

**Multiple Choice Questions I**

**4.1. Two charged particles traverse identical helical paths in a completely opposite sense in a uniform**

$$B = B_0 \hat{k}$$

**magnetic field**

- a) they have equal z-components of momenta
- b) they must have equal charges
- c) they necessarily represent a particle-antiparticle pair
- d) the charge to mass ratio satisfy:  $(e/m)_1 + (e/m)_2 = 0$

**Answer:**

- d) the charge to mass ratio satisfy:  $(e/m)_1 + (e/m)_2 = 0$

**4.2. Biot-Savart law indicates that the moving electrons produce a magnetic field B such that**

- a)  $B \perp v$
- b)  $B \parallel v$
- c) it obeys inverse cube law
- d) it is along the line joining the electrons and point of observation

**Answer:**

- a)  $B \perp v$

**4.3. A current circular loop of radius R is placed in the x-y plane with centre at the origin. Half of the loop with  $x > 0$  is now bent so that it now lies in the y-z plane.**

- a) the magnitude of magnetic moment now diminishes
- b) the magnetic moment does not change
- c) the magnitude of B at  $(0,0,z), z \gg R$  increases
- d) the magnitude of B at  $(0,0,z), z \gg R$  is unchanged

**Answer:**

- a) the magnitude of magnetic moment now diminishes

**4.4. An electron is projected with uniform velocity along the axis of a current carrying long solenoid. Which of the following is true?**

- a) the electron will be accelerated along the axis
- b) the electron path will be circular about the axis
- c) the electron will experience a force at  $45^\circ$  to the axis and hence execute a helical path
- d) the electron will continue to move with uniform velocity along the axis of the solenoid

**Answer:**

- d) the electron will continue to move with uniform velocity along the axis of the solenoid

**4.5. In a cyclotron, a charged particle**

- a) undergoes acceleration all the time
- b) speeds up between the dees because of the magnetic field
- c) speeds up in a dee
- d) slows down within a dee and speeds up between dees

**Answer:**

- c) speeds up in a dee

**4.6. A circular current loop of magnetic moment M is in an arbitrary orientation in an external magnetic field B. The work done to rotate the loop by  $30^\circ$  about an axis perpendicular to its plane is**

- a) MB

- b)  $\sqrt{3} MB/2$   
c)  $MB/2$   
d) zero

**Answer:**

d) zero

## Multiple Choice Questions II

**4.7. The gyro-magnetic ratio of an electron in an H-atom, according to Bohr model is**

- a) independent of which orbit it is in  
b) negative  
c) positive  
d) increases with the quantum number  $n$

**Answer:**

- a) independent of which orbit it is in  
b) negative

**4.8. Consider a wire carrying a steady current,  $I$  placed in a uniform magnetic field  $B$  perpendicular to its length. Consider the charges inside the wire. It is known that magnetic forces do not work. This implies that**

- a) motion of charges inside the conductor is unaffected by  $B$  since they do not absorb energy  
b) some charges inside the wire move to the surface as a result of  $B$   
c) if the wire moves under the influence of  $B$ , no work is done by the force  
d) if the wire moves under the influence of  $B$ , no work is done by the magnetic force on the ions, assumed fixed within the wire

**Answer:**

- b) some charges inside the wire move to the surface as a result of  $B$   
d) if the wire moves under the influence of  $B$ , no work is done by the magnetic force on the ions, assumed fixed within the wire

**4.9. Two identical current carrying coaxial loops, carry current  $I$  in an opposite sense. A simple amperian loop passes through both of them once. Calling the loop as  $C$ ,**

a)

$$\oint_C B \cdot dl = \mp 2\mu_0 I$$

$$\oint_C B \cdot dl$$

- b) the value of  $\oint_C B \cdot dl$  is independent of sense of  $C$   
c) there may be a point on  $C$  where  $B$  and  $dl$  are perpendicular  
d)  $B$  vanishes everywhere on  $C$

**Answer:**

$$\oint_C B \cdot dl$$

- b) the value of  $\oint_C B \cdot dl$  is independent of sense of  $C$

c) there may be a point on C where B and dl are perpendicular

**4.10. A cubical region of space is filled with some uniform electric and magnetic fields. An electron enters the cube across one of its faces with velocity v and a positron enters via opposite face with velocity -v. At this instant,**

- a) the electric forces on both the particles cause identical acceleration
- b) the magnetic forces on both the particles cause equal accelerations
- c) both particles gain or lose energy at the same rate
- d) the motion of the centre of mass (CM) is determined by B alone

**Answer:**

- b) the magnetic forces on both the particles cause equal accelerations
- c) both particles gain or lose energy at the same rate
- d) the motion of the centre of mass (CM) is determined by B alone

