Electromagnetism

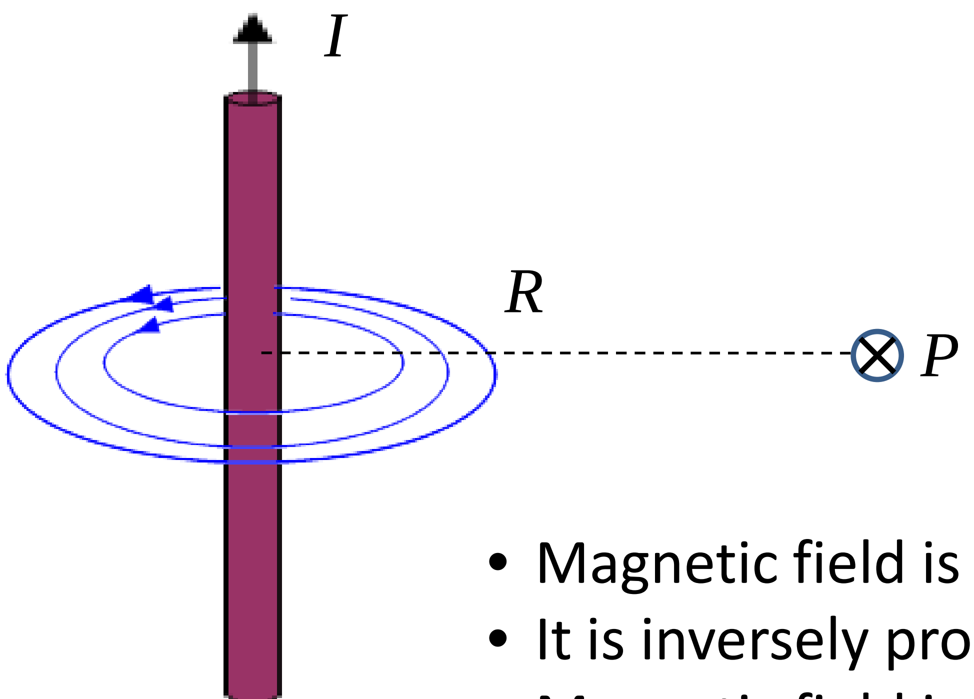
Day 18

ILOs – Day 18

- Identify the magnetic field due to steady current in an infinitely long straight conductor
- Identify the magnetic field along axis of a circular current carrying coil
- Identify the magnetic field produced by a solenoid
- Derive expression for force on a current carrying conductor placed in a magnetic field

Magnetic Field due to steady current in an infinitely long straight conductor

- Let us consider a straight long conductor carrying current *I*
- We want to find out magnetic field effect at the point *P* placed at a distance *R* from the conductor



Magnetic field strength

$$\boxed{\vec{H} = \frac{I}{2\pi R}.\hat{k}}$$

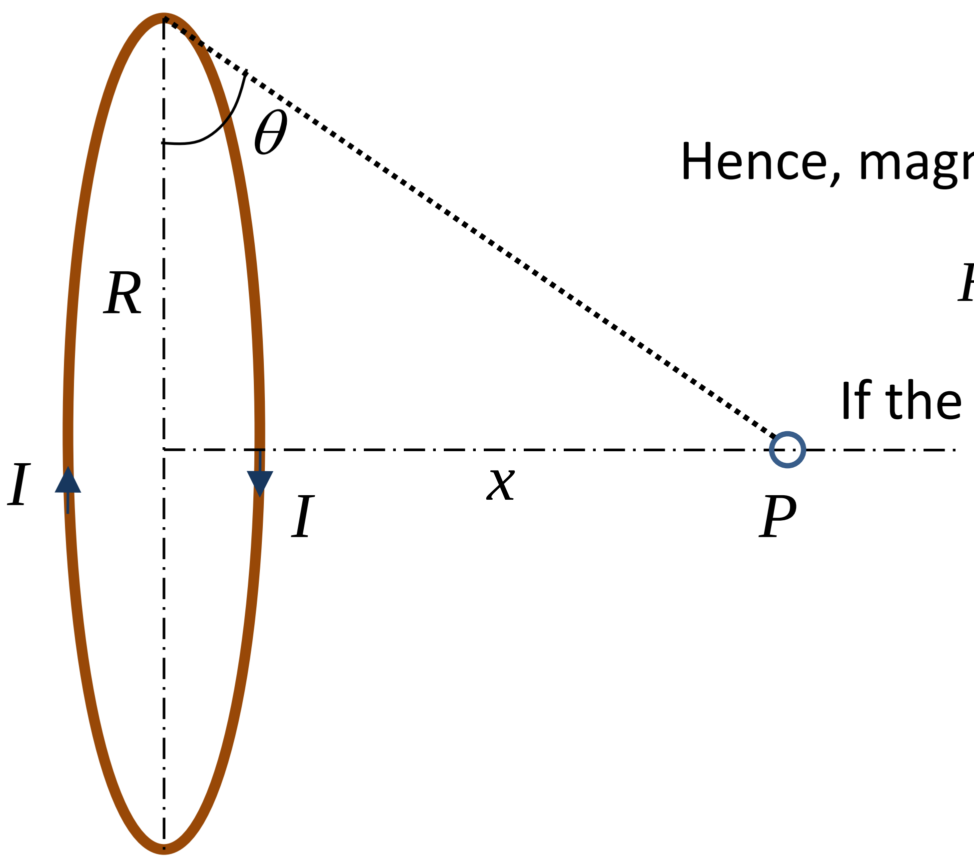
Magnetic flux density

$$\boxed{\vec{B} = \frac{\mu_0 I}{2\pi R}\hat{k}}$$

- Magnetic field is proportional to the current I
- It is inversely proportional to the distance *R*
- Magnetic field is in the direction perpendicular to the straight conductor and *R*

Magnetic Field along axis of a circular current carrying coil

- Let there be a circular coil of radius *R* and carrying current I
- Let P be any point on the axis of the coil at a distance x from the center of the circular loop



