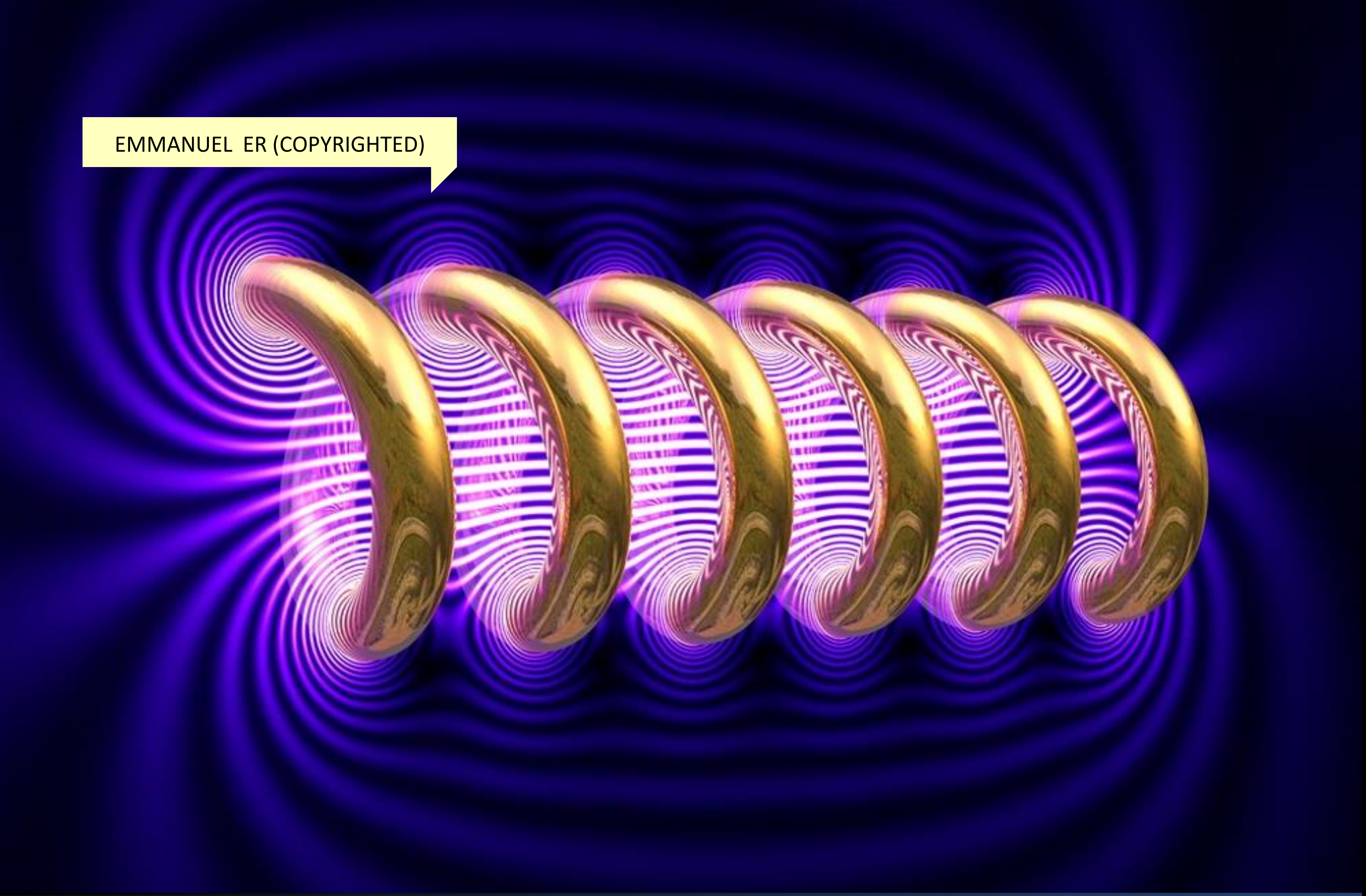
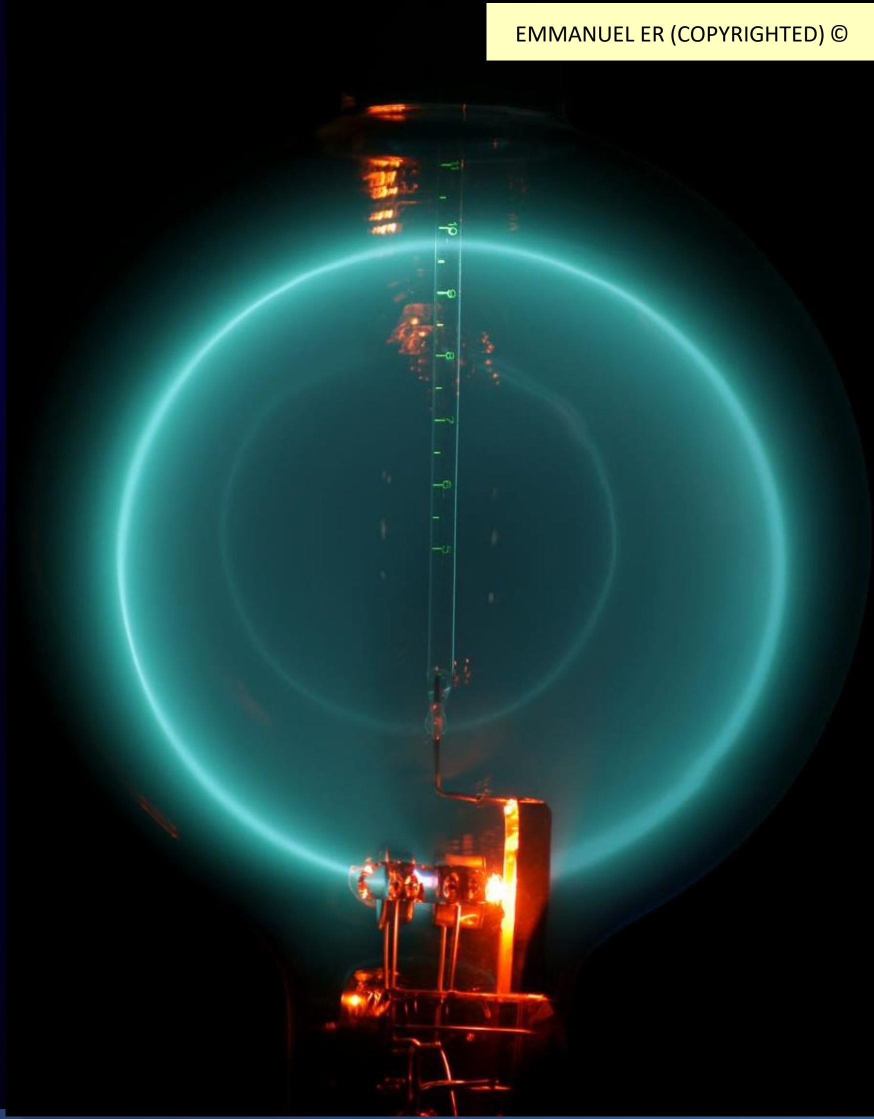




ELECTROMAGNETISM

Overmugged

Content

- Concept of magnetic field
- Magnetic fields due to currents
- Force on a current-carrying conductors
- Force between current-carrying conductors
- Force on a moving charge

Concept of a Magnetic Field

Properties of Magnets

- The term magnet came from the place of its discovery – in a region of Asia Minor known as *Magnesia*.

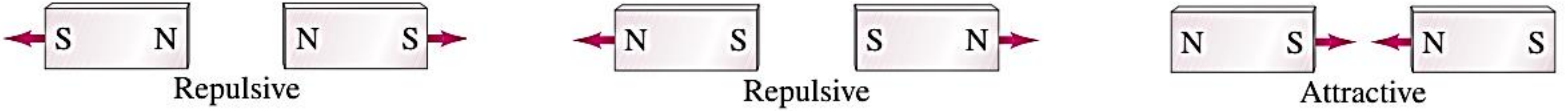
Experiments have shown that:

i. all magnets have two poles: North (**N**) and South (**S**) pole.
ii. like poles repel each other, unlike poles attract.
iii. if you split a magnet, you can't isolate an individual magnetic pole: no **magnetic monopole.**
    - every magnet must have **N** and **S** pole.
iv. a freely suspended magnet aligns approximately parallel to Earth's North-South axis.
v. **N** pole of a magnet points towards the earth's geographic north pole; and **S** pole points towards Earth's south

Concept of a Magnetic Field

Properties of Magnets

Attraction/Repulsion between poles:



No Magnetic monopole:

Magnetic Field

Symbol: $\vec{B}$

SI Unit: Tesla ($\mathrm{T} = \frac{\mathrm{N}}{\mathrm{A \cdot m}}$) [1T=10,000 Gauss]

Vector

- is a region of space in which a magnetic material may experience a force.
- magnetic field may exist due to existence of either *permanent magnet* or *current-carrying wire*.

Magnetic Flux Density

- The magnetic flux density of a magnetic field is numerically equal to the force per unit length per unit current of a long straight current carrying conductor placed at right angles to a uniform magnetic field.
- The SI unit of the Magnetic Flux Density is the **Tesla (T)**

Magnetic Flux Density

- One Tesla is defined as the uniform magnetic flux density which, acting normally to a long straight wire carrying a current of 1 Ampere, causes a force per unit length of $1Nm^{-1}$ on the wire.
- Derivation of the following definitions are from the following formula: For a current carrying conductor placed at right angles in a Magnetic field:

$$\boxed{B = \frac{F}{IL}}$$

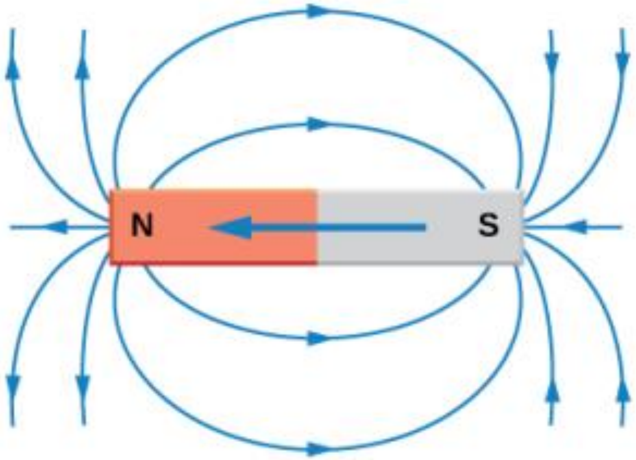
where $B =$ magnetic flux density
$F =$ force on the conductor due to the magnetic field
$I =$ current in the conductor
$L =$ length of the conductor

Magnetic Field Lines

- lines representing magnetic fields where each line has specific direction.
- The direction of a magnetic field line at any point in the field shows the direction of the force that a ‘free’ magnetic *north* pole would experience at that point

Characteristics

1. They are imaginary

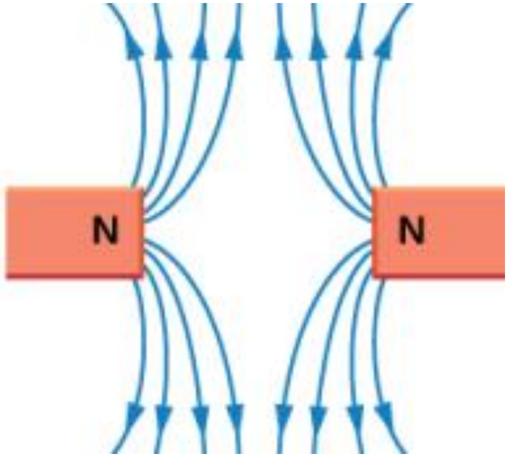


2. By convention, they leave **N** pole and enter **S** pole of a magnet.
   - Note: Unlike electric field lines, magnetic field lines have no start and end point. They continue to go from **S** pole to **N** pole creating closed loops.

