

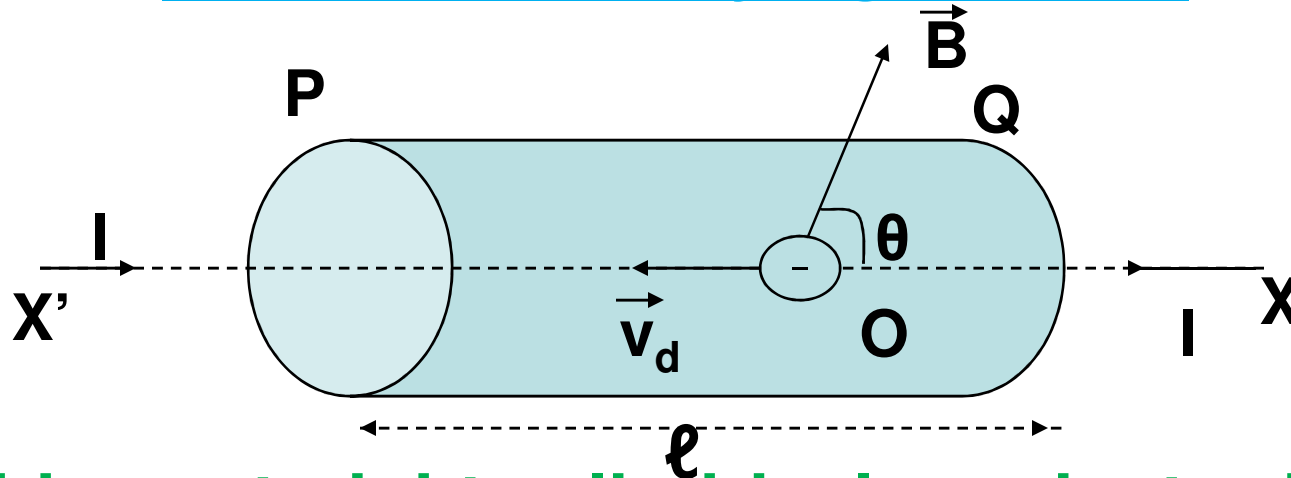
# Gurdeep Singh

**Mata Gujari Sr. Sec. School,  
Fatehgarh Sahib**

Punjab EDUSAT Society (PES)

# Force on a current carrying conductor placed in a magnetic field

## Expression for the force acting on the conductor carrying current



Consider a straight cylindrical conductor PQ of length  $l$ , area of cross-section  $A$  carrying current  $I$  is placed in a uniform magnetic field of induction  $\vec{B}$ .

Let the conductor be placed along X axis and magnetic field acting in XY plane making an angle  $\theta$  with the X axis.

$\vec{v}_d$  = Drift Velocity of electron

$-e$  = Charge on each electron

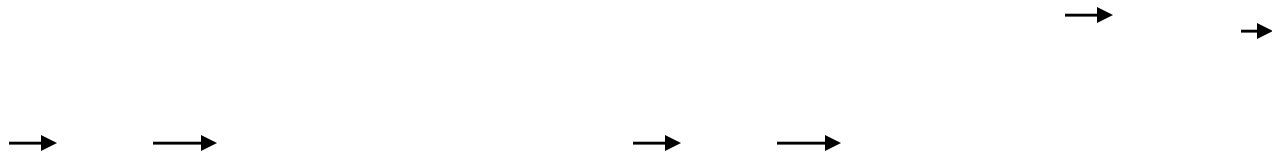
Then, magnetic Lorentz force on an electron is given by  $\vec{f} = -e(\vec{v}_d \times \vec{B})$

If  $n$  is the number density of free electrons i.e. the number of free electrons per unit volume,

Then the total number of free electrons in the conductor will be given by  $N = (A \ell)n$

Therefore, total force on the conductor

$$\vec{F} = N\vec{f} = nA \ell [-e(\vec{v}_d \times \vec{B})] = -nA \ell e(\vec{v}_d \times \vec{B})$$



