विध्न विचारत भीरु जन, नहीं आरम्भे काम, विपति देख छोड़े तुरंत मध्यम मन कर श्याम।
पुरुष सिंह संकल्प कर, सहते विपति अनेक, 'बना' न छोड़े ध्येय को, रघुबर राखे टेक।।

रचितः मानव धर्म प्रणेता
सद्‌गुरु श्री रणछोड़दासजी महाराज

STUDY PACKAGE

This is TYPE 1 Package please wait for Type 2

Subject : PHYSICS

Topic : MAGNETIC EFFECTS OF CURRENT

Teko® CLASSES

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Index

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KEY CONCEPTS

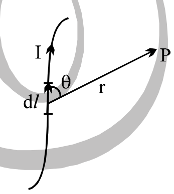
1. A static charge produces only electric field and only electric field can exert a force on it.
A moving charge produces both electric field ans magnetic field and both electric field and magnetic field can exert force on it.
A current carrying conductor produces only magnetic field and only magnetic field can exert a force on it.

2. Magnetic charge (i.e. current) , produces a magnetic field . It can not produce electric field as net charge on a current carrying conductor is zero. A magnetic field is detected by its action on current carrying conductors (or moving charges) and magnetic needles (compass) needles. The vector quantity $\vec{B}$ known as **MAGNETIC INDUCTION** is introduced to characterise a magnetic field . It is a vector quantity which may be defined in terms of the force it produces on electric currents . Lines of magnetic induction may be drawn in the same way as lines of electric field . The number of lines per unit area crossing a small area perpendicular to the direction of the induction bring numerically equal to $\vec{B}$. The number of lines of $\vec{B}$ crossing a given area is referred to as the **MAGNETIC FLUX** linked with that area. For this reason $\vec{B}$ is also called **MAGNETIC FLUX DENSITY** .

3 MAGNETIC INDUCTION PRODUCED BY A CURRENT (BIOT-SAVART LAW):

The magnetic induction dB produced by an element dl carrying a current I at a distance r is given by :

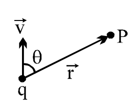
$$dB = \frac{\mu_0 \mu_r}{4\pi} \frac{I d\ell \sin\theta}{r^2} \quad \text{or} \quad \overrightarrow{dB} = \frac{\mu_0 \mu_r}{4\pi} \frac{I\left(d\vec{\ell} \times \vec{r}\right)}{r^3},$$



here the quantity $Id\ell$ is called as current element strength.
μ = permeability of the medium $= \mu_0 \mu_r$; μ_0 = permeability of free space
μ_r = relative permeability of the medium (Dimensionless quantity).
Unit of μ_0 & μ is NA^{-2} or Hm^{-1} ; $\mu_0 = 4\pi \times 10^{-7}\ Hm^{-1}$

4 MAGNETIC INDUCTION DUE TO A MOVING CHARGE

$$dB_P = \frac{\mu_0 q v \sin\theta}{4\pi r^2}$$



In vector form it can be written as $\quad \overrightarrow{dB} = \frac{\mu_0}{4\pi} \frac{q(\vec{v} \times \vec{r})}{r^3}$

5. MAGNETIC INDUCTION DUE TO AN INIFINITE ST. CONDUCTOR

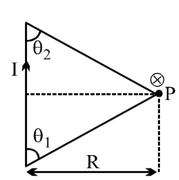
$$B = \frac{\mu_0 I}{2\pi r}$$

6. MAGNETIC INDUCTION DUE TO SEMI INIFINITE ST. CONDUCTOR

$$B = \frac{\mu_0 I}{4\pi r}$$

7. MAGNETIC INDUCTION DUE TO A CURRENT CARRYING STRAIGHT CONDUCTOR

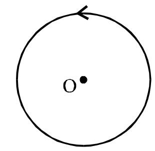
$$B = \frac{\mu_0 I}{4\pi R} (\cos\theta_1 + \cos\theta_2)$$



If the wire is very long $\theta_1 \cong \theta_2 \cong 0^\circ$ then , $B = \frac{\mu_0 I}{2\pi R}$

8. Magnetic Field Due To A Flat Circular Coil Carrying A Current :

(i) At its centre $B = \dfrac{\mu_0 NI}{2R}$, direction $\odot$



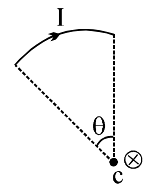
Where N = total number of turns in the coil
I = current in the coil
R = Radius of the coil

(ii) On the axis $B = \dfrac{\mu_0 NIR^2}{2\left(x^2+R^2\right)^{3/2}}$

Where x = distance of the point from the centre . It is maximum at the centre .

9. Magnetic Induction due to Flat Circular Arc

$$B = \frac{\mu_0 I\theta}{4\pi R}$$



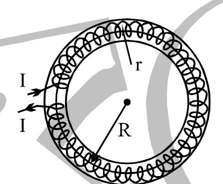
10. Magnetic Induction due to Solenoid

$B = \mu_0 nI$, direction along axis.
where n $\rightarrow$ no. of turns per m.
I $\rightarrow$ current

11. Magnetic Induction due to Toroid

$B = \mu_0 nI$

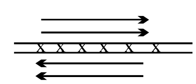
where $n = \dfrac{N}{2\pi R}$ (no. of turns per m)



N = total turns R >> r

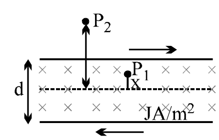
12. Magnetic Induction due to Current Carrying Sheet

$B = \dfrac{1}{2}\mu_0 I$



where I = Linear current density (A/m)

13. Magnetic Induction due to Thick Sheet



At point P_2 $B_{out} = \dfrac{1}{2}\mu_0 Id$

At point P_1 $B_{in} = \mu_0 Jx$

14. Magnetization Intensity (H) :

The magnetic intensity (H) at any point in a magnetic field is defined as $\vec{H} = \dfrac{\vec{B}}{\mu}$, where

B = magnetic induction at the point ; μ = permeability of the medium

15. Gilbert's Magnetism (Earth's Magnetic Field) :

(a) The line of earth's magnetic induction lies in a vetical plane coinciding with the magnetic North - South direction at that place. This plane is called the **magnetic meridian**. Earth's magnetic axis is slightly inclined to the geometric axis of earth and this angle varies from 10.5^0 to 20^0. The Earth's Magnetic poles are opposite to the geometric poles i.e. at earth's north pole, its magnetic south pole is situated and vice versa.

(b) On the magnetic meridian plane , the magnetic induction vector of the earth at any point, generally inclined to the horizontal at an angle called the **MAGNETIC DIP** at that place , such that $\vec{B}$ = total magnetic induction of the earth at that point.

$\vec{B}_v$ = the vertical component of $\vec{B}$ in the magnetic meridian plane = B sin θ .

B_H = the horizontal component of $\vec{B}$ in the magnetic meridian plane = B cos θ .

$\frac{B_v}{B_H} = \tan\theta$.

(c) At a given place on the surface of the earth , the magnetic meridian and the geographic meridian may not coincide . The angle between them is called **"DECLINATION AT THAT PLACE"** .