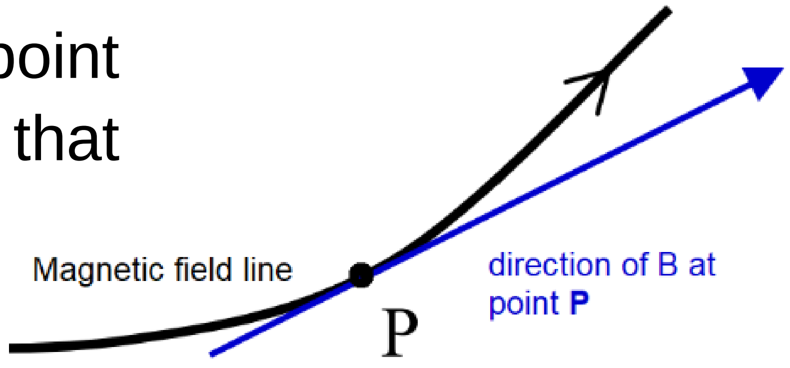
Magnetic Field Lines

Characteristics

3. They do not touch or intersect one another



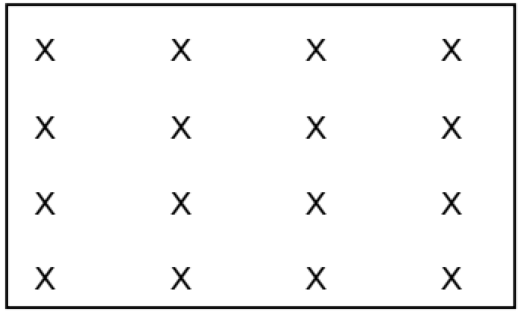
4. Can be straight or curved lines. The tangent to a curved filed line at a point indicates the direction of magnetic field at that point.



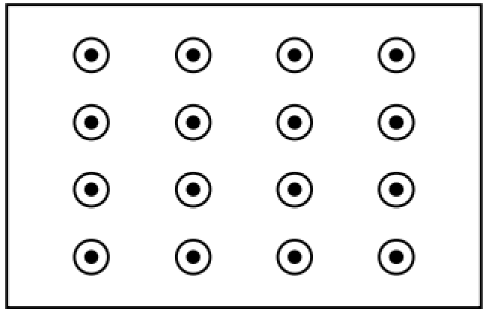
Magnetic Field Lines

Characteristics

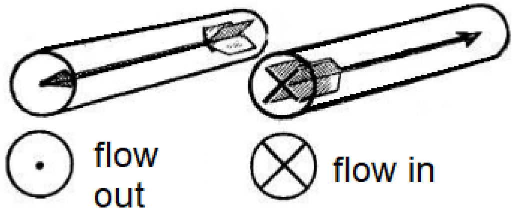
5. They can be re[resented by crosses **x** or dotted circles in a 2D plane



Magnetic field into the paper.



Magnetic field out of the paper.

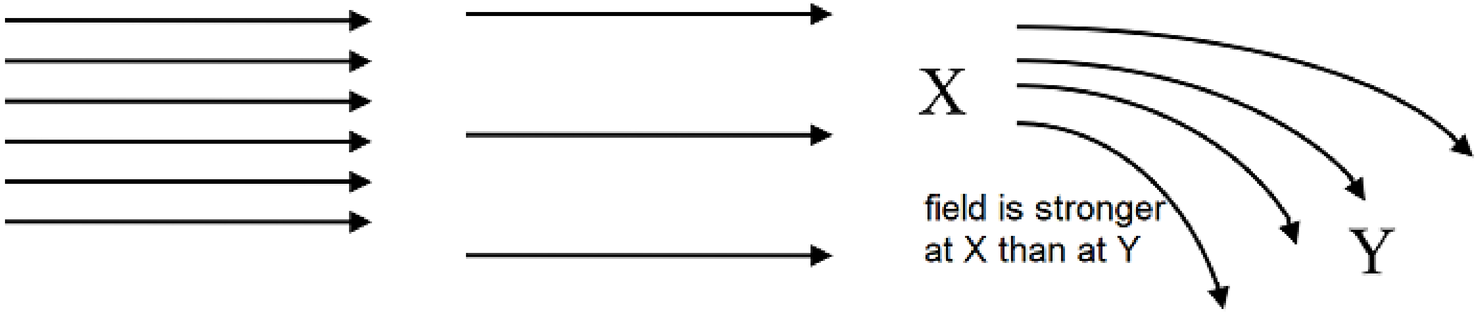


6. Evenly spaced and parallel field lines represent **uniform** magnetic field.
7. The closeness of the lines indicates the strength of the field.

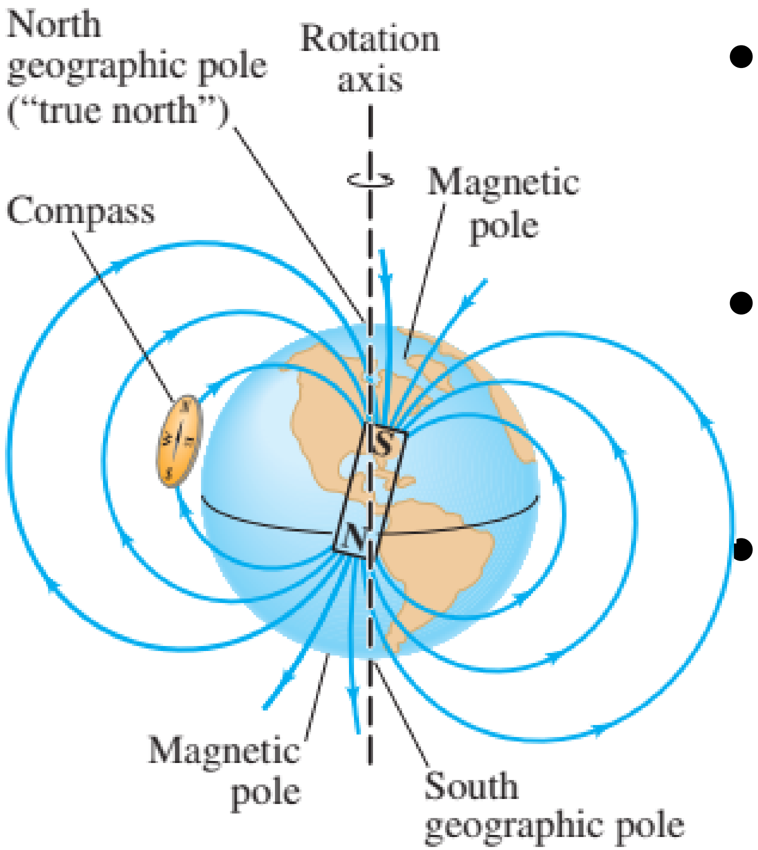
Strong uniform field

Weak uniform field

Non-uniform field

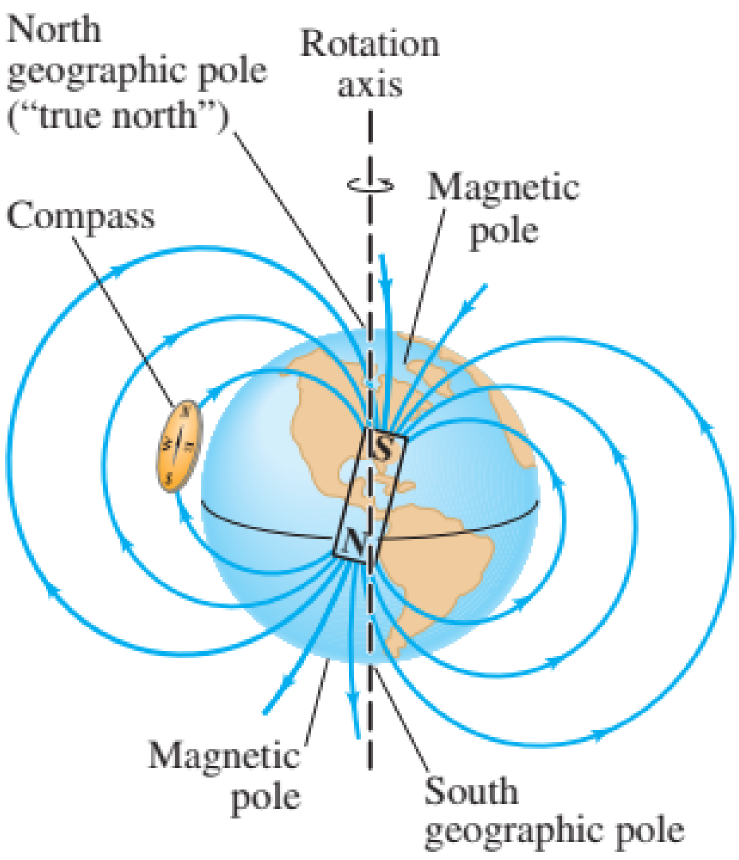


Earth’s Magnetic Field



- is a weak magnetic field believed to be caused by convection currents in Earth’s core.
- The magnitude and direction of this field varies with position over the Earth’s surface and changes gradually with time.
- Earth’s magnetic axis is tilted ~11° with respect to its rotational axis

Earth's Magnetic Field



- Earth's magnetic field at most locations is not tangent to the Earth's surface.

  Angle of dip α (or inclination)

Angle the Earth's $\vec{B}$ makes with the horizontal

- $\alpha = 0.13°$ in Singapore
- $\alpha = 67°$ in New York

Earth's magnetic field $\vec{B}_{earth}$ in horizontal and vertical components

$$B_H = B_{earth} \cos \alpha$$

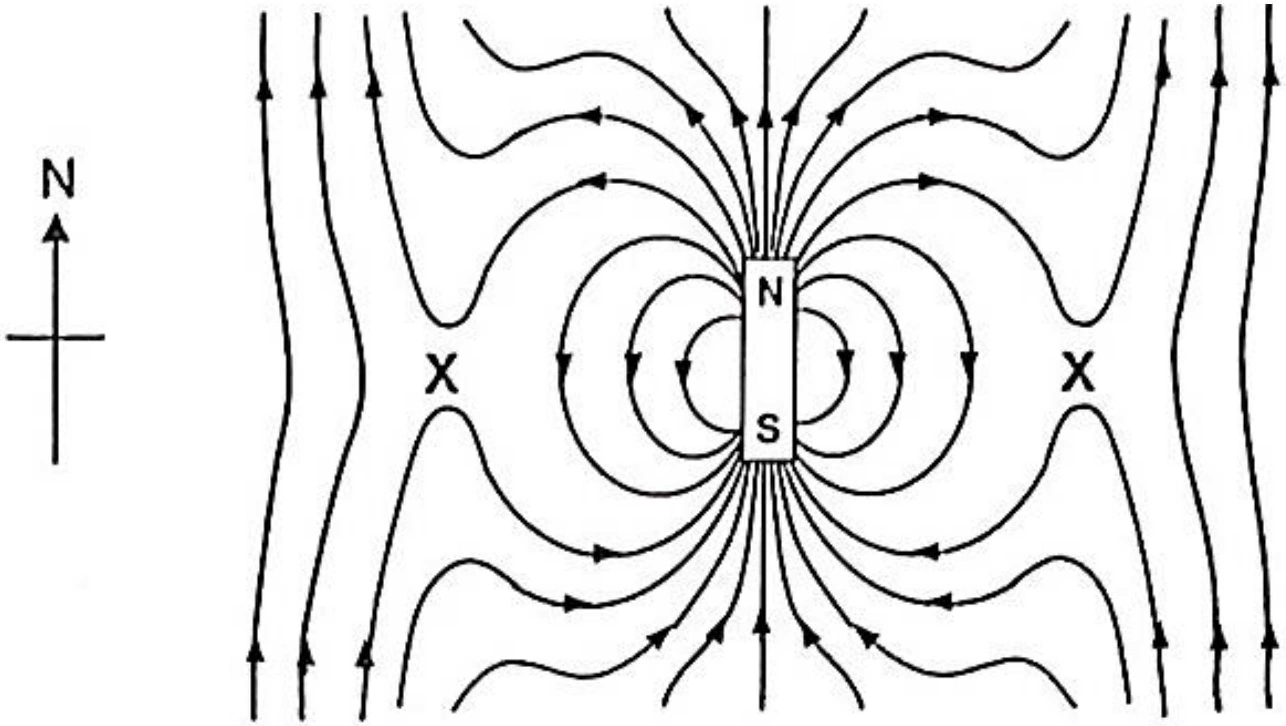
$$B_V = B_{earth} \sin \alpha$$

$$\tan \alpha = \frac{B_V}{B_H}$$

Earth's Magnetic Field

Magnetic Field Pattern of Earth and a Bar Magnet

- The bar magnet with its **N** pole point **N.**



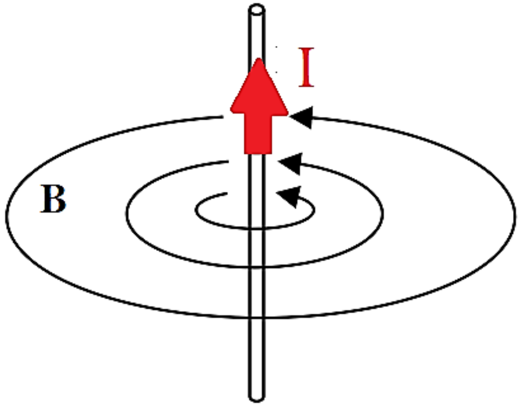
X = Neutral point where the resultant field is zero

MAGNETIC FIELDS due to CURRENTS

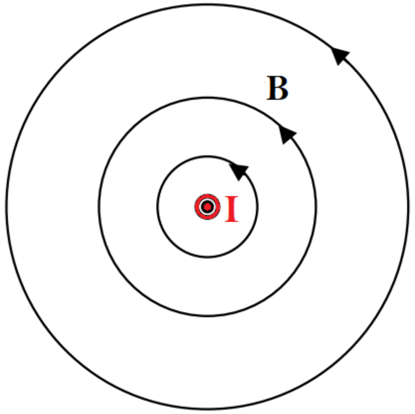
Current-Carrying Straight Wire

- A long straight wire carrying current generates magnetic field patterns consisting of concentric circles, radiating outwards from the wire.
- Compass needles are deflected near a current-carrying wire which indicates a presence of magnetic field.