Magnetic flux density at P is given by:

$$\boxed{B = \frac{\mu_0 I}{2R}\cos^3\theta}$$

Hence, magnetic field intensity at P is given by:

$$H = \frac{B}{\mu_0} \boxed{= \frac{I}{2R}\cos^3\theta}$$

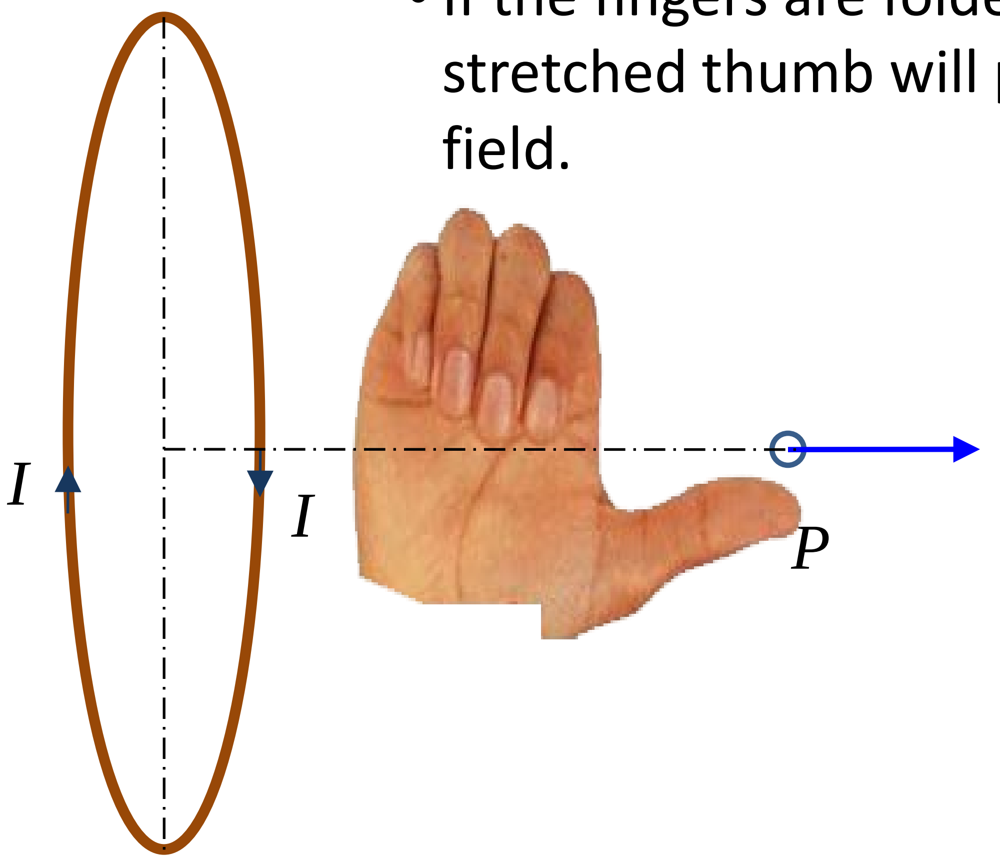
If the coil has *N* number of turns then:

$$\boxed{B = \frac{\mu_0 NI}{2R}\cos^3\theta}$$

$$\boxed{H = \frac{B}{\mu_0} = \frac{NI}{2R}\cos^3\theta}$$

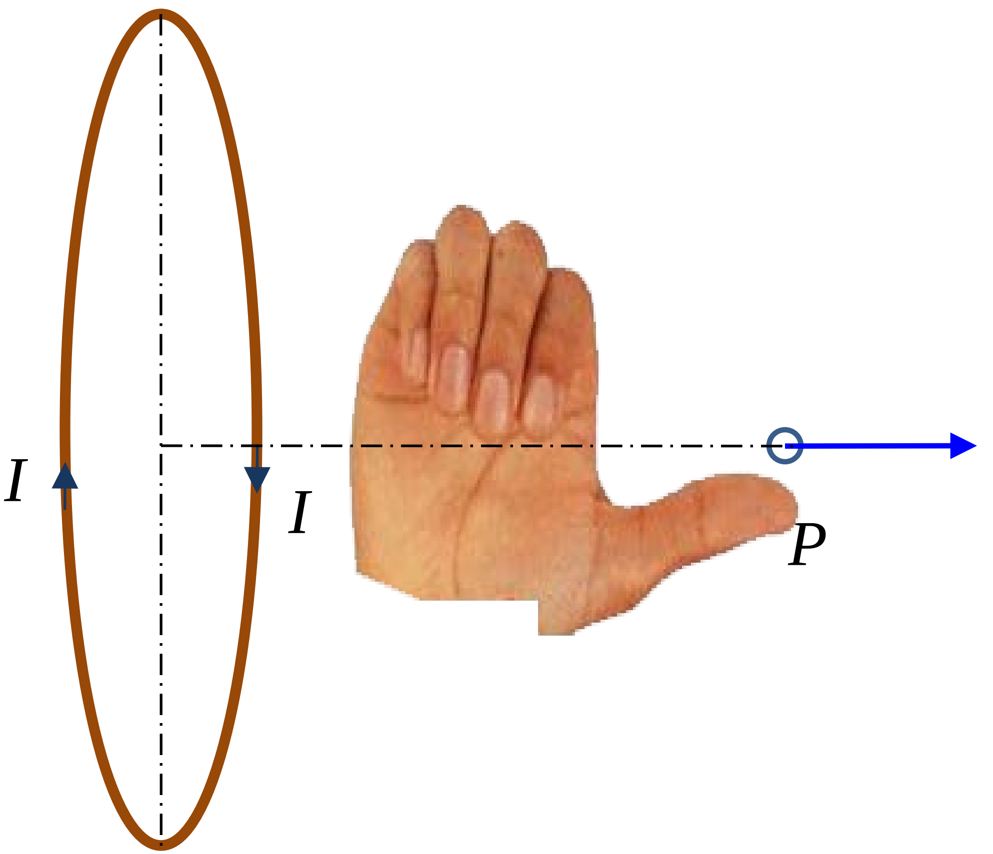
Magnetic Field along axis of a circular current carrying coil

- Direction of resultant magnetic field is along the axis
- Its orientation can be obtained by using right hand thumb rule
- If the fingers are folded along the current, the stretched thumb will point towards the magnetic field.