(d) Lines drawn on earth at different places having same declination angle are called as "isogonic lines" and line of zero declination is called as "agonic lines".

(e) Lines drawn on earth at different places having same dip angle are called as "isoclinic lines" and line of zero dip is called as "aclinic lines".

16. NEUTRAL POINT IN SUPERPOSED MAGNETIC FIELDS :

When more than one magnetic fields are suspended at a point and the vector sum of the magnetic inductions due to different fields , equal to zero , the point is a magnetic neutral point.

17 AMPERES LAW $\oint \vec{B} \cdot d\vec{\ell} = \mu \Sigma I$

Σ I = algebric sum of all the currents .

18. LORENTZ FORCE :

An electric charge 'q' moving with a velocity $\vec{V}$ through a magnetic field of magnetic induction $\vec{B}$ experiences a force $\vec{F}$, given by $\vec{F} = q\vec{V} \times \vec{B}$. There fore, if the charge moves in a space where both electric and magnetic fields are superposed .

$\vec{F}$ = nett electromagnetic force on the charge = $q\vec{E} + q\vec{V} \times \vec{B}$

This force is called the **LORENTZ FORCE .**

19. MOTION OF A CHARGE IN UNIFORM MAGNETIC FIELD :

(a) When $\vec{v}$ is || to $\vec{B}$: Motion will be in a st. line and $\vec{F} = 0$

(b) When $\vec{v}$ is ⊥ to $\vec{B}$: Motion will be in circular path with radius $R = \frac{mv}{qB}$ and angular velocity $\omega = \frac{qB}{m}$ and F = qvB.

(c) When $\vec{v}$ is at ∠ θ to $\vec{B}$: Motion will be helical with radius $R_k = \frac{mv\sin\theta}{qB}$ and pitch $P_H = \frac{2\pi mv\cos\theta}{qB}$ and F = qvBsinθ.

20. MAGNETIC FORCE ON A STRAIGHT CURRENT CARRYING WIRE :

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

I = current in the straight conductor

$\vec{L}$ = length of the conductor in the direction of the current in it

$\vec{B}$ = magnetic induction. (Uniform throughout the length of conduction)

Note : In general force is $\vec{F} = \int I(d\vec{\ell} \times \vec{B})$

21. MAGNETIC INTERACTION FORCE BETWEEN TWO PARALLEL LONG STRAIGHT CURRENTS :

When two long straight linear conductors are parallel and carry a current in each , they magnetically interact with each other , one experiences a force. This force is of :

(i) Repulsion if the currents are anti-parallel (i.e. in opposite direction) or

(ii) Attraction if the currents are parallel (i.e. in the same direction)

This force per unit length on either conductor is given by $F = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{r}$. Where r = perpendicular distance between the parallel conductors

22. MAGNETIC TORQUE ON A CLOSED CURRENT CIRCUIT :

When a plane closed current circuit of 'N' turns and of area 'A' per turn carrying a current I is placed in uniform magnetic field , it experience a zero nett force , but experience a torque given by $\vec{\tau} = NI\,\vec{A}\times\vec{B} = \vec{M}\times\vec{B} = BINA\sin\theta$

When $\vec{A}$ = area vector outward from the face of the circuit where the current is anticlockwise,

$\vec{B}$ = magnetic induction of the uniform magnetic feild. $\vec{M}$ = magnetic moment of the current circuit = $IN\vec{A}$

Note : This expression can be used only if $\vec{B}$ is uniform otherwise calculus will be used.

23. MOVING COIL GALVANOMETER :

It consists of a plane coil of many turns suspended in a radial magnetic feild. when a current is passed in the coil it experiences a torque which produces a twist in the suspension. This deflection is directly proportional to the torque $\therefore$ NIAB = Kθ

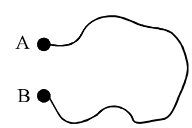
$I = \left(\frac{K}{NAB}\right)\theta$ K = elastic torsional constant of the suspension

$I = C\ \theta$ $C = \frac{K}{NAB}$ = GALVANOMETER CONSTANT.

24. FORCE EXPERIENCED BY A MAGNETIC DIPOLE IN A NON-UNIFORM MAGNETIC FIELD :

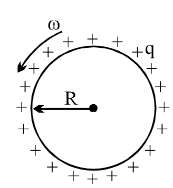
$|\vec{F}| = \left|M\frac{\partial B}{\partial r}\right|$ where M = Magnetic dipole moment.

25. FORCE ON A RANDOM SHAPED CONDUCTOR IN MAGNETIC FIELD



1. Magnetic force on a loop in a uniform $\vec{B}$ is zero
2. Force experienced by a wire of any shape is equivalent to force on a wire joining points A & B in a uniform magnetic field .

26. MAGNETIC MOMENT OF A ROTATING CHARGE:



If a charge q is rotating at an angular velocity ω,

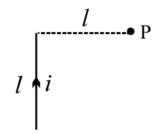
its equivalent current is given as $I = \frac{q\omega}{2\pi}$ & its

magnetic moment is $M = I\pi R^2 = \frac{1}{2}q\omega R^2$.

NOTE: The rate of magnetic moment to Angular momentum of a uniform rotating object which is charged uniformly is always a constant. Irrespective of the shape of conductor $\frac{M}{L} = \frac{q}{2m}$

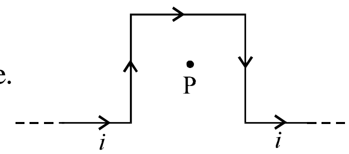
EXERCISE # I

Q.1 Figure shows a straight wire of length l carrying a current i. Find the magnitude of magnetic field produced by the current at point P.

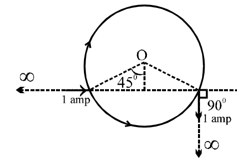


Q.2 Two circular coils A and B of radius $\frac{5}{\sqrt{2}}$ cm and 5 cm respectively carry current 5 Amp and $\frac{5}{\sqrt{2}}$ Amp respectively. The plane of B is perpendicular to plane of A and their centres coincide. Find the magnetic field at the centre.

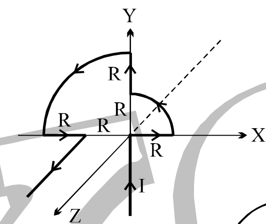
Q.3 Find the magnetic field at the centre P of square of side a shown in figure.



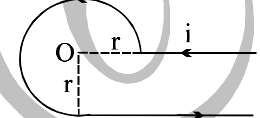
Q.4 What is the magnitude of magnetic field at the centre 'O' of loop of radius $\sqrt{2}$ m made of uniform wire when a current of 1 amp enters in the loop and taken out of it by two long wires as shown in the figure.



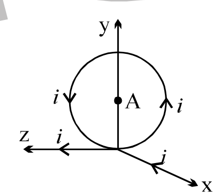
Q.5 Find the magnetic induction at the origin in the figure shown.



Q.6 Find the magnetic induction at point O, if the current carrying wire is in the shape shown in the figure.



Q.7 Find the magnitude of the magnetic induction B of a magnetic field generated by a system of thin conductors along which a current i is flowing at a point A (O, R, O), that is the centre of a circular conductor of radius R. The ring is in yz plane.