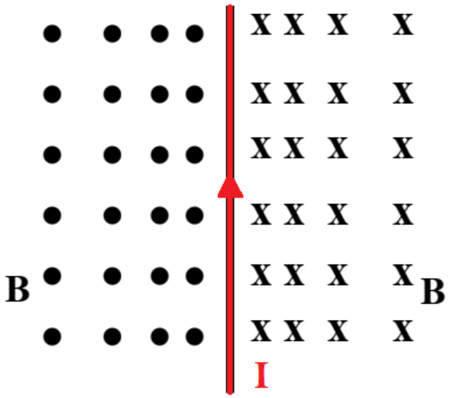
Field Pattern



Isometric View

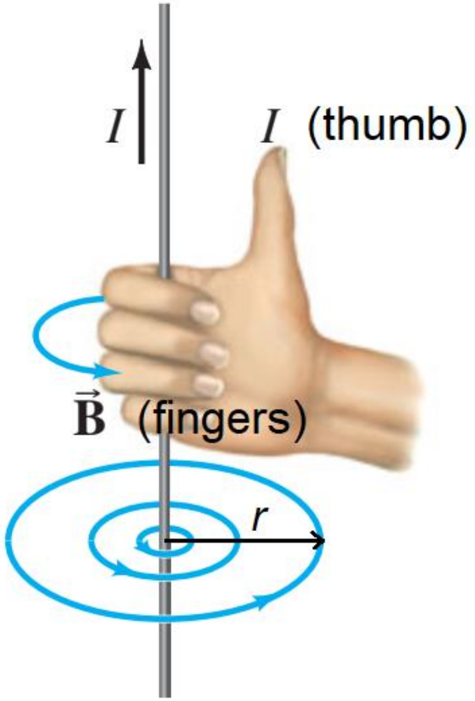


Plane View (Top View)



Side View

MAGNETIC FIELDS due to CURRENTS



Right-Hand Rule

The right-hand grip rule can be used to determine the direction of the magnetic field by a current-carrying wire.

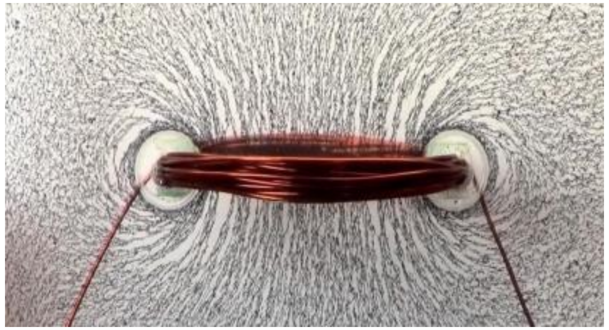
- thumb points in the direction of the conventional current.
- fingers wrapped around the wire point in the direction of B.

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

$B =$ magnetic field at distance r from the wire (magnetic flux density)
$r =$ perpendicular distance from the wire
$I =$ current in the wire
$\mu_0 =$ permeability of free space (vacuum) $= 4\pi \times 10^{-7}$ T m/A

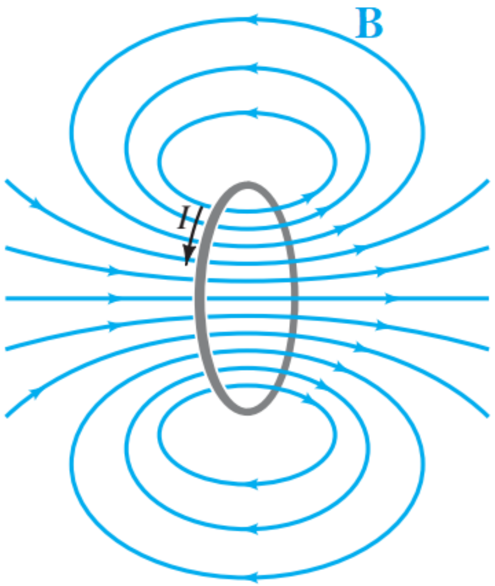
MAGNETIC FIELDS due to CURRENTS

Circular Coil Carrying Current

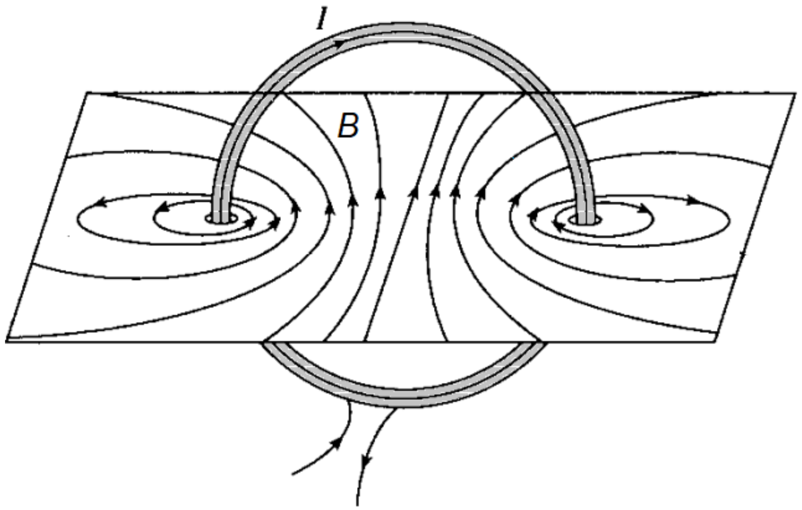


- Iron filings sprinkled around a circular coil.
- Iron filings reorganize according to the magnetic pattern created by the current carrying-circular wire

Field Pattern

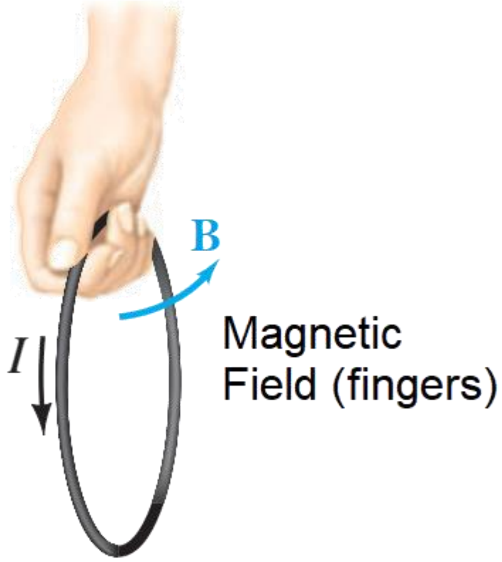


Isometric View



Plane View

MAGNETIC FIELDS due to CURRENTS



Right-Hand Rule

- thumb $\rightarrow I$
- fingers $\rightarrow B$

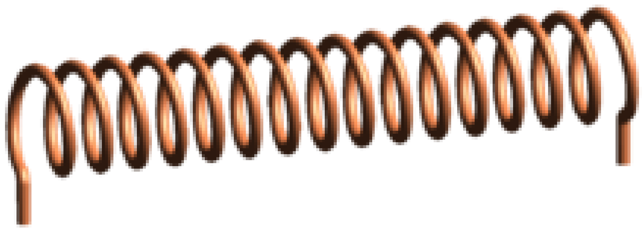
At the center point **P** of a flat circular coil lying on the plane of a paper, the magnetic flux density due to current I is given by

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

B = magnetic flux density
N = number of turns
r = perpendicular distance from the wire
I = current in the wire
μ_0 = permeability of free space (vacuum) $= 4\pi \times 10^{-7}$ T m/A

MAGNETIC FIELDS due to CURRENTS

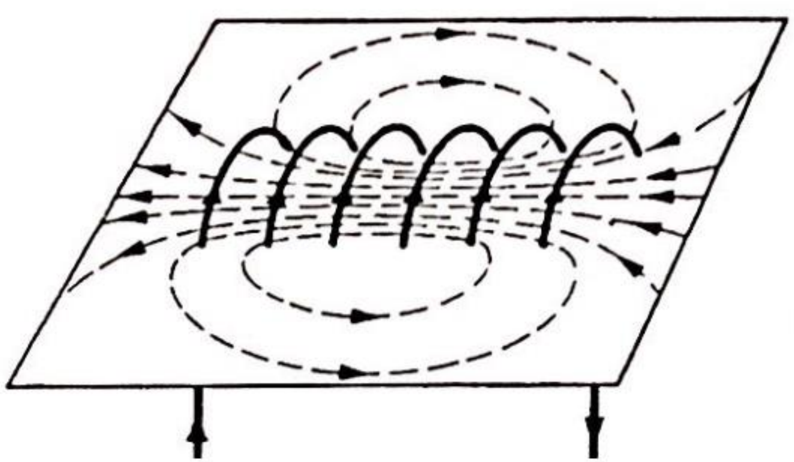
Solenoid

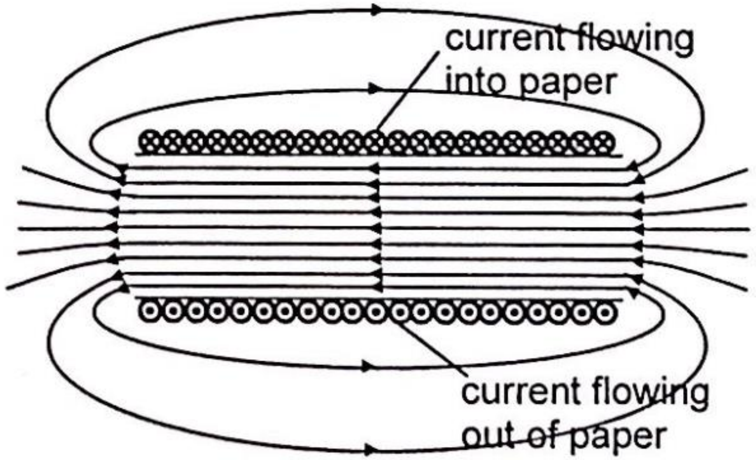


- Solenoid is a long coil of wires consisting of many loops.
- is used to generate controlled magnetic field through the coil

Plane View

Field Pattern





Magnetic field inside a solenoid is **uniform**

MAGNETIC FIELDS due to CURRENTS

Along the axis

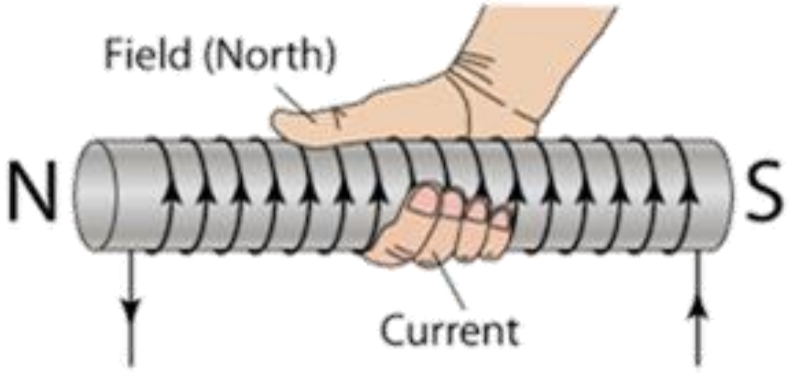
$$\boxed{B = \mu_0 n I}$$

B = magnetic flux density along the axis of the solenoid
n = number of turns per unit length ($n = N/L$)
I = current in the wire
μ_0 = permeability of free space (vacuum) $= 4\pi \times 10^{-7}$ T m/A

At either end

$$\boxed{B = \frac{1}{2}\mu_0 n I}$$

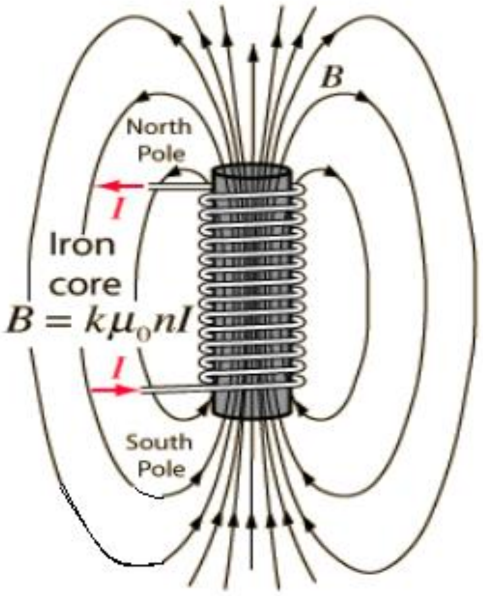
Direction



- The direction of the magnetic field can be determined using right-hand grip rule.
- Curl you fingers in the direction of current. The thumb points in the direction of B-field.

