Lesson 1

Physics 12 – **Magnetic Forces and Fields**

Up until now we have only considered the electrostatic forces acting on charges at rest.
**When the charges are in motion, an extra force acts on them**.

**Magnetic fields** are produced by **electric currents**, which can be relatively large currents in wires, or relatively tiny currents associated with electrons in atomic orbits.

## Magnets

Certain metals, such as iron, cobalt and nickel, have a special property to them that allows them to become permanent or temporary magnets. These metals are referred to as ferromagnetic materials.

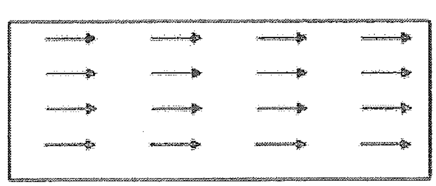
Ferromagnetic materials have something special about the charge movement within their atoms. This has to do with the spin nature of the unpaired electrons in these atoms.

The unpaired electrons have spins that have spins that produce a "cooperative effect" with $10^{15}$ to $10^{20}$ other atoms. The atoms that cooperate in this group are called a magnetic domain. Since the dimensions of these domains are very, very small. Therefore, there are millions of magnetic domains in a magnet. *http://www.magnet.fsu.edu/education/tutorials/java/domains/index.html*

**Un-Magnetized Piece of Ferromagnetic Material** –

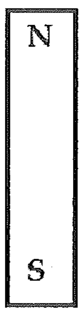
**Magnetized Piece of Ferromagnetic Material** –

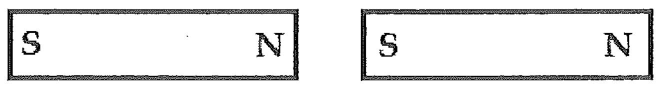
A magnet has two poles - a north pole and a south pole.

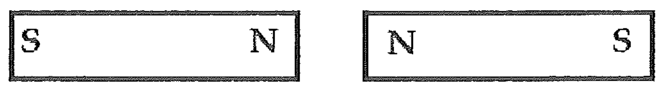


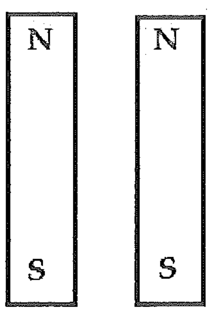
Magnets can ______________ or ________________ other magnets. Magnets are also able to exert forces on each other without touching because they are surrounded by:

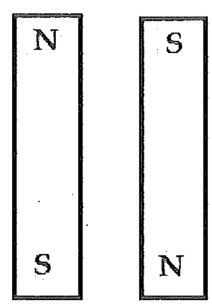
Magnetic fields are **vector** fields and therefore we need to represent the lines as **arrows.**



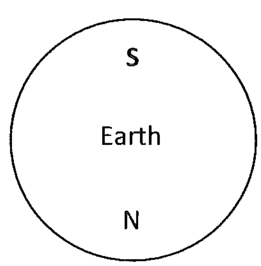



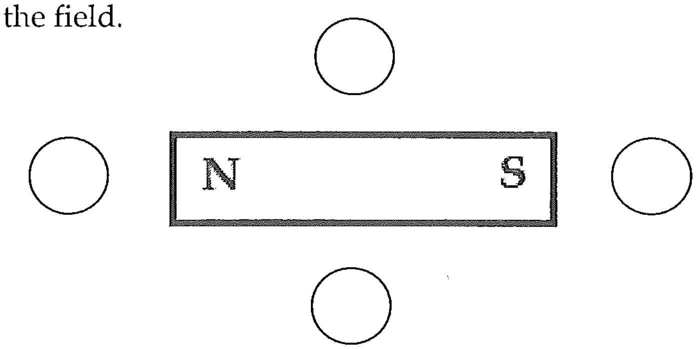




*Note the similarity of magnetic fields to electric fields.*

The end of the magnet in a compass that points north is the *north-seeking pole* (making it the south pole of the magnet). Therefore, the magnetic pole of the earth in the geographic north must be a south magnetic pole!



We define the direction of a magnetic field as the direction that a compass would point when placed in the field.




When magnetic fields interact, we can summarize those interactions:

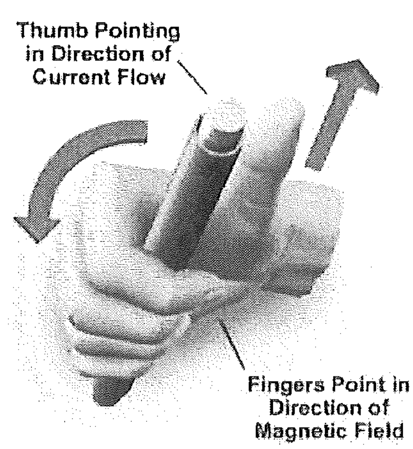
**Like magnetic poles repel** each other, and **unlike poles attract** each other.


## Electromagnetism:

The **Oerstad Experiment** at the University of Copenhagen in 1819 was the first evidence of the connection between electricity and magnetism. This experiment helped lead to the understanding that all magnetic fields are caused by the ________________ of

_____________ ______________, like electrons moving around the nucleus or through wires.

Shortly after Oersted and his experiment were made public, **Andre Marie Ampere** developed the **1st Right Hand Rule**. This rule is used to predict the direction of the -




**The right hand rule uses CONVENTIONAL current.**

example: What is the magnetic field 2.3cm from a straight conductor carrying a current of 7.6A?

Using the 1st right hand rule, it is now possible to show the shape of the magnetic field around a current-carrying wire. The lines of force around a current-carrying wire **circle** the wire.

**1st Right Hand Rule:** Straight wire, circular magnetic field (Left)

**Thumb:** direction

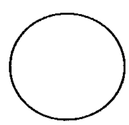
**Curved Fingers:** 

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

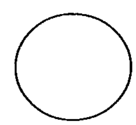
magnitude

Quite often we need to represent a current carrying wire as though you are looking at it from its end. To do this, we draw a circle and indicate the direction of current flow as follows:

If the current flows INTO the page:

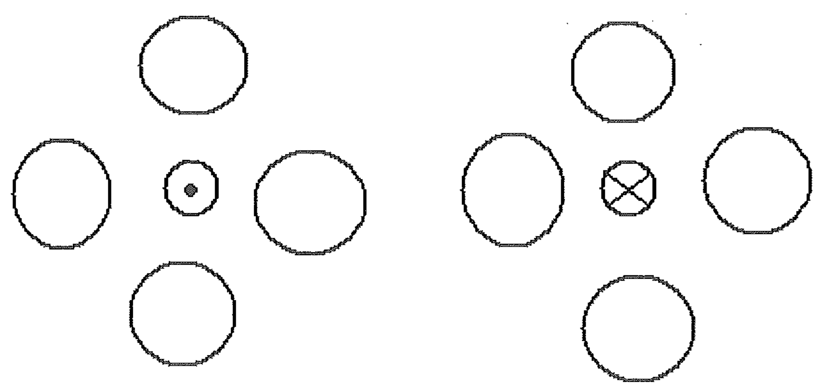


If the current flows OUT OF the page:

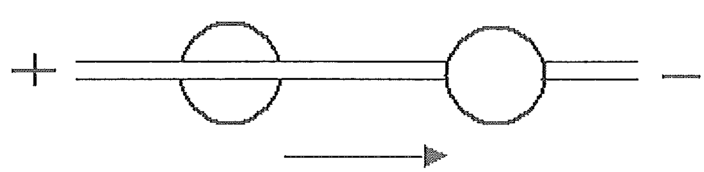


Using the right-hand rule, we can determine the direction of the magnetic field:

In a current-carrying wire going into and out of the page:

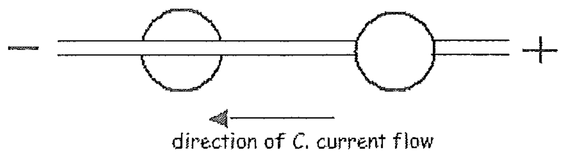


For a non-coiled single wire (+ to -):




direction of C. current flow

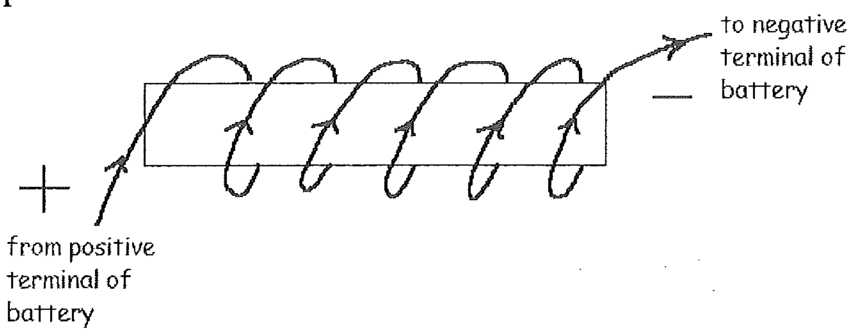
For a non-coiled single wire (- to +):




## Solenoids:

Electromagnets are magnets that produce magnetic field only when an electric current flows through them. These magnets are usually made by winding a coil of wire around a magnetic core material such as iron. This is referred to as a **solenoid.**

**The loops of wire carry the current and therefore the more loops there are, the stronger the magnetic field produced.**




Just like a bar magnet, a **solenoid (electromagnet) has North and South poles.** The poles depend entirely on…\

**2nd Right Hand Rule: (again we are using conventional current)**
(or Left) circular wire, straight magnetic field

**Curved Fingers:** **Thumb:**

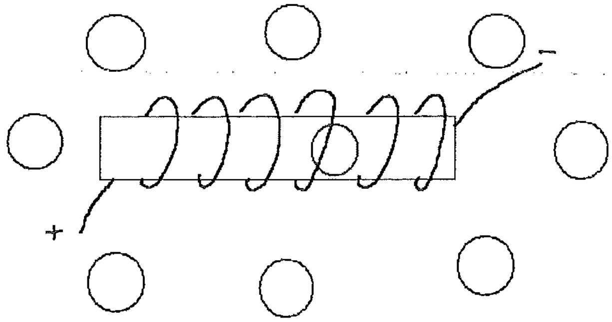
magnitude

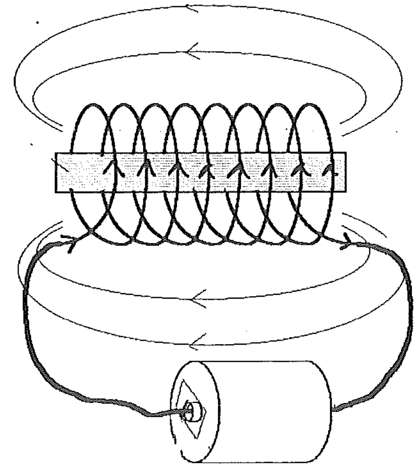
$B = \mu_0 I n$

or

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

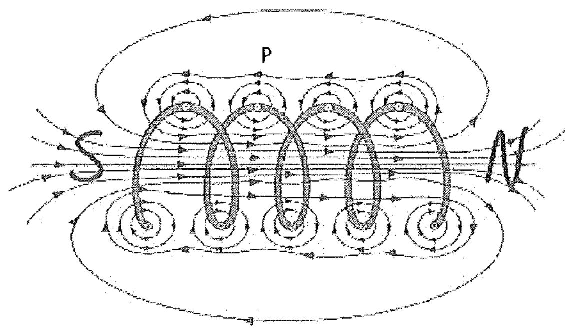
direction



By looking at the diagram below, we can see that the **field outside of a solenoid is weak and non-uniform.**

However, the **field inside the solenoid is strong and uniform.**




In a uniform magnetic field INSIDE the solenoid, we can calculate the strength of the field using:

3rd Hand Rule: Connects 3 things
magnitude   B, I and $F_m$

$F_m = qvB$

$F_m = BI'l$

N   S

↑I   direction

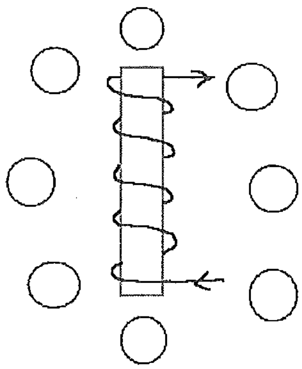
**Example**: A hollow solenoid is 25 cm long and has 1000 loops. If the solenoid has a diameter of 4.0 cm and a current of 9.0 A, what is the magnetic field strength in the solenoid?

Lesson 1 homework

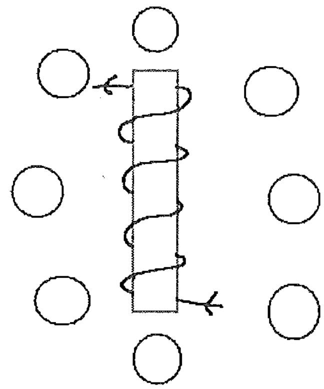
**Questions:**

Indicate the lines of force on the following diagrams by filling in the direction of the compass needles. Then indicate which end of the electromagnet would be the North and South Poles. (Note: the arrows show the direction of conventional current)

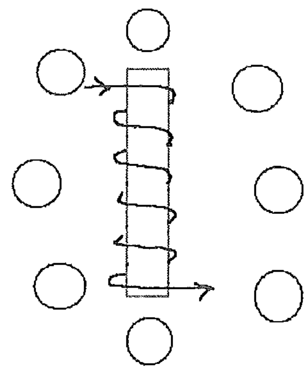
a)



b)

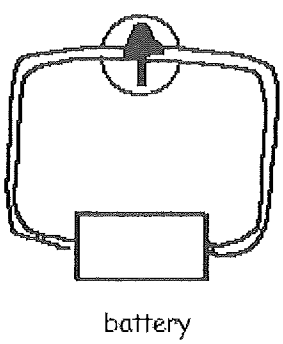


c)

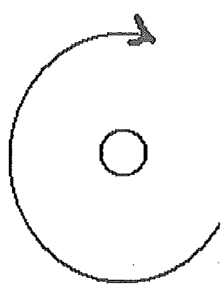


Use the Right-Hand Rule to predict which is the positive and negative terminals of the battery. (Hint: Don't forget to look at where the compass is placed…above or below the wire!!)

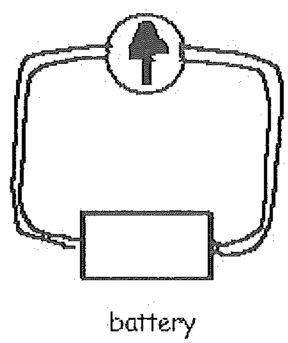
a)




b)

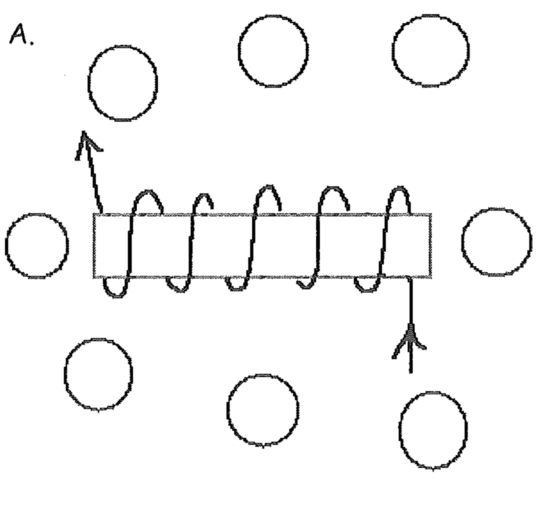


c)

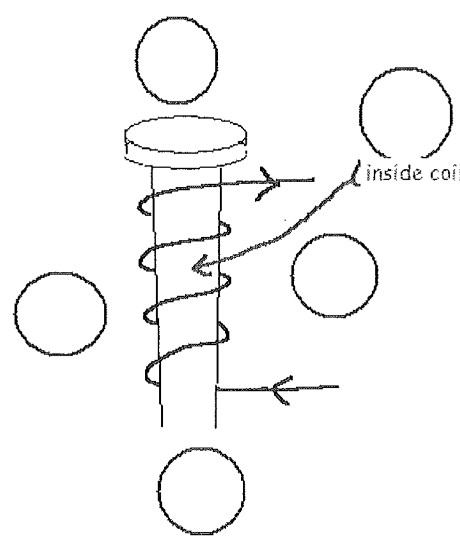



Find the North and South Poles in each example and indicate the direction of all the compass needles.

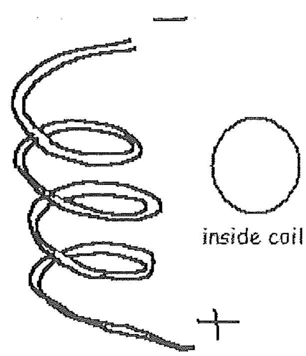
A.



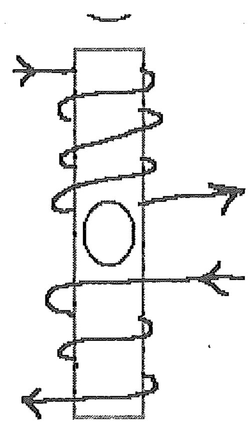
B.



C.

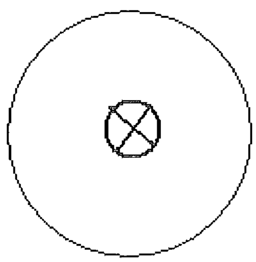



D.

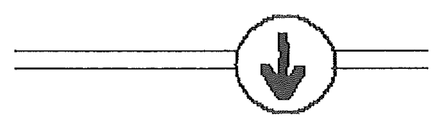


Find the direction of the current: (label the + and – terminals)

A.



B.



1. A 25.0 cm solenoid has 1800 loops and a diameter of 3.00 cm. Calculate the magnetic field in the air core of the solenoid when a current of 1.25 A is flowing through it.

2. An air core solenoid is 25 cm long and carries a current of 0.72 A. If the magnetic field in the core is $2.1 \times 10^{-3}$ T, how many turns does the solenoid have?

3. An air core solenoid is 30.0 cm long and has 775 turns. If the magnetic field in the core is 0.100 T, what is the current flowing through this solenoid?

4. What is the magnetic field near the center of a 0.30 m long solenoid that has 800 turns of wire and carries an electric current of 2.0 A?

Lesson 2.

Physics 12 – **Magnetic Forces**

Last class, we saw that with permanent magnets –

We also saw that magnetic fields surround any current carrying wire. **When a current-carrying conductor (like a wire) is placed in a magnetic field, it will experience a <u>force.</u>**

We are going to look at two types of situations in which magnetic forces act.

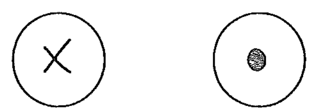
## A. Magnetic Forces on Current Carrying Wires

<u>Parallel Current Carrying Wires</u>

Two parallel wires carrying current in the same direction. Will the fields produced by these wires attract or repel?

**Parallel wires with current flowing in the <u>same</u> direction will…**

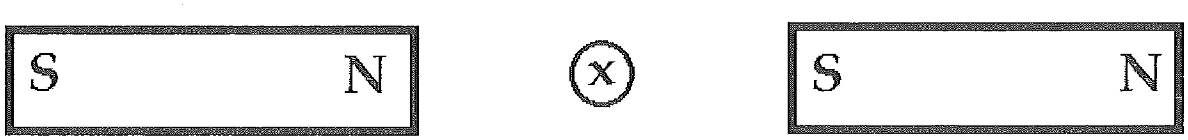
Two parallel wires carrying current in the opposite direction. Will the fields produced by these wires attract or repel?



**Parallel wires with current flowing in the <u>opposite</u> direction will…**

<u>Current Carrying Wires in Magnetic Fields</u>

A current carrying wire is placed between two permanent magnets as shown below.

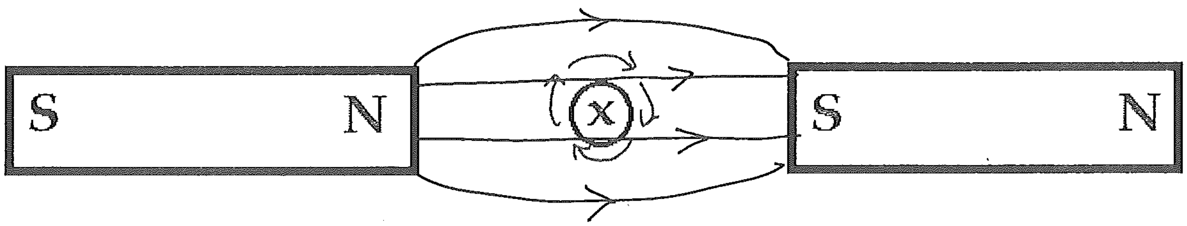



The **<u>area above the wire</u>** sees an interaction between the field produced by the permanent magnets and the field produced by the current carrying wire. These fields point…

These two fields will ________________.

The **area below the wire** also sees an interaction between the two fields. In this area, the fields point…

These two fields will ___________________.

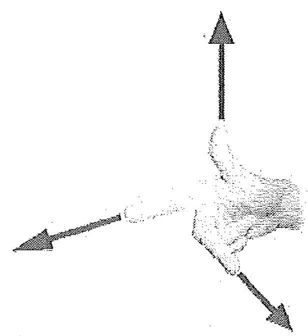



**The 3rd Right Hand Rule:** *To obtain the direction of the force on a conductor in a magnetic field.*

**Thumb:**

**Index Finger:**

**Other Fingers:**



The magnetic force on a conductor can be calculated as:

**Note:** If the conductor is perpendicular to the magnetic field, the formula becomes:

And if the conductor is parallel to the magnetic field, the formula becomes:

## B. Magnetic Forces on Moving Charges in Magnetic Fields

In the same way that charged particles moving through a wire will experience a force in a magnetic field, so will free charged particles. We also use the **3rd Right Hand Rule** to determine the direction of the magnetic force on such a particle.

*IMPORTANT NOTE*: We use **right hand rules** for wires when talking about **conventional current**. All of the same concepts apply if we use our left hand (**left hand rules**) when dealing with **electron flow.**

This logic is also used when dealing with charged particles:

For **positively charged particles**, we use…

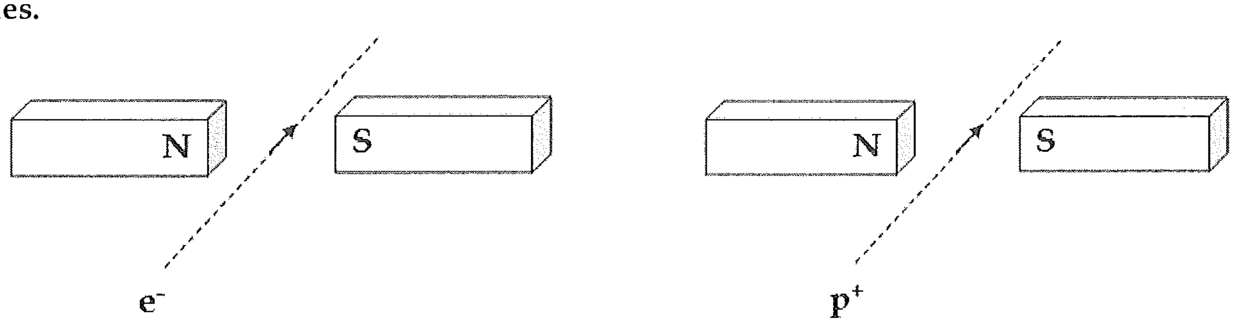
For **negatively charged particles**, we use…

To calculate the magnetic force on a particle, we use:

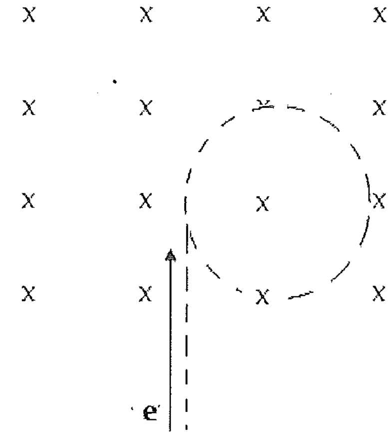
Again, if the particles are moving perpendicular to the field →

If the particles are moving parallel to the field →

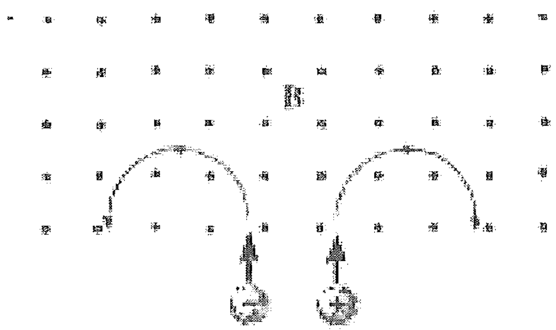
As seen below, moving charges (such as protons, electrons and neutrons) can be deflected by magnetic fields. **They are deflected by the magnitude of the force calculated** by the formula introduced above. Then we use the hand rules to **determine the direction** of the deflection. Remember - **use your right hand for positive particles and your left hand for negative particles.**



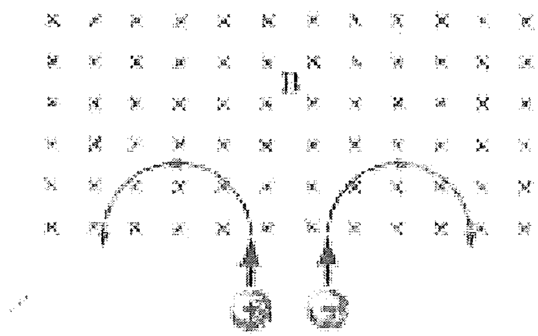
In a vacuum, charged particles can become trapped in a magnetic field. **As the magnetic force acts on the charged particle, the direction of motion is changed. As the direction of motion is changed, so is the direction of force. This results in a circular motion.**



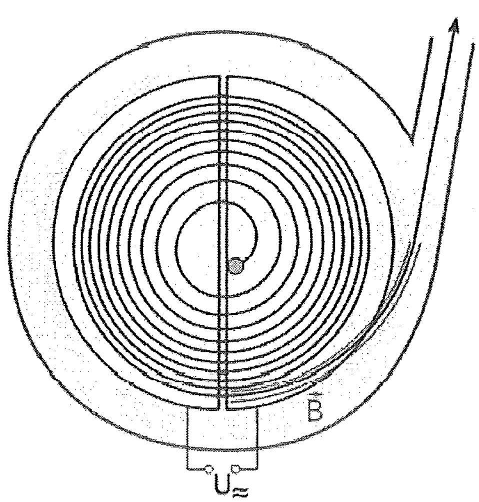

**Magnetic Field Direction – OUT OF THE PAGE**



**Magnetic Field Direction – INTO THE PAGE**

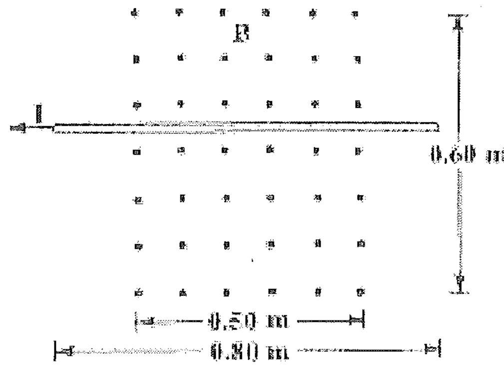


Circular particle accelerators use magnetic fields to bend beams of charged particles. This allows them to reach phenomenal speeds in relatively small spaces. The cyclotron at UBC's TRIUMF contains the largest of its kind in the world. It accelerates a beam of hydrogen anions ($H^-$) to 75% the speed of light and uses a 0.42 T magnetic field. At these speeds, the relativistic mass of a hydrogen anion is $2.524 \times 10^{-27}$ kg. What is the outer radius of the cyclotron?



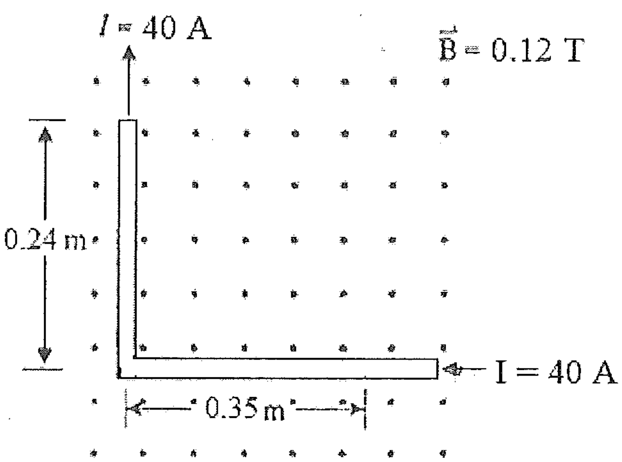

**When charged particles travel in a circular path:**

**Example One:** A wire with a current of 2.0 A is perpendicular to a magnetic field of 0.82 T as shown in the diagram. What are the magnitude and direction of the magnetic force acting on the wire?



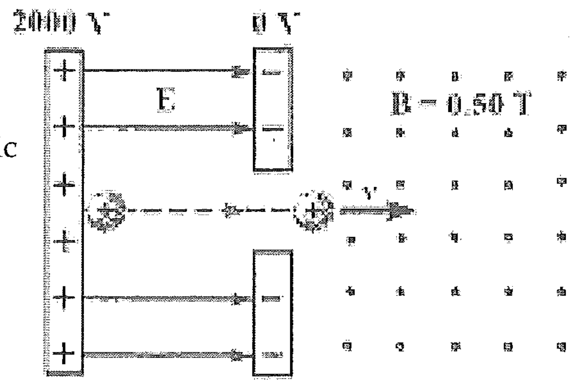

**Example Two**: Calculate the magnitude of the magnetic force on an electron travelling at a speed of 3.60 x $10^4$ m/s perpendicular to a magnetic field of 4.20 T.

**Example Three:** What is the net magnetic force on the L-shaped conductor?




**Example Four:** Calculate the upward acceleration of an electron that is travelling east at a speed of 8.30 x $10^4$ m/s through a magnetic field of 3.10 x $10^{-1}$ T that is directed south.

**Example 5:** A proton is accelerated from rest at the positive plate of the two charged parallel plates with a potential difference of 2000 V. After leaving the plates through a small hole in the negative plate, it enters a uniform magnetic field of 0.50 T in a direction perpendicular to the magnetic field directed out of the page as shown in the diagram.




a) Find the speed of the proton when it leaves the negative plate.

b) Find the magnitude and direction of the magnetic force on the proton.

c) Find the acceleration of the proton.

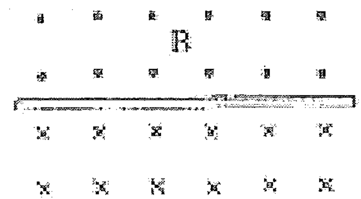
d) Draw the path of the proton.

e) Find the radius of its path in the magnetic field.

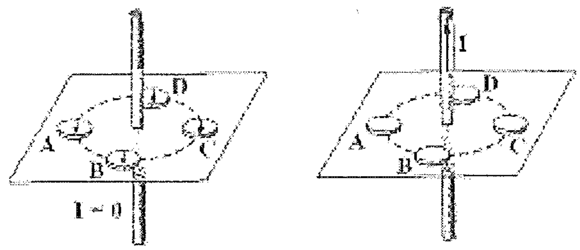
# Lesson 2 homework

**Magnetic Force Problems:**

1. The magnetic field in the diagram is due to the current carrying wire. What is the direction of the current in the wire? (to the right)



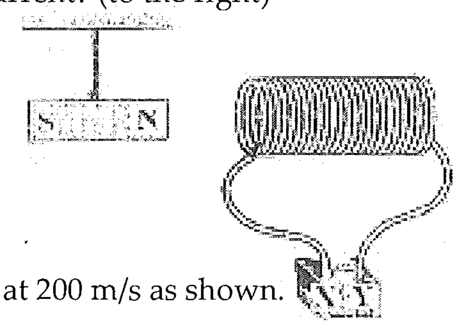

2. When no current is present in the wire, all compass needles point in the same direction. Use arrows to show the direction of the compass needle at each point A, B, C and D when the wire carries a current as shown in the diagram.



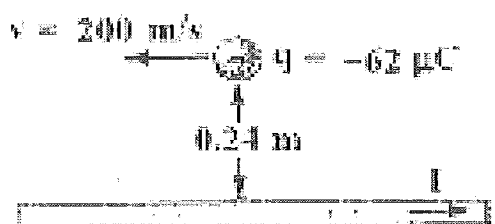

3. When a solenoid is connected to a battery, the north pole of the magnet near the solenoid points towards the solenoid.

   a. What is the direction of the magnetic field due to the current? (to the right)

   b. What is the polarity of the terminal X of the battery? (-)




4. A -62 μC charged particle moves near a current carrying wire at 200 m/s as shown. The separation between the particle and the wire is 0.24 m, and the magnitude of the magnetic force exerted on the particle is $1.2 \times 10^{-8}$ N.




   a. Find the magnitude of the magnetic field at the location of the particle.($9.67 \times 10^{-7}$ T)

   b. Find the current of the wire. (1.16 A)

5. A 450 turn solenoid of length 0.32 m produces a magnetic field of $4.0 \times 10^{-5}$ T at its center. Find the current in the solenoid. ($2.26 \times 10^{-2}$ A)

6. A solenoid of length 0.45 m and a diameter of 0.020 m produces a magnetic field of 1.6 T at its center when it carries a current of 6.8 A. How many turns of wire are contained in this solenoid? ($8.43 \times 10^4$ turns)

7. An electron moving at $1.8 \times 10^3$ m/s enters at a right angle to a magnetic field produced by a 0.28 m long solenoid. A current of 4.2 A flows through the 760 turns of wire in the solenoid.

   a. Find the magnetic field in the solenoid. ($1.43 \times 10^{-2}$ T)

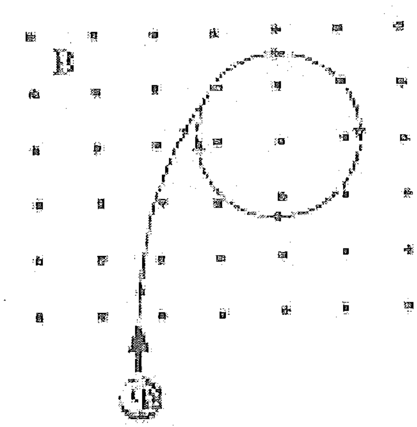
   b. Find the radius of curvature of the electron in the magnetic field of the solenoid. ($7.16 \times 10^{-7}$ m)

8. An electron with a kinetic energy of $3.6 \times 10^{-14}$ J moves perpendicular to a magnetic field of 0.60 T.

   a. Find the magnitude of the magnetic force on the electron. ($2.70 \times 10^{-11}$ N)

   b. Find the radius of the circular path of the electron. ($2.67 \times 10^{-3}$ m)

9. The diagram shows the pathway of a charged particle which is not possible as the particle with a constant velocity enters a uniform magnetic field. Using the principles of physics, explain why the pathway is not possible.

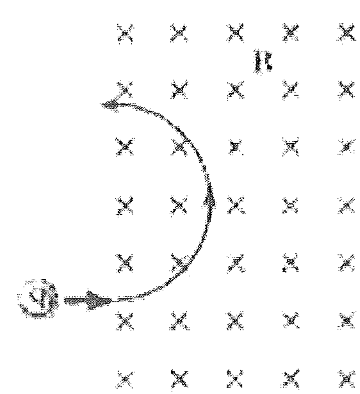


10. What is the mass of a singly charged ion that makes 6.0 revolutions in $1.5 \times 10^{-3}$ s in a $5.6 \times 10^{-2}$ T field with a radius of $5.4 \times 10^{-4}$ m? ($3.57 \times 10^{-25}$ kg)

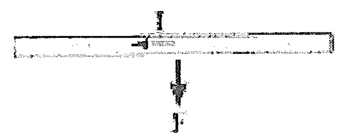
11. When a charged magnetic particle enters a uniform magnetic field, it moves in a circular path as shown in the diagram.

   a. Determine the polarity of the particle. (+)

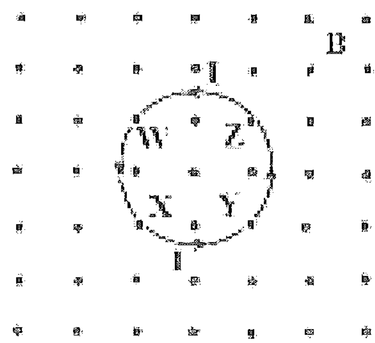
   b. If the magnetic field has a magnitude of 0.20 T, the particle's charge has a magnitude of $1.8 \times 10^{-19}$ C, its speed is $3.0 \times 10^5$ m/s, and the radius of its path is 0.40 m, find the mass of the particle. ($4.8 \times 10^{-26}$ kg)



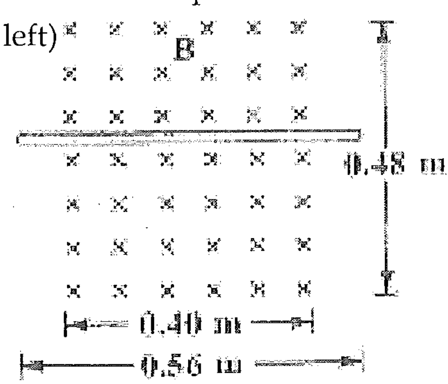
12. A current carrying wire is perpendicular to a magnetic field. Due to the presence of a magnetic field, the wire experiences a magnetic force toward the bottom of the page. What is the direction of the magnetic field? (x)



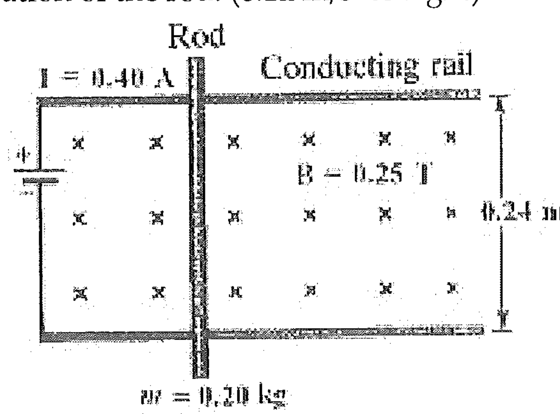

13. The diagram shows current I flowing in a circular coil in a magnetic field B. Use arrows to show the direction of the magnetic force acting on the coil at each point W, X, Y and Z.