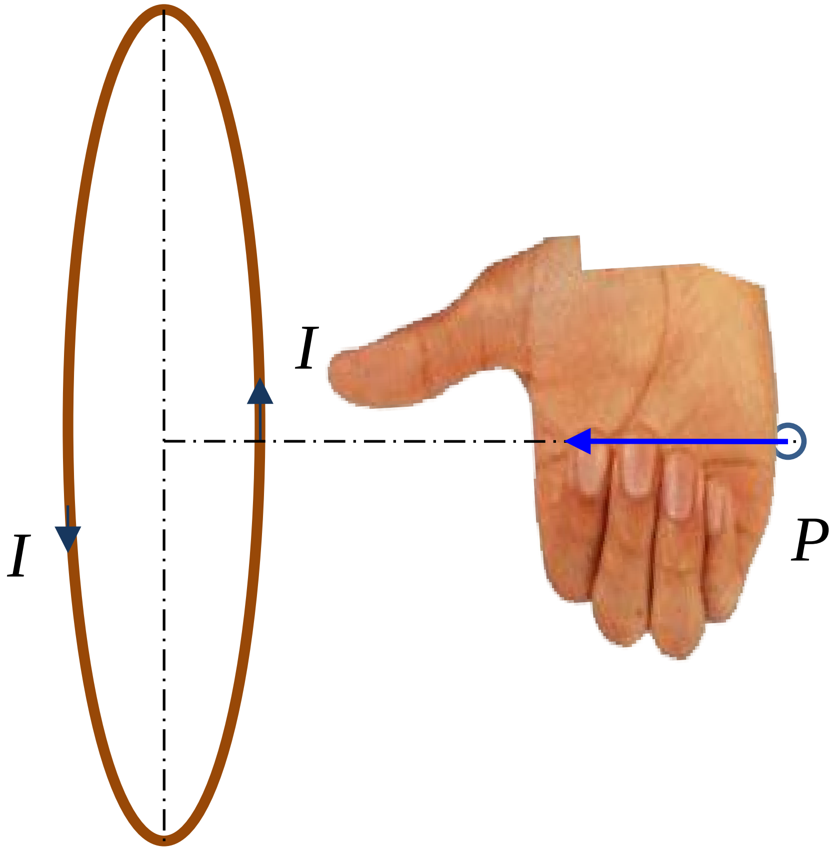
Magnetic Field along axis of a circular current carrying coil

- Magnetic field will be away from the centre of the loop for anti-clockwise current



Magnetic Field along axis of a circular current carrying coil

- Magnetic field will be towards the centre of the loop along its axis for clockwise direction of current