MAGNETIC FIELDS due to CURRENTS

Effect of Ferrous Core



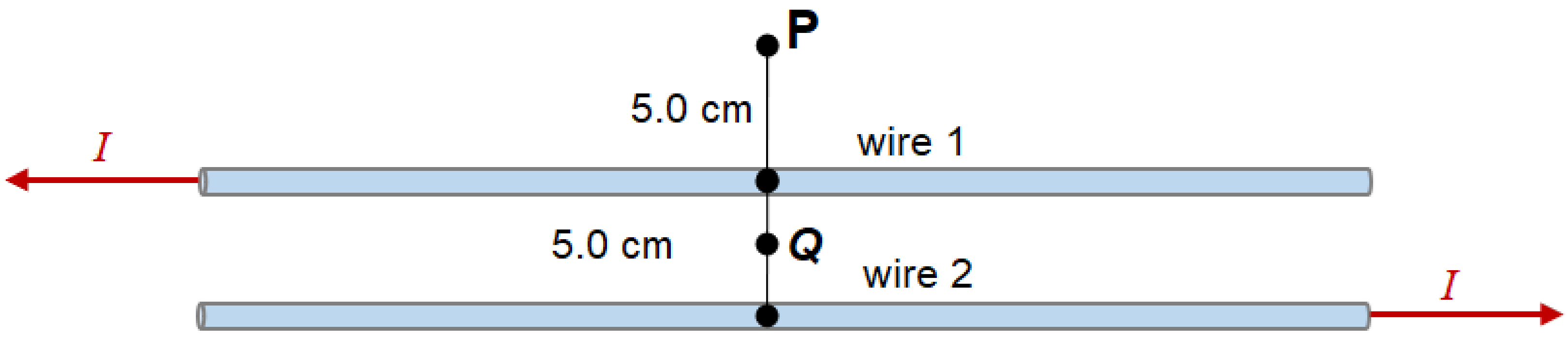
- Inserting a ferrous core into a solenoid strengthens the magnetic field inside the solenoid.
- This ferrous core can be made of iron, cobalt, or nickel.
- Ferrous core becomes magnet when exposed to magnetic field.

$$B = k\mu_0 nI$$

$k =$ effective or apparent permeability of the core

Practice Example 1

Two long straight wires, 5.0 cm apart, lie parallel to each other, and each carry a current of 3.0 A. The current through each wire flows opposite to one another.



(a) What are the directions of magnetic fields due to currents in wire 1 and wire 2 at points **Q** and **P**?

(b) Find the magnetic field (magnetic flux density) at point Q, midpoint between the two wires.

(c) Find the magnetic field (magnetic flux density) at point **P,** 5.0 cm from wire 1.

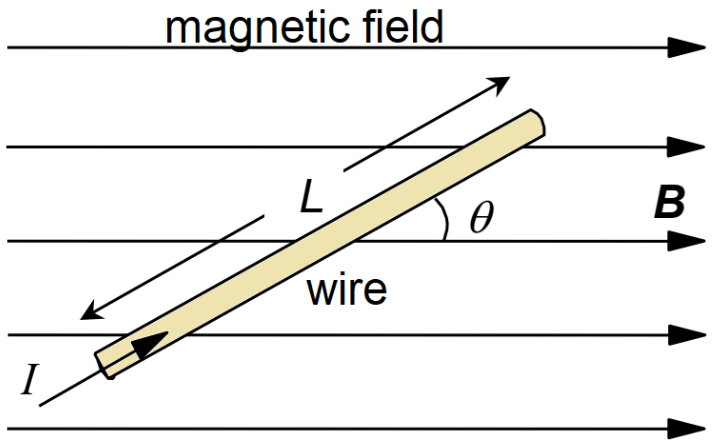
Practice Example 2

Magnetic resonance imaging (MRI) is a noninvasive technique used to produce images of the anatomy and physiological processes of the body. A typical MRI solenoid has length of 1.2 m and diameter of 1.0 m which produces magnetic field of 1.0 T. Calculate the number of turns of wire the solenoid have if the wire's maximum capacity is 100A.

FORCE on a CURRENT-CARRYING CONDUCTOR

F on a Current-Carrying Wire

When a current-carrying conductor is placed in an external magnetic field, a force will be exerted on it if the field has a component perpendicular to the current.



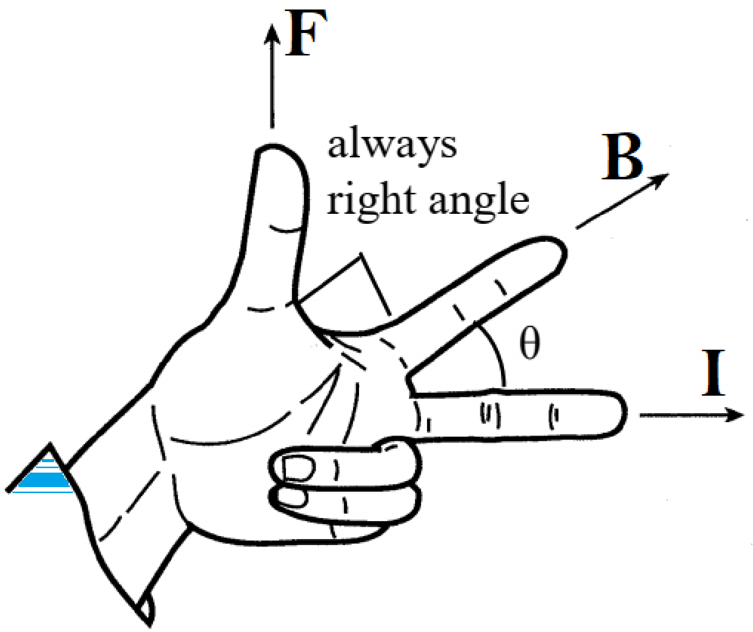
$$\boxed{F = BIL\sin\theta}$$

F = magnitude of the force on the wire
B = magnetic field
L = length of the conductor
I = current through the conductor
θ = angle between I and B

FORCE on a CURRENT-CARRYING CONDUCTOR

F on a Current-Carrying Wire

Direction



The direction of force F is always perpendicular to the plane containing current I and magnetic field B.

You can use the *Fleming's left-hand rule.*

Thumb: F

Index finger: B

Middle: I

Magnetic Flux Density

Symbol: B

Unit: Tesla ($T = \frac{N}{A \cdot m}$) [1T=10,000 Gauss]

Vector

- is defined as the force per unit length per unit current acting on a conductor carrying a current placed at a right angle (90°) to the magnetic field.

$$B = \frac{F}{IL}, \qquad \theta = 90^\circ$$

F = magnitude of the force on the wire
I = current through the conductor
L = length of the conductor

Magnetic Flux

Symbol: Φ

Unit: Weber (W= T m^2)

Scalar

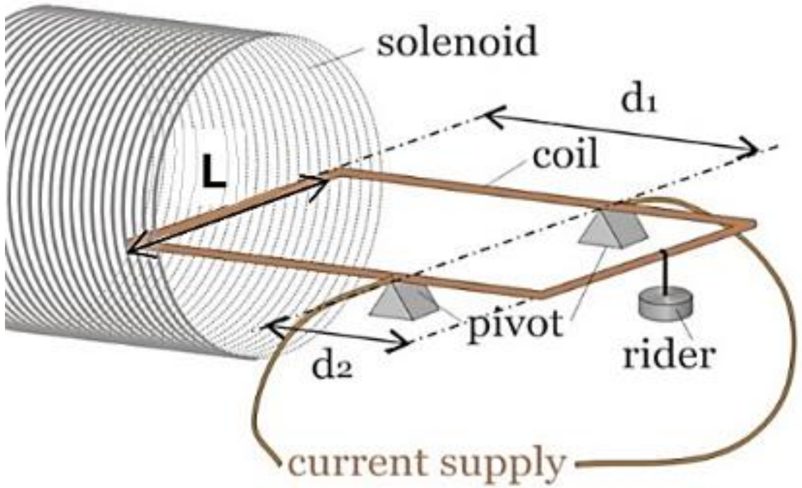
- is defined as product of the magnetic flux density and the area that is perpendicular to the field through the field is passing.

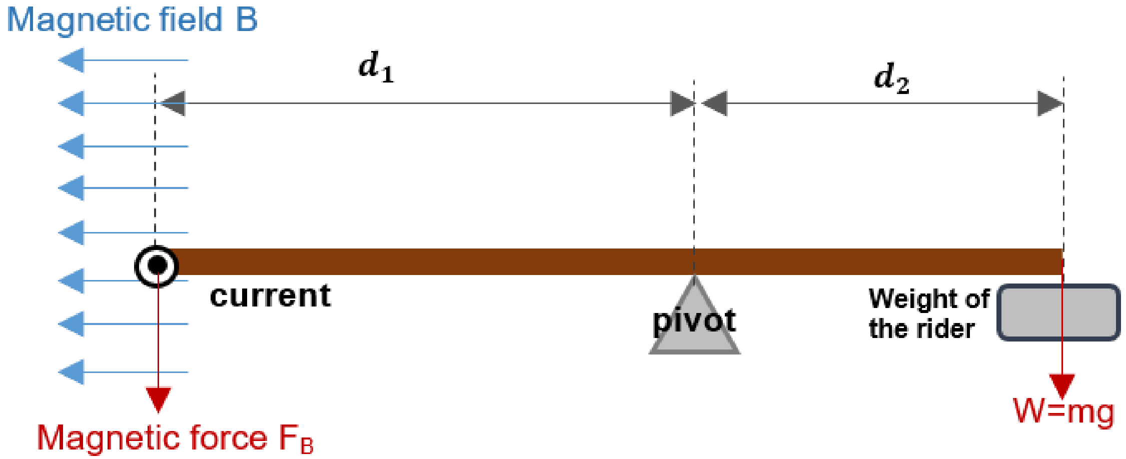
$$\Phi = BA\sin\theta$$

B = magnetic flux density
A = Area
θ = angle between the field and the plane of the area through the field is passing

Current Balance

- is an arrangement that can be used to measure flux density of a magnetic field





- Part of the rectangular coil is placed inside a solenoid and a current I is allowed to flow in the coil such that it would experience a downward force F_B.
- A rider of mass m is hung on the opposite end of the coil.
- The pivot is shifted until the coil is in *rotational equilibrium*.

In rotational equilibrium, the sum of all torque is zero.