14. The diagram shows a current-carrying wire that is perpendicular to a magnetic field of 0.54 T. What is the magnitude and direction of the current that produces a 2.8 N force on the wire directed down the page? (13 A to the left)




15. A 0.20 kg metal rod is lying on the horizontal top of two frictionless conducting rails. Find the magnitude and direction of the acceleration of the rod. ($0.12\ m/s^2$ to right)



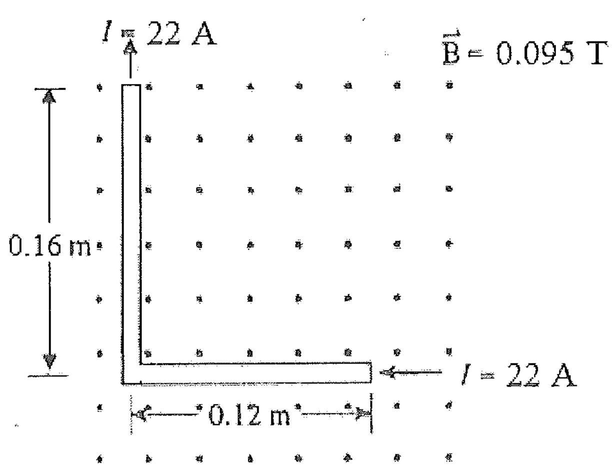
16. Calculate the magnitude and direction of the magnetic force on an alpha particle travelling upward at a speed of $2.11 \times 10^5$ m/s through a magnetic field that it directed down. (0 N)

17. An electron experiences an upward force of $7.1 \times 10^{-14}$ N when it is travelling $2.7 \times 10^5$ m/s south through a magnetic field. What is the magnitude and direction of the magnetic field? (1.64 T [to the right])

18. Calculate the downward acceleration of an electron that is travelling horizontally at a speed of $6.20 \times 10^5$ m/s perpendicular to a horizontal magnetic field of $2.30 \times 10^{-1}$ T. ($2.5 \times 10^{16}$ m/s$^2$)

19. An electron is accelerated by a potential difference and then travels perpendicular through a magnetic field of $7.20 \times 10^{-1}$ T where it experiences a magnetic force of $4.1 \times 10^{-13}$ N. If it is assumed that this electron starts from rest, through what potential difference was it accelerated? (36 V)

20. What is the net magnetic force on the L-shaped conductor? (0.418 N @ 37° N of E)

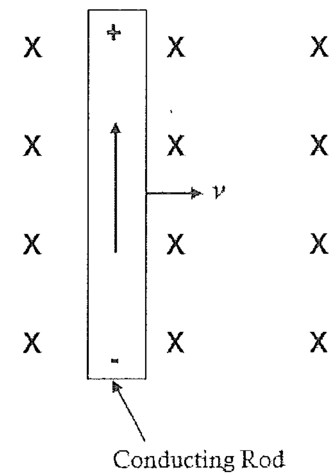


Lesson 3

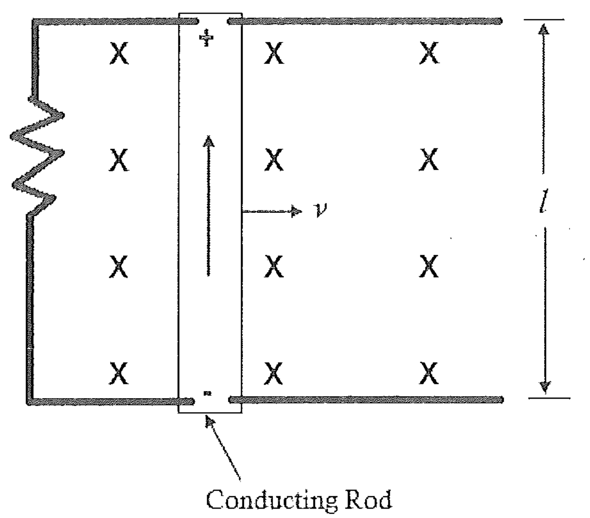
Physics 12 – **Magnetic Induction**

Oerstad determined that ***an electric current will produce a magnetic field***. So the next logical step was to determine if ***a magnetic field could produce an electric current***. Faraday and Henry both independently determined that this was possible.

One way to use a magnetic field to produce an electric current is to move a conducting rod through a magnetic field.



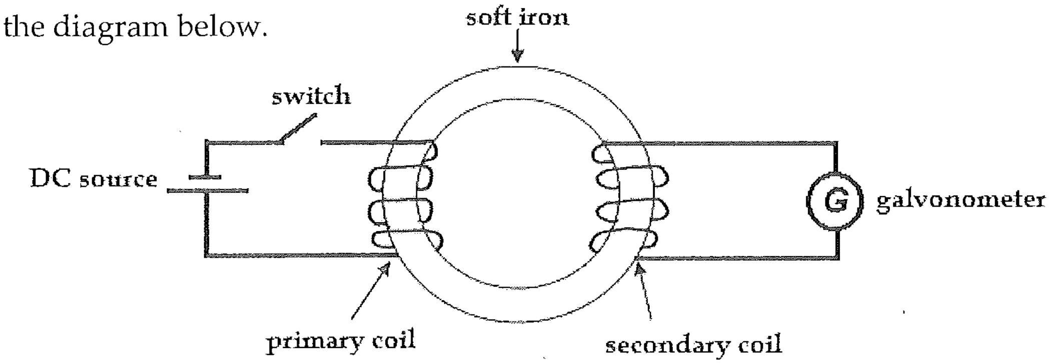

If this conducting rod is then made part of an electric circuit, it will act like a battery (a voltage source), causing charge to move in the circuit just as any battery with an EMF would.




The process of producing an EMF in a conductor by use of a magnetic field is known as **electromagnetic induction**.

> **Electromagnetic Induction** – When a conductor in which an EMF is induced is part of a circuit, the induced EMF will cause a charge to flow through the conductor. This flow of charge is called an **induced current**.

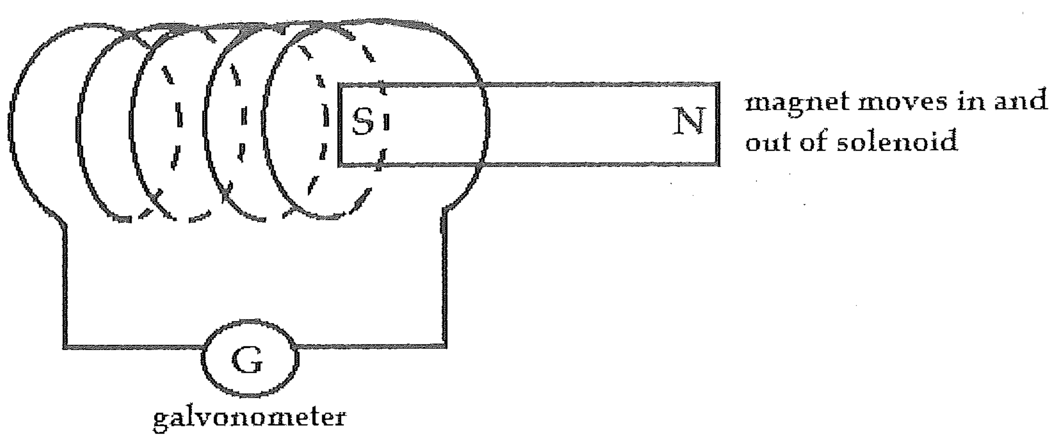
Faraday discovered that he could produce an electric current by using an induction coil as shown in the diagram below.




He found that when the switch of his induction coil was being closed or opened, the galvanometer deflected. This indicated that there was a brief current through the secondary coil.

**One of the key discoveries in this experiment was that while the switch was being closed, the galvanometer deflected in one direction, but while the switch was being opened, the deflection was in the opposite direction.**

In a similar experiment, you can connect a galvanometer to an air core solenoid and move a magnet in and out of the solenoid.

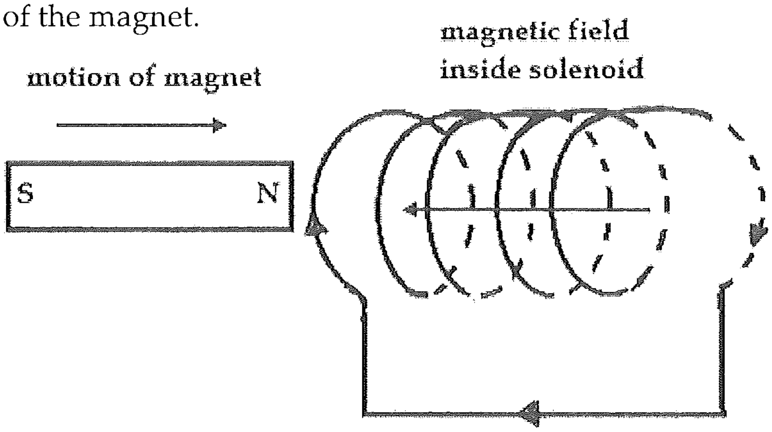



The direction of the induced current can be determined using Lenz's Law.

**Lenz's Law states:**

Lenz's Law is really an application of the law of conservation of energy. Energy cannot be created. You cannot get electrical energy from nothing. It must come from somewhere.

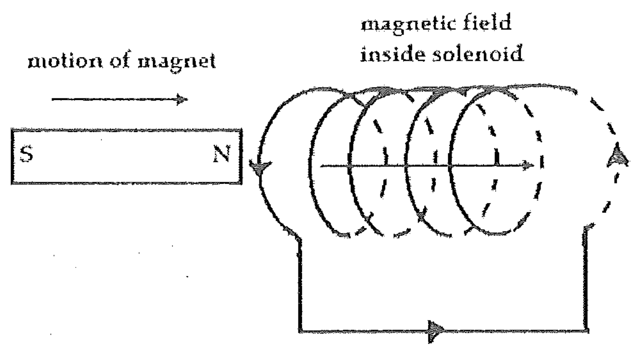
When a magnet is pushed into the coil, a current is induced in the coil. Lenz's Law tells us that the current flows in such a way that the magnetic field inside the coil opposes the magnetic field of the magnet.




According to the Right Hand Rule, when your thumb points in the direction of the North Pole, your fingers point in the direction that the **conventional current** must flow through the windings of the coil.

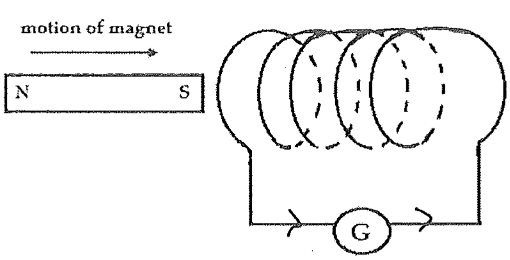
**This field opposes the magnetic field of the magnet. If this was not the case and the magnetic field in the coil did not oppose the magnetic field of the magnet, <u>you would be getting energy from nothing.</u>** WHY?

If the current in the conductor is as shown in the diagram, the magnetic field would attract the magnet. Therefore, no work (NO ENERGY) would be required to slide the magnet into the coil, but electrical energy would be produced → this is energy from nothing and impossible!

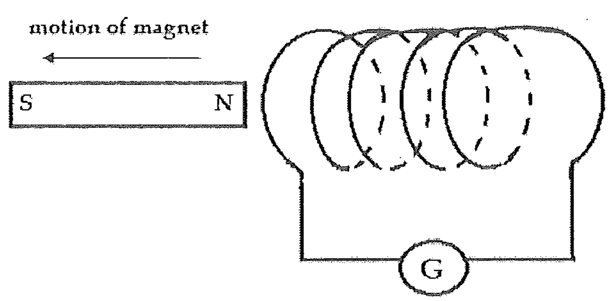



Examples: Find the direction of the induced current through G in the following diagrams.

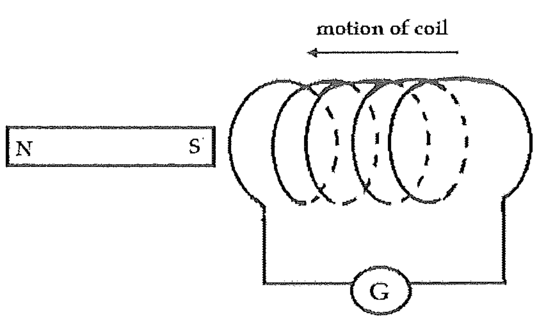
A.




B.

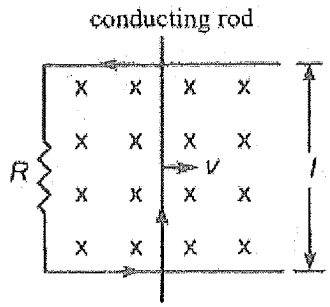



C.



If a conducting rod is moved through a magnetic field, the magnetic field of the induced current must oppose the magnetic field that produced the induced current – again, this illustrates **Lenz's Law.**

We can use the Right Hand Rule to determine the direction of the induced current in this scenario.

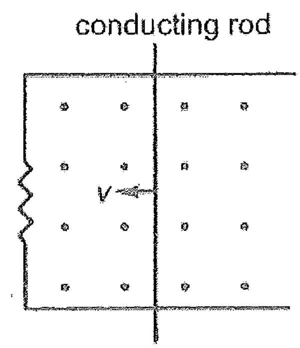



**Pointer Finger –**

**Curved Fingers –**

**Thumb –**

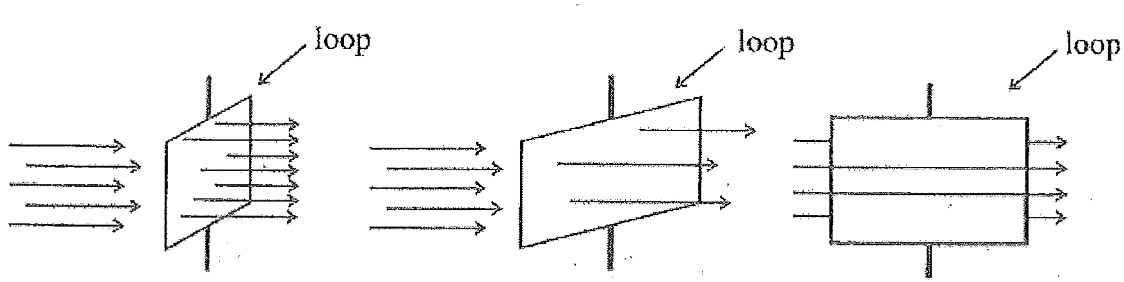
**Example**: What is the direction of the induced current in the following scenario?




## <u>Magnetic Flux</u>

Magnetic flux is defined in terms of magnetic field lines. Recall that the density of these lines represents the magnetic field strength.

The **magnetic flux** through a loop **depends on** the <u>orientation (the angle) of the loop</u>, <u>the magnetic field strength (field lines)</u> and the <u>area of the loop.</u>




$\theta = 0$ $\theta > 0$ but $< 90°$ $\theta = 90°$

**The magnetic flux depends on the number of field lines that pass through the loop**. When the field lines are perpendicular to the plane of the loop, there will be more lines passing through the loop. Conversely, when the field lines are parallel to the plane of the loop, there are no lines that pass through.

**Magnetic Flux –**

Units - T•$m^2$ or webers (Wb)

Faraday's explained how an induced current is produced by using a magnetic field through a changing magnetic flux.

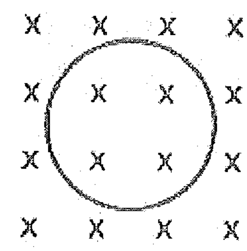
The induced current depends on the rate of change of the magnetic flux. The induced current also depends on the induced EMF.

The formula we use quite often when dealing with induced currents is an algebraic expression of Faraday's Law of Induction -

**Example 1**: A square loop of wire is perpendicular to a 1.50 T magnetic field. If each side of the wire is 2.10 cm, what is the magnetic flux through the loop?

**Example 2:** A 1.80 cm diameter circular coil that contains 50 turns of wire is perpendicular to a 0.250 T magnetic field. If the magnetic field is reduced to zero in a time of 0.100 s, what is the average induced EMF in the coil?

**Example 3**: A circular loop of wire (radius = 2.5 cm) is placed in a magnetic field (B=0.020 T), as shown in the diagram as shown in the diagram. This field is then decreased to 0.010 T in 0.10s.



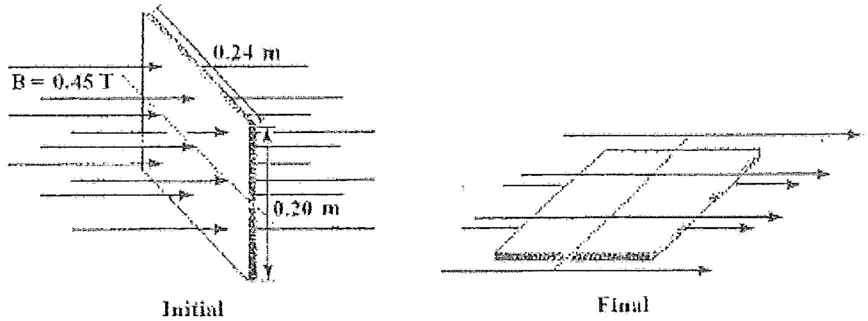
a) What is the average EMF induced in the loop?

b) What is the direction of current through the loop?

Lesson 3 homework.

**Induced Current and Magnetic Flux Problems:**

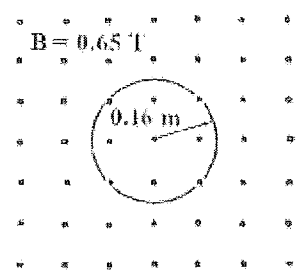
1. The diagram below shows a rectangular coil with 200 turns and dimensions 0.24 m by 0.20 m. Its plane is perpendicular to a magnetic field with magnitude 0.45 T. The coil rotates 90° in 0.12 s so that its plane is now parallel to the magnetic field.



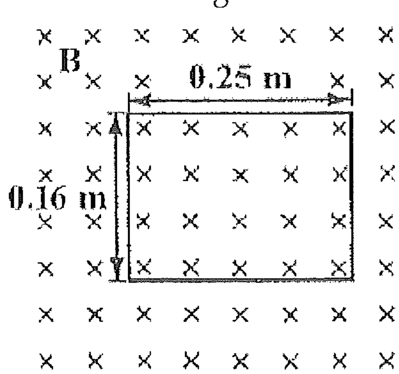

a) What is the magnitude of the induced EMF? (36 V)

b) If the coil has a total resistance of 40 Ω, what is the current induced in the coil? (0.90 A)

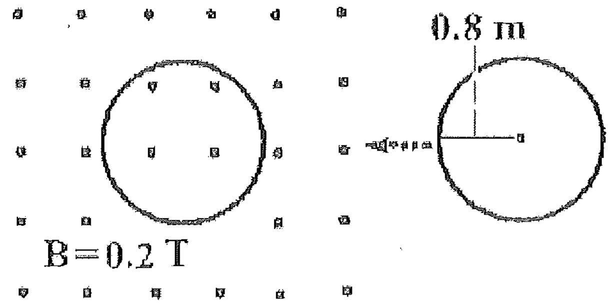
2. A 0.65 T magnetic field passes through a circular coil of radius 0.16 m. Find the magnitude of the magnetic flux through the coil. (0.0523 Wb)



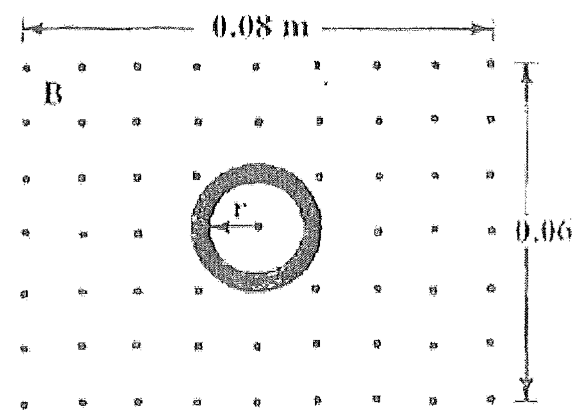

3. The magnetic flux through the surface of a rectangular coil measuring 0.25 m by 0.16 m is $2.4 \times 10^{-3}$ Wb when the coil is placed perpendicular to a magnetic field. Find the strength of the magnetic field. (0.060 T)



4. When a single coil with a radius of 0.80 m of resistance 2.8 Ω is pulled a distance of 0.30 m into a perpendicular 0.20 T magnetic field, an average current of 0.40 A current is produced in the coil. Find the speed with which the coil was pulled. (0.836 m/s)




5. A coil with 800 loops of radius 0.01 m is placed with its plane perpendicular to a uniform 0.16 T magnetic field as shown in the diagram.




a) If the coil rotates 90° in 0.40 s so that's its plane is now parallel to the magnetic field, what is the average EMF induced in the coil? (0.10 V)

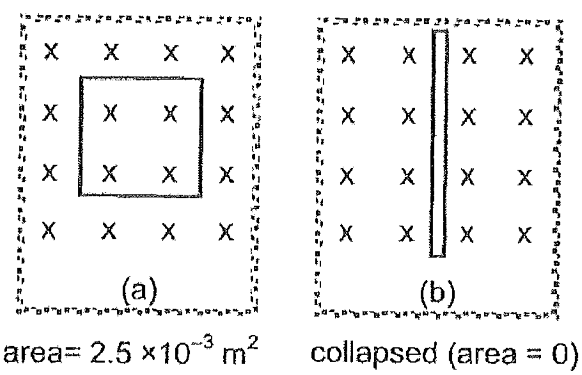
b) If the magnetic field changes from 0.16 T to 0.04 T in the opposite direction in 0.80 s, what is the average EMF induced in the coil? ($6.3 \times 10^{-2}$ V)

c) If the coil moves to the right by 0.01 m in 0.60 s within the magnetic field, what is the average EMF induced in the coil? (0 V)

6. A magnetic field ($B = 3.2 \times 10^{-3}$ T) passes perpendicular through a circular loop of wire (radius = 5.0 cm). What is the magnetic flux through the loop? ($2.51 \times 10^{-5}$ Wb)

7. A circular coil with 200 turns and a radius of 6.0 cm is rotated in a uniform magnetic field ($B = 3.6 \times 10^{-4}$ T). At $t = 0$, the coil is perpendicular to the field, and at $t = 0.015$ s, the coil is parallel to the field. What is the average EMF induced in the coil? ($5.43 \times 10^{-2}$ V)

8. A square-shaped piece of wire with an area of $2.5 \times 10^{-3}$ m$^2$ is perpendicular to a uniform magnetic field ($B = 2.2 \times 10^{-2}$ T) as shown in the diagram (a).




If the square collapses in time of 0.100 s, as shown in diagram (b) above, what is the average induced EMF as it collapses? ($5.5 \times 10^{-4}$ V)

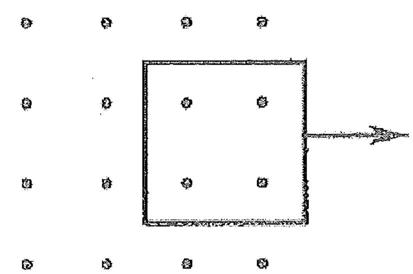
9. Find the average EMF induced in a circular coil with 50 turns and a radius of 0.050 m if the magnetic flux through the loops is changing at a rate of 15.0 Wb/s? (-750 V)

10. A square-shaped coil with 100 turns (area of each square loop = $4.0 \times 10^{-3}$ m$^2$) is perpendicular to a uniform magnetic field. When the coil is rotated through 90° in 0.12 s, the average induced EMF is 0.92 V. What is the magnetic field strength? (0.276 T)

11. A circular coil with 10 turns and a diameter of 25 cm is placed perpendicular to a uniform magnetic field ($B = 2.7 \times 10^{-3}$ T). If the direction of the magnetic field is reversed in 0.30 s, what is the average EMF induced in the coil? ($8.8 \times 10^{-3}$ V)

12. A magnet is quickly removed from a circular coil (25 turns, area = $5.0 \times 10^{-3}$ m$^2$). This changes the magnetic field within the coil at a rate of 0.40 T/s. What is the average EMF induced in the coil? (0.05 V)

13. A square-shaped piece of wire (area = $7.2 \times 10^{-3}$ m$^2$), as shown in the diagram below, has a resistance of 12.0 Ω. Assume that the magnetic field drops uniformly from 1.6 T to 0 T in 0.050 s as the loop is pulled from the magnetic field.

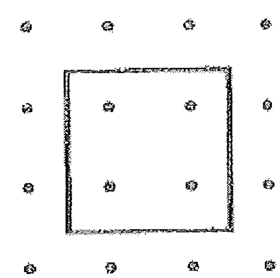


a) What is the average EMF induced in the loop? (0.23 V)

b) What is the current induced in the loop? ($1.92 \times 10^{-2}$ V)

c) What is the direction of the electron flow in the loop? (clockwise)

14. A square-shaped piece of wire (4.0 cm per side), as shown in the diagram below, is placed in a magnetic field (B = 0.20 T). The magnetic field is increased to 0.50 T in 0.30 s.



a) Find the current through the loop if the resistance of the loop is 2.0 Ω. ($8.0 \times 10^{-4}$ A)

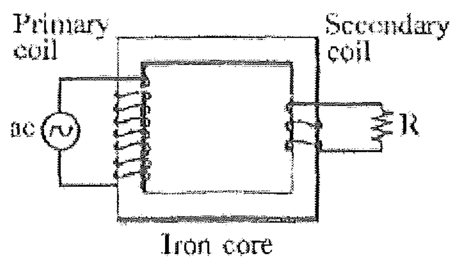
b) Find the direction of the electron flow through the loop. (clockwise)

Lesson 4

Physics 12 – **Transformers**

Transformers are another important application of electromagnetic induction. A **transformer** is a device that is used to convert a potential difference to a higher or lower value.

A transformer consists of a primary coil of $N_P$ turns and a secondary coil of $N_S$ turns.




The changing magnetic flux due to an AC voltage in the primary induces an AC voltage in the secondary.

**Step-up Transformer** – Used to **increase** the potential difference.

**Step–down Transformer** – Used to **decrease** the potential difference.

Although a transformer will increase or decrease the voltage, energy is conserved – you cannot get something for nothing.

Transformer Equation:

From this we can see that as the number of turns increases, the voltage increases, but the current decreases.

In the problems that we will deal with, we will assume that the transformers are *ideal*. That is, no electrical energy is converted to other forms. The efficiency of transformers are usually very high.

**Example 1:** A step-up transformer is used to convert $1.20 \times 10^2$ V to $1.50 \times 10^4$ V. If the primary coil has 24 turns, how many turns does the secondary coil have?

**Example 2:** A set-up transformer has 1000 turns on its primary coil and $1.0 \times 10^5$ turns on its secondary coil. If the transformer is connected to a 120 V power line, what is the step-up voltage?

**Example 3:** A step-down transformer reduces the voltage from 120 V to 12.0 V. If the primary coil has 500 turns and draws $3.0 \times 10^{-2}$ A,

a) What is the power delivered to the secondary coil?

b) What is the current in the secondary coil?

**Power Transmission** – One major application of transformers is in the transmission of electric power. At the power generation plant, there are step-up transformers that will increase the voltage to a very high voltage (100000 V to 500000 V). At the user end (ie. our houses), there are step-down transformers to reduce the voltage to 120 V before any electric power enters our homes or buildings.

Why? **Reason 1** –

**Reason 2** -

Lesson 4 homework

**Transformers and Power Transmission Problems:**

1. Currents of 0.25 A and 0.95 A flow through the primary and secondary coils of a transformer, respectively. If there are $1.0 \times 10^3$ turns in the primary coil, how many turns are in the secondary coil?

2. A step-down transformer has coils of $1.20 \times 10^3$ and $1.50 \times 10^2$ turns. If the transformer is connected to a $1.20 \times 10^2$ V power line and the current in the secondary coil is 5.00 A, what is the current in the primary coil?

3. Near Nick's home, the voltage of the power line is $3.6 \times 10^3$ V. The transformer between his home and the line reduces this voltage to $1.20 \times 10^2$ V. If the transformer is to deliver $2.4 \times 10^3$ J of energy each second to Nick's home, what is the current in;

a) The primary coil?

b) The secondary coil?

4. A step-down transformer ($N_P = 1.50 \times 10^2$, $N_S = 25$) is connected to a $1.20 \times 10^2$ V primary line. If there is a 75 $\Omega$ electrical device placed in the secondary circuit, what is the current in the primary coil?

5. If the voltage and current of the primary coil is 120 V and 3.0 A, what is the power delivered the secondary coil?

6. If the power delivered to the secondary coil of a step-up transformer is 50.0 W from a 120 V power line, what is the current in the primary coil?

7. A transformer ($N_P = 5.5 \times 10^2$, $N_S = 36$) is connected to a 120 V power line. If the current in the primary coil is 1.0 A, what is the power in the secondary coil?

8. A 100 W transformer ($N_S = 1500$) has an input voltage of 9.0 V and an output current of 0.65A. How many turns are there in the primary coil?

9. A transformer has 20 turns in the primary coil and 400 turns in the secondary coil. This transformer produces an output of 5000 V with a 0.02 A current.

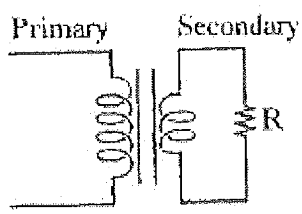
a) Determine the type of transformer.

b) What are the voltage and current in the primary coil?

c) What is the power input?

10. What acts on the secondary coil of a transformer to cause an EMF to occur across its ends even though the primary coil and secondary coil are not connected?

11. An ideal transformer has 1200 primary turns and 30 secondary turns. The input voltage of 120 V AC supplies power to the resistor, R, dissipating 24 W. Find the current in the primary coil and in the secondary coil.




12. An electric device with a resistance of 6.0 Ω requires 9.0 V to operate. An ideal transformer is used to obtain this voltage from the standard 120 V AC.

a) Determine the type of transformer.

b) Find the current in the primary coil.

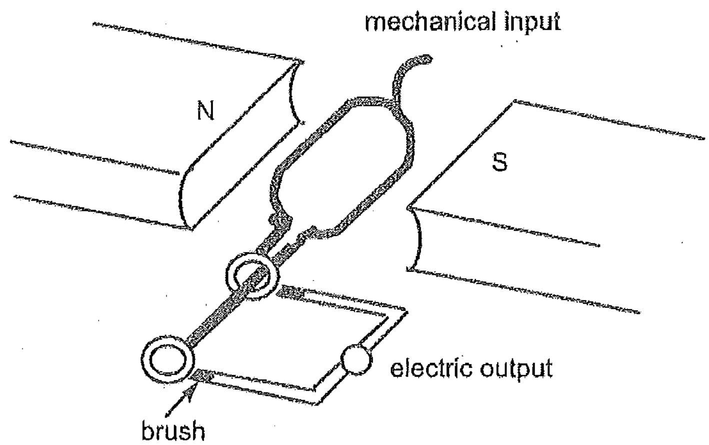
Lesson 5

# Physics 12 – **Electric Motors, Back EMF and Motional EMF**

We already know that batteries convert chemical energy into electrical energy. Electric generators are devices that convert mechanical energy into electrical energy. Generators make use of the principle of electromagnetic induction.

**Generators versus Motors:**

<u>Generators</u> – A loop of wire is rotated through a magnetic field (actually a number of loops are rotated). This changes the magnetic flux → induces an EMF → induces a current flow.




**Motors**: A current carrying conductor passes through the magnetic field. This interaction between magnetic fields causes the loop to rotate.

**Back EMF –** In an electric motor, there are loops of wire that are rotating in a magnetic field. These **<u>loops (called armature)</u>** rotate because of the interactions of magnetic fields. With this rotation, there is an induced EMF and an induced current.

**Direction –**

When a motor is first turned on, the loops are not yet rotating so there is no induced EMF. As the motor very quickly gains speed, the induced back EMF builds very quickly. When the motor is first turned on, the only voltage causing electrons to move is the voltage applied across the motor.

As the armature starts to rotate, the EMF opposes the voltage across the motor. This will **lower** the voltage in the wire loop circuit and therefore lowers the current drawn by the motor. ($V = IR$)

**When the motor reaches its full operating speed, the current drawn by the motor has decreased.**

**Example 1:** A 120 V motor draws 10.0 A when it reaches full operating speed. If the armature of this motor has a resistance of 5.2 Ω, what is the back EMF when it reaches its full operating speed?

**Example 2:** A 120 V motor draws 12.0 A when a motor is operating at full speed. If the armature of this motor has a resistance of 6.0 Ω, what is

a) The current when the motor is initially turned on (remember no back emf)?

b) The back EMF when the armature reaches its full operating speed?

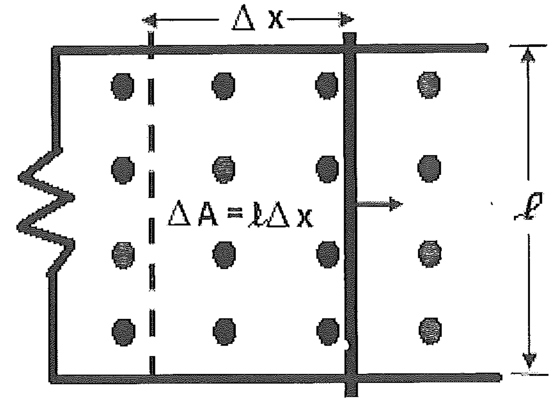
**Example 3:** A 120 V motor draws 3.50 A when it reaches its full operating speed. If it draws 15.0 A when it is initially turned on, what is,

a) The resistance of the armature?

b) The back EMF when it reaches its full operating speed?

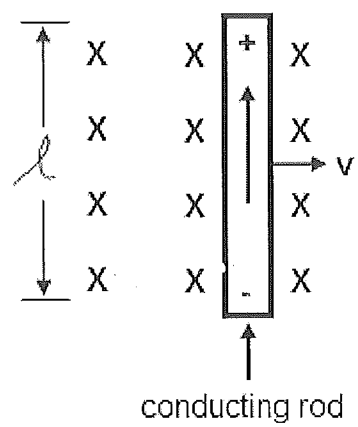
**<u>Induced EMF on a Straight Conductor</u>** - As we have seen, it is not only a loop of wire that is rotated in a magnetic field that produces an induced EMF. A straight conductor that is moved through a magnetic field will also induced an EMF.

**<u>Method One:</u>**



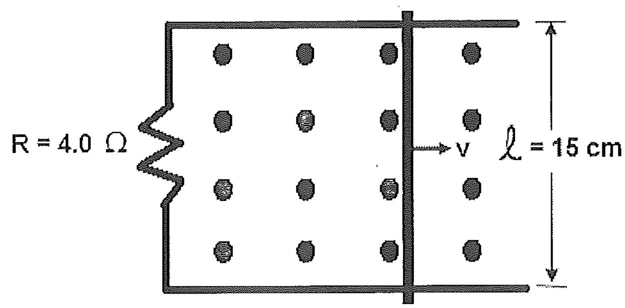

$\Delta A = \ell \Delta x$

**<u>Method Two:</u>**



**Example 1:** A conducting rod 25.0 cm long moves perpendicular to a magnetic field (B=0.20T) at a speed of 1.0 m/s. Calculate the induced EMF in the rod.

**Example 2:** The conducting rod in the diagram below is 15 cm long and is moving at a speed of 2.0 m/s perpendicularly to a 0.30 T magnetic field. If the resistance in the circuit is 4.0 Ω, what is the magnitude and direction of the current through the circuit?



