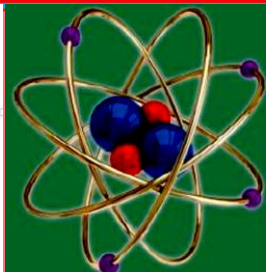


2020

19 العام الدراسي

Academic Year

رؤية
VISION
2021طموح
زايد

UNIT 8

Magnetic Fields of
Moving ChargesPHYSICS
(2019-2020)ريادة العالم انسانيًا وحضاريًا
تبدأ عندما نتعلم كيف نتسامح

إعداد

المعلم : لؤي بني عطا

الفصل الدراسي الثاني

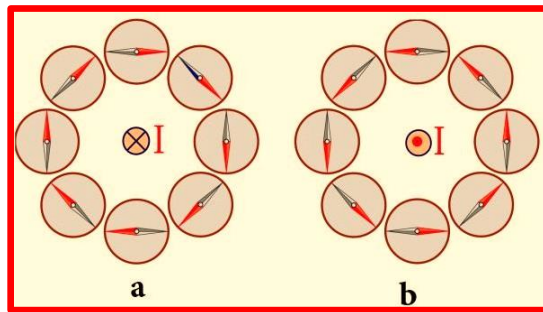
الصف الثاني عشر المتقدم

اسم الطالب / الشعبة /

اسم المدرسة /

8-1 Biot-Savart law

- Orsted observed the deflection of the compass needle placed near a wire carrying an electric current.
- The scientist Orsted was the first to notice that electric current creates a magnetic field
- The deflection depends on the position of the compass from the wire and the direction of the current passing through the wire.
- It was concluded that the current flowing in a wire creates a magnetic field in the form of circles around the wire and its direction depends on the direction of the current
- The field strength decreases as we move away from the axis of the wire



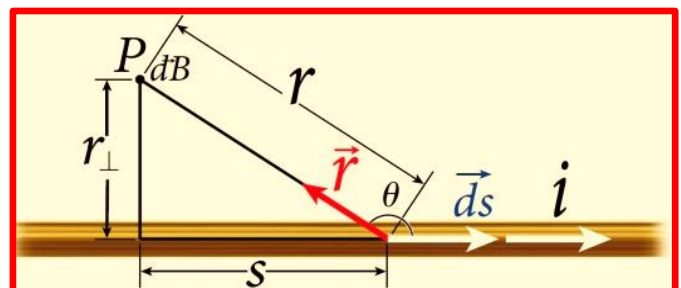
Wire (yellow circle) with current running through it:

(a) Into the page (indicated by the cross)

(b) Out of the page (indicated by the dot). The orientation of a compass needle placed close to the wire is shown at different locations around the wire.

Biot-Savart law

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{id\vec{s} \sin\theta}{r^2}$$



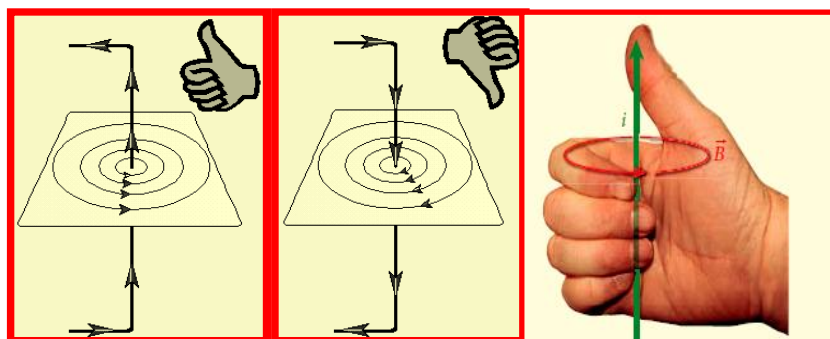
8-2 Magnetic fields due to electric current carrying wires**1- Magnetic field due to electric current carrying long straight wire**

If a continuous electric current passes through a straight wire, it will produce a magnetic field around the wire, characterised by the following:

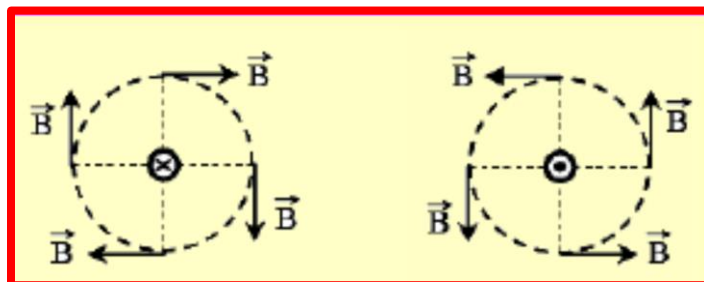
- They are concentric circles
- The density of the circles near the wire increases and its density decreases as we move away from the wire, which means that the field near the wire increases and decreases by moving away from it.
- The field increases with increasing intensity of the current carried by the wire
- The field increases with increasing coefficient of magnetic permeability of the medium surrounding the wire
- Since the magnitude and direction of field is not constant, it is an irregular field

Important Notes

- The direction of the magnetic field at any point is found by applying right-hand rule. If you grab the wire with your right hand so that your thumb points in the direction of the current, your fingers will curl in the direction of the magnetic field.



➤ It denotes the straight wire that carries a current a vertical on paper(into page as ($\otimes$) and out of page as ($\odot$)

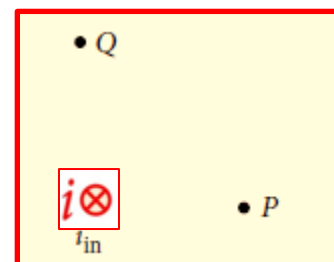


The magnetic field strength can be calculated from the relationship

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

Q) A wire is carrying a current, i , in, into the page as shown in the figure. In which direction does the magnetic field point at points P and Q ?