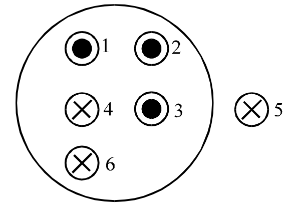


Q.8 Two circular coils of wire each having a radius of 4 cm and 10 turns have a common axis and are 6 cm apart . If a current of 1 A passes through each coil in the opposite direction find the magnetic induction.

(i) At the centre of either coil ;

(ii) At a point on the axis, midway between them.

Q.9 Six wires of current $I_1 = 1A$, $I_2 = 2A$, $I_3 = 3A$, $I_4 = 1A$, $I_5 = 5A$ and $I_6 = 4A$ cut the page perpendicularly at the points 1, 2, 3, 4, 5 and 6 respectively as shown in the figure. Find the value of the integral $\oint \vec{B}.d\vec{l}$ around the closed path.



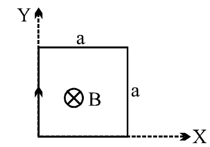
Q.10 Electric charge q is uniformly distributed over a rod of length l. The rod is placed parallel to a long wire carrying a current i. The separation between the rod and the wire is a. Find the force needed to move the rod along its length with a uniform velocity v.

Q.11 An electron moving with a velocity $5 \times 10^6 \, ms^{-1} \, \hat{i}$ in the uniform electric field of $5 \times 10^7 \, Vm^{-1} \, \hat{j}$. Find the magnitude and direction of a minimum uniform magnetic field in tesla that will cause the electron to move undeviated along its original path.

Q.12 A charged particle (charge q, mass m) has velocity v_0 at origin in +x direction. In space there is a uniform magnetic field B in - z direction. Find the y coordinate of particle when is crosses y axis.

Q.13 A conducting circular loop of radius r carries a constant current i. It is placed in a uniform magnetic field $\vec{B}_0$ such that $\vec{B}_0$ is perpendicular to the plane of the loop. Find the magnetic force acting on the loop is

Q.14 A rectangular loop of wire is oriented with the left corner at the origin, one edge along X-axis and the other edge along Y-axis as shown in the figure. A magnetic field is into the page and has a magnitude that is given by $\beta = \alpha y$ where α is contant. Find the total magnetic force on the loop if it carries current i.



Q.15 Two coils each of 100 turns are held such that one lies in the vertical plane with their centres coinciding. The radius of the vertical coil is 20 cm and that of the horizontal coil is 30 cm . How would you neutralize the magnetic field of the earth at their common centre ? What is the current to be passed through each coil ? Horizontal component of earth's magnetic induction = 3.49 x 10^{-5} T and angle of dip = 30º.

Q.16 Find the ratio of magnetic field magnitudes at a distance 10 m along the axis and at 60° from the axis, from the centre of a coil of radius 1 cm, carrying a current 1 amp.

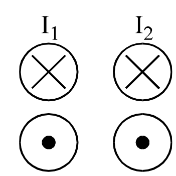
Q.17 A particle of charge +q and mass m moving under the influence of a uniform electric field $E\,\hat{i}$ and a magnetic field $B\,\hat{k}$ enters in I quadrant of a coordinate system at a point (0, a) with initial velocity $v\,\hat{i}$ and leaves the quadrant at a point (2a, 0) with velocity $-2v\,\hat{j}$. Find

(a) Magnitude of electric field

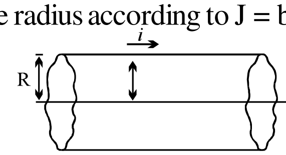
(b) Rate of work done by the electric field at point (0, a)

(c) Rate of work done by both the fields at (2a, 0).

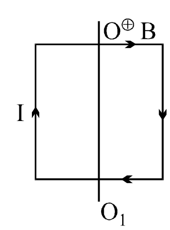
Q.18 A system of long four parallel conductors whose sections with the plane of the drawing lie at the vertices of a square there flow four equal currents. The directions of these currents are as follows :
those marked ⊗ point away from the reader, while those marked with a dot point towards the reader. How is the vector of magnetic induction directed at the centre of the square?



Q.19 A cylindrical conductor of radius R carries a current along its length . The current density J, however, it is not uniform over the cross section of the conductor but is a function of the radius according to J = br, where b is a constant. Find an expression for the magnetic field B.
(a) at $r_1 < R$ & (b) at distance $r_2 > R$, mesured from the axis



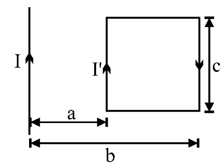
Q.20 A square current carrying loop made of thin wire and having a mass m =10g can rotate without friction with respect to the vertical axis OO_1, passing through the centre of the loop at right angles to two opposite sides of the loop. The loop is placed in a homogeneous magnetic field with an induction B = 10^{-1} T directed at right angles to the plane of the drawing. A current I = 2A is flowing in the loop. Find the period of small oscillations that the loop performs about its position of stable equilibrium.



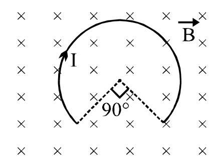
Q.21 A charged particle having mass m and charge q is accelerated by a potential difference V, it flies through a uniform transverse magnetic field B. The field occupies a region of space d. Find the time interval for which it remains inside the magnetic field.

Q.22 A proton beam passes without deviation through a region of space where there are uniform transverse mutually perpendicular electric and magnetic field with E and B. Then the beam strikes a grounded target. Find the force imparted by the beam on the target if the beam current is equal to I.

Q.23 An infinitely long straight wire carries a conventional current I as shown in the figure. The rectangular loop carries a conventional current I' in the clockwise direction. Find the net force on the rectangular loop.



Q.24 An arc of a circular loop of radius R is kept in the horizontal plane and a constant magnetic field B is applied in the vertical direction as shown in the figure. If the arc carries current I then find the force on the arc.



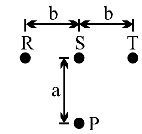
Q.25 Two long straight parallel conductors are separated by a distance of r_1 = 5cm and carry currents i_1 = 10 A & i_2 = 20 A. What work per unit length of a conductor must be done to increase the separation between the conductors to r_2 = 10 cm if, currents flow in the same direction?

<u>List of recommended questions from I.E. Irodov.</u>

3.220, 3.223, 3.224, 3.225, 3.226, 3.227, 3.228, 3.229, 3.230, 3.234, 3.236, 3.237, 3.242 3.243, 3.244, 3.245, 3.251, 3.252, 3.253, 3.254, 3.257, 3.258, 3.269, 3.372, 3.373, 3.383, 3.384, 3.386, 3.389, 3.390, 3.391, 3.396

EXERCISE # II

Q.1 Three infinitely long conductors R, S and T are lying in a horizontal plane as shown in the figure. The currents in the respective conductors are



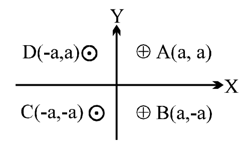
$$I_R = I_0 \sin\left(\omega t + \frac{2\pi}{3}\right)$$
$$I_S = I_0 \sin(\omega t)$$
$$I_T = I_0 \sin\left(\omega t - \frac{2\pi}{3}\right)$$

Find the amplitude of the vertical component of the magnetic field at a point P, distance 'a' away from the central conductor S.