Lesson 5 homework

**Back EMF and Motional EMF Problems:**

1. A DC motor is connected to a 120 V power supply and draws a current of 12 A when it first starts up. At its normal operating speed, the motor draws a current of 3.0 A.

a) Find the resistance of the motor's armature. (10Ω)

b) Find the back EMF when the motor first starts up. (0V)

c) Find the back EMF when the motor is running at normal. (90V)

2. A motor is connected to a 12.0 V power supply and develops a back EMF of 3.2 V when rotating at normal speed. When the armature is prevented from rotating, the current is 3.0 A.

a) Find the resistance of the armature. (4.0 Ω)

b) Find the current in the motor at its normal speed. (2.2 A)

3. A 120 V motor draws 9.0 A when it reaches full operating speed. If the resistance of the armature is 5.0 Ω, what is the

a) back EMF when the motor is operating at full speed? (75 V)

b) back EMF when the motor is initially turned on? (0 V)

c) current when the motor is initially turned on? (24 V)

4. The armature of a 120 V motor slows down because of an increased load (for example, an electric lawnmower enters thick, tall grass). The resistance of the armature is 6.0 Ω, and the current drawn by the motor when operating at full speed is 3.6 A. The current drawn by the motor when the increased load is applied is 8.4 A.

a) Explain why the motor (armature) gets hotter when the increased load slows it down.

b) Explain why the current through the armature increases when the load is increased.

c) What is the back EMF when the motor is

i. operating at full speed (98.4 V)

ii. slowed down because of the increased load (70 V)

5. The current drawn by a 120 V motor when the motor is turned on is 10.0 A and 3.0 A when it is at its full speed.

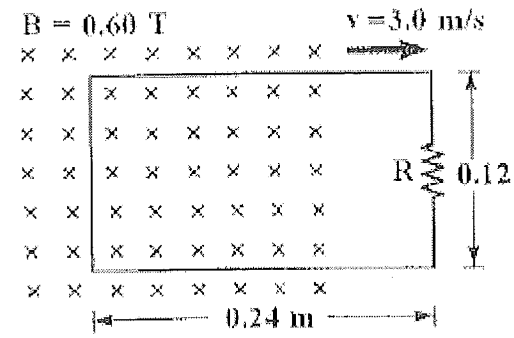
a) What is the resistance of the armature? (12Ω)

b) What is the back EMF when the motor is operating at full speed? (84 V)

6. A single rectangular loop of wire connected to a resistor R is pulled out of a magnetic field of 0.60 T at 3.0 m/s as shown in the diagram.

a) Find the EMF induced in the loop. (0.216 V)

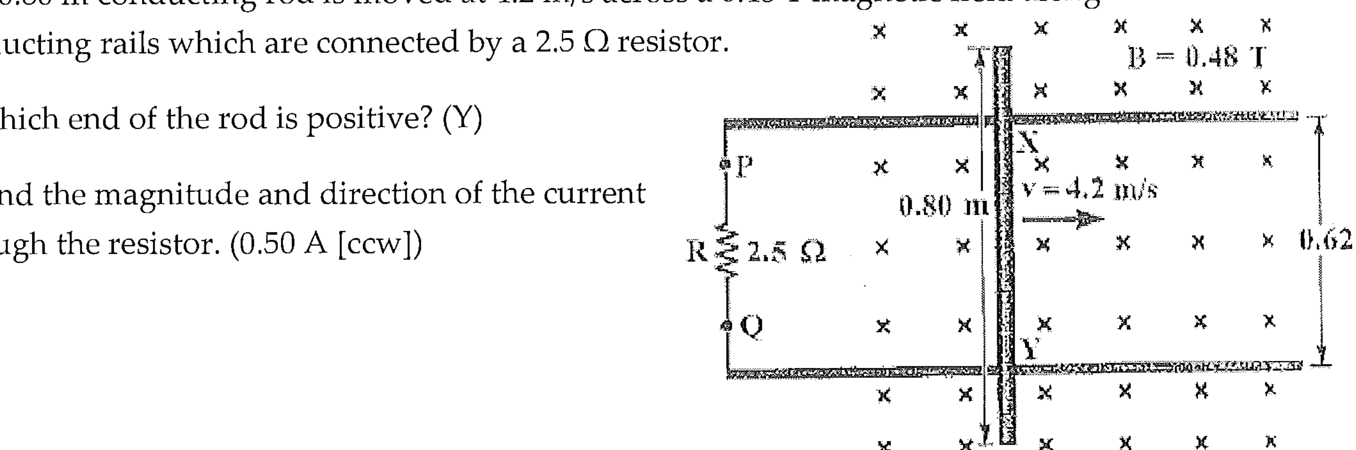
b) If the resistor has a resistance of 0.40 Ω, find the magnitude and direction of the current in the loop. (0.54A [cw])



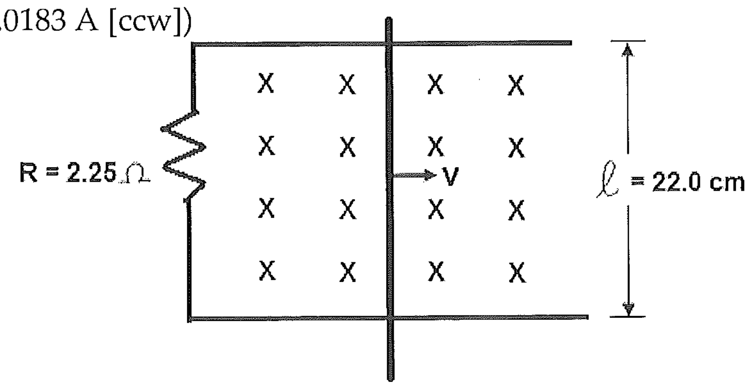

7. A 0.80 m conducting rod is moved at 4.2 m/s across a 0.48 T magnetic field along conducting rails which are connected by a 2.5 Ω resistor.

a) Which end of the rod is positive? (Y)

b) Find the magnitude and direction of the current through the resistor. (0.50 A [ccw])



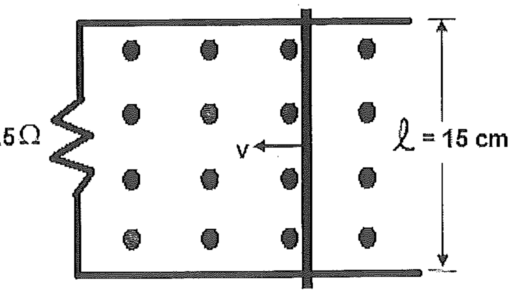

8. A conducting rod is 22.0 cm long. It is moving at a speed of 1.25 m/s perpendicular to a 0.150 T magnetic field. If the resistance in the circuit is 2.25 Ω, what is the magnitude and direction of the current through the circuit? (0.0183 A [ccw])



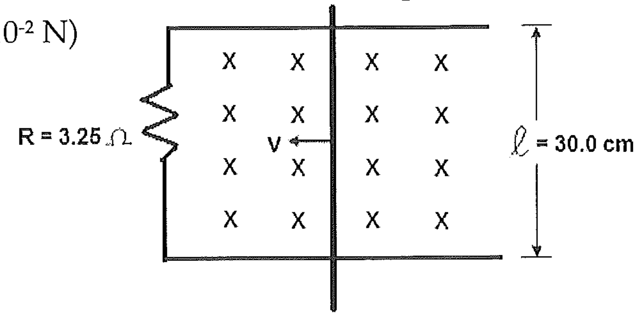
9. The conducting rod in the diagram below is 15 cm long and is moving at a speed of 0.95 m/s perpendicular to the magnetic field. If the resistance in the circuit is 1.5 Ω and a current of 5.6 x $10^{-2}$ A is induced in the circuit,

a) What is the magnitude of the magnetic field? (0.589 T)

b) What is the direction of the induced current? )[ccw])

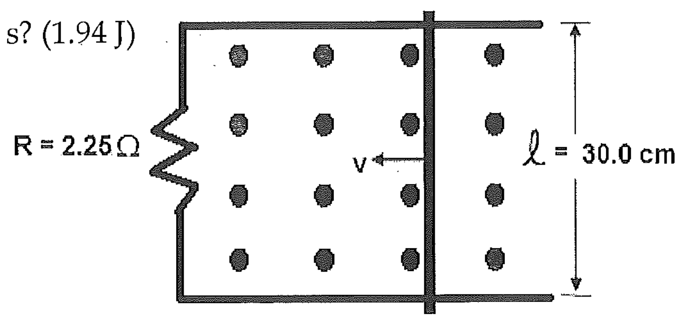



10. The conducting rod in the diagram is 30.0 cm long and is moved perpendicular to a 0.950 T magnetic field. If the resistance in the circuit is 3.25 Ω, what force is required to move the rod at a constant speed of 1.50 m/s? (3.76 x $10^{-2}$ N)

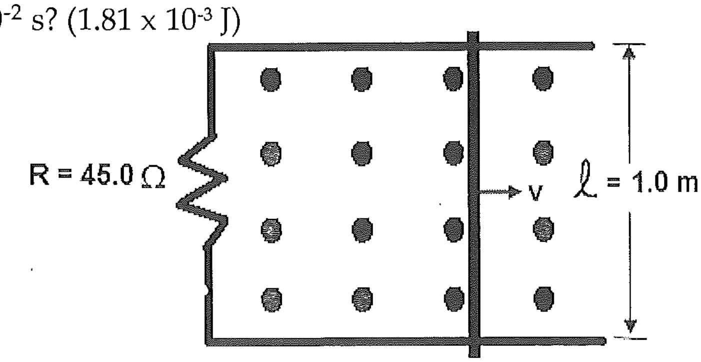



11. A plane with wing span of 6.25 m is flying horizontally at a speed of 95.0 m/s. Given that the vertical component of Earth's magnetic field is 4.70 x $10^{-6}$ T, what is the induced EMF between the tips of the wings? (2.79 x $10^{-3}$ V)

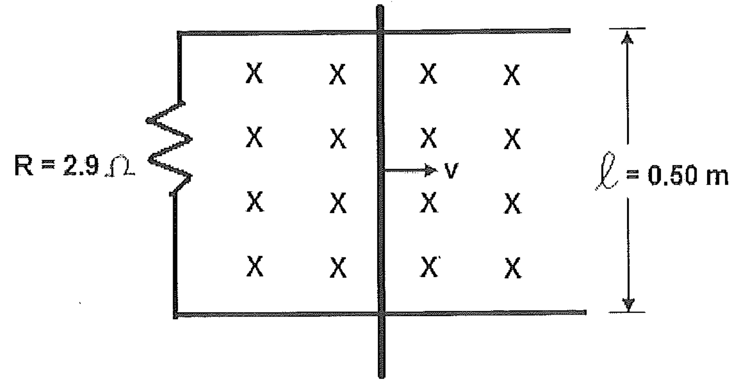
12. The conducting rod in the diagram below is 30.0 cm long and is moving at a speed of 3.00 m/s perpendicular to a 0.600 T magnetic field. If the resistance in the circuit is 2.25 Ω, what is the electric energy dissipated in the resistor in 15.0 s? (1.94 J)




13. The conducting rod in the diagram is 1.0 m long. It is moved at a speed of 3.0 m/s perpendicular to a 0.95 T magnetic field. If the resistance in the circuit is 45.0 Ω, how much work is done against the magnetic field in 1.0 x $10^{-2}$ s? (1.81 x $10^{-3}$ J)



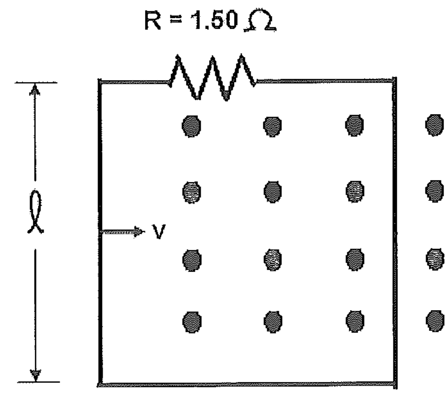
14. The conducting rod in the diagram is 0.50 m long. It is moved at a constant speed perpendicular to a 0.65 T magnetic field. If the resistance in the circuit is 2.9 Ω and the induced current is $5.2 \times 10^{-2}$ A, what is the speed of conducting rod? (0.464 m/s)




15. A rectangular piece of wire is moved at a speed of 1.80 m/s perpendicular to a 1.30 T magnetic field, as shown in the diagram. If the length of the side moving perpendicular to the field is 0.625 m and the resistance in the circuit is 1.50 Ω,

a) What is the induced current? (0.975 A)

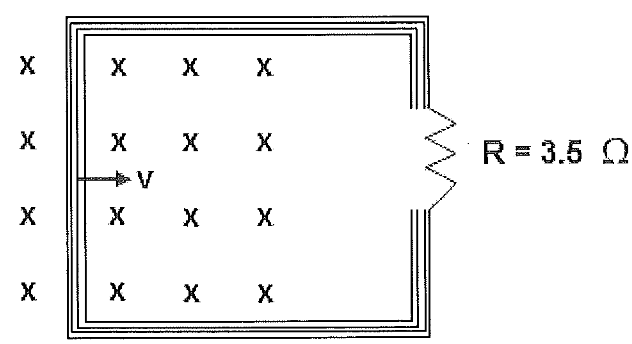
b) What is the direction of the current? ([ccw])




16. A rectangular piece of wire wound 5 times is moved at a speed of 2.7 m/s perpendicular to a 1.1 T magnetic field as shown below. If the length of the side of the wire moving perpendicular to the field is 0.18 m and the resistance in the circuit is 3.5 Ω,

a) What is the induced current? (0.764 A)

b) What is the direction of the current? ([cw])

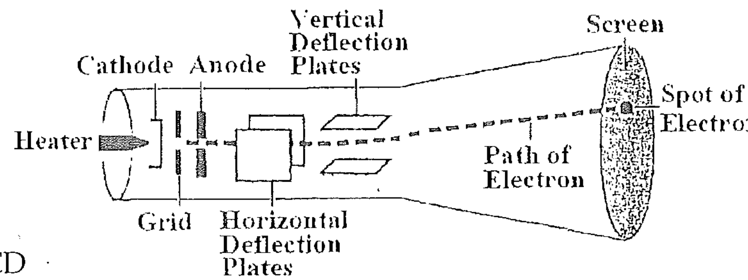


Lesson 6

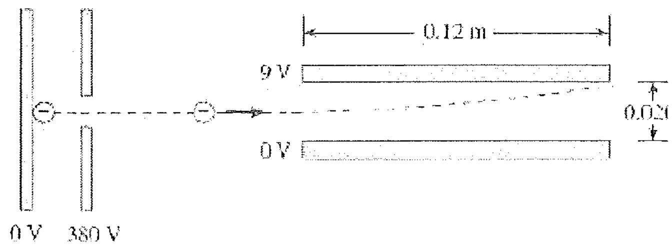
Physics 12 – **Applications of Electromagnetism**

## Cathode Ray Tube (CRT)

A cathode ray tube is a vacuum tube in which a beam of electrons is accelerated, deflected and displayed on a fluorescent screen. Cathode ray tubes are used in oscilloscopes, televisions and computer monitors. We are moving away from this as we develop new technologies such as LCD monitors.




**Example:** A beam of electrons is directed to a region between oppositely charged parallel plates as shown in the diagram.




a) The electron beam is produced by accelerating electrons through an electric potential difference of 380V. What is the speed of the electrons as they leave the 380 V plate?

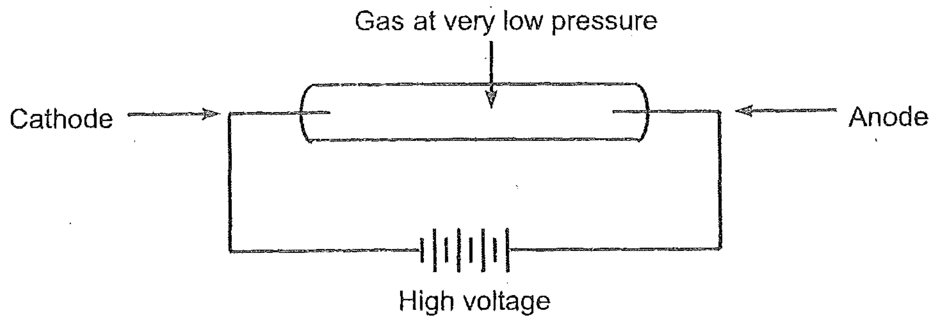
b) What is the electrostatic force on electrons in the region between the deflecting horizontal plates when they are connected to a 9.0 V potential difference?

c) What is the acceleration of the electrons between the deflecting plates?

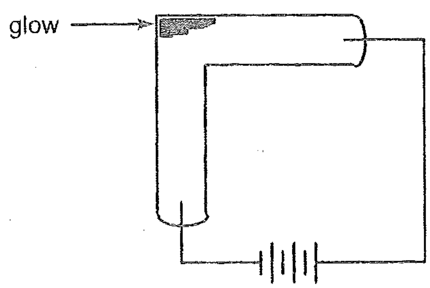
d) What is the final magnitude and direction of the velocity of the electrons as it leaves the second set of plates?

## Cathode Rays:

In the late 1800s, the electron was discovered by J.J. Thomson, who was deflecting fast-moving electrons in a magnetic field. This was done to investigate an electric spark gap in a vacuum or in gases at very low pressure.



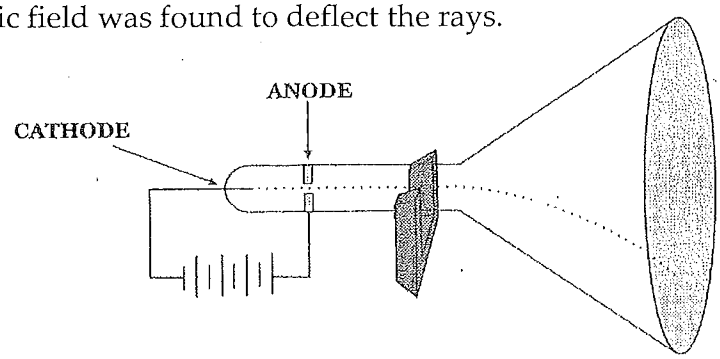

The term cathode ray is used because it was determined the discharge that was observed originated at the negative electrode (the cathode) as the tube glowed with greater intensity opposite the cathode.




J.J. Thomson determined that cathode rays were particles and these particles became known as electrons.

## The Thomson Experiment:

In Thompson's experiment in the late 1800s, cathode rays were passed through a magnetic field. The magnetic field was found to deflect the rays.




The anode is a circular disk with a hole in it. The electrons are accelerated between the cathode and the anode (this is referred to the electron gun or accelerator). Under high voltage, the electrons have a high kinetic energy when they reach the anode.

The beam of high speed electrons then pass through the hole in the anode. Once through the hole, they then pass through a magnetic field.

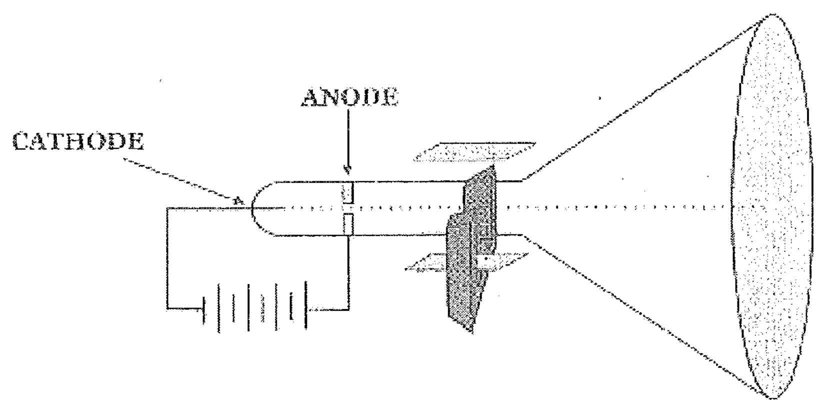
The electrons may be deflected up or down by the magnetic field. The deflection is in an arc as we learned last lesson. (circular motion due to the $F_M$ on the electron)

So...

It is the q/m that Thomson determined to be the charge-to-mass ratio for an electron. He could easily determine the r and B...but he still did not have the speed, the mass or the charge of the electron. (Remember – this is the discovery of it!)

Next, he adjusted the electrical and magnetic fields in the cathode ray gun so that they were equal, but in opposite directions resulting in no deflection and the electrons travelled in a straight line. Thomson obtained the speed of the electron as a ratio of the field strength.

No deflection
(both a magnetic field and an electric field)




$F_E = F_m \quad q\bar{E} = qvB_\perp \qquad v = \dfrac{\bar{E}}{B_\perp}$

With v, B, and r, he could calculate the charge/mass ratio and **<u>this was the first information about the make-up of an electron.</u>**

**Example One:** Charged particles are travelling horizontally at $3.60 \times 10^6$ m/s when they enter a vertical magnetic field of $7.10 \times 10^{-1}$ T. If the radius of the arc of the deflected particles is $9.50 \times 10^{-2}$, m, what is the charge-to-mass ratio of the particles?

**Example Two**: What is the speed of an electron that passes through an electric field of $6.30 \times 10^3$ N/C and a magnetic field of $7.11 \times 10^{-3}$ T undeflected? Assumed the electric and magnetic fields are perpendicular to each other.

**Example Three:** An electron travelling vertically enters a horizontal magnetic field of $7.20 \times 10^{-2}$ T. If the electron is deflected in an arc of radius $3.70 \times 10^{-3}$ m, what is the kinetic energy of the electron?

Lesson 6 homework:

**Applications of Electromagnetism – CRT Problems:**

1. An alpha particle travels through a magnetic field of $4.22 \times 10^{-1}$ T perpendicular to the field. If the radius of the arc of the deflected particles is $1.50 \times 10^{-3}$ m, what is the speed of the particles? ($3.05 \times 10^{4}$ m/s)

2. A proton travels through a magnetic field at a speed of $5.40 \times 10^{5}$ m/s perpendicular to the field. If the radius of the arc of the deflected proton is $7.20 \times 10^{-3}$ m, what is the magnetic field strength? (0.783 T)

3. Calculate the charge-to-mass ratio of a particle that is travelling $3.60 \times 10^{5}$ m/s and is deflected in an arc with a radius of $7.40 \times 10^{-2}$ m as it travels through a perpendicular magnetic field of $6.10 \times 10^{-1}$ T. ($7.98 \times 10^{6}$ C/kg)

4. Alpha particles travel undeflected through magnetic electric fields that are perpendicular to each other. The speed of the alpha particles is $7.80 \times 10^{5}$ m/s and the strength of the magnetic field is $2.20 \times 10^{-1}$ T. If it is assumed that the alpha particles are traveling perpendicular to these fields, what is the strength of the electric field? ($1.72 \times 10^{5}$ N/C)

5. Positive charged particles travel undeflected through magnetic and electric fields that are perpendicular to each other. The magnetic field strength is $6.50 \times 10^{-1}$ T and the strength of the electric field is $2.10 \times 10^{5}$ N/C. If it is assumed the charged particles are travelling perpendicular to these fields, what is the speed of the particles? ($3.23 \times 10^{5}$ m/s)

6. Alpha particles travel through a magnetic field of $3.60 \times 10^{-1}$ T and are deflected in an arc with a radius of $8.20 \times 10^{-2}$ m. If it is assumed that the alpha particles are travelling perpendicular to the field, what is the energy of each alpha particle? ($6.71 \times 10^{-15}$ J)

7. In a CRT (cathode ray tube), electrons are accelerated from rest by a potential difference of $2.50 \times 10^{3}$ V. What is the maximum speed of the electrons? ($2.96 \times 10^{7}$ m/s)

8. In a CRT, an electron reaches a maximum speed of $4.75 \times 10^{7}$ m/s. If this electron is accelerated from rest, what is the potential difference across the tube? (6423 V)

9. In a CRT, electrons are accelerated from rest by a potential difference of $1.40 \times 10^3$ V. These electrons enter a magnetic field with a strength of $2.20 \times 10^{-2}$ T. If it is assumed that the electrons are travelling perpendicular to the field, what is the radius of the arc of the deflected electrons? ($5.75 \times 10^{-3}$ m)

10. Electrons are accelerated from rest in a CRT. These electrons now pass through a magnetic field of $1.40 \times 10^{-2}$ T and through an electric field of $4.20 \times 10^5$ N/C. The fields are perpendicular to each other, and the electrons are not deflected. If it is assumed the electrons are travelling perpendicular to these fields, what is the potential difference across the CRT? (2562 V)

11. A negatively charged particle with a mass of $8.4 \times 10^{-27}$ kg is travelling at a velocity of $5.6 \times 10^5$ m/s perpendicularly through a magnetic field of $2.8 \times 10^{-1}$ T. If the radius of the path of the particle is 3.5 cm, how many excess electrons does this particle carry? (3 electrons)

12. Alpha particles travel at a speed of $3.00 \times 10^6$ m/s through a magnetic field. If the magnetic field strength is $4.2 \times 10^{-2}$ T, what is the radius of the path followed by the alpha particles when the magnetic field is parallel to the direction the alpha particles travel? ($\infty$)

13. A proton moves through a 0.75 T magnetic field in a circle with a radius of 0.30 m. What is the momentum of this proton? ($3.6 \times 10^{-20}$ kg•m/s)

14. Electrons are accelerated from rest through a potential difference. These electrons are then deflected along an arc of radius 0.77 m when they travel through a $2.2 \times 10^{-4}$ T magnetic field. What is the accelerating voltage? (2528 V – NOTE: will be slightly different depending on rounding)

15. An ion with a charge to mass ratio of $1.10 \times 10^{4}$ C/kg travels perpendicular to a magnetic field ($B = 9.10 \times 10^{-1}$ T) in a circular path ($r = 0.240$ m). How long does it take the ion to complete one revolution? ($6.28 \times 10^{-4}$ s)

Lesson 7



Physics 12

## ADDITIONAL PROBLEMS – MAGNETIC FORCES AND FIELDS

1. What is the magnitude and direction of a magnetic field that produces a downward force of $7.30 \times 10^{-13}$ N on a proton that is moving east through the field at a speed of $7.80 \times 10^{4}$ m/s?

(5.85 × $10^{1}$ T south)

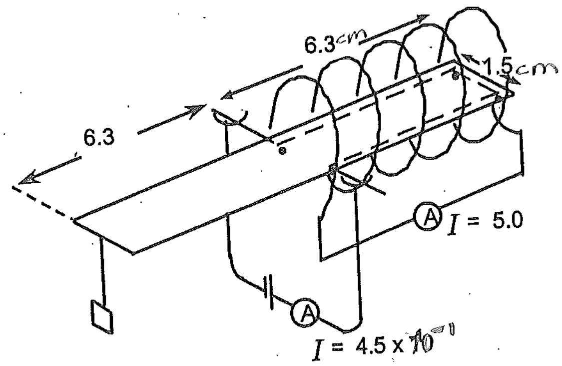
2. Calculate the magnitude and the direction of the magnetic force on an electron travelling west at a speed of $7.22 \times 10^{5}$ m/s through a vertically downward magnetic field of $3.80 \times 10^{-1}$ T.

(4.39 × $10^{-14}$ N north)

3. An alpha particle is accelerated by a potential difference and then travels perpendicular to a magnetic field of $5.50 \times 10^{-1}$ T where it experiences a magnetic force of $6.20 \times 10^{-14}$ N. Assuming this alpha particle starts from rest, through what potential difference is it accelerated?

(1.29 × $10^{3}$ V)

4. A current balance is used to determine the magnetic field intensity in the core of a solenoid. The current balance and the solenoid are described in the diagram.




If the current balance is balanced with a $2.3 \times 10^{-5}$ kg mass, what is the magnetic field strength in the solenoid core?

($3.3 \times 10^{-2}$ T)

5. Calculate the downward acceleration on a proton that is moving horizontally at a speed of $7.50 \times 10^5$ m/s perpendicular to a horizontal magnetic field of $2.70 \times 10^{-1}$ T.

($1.94 \times 10^{13}$ m/s$^2$)

6. A transformer is used to deliver power to a 6.0 V door bell from a $1.20 \times 10^2$ V household power line. If the door bell draws current of 0.20 A, what is the power through the primary coil?

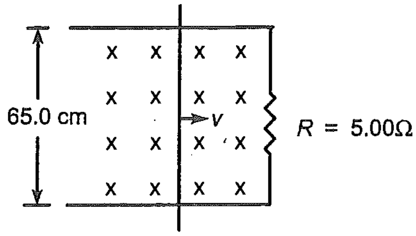
(1.2 W)

7. An electrical substation transformer reduces the voltage from $2.4 \times 10^5$ V to $3.6 \times 10^3$ V. If a current of $4.0 \times 10^2$ A flows through the $3.6 \times 10^3$ V line, what is the power delivered to the transformer by the $2.4 \times 10^5$ V line?

($1.4 \times 10^6$ W)

8. A transformer is used to deliver 9.0 V to a "walkman". If the primary coil has $4.4 \times 10^2$ turns and is connected to a $1.20 \times 10^2$ V household circuit, how many turns are there on the secondary coil?

**9.** The conducting rod in the diagram below is 65.0 cm long and is moving at a speed of 1.10 m/s perpendicular to the magnetic field.




If the resistance in the circuit is 5.00 Ω, and a current of $2.90 \times 10^{-2}$ A is induced in the circuit,

**a)** what is the magnitude of the magnetic field?

(0.203 T)

**b)** what is the direction of the induced current?

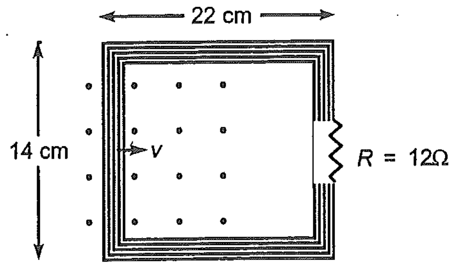
(clockwise)

**10.** A conductor ($l$ = 0.75 m) carries conventional current ($I$ = 2.0 A) vertically downward through a magnetic field ($B = 2.7 \times 10^{-3}$ T) that is directed south. What is the magnitude and the direction of the magnetic force acting on the conductor?

($4.1 \times 10^{-3}$ N West)

**11.** A rectangular coil of wire containing 11 loops is moved at a speed of 1.8 m/s perpendicular to a 0.88 T magnetic field as shown below:




If the length of the sides are as indicated in the diagram, and the resistance in the circuit is 12Ω,

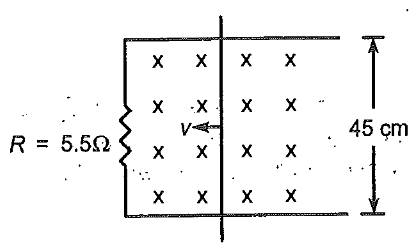
**a)** what is the induced current?

(0.20 A)

**b)** what is the direction of the current?

(counterclockwise)

**12.** The conducting rod in the diagram below is 45 cm long, and is moved at a constant speed perpendicular to a 1.5 T magnetic field.



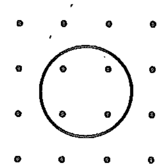

If the resistance in the circuit is 5.5 Ω, and the induced current is $7.5 \times 10^{-2}$ A, what is the speed of the conducting rod?

(0.61 m/s)

13. A conductor ($l$ = 0.250 m) experiences a magnetic force of $2.25 \times 10^{-3}$ N downward when it carries a conventional current ($I$ = 3.50 A) east through a perpendicular magnetic field. What is the magnitude and direction of the magnetic field?

($2.57 \times 10^{-3}$ T South)

14. A circular loop of wire, (radius = 2.5 cm) is placed in a magnetic field ($B$ = 0.010 T) as shown in the diagram



This field is then increased to 0.025 T in 0.10 s.

**a)** What is the average emf induced in the loop?

($2.9 \times 10^{-4}$ V)

**b)** What is the direction of the current through the loop?

(clockwise)

**15.** A 120 V motor draws 1.50 A when it reaches its full operating speed. If it draws 10.0 A when it is initially turned on, find

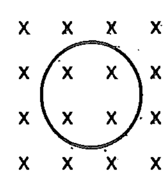
**a)** the resistance of the armature.

(12.0 Ω)

**b)** the back emf when it reaches its full operating speed.

(102 V)

**16.** A circular loop of wire as shown in the diagram (area = $6.2 \times 10^{-3}$ m$^2$) has a resistance of 2.0 Ω.




Assume that the magnetic field drops uniformly from 1.4 T to zero in 0.020 s.

**a)** What is the average emf induced in the loop?

(0.43 V)

**b)** What is the induced current in the loop?

(0.22 A)

**c)** What is the direction of the electron flow in the loop?

(counterclockwise)

**17.** A coil (80 turns, diameter of 0.020 m) is placed between the poles of an electromagnet ($B = 0.75$ T). If the plane of the coil is perpendicular to the magnetic field and the magnetic field is reduced steadily from 0.75 T to zero in 9.0 s, what is the average emf induced in the coil?

($2.1 \times 10^{-3}$ V)

**18.** A 120 V motor draws 20.0 A when the motor is operating at full speed. If the armature of this motor has a resistance of 5.0 Ω, find

**a)** the current when the motor is initially turned on.

(24 A)

**b)** the back emf when the armature reaches its full operating speed.

(20 V)

19. A 120 V motor has an armature resistance of 6.5 Ω and draws 5.0 A when it is operating at full speed.

**a)** What is the current when the motor is initially turned on?

(18 A)

**b)** What is the back emf when it is operating at full speed?

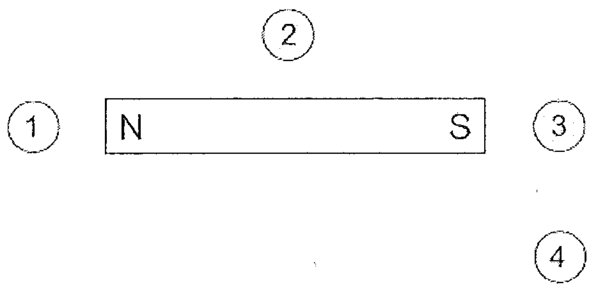
(88 V)

* * * * * * * * * *

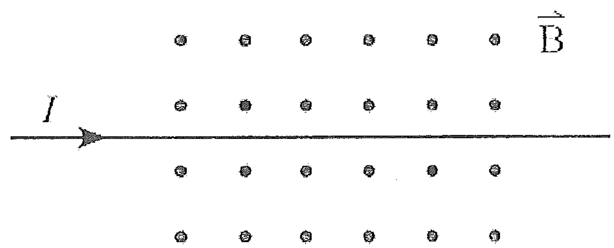
Lesson 8/9

Physics 12 – **Electromagnetism Unit Review**

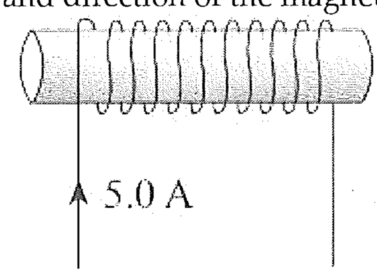
1. A compass is positioned at each of the following locations near a bar magnet. In which location will the compass needle point to the right-hand side of the page?
   a. 1
   b. 2
   c. 3
   d. 4




2. A current carrying conductor is placed in a uniform magnetic field as shown. What is the direction of the magnetic force on this conductor?
   a. Into the page
   b. Out of the page
   c. Towards the top of the page
   d. Towards the bottom of the page



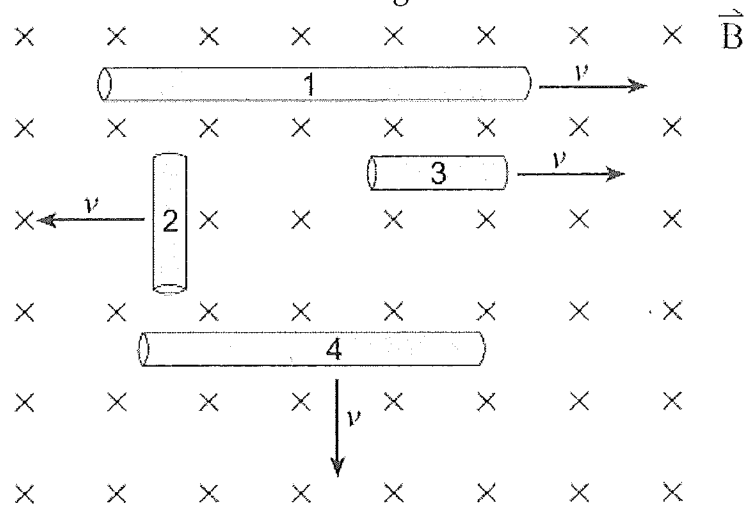

3. A 5.0 A current is flowing through a 0.20 m long solenoid that contains 1500 loops. What are the magnitude and direction of the magnetic field in the center of the solenoid?




| | MAGNITUDE | DIRECTION |
|---|---|---|
| A. | $9.4\times10^{-3}$ T | left |
| B. | $9.4\times10^{-3}$ T | right |
| C. | $4.7\times10^{-2}$ T | left |
| D. | $4.7\times10^{-2}$ T | right |

4. Four conductors of different lengths are moved through a uniform magnetic field at the same speed. Which conductor will induce the greatest EMF?

   a. 1
   b. 2
   c. 3
   d. 4




5. A motor has an armature resistance of 3.5 Ω and is connected to a 12.0 v source. At full speed the current through the armature is 0.18 A. What is the back EMF at full speed?

   a. 0 V
   b. 0.63 V
   c. 11.4 V
   d. 12.0 V

6. A **step-down** transformer has a 500 turn primary that operates at 120 V AC. Which of the following sets of conditions best describes the number of secondary turns and secondary voltage of this transformer?

| | SECONDARY TURNS | SECONDARY VOLTAGE |
|---|---|---|
| A. | 40 | 9.6 V ac |
| B. | 40 | 1 500 V ac |
| C. | 2 000 | 30 V ac |
| D. | 2 000 | 480 V ac |

7. A flexible loop of wire of area $4.5 \times 10^{-2}$ $m^2$ is positioned in a 0.17 T magnetic field as shown in Figure A. The loop is then stretched until its area is zero in a time of 0.35 s (Figure B). What is the average induced EMF in the circuit and the direction of the current through resistor R?