From the relation of drift velocity and current I

$$I = nAev_d$$

Therefore,  $I \vec{l} = nAev_d \vec{l}$

Hence we can write,  $I \vec{l} = -nA \vec{l} e v_d$

$$\vec{F} = I \vec{l} \times \vec{B}$$

$$F = I l B \sin \theta$$

Where  $\theta$  is the smaller angle between  $I \vec{l}$  and  $\vec{B}$

### SPECIAL CASES

1. If  $\theta = 0^\circ$  or  $180^\circ$ ,  $\sin \theta = 0$

Therefore,  $F = I l B (0) = 0 = F_{\min}$

2. If  $\theta = 90^\circ$ ,  $\sin \theta = 1$

Therefore,  $F = I l B = F_{\max}$

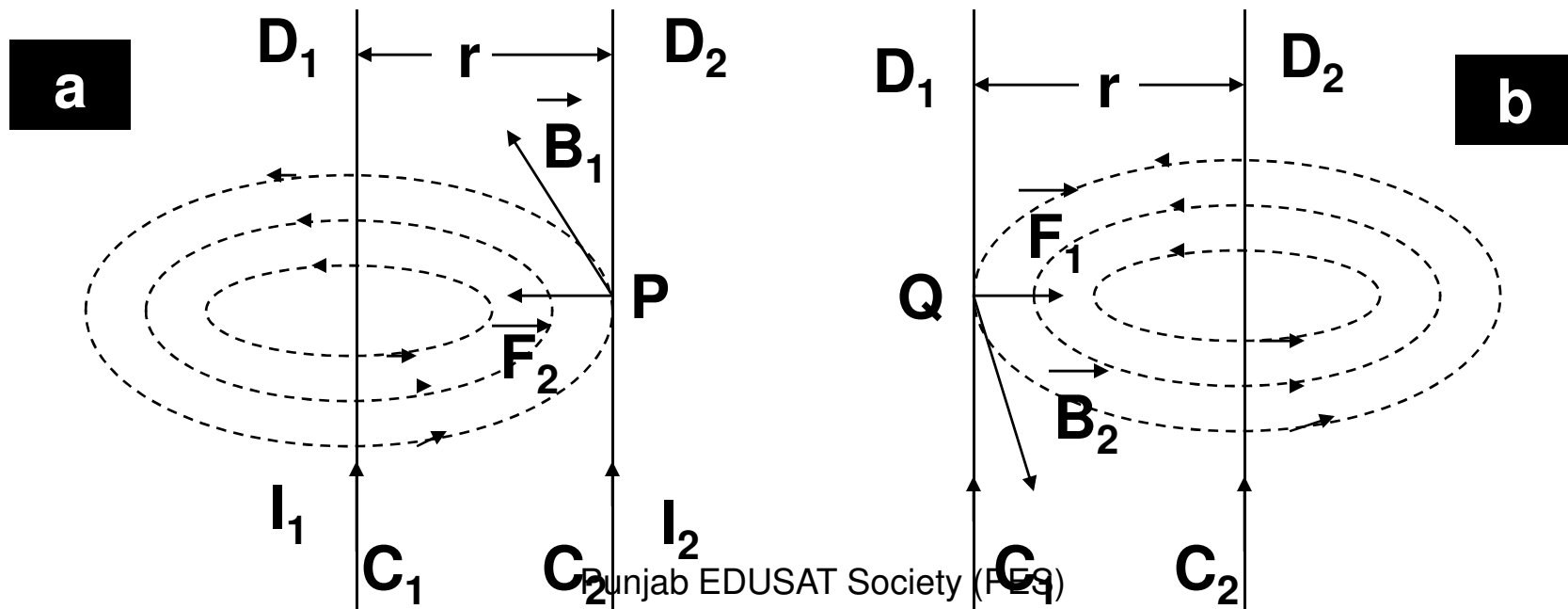
The direction of this force is given by Fleming's left hand rule or right hand screw rule.

It is important to note that so long magnetic field  $\vec{B}$  is uniform across the whole length of the conductor this relation is valid.

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# Force between two parallel conductors carrying current

$C_1D_1$  and  $C_2D_2$ , two infinite long straight conductors carrying current  $I_1$  and  $I_2$  in the same direction. They are held parallel to each other at a distance  $r$  in the plane of paper.