Q.2 Four long wires each carrying current I as shown in the figure are placed at the points A, B, C and D. Find the magnitude and direction of

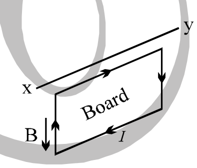
(i) magnetic field at the centre of the square.

(ii) force per metre acting on wire at point D.

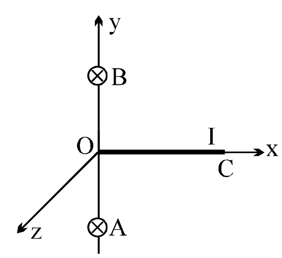


Q.3 An infinite wire, placed along z-axis, has current I_1 in positive z-direction. A conducting rod placed in xy plane parallel to y-axis has current I_2 in positive y-direction. The ends of the rod subtend + 30° and – 60° at the origin with positive x-direction. The rod is at a distance a from the origin. Find net force on the rod.

Q.4 A square cardboard of side *l* and mass *m* is suspended from a horizontal axis XY as shown in figure. A single wire is wound along the periphery of board and carrying a clockwise current I. At t = 0, a vertical downward magnetic field of induction B is switched on. Find the minimum value of B so that the board will be able to rotate up to horizontal level.



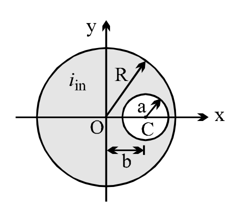
Q.5 A straight segment OC (of length L meter) of a circuit carrying a current I amp is placed along the x-axis. Two infinitely ling straight wires A and B ,each extending form z = – ∞ to + ∞, are fixed at y = – a metre and y = +a metre respectively, as shown in the figure. If the wires A and B each carry a current I amp into plane of the paper. Obtain the expression for the force acting on the segment OC. What will be the force OC if current in the wire B is reversed?



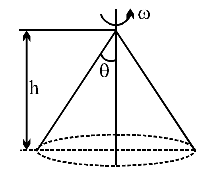
Q.6 A very long straight conductor has a circular cross-section of radius R and carries a current density J. Inside the conductor there is a cylindrical hole of radius *a* whose axis is parallel to the axis of the conductor and a distance b from it. Let the z-axis be the axis of the conductor, and let the axis of the hole be at x = b. Find the magnetic field

(a) on the x = axis at x = 2R

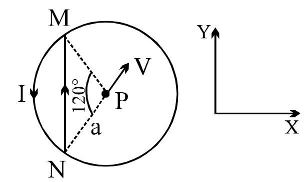
(b) on the y = axis at y = 2R.



Q.7 Q charge is uniformly distributed over the same surface of a right circular cone of semi-vertical angle θ and height h. The cone is uniformly rotated about its axis at angular velocity ω. Calculated associated magnetic dipole moment.



Q.8 A wire loop carrying current I is placed in the X-Y plane as shown in the figure

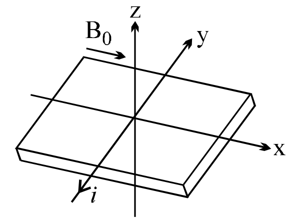


(a) If a particle with charge +Q and mass m is placed at the centre P and given a velocity along NP (fig). Find its instantaneous acceleration

(b) If an external uniform magnetic induction field $\vec{B} = B\,\hat{i}$ is applied, find the torque acting on the loop due to the field.

Q.9 A long straight wire carries a current of 10 A directed along the negative y-axis as shown in figure. A uniform magnetic field B_0 of magnitude 10^{-6} T is directed parallel to the x-axis. What is the resultant magnetic field at the following points?

(a) $x = 0$, $z = 2$ m ; (b) $x = 2$ m, $z = 0$; (c) $x = 0$, $z = -0.5$ m

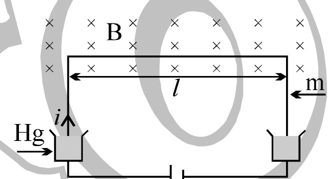


Q.10 A stationary, circular wall clock has a face with a radius of 15cm. Six turns of wire are wound around its perimeter, the wire carries a current 2.0 A in the clockwise direction. The clock is located, where there is a constant , uniform external magnetic field of 70 mT (but the clock still keeps perfect time) at exactly 1:00 pm, the hour hand of the clock points in the direction of the external magnetic field

(a) After how many minutes will the minute hand point in the direction of the torque on the winding due to the magnetic field ?

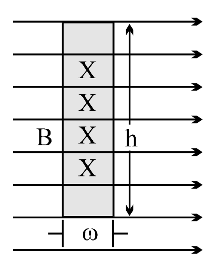
(b) What is the magnitude of this torque.

Q.11 A U-shaped wire of mass m and length l is immersed with its two ends in mercury (see figure). The wire is in a homogeneous field of magnetic induction **B**. If a charge, that is, a current pulse $q = \int i\,dt$, is sent through the wire, the wire will jump up.



Calculate, from the height h that the wire reaches, the size of the charge or current pulse, assuming that the time of the current pulse is very small in comparision with the time of flight. Make use of the fact that impulse of force equals $\int F\,dt$,which equals mv. Evaluate q for $B = 0.1$ Wb/m^2, m = 10gm, ℓ = 20cm & h = 3 meters.[g = 10 m/s^2]

Q.12 A current i, indicated by the crosses in fig. is established in a strip of copper of height h and width w. A uniform field of magnetic induction **B** is applied at right angles to the strip.



(a) Calculate the drift speed v_d for the electrons.

(b) What are the magnitude and dirction of the magnetic force **F** acting on the electrons?

(c) What would the magnitude & direction of homogeneous electric field **E** have to be in order to counter balance the effect of the magnetic field ?

(d) What is the voltage V necessary between two sides of the conductor in order to create this field E? Between which sides of the conductor would this voltage have to be applied ?

(e) If no electric field is applied form the outside the electrons will be pushed somewhat to one side & thereforce will give rise to a uniform electric field E_H across the conductor untill the force of this electrostatic field E_H balanace the magnetic forces encountered in part (b) . What will be the magnitude and direction of the field $\mathbf{E}_H$? Assume that n, the number of conduction electrons per unit volume, is 1.1×10^{29}/m^3 & that h = 0.02 meter , w = 0.1cm , i = 50 amp , & B = 2 webers/meter^2.

Q.13(a) A rigid circular loop of radius r & mass m lies in the xy plane on a flat table and has a current I flowing in it. At this particular place, the earth's magnetic field is $\vec{B} = \vec{B}_x\,\hat{i} + \vec{B}_y\,\hat{j}$. How large must I be before one edge of the loop will lift from table ?

(b) Repeat if, $\vec{B} = \vec{B}_x\,\hat{i} + \vec{B}_z\,\hat{k}$.

Q.14 Zeeman effect . In Bohr's theory of the hydrogen atom the electron can be thought of as moving in a circular orbit of radius r about the proton . Suppose that such an atom is placed in a magnetic field, with the plane of the orbit at right angle to B.