**4.11. A charged particle would continue to move with a constant velocity in a region wherein,**

- a)  $E = 0, B \neq 0$
- b)  $E \neq 0, B \neq 0$
- c)  $E \neq 0, B = 0$
- d)  $E = 0, B = 0$

**Answer:**

- a)  $E = 0, B \neq 0$
- b)  $E \neq 0, B \neq 0$
- d)  $E = 0, B = 0$

### Very Short Answers

**4.12. Verify that the cyclotron frequency  $\omega = eB/m$  has the correct dimensions of  $[T]^{-1}$ .**

**Answer:**

The path traced by the particle in a cyclotron is a circular path in which magnetic force acts as a centripetal force  
 $mv^2/R = evB$

$$eB/m = v/R = \omega$$

$$B = F/ev = [MLT^{-2}]/[AT][LT^{-1}] = [MA^{-1}T^{-2}]$$

$$[\omega] = [eB/m] = [v/R] = [T]^{-1}$$

**4.13. Show that a force that does no work must be a velocity dependent force.**

**Answer:**

$$dW = \vec{F} \cdot \vec{dl} = 0$$

$$\vec{F} \cdot \vec{v} dt = 0$$

$$\vec{F} \cdot \vec{v} = 0$$

**4.14. The magnetic force depends on v which depends on the inertial frame of reference. Does then the magnetic force differ from inertial frame to frame? Is it reasonable that the net acceleration has a different value in different frames of reference?**

**Answer:**

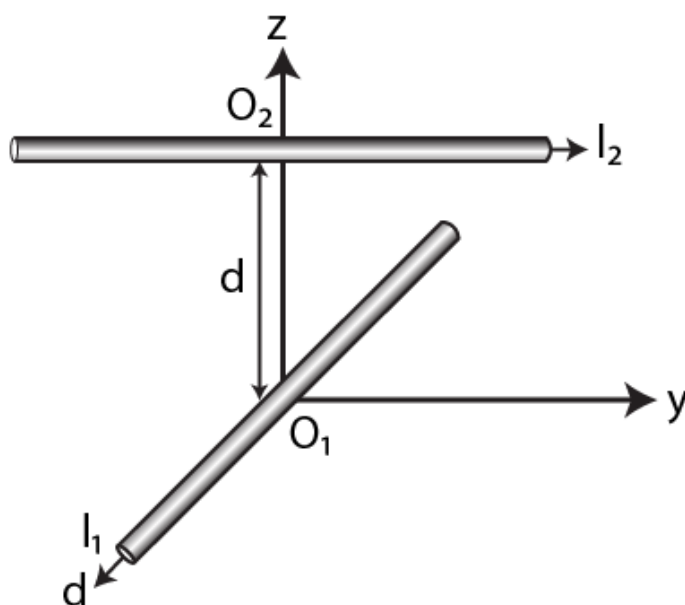
The net acceleration can have a different value in different frames of reference as velocity depends on frame of reference.

**4.15. Describe the motion of a charged particle in a cyclotron if the frequency of the radio frequency (rf) field were doubled.**

**Answer:**

When the frequency of the radio frequency field were doubled, the time period of the radio frequency is halved which results in half revolution of the charges.

**4.16. Two long wires carrying current  $I_1$  and  $I_2$  are arranged as shown in the figure. The one carrying  $I_1$  is along the x-axis. The other carrying current  $I_2$  is along a line parallel to the y-axis given by  $x = 0$  and  $z = d$ . Find the force exerted at  $O_2$  because of the wire along the x-axis.**



**Answer:**

The magnetic field  $B$  on a current carrying conductor is given as  $F = I(L \times B) = ILB \sin\theta$

$O_2$  and  $I_1$  are parallel to the y-axis and are in the direction of  $-Y$

$I_2$  is parallel to the y-axis and is along Y-axis therefore, the angle between  $I_2$  and  $B_1$  is zero. The magnetic force  $F_2$  is given as  $F_2 = B_1 I_2 L_1 \sin 0^\circ = 0$

Therefore, the force on  $O_2$  has current  $I_1$  zero.

## Short Answers

**4.17. A current carrying loop consists of 3 identical quarter circles of radius  $R$ , lying in the positive quadrants of the x-y, y-z, and z-x planes with their centres at the origin, joined together. Find the direction and magnitude of  $B$  at the origin.**

**Answer:**

The vector sum of the magnetic field at the origin due to the quarter is given as

$$\vec{B}_{net} = \frac{1}{4} \left( \frac{\mu_0 I}{2R} \right) (\hat{i} + \hat{j} + \hat{k})$$

**4.18.** A charged particle of charge  $e$  and mass  $m$  is moving in an electric field  $E$  and magnetic field  $B$ . Construct dimensionless quantities and quantities of dimension  $[T]^{-1}$ .