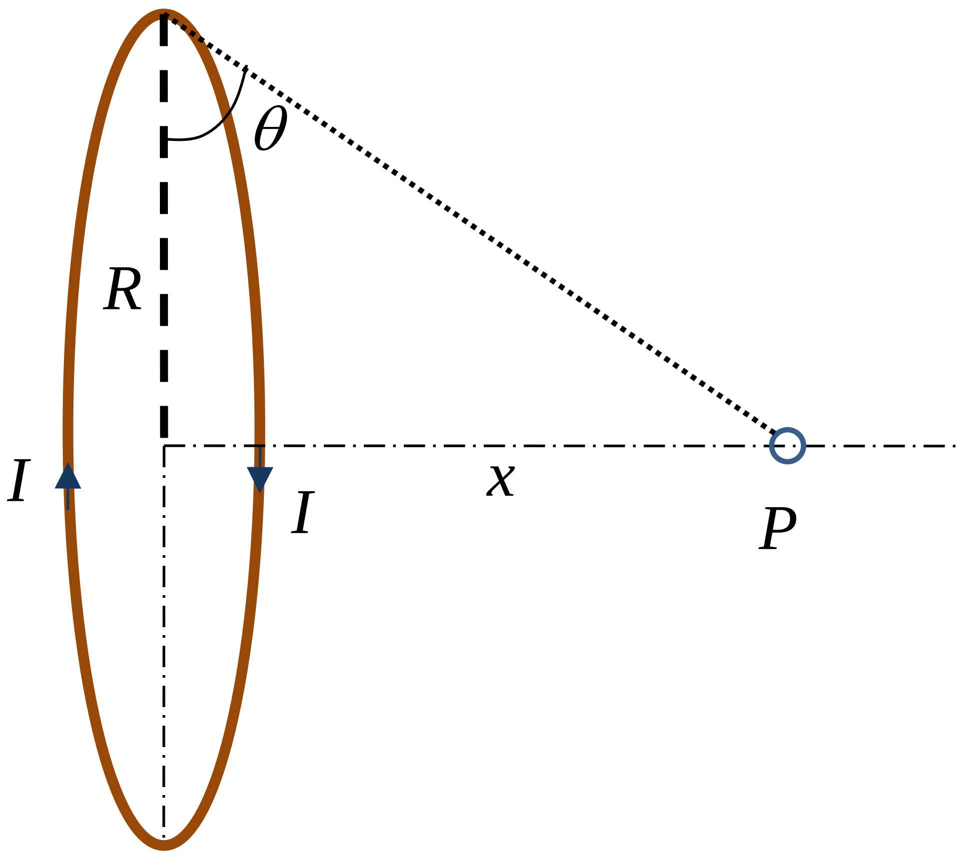


Special Case 1: Magnetic Field at center of the coil

$$\boxed{B = \frac{\mu_0 I}{2R}\cos^3\theta}$$

At the center of the coil, the distance *x*=0

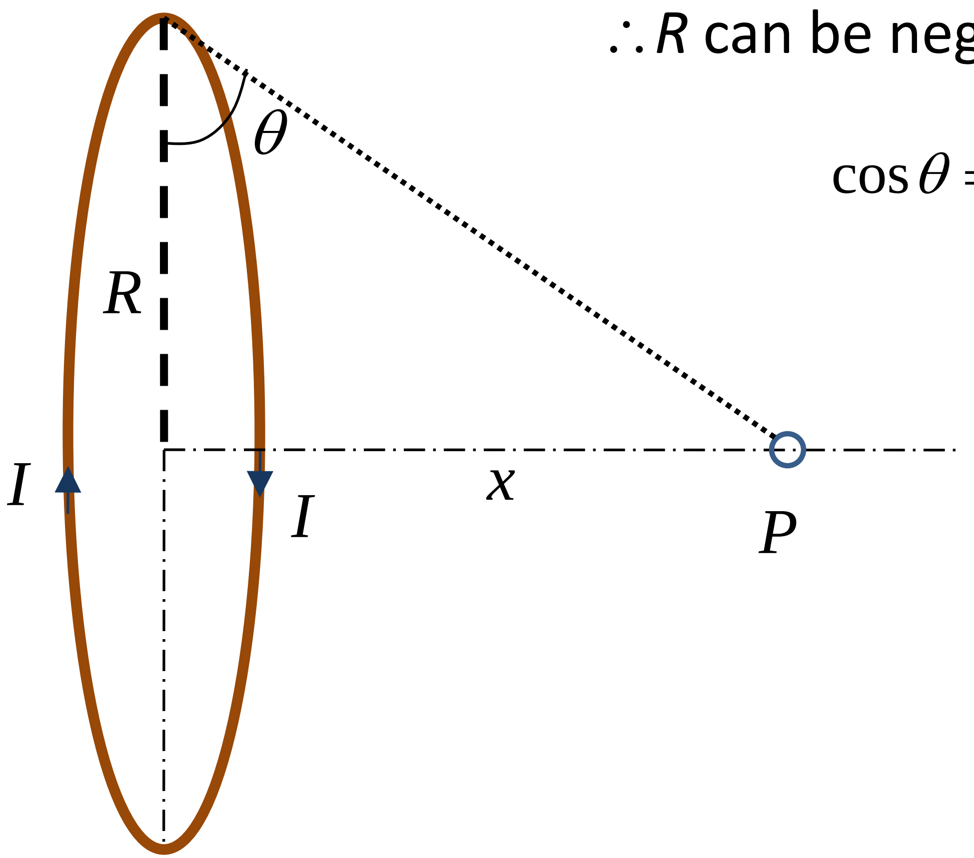
$$\cos\theta = \frac{R}{\sqrt{R^2 + x^2}} = 1$$



$$\boxed{B_{center} = \frac{\mu_0 I}{2R}}$$

$$\boxed{H_{center} = \frac{B_{center}}{\mu_0} = \frac{I}{2R}}$$

Special Case 2: Magnetic field at a point far away from the center



$$\boxed{B = \frac{\mu_0 I}{2R}\cos^3\theta}$$

At far distance, x >>>> R

$\therefore R$ can be neglected with respect to x

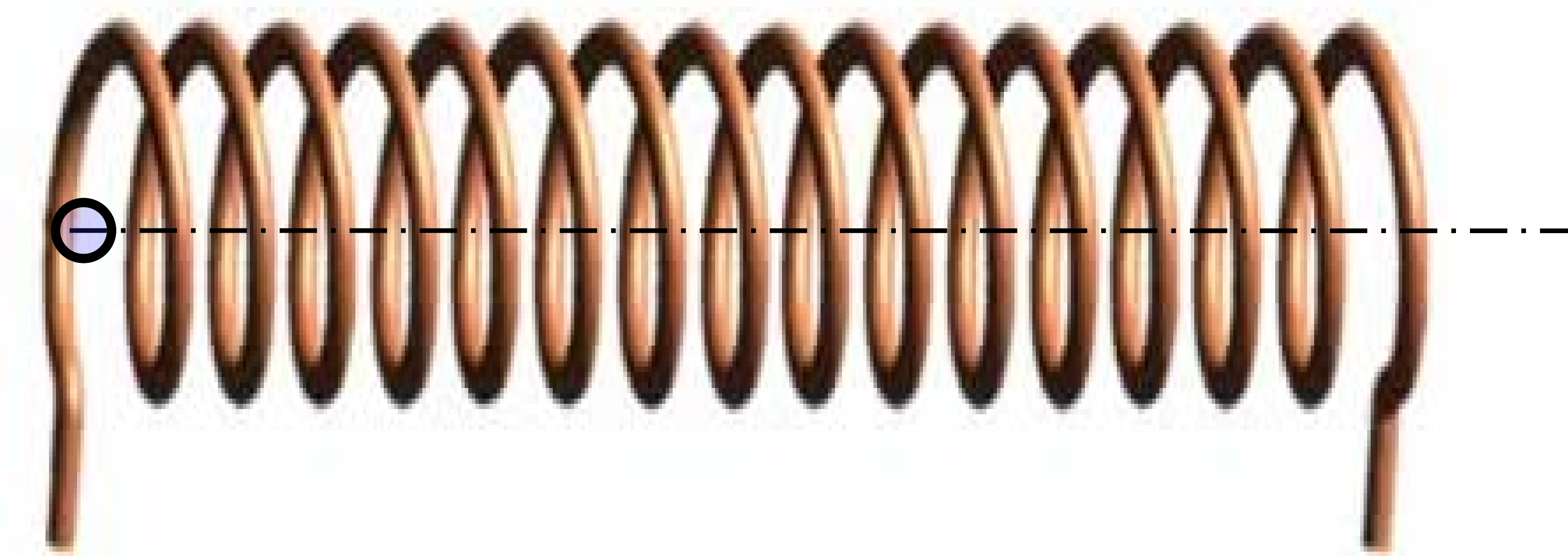
$$\cos\theta = \frac{R}{\sqrt{R^2 + x^2}} \approx \frac{R}{x}$$

$$B = \frac{\mu_0 I}{2R} \times \frac{R^3}{x^3} \boxed{= \frac{\mu_0 I R^2}{2x^3}}$$

$$\boxed{H = \frac{B}{\mu_0} = \frac{IR^2}{2x^3}}$$

Magnetic field produced by a solenoid

- A solenoid is a long wire wound in a close-packed helix carrying a certain current I and the length of the solenoid is much greater than its diameter
- We have to find out the magnetic flux density & field intensity at the centre on the axis of the solenoid