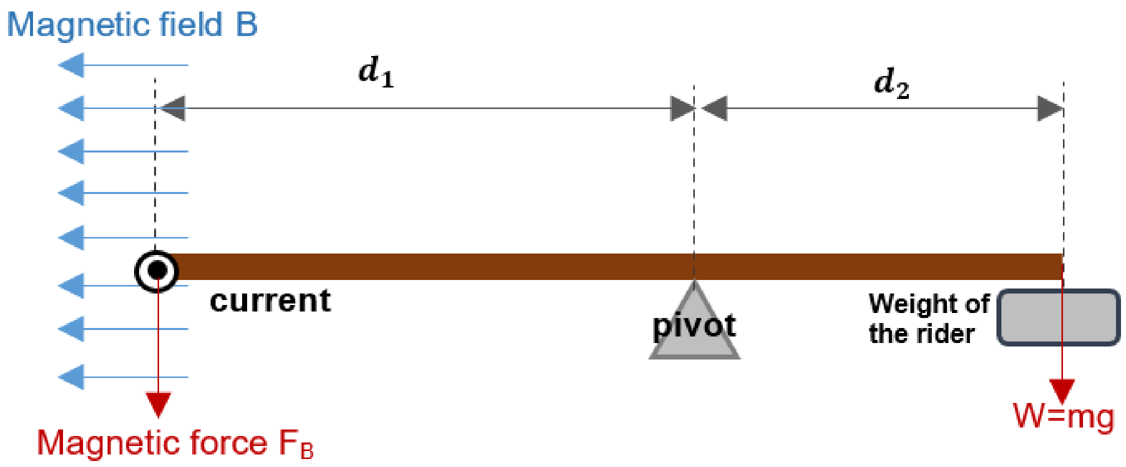
$$F_B d_1 = W d_2$$

where $W = mg$, $F_B = BIL$

Current Balance

Magnetic Flux Density

$$B = \frac{mgd_2}{ILd_1}$$



m = mass of the rider
d_1 = distance of the wire exposed to B field from the pivot.
d_2 = distance of the rider from the pivot
I = current in the rectangular coil
L = length of coil exposed to B-field

Practice Example 3

A 3.0-m long rigid wire carries a 2.5-A current flowing in the positive $x-$ direction. A magnetic field of magnitude 0.75 T is applied on the wire. Find the magnetic force on the wire if

(a) the magnetic field is directed along the +y-axis.

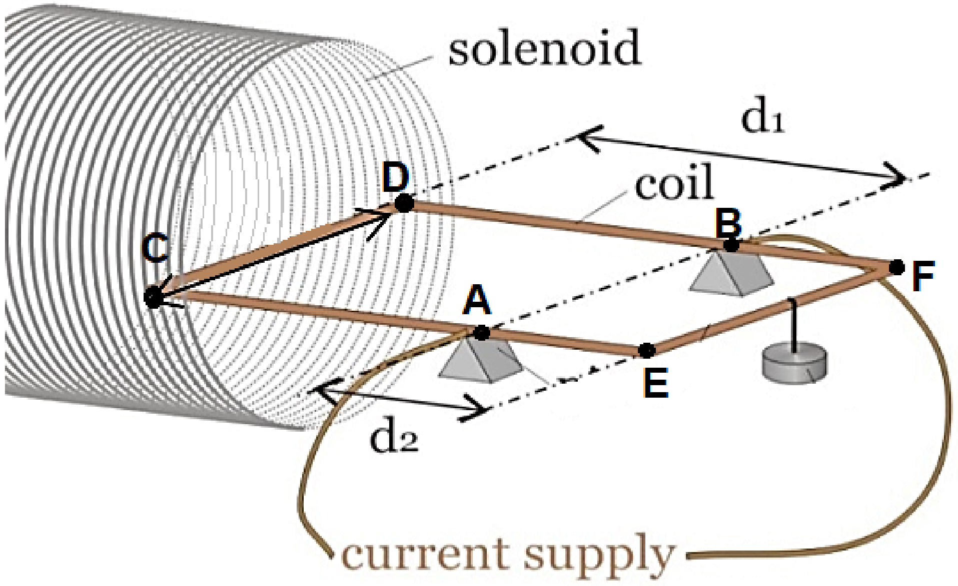
(b) the magnetic field is directed along the negative x-axis.

(c) the magnetic field is directed 30° from +x-axis to +y-axis.

(d) the magnetic field is directed 30° from +y-axis to +x-axis.

Practice Example 4

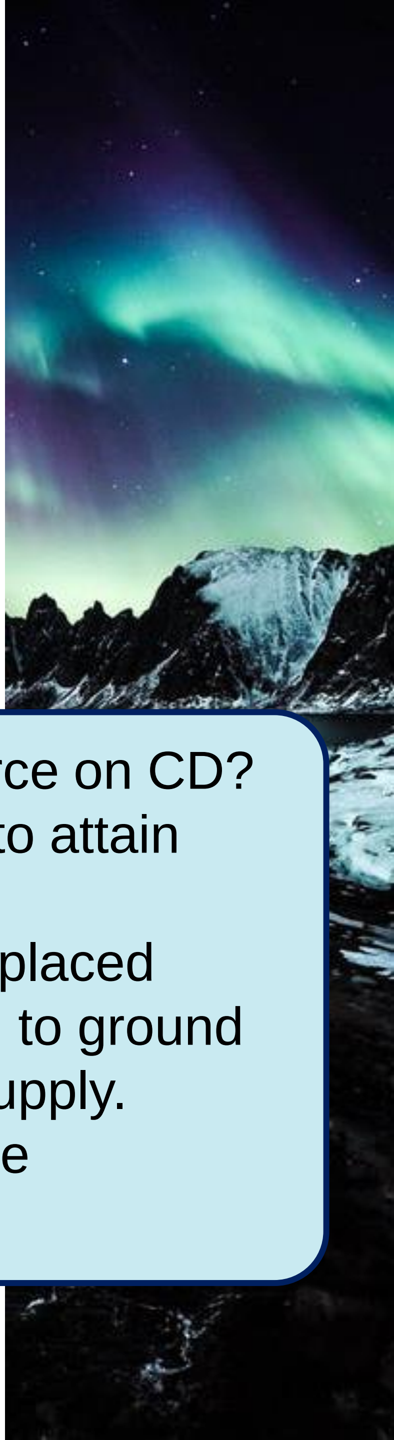
Consider a current balance shown below. The rectangular coil sits on two pivots, at points **A** and **B,** which are 30 cm apart. Length DF and CE is equal to 50 cm while length BF and AE equals 18 cm. The solenoid supplies a magnetic flux density of 5.0 mT while the current supply drives a 2.0A current into the coil.



(a) What is magnitude of the magnetic force on CD?

(b) What should be the mass of the rider to attain rotational equilibrium?

(c) Suppose the entire rectangular coil is placed inside the solenoid. The coil is parallel to ground and is disconnected from the power supply. Calculate the magnetic flux through the rectangular loop?

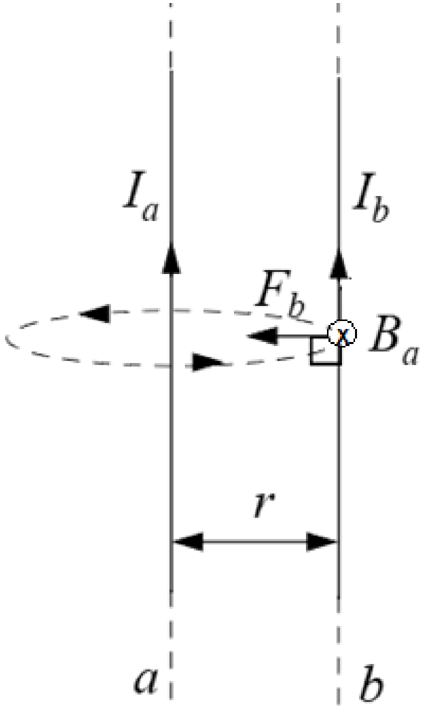


Forces between two parallel wires

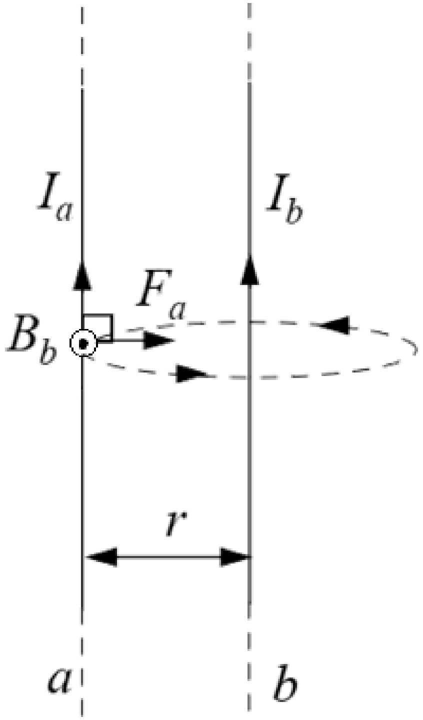
- Each wire experiences a force ($F = BIL\sin\theta$), either attraction or repulsion, depending on the direction of current.

Same current direction

Consider two wires *a* and *b* (both of length *L*) carrying current I_a and I_b separated by distance r.

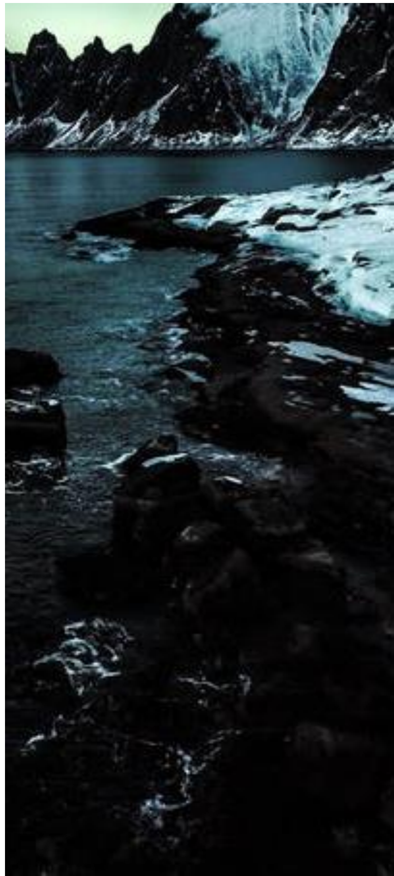


Magnetic force on wire b



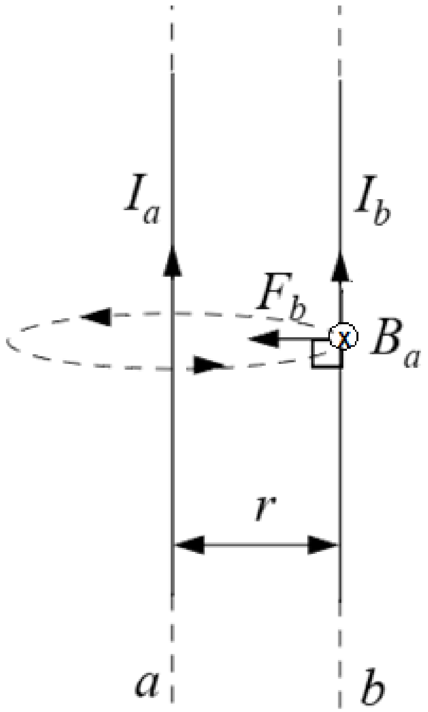
Magnetic force on wire a

- Using right-hand rule, we determine the direction of *B.*
- Using Fleming's left-hand rule, we determine the direction of F

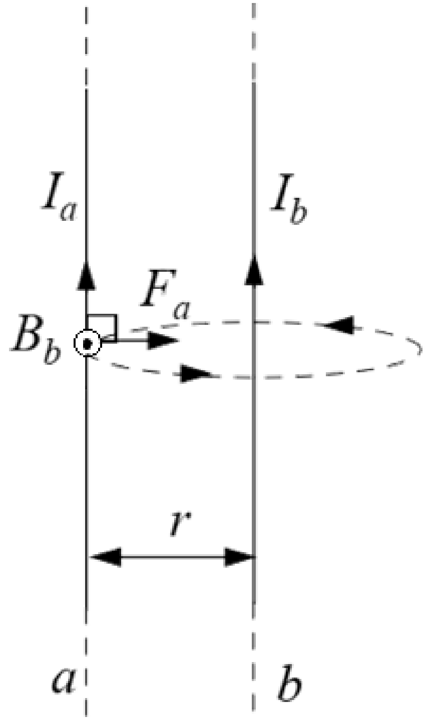


Forces between two parallel wires

Same current direction



Magnetic force on wire b



Magnetic force on wire a

- Magnetic field of wire *a* at the position of wire *b*: **into the page**
- Force on wire b: **towards wire *a***

- Magnetic field of wire *b* at position of wire a: **out of the page**
- Force on wire a: **towards wire *b***

