. The ratio of magnetic induction due to a bar magnet on its axial point and equatorial point will be

(a) $1:1$ (b) $1:2$

(c) $2:1$ (d) $1:4$

129. Two insulated wires of infinite length are lying mutually at right angles to each other as shown in the figure. Current of 2 A and 1.5 A respectively are flowing in them. The value of magnetic induction at point P will be
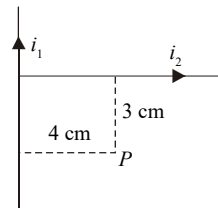
Fig. 23.89

(a) 2×10^{-3} N/A-m   (b) 2×10^{-5} N/A-m

(c) Zero   (d) 2×10^{-4} N/A-m

130. Two current-carrying parallel conductors are shown in the figure. The magnitude and nature of force acting between them per unit length will be
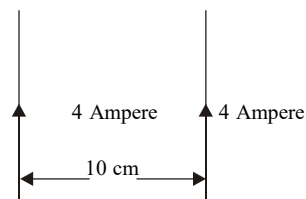
Fig. 23.90

(a) 8×10^{-8} N/m, attractive

(b) 3.2×10^{-5} N/m, repulsive

(c) 3.2×10^{-5} N/m, attractive

(d) 8×10^{-8} N/m, repulsive

PASSAGE 1

Read the following passage and answer the questions given at the end.

To detect leaks in a vacuum system He$^+$ ions are used. Since there is no helium in ordinary air, helium sprayed near a leak in a vacuum system will quickly show up in the output of a vacuum pump connected to such a system. You are assigned the job to design a leak detector that uses He$^+$ ion and a mass spectrometer. The He$^+$ ions emerge at a speed of 10^5 ms^{-1} from a velocity selector. They are curved in a semicircular path by a magnetic field B' and are detected at a distance 10.16 cm from the slit. The magnetic field in velocity selector is 0.2 T.

1. What is the strength of electric field in the velocity selector?

   (a) 2×10^5 NC^{-1} (b) 2×10^3 NC^{-1}

   (c) 2×10^6 NC^{-1} (d) 2×10^4 NC^{-1}

2. What is the strength of magnetic field B' ?

   (a) $0.082\ T$ (b) $0.041\ T$

   (c) $0.164\ T$ (d) none of these

Solution 1. (d) $v = \dfrac{E}{B}$

or $E = Bv = 0.2 \times 10^5$

         $= 2 \times 10^4$ NC^{-1}

Solution 2. (a) $R = \dfrac{mv}{qB'}$

or $B' = \dfrac{mv}{qR} = \dfrac{4 \times 1.66 \times 10^{-27} \times 10^5}{1.6 \times 10^{-19} \times 5.08 \times 10^{-2}}$

         $= 0.082\ T$

PASSAGE 2

Read the following passage and answer the questions given at the end.

To impress your kid of class four, you take two long metal bars and connect them with battery of emf V_0. You then place a thin wire of mass m and length d on the bars. The two bars are separated by d. The length of the bars is L. You apply a magnetic field first outwards and then inwards and the wire moves forward and back ward. The resistance of the wire is r and that of the bars is negligible. Coefficent of friction between the bars and the wire is μ.
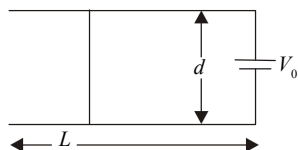
Fig. 23.91

1. If the direction of magnetic field is not varied how long will the wire move after leaving the bars?

   (a) $\dfrac{V_0 lB}{\mu mrg}\ L$ (b) $\left(\dfrac{V_0 lB}{\mu mrg} - 1\right) L$

   (c) $\left(\dfrac{V_0 lB}{\mu mrg} + 1\right) L$ (d) L

2. What is the acceleration of the wire?

   (a) $\dfrac{V_0 lB}{rm}$ (b) $\dfrac{V_0 lB}{rm} - \mu g$

   (c) μg (d) $\dfrac{V_0 lB - \mu g}{m}$

3. If instead of changing the direction of magnetic field, the direction of battery is reversed, what effect will you note?