(a) If the electron is circulating clockwise, as viewed by an observer sighting along B, will the angular frequency increase or decrease?

(b) What if the electron is circulating counterclockwise? Assume that the orbit radius does not change.

Q.15 In above problem show that the change in frequency of rotation caused by the magnete field is given approximately by $\Delta v = \pm\dfrac{Be}{4\pi m}$. Such frequency shifts were actually observed by Zeeman in 1896.

Q.16 A square loop of wire of edge a carries a current i .

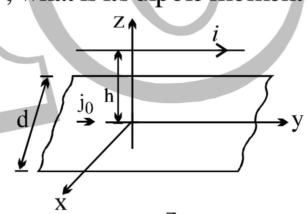
(a) Show that B for a point on the axis of the loop and a distance x from its centre is given by,

$$B = \frac{4\mu_0 i a^2}{\pi\left(4x^2 + a^2\right)\left(4x^2 + 2a^2\right)^{1/2}} .$$

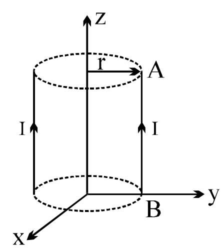
(b) Can the result of the above problem be reduced to give field at $x = 0$?

(c) Does the square loop behave like a dipole for points such that $x >> a$? If so , what is its dipole moment?

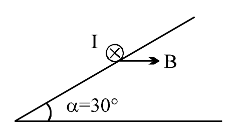
Q.17 A conductor carrying a current i is placed parallel to a current per unit width j_0 and width d, as shown in the figure. Find the force per unit lenght on the coductor.



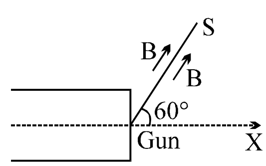
Q.18 Find the work and power required to move the conductor of length l shown in the fig. one full turn in the anticlockwise direction at a rotational frequency of n revolutions per second if the magnetic field is of magnitude B_0 everywhere and points radially outwards from Z-axis. The figure shows the surface traced by the wire AB.



Q.19 The figure shows a conductor of weight 1.0 N and length L = 0.5 m placed on a rough inclined plane making an angle 30^0 with the horizontal so that conductor is perpendicular to a uniform horizontal magnetic field of induction B = 0.10 T. The coefficient of static friction between the conductor and the plane is 0.1. A current of I = 10 A flows through the conductor inside the plane of this paper as shown. What is the force needed to be the applied parallel to the inclined plane to sustaining the conductor at rest?



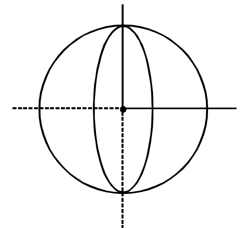
Q.20 An electron gun G emits electron of energy 2kev traveling in the (+)ve x-direction. The electron are required to hit the spot S where GS = 0.1m & the line GS makes an angle of 60° with the x-axis, as shown in the fig. A uniform magnetic field $\vec{B}$ parallel to GS exists in the region outsiees to electron gun. Find the minimum value of B needed to make the electron hit S .



EXERCISE # III

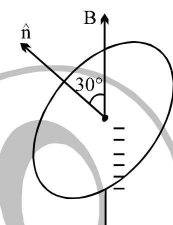
Q.1 A battery is connected between two points A and B the circumference of a uniform conducting ring of radius r and resistance R . One of the arcs AB of the ring subtends an angle θ at the centre . The value of the magnetic induction at the centre due to the current in the ring is : [JEE '95, 2]
(A) zero , only if $\theta = 180^\circ$
(B) zero for all values of θ
(C) proportional to $2(180^\circ - \theta)$
(D) inversely proportional to r

Q.2 Two insulated rings, one slightly smaller diameter than the other, are suspended along their diameter as shown, initially the planes of the rings are mutually perpendicular when a steady current is set up in each of them : [IIT '95, 1]



(A) The two rings rotate to come into a common plane
(B) The inner ring oscillates about its initially position
(C) The outer ring stays stationary while the inner one moves into the plane of the outer ring
(D) The inner ring stays stationary while the outer one moves into the plane of the inner ring

Q.3 An electron in the ground state of hydrogen atom is revolving in anticlock-wise direction in a circular orbit of radius R .
(i) Obtain an expression for the orbital magnetic dipole moment of the electron
(ii) The atom is placed in a uniform magnetic. Induction $\vec{B}$ such that the plane normal of the electron orbit makes an angle of 30^0 with the magnetic induction. Find the torque experienced by the orbiting electron. [JEE '96, 5]



Q.4 A proton, a deuteron and an α-particle having the same kinetic energy are moving in circular trajectories in a constant magnetic field . If r_p, r_d & r_α denote respectively the radii of the trajectories of these particles then : [JEE '97, 1]
(A) $r_\alpha = r_p < r_d$ (B) $r_\alpha > r_d > r_p$ (C) $r_\alpha = r_d > r_p$ (D) $r_p = r_d = r_\alpha$

Q.5 3 infinitely long thin wires each carrying current i in the same direction , are in the x-y plane of a gravity free space . The central wire is along the y-axis while the other two are along $x = \pm d$.
(i) Find the locus of the points for which the magnetic field B is zero .
(ii) If the central wire is displaced along the z-direction by a small amount & released, show that it will execute simple harmonic motion . If the linear density of the wires is λ , find the frequency of oscillation. [JEE '97, 5]

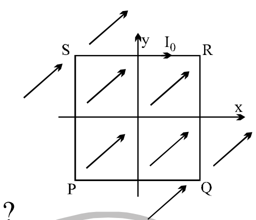
Q.6 Select the correct alternative(s) . [JEE '98, 2 + 2 + 2]
(i) Two very long, straight, parallel wires carry steady currents I & $-$I respectively. The distance between the wires is d. At a certain instant of time, a point charge q is at a point equidistant from the two wires, in the plane of the wires . Its instantaneous velocity $\vec{v}$ is perpendicular to this plane. The magnitude of the force due to the magnetic field acting on the charge at this instant is :
(A) $\frac{\mu_0 Iqv}{2\pi d}$ (B) $\frac{\mu_0 Iqv}{\pi d}$ (C) $\frac{2\mu_0 Iqv}{\pi d}$ (D) 0
(ii) Let $[\in_0]$ denote the dimensional formula of the permittivity of the vaccum and $[\mu_0]$ that of the permeability of the vacuum . If M = mass, L = length, T = time and I = electric current ,
(A) $[\in_0] = M^{-1} L^{-3} T^2 I$ (B) $[\in_0] = M^{-1} L^{-3} T^4 I^2$ (C) $[\mu_0] = MLT^{-2} I^{-2}$ (D) $[\mu_0] = ML^2 T^{-1} I$

(iii) Two particles, each of mass m & charge q, are attached to the two ends of a light rigid rod of length $2R$. The rod is rotated at constant angular speed about a perpendicular axis passing through its centre. The ratio of the magnitudes of the magnetic moment of the system & its angular momentum about the centre of the rod is :

(A) $\frac{q}{2m}$ (B) $\frac{q}{m}$ (C) $\frac{2q}{m}$ (D) $\frac{q}{\pi m}$

Q.7 A particle of mass m & charge q is moving in a region where uniform, constant electric and magnetic fields $\vec{E}$ & $\vec{B}$ are present, $\vec{E}$ & $\vec{B}$ are parallel to each other. At time t = 0 the velocity $\vec{v}_0$ of the particle is perpendicular to $\vec{E}$. (assume that its speed is always << c, the speed of light in vacuum). Find the velocity $\vec{v}$ of the particle at time t. You must express your answer in terms of t, q, m, the vectors $\vec{v}_0$, $\vec{E}$ & $\vec{B}$ and their magnitudes v_0, E & B. [JEE '98, 8]

Q.8 A uniform, constant magnetic field $\vec{B}$ is directed at an angle of 45° to the x-axis in the xy-plane, PQRS is a rigid square wire frame carrying a steady current I_0(clockwise), with its centre at the origin O. At time t = 0, the frame is at rest in the position shown in the figure, with its sides parallel to the x & y axes. Each side of the frame is of mass M & length L.