Forces between two parallel wires

Same current direction

Force on wire *b*

$$F_b = B_a I_b L$$

Since $B_a = \frac{\mu_0 I_a}{2\pi r}$

$$\boxed{F_b = \frac{\mu_0 I_a I_b L}{2\pi r}}$$

Similarly, it can be shown

$$\boxed{F_b = \frac{\mu_0 I_b I_a L}{2\pi r}}$$

which shows

$$\boxed{|F_a| = |F_b|}$$

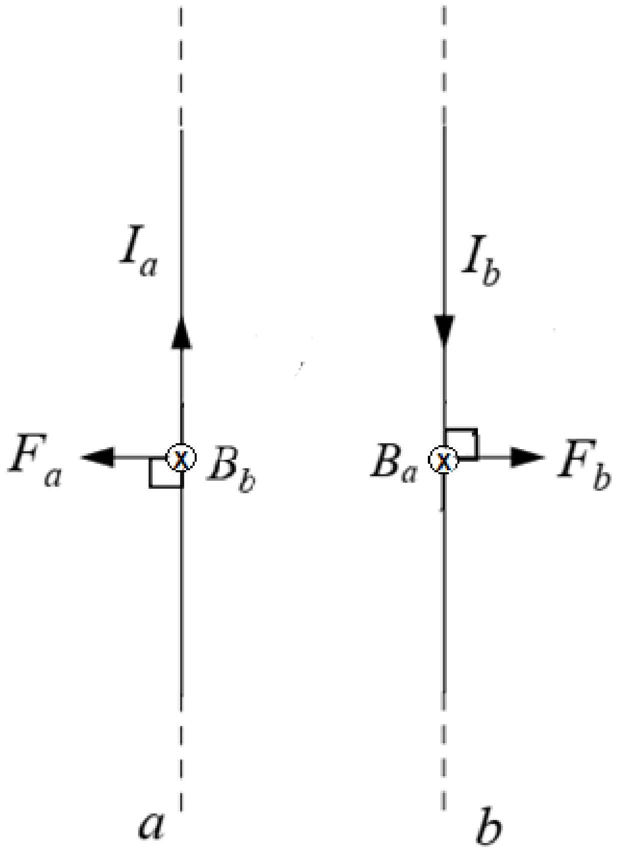
1. F_a and F_b are equal in magnitude, opposite in direction. They constitute an action-reaction pair.
2. Even if currents are unequal, they experience the **same force.**

Forces between two parallel wires

Opposite current direction

For wires carrying in opposite directions, there will be **repulsion** from each other

- Magnetic field of wire *a* at position of wire *b*: **into the page**
- Force on wire b: **away from wire *a***



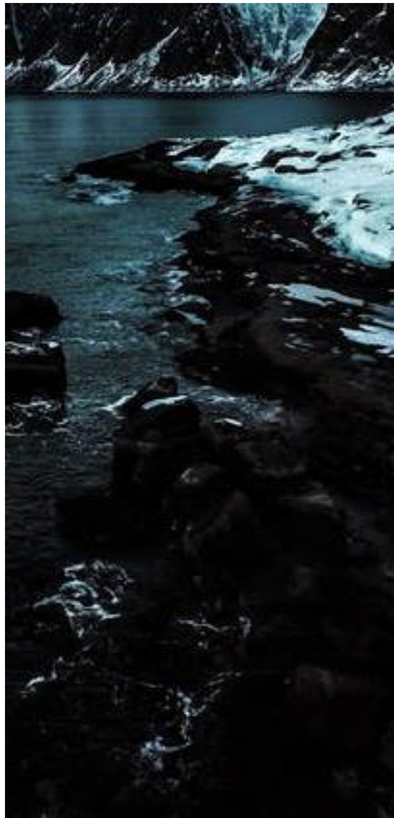
- Magnetic field of wire b at position of wire a: **into the page**
- Force on wire a: **away from wire *b***

Forces between two parallel wires

Opposite current direction

$$|F_a| = |F_b| = \frac{\mu_0 I_b I_a L}{2\pi r}$$

I_x = current in wire x
L = length of both wires
r = separation distance of the two wires
μ_0 = permeability of free space (vacuum) $= 4\pi \times 10^{-7}$ T m/A



1. Same current direction: **Attraction**
2. Opposite current direction: **Repulsion**

Practice Example 5

The two wires of a 3.0-m long extension cord carry a current of 2.0 A and are 2.5 mm apart.

(a)What is the force one wire exerting on the other?

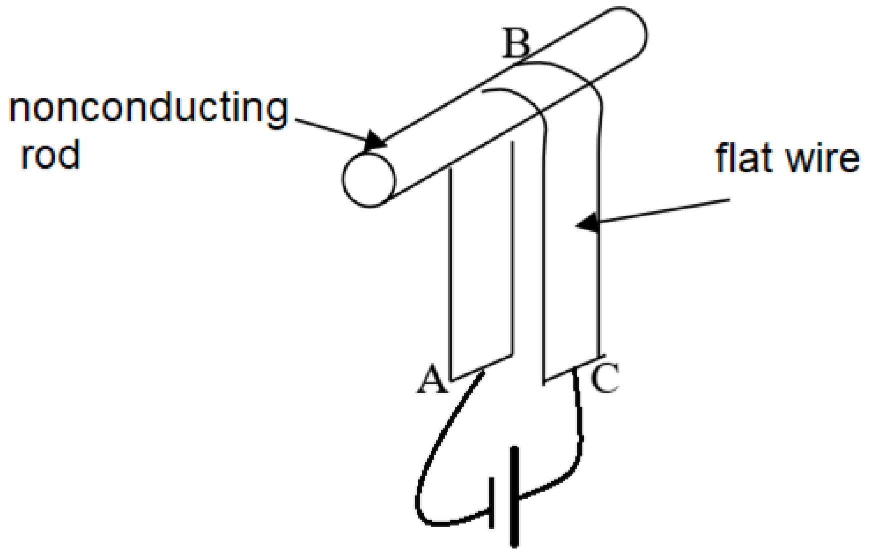
(b) Is the force repulsive or attractive?

Practice Example 6

A flat wire is unrolled and suspended on a nonconducting wire. The terminal of a battery is connected to the end of the wire (point C) while the negative is connected to other end (point A). The wire has length of 5.0 m and the rod has radius of 10cm.

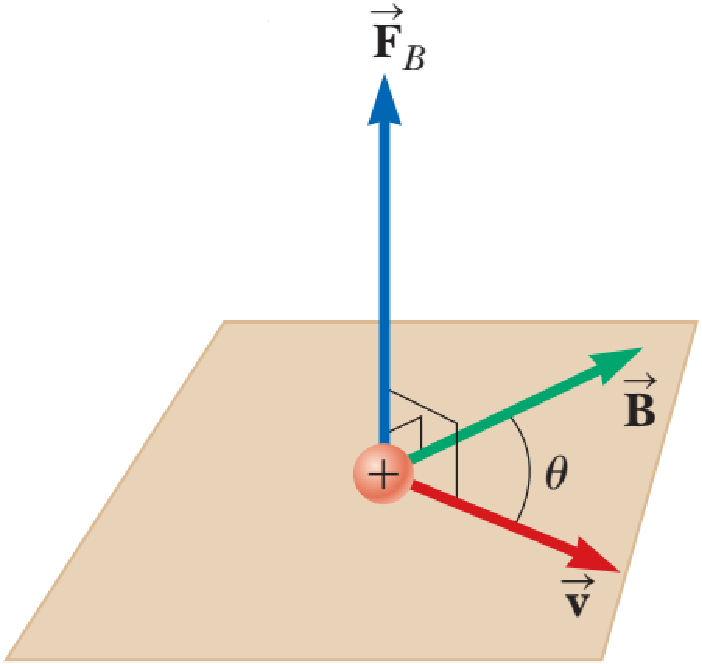
(a) Draw arrows to indicate direction of the conventional current in the flat wire and the directions of forces on segments AB And BC. Explain your answer.

(b) What is the magnitude of the force exerted by the segment BC on AB (or vice versa) if the battery sets up a current of 8.0 A?



Force on a Moving Charge

- A current-carrying wire can experience a force when placed in a magnetic field, a moving charge.
- Since current is a wire consists of moving electric charges, we expect a moving charge in a magnetic field to experience a magnetic force as well



- A moving charge constitutes a current of $I = q/t$
- Assume the particle travels a distance L in time t such that its speed $v = L/t$

The force on the charge is given by

$$F = BIL\sin\theta$$

$$F = B\left(\frac{q}{t}\right)L\sin\theta = Bq\left(\frac{L}{t}\right)\sin\theta$$

$$F = Bqv\sin\theta$$

Force on a Moving Charge

$$F = Bqv\sin\theta$$

B = magnetic flux density
q = charge
v = speed of the particle
θ = angle between B and v

Right-Hand Rule

- The direction of the force can be determine using the *Fleming's Left-Hand rule*:

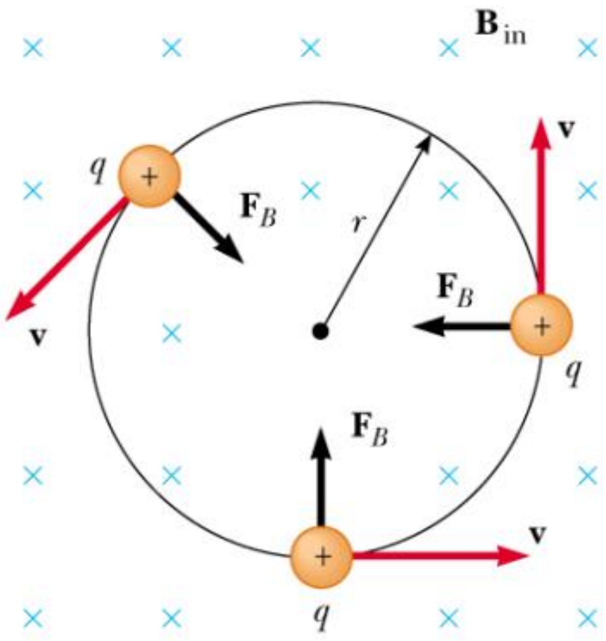
  Thumb: F

  Index finger: B

  Middle: v

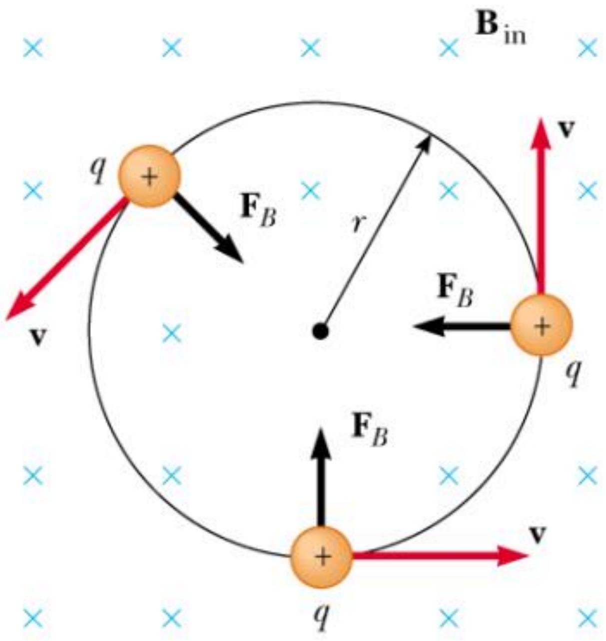
- If the charge of the particle is **negative,** take the **opposite** of the direction you get from *Fleming's Left-Hand rule*.