   (a) The wire can be moved backward or forward by changing the direction of battery.

   (b) The wire will continue to move in the same direction.

   (c) The magnetic field will reverse.

   (d) None of these.

Solution   1. (b) $v^2 = 2\,a_{net}\,L$

       $= 2\left(\dfrac{V_0 lB}{mr} - \mu g\right) L = 2\,\mu g x$

Solution   2. (b) $F = IlB = \dfrac{V_0 lB}{r} = ma$

or $a = \dfrac{V_0 lB}{mr}$

      $a_{net} = \dfrac{V_0 lB}{mr} - \mu g$

Solution 3. (a)

PASSAGE 3

Read the following passage and answer the questions given at the end.

Magnetic forces acting on conducting fluids provide a convenient means of pumping these fluids. For example, this method can be used to pump blood without damage to the cells that can be caused by a mechanical pump. A horizontal tube with rectangular cross-section (height h, width w) is placed at right angles to a uniform magnetic field of magnitude B so that a length l is in the field. The tube is filled with a conducting liquid and an electric current of density J is maintained in the third perpendicular direction as shown in Fig. 23.92.
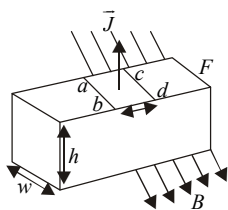
Fig. 23.92

1. Find the difference in pressure between the vertical plane *ab* and vertical plane *cd*.

(a) $\dfrac{IlB}{hL}$ (b) $\dfrac{JlBh}{w}$

(c) JlB (d) $\dfrac{JlBw}{h}$

2. What current density is required to provide a pressure difference of 1 atm between these two points if $B = 2.2T$ and $l = 35$ mm

(a) 1.4×10^3 Am^{-2} (b) 7.2×10^6 Am^{-2}

(c) 1.3×10^5 Am^{-2} (d) 1.3×10^6 Am^{-2}

Solution 1. (c) $\Delta F = IlB$, and

$$\Delta p = \frac{\Delta F}{A} = \frac{IlB}{A} = JlB$$

Solution 2. (d) $J = \dfrac{\Delta p}{lB} = \dfrac{10^5}{2.2 \times 35 \times 10^{-3}}$

$$= 1.3 \times 10^6 \text{ Am}^{-2}$$

PASSAGE 4

Read the following passage and answer the questions given at the end.

A particle with mass m and positive charge q starts from rest at the origin shown in Fig. 23.93. There is a uniform electric field $\vec{E}$ in the $+y$ direction and a magnitic field B directed outward the plane of the page. It is shown in more advanced books that the path is a cycloid whose radius of curvature at the top points is twice the y-co-ordinates at that level.
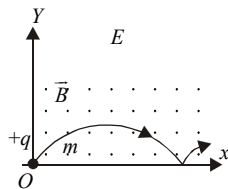
Fig. 23.93

1. The speed at any point is

(a) $\sqrt{\dfrac{3qEy}{m}}$ (b) $\sqrt{\dfrac{qEy}{m}}$

(c) $\sqrt{\dfrac{qEy}{2m}}$ (d) $\sqrt{\dfrac{2qEy}{m}}$

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2. What is the speed at the top?