(a) What is the torque $\vec{\tau}$ about O acting on the frame due to the magnetic field ?

(b) Find the angle by which the frame rotates under the action of this torque in a short interval of time Δt, & the axis about which this rotation occurs (Δt is so short that any variation in the torque during this interval may be neglected) Given the moment of inertia of the frame about an axis through its centre perpendicular to its plane is 4/3 ML^2. [JEE '98, 2 + 6]

Q 9 A charged particle is released from rest in a region of steady and uniform electric and magnetic fields which are parallel to each other. The particle will move in a

(A) straight line (B) circle (C) helix (D) cycloid [JEE'99, 2]

Q.10 The region between x = 0 and x = L is filled with uniform, steady magnetic field $B_0\hat{k}$. A particle of mass *m*, positive charge q and velocity $v_0\hat{i}$ travels along x-axis and enters the region of the magnetic field. Neglect the gravity throughout the question.

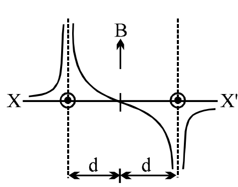
(a) Find the value of L if the particle emerges from the region of magnetic field with its final velocity at an angle 30° to its initial velocity.

(b) Find the final velocity of the particle and the time spent by it in the magnetic field, if the magnetic field now extends upto 2.1L. [JEE '99, 6 + 4]

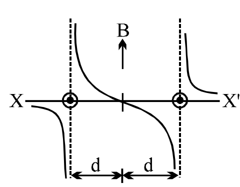
Q.11 (i) A particle of charge q and mass m moves in a circular orbit of radius r with angular speed ω. The ratio of the magnitude of its magnetic moment to that of its angular momentum depends on

(A) ω and q (B) ω, q and m (C) q and m (D) ω and m

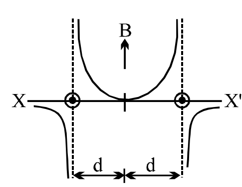
(ii) Two long parallel wires are at a distance 2d apart. They carry steady equal currents flowing out of the plane of the paper, as shown. The variation of the magnetic field B along the XX' is given by



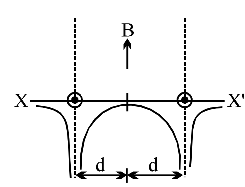
(A)



(B)

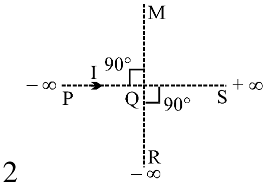


(C)



(D)

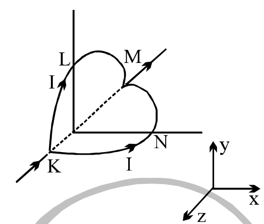
(iii) An infinitely long conductor PQR is bent to form a right angle as shown. A current I flows through PQR. The magnetic field due to this current at the point M is H_1. Now, another infinitely long straight conductor QS is connected at Q so that the current in PQ remaining unchanged. The magnetic field at M is now H_2. The ratio H_1/H_2 is given by



(A) 1/2 (B) 1 (C) 2/3 (D) 2

(iv) An ionized gas contains both positive and negative ions. If it is subjected simultaneously to an electric field along the +x direction and a magnetic field along the +z direction, then
(A) positive ions deflect towards +y direction and negative ions towards −y direction
(B) all ions deflect towards +y direction.
(C) all ions deflect towards −y direction
(D) positive ions deflect towards −y direction and negative ions towards +y direction.[JEE 2000 (Scr)]

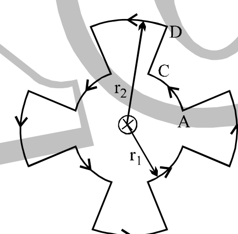
Q.12 A circular loop of radius R is bent along a diameter and given a shape as shown in the figure. One of the semicircles (KNM) lies in the $x-z$ plane and the other one (KLM) in the $y-z$ plane with their centers at the origin. Current I is flowing through each of the semicircles as shown in figure.



(i) A particle of charge q is released at the origin with a velocity $v = -v_0\,\hat{i}$. Find the instantaneous force f on the particle. Assume that space is gravity free.

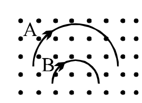
(ii) If an external uniform magnetic field $B\,\hat{j}$ is applied, determine the forces F_1 and F_2 on the semicircles KLM and KNM due to this field and the net force F on the loop. [JEE 2000 Mains, 4 + 6]

Q.13 A current of 10A flows around a closed path in a circuit which is in the horizontal plane as shown in the figure. The circuit consists of eight alternating arcs of radii $r_1 = 0.08$ m and $r_2 = 0.12$ m. Each arc subtends the same angle at the centre.



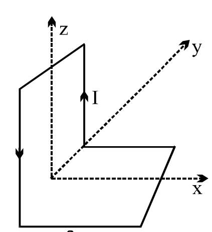
(a) Find the magnetic field produced by this circuit at the centre.
(b) An infinitely long straight wire carrying a current of 10A is passing through the centre of the above circuit vertically with the direction of the current being into the plane of the circuit. What is the force acting on the wire at the centre due to the current in the circuit? What is the force acting on the arc AC and the straight segment CD due to the current at the centre? [JEE 2001, 5 + 5]

Q.14 Two particles A and B of masses m_A and m_B respectively and having the same charge are moving in a plane. A uniform magnetic field exists perpendicular to this plane. The speeds of the particles are v_A and v_B respectively and the trajectories are as shown in the figure. Then



(A) $m_Av_A < m_Bv_B$ (B) $m_Av_A > m_Bv_B$
(C) $m_A < m_B$ and $v_A < v_B$ (D) $m_A = m_B$ and $v_A = v_B$ [JEE, 2001 (Scr)]

Q.15 A non-planar loop of conducting wire carrying a current I is placed as shown in the figure. Each of the straight sections of the loop is of length 2a. The magnetic field due to this loop at the point P (a, 0, a) points in the direction



(A) $\frac{1}{\sqrt{2}}(-\hat{j}+\hat{k})$ (B) $\frac{1}{\sqrt{3}}(-\hat{j}+\hat{k}+\hat{i})$