Motion of Charged Particle in Magnetic Field



- When a charge is moving perpendicular to a uniform magnetic field, it experiences a magnetic force F_B.
- Using *Fleming's LHR*, the magnetic force points in a direction perpendicular to the particle's motion.
- As you see on the left, F_B points to the center of the circle.
- The magnetic force changes particle's motion without changing the particle's speed.
- F_B provides centripetal force so that the particle moves in a **circular motion.**

Motion of Charged Particle in Magnetic Field



Using Newton's 2nd Law:

$$F_{net} = ma \quad \rightarrow \quad F_B = ma$$

Motion is a uniform circular motion so

$$F_B = \frac{mv^2}{r} \quad \rightarrow \quad Bqv = \frac{mv^2}{r}$$

Radius of the circular path:

$$\boxed{r = \frac{mv}{Bq}}$$

Period of the circular motion

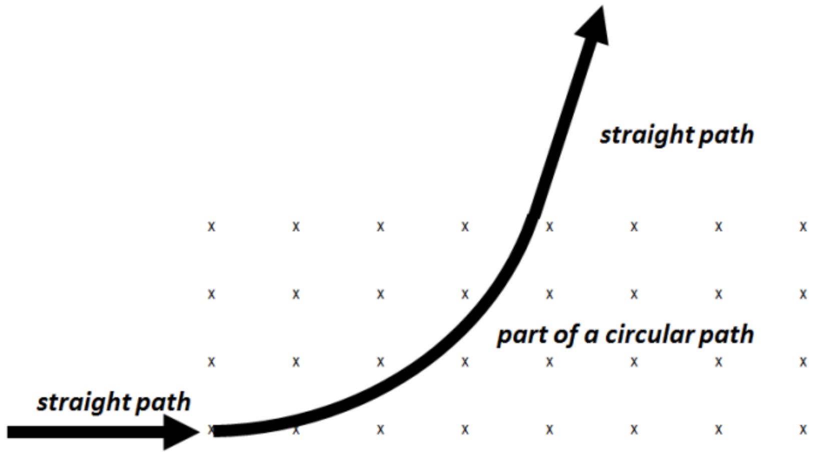
$$\omega = \frac{v}{r} = \frac{qB}{m} \quad \text{(angular speed)}$$

$$\boxed{T = \frac{2\pi}{\omega} = \frac{2\pi m}{qB}}$$

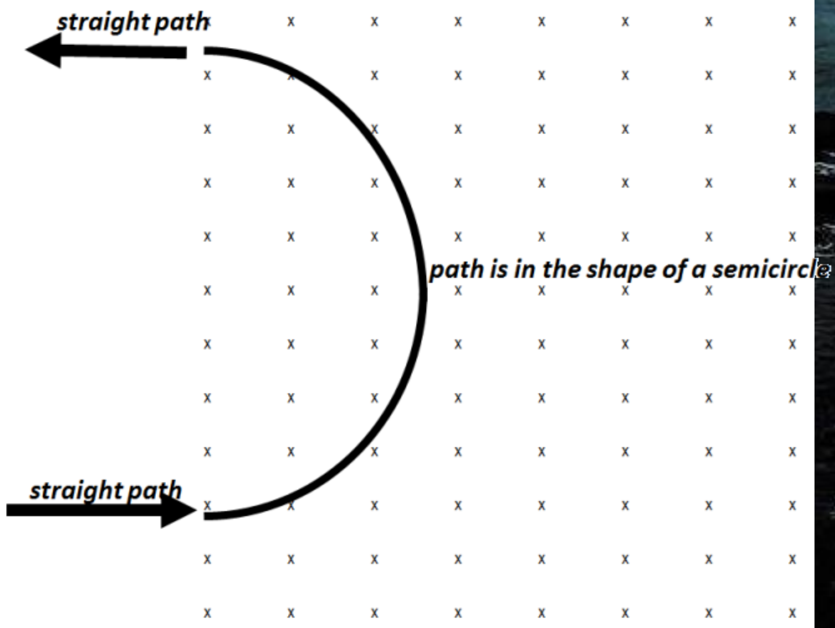
Motion of Charged Particle in Magnetic Field

Other Cases

1. Particle is outside the magnetic field at first, then it enters a region of uniform magnetic field



2. Particle is outside the magnetic field at first, then it enters a larger region wherein a magnetic field is present



Motion of Charged Particle in Crossed Field

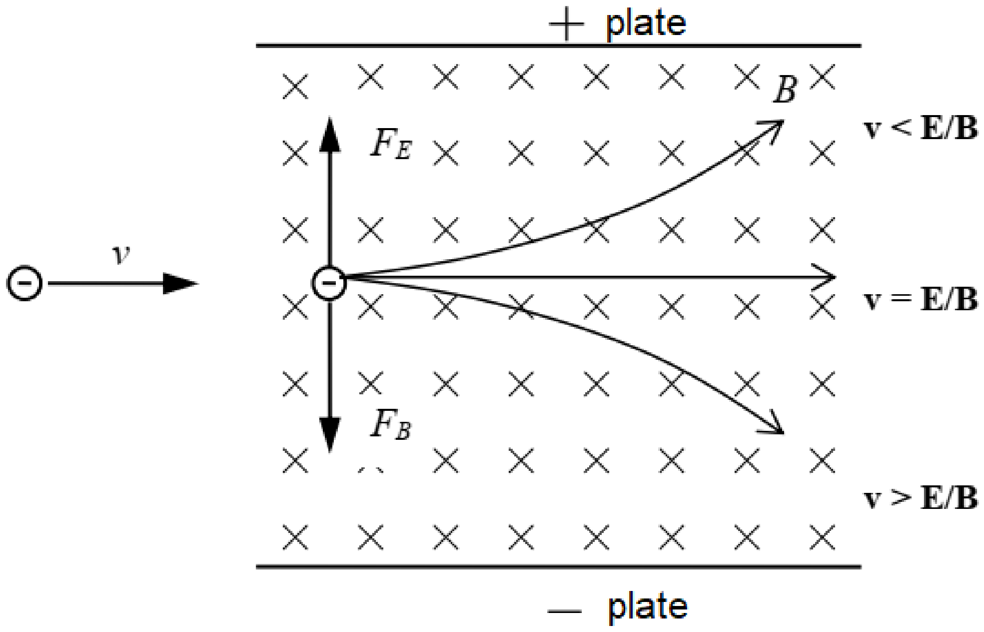
Velocity Selector

- used as the beginning section of a mass spectrometer where a charged particle of a particular velocity can only pass through.

Consider an electron of velocity v projected into a crossed *E*- and *B*-field.

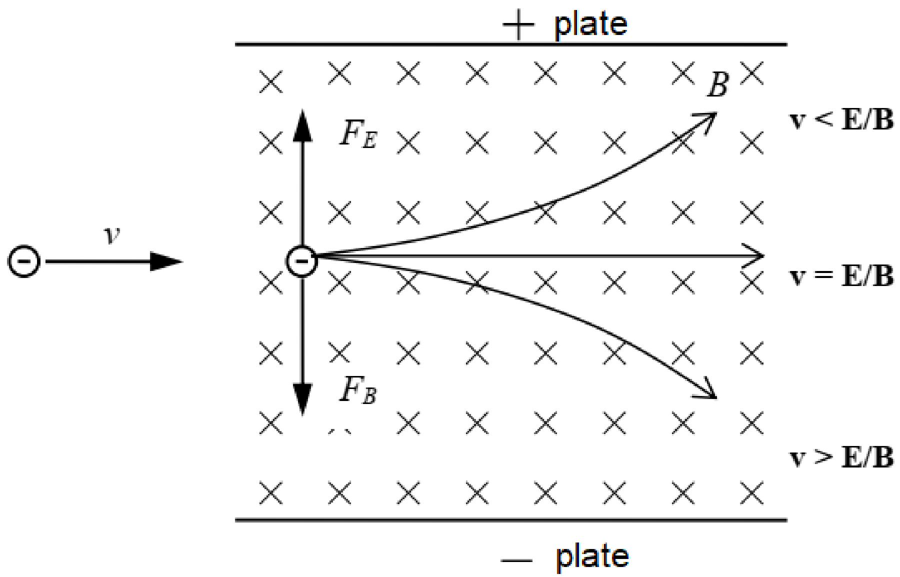
***E*-field**: downwards (negative to positive plate)

***B*-field**: into the page



Motion of Charged Particle in Crossed Field

Velocity Selector



- Upon entering the crossed fields, the electron experiences two forces: **electric force $\boldsymbol{F_E}$ and magnetic force $\boldsymbol{F_B}$.**

$\boldsymbol{F_E = q_e E}$ upwards (opposite of E-field because charge is negative)

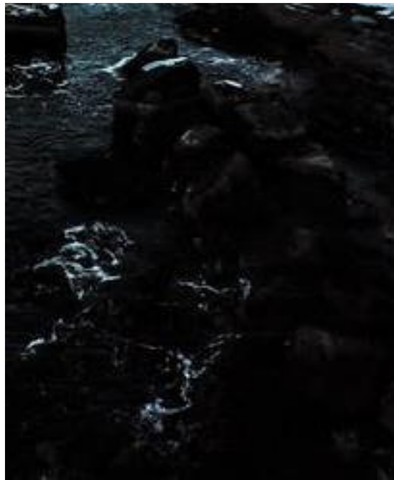
$\boldsymbol{F_B = B q_e v}$ downwards (opposite of the *Fleming's* LHR)

- For the electron to pass through, the net force acting on the electron must be zero ($F_{net} = 0$).

$$F_{net} = 0 \quad \rightarrow \quad F_E - F_B = 0 \quad \rightarrow \quad F_E = F_B$$

$$q_e E = B q_e v$$

$$\boxed{v = \frac{E}{B}}$$



- For a beam of particles having different velocities, only those with $v = E/B$ pass through the velocity selector

Motion of Charged Particle in Crossed Field

Velocity Selector

Forces	Velocity	Deflection
$F_E = F_B$	$v = \frac{E}{B}$	Undeflected
$F_E < F_B$	$v > \frac{E}{B}$	Deflected downwards
$F_E > F_B$	$v < \frac{E}{B}$	Deflected upwards

Practice Example 7

The solar wind is a stream of energized, charged particles, primarily electrons and protons, released from the upper atmosphere of the Sun. Suppose a proton is travelling toward the earth's equator at a speed of 900 km/s. At this point, the magnetic field of the earth is $50\,\mu T$ directed parallel to the earth's surface. Find the direction and magnitude of the force on the proton.

When viewed in a 2D world map, the particle motion points into the page.

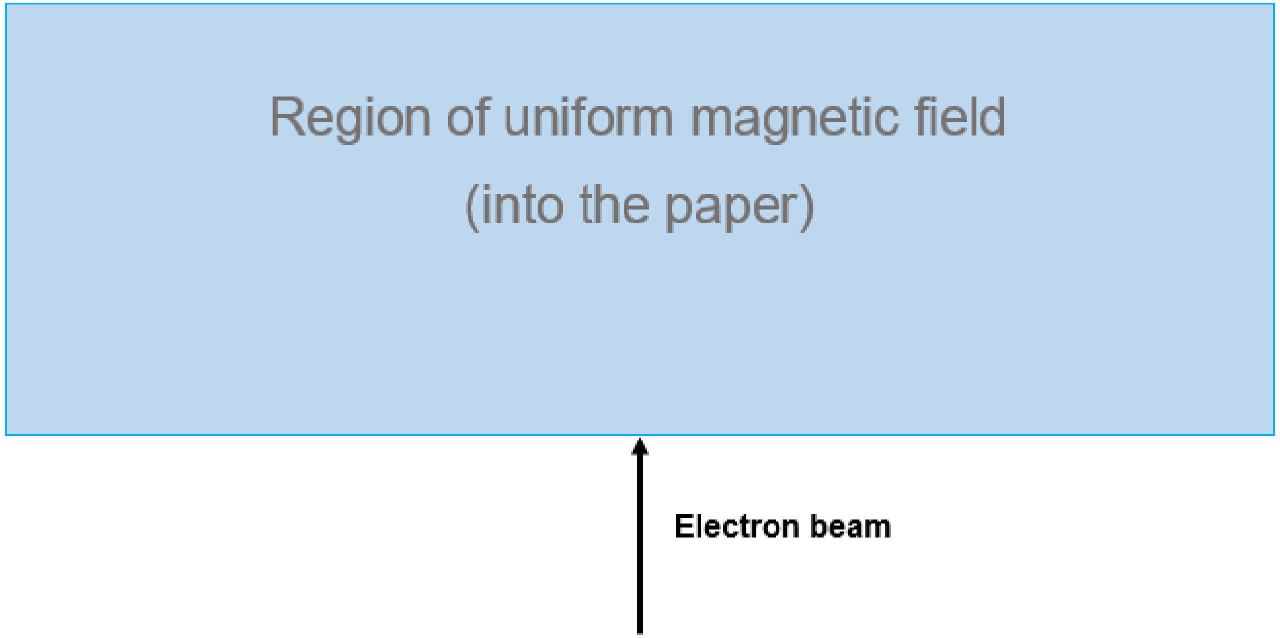
Practice Example 8

An electron beam is projected in a region of magnetic field as shown below. The electrons enter the region at a speed of 28,000 km/s perpendicular to the magnetic field of $3.5 \times 10^{-4} T$. ($m_e = 9.11 \times 10^{-31} kg$).

(a) Draw the path the electrons take upon entering the B-field.

(b) Calculate the force (magnitude and direction) on an electron in the electron beam

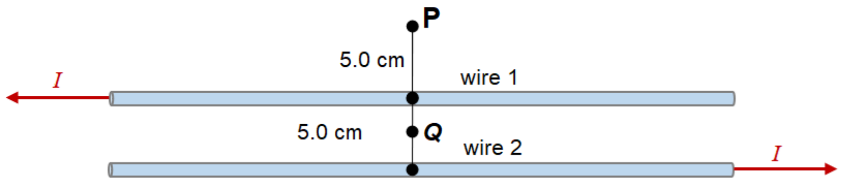
(c) Find the radius of curvature of the electrons' path.