(a) $\dfrac{E}{B}$ (b) $\dfrac{E}{2B}$

(c) $\dfrac{2E}{B}$ (d) $\dfrac{B}{2E}$

3. What is the nature of motion?

(a) periodic (b) aperiodic

(c) SHM (d) oscillatory

(e) none of these

Solution 1. (d) $a = \dfrac{qE}{m}$, $v^2 = 2ay = \dfrac{2qEy}{m}$

or $v = \sqrt{\dfrac{2qEy}{m}}$
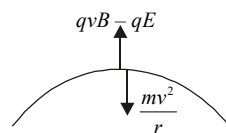
Fig. 23.94

Solution 2. (c) At top $\dfrac{mv^2}{r} = qvB - qE$

$$qvB = \frac{mv^2}{r} + qE = \frac{m(2qEy)}{2ym} + qE$$

or $qvB = 2qE$ or $v = \dfrac{2E}{B}$

Solution 3. (a)

PASSAGE 5

Read the following passage and answer the questions given at the end.

A long horizontal wire *AB* rests on the surface of a table and carries a vertical current *I*. Horizontal wire *CD* is vertically above wire *AB*. It is free to slide up and down on the two vertical metal guides *C* and *D* as shown in figure. Wire *CD* is connected through the sliding contacts to another wire that also carries a current *I* in the opposite direction to the current in wire *AB*. The mass per unit length of the wire CD is λ.
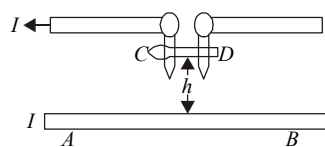
Fig. 23.95

1. To what height *h* the wire will stay in equilibrium?

(a) $\dfrac{\mu_0 I^2}{2\pi\lambda g}$ (b) $\dfrac{\mu_0 I^2}{\pi\lambda g}$

(c) $\dfrac{\mu_0 I^2}{4\pi\lambda g}$ (d) $\dfrac{\mu_0 I^2}{3\pi\lambda g}$

(e) none of these

2. Will the wire CD execute SHM if disturbed slightly?

(a) No   (b) Yes

(c) Cannot say

Solution   1. (a) $IlB = mg$

or $IB = \dfrac{m}{l}\,g$ or $I\left(\dfrac{\mu_0 I}{2\pi h}\right) = \lambda g$

or $h = \dfrac{\mu_0 I^2}{2\pi\lambda g}$

Solution   2. (b) $I\left(\dfrac{\mu_0 I}{2\pi(h+x)}\right)$

$= \lambda g$ or $\dfrac{I^2\mu_0}{2\pi h\left(1+\dfrac{x}{h}\right)} = \lambda g$

or $\dfrac{I^2\mu_0}{2\pi h}\left(1-\dfrac{x}{h}\right) = \lambda g$ shows it will execute SHM

$\therefore$ $a \propto -x$.

PASSAGE 6

Read the following passage and answer the questions given at the end.

You are asked to do an experiment to study the effect of magnetic field on charged particle. You take two long wires having resistance 10 Ω and 25 Ω. Separate them by 5 cm and keep them parallel. The two are connected to a battery of 100 V as shown in Figure.
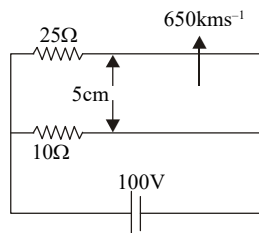
Fig. 23.96

The battery branch is kept quite far away from the two conductors. A proton is allowed to enter the plane of the wires directed towards the upper wire with a velocity 650 km s^{-1} exactly in the middle of the wire.

1. In which direction is proton deflected?

(a) 10 Ω side conductor   (b) 25 Ω side conductor

(c) goes undeviated   (d) none of these

2. The initial acceleration of the proton is

(a) 2.9×10^8 ms^{-2} (b) 3.31×10^2 ms^{-2}

(c) 3.12×10^8 ms^{-2} (d) none of these

Solution   1. (d) Towards right

Solution   2. (c) $F = qvB$

$= qv\left[\dfrac{\mu_0 I_1}{2\pi d} - \dfrac{\mu_0 I_2}{2\pi d}\right] = \dfrac{qv\mu_0}{2\pi d}\,[I_1 - I_2]$

$a = \dfrac{1.6\times 10^{-19}\times 650\times 10^3\left[10-4\right]\times 4\pi\times 10^{-7}}{2\pi\times 2.5\times 10^{-2}\times 1.6\times 10^{-27}}$

$= 3.12 \times 10^8$ ms^{-2}

PASSAGE 7

Read the following passage and answer the questions given at the end.