**Answer:**

$$mv^2/R = evB$$

$$eB/m = v/R = \omega$$

$$B = F/ev = [MA^{-1}T^{-2}]$$

$$[\omega] = [eB/m] = [v/R] = [T^{-1}]$$

**4.19.** An electron enters with a velocity  $v = v_0\hat{i}$  into a cubical region in which there are uniform electric and magnetic fields. The orbit of the electron is found to spiral down inside the cube in plane parallel to the  $x$ - $y$  plane. Suggest a configuration of fields  $E$  and  $B$  that can lead to it.

**Answer:**

The configuration of the fields  $E$  and  $B$  are spiral path.

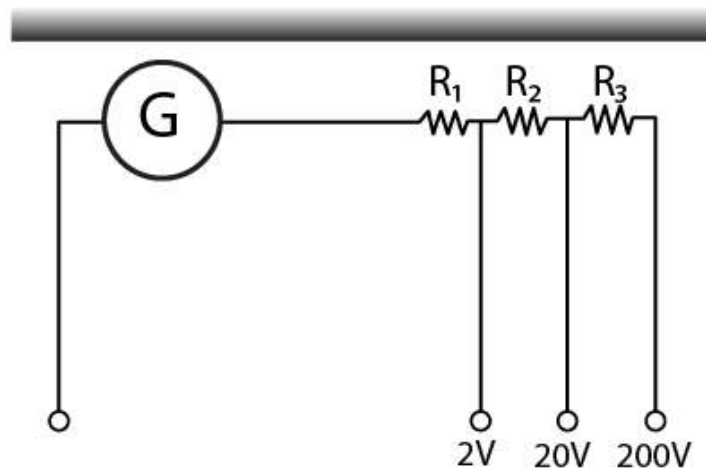
**4.20.** Do magnetic forces obey Newton's third law. Verify for two current elements  $dl_1 = dl\hat{i}$  located

at the origin and  $dl_2 = dl\hat{j}$  located at  $(0, R, 0)$ . Both carry current  $I$ .

**Answer:**

The magnetic forces do not obey Newton's third law if there is no current flowing in the conductor which is placed parallel to each other.

**4.21.** A multirange voltmeter can be constructed by using a galvanometer circuit as shown in the figure. We want to construct a voltmeter that can measure 2V, 20V, and 200V using galvanometer of resistance  $10\Omega$  and that produces maximum deflection for current of 1 mA. Find  $R_1$ ,  $R_2$ , and  $R_3$  that have to be used.



