

**SUBJECT : SCIENCE (PHY)**

**CHAPTER-13:**

**MAGNETIC EFFECT OF ELECTRIC CURRENT**

**TOPIC-5:**

**FORCE ON A CURRENT CARRYING  
CONDUCTOR PLACED IN A MAGNETIC FIELD:**

## **OBJECTIVES:**

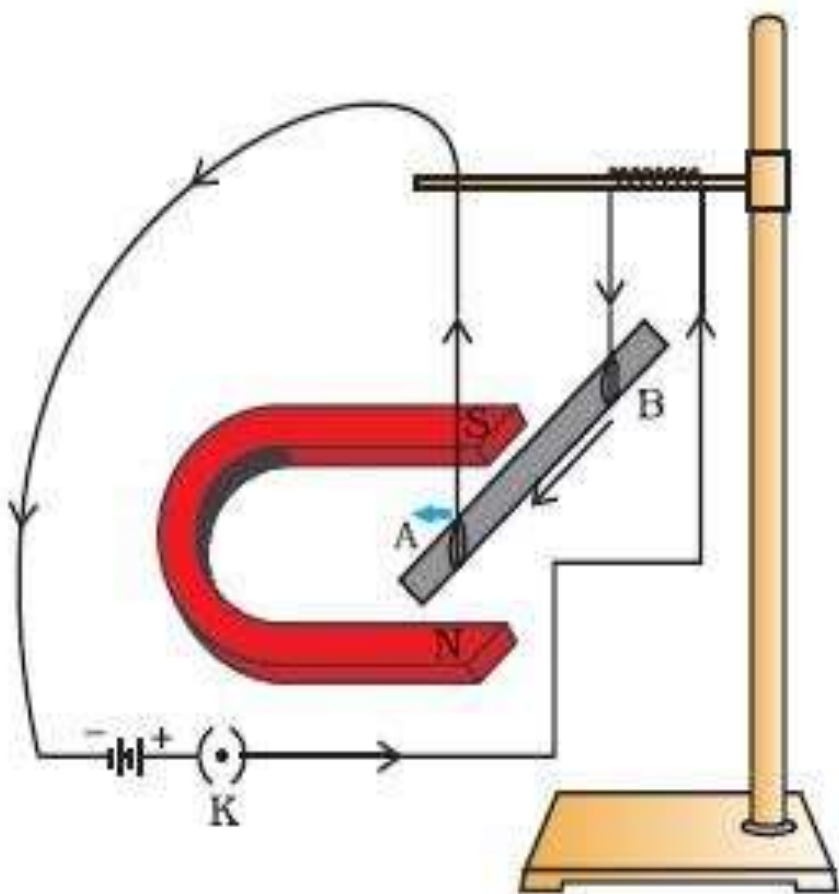
**Upon completion of the topic, you will be able to**

1. EXPLAIN WHAT HAPPEN WHEN CURRENT CARRYING CONDUCTOR IS PLACED IN A MAGNETIC FIELD
2. FIND THE DIRECTION OF FORCE ON THE CONDUCTOR PLACED IN MAGNETIC FIELD.
3. STATE FLEMING'S LEFT HAND RULE
4. EXPLAIN THE CONDITION FOR MAXIMUM FORCE ACTING ON CONDUCTOR IN THE MAGNETIC FIELD
5. EXPLAIN THE CONDITION FOR MINIMUM FORCE ACTING ON CONDUCTOR IN THE MAGNETIC FIELD
6. WRITE THE NAME OF FACTORS ON WHICH THE FORCE DEPEND
7. WRITE THE EXPRESSION OF FORCE IN TERMS OF LENGTH & CURRENT OF CONDUCTOR
8. WRITE THE EXPRESSION OF FORCE IN TERMS OF ELECTRIC CHARGE & VELOCITY OF CHARGE THROUGH CONDUCTOR