(C) $\frac{1}{\sqrt{3}}(\hat{i}+\hat{j}+\hat{k})$ (D) $\frac{1}{\sqrt{2}}(\hat{i}+\hat{k})$ [JEE, 2001 (Scr)]

Q.16 A coil having N turns is wound tightly in the form of a spiral with inner and outer radii a and b respectively. When a current I passes through the coil, the magnetic field at the centre is [JEE, 2001 Screening]

(A) $\frac{\mu_0 NI}{b}$ (B) $\frac{2\mu_0 NI}{a}$ (C) $\frac{\mu_0 NI}{2(b-a)} \ln\frac{b}{a}$ (D) $\frac{\mu_0 I^N}{2(b-a)} \ln\frac{b}{a}$

Q.17 A particle of mass m and charge q moves with a constant velocity v along the positive x direction. It enters a region containing a uniform magnetic field B directed along the negative z direction, extending from x = a to x = b. The minimum value of v required so that the particle can just enter the region x > b is

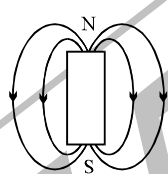
(A) q b B/m (B) q(b – a) B/m (C) q a B/m (D) q(b + a) B/2m

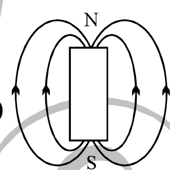
[JEE 2002 (screening), 3]

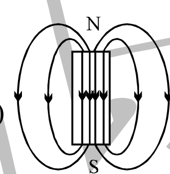
Q.18 A long straight wire along the z-axis carries a current I in the negative z direction. The magnetic vector field $\vec{B}$ at a point having coordinates (x, y) in the z = 0 plane is [JEE 2002 (screening), 3]

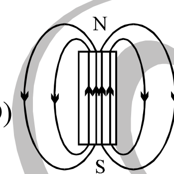
(A) $\frac{\mu_0 I}{2\pi}\frac{(y\hat{i}-x\hat{j})}{(x^2+y^2)}$ (B) $\frac{\mu_0 I}{2\pi}\frac{(x\hat{i}+y\hat{j})}{(x^2+y^2)}$ (C) $\frac{\mu_0 I}{2\pi}\frac{(x\hat{j}-y\hat{i})}{(x^2+y^2)}$ (D) $\frac{\mu_0 I}{2\pi}\frac{(x\hat{i}-y\hat{j})}{(x^2+y^2)}$

Q.19 The magnetic field lines due to a bar magnet are correctly shown in [JEE 2002 (screening), 3]

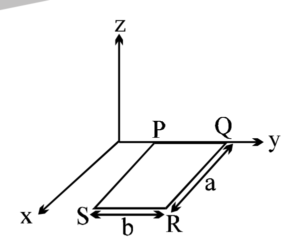
(A) 

(B) 

(C) 

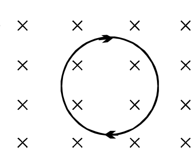
(D) 

Q.20 A rectangular loop PQRS made from a uniform wire has length a, width b and mass m. It is free to rotate about the arm PQ, which remains hinged along a horizontal line taken as the y-axis (see figure). Take the vertically upward direction as the z-axis. A uniform magnetic field $\vec{B} = (3\hat{i} + 4\hat{k})B_0$ exists in the region. The loop is held in the x-y plane and a current I is passed through it. The loop is now released and is found to stay in the horizontal position in equilibrium.



(a) What is the direction of the current I in PQ?
(b) Find the magnetic force on the arm RS.
(c) Find the expression for I in terms of B_0, a, b and m. [JEE 2002, 1+1+3]

Q.21 A circular coil carrying current I is placed in a region of uniform magnetic field acting perpendicular to a coil as shown in the figure. Mark correct option [JEE 2003 (Scr)]



(A) coil expands (B) coil contracts
(C) coil moves left (D) coil moves right

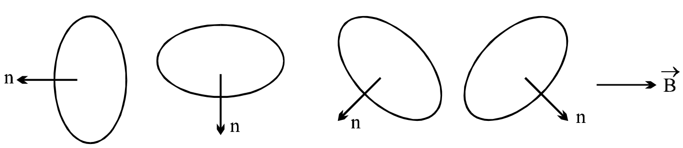
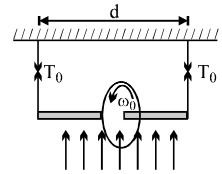
Q.22 

Figure represents four positions of a current carrying coil is a magnetic field directed towards right. $\hat{n}$ represent the direction of area of vector of the coil. The correct order of potential energy is : [JEE 2003 (Scr)]

(A) I > III > II > IV (B) I < III < II < IV
(C) IV < I < II < II (D) II > II > IV > I

Q.23 A wheel of radius R having charge Q, uniformly distributed on the rim of the wheel is free to rotate about a light horizontal rod. The rod is suspended by light inextensible stringe and a magnetic field B is applied as shown in the figure. The initial tensions in the strings are T_0. If the breaking tension of the strings are $\frac{3T_0}{2}$, find the maximum angular velocity ω_0 with which the wheel can be rotate. [JEE 2003]



Q.24 A proton and an alpha particle, after being accelerated through same potential difference, enter a uniform magnetic field the direction of which is perpendicular to their velocities. Find the ratio of radii of the circular paths of the two particles. [JEE 2004]

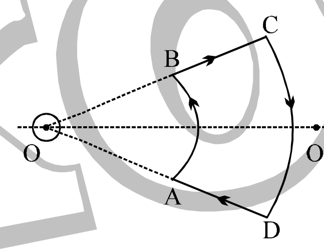
Q.25 In a moving coil galvanometer, torque on the coil can be expressed as $\tau = ki$, where i is current through the wire and k is constant. The rectangular coil of the galvanometer having numbers of turns N, area A and moment of inertia I is placed in magnetic field B. Find

(a) k in terms of given parameters N, I, A and B.

(b) the torsional constant of the spring, if a current i_0 produces a deflection of $\pi/2$ in the coil in reaching equilibrium position.

(c) the maximum angle through which coil is deflected, id charge Q is passed through the coil almost instantaneously. (Ignore the damping in mechanical oscillations) [JEE 2005]

Q.26 An infinite current carrying wire passes through point O and in perpendicular to the plane containing a current carrying loop ABCD as shown in the figure. Choose the correct option (s).