**Answer:**

$$i_G(G+R_1) = 2 \text{ for 2V range}$$

$$i_G(G+R_1+R_2) = 20 \text{ for 20V range}$$

$$i_G(G+R_1+R_2+R_3) = 200 \text{ for } 200\text{V range}$$

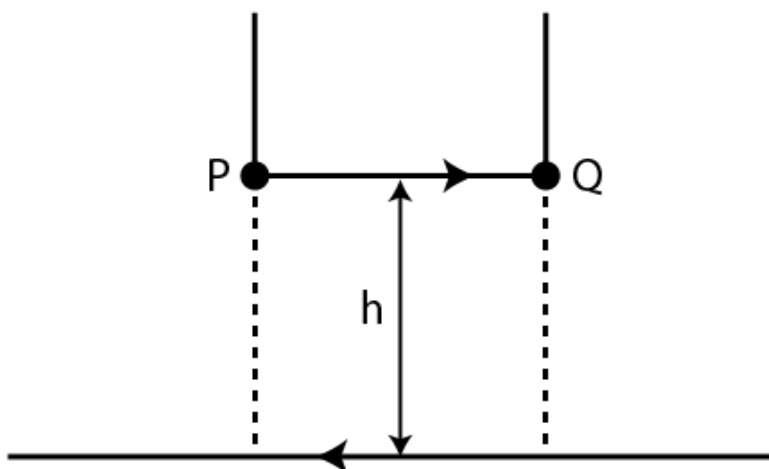
Solving the above, we get

$$R_1 = 1990 \, \Omega$$

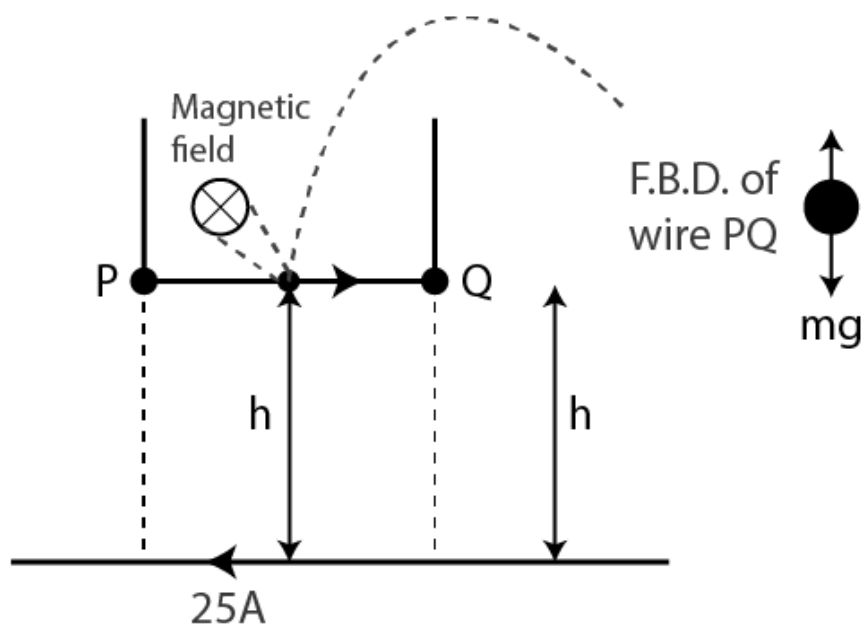
$$R_2 = 18\text{k}\Omega$$

$$R_3 = 180 \text{ k}\Omega$$

**4.22.** A long straight wire carrying current of 25 A rests on a table as shown in the figure. Another wire PQ of length 1 m, mass 2.5 g carries the same current but in the opposite direction. The wire PQ is free to slide up and down. To what height will PQ rise?



**Answer:**



The magnetic field produced by a long straight current carrying wire is given as

$$B = \mu_0 I / 2\pi h$$

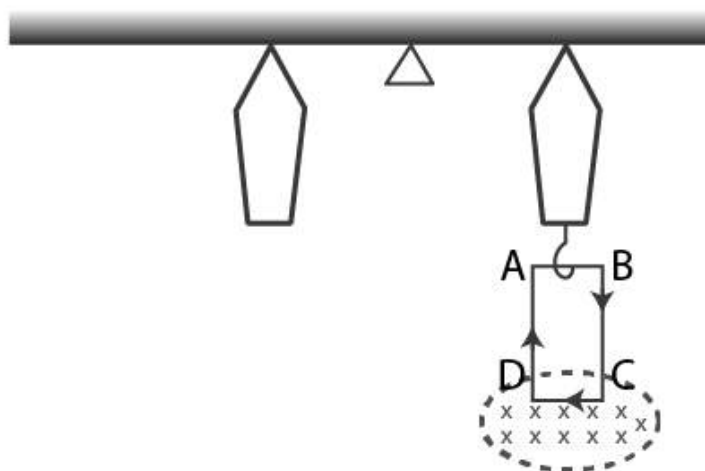
Magnetic force on the small conductor is  $F = BIl \sin \theta = BIl$

$$F = mg = \mu_0 I^2 l / 2\pi h$$

$$h = 0.51 \text{ cm}$$

## Long Answers

**4.23.** A 100 turn rectangular coil ABCD is hung from one arm of a balance. A mass 500 g is added to the other arm to balance the weight of the coil. A current 4.9 A passes through the coil and a constant magnetic field of 0.2 T acting inward is switched on such that only arm CD of length 1 cm lies in the field. How much additional mass 'm' must be added to regain the balance?



**Answer:**

When  $t = 0$ , the external magnetic field is off.

$$Mgl = W_{\text{coil}} l$$

$$0.5 \text{ gl} = W_{\text{coil}} l$$

$$W_{\text{coil}} = 0.5 \times 9.8 \text{ N}$$

Let  $m$  be the mass which is added to regain the balance

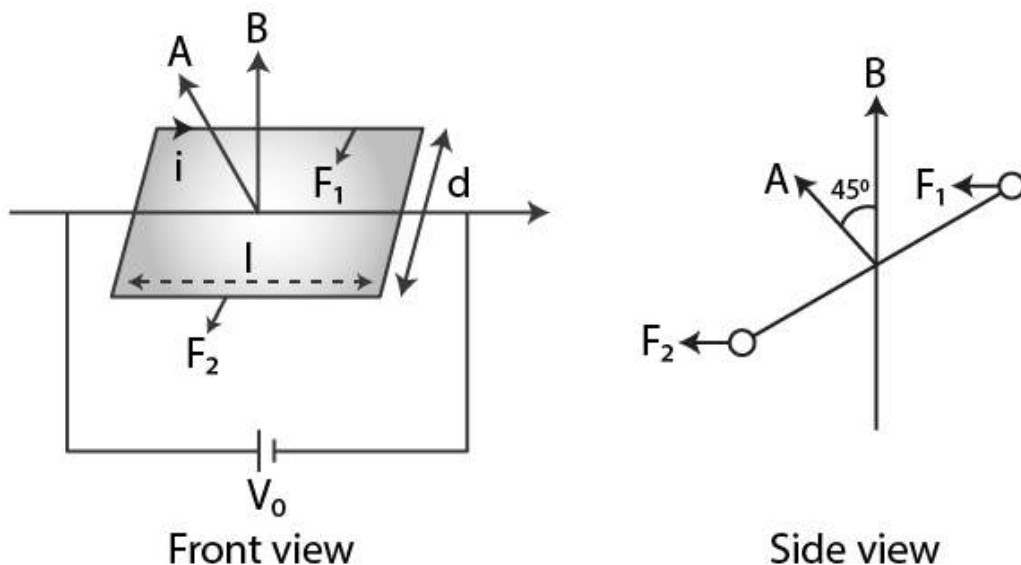
When the magnetic field is switched is on,