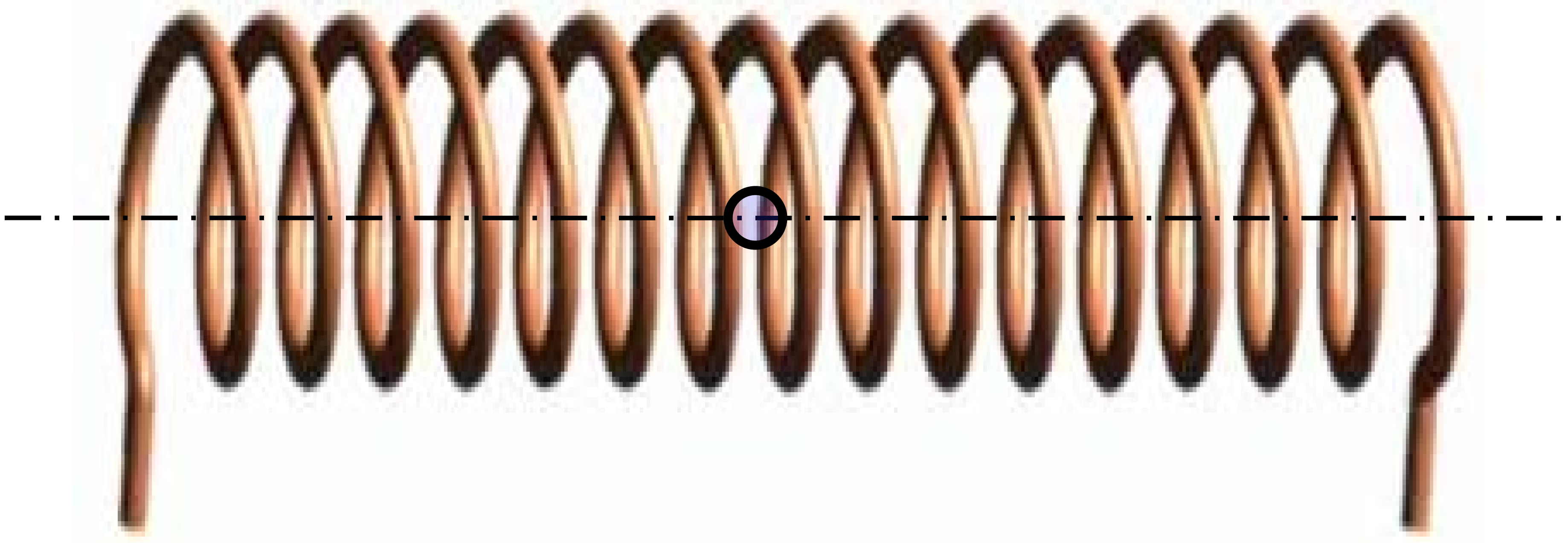


Magnetic field produced by a solenoid

Magnetic flux density at the center inside the solenoid can be calculated as:

$$\boxed{B = \frac{\mu_0 N I}{L}}$$

Hence, magnetic field intensity is given by: $\boxed{H = \frac{B}{\mu_0} = \frac{NI}{L}}$

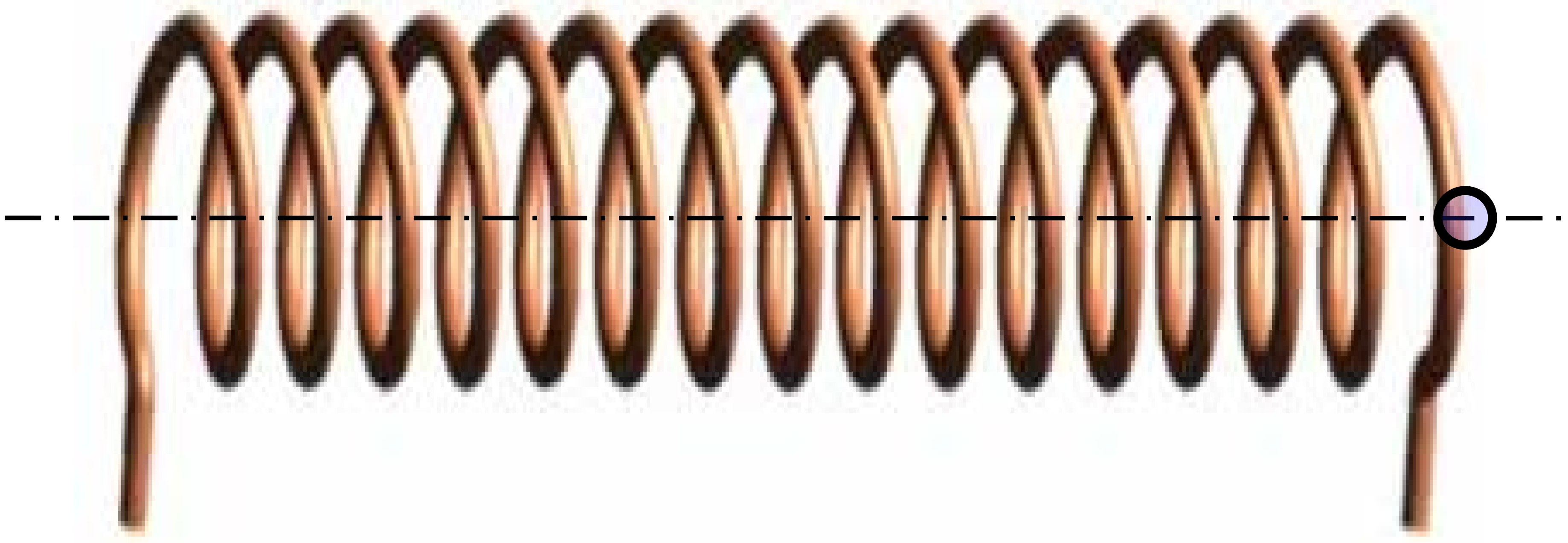


Magnetic field produced by a solenoid

Magnetic flux density at the end of the solenoid can be calculated as:

$$\boxed{B = \frac{\mu_0 N I}{2L}}$$

Hence, magnetic field intensity is given by: $\boxed{H = \frac{B}{\mu_0} = \frac{NI}{2L}}$