## FORCE ON CURRENT CARRYING CONDUCTOR PLACED IN A MAGNETIC FIELD:

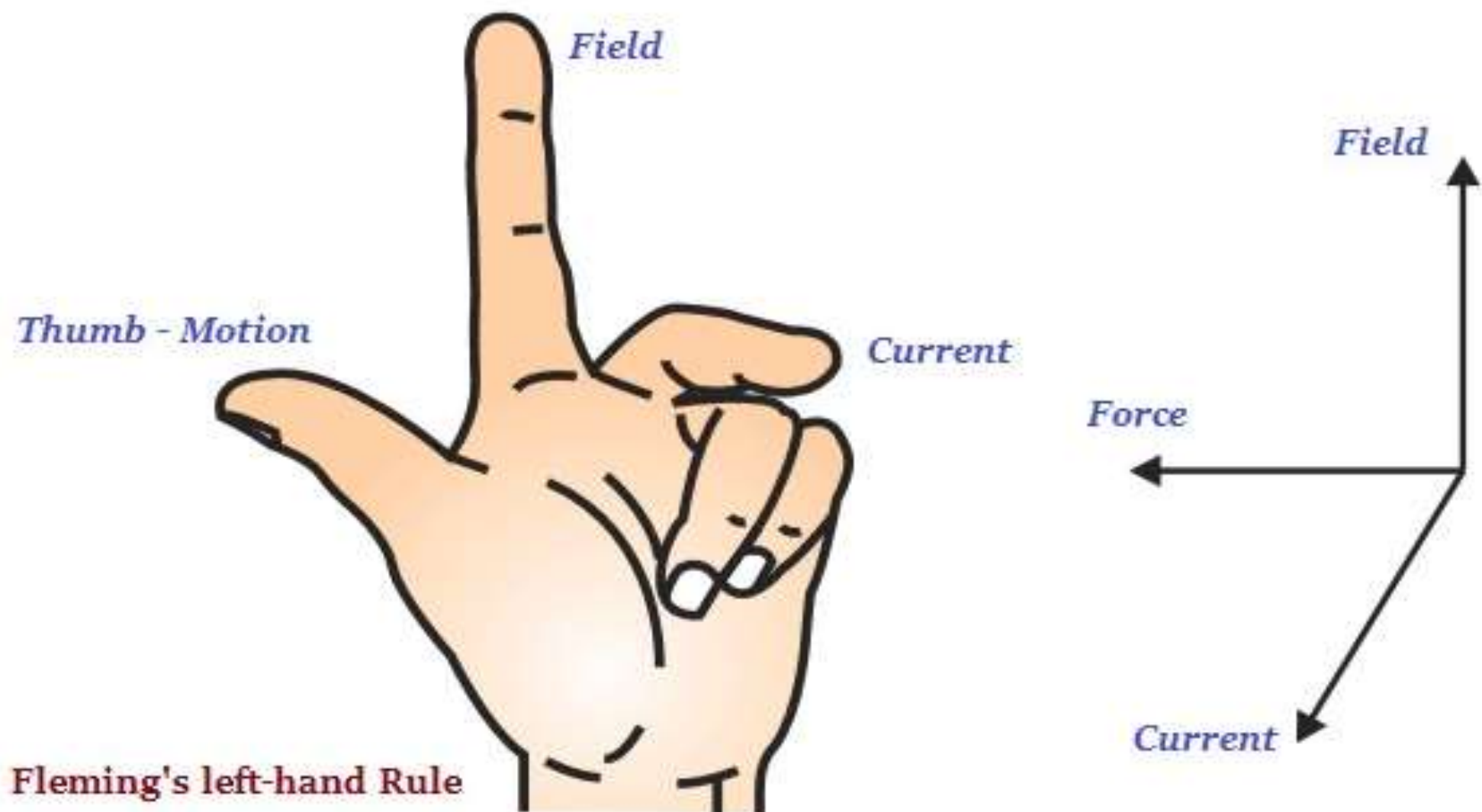
### Activity :