$$Mgl + mgl = (ILC)l$$

$$m = 1 \text{ g}$$

**4.24.** A rectangular conducting loop consists of two wires on two opposite sides of length  $l$  joined together by rods of length  $d$ . The wires are each of the same material but with cross-sections differing by a factor of 2. The thicker wire has a resistance  $R$  and the rods are of low resistance, which in turn are connected to a constant voltage source  $V_0$ . The loop is placed in uniform a magnetic field  $B$  at  $45^\circ$  to its plane. Find  $\tau$ , the torque exerted by the magnetic field on the loop about an axis through the centres of rods.

**Answer:**



Force and torque on the first wire is given as

$$F_1 = i_1 l B \sin 90^\circ = V_0/2R \cdot lB$$

$$\tau_1 = d/2\sqrt{2}$$

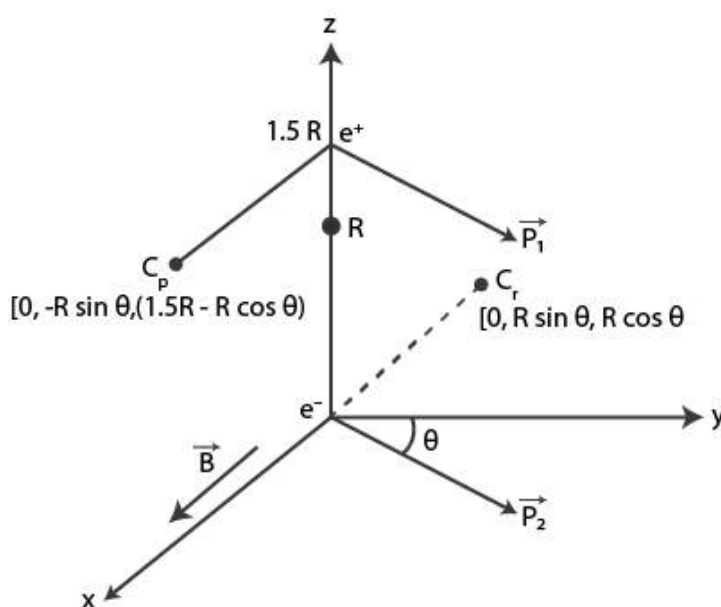
$$F_1 = V_0 l d B / 2\sqrt{2} R$$

$$\tau = 1/4\sqrt{2} V_0 A B / R$$

4.25. An electron and a positron are released from  $(0, 0, 0)$  and  $(0, 0, 1.5R)$  respectively, in a uniform

magnetic field  $B = B_0 \hat{i}$  each with an equal momentum of magnitude  $p = eBR$ . Under what conditions on the direction of momentum will the orbits be non-intersecting circles?

Answer:





When the centres are greater than  $2R$ , then the circular orbits of electron and positron shall not overlap.

Let  $d$  be the distance between  $C_p$  and  $C_e$

$$\text{Then } d^2 = 4R^2 + 9/4R^2 - 6R^2 \cos\theta$$

As  $d$  is greater than  $2R$ ,

$$9/4 > 6 \cos \theta \text{ or } \cos \theta < 3/8$$

**4.26. A uniform conducting wire of length  $12a$  and resistance  $R$  is wound up as a current carrying coil in the shape of i) an equilateral triangle of side  $a$ ; ii) a square of sides  $a$  and iii) a regular hexagon of sides  $a$ . The coil is connected to a voltage source  $V_0$ . Find the magnetic moment of the coils in each case.**

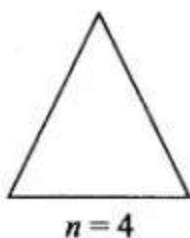
**Answer:**

a) An equilateral triangle with side  $a$

No. of loops = 4

$$\text{Area of the triangle } A = \sqrt{3}/4 a^2$$

$$\text{Magnetic moment, } m = Ia2\sqrt{3}$$



b) For a square with sides  $a$

$$\text{Area, } A = a^2$$

No. of loops = 3

$$\text{Magnetic moment, } m = 3Ia^2$$

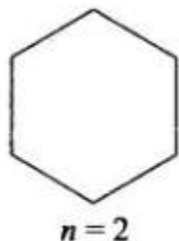


c) For a regular hexagon with sides  $a$

$$\text{Area, } A = 6\sqrt{3}/4 a^2$$

No. of loops = 2

$$\text{Magnetic moment, } m = 3\sqrt{3}a^2I$$



4.27. Consider a circular current-carrying loop of radius  $R$  in the  $x$ - $y$  plane with centre at origin. Consider

$$\oint (L) = \left| \int_{-L}^L B \cdot dl \right|$$

the line integral

taken along  $z$ -axis.