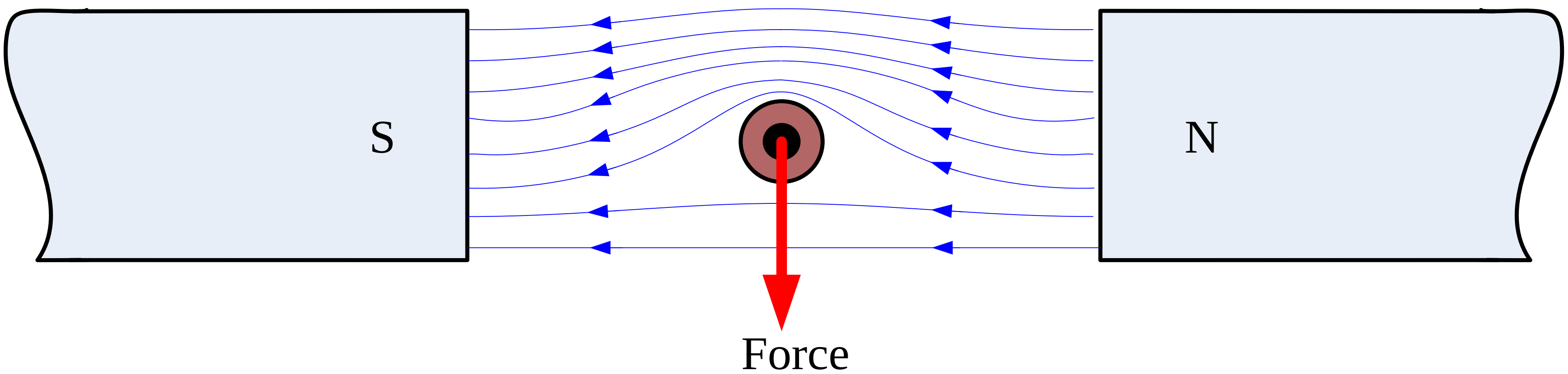


Force on a current carrying conductor placed in a magnetic field

- Lorentz force
- Fleming’s left hand rule
- Force between two parallel current carrying conductors

Force on a current carrying conductor placed in a magnetic field

- A current carrying conductor produces a magnetic field
- When such a conductor is placed in another magnetic field,
- The two magnetic fields interact with each other
- And a mechanical force is experienced by the conductor



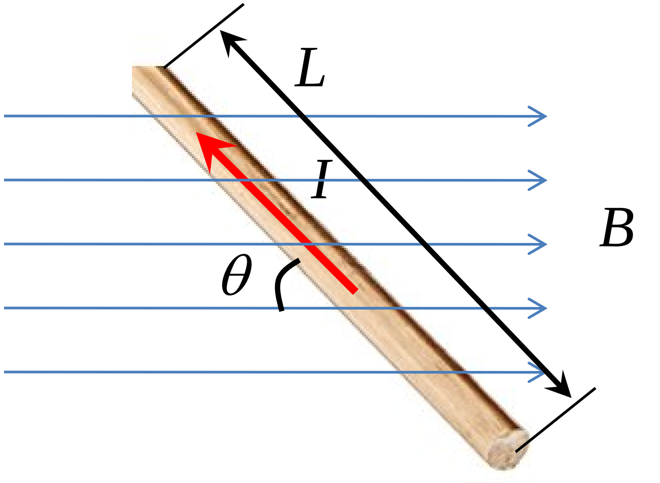
Force on a current carrying conductor placed in a magnetic field

- **Lorentz force**
- Fleming's left hand rule
- Force between two parallel current carrying conductors

Lorentz Force

- Conductor of length L
- Carrying a steady current of I
- Placed in a uniform magnetic field of flux density B
- Then mechanical force experienced by the conductor :

$$F = q(V \times B)$$



- q is the charge
- V is the velocity of charge flow

$$I = \frac{q}{t} \qquad V = \frac{L}{t}$$

$$F = q(V \times B) = It\left(\frac{L}{t} \times B\right) = I(L \times B) \boxed{= BIL\sin\theta}$$

- θ is the angle between the conductor and the flux density vector (lines of force)

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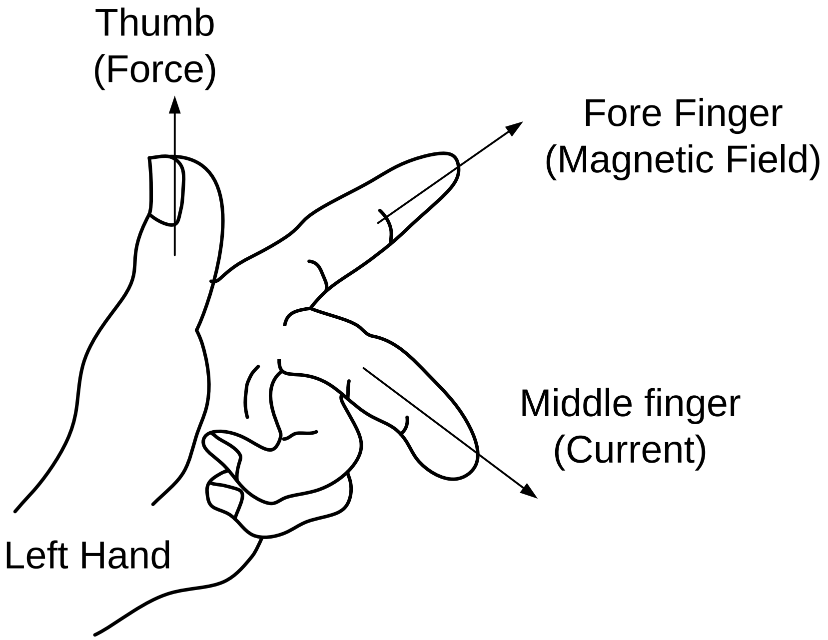
Force on a current carrying conductor placed in a magnetic field

- Lorentz force
- **Fleming’s left hand rule**
- Force between two parallel current carrying conductors

Lorentz Force $\boxed{F = BIL\sin\theta}$

Direction of this force can be determined by ***Fleming's left hand rule***

- The thumb, the fore finger and the middle finger of the left hand are stretched perpendicular to each other
- If the fore finger points to the direction of magnetic field
- The middle finger towards the direction of flow of current
- The thumb will indicate direction of force on the conductor