Figure A

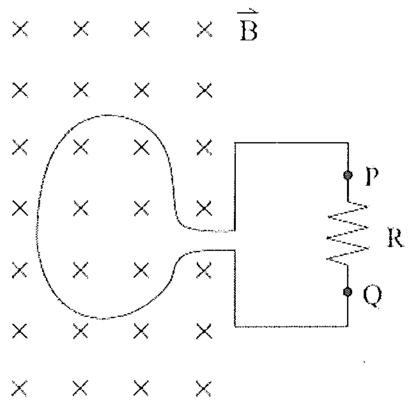
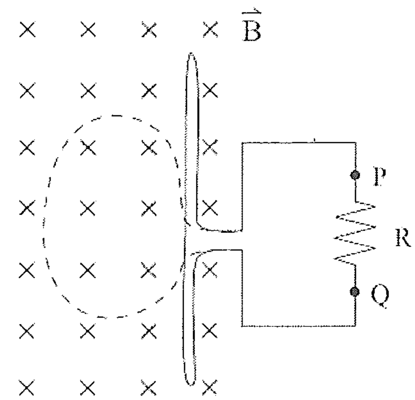
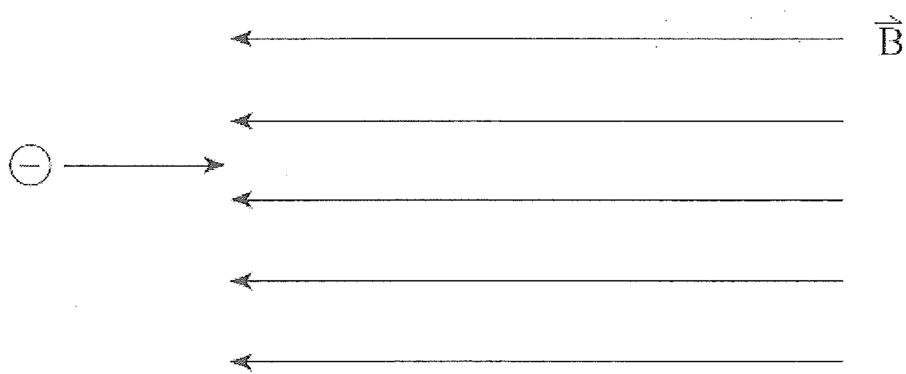



Figure B




| | AVERAGE EMF | DIRECTION OF CURRENT THROUGH R |
|---|---|---|
| A. | $2.2 \times 10^{-2}$ V | P to Q |
| B. | $2.2 \times 10^{-2}$ V | Q to P |
| C. | $4.9 \times 10^{-1}$ V | P to Q |
| D. | $4.9 \times 10^{-1}$ V | Q to P |

8. An electron enters a uniform magnetic field as shown below.




The path of the electron upon entering the field would be

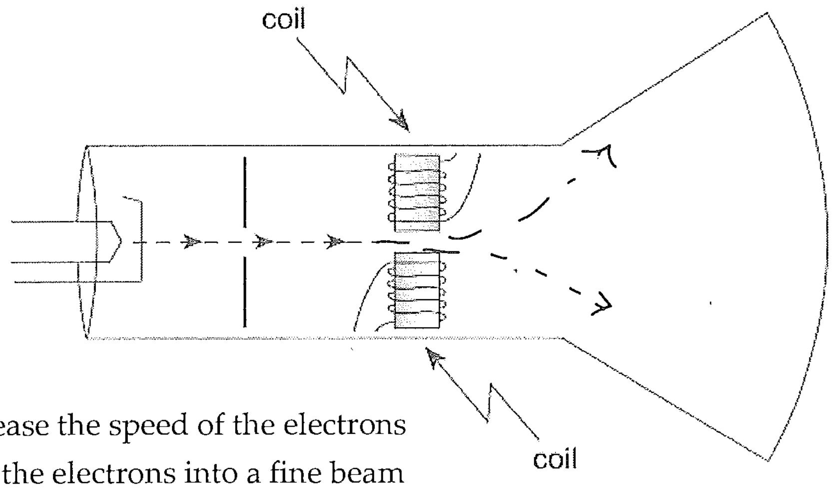
a. Linear

b. Circular

c. Parabolic

d. Hyperbolic

9. The diagram below represents a cross-sectional view from the side of a cathode ray tube. What is the purpose of the coils in a functional cathode ray tube?



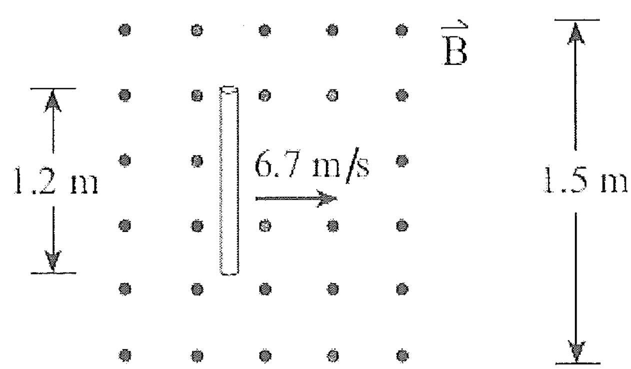

a. They increase the speed of the electrons
b. The focus the electrons into a fine beam
c. They deflect the electrons into or out of the page
d. They deflect the electrons toward the top or bottom of the page

10. A solenoid of length 0.35 m and a diameter of 0.040 m carries a current of 5.0 A through its windings. If the magnetic field in the center of the solenoid is $2.8 \times 10^{-2}$ T, what is the number of turns per meter for this solenoid?

a. $1.8 \times 10^2$ turns/m
b. $7.8 \times 10^2$ turns/m
c. $1.6 \times 10^2$ turns/m
d. $4.5 \times 10^2$ turns/m

11. A 1.2 m length of wire is pulled through a uniform 0.045 T magnetic field at 6.7 m/s as shown. What EMF is generated between the ends of the wire?

a. 0 V
b. 0.090 V
c. 0.36 V
d. 0.45 V

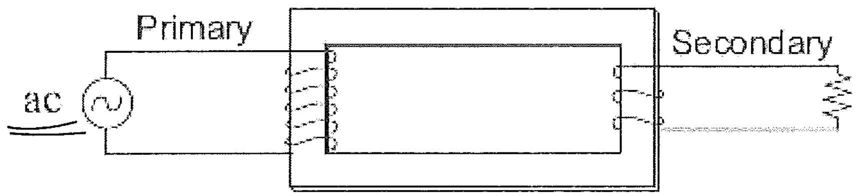


12. A DC motor is connected to a 12.0 V power supply. When the armature is rotating, the current through it is 0.78 A and the back EMF is 10.6 V. What is the resistance of the armature?

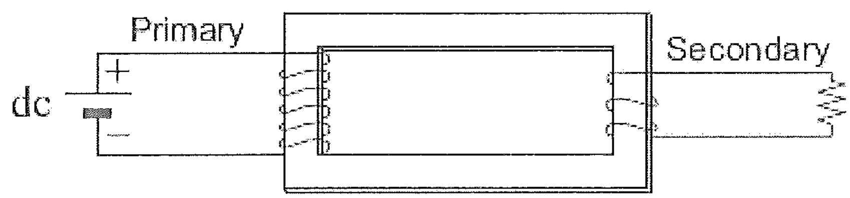
a. 1.4 Ω
b. 1.8 Ω
c. 14 Ω
d. 15 Ω

13. In which of the following diagrams is the secondary **current** greater than the primary **current**?

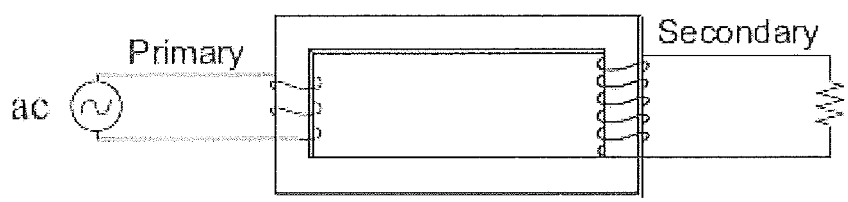
A.



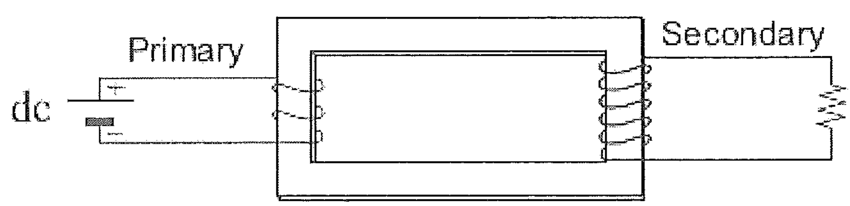

B.



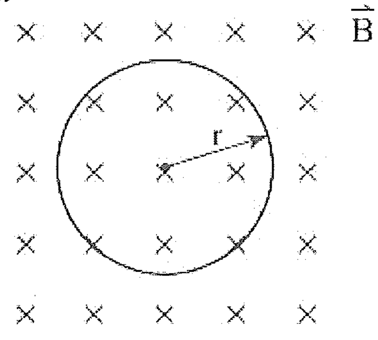

C.




D.



14. An electron circulates in a uniform $5.0 \times 10^{-4}$ T magnetic field as shown. If the electron $3.2 \times 10^{-18}$ J of kinetic energy, what is the radius of orbit, $r$?




a. $2.3 \times 10^{-7}$ m

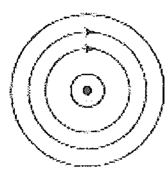
b. $4.6 \times 10^{-4}$ m

c. $2.5 \times 10^{-3}$ m

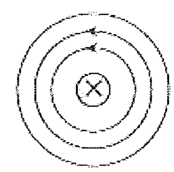
d. $3.0 \times 10^{-2}$ m

15. Which of the following diagrams shown the magnetic field produced by a long current-carrying wire?

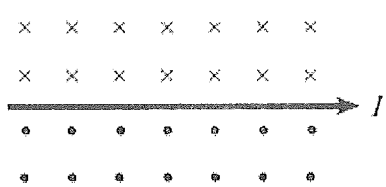
A.



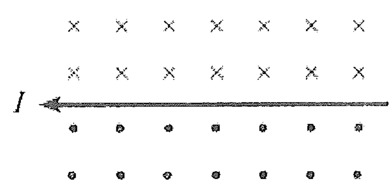
B.



C.




D.




16. Which of the following devices has commonly used a cathode ray tube?

a. Kettle

b. Televisions

c. Battery

d. Incandescent bulb

17. An electric motor is connected to a constant source of potential. Considering back EMF, which of the following observations is correct?

a. At full speed the applied voltage increases

b. At full speed the armature resistance increases

c. If the motor is kept from rotating at full speed, the armature heats up

d. If the motor is kept from rotating at full speed, the armature temperature decreases.

18. Which of the following are correct units for magnetic flux?

a. T

b. Wb

c. V/m

d. N•m$^2$

19. In a step-up transformer, how does the secondary voltage $V_S$ compare with the primary voltage $V_P$, and the number of turns in the secondary $N_S$ compare with the number of turns in the primary $N_P$?

| | VOLTAGE | NUMBER OF TURNS |
|---|---|---|
| A. | $V_s < V_p$ | $N_s > N_p$ |
| B. | $V_s > V_p$ | $N_s > N_p$ |
| C. | $V_s < V_p$ | $N_s < N_p$ |
| D. | $V_s > V_p$ | $N_s < N_p$ |

20. An ideal transformer has a potential difference of 130 V AC across the primary windings and a potential difference of 780 V AC across the secondary windings. There are 390 turns in the secondary. The secondary current is

a. Twice the primary current

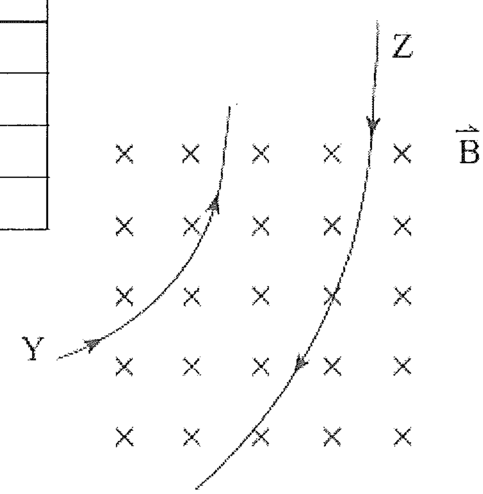
b. One half the primary current

c. Six times the primary current

d. One-sixth the primary current

21. Two particles Y and Z with equal mass and speed enter a uniform magnetic field and follow the paths as shown. How do their magnitude and polarity of charge compare?

| | MAGNITUDE OF CHARGE | POLARITY |
|---|---|---|
| A. | Y < Z | same charge |
| B. | Y < Z | opposite charge |
| C. | Y > Z | same charge |
| D. | Y > Z | opposite charge |



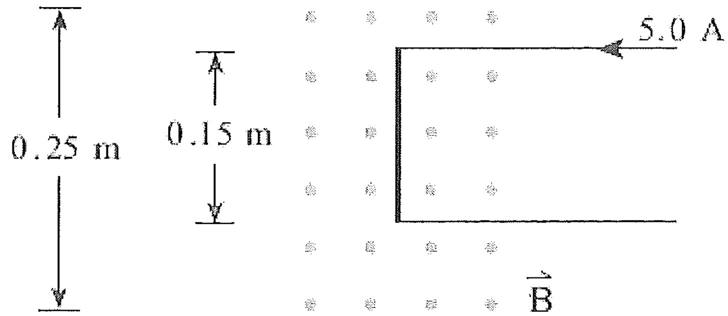
22. A wire carrying a current of 5.0 A is in a uniform $3.2 \times 10^{-2}$ T magnetic field as shown. What is the force on the 0.15 m length of wire?

a. 0 N

b. $1.6 \times 10^{-2}$ N

c. $2.4 \times 10^{-2}$ N

d. $4.0 \times 10^{-2}$ N



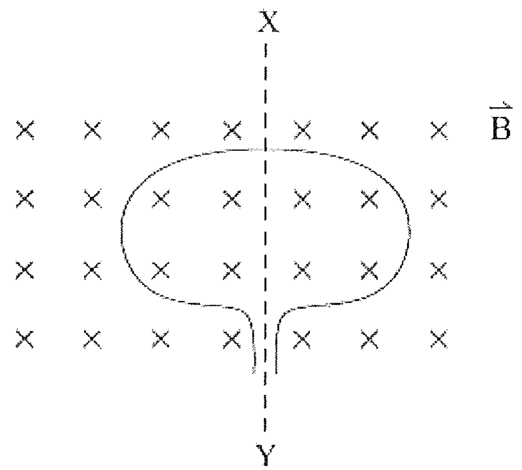

23. A single coil of wire of area $6.0 \times 10^{-3}$ m² is positioned in a uniform 0.18 T magnetic field as shown. The coil is rotated 90° about axis XY in 0.0042 s. What average EMF is induced by the coil?

a. 0 V

b. 0.13 V

c. 0.26 V

d. 43 V



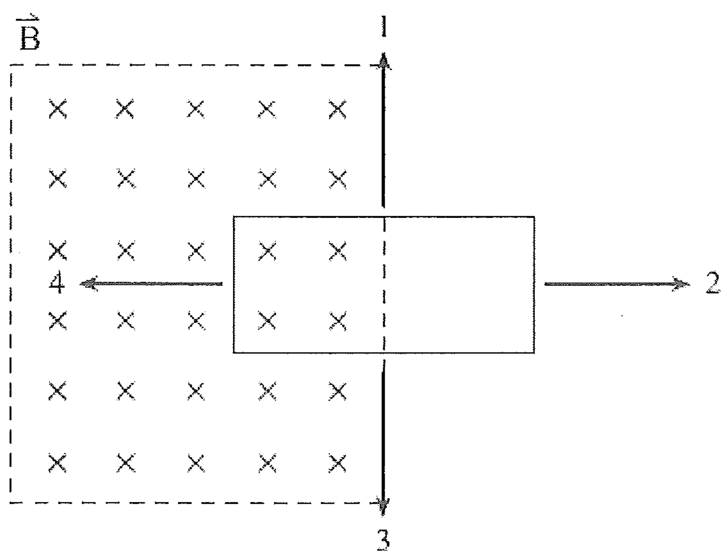

24. A part of a coil of wire is placed in a uniform magnetic field as shown. Which two directions of motion would immediately induce an EMF in the coil?

a. 1 and 2

b. 1 and 3

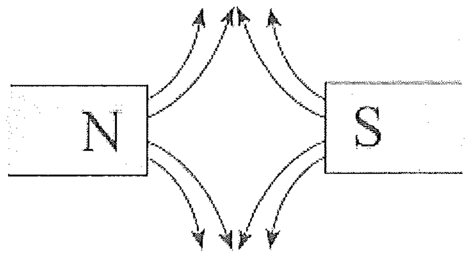
c. 2 and 3

d. 2 and 4

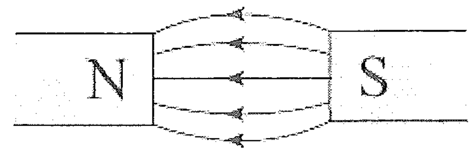


25. Which of the following diagrams best shows the magnetic field lines between the poles of two permanent magnets?

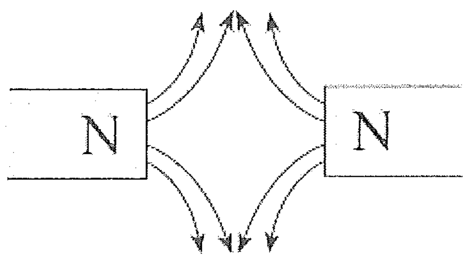
A.



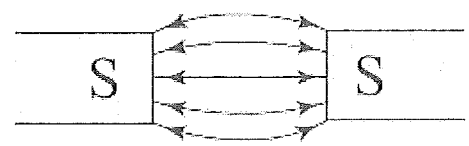

B.



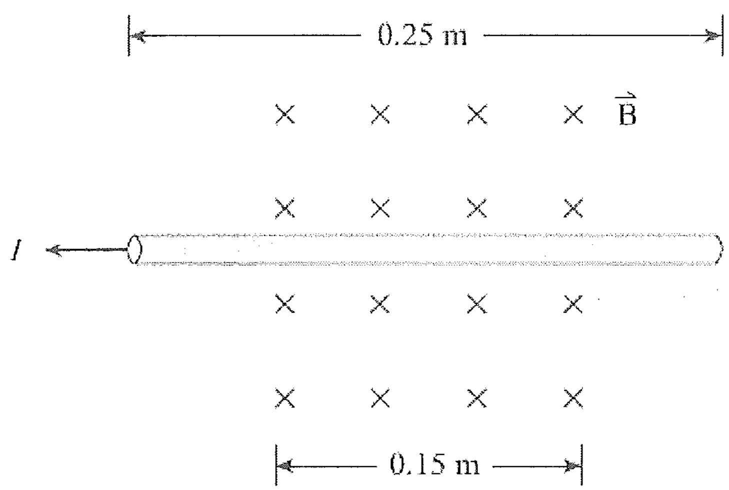

C.




D.




26. A wire carrying 12 A of current is placed in a magnetic field of strength 0.63 T. What are the magnitude and direction of the magnetic force acting on the wire?




| | FORCE | DIRECTION |
|---|---|---|
| A. | 1.1 N | down the page |
| B. | 1.1 N | up the page |
| C. | 1.9 N | down the page |
| D. | 1.9 N | up the page |

27. A particle having a charge of $3.2 \times 10^{-19}$ C follows a circular path of 0.45 m radius while travelling at a speed of $1.2 \times 10^{4}$ m/s in a 0.78 T magnetic field. What is the mass of the particle?

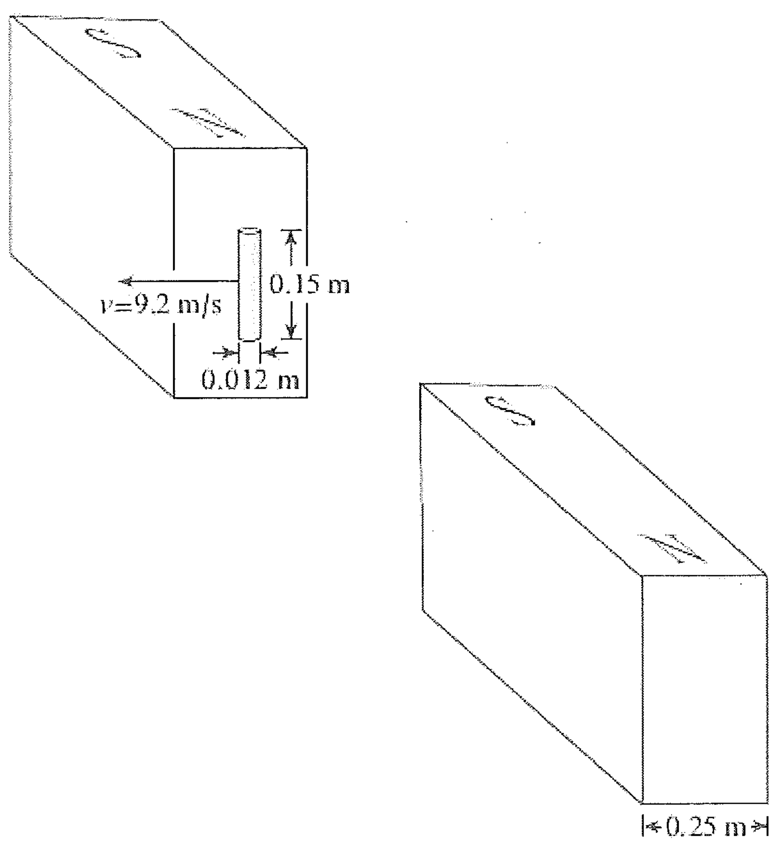
a. $7.8 \times 10^{-28}$ kg
b. $9.4 \times 10^{-24}$ kg
c. $1.1 \times 10^{-19}$ kg
d. $3.0 \times 10^{-15}$ kg

28. A 460-turn solenoid having a diameter of 0.024 m is 0.14 m long. What is the magnetic field at the center of the solenoid when a 13 A current flows through it?

a. 0 T
b. $5.3 \times 10^{-2}$ T
c. $3.1 \times 10^{-1}$ T
d. $6.3 \times 10^{-1}$ T

29. A conducting rod is moving perpendicular to a uniform magnetic field of 0.23 T at a velocity of 9.2 m/s. What EMF is generated during this motion?

a. 0 V
b. 0.025 V
c. 0.32 V
d. 0.53 V



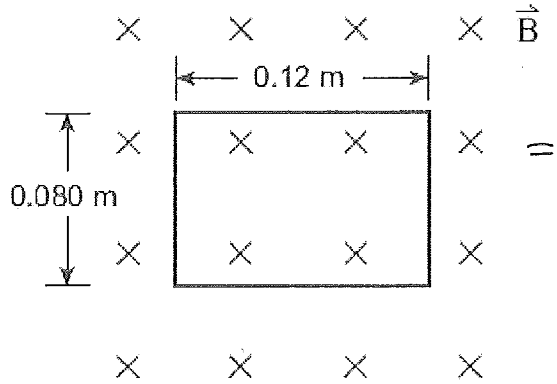
30. A rectangular coil measuring 0.12 m by 0.080 m is placed perpendicular to a 0.85 T magnetic field as shown. What is the magnetic flux through the coil?

a. 0 Wb

b. $8.2 \times 10^{-3}$ Wb

c. $6.8 \times 10^{-2}$ Wb

d. $1.0 \times 10^{-1}$ Wb



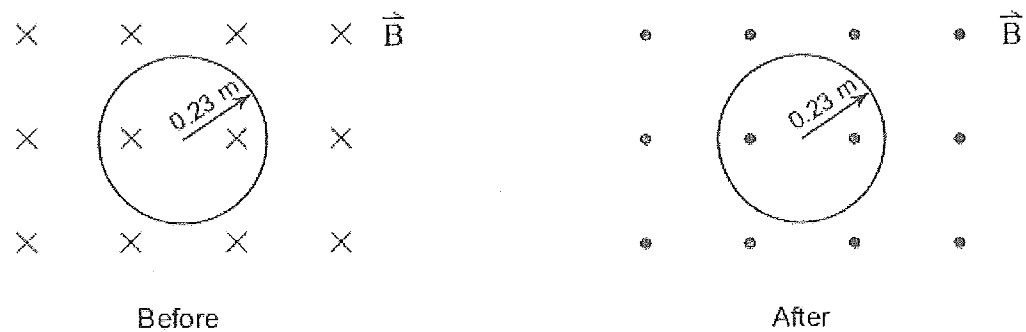

31. A single loop of wire of radius 0.23 m is placed in a single 0.75 T magnetic field as shown. The magnetic field is changed to a strength of 0.50 T in the opposite direction in 0.61 s. What is the average EMF induced in the coil?

a. 0.068 V

b. 0.094 V

c. 0.34 V

d. 0.47 V



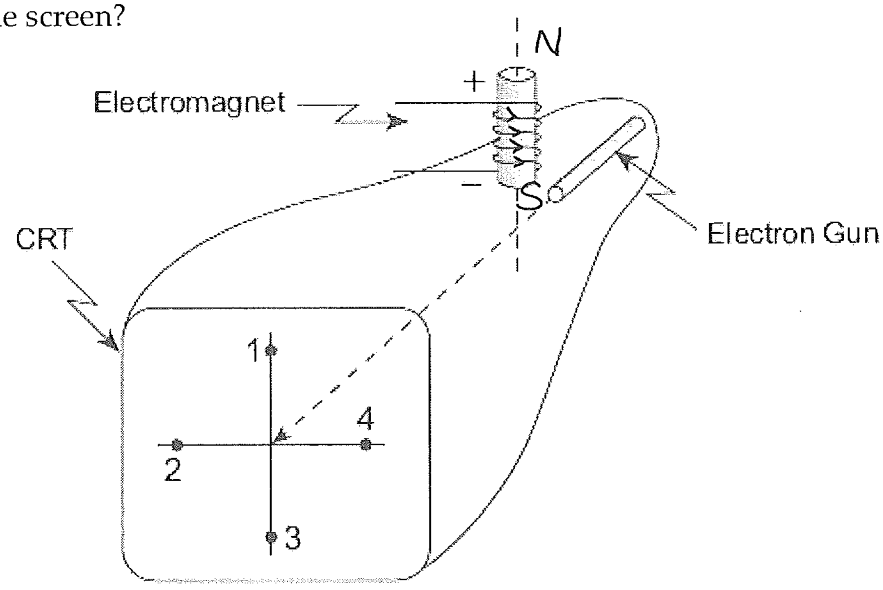

32. With the electromagnet turned off, electrons in the cathode ray tube strike the center of the screen as shown. When the electromagnet is turned on, where will the electron beam now hit the screen?

a. 1

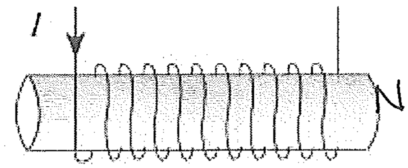
b. 2

c. 3

d. 4

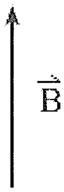


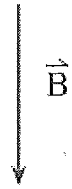
33. An electric current flows through a solenoid as shown below. What is the direction of the magnetic field inside the solenoid?



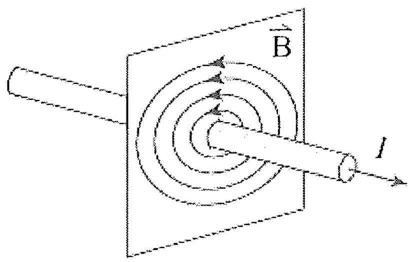

A. 

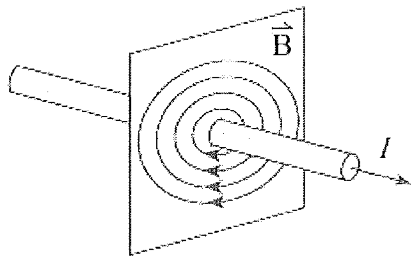

B. 

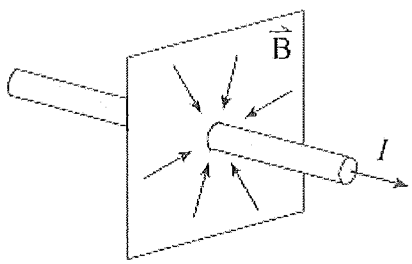

C. 

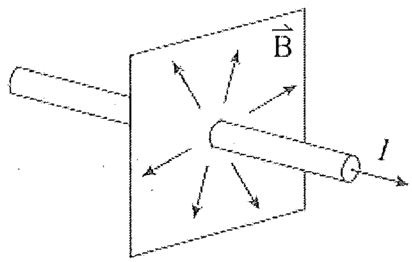

D. 


34. Which of the following diagrams best show the magnetic field due to a long straight wire carrying a conventional current I as shown?

A. 


B. 


C. 


D. 


35. A proton is traveling at $2.3 \times 10^{6}$ m/s in a circular path in a 0.75 T magnetic field. What is the magnitude of the force on the proton?

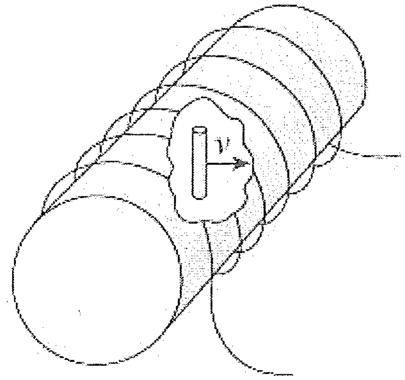
a. $1.6 \times 10^{-24}$ N

b. $2.9 \times 10^{-21}$ N

c. $2.8 \times 10^{-13}$ N

d. 1.7 N

36. A solenoid of length 0.75 m has a radius 0.092 m. A current of 25 A flows through its 4700 turns. Within this solenoid a 0.10 m long conductor moves at 4.3 m/s perpendicular to the field in the solenoid. What EMF is induced between the ends of the conductor?



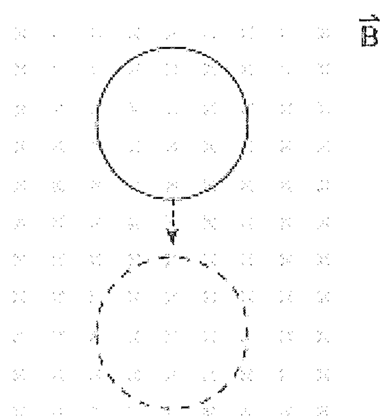

a. 0.085 V

b. 0.197 V

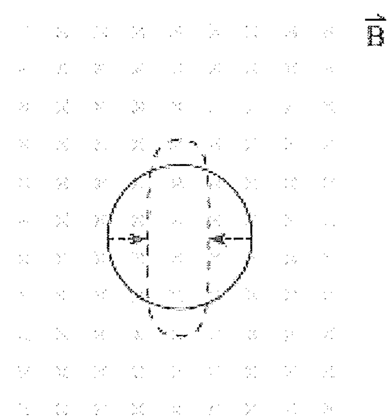
c. 0.430 V

d. 4.80 V

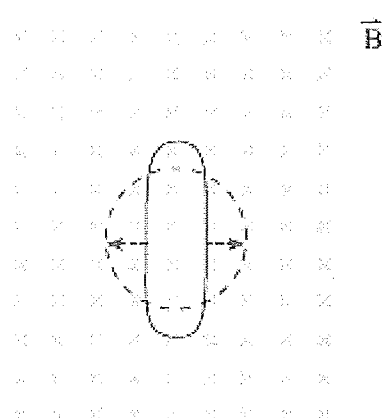
37. In which of the following situations would the greatest EMF be induced in the coil? All changes occur in the same time interval.

A.


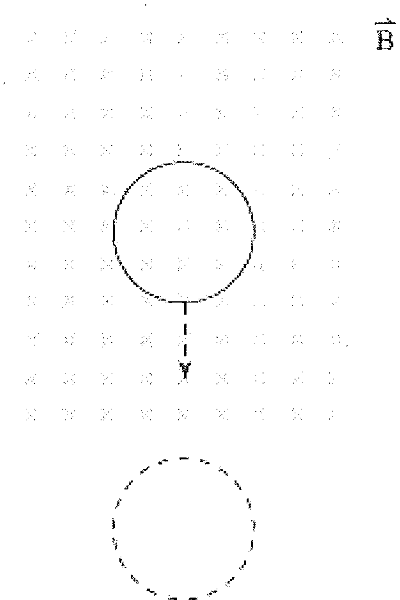

coil moves

B.



coil changes shape

C.



coil changes shape

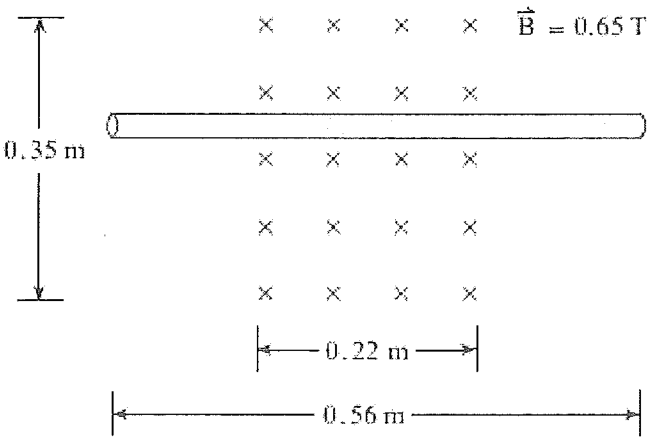
D.



coil moves

38. A motor is connected to a 12 V DC supply and draws 5.0 A when it firsts starts up. What will be the back EMF when the motor is operating at full speed and drawing 1.2 A?

a. 7.0 V
b. 7.8 V
c. 9.1 V
d. 10.8 V

39. A long conductor is placed in a 0.65 T magnetic field as shown below. What are the magnitude and direction of the current that produces a 1.6 N force on the wire directed up the page?




| | MAGNITUDE OF CURRENT | DIRECTION OF CURRENT |
|---|---|---|
| A. | 4.4 A | Right |
| B. | 4.4 A | Left |
| C. | 11 A | Right |
| D. | 11 A | Left |

40. A proton has a speed of $5.0 \times 10^6$ m/s while travelling perpendicular to a 0.14 T magnetic field. What is the magnetic force on the proton?

a. $1.6 \times 10^{-26}$ N

b. $8.4 \times 10^{-21}$ N

c. $2.2 \times 10^{-20}$ N

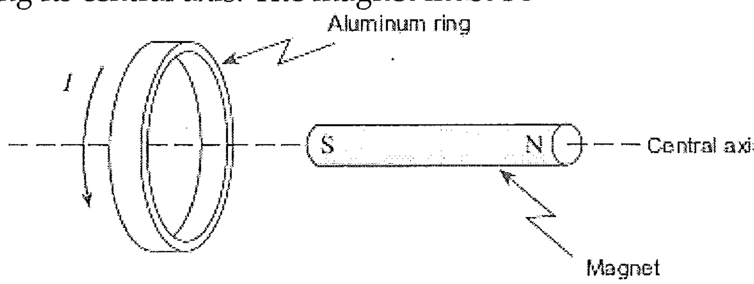
d. $1.1 \times 10^{-13}$ N

41. The flux through a circular coil with a radius of 0.075 m is 0.013 Wb when placed perpendicular to a magnetic field. What is the strength of the magnetic field?

   a. 0 T
   b. 0.17 T
   c. 0.74 T
   d. 2.3 T

42. The diagram below shows an aluminum ring and the current induced in it by the nearby magnet that is free to move along its central axis. The magnet must be

   a. Stationary
   b. Moving to the left
   c. Moving to the right
   d. Spinning about its central axis



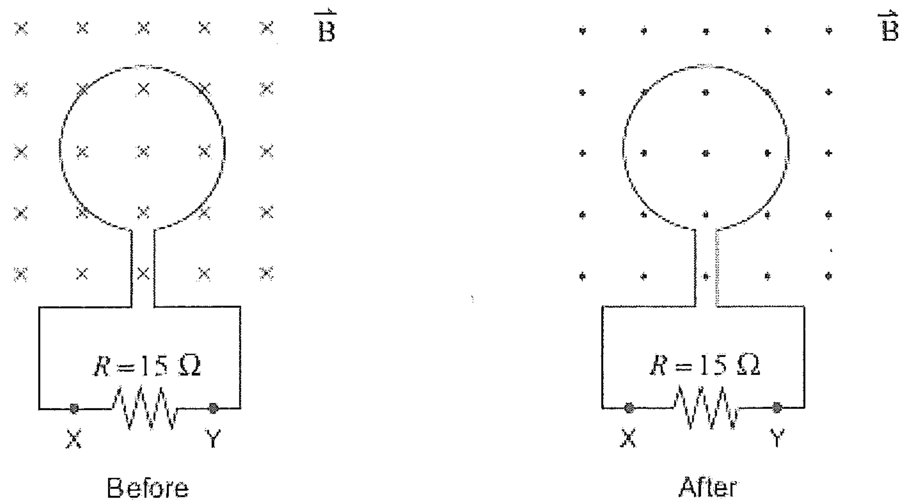

43. A computer adaptor contains a transformer that converts 120 V AC across its primary windings to 24 V AC across its secondary windings. The primary current is 1.2 A. What is the secondary current and what is the type of the transformer?

| | MAGNITUDE OF CURRENT | DIRECTION OF CURRENT |
|---|---|---|
| A. | 0.24 A | Step-up |
| B. | 0.24 A | Step-down |
| C. | 6.0 A | Step-up |
| D. | 6.0 A | Step-down |

44. A charged particle travels in a circular path in a magnetic field. What changes to the magnetic field and to the velocity of the particle would both cause the radius of its path to decrease?

| | CHANGE TO THE MAGNETIC FIELD | CHANGE TO THE VELOCITY |
|---|---|---|
| A. | increase | increase |
| B. | increase | decrease |
| C. | decrease | increase |
| D. | decrease | decrease |

45. A loop of wire of area 0.32 m² is placed in a 0.75 T magnetic field as shown. The magnetic field is changed to 0.35 T in the opposite direction in 0.45 s. What are the magnitude and direction of current through the 15 Ω resistor?




| | MAGNITUDE OF CURRENT | DIRECTION OF CURRENT |
|---|---|---|
| A. | 0.019 A | X to Y |
| B. | 0.019 A | Y to X |
| C. | 0.052 A | X to Y |
| D. | 0.052 A | Y to X |

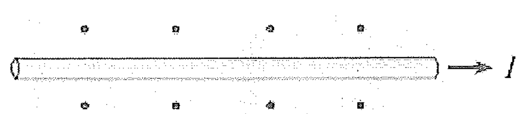
46. The direction of a magnetic field is determined to be the direction in which

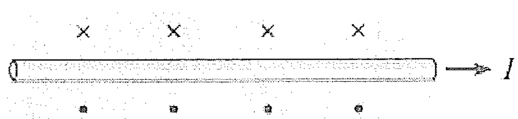
a. A positive charge would tend to move
b. A negative charge would tend to move
c. The north end of a compass needle would point
d. The south end of a compass needle would point

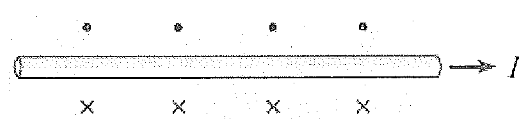
47. Which diagram shows the magnetic field created near a conductor carrying current towards the right?