- To the right at P and upward (toward the top of the page) at Q
- Upward at P and to the right at Q
- Downward at P and to the right at Q
- Upward at P and to the left at Q

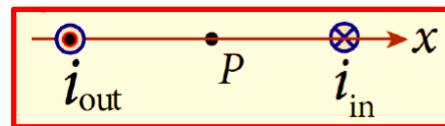


Q) Assume that a lightning bolt can be modeled as a long, straight line of current. If 15.0 C of charge passes by a point in 1.50×10^{-3} s, **what is the magnitude of the magnetic field** at a perpendicular distance 26.0 m from the lightning bolt?

- $7.69 \cdot 10^{-5}$ T
- $9.22 \cdot 10^{-3}$ T
- $4.21 \cdot 10^{-2}$ T
- $1.11 \cdot 10^{-1}$ T
- $2.22 \cdot 10^2$ T

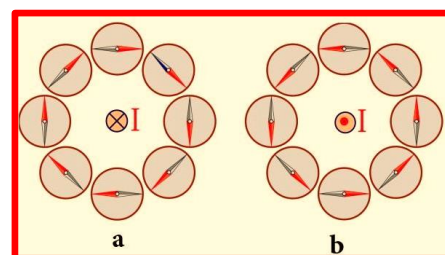
Q) Wire 1 has a current flowing out of the page, i_{out} , as shown in the figure. Wire 2 has a current flowing into the page, i_{in} . **What is the direction of the magnetic field at point P?**

- a) Upward in the plane of the page
b) To the right
c) Downward in the plane of the page
d) To the left
e) The magnetic field at point P is zero



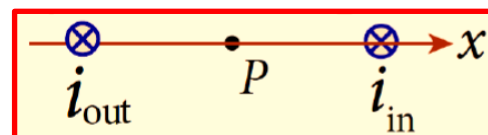
Q) In Figure, compass needles show the magnetic field around a current-carrying wire. In the figure, the north-pointing end of the compass needle **corresponds to**

- a) The red end.
b) The pale blue end.
c) Either the red end or the pale blue end, depending on how the compass is moved toward the wire.
d) The end cannot be identified from the information contained in the figure.



Q) Wire 1 has a current flowing into the page, i_{in} , as shown in the figure. Wire 2 has a current flowing into the page, i_{in} . **What is the direction of the magnetic field at point P?**

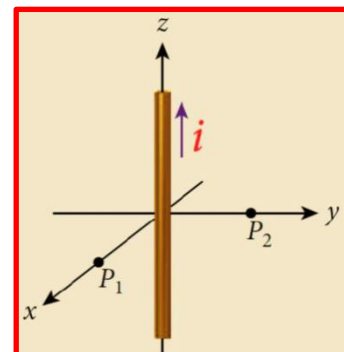
- a) Upward in the plane of the page
b) To the right
c) Downward in the plane of the page
d) To the left
e) The magnetic field at point P is zero



The wire in the figure is carrying a current i in the positive z-direction.

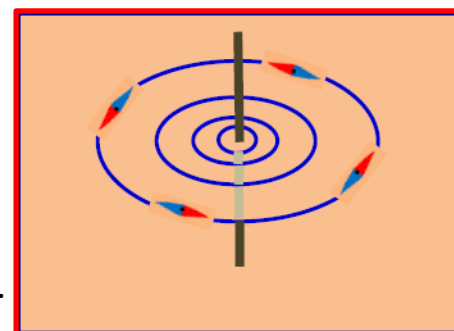
Q) What is the direction of the resulting magnetic field at point P_1 ? **What is the direction** of the resulting magnetic field at point P_2 ?

- P_1 towards (Y) positive and P_2 towards (X) positive
- P_1 towards (Y) positive and P_2 towards (X) negative
- P_1 towards (Y) negative and P_2 towards (X) positive
- P_1 towards (Y) negative and P_2 towards (X) negative



Q) The opposite diagram shows the magnetic field lines created by the passage of a continuous current in a straight and long conductor and a number of magnetic needles.

- Imad inferred from the graph that the magnitude of the magnetic field strength varies by changing the distance from the axis of the conductor. Supported this reasoning by the scientific evidence shown in the drawing

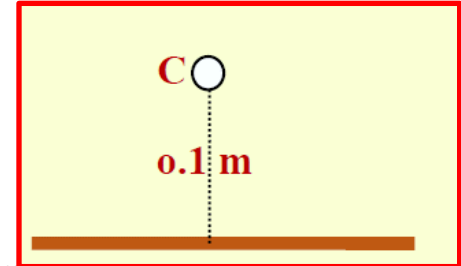


- What changes will happen to the drawing if the electric current passing through the conductor is increased without changing its direction?

- Determine the direction of the electrical current passing through the conductor by drawing an arrow on the straight conductor

Q) The opposite figure shows a straight wire carrying a continuous electric current, if the magnitude of the magnetic field at the point (C) ($2.0 \times 10^{-5} \text{ T}$) and its direction perpendicular to the plane of the paper outward

1- **Calculate the intensity** of the current passing through the wire and determine its direction



10 A

2- **Calculate** the magnetic force that the field affects an electron moving at the page plane from left to right when it's moment passes by the point (C) at the speed of its amount ($3 \times 10^4 \text{ m/s}$) and its direction .