Force on a current carrying conductor placed in a magnetic field

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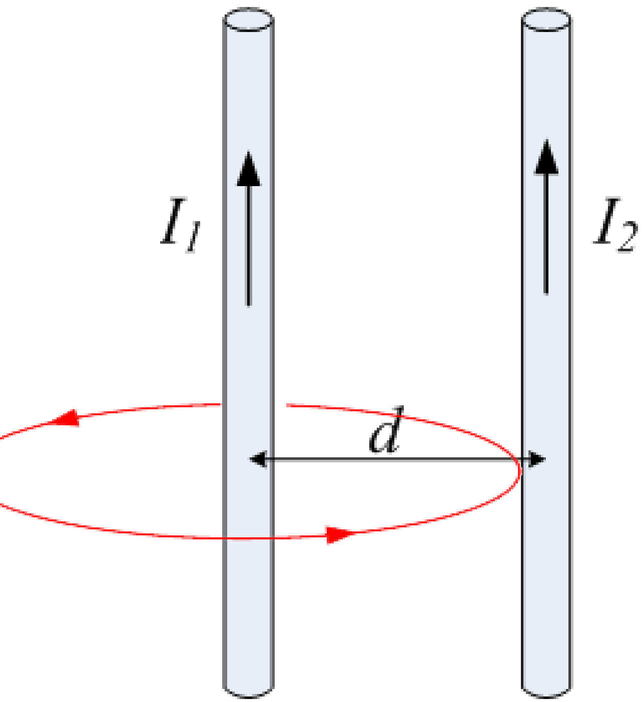
Force on a current carrying conductor placed in a magnetic field

- Lorentz force
- Fleming's left hand rule
- **Force between two parallel current carrying conductors**

Force between two parallel current carrying conductors

- Two conductors lying side by side
- Both the current carrying conductors will produce their own magnetic fields
- These two magnetic fields will interact with each other to produce force



Magnetic field intensity due to current I_1 in the first conductor on the second conductor placed at a distance *d is*:

$$H = \frac{I_1}{2\pi d}$$

Thus, flux density

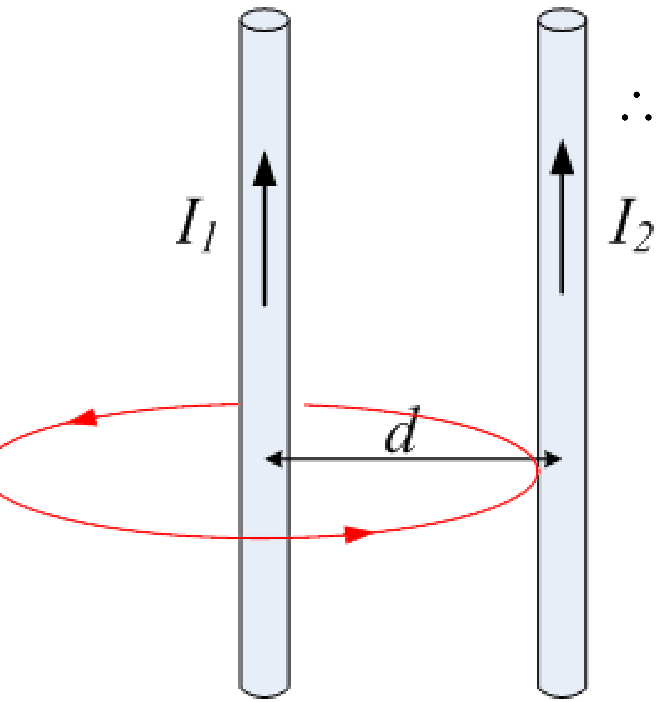
$$B = \mu_0 \mu_r H = \frac{\mu_0 \mu_r I_1}{2\pi d}$$

Force between two parallel current carrying conductors

$$B = \frac{\mu_0 \mu_r I_1}{2\pi d}$$

- Assuming both conductors to be placed in air, $\mu_r = 1$

$$B = \frac{\mu_0 I_1}{2\pi d}$$



$\therefore$ Force experienced by the second conductor is:

$$F = BI_2 L \sin\theta$$

Since the magnetic field is in a plane perpendicular to the axes of the two parallel conductors, the angle $\theta = 90^0$

$$F = BI_2 L = \frac{\mu_0 I_1}{2\pi R} I_2 L = \frac{\mu_0 I_1 I_2}{2\pi R} L$$

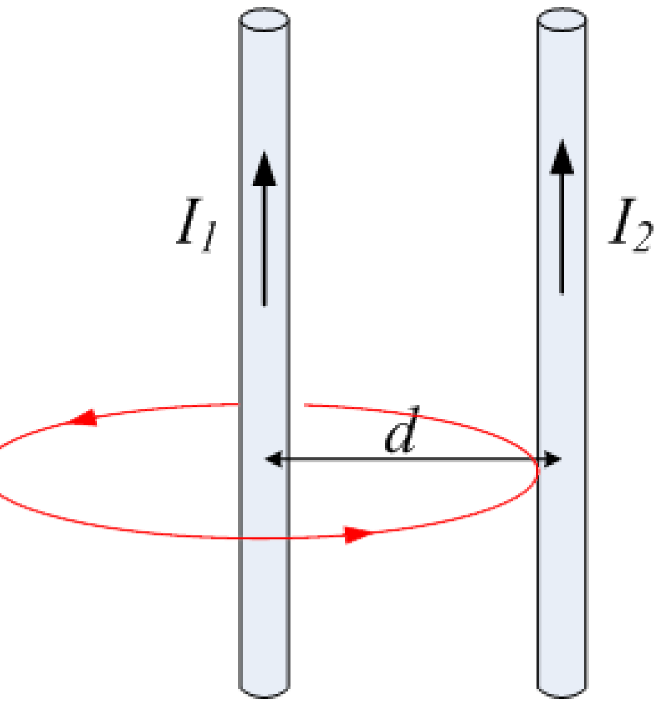
$$= \frac{4\pi \times 10^{-7} \times I_1 I_2}{2\pi R} L \boxed{= \frac{2 I_1 I_2 L}{R} \times 10^{-7}}$$