- Take Place a strong horse-shoe magnet in such a way that the rod lies between the two poles with the magnetic field directed upwards. For this put the north pole of the magnet vertically below and south pole vertically above the aluminium rod (Fig. 13.12).
- a small aluminium rod AB (of about 5 cm). Using two connecting wires suspend it horizontally from a stand, as shown in Fig. 13.12.
- Connect the aluminium rod in series with a battery, a key and a rheostat.
- Now pass a current through the aluminium rod from end B to end A.
- What do you observe? It is observed that the rod is displaced towards the left. You will notice that the rod gets displaced.
- Reverse the direction of current flowing through the rod and observe the direction of its displacement. It is now towards the right. Why does the rod get displaced?



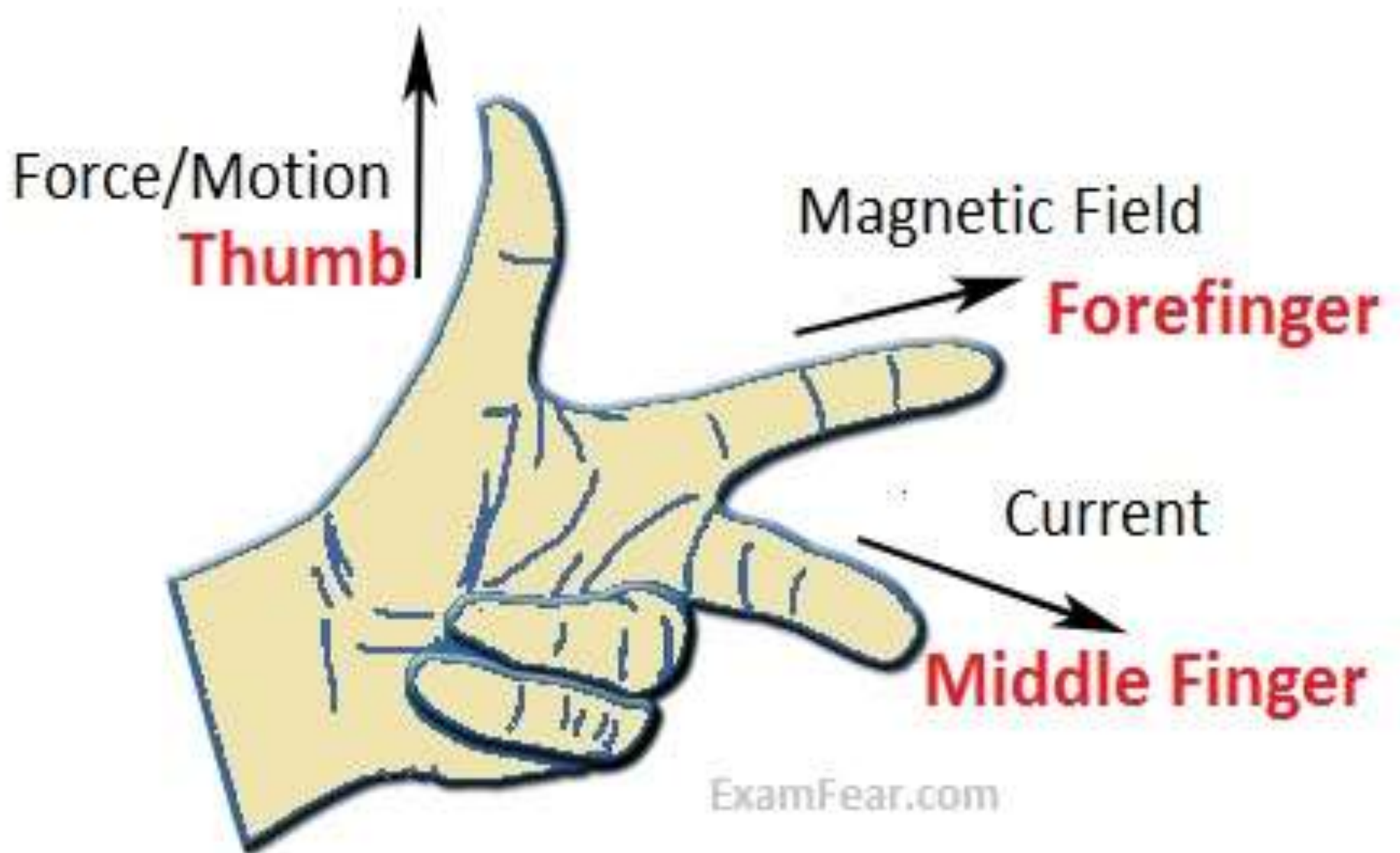
The displacement of the rod in the above activity suggests that a force is exerted on the current-carrying aluminium rod when it is placed in a magnetic field. It also suggests that the direction of force is also reversed when the direction of current through the conductor is reversed. Now change the direction of field to vertically downwards by interchanging the two poles of the magnet. It is once again observed that