SUGGESTED SOLUTIONS TO PRACTICE EXAMPLES

Practice Example 1

Two long straight wires, 5.0 cm apart, lie parallel to each other, and each carry a current of 3.0 A. The current through each wire flows opposite to one another.



(a) What are the directions of magnetic fields due to currents in wire 1 and wire 2 at points **Q** and **P**?

(b) Find the magnetic field (magnetic flux density) at point Q, midpoint between the two wires.

(c) Find the magnetic field (magnetic flux density) at point **P,** 5.0 cm from wire 1.

(a) Direction of magnetic field at point **Q**:

B_{1Q}:________out of the page________ (wire 1)

B_{2Q}:________out of the page________ (wire 2)

Direction of magnetic field at point **P**:

B_{1P}:________into the page________ (wire 1)

B_{2P}:________out of the page________ (wire 2)

(b)If we take direction *into the page* as the positive direction

$$B_{1Q} = \frac{\mu_o I}{2\pi r} = -\frac{(4\pi \times 10^{-7})(3.0)}{2(3.14)(0.025)} = -2.4 \times 10^{-5} T$$

$$B_{2Q} = \frac{\mu_o I}{2\pi r} = -\frac{(4\pi \times 10^{-7})(3.0A)}{2(3.14)(0.025)} = -2.4 \times 10^{-5} T$$

$B_Q = B_{1Q} + B_{2Q} = -4.8 \times 10^{-5} T$ or $4.8 \times 10^{-5} T$ out of the page

Practice Example 1

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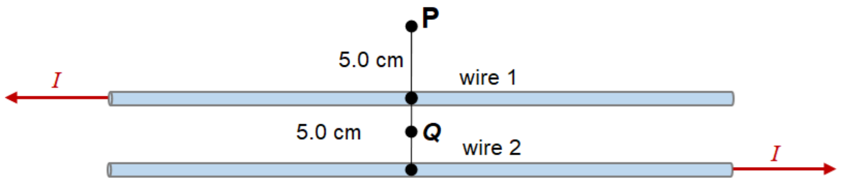

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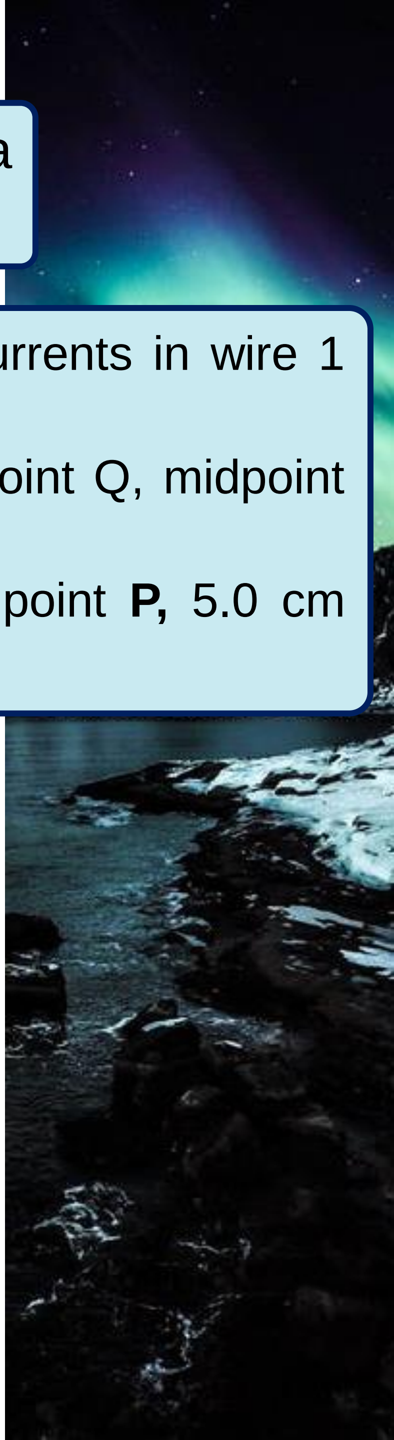
(c) If we take direction *into the page* as the positive direction

$$B_{1P} = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi\times10^{-7})(3.0A)}{2(3.14)(0.05)} = +1.2\times10^{-5}T$$

$$B_{2P} = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi\times10^{-7})(3.0A)}{2(3.14)(0.1)} = -6.0\times10^{-6}T$$

$B_Q = B_{1Q} + B_{2Q} = +6.0\times10^{-6}$ into of the page



Practice Example 2

Magnetic resonance imaging (MRI) is a noninvasive technique used to produce images of the anatomy and physiological processes of the body. A typical MRI solenoid has length of 1.2 m and diameter of 1.0 m which produces magnetic field of 1.0 T. Calculate the number of turns of wire the solenoid have if the wire's maximum capacity is 100A.

Solution:

$$B = \mu_0 n I = \mu_0 \left(\frac{N}{L}\right) I$$

$$\rightarrow N = \frac{BL}{\mu_0 I} = \frac{(1T)(1.2\ m)}{(4\pi \times 10^{-7})(100A)}$$

$$N = 9549 \text{ turns}$$

Practice Example 3

A 3.0-m long rigid wire carries a 2.5-A current flowing in the positive $x -$ direction. A magnetic field of magnitude 0.75 T is applied on the wire. Find the magnetic force on the wire if

(a) the magnetic field is directed along the +y-axis.

(b) the magnetic field is directed along the negative x-axis.

(c) the magnetic field is directed 30° from +x-axis to +y-axis.

(d) the magnetic field is directed 30° from +y-axis to +x-axis.

(a) $F = ILB \sin\theta$

$$F = (2.5)(3)(0.75) \sin 90$$

$$F = 5.63\ N$$

(b) $F = ILB \sin\theta$

$$F = (2.5)(3)(0.75) \sin 180$$

$$F = 0$$

(c) $F = ILB \sin\theta$

$$F = (2.5)(3)(0.75) \sin 30$$

$$F = 2.81\ N$$

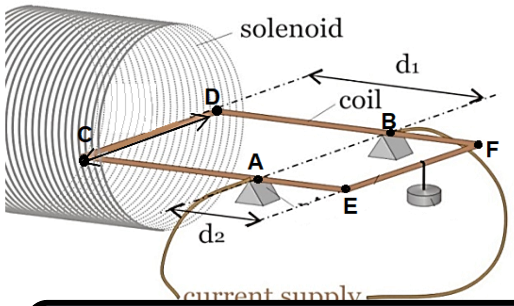
(d) $F = ILB \sin\theta$

$$F = (2.5)(3)(0.75) \sin 60$$

$$F = 3.90\ N$$

Practice Example 4

Consider a current balance shown below. The rectangular coil sits on two pivots, at points **A and B,** which are 30 cm apart. Length DF and CE is equal to 50 cm while length BF and AE equals 18 cm. The solenoid supplies a magnetic flux density of 5.0 mT while the current supply drives a 2.0A current into the coil.



(a) $F = ILB\sin\theta$

$$F = (2.0)(0.30)(5\times10^{-3})\sin 90$$

$$F = 3.0\times10^{-3}N$$

(b) $B = \frac{mgd_2}{ILd_1} \rightarrow m = \frac{BILd_1}{gd_2}$

$d_1 = 50 - 18 = 32cm,\ d_2 = 18cm$

$$m = \frac{(5\times10^{-3})(2)(0.3)(0.32)}{(9.81)(0.18)} = 5.44\times10^{-4}g$$

(c) $\theta = 0$

$$\Phi = BA\sin\theta = 0$$

Practice Example 5

The two wires of a 3.0-m long extension cord carry a current of 2.0 A and are 2.5 mm apart.

(a) What is the force one wire exerting on the other?

(b) Is the force repulsive or attractive?

(a) **Solution:**

$$|F_a| = |F_b| = \frac{\mu_0 I_b I_a L}{2\pi r} = \frac{(4\pi \times 10^{-7})(2)(2)(3)}{2(3.14)(2.5 \times 10^{-3})}$$

$$|F| = 9.6 \times 10^{-4} N$$

(b) The current flows in the same direction so force is **attractive.**

Practice Example 6

A flat wire is unrolled and suspended on a nonconducting wire. The terminal of a battery is connected to the end of the wire (point C) while the negative is connected to other end (point A). The wire has length of 5.0 m and the rod has radius of 10cm.

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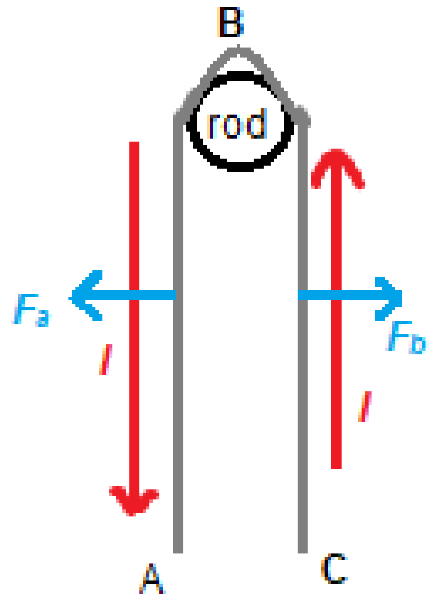

- Conventional current flows from positive terminal to negative terminal of the power source
- Since the current flows in the opposite direction, forces must be repulsive

(b) **Solution:**

$r =$ diameter of rod $= 20cm$

$$|F_{AB}| = \frac{\mu_0 I I L}{2\pi r} = \frac{(4\pi \times 10^{-7})(8)(8)(5)}{2(3.14)(0.2)}$$

$$|F_{AB}| = 3.2 \times 10^{-4} N$$

$$|F_{BC}| = 3.2 \times 10^{-4} N$$

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When viewed in a 2D world map, the particle motion points into the page.

Solution:

$\theta = 90°$ since v and B are perpendicular

$$F = qvB\sin\theta$$

$$F = (1.6 \times 10^{-19})(900 \times 10^{3})(5 \times 10^{-5})\sin 0$$

$$F = 7.2 \times 10^{-18} N$$

When viewed in a world map, B is due north (upwards). Using Fleming's RHL, the force is due East (to the right).

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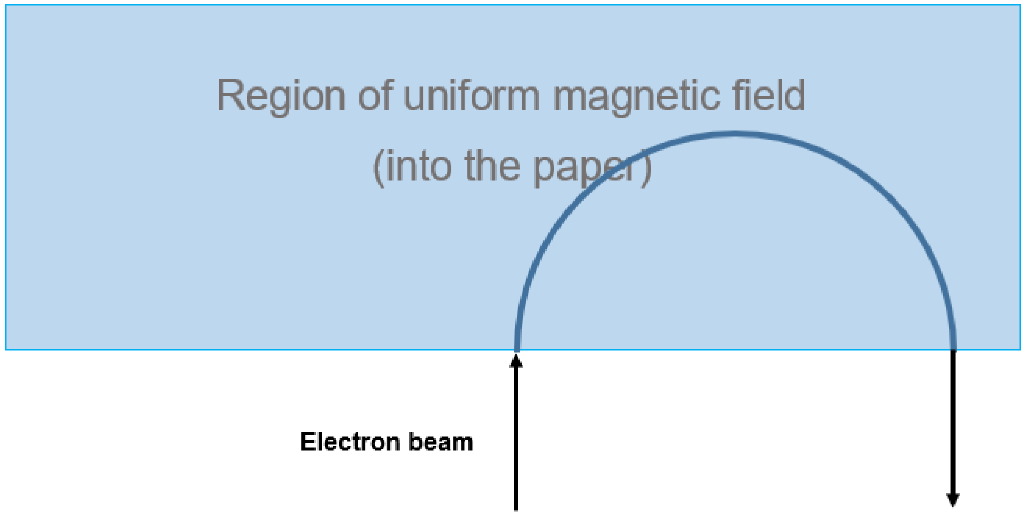

(b) Solution:

$$\boldsymbol{F} = qvB \sin\theta$$

$$\boldsymbol{F} = (1.6 \times 10^{-19})(2.8 \times 10^{7})(3.5 \times\ 10^{-4}) \sin 0$$

$F = 1.57 \times 10^{-15} N$ towards the center of semicircle

(b) Solution:

$$r = \frac{m_e v}{Bq}$$

$$r = \frac{(9.11 \times 10^{-31})(2.8 \times 10^{7})}{(3.5 \times\ 10^{-4})(1.6 \times 10^{-19})}$$

$$r = 0.46m$$