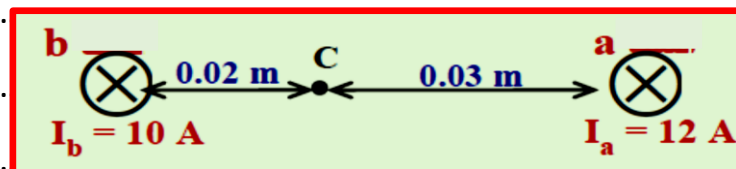
 $9.6 \times 10^{-20} \text{ N}$

Q) Electron extrusion from electron cannon with ($4.0 \times 10^5 \text{ m/s}$) and then move parallel to a long straight wire carrying a current of (15 A) and a distance (5.0 cm) above it.

Determine the amount and direction of the electron acceleration the moment the electron exits the cannon?

 $4.2 \times 10^{12} \text{ m/s}$

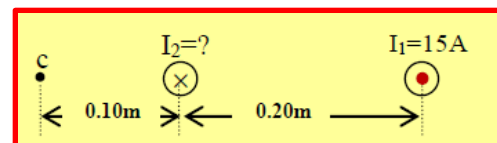
Q) (a.b) two long, straight and parallel wires, away from each other (0.05 m) in the air, and in each of them pass a continuous current. **Calculate the amount and determine** the direction of the magnetic field strength at the point (C) resulting from the two wires.



$$2 \times 10^{-5} \text{ T}$$

Q) The opposite figure is a cross section of two straight wires carrying two continuous currents, I_1, I_2 and the distance between them (0.20), Point c is located along the line connecting them and is a distance (0.10m) from I_2 . **Answer the following**

1-What is the current intensity that causes the total magnetic field at point C zero?



$$5 \text{ A}$$

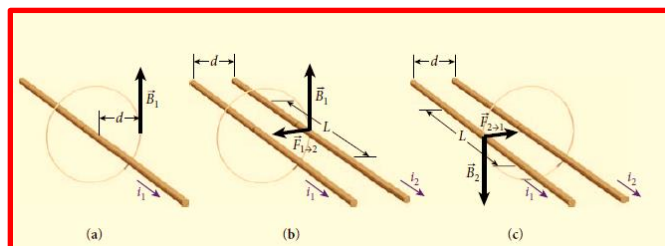
2-What happens to the amount of force exchanged between the two wires if the distance between them decreases to a quarter?

Two Parallel Wires

- When placing two long parallel wires that two currents pass through them, each wire locates in the magnetic field generated by the other wire and is calculated from the relationship $B_1 = \frac{\mu_0 i_1}{2 \pi d}$

d: the vertical distance between the two wires

B_1 : magnetin field from the first wire and affecting at each point on the second wire



- The second wire is affected by a magnetic force calculated from the relationship

$$F = iLxB$$

Thus the magnetic force affected the first wire on the second is equal

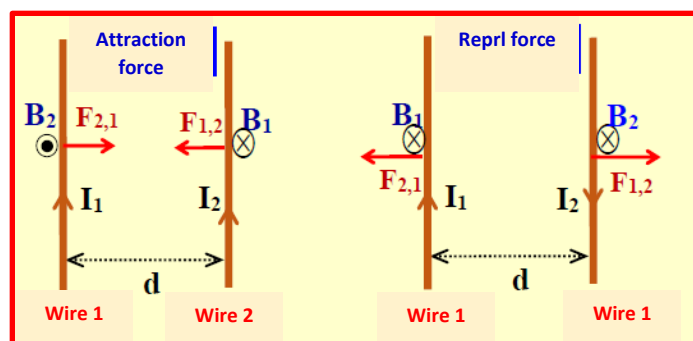
$$F_{1/2} = i_2 L B_1 = i_2 L \frac{\mu_0 i_1}{2 \pi d} = \frac{\mu_0 i_1 i_2 L}{2 \pi d}$$

Each two parallel wires carry two continuous electric current and each is located in the magnetic field of the second. Exchanging according to the Newton's third law **magnetic force** can be calculated by the following relationship

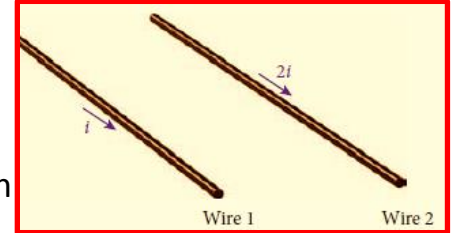
$$F_{1/2} = I_2 L B_1 \text{ and } F_{2/1} = I_1 L B_2$$

- The first wire is also affected in the same way by the magnetic force of the second wire

$$F_{2/1} = \frac{\mu_0 i_1 i_2 L}{2 \pi d}$$

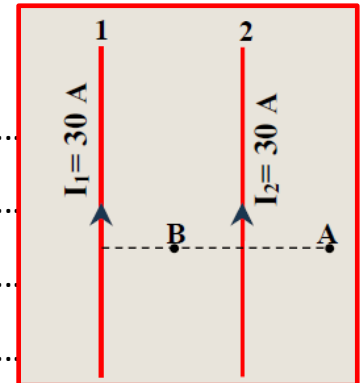


Q) Two parallel wires are near each other as shown in the figure. Wire 1 carries current i , and wire 2 carries current $2i$. Which statement about the magnetic forces that the two wires exert on each other is correct?



- a) The two wires exert no forces on each other.
- b) The two wires exert attractive forces of the same magnitude on each other.
- c) The two wires exert repulsive forces of the same magnitude on each other.
- d) Wire 1 exerts a stronger force on wire 2 than wire 2 exerts on wire 1.
- e) Wire 2 exerts a stronger force on wire 1 than wire 1 exerts on wire 2.

Q) The opposite figure shows two long straight and parallel wires and the distance between them is equal 20cm , between them air . Point B is halfway between the two wires and point A at a distance 5cm from wire 2 . What is the magnitude and direction of the magnetic field at each point arising from each of the two currents?