## FLEMING'S LEFT HAND RULE:



we considered the direction of the current and that of the magnetic field perpendicular to each other and found that the force is perpendicular to both of them. The three directions can be illustrated through a simple rule, called Fleming's left-hand rule

*According to this rule, stretch the thumb, forefinger and middle finger of your left hand such that they are mutually perpendicular ( Fig ). If the first finger points in the direction of magnetic field and the second finger in the direction of current, then the thumb will point in the direction of motion or the force acting on the conductor.*



### **Fleming's Left Hand Rule**

A current carrying conductor placed in a magnetic field experiences a force. If the direction of the field and that of current are mutually perpendicular to each other, then the force acting on the conductor will be perpendicular to both and that can be determined using the Fleming's left-hand rule. When current establishes in the conductor, it gets displaced which verifies the existence of a force on the conductor.



#### ✓ 4.07.2. FACTORS ON WHICH THE FORCE ACTING ON THE CURRENT CARRYING CONDUCTOR DEPEND

The force acting on a current carrying conductor placed in the magnetic field depends upon :

- (i) **The strength of the magnetic field.** If the conductor is placed in a strong magnetic field, it experiences a large force. That is,  $F \propto B$  (strength of magnetic field)
- (ii) **The strength of the electric current.** If large current flows through the conductor placed in the magnetic field, it experiences a large force. That is,  $F \propto I$
- (iii) **The length of the conductor.** A long conductor experiences a greater force than the short conductor, when placed in the magnetic field. That is,  $F \propto l$

#### Magnitude of the force acting on a current carrying conductor placed in a magnetic field

We have seen that the force acting on a current carrying conductor placed perpendicular to the magnetic field depends upon (i) the strength of the magnetic field ( $B$ ), (ii) the amount of current ( $I$ ) flowing through the conductor and (iii) the length ( $l$ ) of the conductor.

That is

$$F \propto BIl$$

or

$$F = kBIl \quad \dots(1)$$

If  $k = 1$ ,

$$F = BIl \quad \dots(2)$$

Eqn. (2) gives the magnitude of the force acting on a current carrying conductor placed perpendicular to the magnetic field.

**Note :** (i) A current carrying conductor placed perpendicular to the magnetic field experiences a maximum force ( $F = BIl$ ).

(ii) **No force** is experienced by a current carrying conductor when placed parallel to the magnetic field.

$$\text{i.e. } F = 0$$

Definition of Field strength(B):

We know that  $F = BIl$

$$B = \frac{F}{Il}$$

..(3)

Thus, magnetic field (B) is defined as the force acting per unit current per unit length of a conductor placed perpendicular to the direction of the magnetic field.