A.

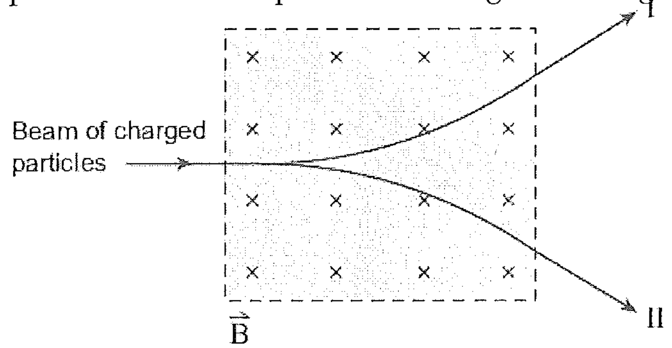


B.



C.



D.


48. A beam of positively and negatively charged particles enters a magnetic field as shown. Which paths illustrate the positive and negative charges leaving the magnetic field region?




| | PATH OF POSITIVE CHARGES | PATH OF NEGATIVE CHARGES |
|---|---|---|
| A. | I | I |
| B. | I | II |
| C. | II | I |
| D. | II | II |

49. A solenoid has a length of 0.30 m, a diameter of 0.040 m and 500 windings. The magnetic field at its center is 0.045 T. What is the current in the windings?

a. 2.9 A
b. 3.0 A
c. 21 A
d. 170 A

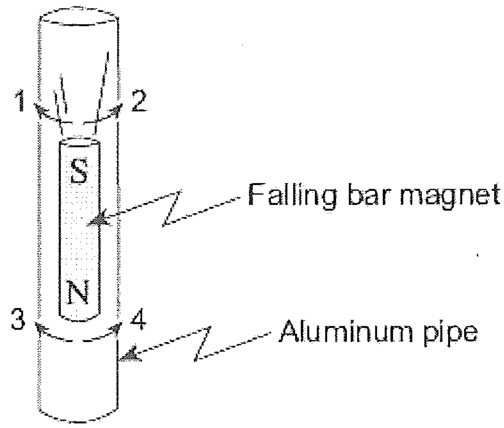
50. An aircraft with a wingspan of 24 m flies at 85 m/s perpendicular to a magnetic field. An EMF of 0.19 V is induced across the wings of the aircraft. What is the magnitude of the magnetic field?

a. $9.3 \times 10^{-5}$ T
b. $5.4 \times 10^{-2}$ T
c. $6.7 \times 10^{-1}$ T
d. $3.9 \times 10^{2}$ T

51. As a carpenter drills into a beam, friction on the drill bit causes the armature of the drill to slow down. How will the back EMF and current through the armature change as the drill slows down?

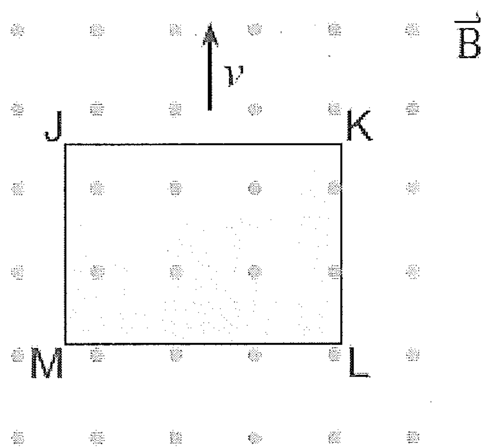
| | BACK EMF | CURRENT |
|---|---|---|
| A. | Increase | Increase |
| B. | Increase | Decrease |
| C. | Decrease | Increase |
| D. | Decrease | Decrease |

52. The diagram shows a bar magnet falling through an aluminum pipe. Electric currents are induced in the pipe immediately above and below the falling magnet. In which direction do these currents flow?




| | ABOVE THE MAGNET | BELOW THE MAGNET |
|---|---|---|
| A. | 1 | 3 |
| B. | 1 | 4 |
| C. | 2 | 3 |
| D. | 2 | 4 |

53. A metal block moves with a constant speed in a uniform magnetic field. Which side of the block is positive?



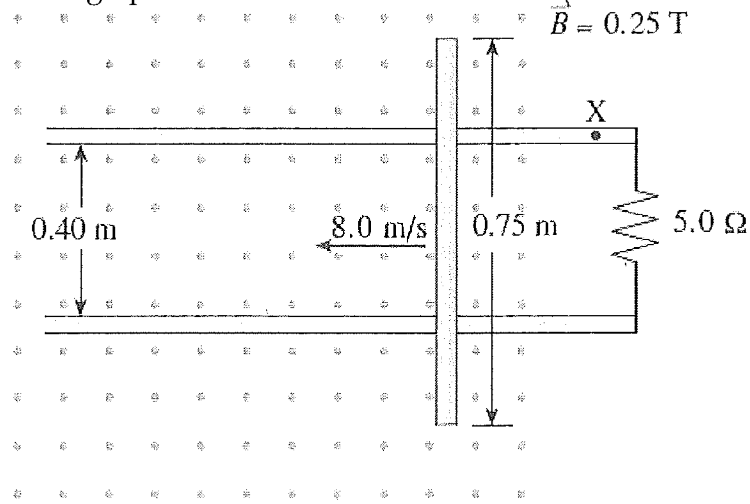

a. JK

b. KL

c. LM

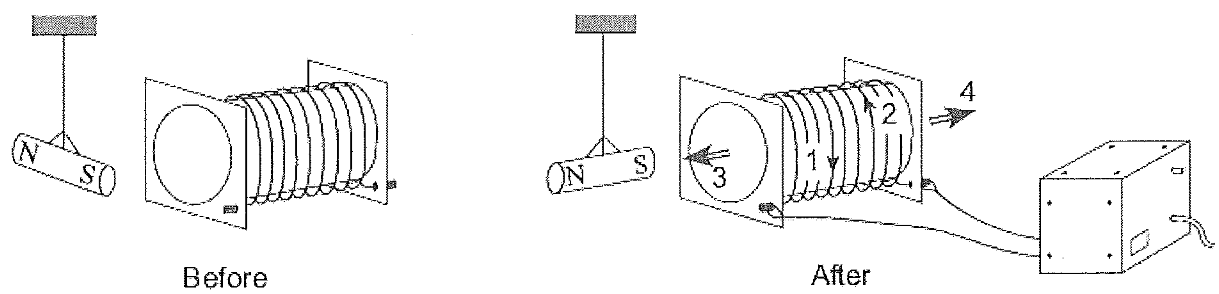
d. MJ

54. A 0.75 m conducting rod is moved 8.0 m/s across a 0.25 T magnetic field along metal rails. The electrical resistance of the system is 5.0 Ω. What are the magnitude and direction of the current through point X?



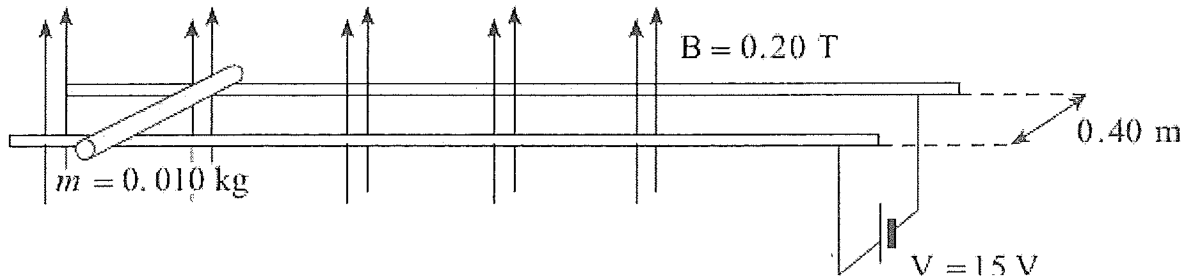

| | MAGNITUDE OF CURRENT | DIRECTION OF CURRENT THROUGH X |
|---|---|---|
| A. | 0.16 A | Left |
| B. | 0.16 A | Right |
| C. | 0.30 A | Left |
| D. | 0.30 A | Right |

55. The diagram shows a magnet suspended near a solenoid. After the solenoid has been connected to a power supply, the magnet rotates to a new position with its south pole pointing towards the solenoid. Which arrows show the direction of the current in the solenoid and the direction of the magnetic field caused by this current?



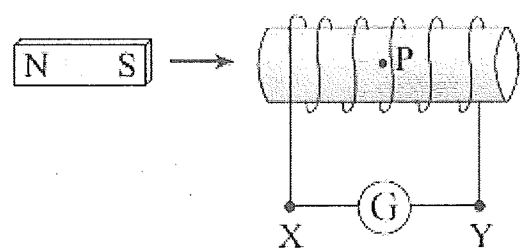

| | DIRECTION OF CURRENT | DIRECTION OF MAGNETIC FIELD |
|---|---|---|
| A. | 1 | 3 |
| B. | 1 | 4 |
| C. | 2 | 3 |
| D. | 2 | 4 |

56. The diagram shows a 0.010 kg metal rod resting on two long horizontal frictionless rails which remain 0.40 m apart. The circuit has a resistance of 3.0 Ω and is located in a uniform 0.20 T magnetic field. Find the initial acceleration and maximum velocity for the rod.




| | INITIAL ACCELERATION | MAXIMUM VELOCITY |
|---|---|---|
| A. | 40 $m/s^2$ | 190 m/s |
| B. | 40 $m/s^2$ | 300 m/s |
| C. | 120 $m/s^2$ | 190 m/s |
| D. | 120 $m/s^2$ | 300 m/s |

57. A bar magnet is moving toward a solenoid. What is the direction of the current through the galvanometer and what is the direction of the magnetic field produced by this current at location P inside the solenoid?




| | DIRECTION OF THE CURRENT THROUGH THE GALVANOMETER | DIRECTION OF THE MAGNETIC FIELD AT P |
|---|---|---|
| A. | From X to Y | Right |
| B. | From X to Y | Left |
| C. | From Y to X | Right |
| D. | From Y to X | Left |

WRITTEN PRACTICE QUESTIONS

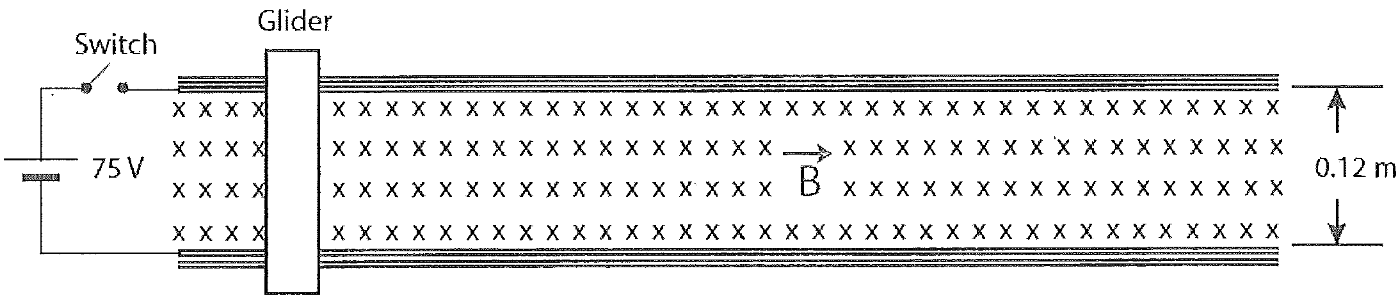
1. A single loop of wire of area $5.0 \times 10^{-3}$ $m^2$ and resistance 1.8 $\Omega$ is perpendicular to a uniform magnetic field B The field then decreases to zero in 0.0012 s inducing an average current of 0.083 A in the loop. What was the initial value of the magnetic field B?

2. An electron is accelerated from rest through a potential difference of 750 V. It then enters a uniform 0.0023 T magnetic field at right angles to the field.
    a. What is the speed of the electron?

    b. What is the radius of its path in the magnetic field?

3. An electric device operates on 9.0 V AC and has a total resistance of 21 $\Omega$. An ideal transformer is used to change the incoming line voltage of 120 V to the operating voltage of 9.0 V AC.
    a. Is the transformer a step-up or step-down transformer?
    b. What is the current in the primary side?

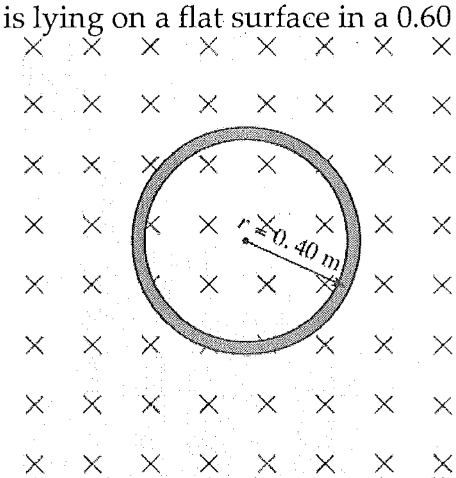
4. The diagram below shows a pair of horizontal parallel rails 0.12 m apart with a uniform magnetic field of 0.055 T directed vertically downward between the rails. There is a glider of mass 9.5 x $10^{-2}$ kg across the rails. The internal resistance of the 75 V power supply is 0.30 Ω and the electrical resistance of the rails and glider is negligible. Assume friction is also negligible.




a) When the switch is closed, what is the initial acceleration of the glider?

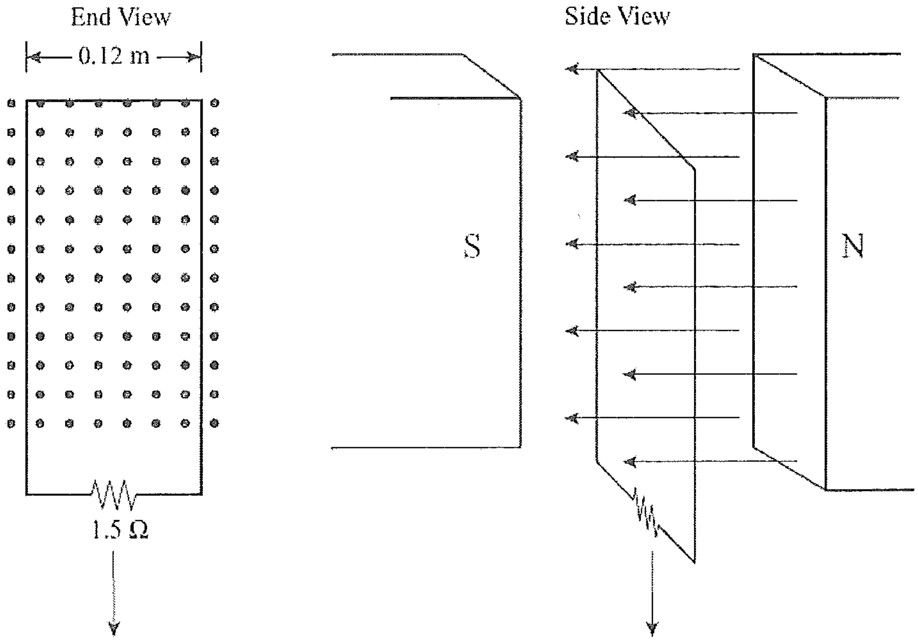
b) What is the value of the terminal velocity as limited by the back EMF produced by the moving glider?

5. A coil of wire containing 50 loops is lying on a flat surface in a 0.60 T magnetic field pointing directly into the surface.




The magnetic field then changes to a value of 0.10 T in the opposite direction in 2.10 s. What is the average EMF induced in the coil during the time that the magnetic field was changing?

6. A rectangular conducting loop of mass 0.045 kg and resistance 1.5 Ω is dropped in the direction shown through a uniform horizontal magnetic field of 1.8 T. At what speed will this loop be falling through the magnetic field when it stops accelerating?




7. Suppose a coil and a magnet were each moving with the same velocity relative to the earth. Would there be an induced current in the coil? Explain.

8. Does a bolt of lightning contain moving charges as it strikes the ground?

**Multiple Choice Questions:**

1. B
2. D
3. C
4. D
5. C
6. A
7. A
8. A
9. D
10. D
11. C
12. B
13. A
14. D
15. D
16. B
17. C
18. B
19. B
20. D
21. D
22. C
23. C
24. D
25. C
26. A
27. B
28. B
29. C
30. B
31. C
32. D
33. A
34. A
35. C
36. A
37. D
38. C
39. C
40. D
41. C
42. C
43. D
44. B
45. D
46. C
47. D
48. B
49. C
50. A
51. C
52. C
53. B
54. B
55. C
56. A
57. A

**Written Questions:**

1. 0.036 T
2. A) $1.62 \times 10^7$ m/s
   B) 0.040 m
3. A) step down
   B) 0.032 A
4. A) 17.4 $m/s^2$
   B) $1.14 \times 10^4$ m/s
5. 8.4 V
6. 14.2 m/s
7. check solutions
8. look it up!

# Electromagnetism

# Key

Physics 12 – **Magnetic Forces and Fields**

Up until now we have only considered the electrostatic forces acting on charges at rest. **<u>When the charges are in motion, an extra force acts on them</u>**. = Magnetic Force

**Magnetic fields** are produced by **electric currents**, which can be relatively large currents in wires, or relatively tiny currents associated with electrons in atomic orbits.

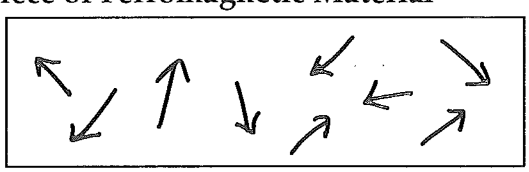
## <u>Magnets</u>

Certain metals, such as iron, cobalt and nickel, have a special property to them that allows them to become permanent or temporary magnets. These metals are referred to as ferromagnetic materials.

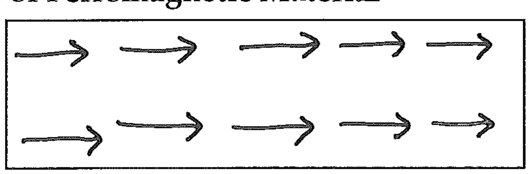
Ferromagnetic materials have something special about the charge movement within their atoms. This has to do with the spin nature of the unpaired electrons in these atoms.

The unpaired electrons have spins that have spins that produce a "cooperative effect" with $10^{15}$ to $10^{20}$ other atoms. The atoms that cooperate in this group are called a magnetic domain. Since the dimensions of these domains are very, very small. Therefore, there are millions of magnetic domains in a magnet. *http://www.magnet.fsu.edu/education/tutorials/java/domains/index.html*

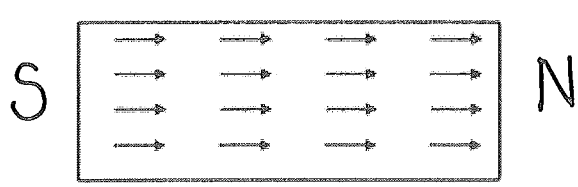
**Un-Magnetized Piece of Ferromagnetic Material –**



**Magnetized Piece of Ferromagnetic Material –**



A magnet has <u>two poles - a north pole and a south pole</u>.




• each arrow represents a magnetic domain (the group of atoms with unpaired electrons the spin in the same direction)

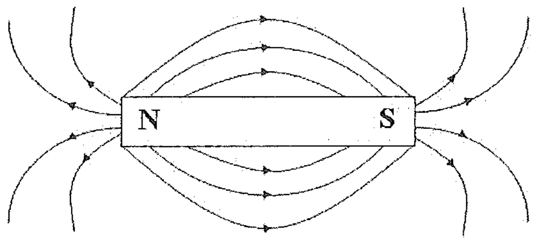
• when the domains <u>all rotate</u> in the same direction = <u>magnet</u>

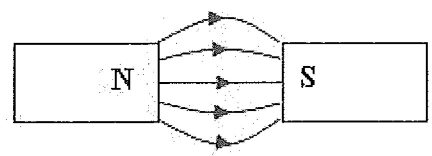
*north pole is the end that points toward the north magnetic pole of the Earth when it is suspended.

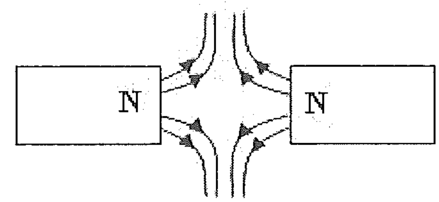
Magnets can attract or repel other magnets. Magnets are also able to exert forces on each other without touching because they are surrounded by:

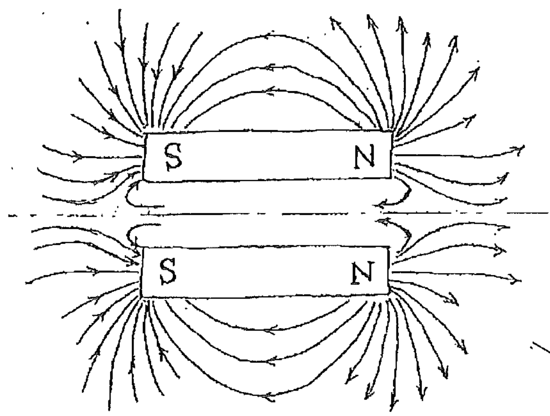
magnetic Fields

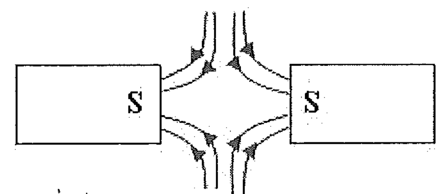
Magnetic fields are **vector** fields and therefore we need to represent the lines as **arrows.**

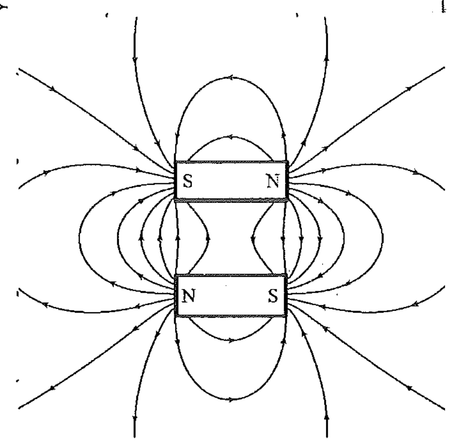


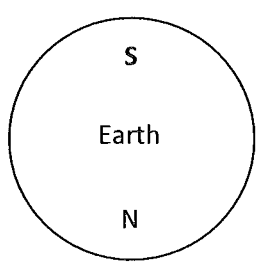



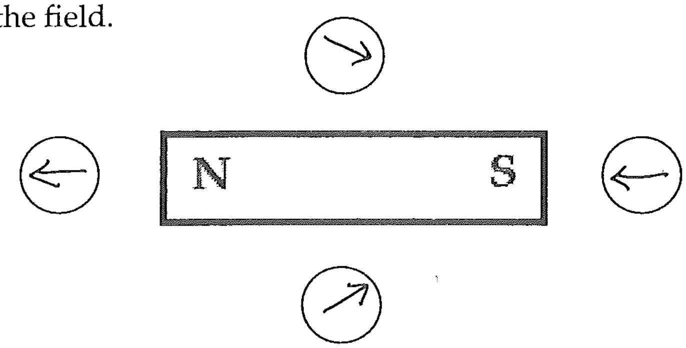




***Note the similarity of magnetic fields to electric fields.***

The end of the magnet in a compass that points to magnetic north is the *north-seeking pole* (making it the south pole of the magnet). Therefore, the magnetic pole of the earth in the geographic north must be a south magnetic pole!



We define the direction of a magnetic field as the direction that a compass would point when placed in the field.




When magnetic fields interact, we can summarize those interactions:

**<u>Like magnetic poles repel</u>** each other, and **<u>unlike poles attract</u>** each other.

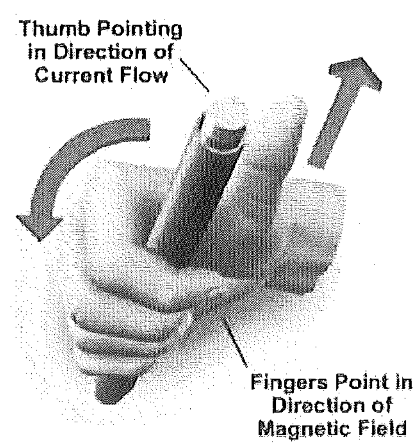

## <u>Electromagnetism:</u>

The **Oerstad Experiment** at the University of Copenhagen in 1819 was the first evidence of the connection between electricity and magnetism. This experiment helped lead to the understanding that all magnetic fields are caused by the movement of charged particles, like electrons moving around the nucleus or through wires.

Shortly after Oersted and his experiment were made public, **Andre Marie Ampere** developed the **<u>1st Right Hand Rule</u>**.

This rule is used to predict the direction of the -

magnetic field around a current carrying wire.




**The right hand rule uses CONVENTIONAL current.**

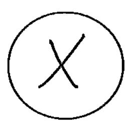
Using the 1st right hand rule, it is now possible to show the shape of the magnetic field around a current-carrying wire. The lines of force around a current-carrying wire **circle** the wire.

**<u>1st Right Hand Rule:</u>**

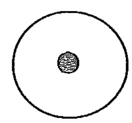
**Thumb:** direction of conventional current flow (+ to -) **Curved Fingers:** magnetic field

Quite often we need to represent a current carrying wire as though you are looking at it from its end. To do this, we draw a circle and indicate the direction of current flow as follows:

If the current flows INTO the page:

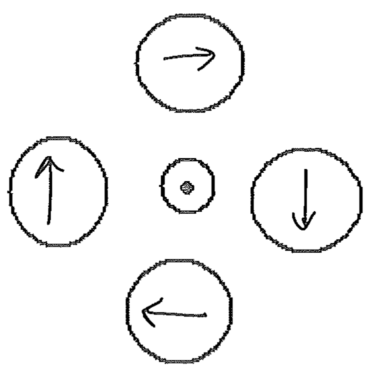


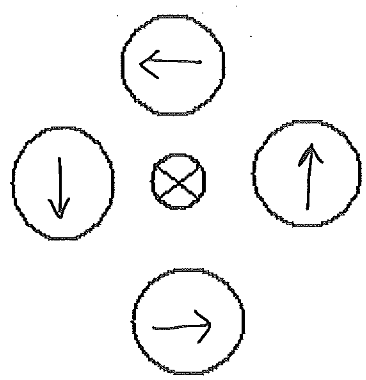
If the current flows OUT OF the page:



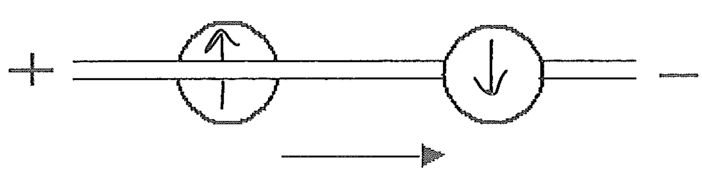
Using the right-hand rule, we can determine the direction of the magnetic field:

In a current-carrying wire going into and out of the page:



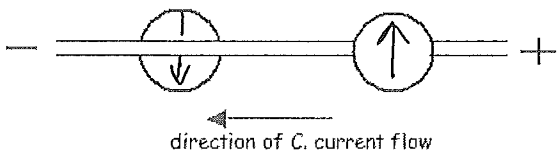


For a non-coiled single wire (+ to -):




direction of C. current flow

For a non-coiled single wire (- to +):

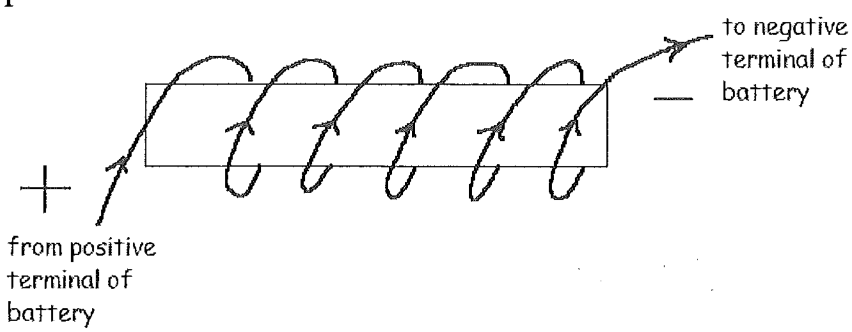



## Solenoids:

Electromagnets are magnets that produce magnetic field only when an electric current flows through them. These magnets are usually made by winding a coil of wire around a magnetic core material such as iron. This is referred to as a **solenoid.**

* useful because they can be turned on and off!

**The loops of wire carry the current and therefore the more loops there are, the stronger the magnetic field produced.**

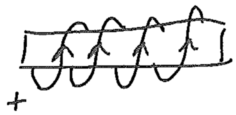



Just like a bar magnet, a **solenoid (electromagnet) has North and South poles.** The poles depend entirely on... which way the wire is coiled.

**2nd Right Hand Rule: (again we are using conventional current)**

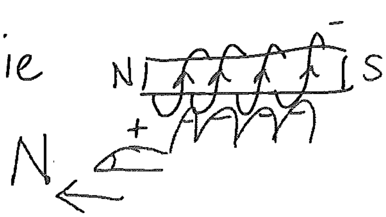
**Curved Fingers:** in direction of current flow

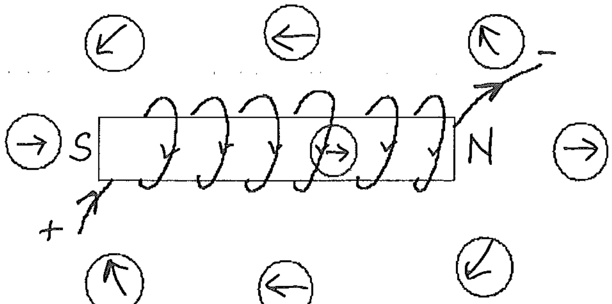
ie



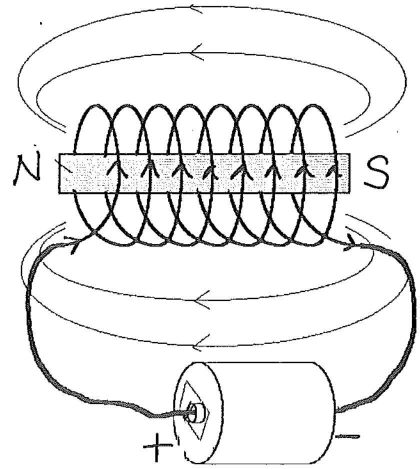

**Thumb:** points to the N pole of the solenoid

ie





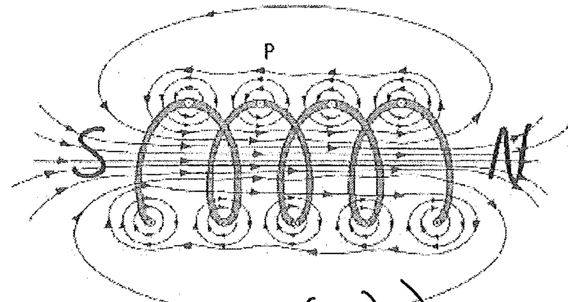

* the compass inside the coil points North




By looking at the diagram below, we can see that the **field outside of a solenoid is weak and non-uniform.**

However, the **field inside the solenoid is strong and uniform.**

magnetic Flux Density = Magnetic Field Strength $\rightarrow B$




(measured in Teslas (T)) $T = \frac{N}{A \cdot m}$

In a uniform magnetic field INSIDE the solenoid, we can calculate the strength of the field using:

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

unit = Tesla (T)

$B$ = Magnetic Field Strength

$\mu_0$ = permeability of free space ($4\pi \times 10^{-7}$ T·m/A)

$I$ = current

$n$ = loops per meter $\rightarrow \frac{N \text{ (total loops)}}{l \text{ (length)}}$

circular wire, straight magnetic field.

2nd hand rule

**Example**: A hollow solenoid is 25 cm long and has 1000 loops. If the solenoid has a diameter of 4.0 cm and a current of 9.0 A, what is the magnetic field strength in the solenoid?

$$B = \mu_0 I n = (4\pi \times 10^{-7})(9.0)\left(\frac{1000}{0.25}\right)$$

$$= 0.045\ T$$

1st hand rule

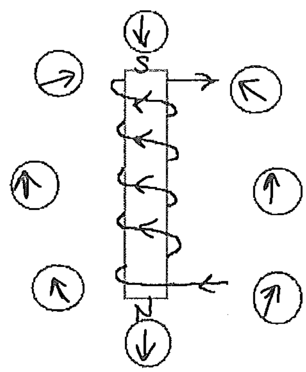
Straight wire circular magnetic field:
Find the magnitude of a magnetic field 2.3cm from a conductor carrying 7.6A

$$B = \frac{\mu_0 I}{2\pi R} = \frac{4\pi \times 10^{-7} \times 7.6A}{2\pi \times 2.3 \times 10^{-2} m} = 6.6 \times 10^{-5}\ T$$

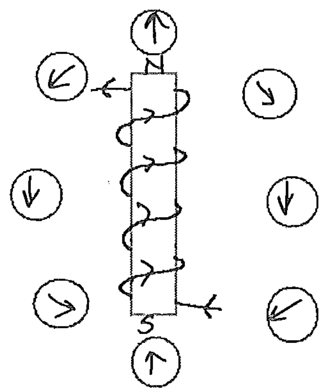
## Questions:

Indicate the lines of force on the following diagrams by filling in the direction of the compass needles. Then indicate which end of the electromagnet would be the North and South Poles. (Note: the arrows show the direction of conventional current)

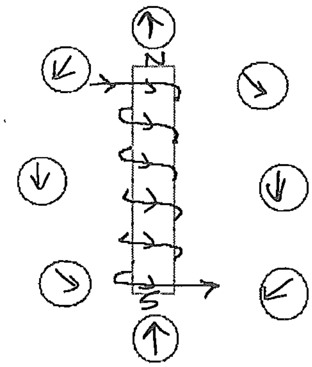
a)




b)

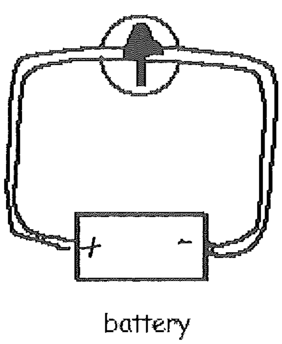



c)

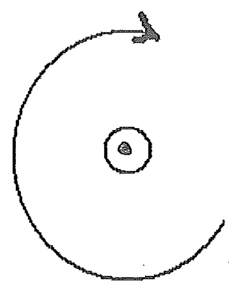



Use the Right-Hand Rule to predict which is the positive and negative terminals of the battery. (Hint: Don't forget to look at where the compass is placed…above or below the wire!!)