Two long straight conducting wires with linear mass density λ are suspended using cords so that both of them are horizontal and parallel to each other at a distance d apart. The back ends of the wires are connected by a low resistance slack wire. A charged capacitor is now added across the wires such that its positive terminal is connected to far end and negative terminal is connected to near end as shown in figure. The capacitance of the capacitor is C. These connections are also made by slack wires. Assume that time to discharge is negligible. Initial charge on capacitor is Q_0.
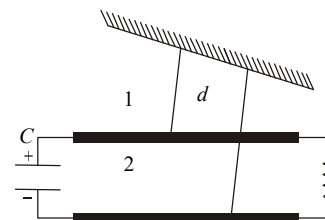
Fig. 23.97

1. The wires 1 and 2

(a) move apart   (b) come closer

(c) remain at their position

(d) none of these

2. The initial velocity of the wires is

(a) $\dfrac{\mu_0 Q_0^2}{4\pi\lambda dRC}$ (b) $\dfrac{\mu_0 Q_0^2}{2\pi\lambda dRC}$

(c) $\dfrac{\mu_0 Q_0^2}{8\pi\lambda dRC}$ (d) $\dfrac{2\mu_0 Q_0^2}{4\pi\lambda RdC}$

Solution   1. (a) since the current in the two is in opposite directions.

Solution **1.** (a) $\qquad F = IlB \Rightarrow \dfrac{mdv}{dt}$

$\qquad\qquad\qquad = Il\left(\dfrac{\mu_0 I}{2\pi d}\right)$

or $\qquad \dfrac{dv}{dt} = \dfrac{\mu_0 I^2}{2\pi d\lambda}$ $\qquad\qquad Q = Q_0\left(1 - e^{-t/RC}\right)$

$\qquad \dfrac{dQ}{dt} = I = \dfrac{Q_0}{RC} e^{-t/RC}$

or $\qquad \dfrac{dv}{dt} = \dfrac{\mu_0 Q_0^2}{2\pi\lambda d (RC)^2} e^{-2t/RC}$

or $\qquad \displaystyle\int dv = V = \dfrac{\mu_0 Q_0^2}{2\pi\lambda d (RC)^2}\displaystyle\int e^{-2t/RC}$

$\qquad\qquad\qquad = \dfrac{\mu_0 Q_0^2}{2\pi\lambda d (RC)^2}\,\dfrac{e^{-2t/Rc}}{\dfrac{2}{RC}}$

or $\qquad V_0 = \left. V\right|_{t=0} = \left. \dfrac{\mu_0 Q_0^2}{4\pi\lambda dRC} e^{-2t/RC}\right|_{t=0}$