SI Unit of Magnetic field strength (B):

SI unit of magnetic field is **tesla**. The symbol of tesla is T.  
From eqn. (3),

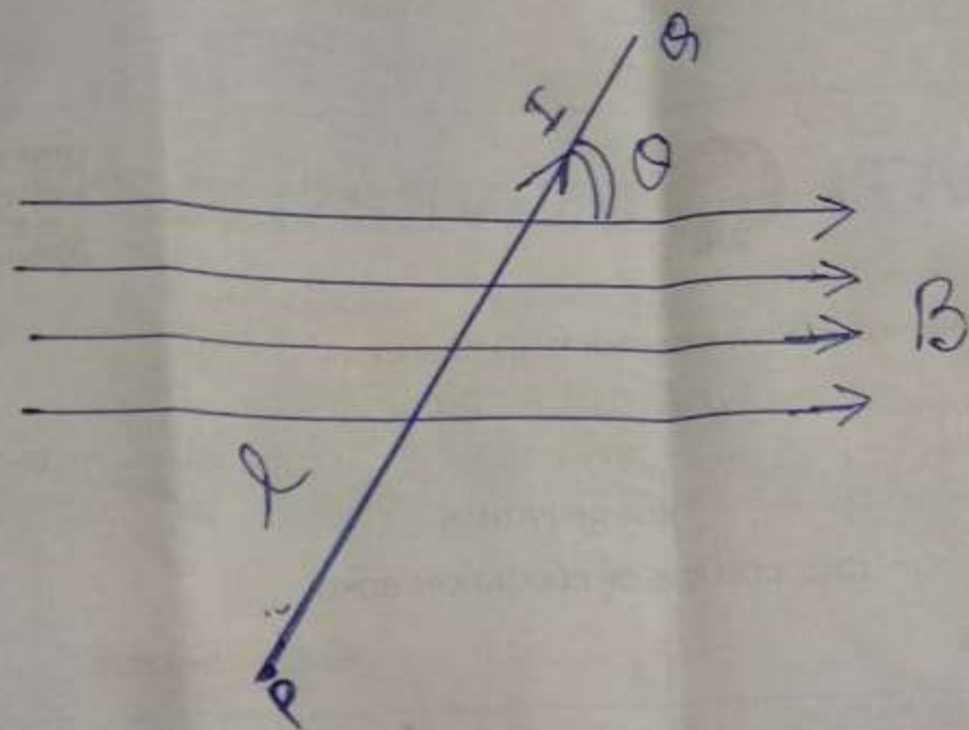
$$\text{SI unit of magnetic field} = \frac{\text{SI unit of force}}{\text{SI unit of current} \times \text{SI unit of length}}$$

i.e.  $\underline{1 \text{ tesla}} = \frac{1 \text{ N}}{1 \text{ ampere} \times 1 \text{ m}} = \underline{1 \text{ N A}^{-1} \text{ m}^{-1}}$

Thus, magnetic field is said to be 1 tesla if a conductor 1 metre long carrying 1 ampere current experiences 1 N force, when placed perpendicular to the direction of the magnetic field.



## FACTORS ON WHICH FORCE DEPEND:



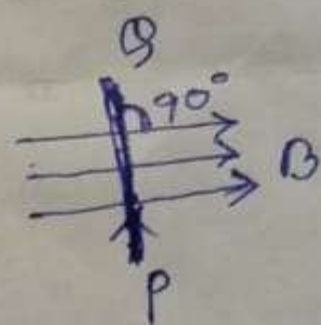
$PQ = \text{conductor}$   
 $PQ = l = \text{length of conductor}$

$$F = BIl \sin \theta$$

cases: ① If  $\theta = 0$ , or  $\theta = 180$ ,  $\sin \theta = 0$   
 $F = 0$  (Minimum Force)



② If  $\theta = 90$ ,  $\sin \theta = \sin 90 = 1$   
 $F = BIl$  (Maximum)



Factors:

- ①  $F \propto B$
- ②  $F \propto I$
- ③  $F \propto l$
- ④  $F \propto \sin \theta$



### Force acting on a moving charge in a magnetic field

The current flowing in a conductor or a metallic wire is due to the moving free electrons, each having an electric charge of magnitude  $1.6 \times 10^{-19} \text{C}$ . The force acting on a current carrying conductor placed perpendicular to a magnetic field is equal to the force acting on a **net charge** moving in the conductor. The net charge is equal to the sum of the charges on the electrons moving in the conductor to form an electric current.