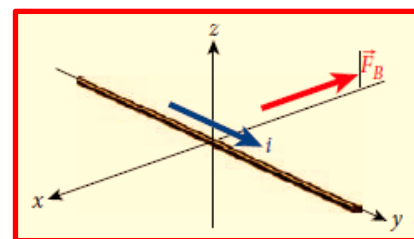


$$1.44 \times 10^{-4} T$$

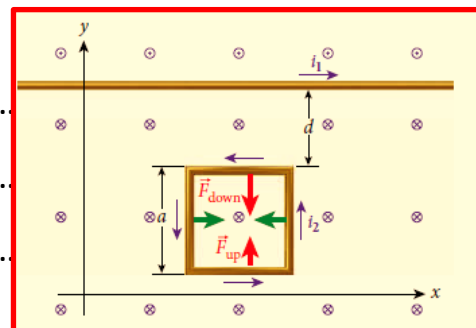
Q) A wire is carrying a current, i , in the positive y -direction, as shown in the figure. The wire is located in a uniform magnetic field $\vec{B}$, oriented in such a way that the magnetic force on the wire is maximized. The magnetic force acting on the wire, F_B , is in the negative x -direction.

What is the direction of the magnetic field?

- a) the positive x -direction b) the negative x -direction
c) the negative y -direction d) the positive z -direction
e) the negative z -direction



Q) A long, straight wire is carrying a current of magnitude $i_1 = 5.00$ A toward the right (Figure). A square loop with sides of length $a = 0.250$ m is placed with its sides parallel and perpendicular to the wire at a distance $d = 0.100$ m from the wire. The square loop carries a current of magnitude $i_2 = 2.20$ A in the counterclockwise direction. **What is the net magnetic force on the square loop?**

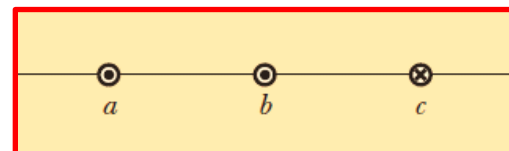


$$(-3.93 \cdot 10^{-6}) \hat{y} \text{ N.}$$

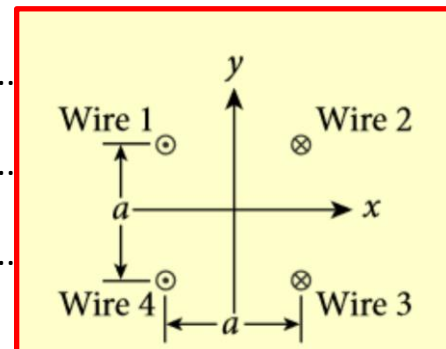
Q) Two straight, parallel, superconducting wires 4.5 mm apart carry equal currents of 15,000 A in opposite directions. **What force, per unit length**, does each wire exert on the other?

$$1.0 \times 10^4 \text{ N/m}$$

Q) The figure here shows three long, straight, parallel, equally spaced wires with identical currents either into or out of the page. Rank the wires according to the magnitude of the force on each due to the currents in the other two wires, greatest first.



Q) Four wires are each carrying a current of magnitude $i = 1.00 \text{ A}$. The wires are located at the four corners of a square with side $a = 3.70 \text{ cm}$. Two of the wires are carrying current into the page, and the other two are carrying current out of the page as shown in the figure. **What is the y-component of the magnetic field at the center of the square?**



Definition of the ampere

An ampere (A) is the constant current that, if maintained in two straight, parallel conductors of infinite length and negligible circular cross section, that are placed 1 m apart in vacuum, would produce between these conductors a force of $2 \times 10^{-7} N$ per meter of length

There is a relationship between the value of magnetic permeability of free space μ_0 and the value of the electric permittivity of free space ϵ_0

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

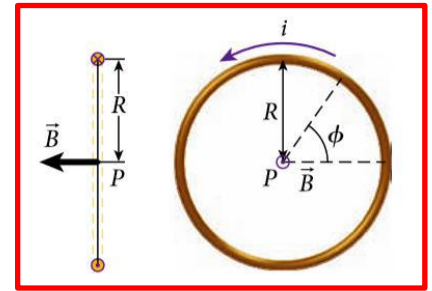
Magnetic field due to a wire loop

The magnitude of the magnetic field at the center of a circular current-carrying loop of wire is given by:

$$B = \frac{\mu_0 i}{2R}$$

The magnetic field at the center of a circular coil consists of N roll:

$$B = \frac{\mu_0 i N}{2R}$$

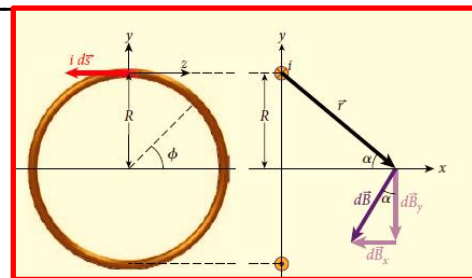


The direction of the magnetic field at the center of a circular current-carrying loop of wire is determined by using the third right hand rule:

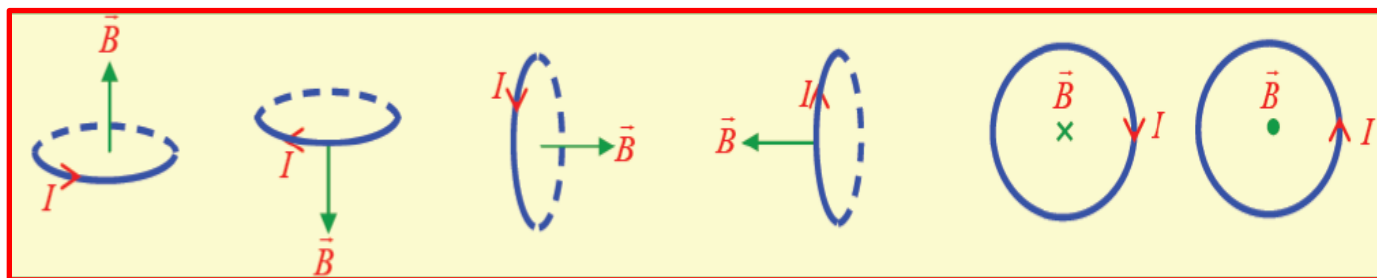
- points your thumb in the direction of the current element.
- points your index finger in the direction of the radial vector from the current element.
- your middle finger then points to the magnetic field line direction.

The magnitude of the magnetic field from the loop along the axis of the loop is given by:

$$B = \frac{\mu_0 i}{2} \frac{R^2}{(R^2 + x^2)^{3/2}}$$

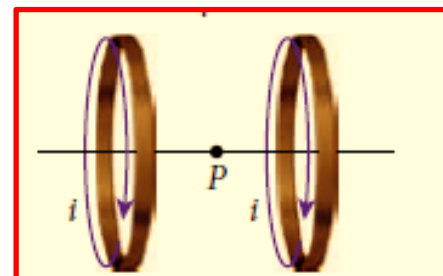


Examples of determining the direction of the magnetic field at the center of a circular coil:

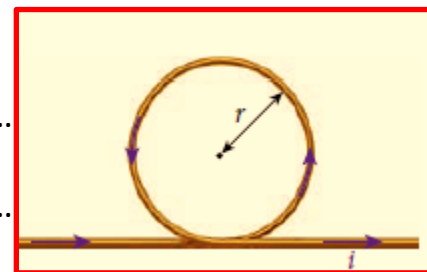


Q) Two identical wire loops carry the same current i as shown in the figure. **What is the direction of the magnetic field at point P?**

- Upward (toward the top of the page).
- Toward the right.
- Downward.
- Toward the left.

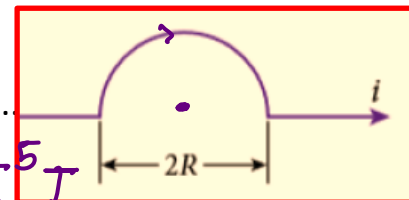


Q) A loop with radius $r = 8.30$ mm is formed in the middle of a long, straight insulated wire carrying a current of magnitude $i = 26.5$ m as shown in the figure. **What is the magnitude of the magnetic field at the center of the loop?**



$$\vec{B} = 2.64 \cdot 10^{-6} \text{ T, out of the page.}$$

Q) Find the magnetic field in the center of a wire semicircle like that shown in the figure, with radius $R = 10.0 \text{ cm}$, if the current is $i = 12.0 \text{ A}$.



$$B = \frac{\mu_0 i}{2r} = \frac{1.26 \times 10^{-6} \times 12}{(2 \times 0.1)} = 7.56 \times 10^{-5} \text{ T}$$

Q) A long straight wire holds a continuous current of intensity (2A) where a portion of the wire is wrapped in a circular ring (only one turn) radius (0.02 m) in air (as shown in the figure)

1- **Calculate the amount of the magnetic field and determine** its direction at the center of the

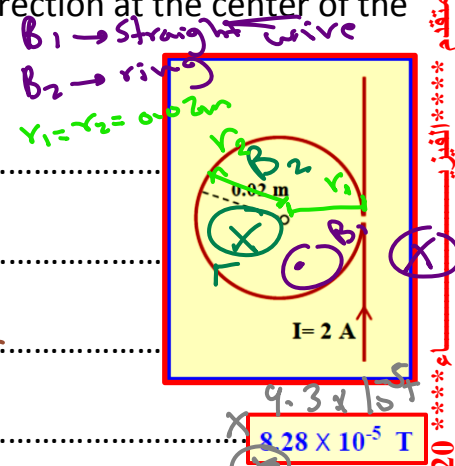
ring

$$B_{\text{net at center}} = B_1 + B_2$$

$$B_1 = \frac{\mu_0 I_1}{2\pi r} = \frac{1.26 \times 10^{-6} \times 2}{(2\pi \times 0.02)} = 10^{-5} \text{ T}$$

$$B_2 = \frac{\mu_0 I_2}{2r} = \frac{1.26 \times 10^{-6} \times 2}{2 \times 0.02} = 6.3 \times 10^{-5} \text{ T}$$

$$B_{\text{net}} = 4.3 \times 10^{-5} \text{ T}$$



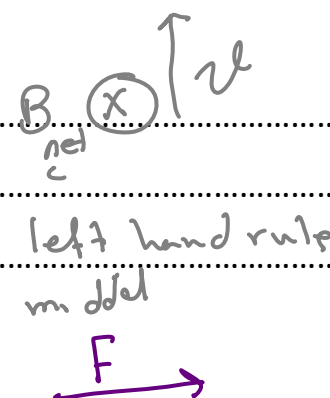
2- **Calculate how much force** an electron is affected as it passes by the center of the loop vertically at its level with velocity $(3 \times 10^5 \text{ m/s})$

$$F = qvB \sin 90$$

$$= (1.6 \times 10^{-19}) \times (3 \times 10^5) \times (4.3 \times 10^{-5}) \times 1$$

$$= 2 \times 10^{-8} \text{ N}$$

east



8-3 Ampere's law

The line integral of $\oint \vec{B} \cdot d\vec{s}$ around any closed path equals $\mu_0 i_{enc}$, where i is the total steady current passing through any surface bounded by the closed path :

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 i_{enc}$$

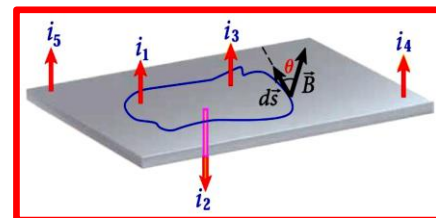
The symbol $\oint$ means that the integrand, $\vec{B} \cdot d\vec{s}$, is integrated over a closed loop, called an

Amperian loop.

i_{enc} , which is also similar to Gauss's Law, where the chosen closed surface encloses a total net charge.