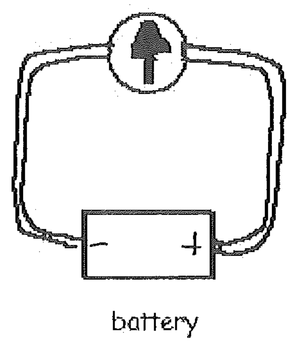
a)




b)

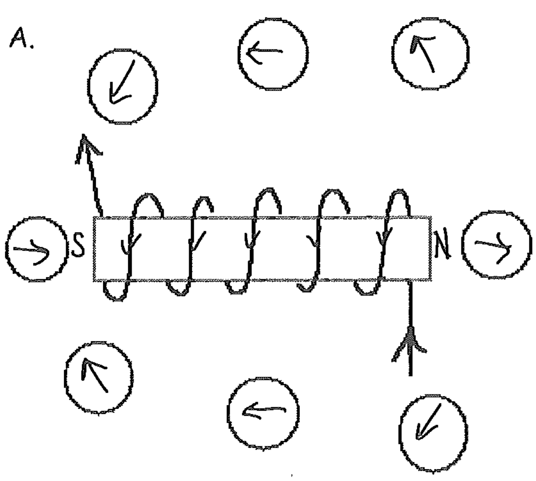


c)

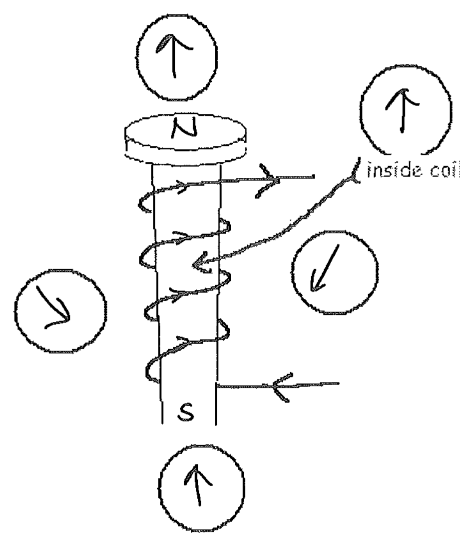



Find the North and South Poles in each example and indicate the direction of all the compass needles.

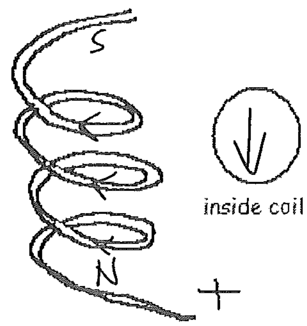
A.



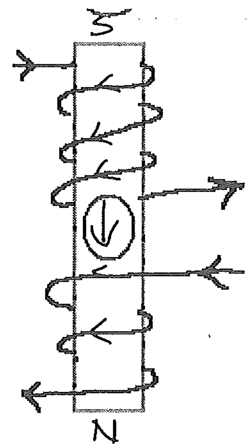

B.



C.

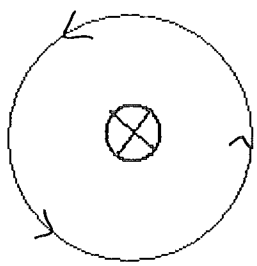



D.

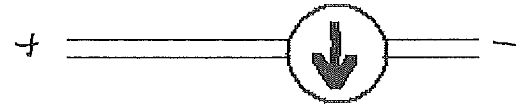



Find the direction of the current: (label the + and – terminals)

A.



B.




1. A 25.0 cm solenoid has 1800 loops and a diameter of 3.00 cm. Calculate the magnetic field in the air core of the solenoid when a current of 1.25 A is flowing through it.

$$B = \mu_0 I n = (4\pi \times 10^{-7})(1.25)\left(\frac{1800}{0.25}\right) = \underline{1.13 \times 10^{-2}\ T}$$

2. An air core solenoid is 25 cm long and carries a current of 0.72 A. If the magnetic field in the core is 2.1 x $10^{-3}$ T, how many turns does the solenoid have?

$$B = \mu_0 I n \quad 2.1 \times 10^{-3} = (4\pi \times 10^{-7})(0.72)\left(\frac{N}{0.25}\right)$$

$N = \underline{580 \text{ turns}}$

3. An air core solenoid is 30.0 cm long and has 775 turns. If the magnetic field in the core is 0.100 T, what is the current flowing through this solenoid?

$$B = \mu_0 I n \quad 0.100 = (4\pi \times 10^{-7})(I)\left(\frac{775}{0.30}\right) \quad I = \underline{31 A}$$

4. What is the magnetic field near the center of a 0.30 m long solenoid that has 800 turns of wire and carries an electric current of 2.0 A?

$$B = (4\pi \times 10^{-7})(2.0)\left(\frac{800}{0.30}\right) \quad B = \underline{6.7 \times 10^{-3}\ T}$$

Physics 12 – **Magnetic Forces**

Last class, we saw that with permanent magnets – • opposite poles attract
• like poles repel

We also saw that magnetic fields surround any current carrying wire. **When a current-carrying conductor (like a wire) is placed in a magnetic field, it will experience a <u>force.</u>**

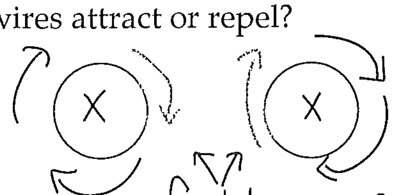
We are going to look at two types of situations in which magnetic forces act.

## A. Magnetic Forces on Current Carrying Wires

<u>Parallel Current Carrying Wires</u>

Two parallel wires carrying current in the same direction. Will the fields produced by these wires attract or repel?

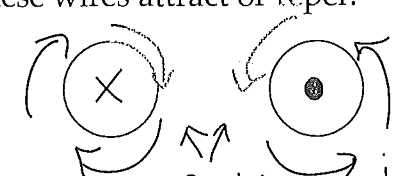
*RHR



*fields are opposite

**Parallel wires with current flowing in the <u>same</u> direction will…** Attract!

Two parallel wires carrying current in the opposite direction. Will the fields produced by these wires attract or repel?

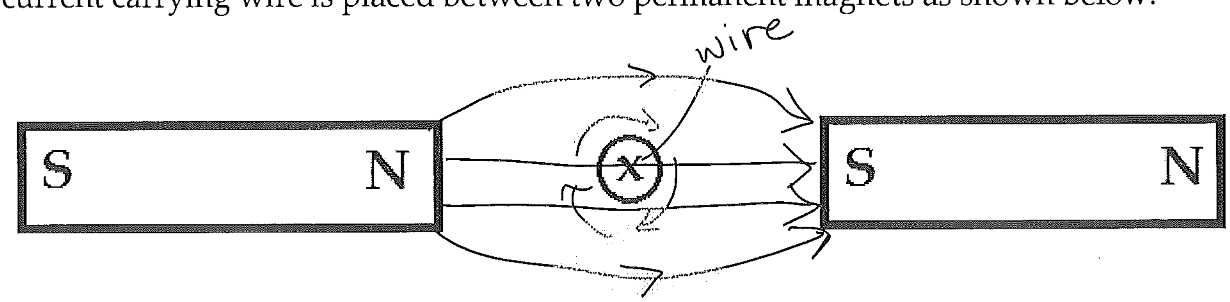


*fields are in same dir.

**Parallel wires with current flowing in the <u>opposite</u> direction will…** Repel!

<u>Current Carrying Wires in Magnetic Fields</u>

A current carrying wire is placed between two permanent magnets as shown below.

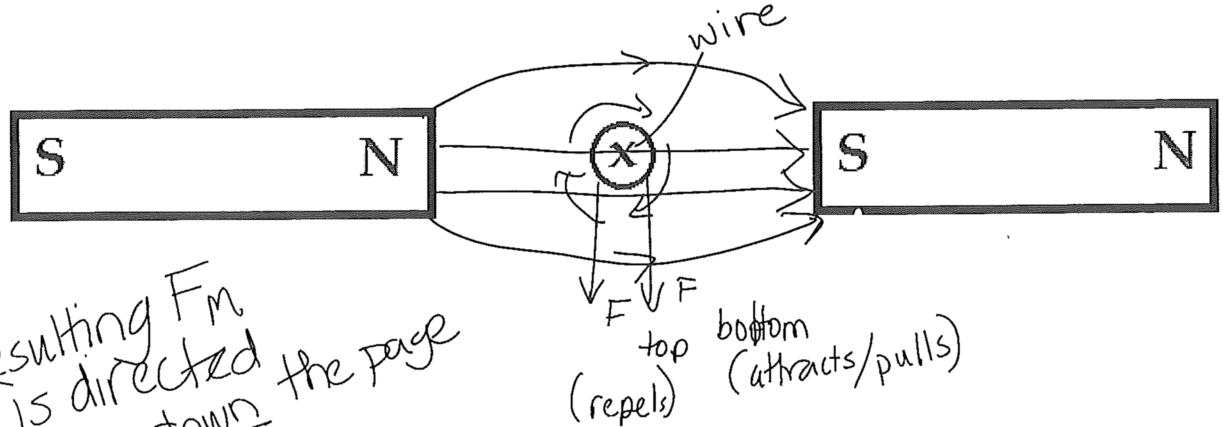



The **<u>area above the wire</u>** sees an interaction between the field produced by the permanent magnets and the field produced by the current carrying wire. These fields point… in the same direction.

These two fields will repel.

The **area below the wire** also sees an interaction between the two fields. In this area, the fields point... in the opposite direction

These two fields will attract.



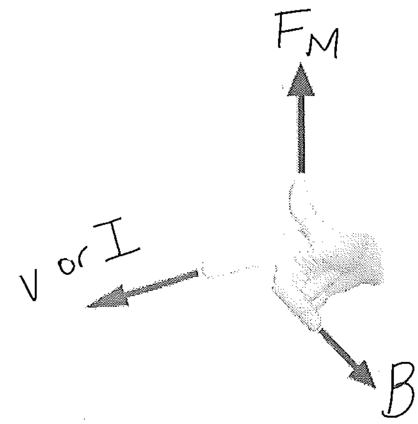

☆ resulting $F_M$ is directed down the page

**The 3rd Right Hand Rule:** *To obtain the direction of the force on a conductor in a magnetic field.*

**Thumb:** direction of $F_M$

**Index Finger:** direction of current or motion of particle

**Other Fingers:** direction of magnetic field.




The magnetic force on a conductor can be calculated as:

$$\boxed{F_M = B \ell I \sin\theta}$$

B = field stength (T)
$\ell$ = length of conductor (m)
I = current (A)
$\theta$ = orientation to field.

**Note:** If the conductor is perpendicular to the magnetic field, the formula becomes:

$$F_M = B\ell I \quad (\sin 90^\circ = 1)$$

And if the conductor is parallel to the magnetic field, the formula becomes:

$$F_M = 0 \quad (\sin 0^\circ = 0)$$

## B. Magnetic Forces on Moving Charges in Magnetic Fields

In the same way that charged particles moving through a wire will experience a force in a magnetic field, so will free charged particles. We also use the **3rd Right Hand Rule** to determine the direction of the magnetic force on such a particle.

*IMPORTANT NOTE*: We use **right hand rules** for wires when talking about **conventional current**. All of the same concepts apply if we use our left hand (**left hand rules**) when dealing with **electron flow**.

This logic is also used when dealing with charged particles:

For **positively charged particles**, we use… RHR

For **negatively charged particles**, we use… LHR (same rules but using left hand)

To calculate the magnetic force on a particle, we use:

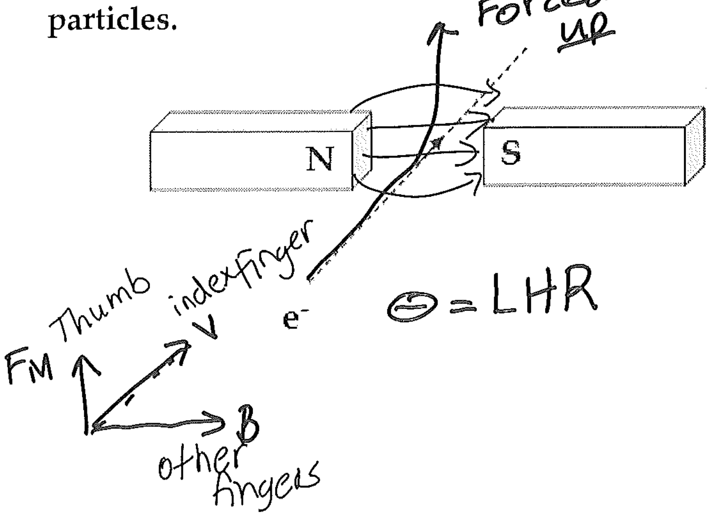
$$\boxed{F_M = qvB\sin\theta}$$

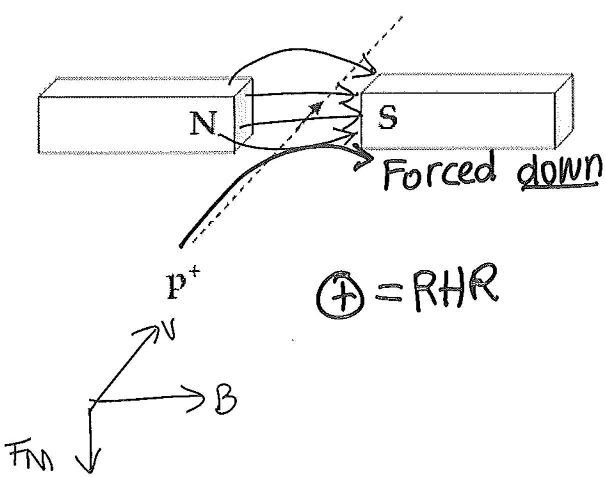
$q$ = charge (C)
$v$ = velocity (m/s)
$B$ = fieldstrength (T)
$\theta$ = orientation to field

Again, if the particles are moving perpendicular to the field → $F_M = qvB$

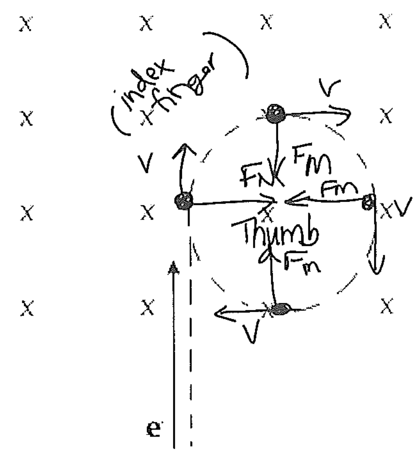
If the particles are moving parallel to the field → $F_M = 0$

As seen below, moving charges (such as protons, electrons and neutrons) can be deflected by magnetic fields. **They are deflected by the magnitude of the force calculated** by the formula introduced above. Then we use the hand rules to **determine the direction** of the deflection. Remember - **use your right hand for positive particles and your left hand for negative particles.**

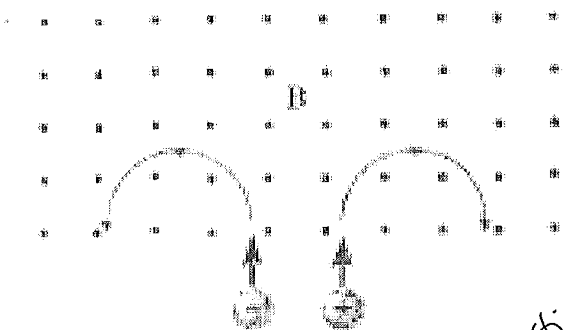


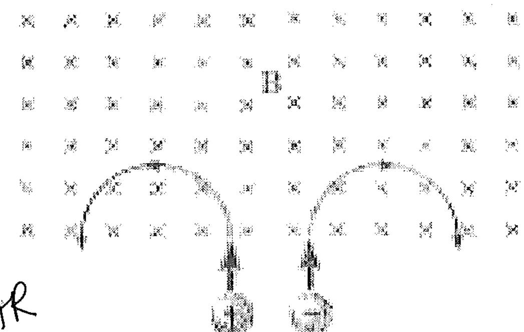
In a vacuum, charged particles can become trapped in a magnetic field. **As the magnetic force acts on the charged particle, the direction of motion is changed. As the direction of motion is changed, so is the direction of force. This results in a circular motion.**




**Magnetic Field Direction – OUT OF THE PAGE**

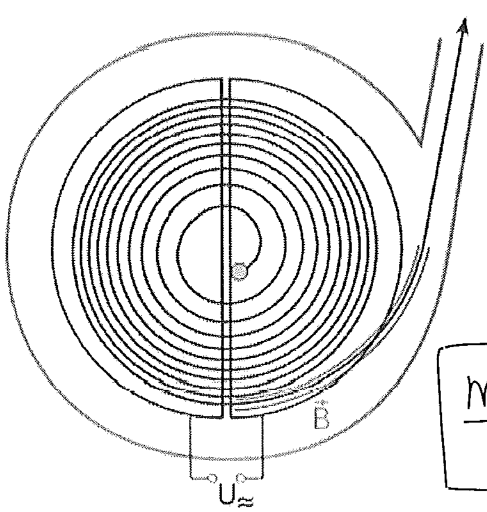



**Magnetic Field Direction – INTO THE PAGE**




*practice RHR (+) & LHR (−)

Circular particle accelerators use magnetic fields to bend beams of charged particles. This allows them to reach phenomenal speeds in relatively small spaces. The cyclotron at UBC's TRIUMF contains the largest of its kind in the world. It accelerates a beam of hydrogen anions ($H^-$) to 75% the speed of light and uses a 0.42 T magnetic field. At these speeds, the relativistic mass of a hydrogen anion is $2.524 \times 10^{-27}$ kg. What is the outer radius of the cyclotron?




**When charged particles travel in a circular path:**

$$F_C = F_M$$

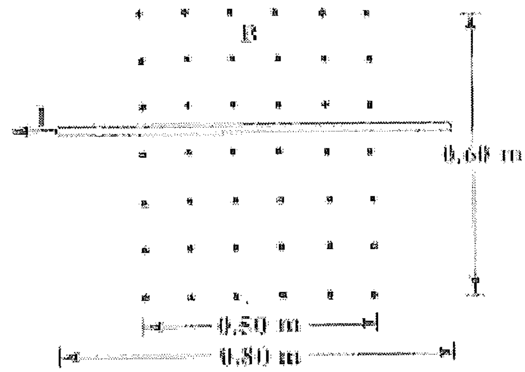
$$\frac{mv^2}{r} = q\cancel{v}B$$

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

$$\frac{(2.524\times10^{-27})(0.75)(3.0\times10^8)}{r} = (1.6\times10^{-19})(0$$

$r = 8.45\ m$

**Example One:** A wire with a current of 2.0 A is perpendicular to a magnetic field of 0.82 T as shown in the diagram. What are the magnitude and direction of the magnetic force acting on the wire?



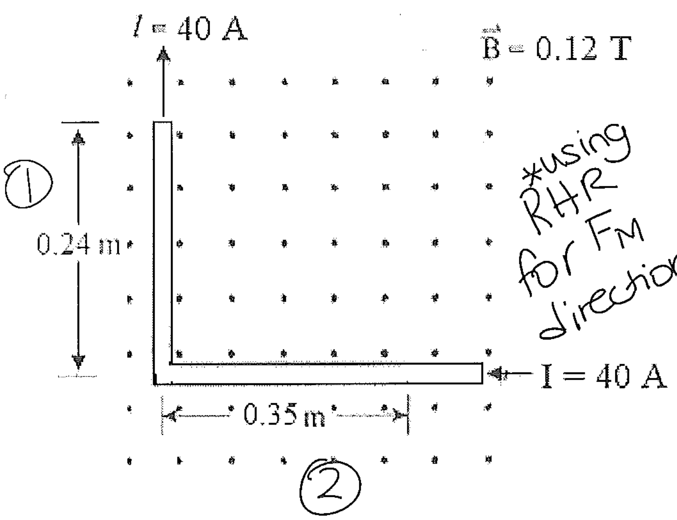

$F_M = BlI$
$= (0.82)(0.50)(2.0)$
$= \underline{0.82\ N}$

direction (RHR) → V (index), Fingers B, Thumb ($F_m$) $= \underline{[up]}$

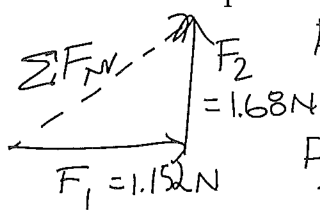
**Example Two:** Calculate the magnitude of the magnetic force on an electron travelling at a speed of 3.60 x 10⁴ m/s perpendicular to a magnetic field of 4.20 T.

$F_M = qvB = (1.6 \times 10^{-19})(3.6 \times 10^4)(4.20) = \underline{2.42 \times 10^{-14}\ N}$

**Example Three:** What is the net magnetic force on the L-shaped conductor?




*using RHR for $F_M$ direction




$F_1 = BlI = (0.12)(0.24)(40)$
$= 1.152\ N$

$F_2 = BlI = (0.12)(0.35)(40)$
$= 1.68\ N$

$\Sigma F_M = \sqrt{1.152^2 + 1.68^2}$
$= \underline{2.04\ N\ @\ 56°\ N\ of\ E}$

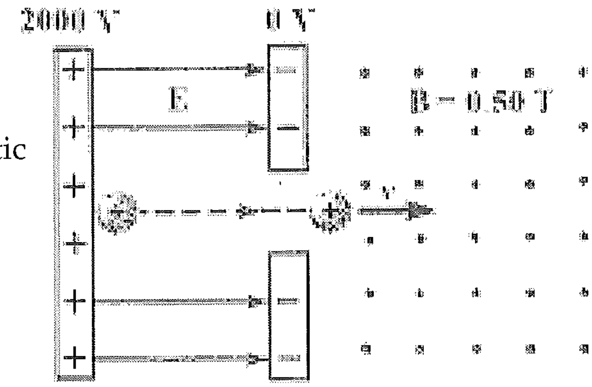
**Example Four:** Calculate the upward acceleration of an electron that is travelling east at a speed of 8.30 x 10⁴ m/s through a magnetic field of 3.10 x 10⁻¹ T that is directed south.

$F_M = qvB = (1.6 \times 10^{-19})(8.30 \times 10^4)(0.310) = 4.12 \times 10^{-15} N$

$\Sigma F = m\vec{a} \qquad 4.2 \times 10^{-15} = (9.11 \times 10^{-31})\vec{a}$

$\vec{a} = \underline{4.52 \times 10^{15}\ m/s^2}$

**Example 5:** A proton is accelerated from rest at the positive plate of the two charged parallel plates with a potential difference of 2000 V. After leaving the plates through a small hole in the negative plate, it enters a uniform magnetic field of 0.50 T in a direction perpendicular to the magnetic field directed out of the page as shown in the diagram.




a) Find the speed of the proton when it leaves the negative plate.

b) Find the magnitude and direction of the magnetic force on the proton.

c) Find the acceleration of the proton.

d) Draw the path of the proton.

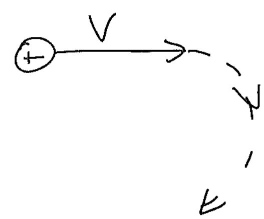
e) Find the radius of its path in the magnetic field.

a) $\Delta V = \frac{\Delta E}{q}$ $\quad 2000 = \frac{\Delta E}{1.6\times10^{-19}}$ $\quad \Delta E = KE = 3.2\times10^{-16} = \frac{1}{2}(1.67\times10^{-27})v$

$v = 6.19\times10^{5}\ m/s$

b) $F_m = qvB = (1.6\times10^{-19})(6.19\times10^{5})(0.50) = 4.95\times10^{-14}\ N$

direction → ⊕ = RHR = ↓ [down page]

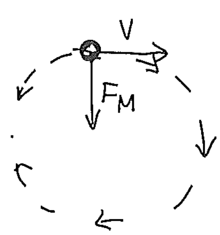



$\Sigma F = m\vec{a}$

c) $4.95\times10^{-14} = (1.67\times10^{-27})\vec{a}$

$\vec{a} = 2.97\times10^{13}\ m/s^2$

d) circular path:



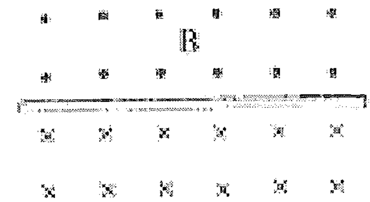

e) $F_c = F_M$

$\frac{mv}{r} = qB$

$\frac{(1.67\times10^{-27})(6.19\times10^{5})}{r} = (1.6\times10^{-19})(0.50)$ $\quad r = 1.3\times10^{-2}\ m$

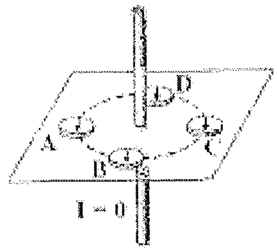
## Magnetic Force Problems:

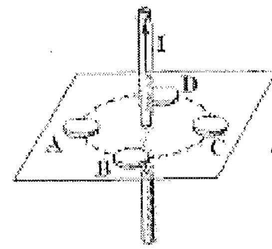
1. The magnetic field in the diagram is due to the current carrying wire. What is the direction of the current in the wire? (to the right)




RHR #1 → to the right

2. When no current is present in the wire, all compass needles point in the same direction. Use arrows to show the direction of the compass needle at each point A, B, C and D when the wire carries a current as shown in the diagram.




RHR #1

D ←

A ↓    ↑ C

→ B

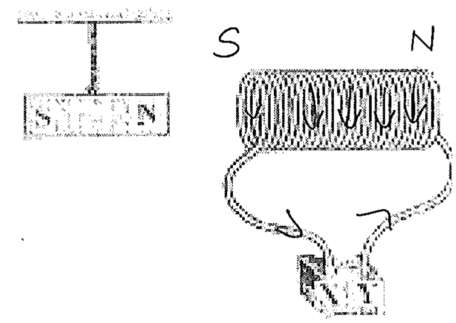
Thumb

Curved fingers

3. When a solenoid is connected to a battery, the north pole of the magnet near the solenoid points towards the solenoid.

   a. What is the direction of the magnetic field due to the current? (to the right)

   b. What is the polarity of the terminal X of the battery? (-)

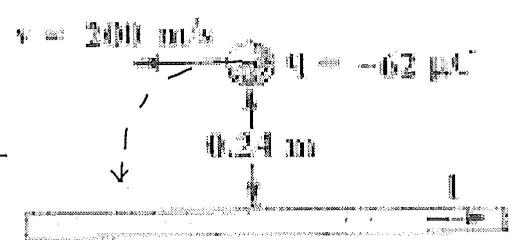



a) RHR#2 = right (towards N)

b) conventional current

X → ⊖   Y → ⊕

4. A -62 μC charged particle moves near a current carrying wire at 200 m/s as shown. The separation between the particle and the wire is 0.24 m, and the magnitude of the magnetic force exerted on the particle is $1.2 \times 10^{-8}$ N.




   a. Find the magnitude of the magnetic field at the location of the particle.($9.67 \times 10^{-7}$ T)

$F_M = qvB$

$1.2\times10^{-8} = (62\mu C)(200)(B)$

$B = 9.67\times10^{-7}\ T$

   b. Find the current of the wire. (1.16 A)

$B = \mu_0 \frac{N}{\ell} I$

$9.67\times10^{-7} = (4\pi\times10^{-7})\left(\frac{1}{2\pi(0.24)}\right)(I)$

$I = 1.16\ A$

5. A 450 turn solenoid of length 0.32 m produces a magnetic field of $4.0 \times 10^{-5}$ T at its center. Find the current in the solenoid. ($2.26 \times 10^{-2}$ A)

$B = \mu_o \frac{N}{l} I$ $\quad 4.0 \times 10^{-5} = \mu_o \frac{450}{0.32} I$ $\quad \underline{I = 2.26 \times 10^{-2}\ A}$

6. A solenoid of length 0.45 m and a diameter of 0.020 m produces a magnetic field of 1.6 T at its center when it carries a current of 6.8 A. How many turns of wire are contained in this solenoid? ($8.43 \times 10^4$ turns)

$B = \mu_o \left(\frac{N}{l}\right) I$ $\quad 1.6 = \mu_o \left(\frac{N}{0.45}\right)(6.8)$ $\quad \underline{N = 8.43 \times 10^4 \text{ turns}}$

7. An electron moving at $1.8 \times 10^3$ m/s enters at a right angle to a magnetic field produced by a 0.28 m long solenoid. A current of 4.2 A flows through the 760 turns of wire in the solenoid.

$B = \mu_o \left(\frac{N}{l}\right) I = \mu_o \left(\frac{760}{0.28}\right) 4.2$

a. Find the magnetic field in the solenoid. ($1.43 \times 10^{-2}$ T)

$= 1.43 \times 10^{-2}\ T$

b. Find the radius of curvature of the electron in the magnetic field of the solenoid. ($7.16 \times 10^{-7}$ m)

$F_c = F_m \quad \frac{mv}{r} = qB \quad \frac{(9.11 \times 10^{-31})(1800)}{r} = (1.6 \times 10^{-19})(1.43 \times 10^{-2})$

$r = 7.16 \times 10^{-7}\ m$

8. An electron with a kinetic energy of $3.6 \times 10^{-14}$ J moves perpendicular to a magnetic field of 0.60 T.

a. Find the magnitude of the magnetic force on the electron. ($2.70 \times 10^{-11}$ N)

b. Find the radius of the circular path of the electron. ($2.67 \times 10^{-3}$ m)

$3.6 \times 10^{-14} = \frac{1}{2}(9.11 \times 10^{-31})v^2$

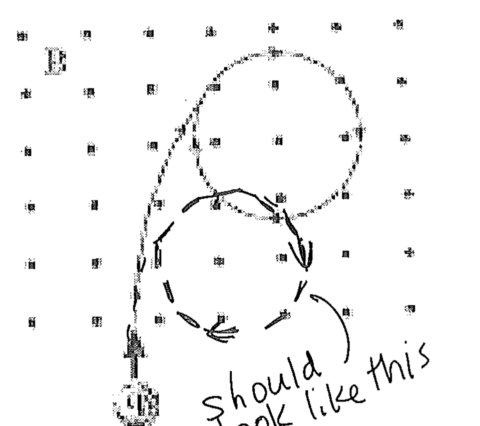
$v = 2.81 \times 10^8\ m/s$

$F_m = qvB = (1.6 \times 10^{-19})(2.81 \times 10^8)(0.60)$

$= 2.70 \times 10^{-11}\ N$

$\frac{(9.11 \times 10^{-31})(2.81 \times 10^8)}{r} = (1.6 \times 10^{-19})(0.60) \quad r = 2.67 \times 10^{-3}\ m$

9. The diagram shows the pathway of a charged particle which is not possible as the particle with a constant velocity <u>enters</u> a uniform magnetic field. Using the principles of physics, explain why the pathway is not possible.




since the magnetic force is directed to the center of the circle (constant v.) as soon as the particle <u>enters</u> the field = pathway shown is not possible

→ elemental charge

10. What is the mass of a singly charged ion that makes 6.0 revolutions in $1.5 \times 10^{-3}$ s in a $5.6 \times 10^{-2}$ T field with a radius of $5.4 \times 10^{-4}$ m? ($3.57 \times 10^{-25}$ kg)

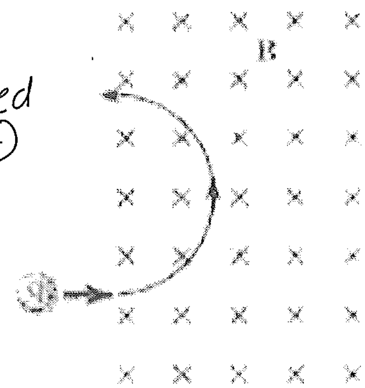
$T = \frac{1.5\times10^{-3}}{6.0} = 2.5\times10^{-4}$

$F_c = F_m$ $\quad \frac{mv}{r} = qB \quad \frac{m2\pi}{T} = qB$

$\left(v = \frac{2\pi r}{T}\right) \quad \frac{m\left(\frac{2\pi \cancel{r}}{T}\right)}{\cancel{r}} = qB \quad \frac{m2\pi}{(2.5\times10^{-4})} = (1.6\times10^{-19})(5.6\times10^{-2})$

$\boxed{m = 3.57\times10^{-2}\text{ kg}}$

11. When a charged magnetic particle enters a uniform magnetic field, it moves in a circular path as shown in the diagram.



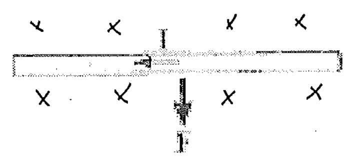

a. Determine the polarity of the particle. (+) RHR needed

b. If the magnetic field has a magnitude of 0.20 T, ∴ (+) the particle's charge has a magnitude of $1.8 \times 10^{-19}$ C, its speed is $3.0 \times 10^5$ m/s, and the radius of its path is 0.40 m, find the mass of the particle. ($4.8 \times 10^{-26}$ kg)

$\frac{mv}{r} = qB$

$\frac{m(3.0\times10^5)}{0.40} = (1.8\times10^{-19})(0.20) \quad m = 4.8\times10^{-26}\text{ Kg}$

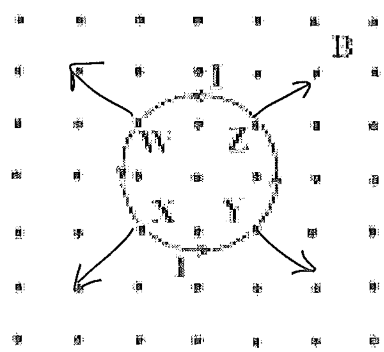
12. A current carrying wire is perpendicular to a magnetic field. Due to the presence of a magnetic field, the wire experiences a magnetic force toward the bottom of the page. What is the direction of the magnetic field? (x)



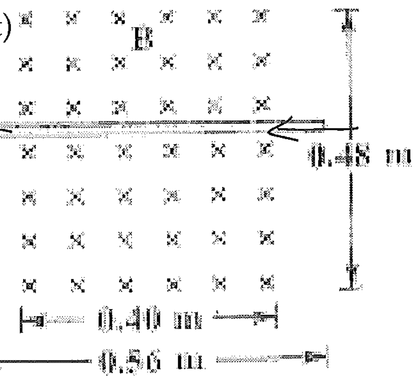

RHR → into page

13. The diagram shows current I flowing in a circular coil in a magnetic field B. Use arrows to show the direction of the magnetic force acting on the coil at each point W, X, Y and Z.

RHR



14. The diagram shows a current-carrying wire that is perpendicular to a magnetic field of 0.54 T. What is the magnitude and direction of the current that produces a 2.8 N force on the wire directed down the page? (13 A to the left)




$I \leftarrow$

$F_m = BlI$

$2.8 = (0.54)(0.40)I$

$I = \underline{13\,A}$ (to left)

use RHR

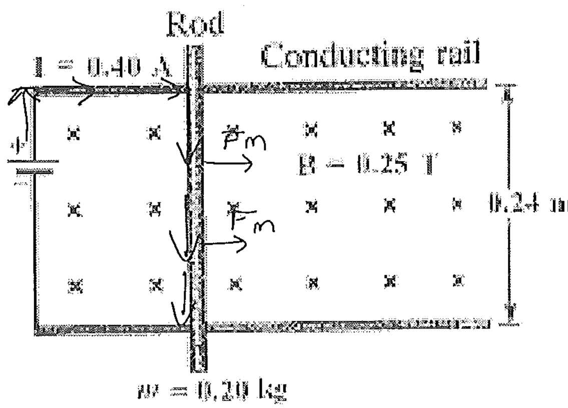
15. A 0.20 kg metal rod is lying on the horizontal top of two frictionless conducting rails. Find the magnitude and direction of the acceleration of the rod. (0.12 m/s² to right)

$F_m = BlI = (0.25)(0.24)(0.40)$

$= \underline{0.024\,N}$

$0.024 = (0.20)\vec{a}$

$\vec{a} = 0.12\ m/s^2$ to right




16. Calculate the magnitude and direction of the magnetic force on an alpha particle travelling upward at a speed of 2.11 x 10⁵ m/s through a magnetic field that it directed down. (0 N)

$\underline{\text{parallel}}$ $F_m = \underline{0\ N}$ $\uparrow\downarrow$

17. An electron experiences an upward force of 7.1 x 10⁻¹⁴ N when it is travelling 2.7 x 10⁵ m/s south through a magnetic field. What is the magnitude and direction of the magnetic field? (1.64 T [to the ~~right~~ LEFT])

$F_m = qvB$

$7.1\times10^{-14} = (1.6\times10^{-19})(2.7\times10^{5})B$

$B = 1.64\ T$ [to the right]

18. Calculate the downward acceleration of an electron that is travelling horizontally at a speed of 6.20 x 10⁵ m/s perpendicular to a horizontal magnetic field of 2.30 x 10⁻¹ T. (2.5 x 10¹⁶ m/s²)

$F_m = qvB = (1.6\times10^{-19})(6.2\times10^{5})(2.30\times10^{-1}) = 2.28\times10^{-14}\ N$

$2.28\times10^{-14} = (9.11\times10^{-31})\vec{a}$ $\vec{a} = 2.50\times10^{16}\ m/s^2$

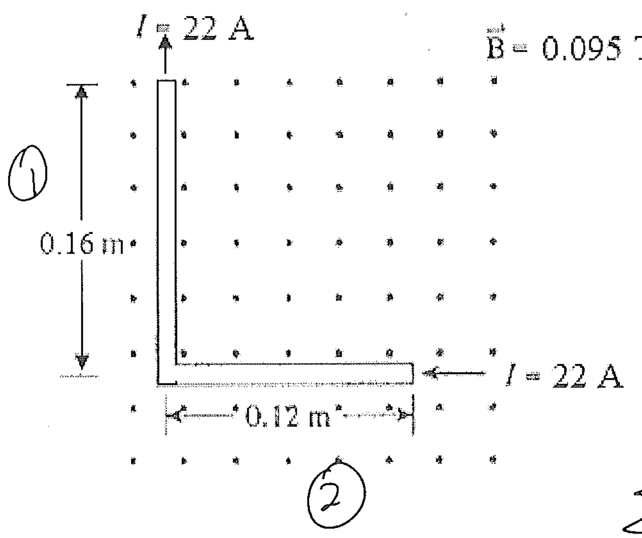
19. An electron is accelerated by a potential difference and then travels perpendicular through a magnetic field of $7.20 \times 10^{-1}$ T where it experiences a magnetic force of $4.1 \times 10^{-13}$ N. If it is assumed that this electron starts from rest, through what potential difference was it accelerated? (36 V)

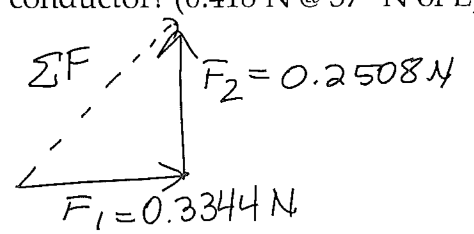
$4.1 \times 10^{-13} = (1.6 \times 10^{-19}) v (0.72)$ $\quad v = 3.56 \times 10^{6}$ m/s

$KE = \frac{1}{2}(9.11 \times 10^{-31})(3.56 \times 10^{6})^2 = 5.77 \times 10^{-18}$ J

$\Delta V = \dfrac{5.77 \times 10^{-18}}{1.6 \times 10^{-19}}$ $\quad \underline{\Delta V = 36 \text{ V}}$

20. What is the net magnetic force on the L-shaped conductor? (0.418 N @ 37° N of E)




$F_1 = BlI = (0.095)(0.16)(22) = 0.3344$ N

$F_2 = BlI = (0.095)(0.12)(22) = 0.2508$ N

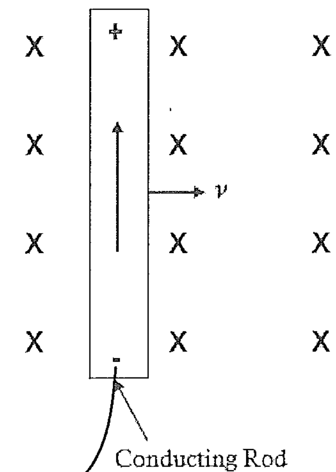
$\Sigma F = \sqrt{0.3344^2 + 0.2508^2}$
$= 0.418$ N @ 37° N of E

# Physics 12 – **Magnetic Induction**

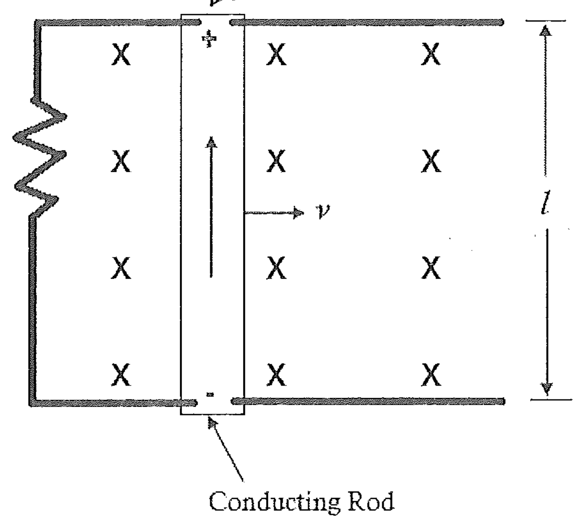
Oerstad determined that ***an electric current will produce a magnetic field***. So the next logical step was to determine if ***a magnetic field could produce an electric current***. Faraday and Henry both independently determined that this was possible.