We know, force acting on a current carrying conductor placed perpendicular to the magnetic field is given by

$$F = BIl \quad F = BIl \quad \dots(1)$$

But  $I = \frac{Q}{t}$ , where  $Q$  is the net charge moving through the conductor.

$\therefore$  Eqn. (1) becomes

$$F = B \left( \frac{Q}{t} \right) l = BQ \left( \frac{l}{t} \right)$$

Now  $\frac{l}{t} = v$ , velocity of charge (or electron)

$$F = BQv \quad F = BQv \quad \dots(2)$$

Eqn. (2) is the expression for the force acting on a charge  $Q$  moving with velocity  $v$  perpendicular to the magnetic field  $B$ . This force makes the charged particle to move in a circular path with a constant speed. However, the *velocity* and hence *momentum* of the charged particle change continuously due to the change in the direction of its motion.

## NUMERICAL:

### QUES-1:

Calculate the force acting on a wire of length 1 m through which a current is placed perpendicular to the direction of magnetic field of strength 0.4 T.

$$l = 1 \text{ m} ; I = 0.2 \text{ A} ; B = 0.4 \text{ T}$$

$F = BIl$ , we get

$$F = 0.4 \text{ T} \times 0.2 \text{ A} \times 1 \text{ m} = 0.4 \text{ NA}^{-1}\text{m}^{-1} \times 0.2 \text{ A} \times 1 \text{ m}$$
$$= 0.08 \text{ N} \quad (\because 1 \text{ T} = 1 \text{ NA}^{-1}\text{m}^{-1})$$

### QUES-2:

A particle having charge  $1.6 \times 10^{-19} \text{ C}$  travelling at a speed  $3.0 \times 10^6 \text{ ms}^{-1}$  in a uniform magnetic field of 0.04 T. Calculate the force acting on the particle.

$$Q = 1.6 \times 10^{-19} \text{ C} ; v = 3.0 \times 10^6 \text{ ms}^{-1} ; B = 0.04 \text{ T}$$

$F = BQv$ , we get

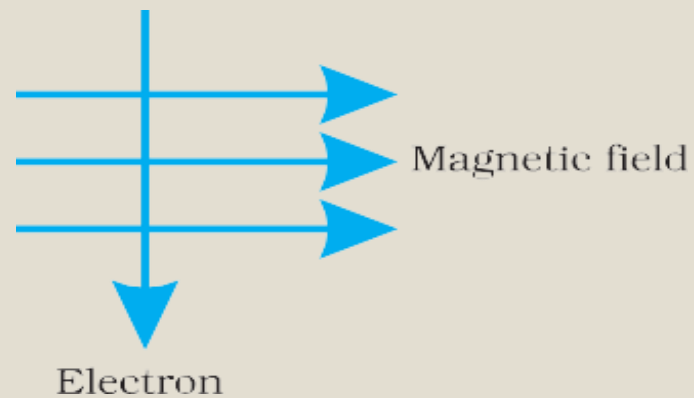
$$F = 0.04 \text{ T} \times 1.6 \times 10^{-19} \text{ C} \times 3.0 \times 10^6 \text{ ms}^{-1}$$
$$= 0.04 \text{ NA}^{-1} \text{ m}^{-1} \times 1.6 \times 10^{-19} \text{ C} \times 3.0 \times 10^6 \text{ ms}^{-1}$$
$$= 19.2 \times 10^{-15} \text{ N.}$$

## QUESTIONS

### QUESTION-1:

*An electron enters a magnetic field at right angles to it, as shown in Fig. The direction of force acting on the electron will be*

- (a) to the right.      ( b)    to the left.  
(c) out of the page.   ( d)    into the page.



**ANSWER-1:** Answer is option (d). The direction of force is perpendicular to the direction of magnetic field and current as given by Fleming's left hand rule. Since the direction of current is taken opposite to the direction of motion of electrons, the force is therefore directed into the page.



### Question 2:

Which of the following property of a proton can change while it moves freely in a magnetic field? (There may be more than one correct answer.)