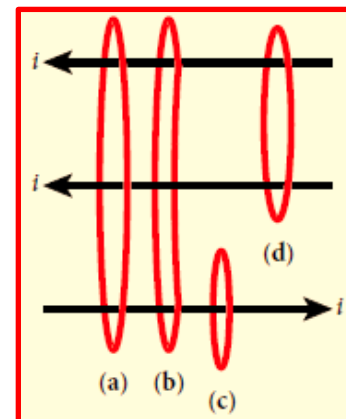
In the opposite figure

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 (i_1 - i_2 + i_3)$$

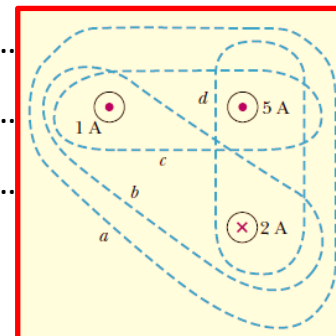


Q) Three wires are carrying currents of the same magnitude, i , in the directions shown in the figure. Four Amperian loops (a), (b), (c), and (d) are shown. For which Amperian loop is the magnitude of $\oint \vec{B} \cdot d\vec{s}$ the greatest?

- a) Loop a
- b) Loop b
- c) Loop c
- d) Loop d
- e) All four loops yield the same value of $\oint \vec{B} \cdot d\vec{s}$

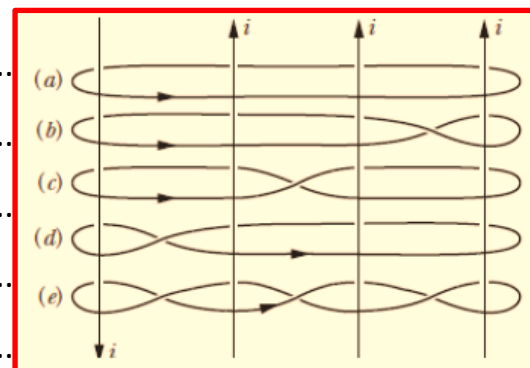


Q) Rank the magnitudes of $\oint \vec{B} \cdot d\vec{s}$ for the closed paths in Figure, from least to greatest

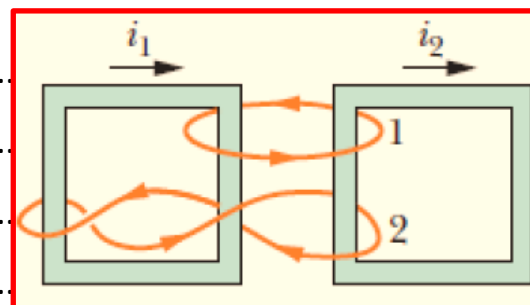


Q) The opposite figure shows four equal currents and five amp loops

Rank the magnitudes of $\oint \vec{B} \cdot d\vec{s}$ for the closed paths in Figure, from greatest to least



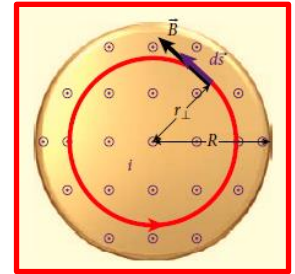
Q) The opposite shape has two imperial rings enclosed by two conductors, two electric current where $i_1 = 5A$ and $i_2 = 3A$. How much $\oint \vec{B} \cdot d\vec{s}$ in the tow rings 1 and 2



$$(1) = -2.5 \times 10^{-6} T.m, (2) = -1.6 \times 10^{-5} T.m$$

Magnetic Field inside a long, Straight Wire

- Figure shows a current, i , flowing out of the page in a wire with a circular cross section of radius R
- The current is uniformly distributed over the cross-sectional area of the wire
- To find the magnetic field due to this current, we use an Amperian loop with radius $r_{\perp}$
- Therefore, $\vec{B}$ must be tangential to the Amperian loop.
- we can rewrite the integral of Ampere's Law as : $\oint \vec{B} \cdot d\vec{s} = B \int d\vec{s} = B2\pi r_{\perp}$
- We can calculate the enclosed current from the ratio of the area of the Amperian loop to the cross-sectional area of the wire :



$$i_{enc} = i \frac{A_{loop}}{A_{wire}} = i \frac{\pi r_{\perp}^2}{\pi R^2}$$

- Thus, we obtain : $B2\pi r_{\perp} = \mu_0 i \frac{\pi r_{\perp}^2}{\pi R^2}$
- To calculate the magnetic field inside the wire.