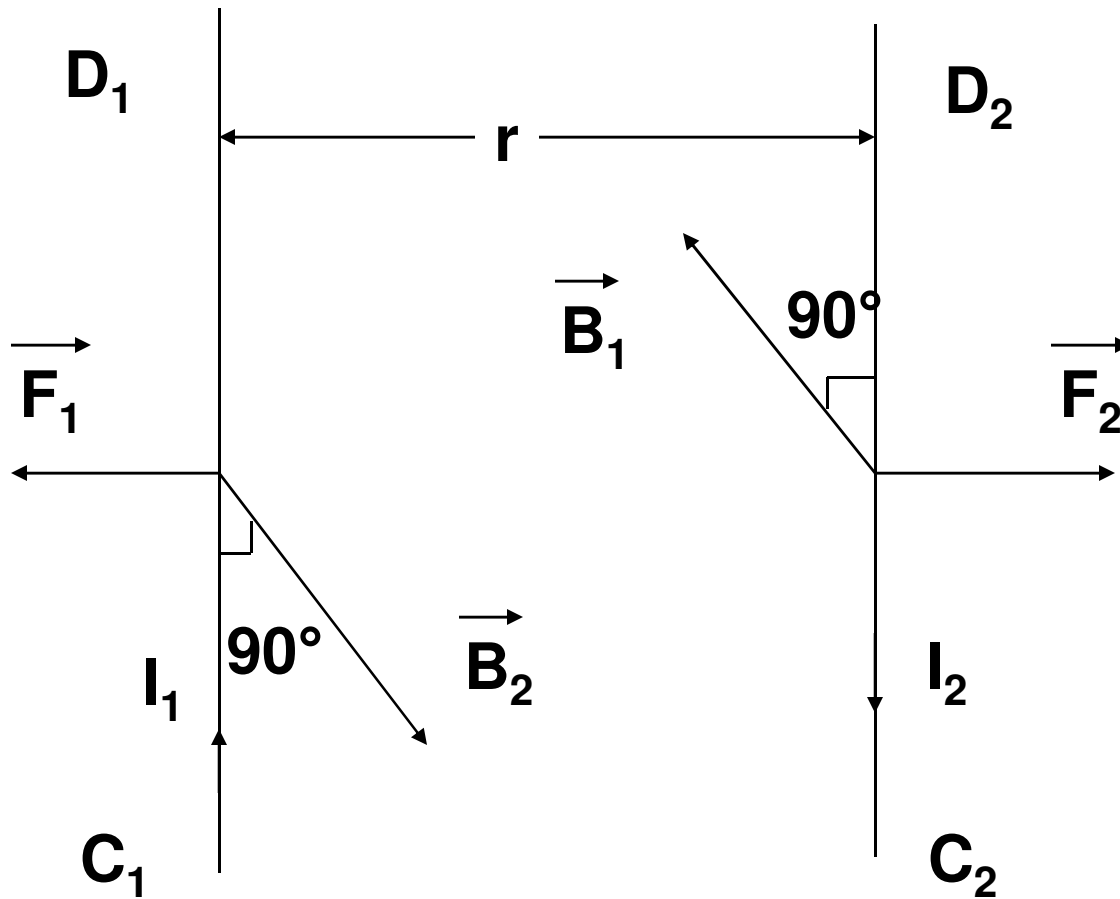
**Magnetic Field induction at point P on  $C_2D_2$  due to current passing through  $C_1D_1$  is given by,**

$$B_1 = \frac{\mu_0 2 I_1}{4 \pi r}$$

**As the current carrying conductor  $C_2D_2$  lies in the magnetic field  $B_1$  therefore, unit length of  $C_2D_2$  will experience a force  $F_2 = B_1 I_2 \times 1 = B_1 I_2$**

$$F_2 = \frac{\mu_0 2 I_1 I_2}{4 \pi r}$$

**According to Fleming's left hand rule force on conductor  $C_2D_2$  acts in the plane of the paper and directed towards  $C_1D_1$ . Similarly, it can be shown that the conductor  $C_1D_1$  experiences a force which is directed towards  $C_2D_2$  and hence they attract each other.**



**If the current in the conductors  $C_1D_1$  and  $C_2D_2$  are in opposite directions they repel each other with the same force.**

# Definition of the Ampere

$$F = \frac{\mu_0}{4\pi} \frac{2I_1 I_2}{r}$$

$$I_1 = I_2 = 1 \text{ A} ; r = 1\text{m}$$

$$F = \frac{10^{-7} \times 2 \times 1 \times 1}{1}$$

$$F = 2 \times 10^{-7} \text{ Nm}^{-1}$$

Thus, 1 ampere is that much current which when flowing through each of the two parallel infinite straight conductors of negligible cross-section in free space at a distance 1m apart will repel or attract each other with a force of  $2 \times 10^{-7} \text{ Nm}^{-1}$  of their lengths.

## Numerical Problem

**Q: Two parallel wires 1m apart, carry currents of magnitude 1A and 3A respectively in opposite directions. Calculate the force per unit length acting between these wires and the nature of the force?**

**Solution :  $F = \frac{\mu_0}{4\pi} \frac{2I_1 I_2}{r}$**

**$I_1 = 1A ; I_2 = 3A ; r = 1m$**

**$F = 10^{-7} \times \frac{2 \times 1 \times 3}{1} = 6 \times 10^{-7} \text{ Nm}^{-1}$**

**Nature of the force is repulsive.**