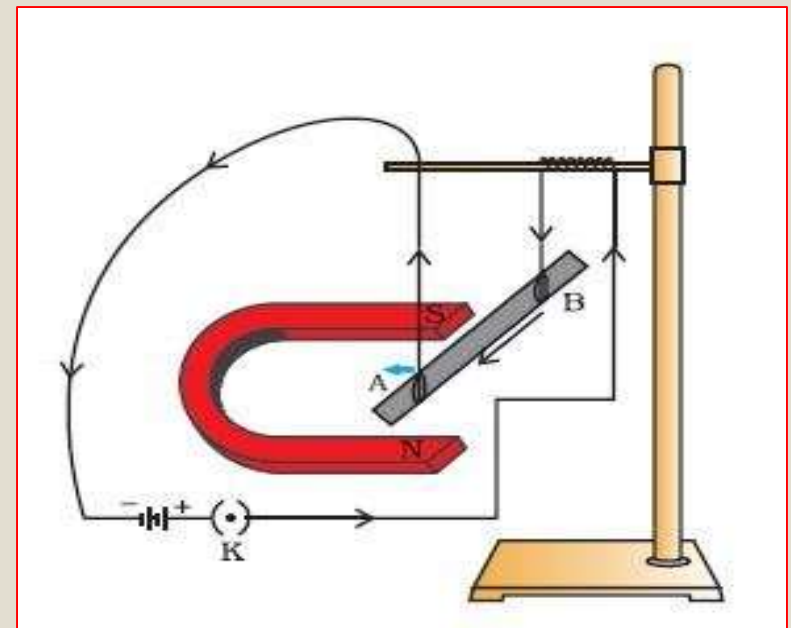
- a) Mass                      b) Speed                      (c) Velocity                      (d) Momentum

### Answer 2:

- (c) Velocity and                      (d) Momentum

### Question 3:

In Fig, how do you think the displacement of rod AB will be affected if  
(i) current in rod AB is increased; (ii) a stronger horse-shoe magnet is used; and  
(iii) length of the rod AB is increased?



### Answer 3:

- (i) If current in rod AB is increased, the displacement will also increase.  
(ii) If we use a stronger horse-shoe magnet then the displacement of rod AB will increase.  
(iii) If length of the rod is increased, force acting on it will increase and, hence, displacement of the rod increases.

### Question 4:

A positively-charged particle (alpha-particle) projected towards west is deflected towards north by a magnetic field. The direction of magnetic field is

- (a) towards south                      (b) towards East                      (c) upward                      (d) downward

### Answer 4: (c) upward

In accordance with Fleming's left-hand rule, the direction of magnetic field is vertically upward.

### **Question 5:**

#### **How is magnetism important in Medical Science?**

#### **Answer 5:**

An electric current always produces a magnetic field. Even weak ion currents that travel along the nerve cells in our body produce magnetic fields. When we touch something, our nerves carry an electric impulse to the muscles we need to use. This impulse produces a temporary magnetic field. These fields are very weak and are about one-billionth of the earth's magnetic field. Two main organs in the human body where the magnetic field produced is significant, are the heart and the brain. The magnetic field inside the body forms the basis of obtaining the images of different body parts. This is done using a technique called Magnetic Resonance Imaging (MRI). Analysis of these images helps in medical diagnosis. Magnetism has, thus, got important uses in medicine

### **Question 6:**

When is the force experienced by a current-carrying conductor placed in a magnetic field largest?