$$\oint (L)$$

a) show that  $\oint (L)$  monotonically increases with  $L$

$$\oint (\infty) = \mu_0 I$$

b) use an appropriate Amperian loop to that

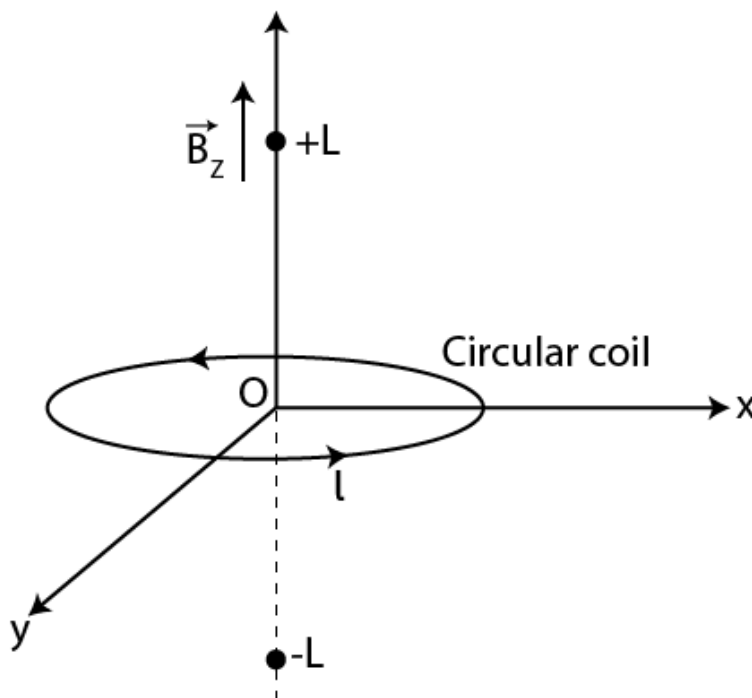
where  $I$  is the current in the wire

c) verify directly the above result

d) suppose we replace the circular coil by a square coil of sides  $R$  carrying the same current  $I$ . What can

you say about  $\oint (\infty)$  and  $\oint (L)$

Answer:



a) Magnetic field due to a circular current-carrying loop is given as

$$\mathfrak{I}(L) = \int_{-L}^{+L} B dl = 2BL$$

It is a monotonically increasing function of L

b) The Amperian loop is given as

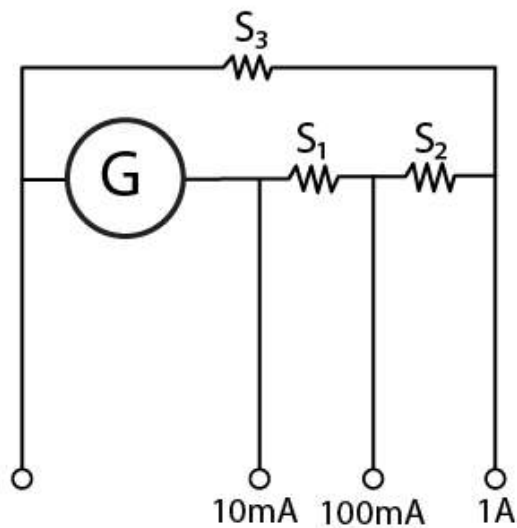
$$\mathfrak{I}(\infty) = \oint_{-\infty}^{+\infty} \vec{B} \cdot \vec{dl} = \mu_0 I$$

c) The magnetic field at the axis of the circular coil is given as  $\mu_0 I$

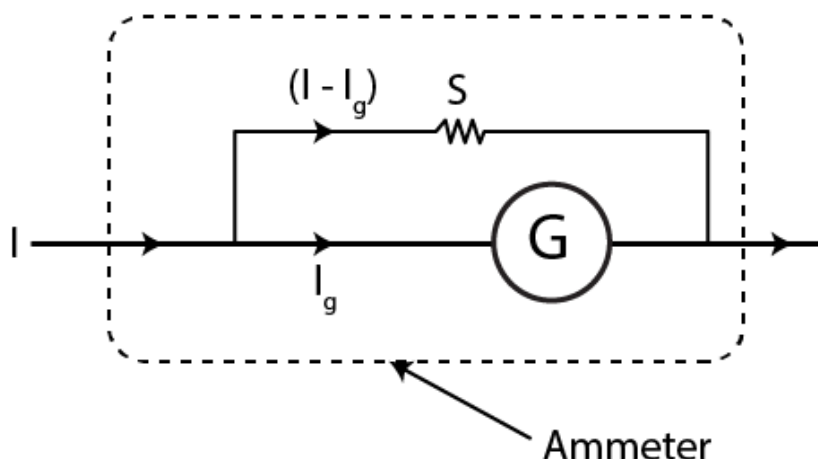
d) When a circular coil is replaced with a square coil, it is given as

$$\mathfrak{I}(\infty)_{\text{square}} = \mathfrak{I}(\infty)_{\text{circular coil}}$$