Force between two parallel current carrying conductors

$$\boxed{F = \frac{2I_1 I_2 L}{R} \times 10^{-7}} \quad \text{N}$$

$\therefore$ Force per unit length of the second conductor is:

$$\boxed{F = \frac{2I_1 I_2}{R} \times 10^{-7}} \quad \text{N/m}$$

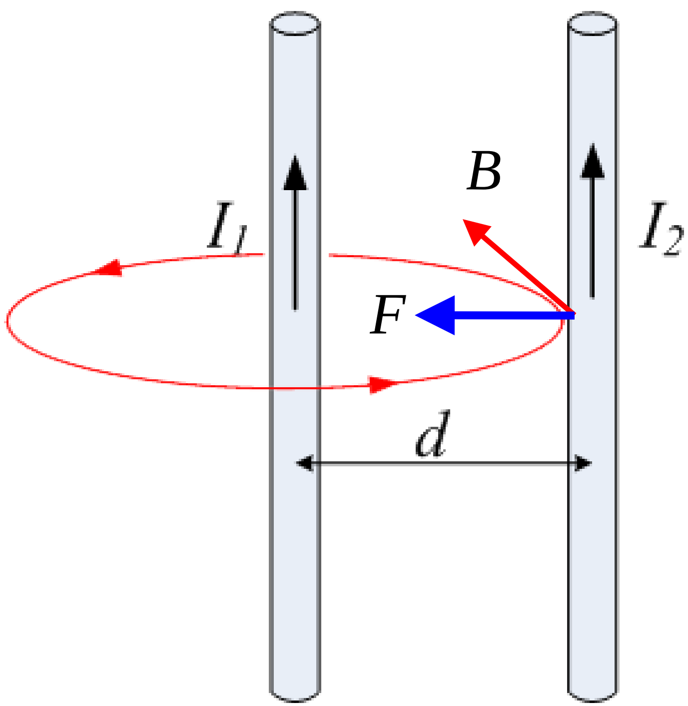


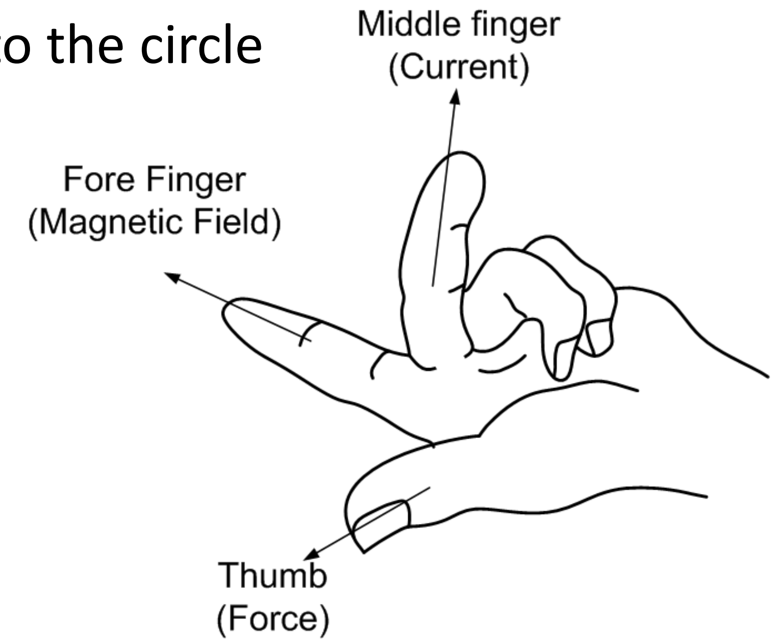
The first conductor will also experience the same magnitude of force due to magnetic field created by current in the second conductor.

Force between two parallel current carrying conductors

<u>Direction of the force</u> (force on the 2nd conductor due to magnetic field of the 1st conductor)**<u>: Fleming's Left Hand Rule</u>**

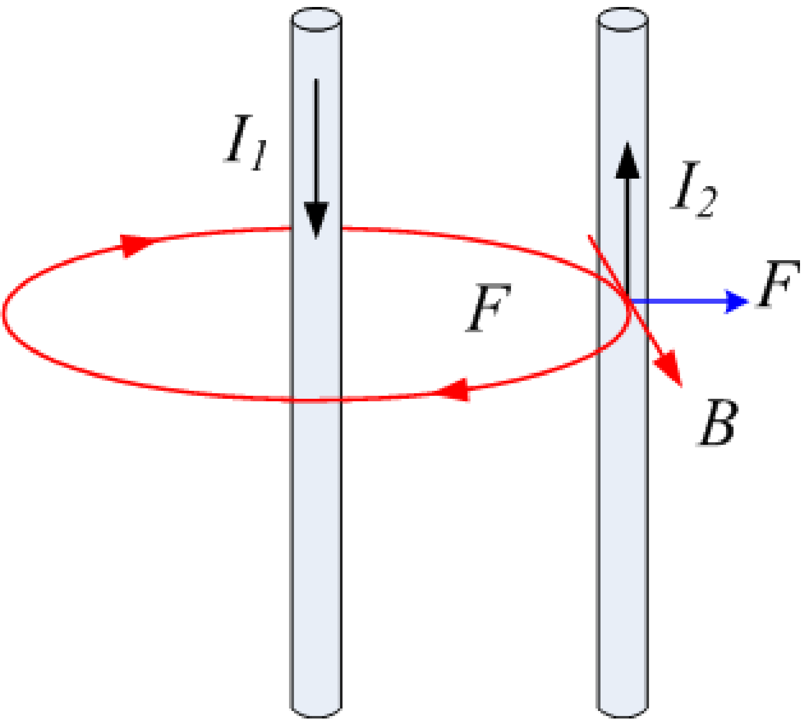
Magnetic field (B) is tangential to the circle





When the two conductors carry **current in the same direction**, force on the second conductor **is attractive**, i.e. **towards the first conductor**. In a similar way, the first conductor will also be pulled towards the second conductor.

Force between two parallel current carrying conductors



When the two conductors carry current in **opposite direction**, the force will **be repulsive** and the two conductors will be pushed away from each other.