#### **Answer 6:**

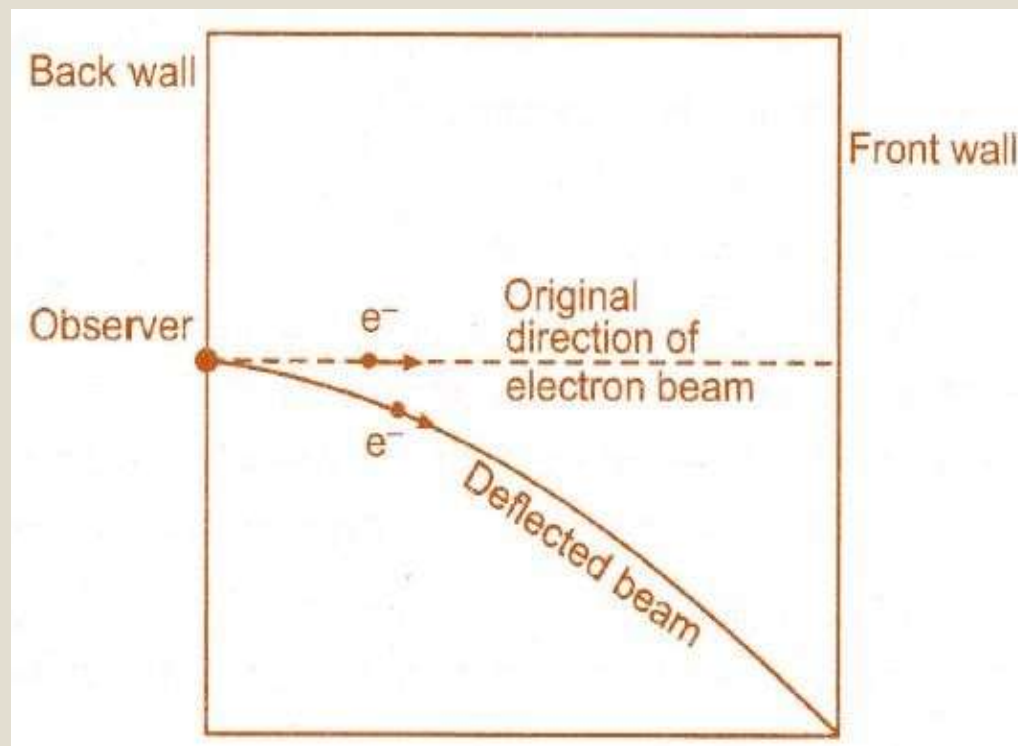
The force experienced by a current-carrying conductor placed in a magnetic field is largest when the current-carrying conductor is placed in a direction perpendicular to that of magnetic field.

### **Question 7:**

Imagine that you are sitting in a chamber with your back to one wall. An electron beam, moving horizontally from back wall towards the front wall, is deflected by a strong magnetic field to your right side. What is the direction of magnetic field?

**Answer 7:**

An electron beam moving horizontally from back wall towards the front wall is equivalent to a current flowing in the opposite direction (i.e., from front wall towards the back wall). The deflection of electron beam as seen by observer is to his right side and is shown in Figure. On applying Fleming's left-hand rule we find that the magnetic field is acting in vertically downward direction.

**Question-8:**

Force acts on a conductor placed in a magnetic field when current is passed through it. Name an electric device that works based on this principle.

**Answer-8:**

Electric Motor.

**Question-9:** The expression for maximum Force acting on a current carrying conductor placed in a magnetic field is  $F = BIl$ . Show that  $F = BIl = BQv$ .

Where  $B$  = magnetic field strength,  $I$  = current,  $l$  = length of conductor,  $Q$  = amount of electric charge passing through the conductor,  $v$  = velocity of charge.



### Answer-9:

We know  $I = Q/t$  and velocity  $v = \text{displacement/time} = \text{length of conductor} = l/t$

$$\begin{aligned}\text{Now } F &= BIl \\ &= B (Q/t) l \\ &= B Q (l/t) \\ &= BQ v \quad \text{since } v = l/t\end{aligned}$$

Thus :  $F = BIl = BQv$

### ACTIVITY/PROJECT

1. Draw magnetic lines of force around a bar magnet using magnetic compass.
2. Draw magnetic lines of force in the following situations
  - (a) placing north pole of one bar magnet facing south pole of another bar magnet.
  - (b) Placing north pole of one bar magnet facing North pole of another bar magnet.(Use Magnetic compass in both the case)