**4.28.** A multirange current meter can be constructed by using a galvanometer circuit shown in the figure. We want a current meter that can measure 10 mA, 100 mA, and 1 A using a galvanometer of resistance  $10\Omega$  and that produces maximum deflection for current of 1 mA. Find S1, S2, and S3 that have to be used.



**Answer:**



$I_1$  is measured as  $= 10 \text{ mA} = I_G G = (I_1 - I_G)(S_1 + S_2 + S_3)$

$I_2$  is measured as  $= 100 \text{ mA} = I_G(G + S_1) = (I_2 - I_G)(S_2 + S_3)$

$I_3$  is measured as  $= 1 \text{ A} = I_G(G + S_1 + S_2) = (I_3 - I_G)(S_3)$

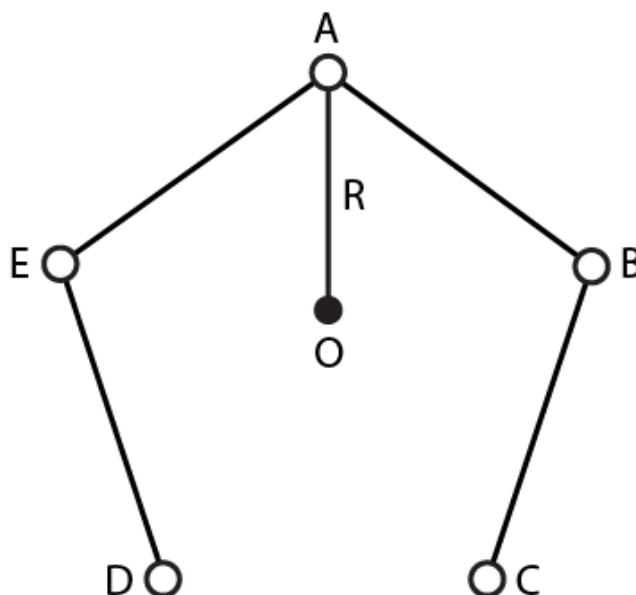
$S_1 = 1 \Omega$

$S_2 = 0.1 \Omega$

$S_3 = 0.01 \Omega$

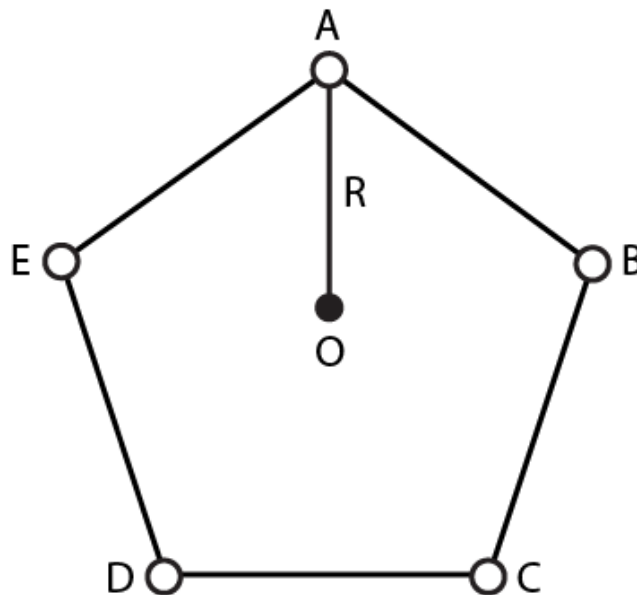
**4.29.** Five long wires A, B, C, D, and E each carrying  $I$  are arranged to form edges of a pentagonal prism as shown in the figure. Each carries current out of the plane of paper.