One way to use a magnetic field to produce an electric current is to move a conducting rod through a magnetic field. How does this work?

* An EMF is induced in the rod (charges move inside the rod = one end is ⊕ and the other ⊖)




If this conducting rod is then made part of an electric circuit, it will act like a battery (a voltage source), causing charge to move in the circuit just as any battery with an EMF would.

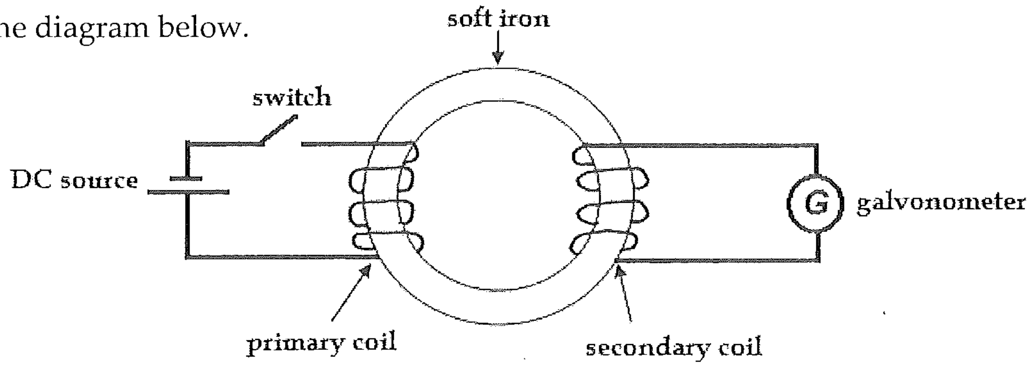



= movement of charge = current

The process of producing an EMF in a conductor by use of a magnetic field is known as **electromagnetic induction**.

> **Electromagnetic Induction** – When a conductor in which an EMF is induced is part of a circuit, the induced EMF will cause a charge to flow through the conductor. This flow of charge is called an **induced current**.

Faraday discovered that he could produce an electric current by using an induction coil as shown in the diagram below.

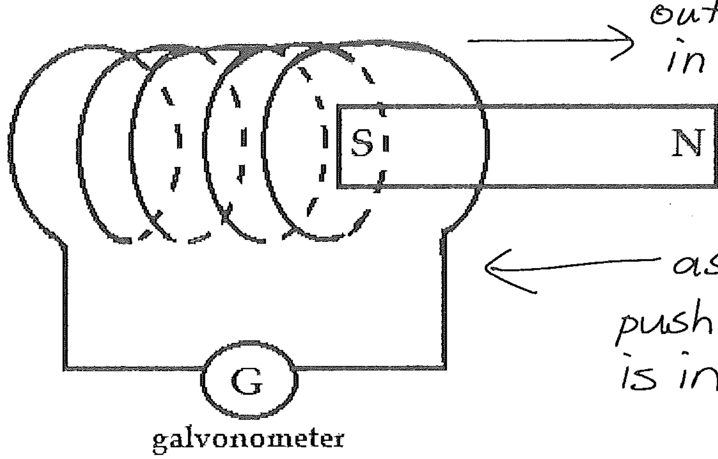



He found that when the switch of his induction coil was being closed or opened, the galvanometer deflected. This indicated that there was a brief current through the secondary coil.

**One of the key discoveries in this experiment was that while the switch was being closed, the galvanometer deflected in one direction, but while the switch was being opened, the deflection was in the opposite direction.**

In a similar experiment, you can connect a galvanometer to an air core solenoid and move a magnet in and out of the solenoid.

as the magnet is pulled out, the deflection is in one direction




as the magnet is pushed in, the deflection is in the other direction.

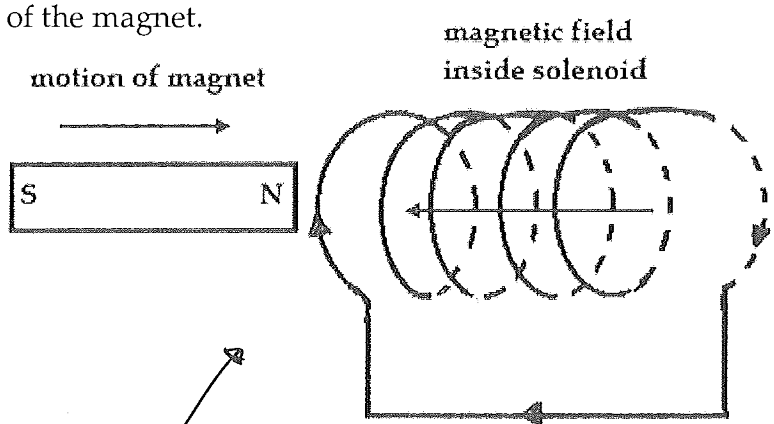
The direction of the induced current can be determined using Lenz's Law.

**Lenz's Law states:** the induced current flows in a direction as to produce a magnetic force that opposes the direction of the applied force (motion)

*KEY

Lenz's Law is really an application of the law of conservation of energy. Energy cannot be created. You cannot get electrical energy from nothing. It must come from somewhere.

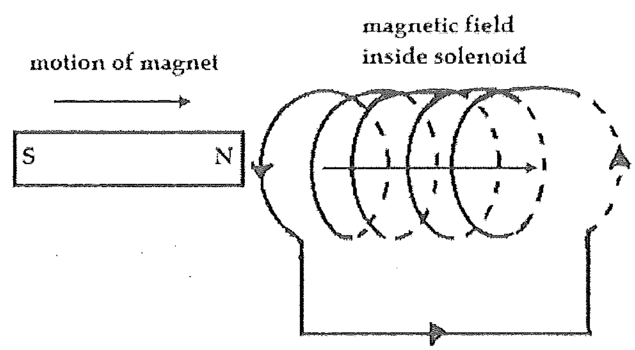
When a magnet is pushed into the coil, a current is induced in the coil. Lenz's Law tells us that the current flows in such a way that the magnetic field inside the coil opposes the magnetic field of the magnet.




According to the Right Hand Rule, when your thumb points in the direction of the North Pole, your fingers point in the direction that the **conventional current** must flow through the windings of the coil.

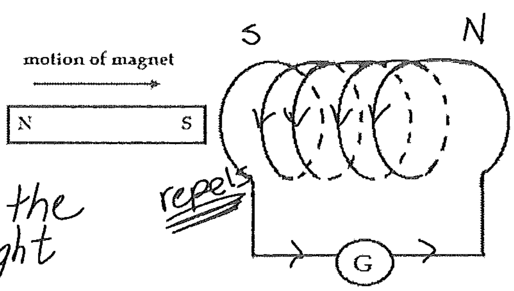
**This field opposes the magnetic field of the magnet. If this was not the case and the magnetic field in the coil did not oppose the magnetic field of the magnet, <u>you would be getting energy from nothing.</u>** WHY?

If the current in the conductor is as shown in the diagram, the magnetic field would attract the magnet. Therefore, no work (NO ENERGY) would be required to slide the magnet into the coil, but electrical energy would be produced → this is energy from nothing and impossible!



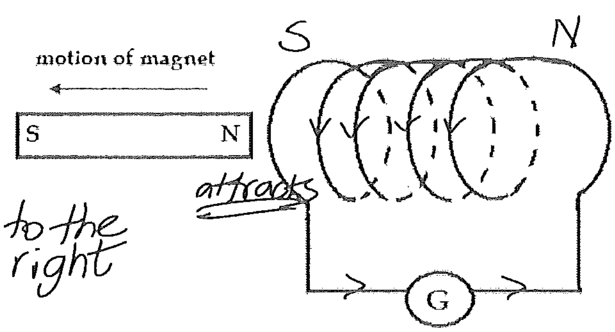

Examples: Find the direction of the induced current through G in the following diagrams.

A.



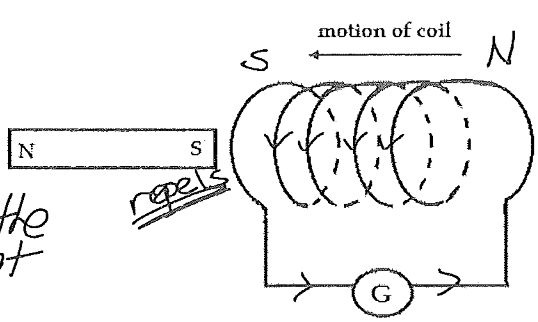

to the right

B.




to the right

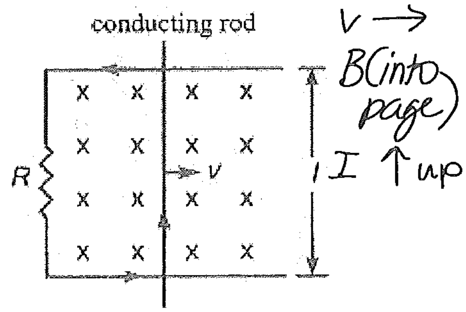
C.




to the right

If a conducting rod is moved through a magnetic field, the magnetic field of the induced current must oppose the magnetic field that produced the induced current – again, this illustrates **Lenz's Law.**

We can use the Right Hand Rule to determine the direction of the induced current in this scenario. =counterclockwise current



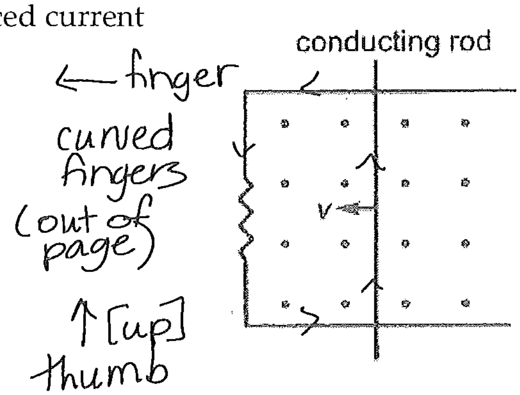

**Pointer Finger** – velocity direction

**Curved Fingers** – magnetic field

**Thumb** – direction of current

**Example**: What is the direction of the induced current in the following scenario?

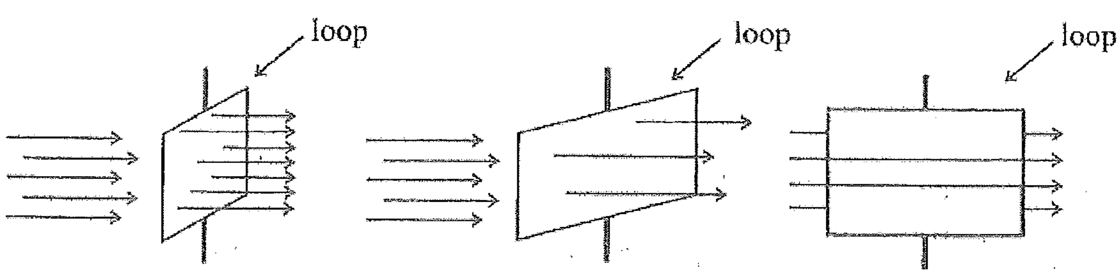
counterclockwise




## Magnetic Flux

Magnetic flux is defined in terms of magnetic field lines. Recall that the density of these lines represents the magnetic field strength.

The **magnetic flux** through a loop **depends on** the <u>orientation (the angle) of the loop</u>, <u>the magnetic field strength (field lines)</u> and the <u>area of the loop.</u>




$\theta = 0$ $\qquad$ $\theta > 0$ but $< 90°$ $\qquad$ $\theta = 90°$

**The magnetic flux depends on the number of field lines that pass through the loop**. When the field lines are perpendicular to the plane of the loop, there will be more lines passing through the loop. Conversely, when the field lines are parallel to the plane of the loop, there are no lines that pass through.

**Magnetic Flux** –

$$\boxed{\Phi = BA\cos\theta}$$

B = field strength (T)
A = area of loop ($m^2$)
$\theta$ = angle of field to the perpendicular

Units - T•$m^2$ or webers (Wb)

Faraday's explained how an induced current is produced by using a magnetic field through a changing magnetic flux.

– faster the change, the greater the induced current

The induced current depends on the rate of change of the magnetic flux. The induced current also depends on the induced EMF.

$$\mathcal{E} \propto \frac{\Delta\Phi}{\Delta t}$$

The formula we use quite often when dealing with induced currents is an algebraic expression of Faraday's Law of Induction -

$$\boxed{\mathcal{E} = -N\frac{\Delta\Phi}{\Delta t}}$$

- the negative sign relates to Lenz's Law (opposing forces)
- N → # of loops in the coil involved

*this is the basis of electric generators

**Example 1**: A square loop of wire is perpendicular to a 1.50 T magnetic field. If each side of the wire is 2.10 cm, what is the magnetic flux through the loop?

$A = (0.021)(0.021) = 4.41 \times 10^{-4}\ m^2$

$\Phi = BA\cancel{\cos\theta}$
$= (1.50)(4.41 \times 10^{-4}) = 6.62 \times 10^{-4}$ Wb

**Example 2:** A 1.80 cm diameter circular coil that contains 50 turns of wire is perpendicular to a 0.250 T magnetic field. If the magnetic field is reduced to zero in a time of 0.100 s, what is the average induced EMF in the coil?

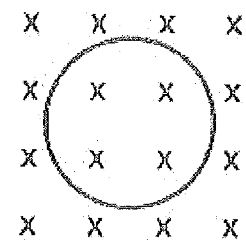
$\Delta\Phi = \Phi_f - \Phi_0 = 0 - (0.250)(\pi \cdot 0.009^2)$
$= -6.36 \times 10^{-5}$ Wb

$\mathcal{E} = -N\frac{\Delta\Phi}{\Delta t} = -50\left(\frac{-6.36 \times 10^{-5}}{0.100}\right)$
$= 3.18 \times 10^{-2}$ V

$B_o$

**Example 3**: A circular loop of wire (radius = 2.5 cm) is placed in a magnetic field (B=0.020 T), as shown in the diagram as shown in the diagram. This field is then decreased to 0.010 T in 0.10s.

$B_F$



a) What is the average EMF induced in the loop?

b) What is the direction of current through the loop?

a) $\mathcal{E} = -N\left(\frac{\Delta\Phi}{\Delta t}\right)$

$$\Delta\Phi = (0.010)(1.96\times10^{-3}) - (0.020)(1.96\times10^{-3})$$
$$= \underline{-1.96\times10^{-5}\ V}$$

$$A = \pi(0.025)^2$$
$$= 1.96\times10^{-3}\ m^2$$

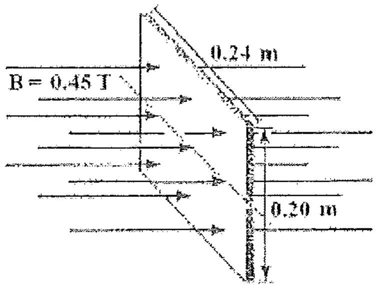
b) use RHR → thumb into page (x)
& curved fingers = direction of conventional current

= <u>clockwise</u>

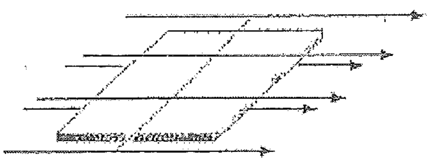
**Induced Current and Magnetic Flux Problems:**

1. The diagram below shows a rectangular coil with 200 turns and dimensions 0.24 m by 0.20 m. Its plane is perpendicular to a magnetic field with magnitude 0.45 T. The coil rotates 90° in 0.12 s so that its plane is now parallel to the magnetic field.

$$\Delta\Phi = 0 - (0.45)(0.24 \cdot 0.20)$$
$$= -0.0216 \text{ Wb}$$




Initial



Final

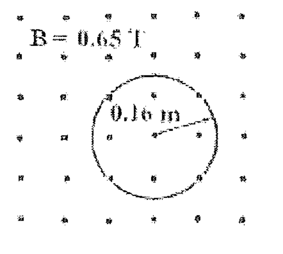
a) What is the magnitude of the induced EMF? (36 V)

$$\mathcal{E} = -200\left(\frac{-0.0216}{0.12}\right) = \underline{36 \text{ V}}$$

b) If the coil has a total resistance of 40 Ω, what is the current induced in the coil? (0.90 A)

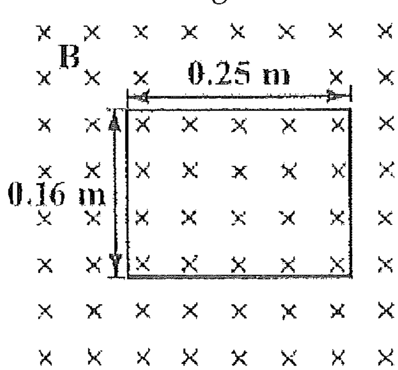
$$V = IR \qquad 36 = I(40) \qquad I = \underline{0.90 \text{ A}}$$

2. A 0.65 T magnetic field passes through a circular coil of radius 0.16 m. Find the magnitude of the magnetic flux through the coil. (0.0523 Wb)




$$\Phi = BA = 0.65(\pi \cdot 0.16^2)$$
$$= 0.0523 \text{ Wb}$$

3. The magnetic flux through the surface of a rectangular coil measuring 0.25 m by 0.16 m is 2.4 x $10^{-3}$ Wb when the coil is placed perpendicular to a magnetic field. Find the strength of the magnetic field. (0.060 T)




$$2.4 \times 10^{-3} = B(0.25 \cdot 0.16)$$
$$B = \underline{0.060 \text{ T}}$$

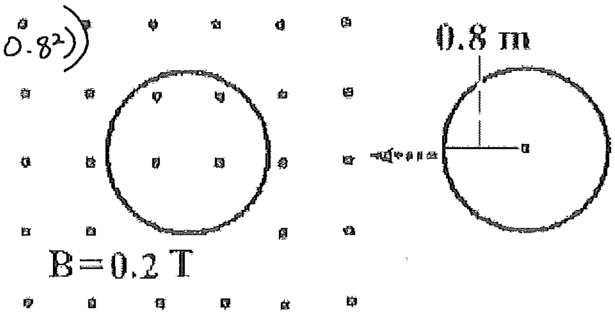
4. When a single coil with a radius of 0.80 m of resistance 2.8 Ω is pulled a distance of 0.30 m into a perpendicular 0.20 T magnetic field, an average current of 0.40 A current is produced in the coil. Find the speed with which the coil was pulled. (0.836 m/s) $\mathcal{E} = IR$

$= (0.40)(2.8)$

$= 1.12\,V$

$-1.12 = -1\dfrac{(0.20\cdot(\pi\cdot 0.8^2))}{\Delta t}$

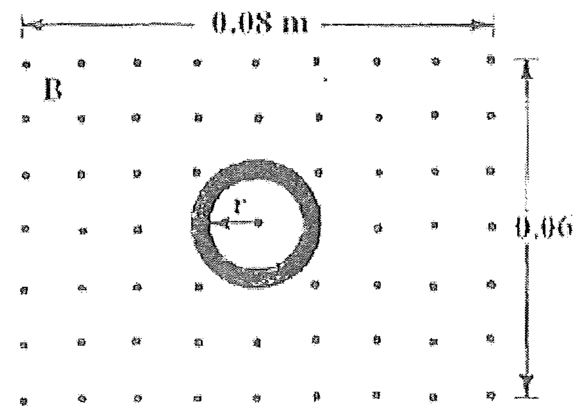
$\Delta t = 0.359\,s$




$v = \dfrac{d}{t} = \dfrac{0.30\,m}{0.359\,s}$

$v = 0.836\,m/s$

5. A coil with 800 loops of radius 0.01 m is placed with its plane perpendicular to a uniform 0.16 T magnetic field as shown in the diagram.




a) If the coil rotates 90° in 0.40 s so that's its plane is now parallel to the magnetic field, what is the average EMF induced in the coil? (0.10 V)

b) If the magnetic field changes from 0.16 T to 0.04 T in the opposite direction in 0.80 s, what is the average EMF induced in the coil? (6.3 x $10^{-2}$ V)

c) If the coil moves to the right by 0.01 m in 0.60 s within the magnetic field, what is the average EMF induced in the coil? (0 V)

a) $\mathcal{E} = -800\left(\dfrac{0 - (0.16)(\pi\cdot(0.01)^2)}{0.40}\right)$ $\quad \mathcal{E} = 0.101\,V$

b) $\mathcal{E} = -800\left(\dfrac{-(0.04)(0.01^2\pi) - (0.16)(0.01^2\pi)}{0.80}\right)$ $\quad \mathcal{E} = 6.28\times10^{-2}\,V$

c) same B so no change in flux = $\mathcal{E} = 0\,V$

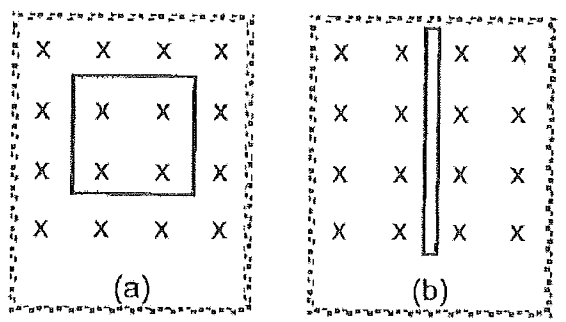
6. A magnetic field (B = 3.2 x $10^{-3}$ T) passes perpendicular through a circular loop of wire (radius = 5.0 cm). What is the magnetic flux through the loop? (2.51 x $10^{-5}$ Wb)

$\Phi = BA = (3.2\times10^{-3})(\pi\cdot(0.05)^2) = 2.51\times10^{-5}\,Wb$

7. A circular coil with 200 turns and a radius of 6.0 cm is rotated in a uniform magnetic field ($B = 3.6 \times 10^{-4}$ T). At $t = 0$, the coil is perpendicular to the field, and at $t = 0.015$ s, the coil is parallel to the field. What is the average EMF induced in the coil? ($5.43 \times 10^{-2}$ V)

$$\mathcal{E} = -200\left(\frac{0-(3.6\times10^{-4})(\pi\cdot(0.06)^2)}{0.015}\right) \qquad \mathcal{E} = \underline{5.43\times10^{-2}\ \text{V}}$$

8. A square-shaped piece of wire with an area of $2.5 \times 10^{-3}$ $m^2$ is perpendicular to a uniform magnetic field ($B = 2.2 \times 10^{-2}$ T) as shown in the diagram (a).



area= $2.5 \times 10^{-3}$ $m^2$ collapsed (area = 0)

$$\mathcal{E} = -1\left(\frac{0-(2.2\times10^{-2})(2.5\times1}{0.100}\right.$$

$$\mathcal{E} = \underline{5.5\times10^{-4}\ \text{V}}$$

If the square collapses in time of 0.100 s, as shown in diagram (b) above, what is the average induced EMF as it collapses? ($5.5 \times 10^{-4}$ V)

9. Find the average EMF induced in a circular coil with 50 turns and a radius of 0.050 m if the magnetic flux through the loops is changing at a rate of 15.0 Wb/s? (-750 V)

$$\mathcal{E} = -50(15.0) \qquad \mathcal{E} = \underline{-750\ \text{V}}$$

10. A square-shaped coil with 100 turns (area of each square loop = $4.0 \times 10^{-3}$ $m^2$) is perpendicular to a uniform magnetic field. When the coil is rotated through 90° in 0.12 s, the average induced EMF is 0.92 V. What is the magnetic field strength? (0.276 T)

$$0.92 = -100\left(\frac{0-(B)(4.0\times10^{-3})}{0.12}\right) \qquad B = \underline{0.276\ \text{T}}$$

11. A circular coil with 10 turns and a diameter of 25 cm is placed perpendicular to a uniform magnetic field ($B = 2.7 \times 10^{-3}$ T). If the direction of the magnetic field is reversed in 0.30 s, what is the average EMF induced in the coil? ($8.8 \times 10^{-3}$ V)

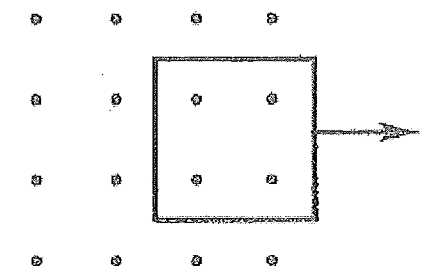
$$\mathcal{E} = -10\left(\frac{(-2.7\times10^{-3}\cdot\pi\cdot(0.125)^2)-(2.7\times10^{-3}\cdot\pi\cdot(0.125)^2)}{0.30}\right)$$

$$\mathcal{E} = \underline{8.8\times10^{-3}\ \text{V}}$$

12. A magnet is quickly removed from a circular coil (25 turns, area = 5.0 x $10^{-3}$ $m^2$). This changes the magnetic field within the coil at a rate of 0.40 T/s. What is the average EMF induced in the coil? (0.05 V)

$$\mathcal{E} = -25\left(0 - (5.0\times10^{-3})(0.40)\right) = \underline{0.05\,V}$$

13. A square-shaped piece of wire (area = 7.2 x $10^{-3}$ $m^2$), as shown in the diagram below, has a resistance of 12.0 Ω. Assume that the magnetic field drops uniformly from 1.6 T to 0 T in 0.050 s as the loop is pulled from the magnetic field.



a) What is the average EMF induced in the loop? (0.23 V)

b) What is the current induced in the loop? (1.92 x $10^{-2}$ V)

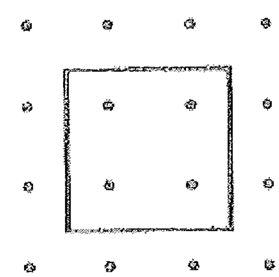
c) What is the direction of the electron flow in the loop? (clockwise)

a) $\mathcal{E} = -1\left(0 - \frac{(1.6)(7.2\times10^{-3})}{0.050}\right) = \underline{0.23\ V}$

b) $0.23 = I(12)$ $\quad I = \underline{1.92\times10^{-2}\ A}$

c) LHR → clockwise

14. A square-shaped piece of wire (4.0 cm per side), as shown in the diagram below, is placed in a magnetic field (B = 0.20 T). The magnetic field is increased to 0.50 T in 0.30 s.



a) Find the current through the loop if the resistance of the loop is 2.0 Ω. (8.0 x $10^{-4}$ A)

b) Find the direction of the electron flow through the loop. (counter clockwise)

a) $\mathcal{E} = -1\left(\frac{(0.50)(0.04^2) - (0.20)(0.04^2)}{0.30}\right)$

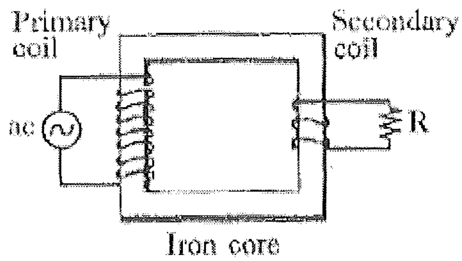
$\mathcal{E} = -0.0016\,V = I(2.0)$ $\quad I = \underline{8.0\times10^{-4} A}$

b) LHR → clockwise

Physics 12 – **Transformers**

Transformers are another important application of electromagnetic induction. A **transformer** is a device that is used to convert a potential difference to a higher or lower value.

A transformer consists of a primary coil of $N_P$ turns and a secondary coil of $N_S$ turns.




The changing magnetic flux due to an AC voltage in the primary induces an AC voltage in the secondary.

**Step-up Transformer –** Used to **increase** the potential difference.

$N_S$ is greater than $N_P$ ⇝ $V_S > V_P$
(more coils)

**Step–down Transformer –** Used to **decrease** the potential difference.

$N_P$ is greater than $N_S$ ⇝ $V_P > V_S$

Although a transformer will increase or decrease the voltage, energy is conserved – you cannot get something for nothing. Energy must be conserved.

Transformer Equation: $$\boxed{\frac{V_P}{V_S} = \frac{N_P}{N_S}}$$

*if Energy is conserved, then power output must equal power input.

$$I_P V_P = I_S V_S$$

$$\frac{I_S}{I_P} = \frac{N_P}{N_S} \quad \text{or} \quad \boxed{\frac{I_S}{I_P} = \frac{N_P}{N_S} = \frac{V_P}{V_S}}$$

From this we can see that as the number of turns increases, the voltage increases, but the current decreases.

In the problems that we will deal with, we will assume that the transformers are *ideal*. That is, no electrical energy is converted to other forms. The efficiency of transformers are usually very high.

**Example 1:** A step-up transformer is used to convert 1.20 x $10^2$ V to 1.50 x $10^4$ V. If the primary coil has 24 turns, how many turns does the secondary coil have?

$$\frac{V_P}{V_S} = \frac{N_P}{N_S} \qquad \frac{120}{1.5 \times 10^4} = \frac{24}{N_S} \qquad \underline{N_S = 3000 \text{ turns}}$$

**Example 2:** A set-up transformer has 1000 turns on its primary coil and 1.0 x $10^5$ turns on its secondary coil. If the transformer is connected to a 120 V power line, what is the step-up voltage?

$$\frac{V_P}{V_S} = \frac{N_P}{N_S} \qquad \frac{120}{V_S} = \frac{1000}{1.0 \times 10^5} \qquad \underline{V_S = 1.2 \times 10^4 \text{ V}}$$

**Example 3:** A step-down transformer reduces the voltage from 120 V to 12.0 V. If the primary coil has 500 turns and draws 3.0 x $10^{-2}$ A,

a) What is the power delivered to the secondary coil?

b) What is the current in the secondary coil?

a) $$\frac{V_P}{V_S} = \frac{I_S}{I_P} \qquad \frac{120}{12.0} = \frac{I_S}{3.0 \times 10^{-2}}$$

b) $I_S = 0.30\text{A}$

$$P_S = (0.30)(12.0) = 3.6\text{W}$$

**Power Transmission** – One major application of transformers is in the transmission of electric power. At the power generation plant, there are step-up transformers that will increase the voltage to a very high voltage (100000 V to 500000 V). At the user end (ie. our houses), there are step-down transformers to reduce the voltage to 120 V before any electric power enters our homes or buildings.

Why? **Reason 1** – As we increase voltage, current decreases ($P = IV$)

*with less current, less heat is produced by any resistance = less electric energy/power lost

**Reason 2** - There is a limit to the amount of current that flows through a wire safely.

**Transformers and Power Transmission Problems:**

1. Currents of 0.25 A and 0.95 A flow through the primary and secondary coils of a transformer, respectively. If there are 1.0 x $10^3$ turns in the primary coil, how many turns are in the secondary coil? (263) $\frac{N_P}{N_S} = \frac{I_S}{I_P}$ $\frac{1000}{N_S} = \frac{0.95}{0.25}$ $N_S = \underline{263 \text{ turns}}$

2. A step-down transformer has coils of 1.20 x $10^3$ and 1.50 x $10^2$ turns. If the transformer is connected to a 1.20 x $10^2$ V power line and the current in the secondary coil is 5.00 A, what is the current in the primary coil? (0.625 A) $\frac{N_P}{N_S} = \frac{I_S}{I_P}$ $\frac{1200}{150} = \frac{5.0}{I_P}$ $I_P = 0.625A$

3. Near Nick's home, the voltage of the power line is 3.6 x $10^3$ V. The transformer between his home and the line reduces this voltage to 1.20 x $10^2$ V. If the transformer is to deliver 2.4 x $10^3$ J of energy each second to Nick's home, what is the current in;

a) The primary coil? (0.67 A) $P_S = I_S V_S$ $\frac{2400}{1} = I_S(120)$

b) The secondary coil? (20 A) $\frac{V_P}{V_S} = \frac{I_S}{I_P}$ $\frac{3600}{120} = \frac{20}{I_P}$ $I_S = \underline{20 \text{ A}}$

$I_P = \underline{0.67 \text{ A}}$

4. A step-down transformer ($N_P$ = 1.50 x $10^2$, $N_S$ = 25) is connected to a 1.20 x $10^2$ V primary line. If there is a 75 Ω electrical device placed in the secondary circuit, what is the current in the primary coil? (0.27 A) $V_S = 20 \text{ V}$

$\frac{N_P}{N_S} = \frac{V_P}{V_S}$ $\frac{150}{25} = \frac{120}{V_S} = \frac{0.27}{I_P}$ $20 = I(75)$ $\underline{I_S = 0.27A}$

$I_P = 4.5 \times 10^{-2} A$

5. If the voltage and current of the primary coil is 120 V and 3.0 A, what is the power delivered the secondary coil? (360 W) $= IV = (3.0)(120) = 360 \text{ W}$

$P_{in} = P_{out} = \underline{360W}$

6. If the power delivered to the secondary coil of a step-up transformer is 50.0 W from a 120 V power line, what is the current in the primary coil? (0.42 A)

$50 = I(120)$ $I = \underline{0.42 \text{ A}}$

7. A transformer ($N_P = 5.5 \times 10^2$, $N_S = 36$) is connected to a 120 V power line. If the current in the primary coil is 1.0 A, what is the power in the secondary coil? (120 W)

$P = IV = (1.0)(120)$ $\quad P_s = 120\,W$

8. A 100 W transformer ($N_S = 1500$) has an input voltage of 9.0 V and an output current of 0.65A. How many turns are there in the primary coil? (88) $\frac{N_P}{N_S} = \frac{I_S}{I_P}$ $\quad \frac{N_P}{1500} = \frac{0.65}{11.1}$

$P = IV$ $\quad 100 = I(9.0)$ $\quad I = 11.1\,A$

$N_P = 88$ turns

9. A transformer has 20 turns in the primary coil and 400 turns in the secondary coil. This transformer produces an output of 5000 V with a 0.02 A current.