(A) Net force on the loop is zero.
(B) Net torque on the loop is zero.
(C) As seen from O, the loop rotates clockwise.
(D) As seen from O, the loop rotates anticlockwise [JEE 2006]

ANSWER KEY

EXERCISE # I

Q.1 $\dfrac{\sqrt{2}\,\mu_0 i}{8\pi l}$ Q.2 $\dfrac{\sqrt{5}}{2\sqrt{2}}\,4\pi \times 10^{-5}$ T Q.3 $\dfrac{(2\sqrt{2}-1)\mu_0 i}{\pi a}$

Q.4 zero Q.5 $\dfrac{\mu_0 I}{4R}\left(\dfrac{3}{4}\hat{k}+\dfrac{1}{\pi}\hat{j}\right)$ Q.6 $\dfrac{\mu_0 i}{4\pi r}\left[\dfrac{3}{2}\pi+1\right]$

Q.7 $B = \dfrac{\mu_0 i}{4\pi R}\sqrt{2\left(2\pi^2 - 2\pi + 1\right)}$ Q.8 (i) 1.3×10^{-4}T, (ii) zero Q.9 μ_0 weber.m^{-1}

Q.10 $\dfrac{\mu_0 iqv}{2\pi a}$ Q.11 $10\hat{k}$ Q.12 $\dfrac{2mv_0}{qB}$ Q.13 zero

Q.14 $F = \alpha a^2 i\,\hat{j}$ Q.15 $i_1 = 0.1110$ A, $i_2 = 0.096$ A Q.16 $4/\sqrt{7}$

Q.17 (a) $\dfrac{3mv^2}{4qa}$, (b) $\dfrac{3mv^3}{4a}$, (c) zero Q.18 In the plane of the drawing from right to left

Q.19 $B_1 = \dfrac{\mu_0 b r_1^2}{3}$, $B_2 = \dfrac{\mu_0 b R^3}{3r_2}$ Q.20 $T_0 = 2\pi\sqrt{\dfrac{m}{6IB}} = 0.57$ s

Q.21 $t = m\dfrac{\alpha}{qB}$, where $\alpha = \sin^{-1}\left(\dfrac{dB\sqrt{q}}{\sqrt{2mV}}\right)$

Q.22 $\dfrac{mEI}{Be}$ Q.23 $\dfrac{\mu_0 I I' C}{2\pi}\left[\dfrac{1}{a}-\dfrac{1}{b}\right]$ to the left

Q.24 $\sqrt{2}$ I R B Q.25 $\dfrac{W}{\ell} = \dfrac{\mu_0 I_1 I_2}{2\pi}\,\ell n\dfrac{r_2}{r_1} = 27.6\ \mu$J/m

EXERCISE # II

Q.1 $\dfrac{\mu_0 I_0}{2\pi}\dfrac{\sqrt{3}\,b}{(a^2+b^2)}$ Q.2 (i) $\dfrac{\mu_0}{4\pi}\left(\dfrac{4I}{a}\right)$ along Y-axis,

(ii) $\dfrac{\mu_0}{4\pi}\left(\dfrac{I^2}{2a}\right)\sqrt{10}$, $\tan^{4}\left(\dfrac{1}{3}\right)+\pi$ with positive axis

Q.3 $\frac{\mu_0 I_1 I_2}{4\pi} \ln(3)$ along – ve z direction

Q.4 $\frac{mg}{2Il}$

Q.5 $F = \left(\frac{\mu_0 I^2}{2\pi}\right) \ell n\left(\frac{L^2 + a^2}{a^2}\right) \left(-\hat{k}\right)$, zero

Q.6 (a) $B = \frac{\mu_0 J}{2}\left(\frac{a^2}{2R-b} - \frac{R}{2}\right)$, (b) $B_x = \mu_0 J R\left(\frac{1}{4} - \frac{a^2}{4R^2+b^2}\right)$, $B_y = -\frac{\mu_0 J}{2}\left(\frac{a^2 b}{4R^2+b^2}\right)$

Q.7 $\frac{Q_\omega}{4} h^2 \tan^2\theta$

Q.8 (a) $\frac{QV}{m}\frac{\mu_0 I}{6a}\left(\frac{3\sqrt{3}}{\pi} - 1\right)$, (b) $\vec{\tau} = BI\left(\frac{\pi}{3} - \frac{\sqrt{3}}{4}\right)a^2\hat{j}$

Q.9 **(a)** 0 **(b)** 1.41×10^{-6} T, 45° in xz-plane, **(c)** 5×10^{-6} T, +x-direction]

Q.10 **(a)** 20 min. **(b)** 5.94×10^{-2} Nm

Q.11 $\sqrt{15}$ C

Q.12 **(a)** 1.4×10^{-4} m/s **(b)** 4.5×10^{-23} N (down) **(c)** 2.8×10^{-4} V/m (down)
(d) 5.7×10^{-6} V (top +, bottom –) **(e)** same as (c)

Q.13 **(a)** $I = \frac{mg}{\pi r\left(B_x^2 + B_y^2\right)^{1/2}}$ **(b)** $I = \frac{mg}{\pi r B_x}$

Q.14 **(a)** increase, **(b)** decrease

Q.17 $\frac{\mu_0 i J_0}{\pi} \tan^{-1}\left(\frac{d}{2h}\right)(-\hat{k})$

Q.18 $-2\pi r B_0 i l$, $-2\pi r B_0 i l n$

Q.19 $0.62 \text{ N} < F < 0.88 \text{ N}$

Q.20 $B_{min} = 4.7 \times 10^{-3}$ T

EXERCISE # III

Q.1 B

Q.2 A

Q.3 (i) $m = \frac{eh}{4\pi m}$; $|\vec{\tau}| = \frac{ehB}{8\pi m}$

Q.4 A

Q.5 $z = 0, x = \pm\frac{d}{\sqrt{3}}$, (ii) $\frac{I}{2\pi d}\sqrt{\frac{\mu_0}{\pi\lambda}}$

Q.6 (i) D (ii) B, C (iii) A

Q.7 $\vec{v} = \frac{q}{m}\vec{E}t + \vec{v}_0 \cos\omega t + [v_0 \sin\omega t]\,\hat{k}$, where $\omega = \frac{qB}{m}$; $\hat{k} = (\vec{v}_0 \times \vec{E})/|\vec{v}_0 \times \vec{E}|$

Q.8 (a) $\vec{\tau} = \frac{BI_0L^2}{\sqrt{2}}\left(\hat{i} - \hat{j}\right)$ (b) $\theta = \frac{3}{4}\frac{BI_0}{M}\Delta t^2$

Q.9 A

Q.10 (a) $\frac{mv_0}{2qB_0}$ (b)velocity=-v, time= $\frac{\pi m}{qB_0}$ Q.11 (i) C (ii) B (iii) C (iv) C

Q.12 (i) $-\frac{\mu_0 I}{4R} q v_0 \hat{k}$ (ii) $F_1 = 2IRB$ $F_2 = 2IRB$, Net force $= F_1 + F_2 = 4IRB\,\hat{i}$

Q.13 (a) 6.6×10^{-5}T, (b) 0, 0, 8×10^{-6}Nt

Q.14 B Q.15 D Q.16 C Q.17 B Q.18 A Q.19 D

Q.20 (a) current in loop PQRS is clockwise from P to QRS., (b) $\vec{F} = BI_0 b\,(3\hat{k}-4\hat{i})$, (c) $I = \frac{mg}{6bB_0}$

Q.21 A Q.22 A Q.23 $\omega = \frac{dT_0}{QR^2B}$ Q.24 $\frac{r_p}{r_\alpha} = \sqrt{\frac{m_p}{m_\alpha}.\frac{q_\alpha}{q_p}} = \frac{1}{\sqrt{2}}$

Q.25 (a) k = NAB, (b) $C = \frac{2i_0 NAB}{\pi}$, (c) $Q \times \sqrt{\frac{NAB\pi}{2li_0}}$ Q.26 A,C