- what will be magnetic induction at a point on the axis O? Axis is at a distance  $R$  from each wire
- what will be the field if current in one of the wires is switched off
- what if current in one of the wire A is reversed



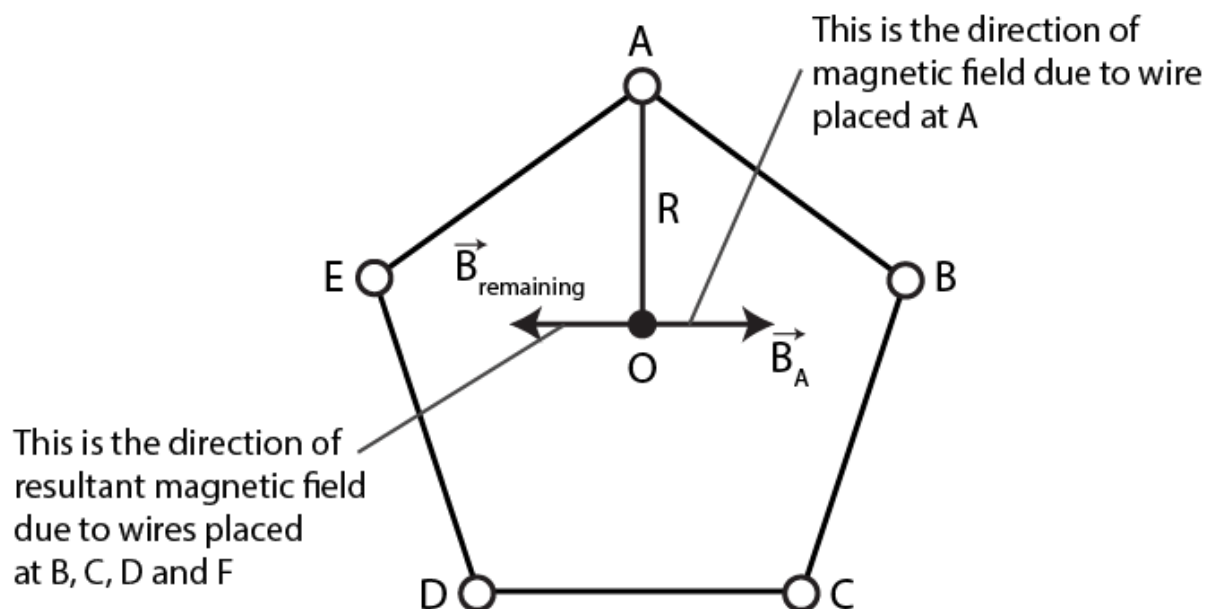
**Answer:**

a)



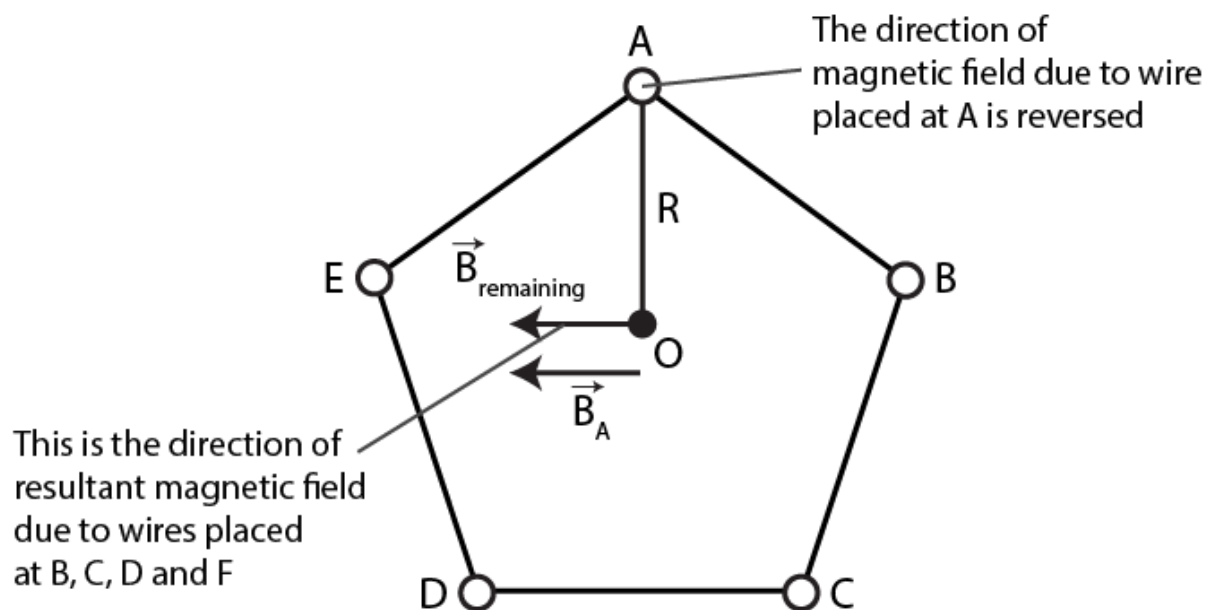
The magnetic induction at a point on the axis will be 0 which is represented by R as A, B, C, D, and E are perpendicular to the plane of paper at the given locations.

b)



When the current in one of the wires is switched off, the field  $\mu_0/2\pi i/R$  will be perpendicular to AO towards left.

c)



If the current is reversed, then the total magnetic field induction at O is  $\mu_0/4\pi R \ 2I/R$