or $\qquad V_0 = \dfrac{\mu_0 Q_0^2}{4\pi\lambda dRC}$

Answers to Questions for Practice

| #	Ans	#	Ans	#	Ans	#	Ans	#	Ans	#	Ans	#	Ans
1.	(a, d)	2.	(c, d)	3.	(a, b, d)	4.	(b)	5.	(a, b)	6.	(a, b)	7.	(b, d)
8.	(a, b)	9.	(b, c)	10.	(c, d)	11.	(b, c, d)	12.	(a, b, c)	13.	(b, c)	14.	(b, c)
15.	(b, c)	16.	(a)	17.	(a, d)	18.	(a, d)	19.	(b, d)	20.	(a, b)	21.	(b, d)
22.	(a, b)	23.	(a, b, c, d)	24.	(a, b, c)	25.	(a, b)	26.	(b, c)	27.	(a, b, c)	28.	(a,b,c)
29.	(a, b)	30.	(a)	31.	(a, b, c, d)	32.	(b)	33.	(a, b)	34.	(a, d)	35.	(a, b)
36.	(a, c)	37.	(b)	38.	(b, d)	39.	(b)	40.	(a, b)	41.	(d)	42.	(a)
43.	(c)	44.	(d)	45.	(c)	46.	(b)	47.	(a)	48.	(a)	49.	(a)
50.	(b)	51.	(b)	52.	(c)	53.	(c)	54.	(a)	55.	(b)	56.	(a)
57.	(a)	58.	(c)	59.	(d)	60.	(a)	61.	(b)	62.	(c)	63.	(b)
64.	(a)	65.	(b)	66.	(a)	67.	(a)	68.	(c)	69.	(a)	70.	(b)
71.	(b)	72.	(a)	73.	(a)	74.	(b)	75.	(a)	76.	(c)	77.	(a)
78.	(c)	79.	(a)	80.	(b)	81.	(c)	82.	(a)	83.	(b)	84.	(a)
85.	(a)	86.	(b)	87.	(d)	88.	(a)	89.	(b)	90.	(d)	91.	(c)
92.	(d)	93.	(c)	94.	(d)	95.	(a)	96.	(a)	97.	(d)	98.	(c)
99.	(c)	100.	(d)	101.	(a)	102.	(d)	103.	(d)	104.	(a)	105.	(b)
106.	(c)	107.	(d)	108.	(a)	109.	(b)	110.	(b)	111.	(b)	112.	(b)
113.	(b)	114.	(a)	115.	(a)	116.	(a)	117.	(a)	118.	(b)	119.	(b)
120.	(d)	121.	(a)	122.	(b)	123.	(b)	124.	(c)	125.	(a)	126.	(d)
127.	(a)	128.	(c)	129.	(b)	130.	(c)								

EXPLANATION

9. (a,d)

10. (b,d)

Fig. 23.98

The magnitude of the magnetic field depends only on the distance from the x-axis. Points A and C are at dis-

tances of 1 unit each from the x-axis. Points B and D are at distances of $\sqrt{2}$ unit each from the x-axis.

11. (a,b)

Fig. 23.99

A is stationary and observes the current l. B observes the free electrons to be at rest, but the unbalanced

positive charges in the conductor will appear to move in the direction opposite to that of v. Thus, A and B observe the same current and hence the same magnetic field.

15. (a,b,c) For B_2 and B_3 the contributions due to outer section oppose the contributions due to the inner sections, thus B_1 and B_4 are greater than B_2 and B_3. For B_4 there is a section with radius < b and hence it contributes more than the semicirular section of radius b for B_1. Thus $B_4 > B$.

 For B_3 there is a section with radius > b and hence it contributes less than the semicirular section of radius b does for B_2. Thus $B_3 < B_2$

16. (a,b)

18. (a,b,c) To find the Ampere force on a conductor of any shape, replace the conductor by an imaginary straight conductor joining the two ends of the given conductor.

19. (a,b,c) The field at the centre of the loop due to the straight part is $\mu_0 i/(2\pi r)$, directed into the paper, and the field due to the loop is $\mu_0 i/(2r)$, directed out of the paper.

21. (a) To find the magnetic field outside a thick conductor, the current may be assumed to flow along the axis. As points 1, 2, 3 are equidistant from the axis, $B_1 = B_2 = B_3$.

26. (a,b) Current in AB and CD causes magnetic fields in the same direction on T, upward in this case. Hence there is a net magnetic field over T.

29. (b,d) The magnetic field over T is proportional to i. Hence, the Ampere force is proportional to i^2. If i is reversed, the direction of B will also reverse. The direction of the Ampere force remains the same.

30. (b) Treat the gas as a thick conductor carrying a uniform current. Apply Ampere's law to find the magnetic field. Then apply the left hand rule to find the direction of the Ampere force.