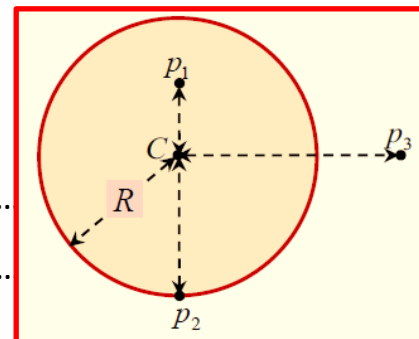
$$B = \left(\frac{\mu_0 i}{2\pi R^2} \right) r_{\perp}$$

- To calculate the magnetic field outside the wire

$$B = \frac{\mu_0 i}{2\pi r_{\perp}}$$

Q) Straight and long cylindrical wire, radius of circular section ($R = 2\text{cm}$), an electric current passes through it (5mA) vertically into page, **Calculate the amount and direction of the magnetic field at the following points**

a-At a point (P_1) away (1cm) from the center



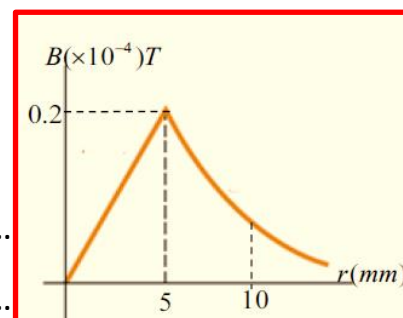
b-At a point (P_2) away (2cm) from the center

c-At a point (P_3) away (4cm) from the center

(a) $2.5 \times 10^{-8} \text{ T}$, (b) $5 \times 10^{-8} \text{ T}$, (c) $2.5 \times 10^{-8} \text{ T}$

Q) The opposite graph represents the relationship between the magnetic field strength at a point and the electric current passing through in a straight cylindrical wire, and the distance from the center of the wire.

a-How strong is the electric current passing through the wire?



b-What is the intensity of the magnetic field at point away 1mm from the center

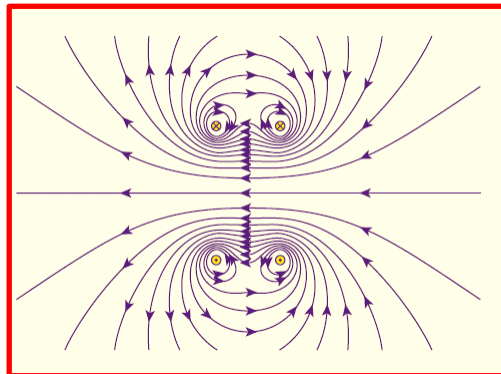
c- What is the intensity of the magnetic field at point away 10mm from the center?

(a) $0.5 A$, (b) $4 \times 10^{-6} T$, (c) $1 \times 10^{-5} T$

8-4 Magnetic Fields of Solenoids and toroids

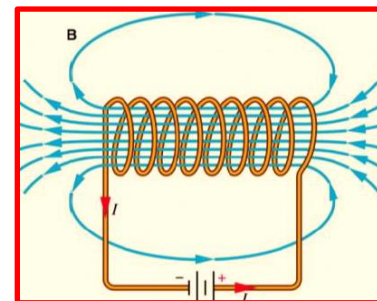
Helmholtz coil

- ✓ A Helmholtz coil consists of two coaxial wire loops
- ✓ Each coaxial loop consists of multiple loops (windings or turns) of a single wire
- ✓ The magnetic field lines from a Helmholtz coil (of uniform magnetic field (characterized by horizontal parallel segments of the field lines) in the center between the loops
- ✓ Non uniform magnetic field lines from out of a Helmholtz coil



Solenoid:

- ✓ consisting of many loops of a wire wound close together (A group of turns and their number N)
- ✓ The magnetic field lines are very close together on the inside of the solenoid and far apart on the outside.
- ✓ the magnetic field is much stronger inside the solenoid than outside the solenoid
- ✓ The amount of magnetic field inside the coil is calculated near its axis using the relationship $B = \mu_0 n i$ Where n is the number of turns, in unit lengths $n = \frac{N}{L}$
 N : The number of file turns , L : File length $B = \frac{\mu_0 N i}{L}$
- ✓ An *ideal* solenoid has a magnetic field of zero outside and of a uniform constant finite value inside
- ✓ The magnetic strength can be greatly increased by placing an iron leg inside the coil (the iron permeability coefficient of iron is very large.
- ✓ To determine the direction of the magnetic field generated by solenoid by right-hand rule



Inside the coil the direction of the field is from south to the North Pole

Q) The solenoid of the STAR detector at the Brookhaven National Laboratory, has a magnetic field of magnitude 0.50 T when carrying a current of 400 A. The solenoid is 8.0 m long. **What is the number of turns in this solenoid, assuming that it is an ideal solenoid?**

8000 turns.

Q) Two solenoids have the same length, but solenoid 1 has 15 times the number of turns, $1/9$ the radius, and 7 times the current of solenoid 2. **Calculate the ratio of the magnetic field inside solenoid 1 to the magnetic field inside solenoid 2.**

- a) 105 b) 123 c) 144 d) 168 e) 197

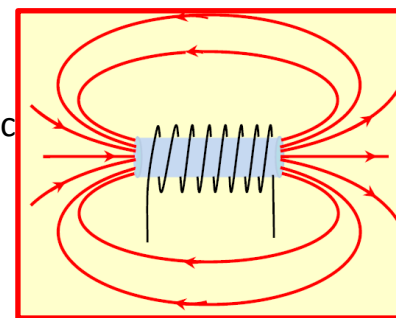
Q) The opposite figure shows magnetic field lines caused by a continuous electric current passing in a core antenna solenoid. **Answer the following:**

1-**Locate the north magnetic** pole of the coil, and then draw magnetic field lines inside the coil

2-**Determine the direction** of the current passing in the coil.

3-**Write two ways to increase** the intensity of the magnetic field inside the coil?

4- If the file contains (200 turns per cm) from its length, the intensity of the magnetic field at a point on its axis is equal 2G. **How much current is through the solenoid wire**



Toroid

- ❖ When the solenoid is bent, its ends meet, forming a circular shape
- ❖ The wire forms a series of rings, each carrying the same current
- ❖ The magnetic field is always directed tangential to the Amperian loop, so we have



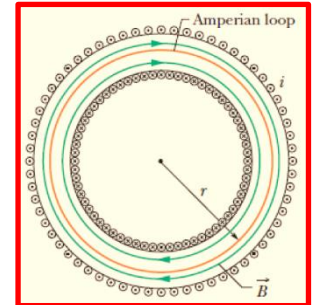
$$\oint \vec{B} \cdot d\vec{s} = B2\pi r$$

- ❖ The enclosed current is the number of loops (or turns), N , in the toroid times the current, i , in the wire (in each loop); so, Ampere's law gives us

$$B2\pi r = \mu_0 N i$$

- ❖ the magnitude of the magnetic field inside of a toroidal magnet is given by:

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



The amount of magnetic field inside the annulus depends on:

(1- Radius

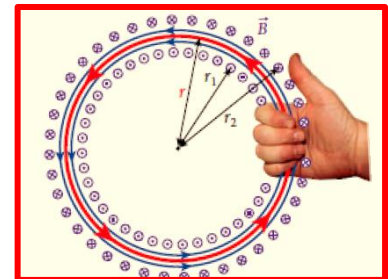
2-Number of turns

3-Current intensity)

To determine the direction of the magnetic field generated by the toroid coil.

*** Fingers are the direction of the conventional current

*** Thumb is the direction of the the magnetic field inside the toroid coil



✚ If the radius of the toroid coil (r)

✚ Solenoid diameter of the toroid coil (d)

✚ Number of turns (N)

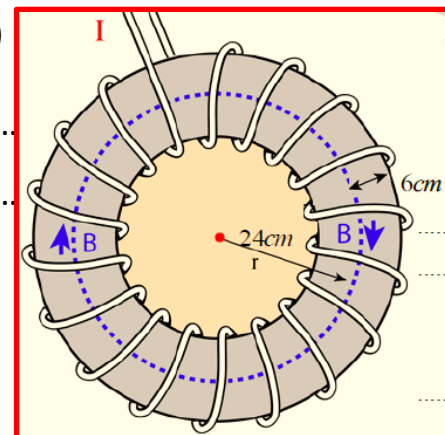
✚ The length of the wire that formed the toroid coil (L) $\Rightarrow L = N\pi d \Rightarrow N = \frac{L}{\pi d}$

$$B = \frac{\mu_0 Li}{2\pi^2 rd}$$

Q) A toroid coil is made of a wire of length 300m so that the radius of its cross section 6cm the average radius of the toroid coils 24cm, if a current passes its intensity 4.5A. Calculate:

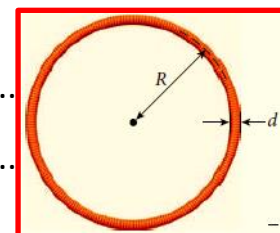
a- The number of turns the wire can make of the toroid coils (N)

b-The intensity of the magnetic field at the center of the toroid coil. And on the drawing, determine the direction of current flowing in the coil wire.



(a) 796.18, (b) $2.985 \times 10^{-3} T$

Q) A toroidal magnet is made from 202 m of copper wire that is capable of carrying a current of magnitude $i = 2.40 A$. The toroid has an average radius $R = 15.0 cm$ and a crosssectional diameter $d = 1.60 cm$. **What is the largest magnetic field** that can be produced at the average toroidal radius, R ?

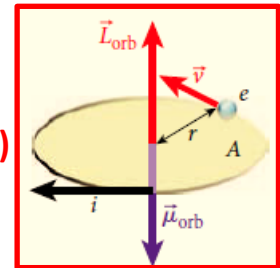


0.0128597 T

8-5 Atoms as Magnets

- ❖ The atoms that make up all matter contain moving electrons
- ❖ When the electrons are moving which form current loops that produce magnetic fields.
- ❖ In most materials, these current loops are randomly oriented and produce no net magnetic field
- ❖ Some materials have some fraction of these current loops aligned. These materials, called magnetic materials

- ❖ The Figure shows an electron moving (v) rapidly in a radius orbit (r)
- ❖ The moving electron's charge can be considered as electric current (i)



$$i = \frac{q}{t} = \frac{e}{T} = \frac{ev}{2\pi r}$$

- ❖ The magnitude of the magnetic dipole moment of the orbiting electron is given by

$$\mu_{orb} = iA = \frac{ev}{2\pi r} (\pi r^2) = \frac{ver}{2}$$

- ❖ The magnitude of the orbital angular momentum of the electron is

$$L_{orb} = rp = rmv = \frac{2m\mu_{orb}}{e}$$

Because the magnetic dipole moment and the angular momentum are vector quantities, we

can write

$$\vec{\mu}_{orb} = - \frac{e}{2m} \vec{L}_{orb}$$

Where the negative sign is needed because of the definition of the current as the direction of the flow of positive charge

Q) In the Bohr model of a hydrogen atom, the radius of the orbit of the electron is $r = 5.29 \times 10^{-11}$ m. the electron's linear velocity $v = 2.19 \times 10^6$ m/s . **Find the following:**

a) **Electric current**

.....

.....

b) (**Magnetic dipole moment**) the magnetic orbital moment of a hydrogen atom μ

.....

.....

c) **The amount of angular motion** of the electron $\vec{L}_{orb}$

.....

.....

(a) 1.0544, (b) $9.268 \times 10^{-24} \text{ m}^2 \cdot \text{A}$, (c) $1.055 \times 10^{-34} \text{ kg} \cdot \text{m}^2 / \text{s}$