$\frac{N_P}{N_S} = \frac{20}{400} = \frac{V_P}{5000} = \frac{0.02}{I_P}$

a) Determine the type of transformer. step-up transformer

b) What are the voltage and current in the primary coil? (250 V, 0.40 A)

b) $V_P = 250\,V$ $\quad I_P = 0.40\,A$

c) What is the power input? (100 W)

c) $P = IV = (0.40)(250) = 100\,W$

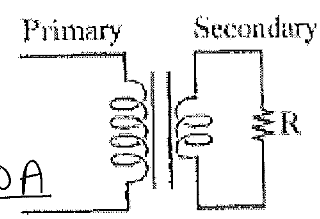
10. What acts on the secondary coil of a transformer to cause an EMF to occur across its ends even though the primary coil and secondary coil are not connected?

the changing current & magnetic field in the primary coil induces an EMF in the secondary coil

11. An ideal transformer has 1200 primary turns and 30 secondary turns. The input voltage of 120 V AC supplies power to the resistor, R, dissipating 24 W. Find the current in the primary coil and in the secondary coil. (0.20 A, 8.0 A)

$\frac{N_P}{N_S} = \frac{I_S}{I_P} = \frac{V_P}{V_S}$ $\quad \frac{1200}{30} = \frac{120}{V_S}$ $\quad V_S = 3.0\,V$

$24 = I_S(3.0)$ $\quad I_S = 8.0\,A$ $\quad \frac{1200}{30} = \frac{8.0}{I_P}$ $\quad I_P = 0.20\,A$




12. An electric device with a resistance of 6.0 Ω requires 9.0 V to operate. An ideal transformer is used to obtain this voltage from the standard 120 V AC.

a) Determine the type of transformer. step-down

b) $9.0 = I(6.0)$ $\quad I = 1.5\,A$

b) Find the current in the primary coil. (0.11 A) $P_S = P_P$ $\quad I_P(120) = (1.50)(9.0)$

$I_P = 0.11\,A$

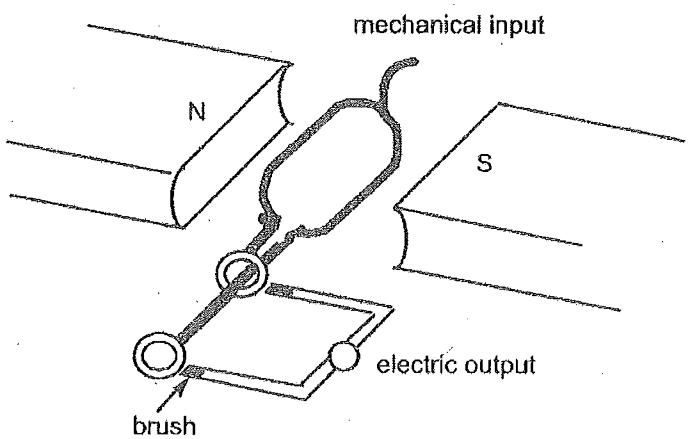
Physics 12 – **Electric Motors, Back EMF and Motional EMF**

We already know that batteries convert chemical energy into electrical energy. Electric generators are devices that convert mechanical energy into electrical energy. Generators make use of the principle of electromagnetic induction.

**Generators versus Motors:**

<u>**Generators**</u> – A loop of wire is rotated through a magnetic field (actually a number of loops are rotated). This changes the magnetic flux → induces an EMF → induces a current flow.

mechanical → electric energy




**Motors**: A current carrying conductor passes through the magnetic field. This interaction between magnetic fields causes the loop to rotate.

electric → mechanical energy

**Back EMF** – In an electric motor, there are loops of wire that are rotating in a magnetic field. These <u>**loops (called armature)**</u> rotate because of the interactions of magnetic fields. With this rotation, there is an induced EMF and an induced current.

**Direction** – the <u>induced EMF</u> will <u>oppose</u> the voltage across the motor (Lenz's Law)

= <u>Back EMF</u>

$$\boxed{V_{Back} = \mathcal{E} - Ir}$$

$\mathcal{E}$ = EMF supplied by power source

$I$ = current <u>when motor reaches full speed</u>

$r$ = resistance of motor

When a motor is first turned on, the loops are not yet rotating so there is no induced EMF. As the motor very quickly gains speed, the induced back EMF builds very quickly. When the motor is first turned on, the only voltage causing electrons to move is the voltage applied across the motor.

As the armature starts to rotate, the EMF opposes the voltage across the motor. This will **lower** the voltage in the wire loop circuit and therefore lowers the current drawn by the motor. ($V = IR$)

**When the motor reaches its full operating speed, the current drawn by the motor has decreased.**

**Example 1**: A 120 V motor draws 10.0 A when it reaches full operating speed. If the armature of this motor has a resistance of 5.2 Ω, what is the back EMF when it reaches its full operating speed?

$V_b = \mathcal{E} - Ir$

$= 120 - (10.0)(5.2)$

$V_b = \underline{68\ V}$

**Example 2:** A 120 V motor draws 12.0 A when a motor is operating at full speed. If the armature of this motor has a resistance of 6.0 Ω, what is

a) The current when the motor is initially turned on (remember no back emf)?

b) The back EMF when the armature reaches its full operating speed?

a) $0 = 120 - I(6.0)$ $\quad I = 20\ A$

b) $V_b = 120 - 12(6.0)$ $\quad V_b = 48\ V$

**Example 3**: A 120 V motor draws 3.50 A when it reaches its full operating speed. If it draws 15.0 A when it is initially turned on, what is,

a) The resistance of the armature? $0 = 120 - 15.0r$ $\quad r = \underline{8.0\ \Omega}$

b) The back EMF when it reaches its full operating speed?

$V_B = 120 - 3.50(8.0)$ $\quad V_B = \underline{92\ V}$

**Induced EMF on a Straight Conductor** - As we have seen, it is not only a loop of wire that is rotated in a magnetic field that produces an induced EMF. A straight conductor that is moved through a magnetic field will also induced an EMF.

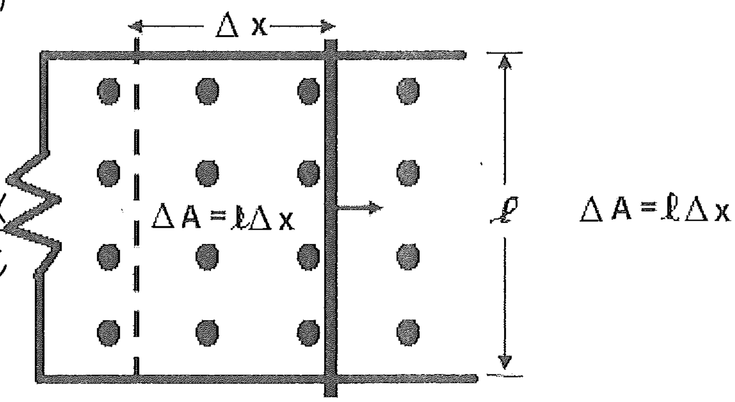
**Method One:** Faraday's Law of Induction:

$\Phi = B_\perp A$

$\mathcal{E} = \frac{\Delta\Phi}{\Delta t} = \frac{B_\perp \overbrace{\ell \Delta x}^{A}}{\Delta t}$ and $v = \frac{\Delta x}{\Delta t}$

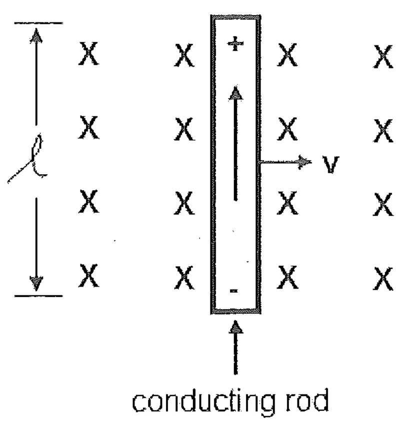
only the one conductor

$\therefore \boxed{\mathcal{E} = B_\perp \ell v}$




**Method Two:** based on the conducting rod experiencing a force → $F_M = qvB_\perp$

* since charge will move within rod
= potential difference
⊕ top & ⊖ bottom
(determined through RHR)




Work was done to move charge in rod

$W = F \cdot d$ or $\Delta E = F_m \cdot \ell$ ($\ell$ = length of rod)

$F_m = qvB_\perp$ and $\Delta E = q \cdot \Delta V$

$q \cdot \Delta V = qvB_\perp \cdot \ell$

$\mathcal{E} = B_\perp \ell v$

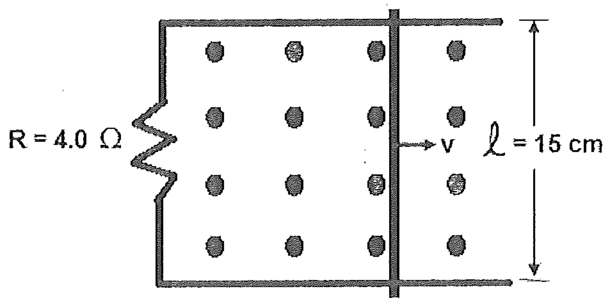
$\boxed{\mathcal{E} = B_\perp \ell \cdot v}$

for conducting rod

**Example 1:** A conducting rod 25.0 cm long moves perpendicular to a magnetic field (B=0.20T) at a speed of 1.0 m/s. Calculate the induced EMF in the rod.

$$\mathcal{E} = B\ell v = (0.20)(0.25)(1.0) = \underline{0.05\,V}$$

**Example 2:** The conducting rod in the diagram below is 15 cm long and is moving at a speed of 2.0 m/s perpendicularly to a 0.30 T magnetic field. If the resistance in the circuit is 4.0 Ω, what is the magnitude and direction of the current through the circuit?




$$\mathcal{E} = B\ell v = (0.30)(0.15)(2.0) = 0.09\,V$$

$$V = IR$$

$$0.09 = I(4.0) \qquad \boxed{I = 2.25 \times 10^{-2}\,A}$$

direction: RHR

- fingers out of page
- index →
- ↓ thumb

$\boxed{\text{clockwise}}$

**Back EMF and Motional EMF Problems:**

1. A DC motor is connected to a 120 V power supply and draws a current of 12 A when it first starts up. At its normal operating speed, the motor draws a current of 3.0 A.

a) Find the resistance of the motor's armature. (10Ω) $0 = 120 - 12r \quad r = \underline{10\,\Omega}$

b) Find the back EMF when the motor first starts up. (0V) $= \underline{0V}$ (no back EMF)

c) Find the back EMF when the motor is running at normal. (90V) $V_b = 120 - 3.0(10)$ $= \underline{90V}$

2. A motor is connected to a 12.0 V power supply and develops a back EMF of 3.2 V when rotating at normal speed. When the armature is prevented from rotating, the current is 3.0 A.

a) Find the resistance of the armature. (4.0 Ω) $0 = 12 - 3.0r \quad r = \underline{4.0\,\Omega}$

b) Find the current in the motor at its normal speed. (2.2 A) $3.2 = 12 - I(4.0)$ $I = \underline{2.2\,A}$

3. A 120 V motor draws 9.0 A when it reaches full operating speed. If the resistance of the armature is 5.0 Ω, what is the

a) back EMF when the motor is operating at full speed? (75 V) a) $V_b = 120 - (9.0)(5.0)$ $V_b = \underline{75\,V}$

b) back EMF when the motor is initially turned on? (0 V) b) 0 V

c) current when the motor is initially turned on? (24 V) c) $0 = 120 - I(5.0)$ $I = \underline{24\,V}$

4. The armature of a 120 V motor slows down because of an increased load (for example, an electric lawnmower enters thick, tall grass). The resistance of the armature is 6.0 Ω, and the current drawn by the motor when operating at full speed is 3.6 A. The current drawn by the motor when the increased load is applied is 8.4 A.

a) Explain why the motor (armature) gets hotter when the increased load slows it down.

slows → = more current = more heat due to resistance

b) Explain why the current through the armature increases when the load is increased.

armature slows = $\downarrow V_b$

c) What is the back EMF when the motor is

i. operating at full speed (98.4 V) $V_b = 120 - (3.6)(6.0) \quad V_b = \underline{98.4V}$

ii. slowed down because of the increased load (70 V)

$V_b = 120 - (8.4)(6.0) \quad V_b = \underline{70\,V}$

5. The current drawn by a 120 V motor when the motor is turned on is 10.0 A and 3.0 A when it is at its full speed.

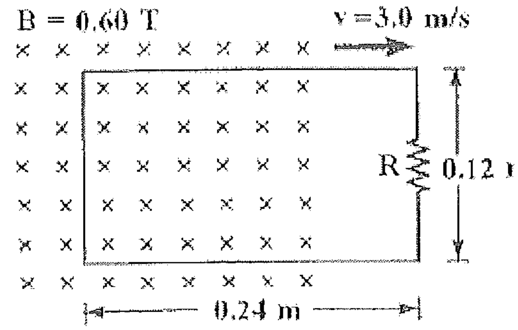
a) What is the resistance of the armature? (12Ω)

$0 = 120 - (10.0)(r)$ $\quad r = 12\,\Omega$

b) What is the back EMF when the motor is operating at full speed? (84 V)

$V_b = 120 - (3.0)(12)$ $\quad V_b = 84\,V$

6. A single rectangular loop of wire connected to a resistor R is pulled out of a magnetic field of 0.60 T at 3.0 m/s as shown in the diagram.



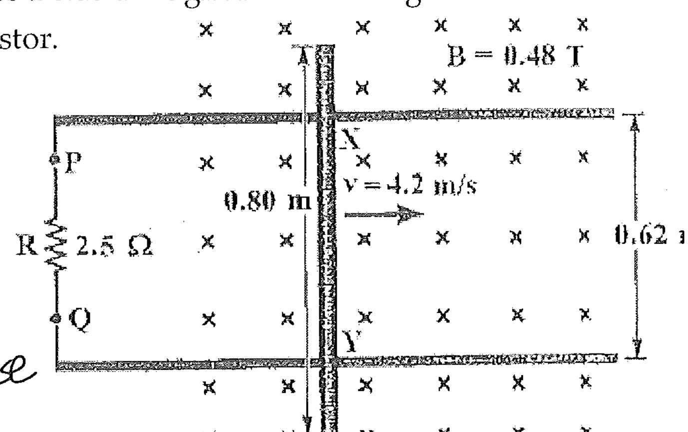

a) Find the EMF induced in the loop. (0.216 V)

b) If the resistor has a resistance of 0.40 Ω, find the magnitude and direction of the current in the loop. (0.54A [cw])

a) $\mathcal{E} = B\ell v = (0.60)(0.12)(3.0)$
$= 0.216\ V$

b) $0.216 = I(0.40)$
$I = 0.54\ A$ clockwise

7. A 0.80 m conducting rod is moved at 4.2 m/s across a 0.48 T magnetic field along conducting rails which are connected by a 2.5 Ω resistor.




a) Which end of the rod is positive? (Y)

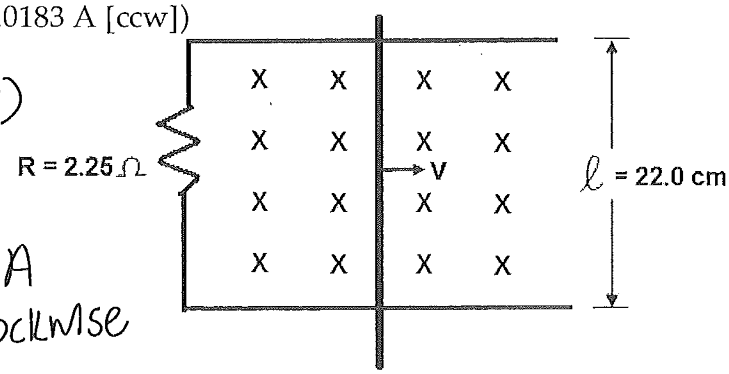
b) Find the magnitude and direction of the current through the resistor. (0.50 A [ccw])

$\mathcal{E} = B\ell v = (0.48)(0.62)(4.2) = 1.25\ V$

$1.25 = I(2.5)$ $\quad I = 0.50\ A$

counterclockwise

8. A conducting rod is 22.0 cm long. It is moving at a speed of 1.25 m/s perpendicular to a 0.150 T magnetic field. If the resistance in the circuit is 2.25 Ω, what is the magnitude and direction of the current through the circuit? (0.0183 A [ccw])



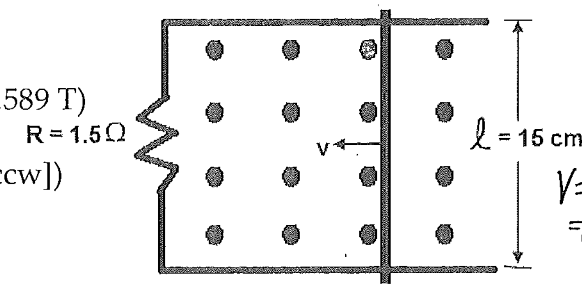

$\mathcal{E} = B\ell v = (0.150)(0.22)(1.25)$

$\mathcal{E} = 0.0413\,V$

$0.0413 = I(2.25)$ $\quad I = 0.0183A$

counterclockwise

9. The conducting rod in the diagram below is 15 cm long and is moving at a speed of 0.95 m/s perpendicular to the magnetic field. If the resistance in the circuit is 1.5 Ω and a current of $5.6 \times 10^{-2}$ A is induced in the circuit,



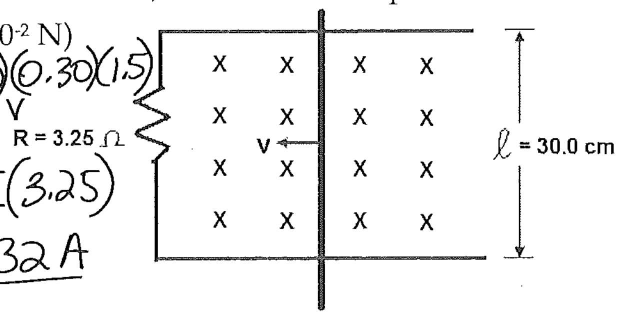

$V = (0.056)(1.5)$
$= 0.084\text{V}$

a) What is the magnitude of the magnetic field? (0.589 T)

b) What is the direction of the induced current? )[ccw])

a) $0.084 = B(0.15)(0.95)$ $B = 0.589\ T$
b) counterclockwise

10. The conducting rod in the diagram is 30.0 cm long and is moved perpendicular to a 0.950 T magnetic field. If the resistance in the circuit is 3.25 Ω, what force is required to move the rod at a constant speed of 1.50 m/s? ($3.76 \times 10^{-2}$ N)




$F_m = BlI$
$= (0.95)(0.30)(0.132)$
$= 3.76 \times 10^{-2}\ N$

$\mathcal{E} = (0.950)(0.30)(1.5)$
$= 0.428\ V$
$0.428 = I(3.25)$
$I = 0.132\ A$

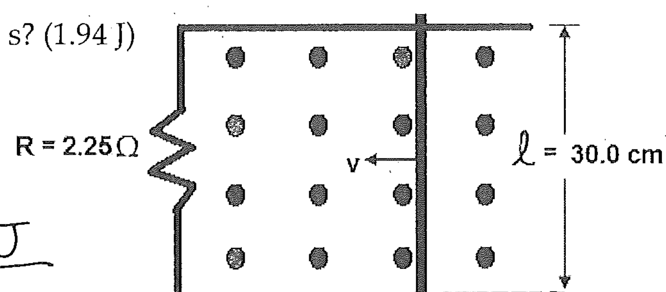
11. A plane with wing span of 6.25 m is flying horizontally at a speed of 95.0 m/s. Given that the vertical component of Earth's magnetic field is $4.70 \times 10^{-6}$ T, what is the induced EMF between the tips of the wings? ($2.79 \times 10^{-3}$ V) $\mathcal{E} = Blv = (4.7 \times 10^{-6})(6.25)(95.0)$
$= 2.79 \times 10^{-3}\ V$

12. The conducting rod in the diagram below is 30.0 cm long and is moving at a speed of 3.00 m/s perpendicular to a 0.600 T magnetic field. If the resistance in the circuit is 2.25 Ω, what is the electric energy dissipated in the resistor in 15.0 s? (1.94 J)

$\mathcal{E} = Blv = (0.60)(0.30)(3.0) = 0.54\ V$

$P = \frac{V^2}{R} = \frac{0.54^2}{2.25} = 0.130\ W$

$P = \frac{\Delta E}{t}$ $\quad 0.130 = \frac{\Delta E}{15}$ $\quad \Delta E = 1.94\ J$

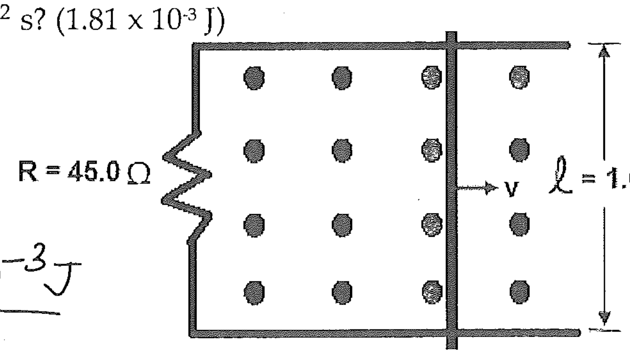



13. The conducting rod in the diagram is 1.0 m long. It is moved at a speed of 3.0 m/s perpendicular to a 0.95 T magnetic field. If the resistance in the circuit is 45.0 Ω, how much work is done against the magnetic field in $1.0 \times 10^{-2}$ s? ($1.81 \times 10^{-3}$ J)

$\mathcal{E} = (0.95)(1.0)(3.0) = 2.85\ V$

$P = \frac{2.85^2}{45.0} = 0.181\ W$

$P = \frac{\Delta E}{t}$ $\quad 0.181 = \frac{\Delta E}{1.0 \times 10^{-2}}$ $\quad W = \Delta E$
$= 1.81 \times 10^{-3}\ J$

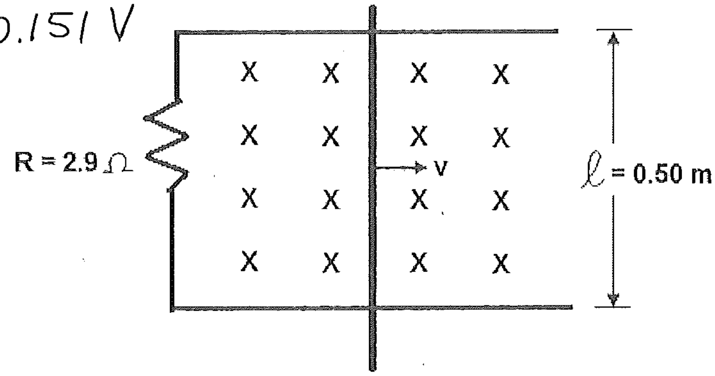


14. The conducting rod in the diagram is 0.50 m long. It is moved at a constant speed perpendicular to a 0.65 T magnetic field. If the resistance in the circuit is 2.9 Ω and the induced current is $5.2 \times 10^{-2}$ A, what is the speed of conducting rod? (0.464 m/s)

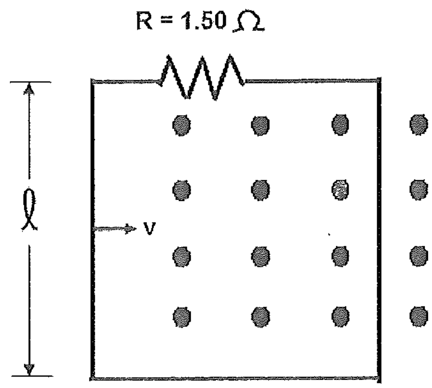
$V = IR = (5.2 \times 10^{-2})(2.9) = 0.151$ V

$0.151 = (0.65)(0.50)\,v$

$v = \underline{0.464 \text{ m/s}}$




15. A rectangular piece of wire is moved at a speed of 1.80 m/s perpendicular to a 1.30 T magnetic field, as shown in the diagram. If the length of the side moving perpendicular to the field is 0.625 m and the resistance in the circuit is 1.50 Ω,




a) What is the induced current? (0.975 A)

b) What is the direction of the current? ([ccw])

a) $\mathcal{E} = (1.3)(0.625)(1.80) = 1.46$ V

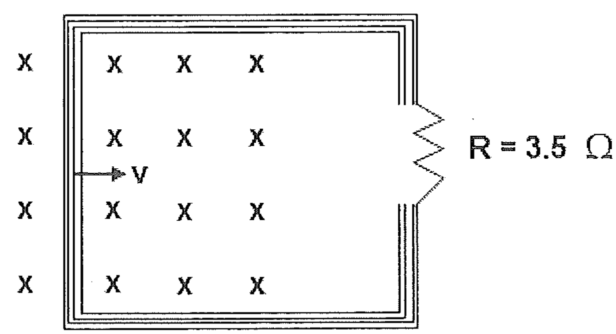
$1.46 = I(1.50)$   $I = \underline{0.975A}$

b) counter-clockwise

16. A rectangular piece of wire wound 5 times is moved at a speed of 2.7 m/s perpendicular to a 1.1 T magnetic field as shown below. If the length of the side of the wire moving perpendicular to the field is 0.18 m and the resistance in the circuit is 3.5 Ω,

a) What is the induced current? (0.764 A)

b) What is the direction of the current? ([cw])




a) $\mathcal{E} = 5(1.1 \cdot 0.18 \cdot 2.7)$

$= 2.67$ V

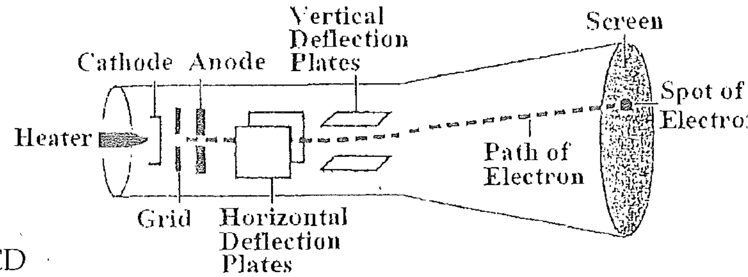
$2.67 = I(3.5)$   $I = \underline{0.764A}$

b) clockwise

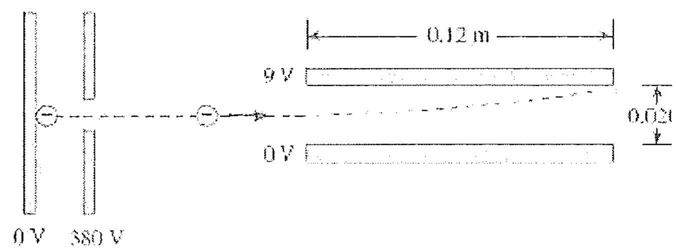
Physics 12 – **Applications of Electromagnetism**

## Cathode Ray Tube (CRT)

A cathode ray tube is a vacuum tube in which a beam of electrons is accelerated, deflected and displayed on a fluorescent screen. Cathode ray tubes are used in oscilloscopes, televisions and computer monitors. We are moving away from this as we develop new technologies such as LCD monitors.




**Example:** A beam of electrons is directed to a region between oppositely charged parallel plates as shown in the diagram.




a) The electron beam is produced by accelerating electrons through an electric potential difference of 380V. What is the speed of the electrons as they leave the 380 V plate?

$\Delta V = \frac{\Delta E}{q}$ $\quad 380 = \frac{\Delta E}{1.6\times10^{-19}}$ $\quad \Delta E = KE = 6.08\times10^{-17} = \frac{1}{2}(9.11\times10^{-31})v^2$

$v = 1.15\times10^{7}\ m/s$

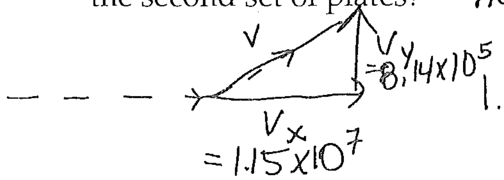
b) What is the electrostatic force on electrons in the region between the deflecting horizontal plates when they are connected to a 9.0 V potential difference?

$E = \frac{\Delta V}{d} = \frac{9}{0.020} = 450\ N/C$ $\quad E = \frac{F_e}{q}$ $\quad 450 = \frac{F_e}{1.6\times10^{-16}}$ $\quad F_e = 7.2\times10^{-17}\ N$

c) What is the acceleration of the electrons between the deflecting plates?

$7.2\times10^{-17} = (9.11\times10^{-31})\vec{a}$ $\quad \vec{a} = 7.9\times10^{13}\ m/s^2$

d) What is the final magnitude and direction of the velocity of the electrons as it leaves the second set of plates? horizontal: $V_x = \frac{d_x}{t}$




$1.15\times10^{7} = \frac{0.12}{t}$ $\quad t = 1.03\times10^{-8}\ s$

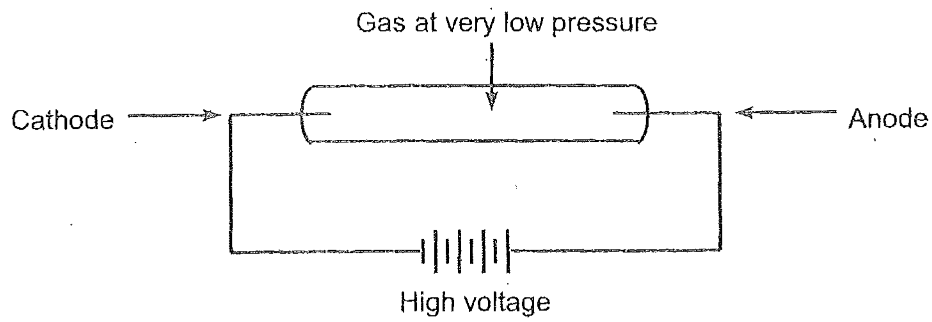
vertical: $\vec{a} = \frac{v_F - v_0}{t}$

$7.9\times10^{13} = \frac{V_F - 0}{1.03\times10^{-8}}$ $\quad V_F = 8.14\times10^{5}\ m/s$

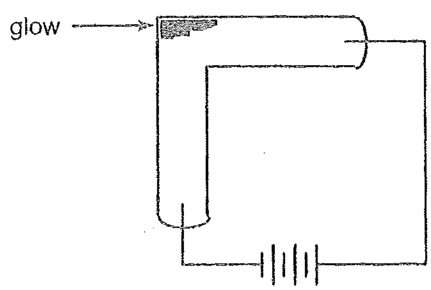
$V = \sqrt{(1.15\times10^7)^2 + (8.14\times10^5)^2}$
$= 1.15\times10^{7}\ m/s$ @ $4.0°$ N of E

## Cathode Rays:

In the late 1800s, the electron was discovered by J.J. Thomson, who was deflecting fast-moving electrons in a magnetic field. This was done to investigate an electric spark gap in a vacuum or in gases at very low pressure.



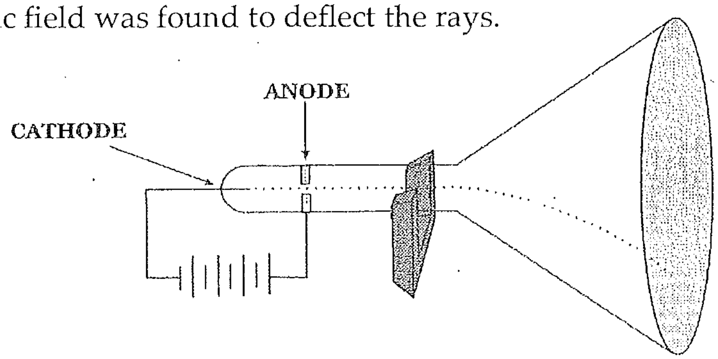

The term cathode ray is used because it was determined the discharge that was observed originated at the negative electrode (the cathode) as the tube glowed with greater intensity opposite the cathode.




J.J. Thomson determined that cathode rays were particles and these particles became known as electrons.

## The Thomson Experiment:

In Thompson's experiment in the late 1800s, cathode rays were passed through a magnetic field. The magnetic field was found to deflect the rays.




The anode is a circular disk with a hole in it. The electrons are accelerated between the cathode and the anode (this is referred to the electron gun or accelerator). Under high voltage, the electrons have a high kinetic energy when they reach the anode.

The beam of high speed electrons then pass through the hole in the anode. Once through the hole, they then pass through a magnetic field.

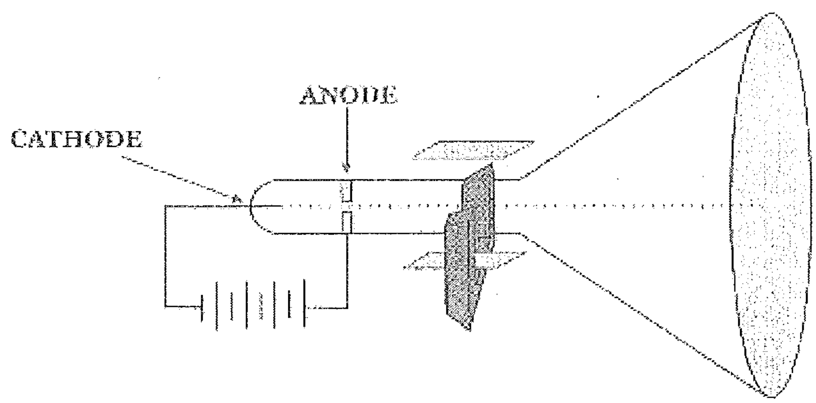
The electrons may be deflected up or down by the magnetic field. The deflection is in an arc as we learned last lesson. (circular motion due to the $F_M$ on the electron)

So... $F_C = F_M$ $\quad \frac{mv^{\cancel{2}}}{r} = q\cancel{v}B$ $\quad$ or $\quad \frac{q}{m} = \frac{v}{Br}$

It is the q/m that Thomson determined to be the charge-to-mass ratio for an electron. He could easily determine the r and B…but he still did not have the speed, the mass or the charge of the electron. (Remember – this is the discovery of it!)

Next, he adjusted the electrical and magnetic fields in the cathode ray gun so that they were equal, but in opposite directions resulting in no deflection and the electrons travelled in a straight line. Thomson obtained the speed of the electron as a ratio of the field strength.

No deflection
(both a magnetic field and an electric field)




$F_E = F_m \quad q\bar{E} = qvB_\perp$ $\qquad v = \frac{\bar{E}}{B_\perp}$

With v, B, and r, he could calculate the charge/mass ratio and **this was the first information about the make-up of an electron.**

**Example One:** Charged particles are travelling horizontally at $3.60 \times 10^6$ m/s when they enter a vertical magnetic field of $7.10 \times 10^{-1}$ T. If the radius of the arc of the deflected particles is $9.50 \times 10^{-2}$, m, what is the charge-to-mass ratio of the particles? $\boxed{F_m = F_c}$ $qvB = \frac{mv^2}{R}$

$$\frac{q}{m} = \frac{v}{Br} = \frac{3.60\times10^6}{(0.71)(9.5\times10^{-2})} = 5.34\times10^7 \ C/kg$$

charge-to-mass

**Example Two:** What is the speed of an electron that passes through an electric field of $6.30 \times 10^3$ N/C and a magnetic field of $7.11 \times 10^{-3}$ T undeflected? Assumed the electric and magnetic fields are perpendicular to each other. $\boxed{F_m = F_e}$ $\therefore$ $\cancel{q}vB = E\cancel{q}$

$$\boxed{v = \frac{E}{B_\perp}}$$ useful derivation

$$= \frac{6.30\times10^3}{7.11\times10^{-3}} = 8.86\times10^5 \ m/s$$

**Example Three:** An electron travelling vertically enters a horizontal magnetic field of $7.20 \times 10^{-2}$ T. If the electron is deflected in an arc of radius $3.70 \times 10^{-3}$ m, what is the kinetic energy of the electron?

$$\frac{q}{m} = \frac{v}{B_\perp r} \qquad \frac{1.6\times10^{-19}}{9.11\times10^{-31}} = \frac{v}{(7.2\times10^{-2})(3.7\times10^{-3})}$$

$$v = 4.68\times10^7 \ m/s$$

$$KE = \frac{1}{2}(9.11\times10^{-31})(4.68\times10^7)^2$$
$$= 9.97\times10^{-16} \ J$$

Applications of Electromagnetism – CRT Problems:

1. An alpha particle travels through a magnetic field of 4.22 x $10^{-1}$ T perpendicular to the field. If the radius of the arc of the deflected particles is 1.50 x $10^{-3}$ m, what is the speed of the particles? (3.05 x $10^{4}$ m/s)

$$\frac{mv}{r} = qB \qquad \frac{(6.65\times10^{-27})(v)}{1.5\times10^{-3}} = (3.20\times10^{-19})(4.22\times10^{-1})$$

$$v = 3.05\times10^{4}\ m/s$$

2. A proton travels through a magnetic field at a speed of 5.40 x $10^{5}$ m/s perpendicular to the field. If the radius of the arc of the deflected proton is 7.20 x $10^{-3}$ m, what is the magnetic field strength? (0.783 T)

$$\frac{mv}{r} = qB \qquad \frac{(1.67\times10^{-27})(5.4\times10^{5})}{7.2\times10^{-3}} = (1.6\times10^{-19})B$$

$$B = 0.783\ T$$

3. Calculate the charge-to-mass ratio of a particle that is travelling 3.60 x $10^{5}$ m/s and is deflected in an arc with a radius of 7.40 x $10^{-2}$ m as it travels through a perpendicular magnetic field of 6.10 x $10^{-1}$ T. (7.98 x $10^{6}$ C/kg)

$$\frac{q}{m} = \frac{v}{Br} = \frac{3.6\times10^{5}}{(0.61)(0.074)} = 7.98\times10^{6}\ m/s$$

4. Alpha particles travel undeflected through magnetic electric fields that are perpendicular to each other. The speed of the alpha particles is 7.80 x $10^{5}$ m/s and the strength of the magnetic field is 2.20 x $10^{-1}$ T. If it is assumed that the alpha particles are traveling perpendicular to these fields, what is the strength of the electric field? (1.72 x $10^{5}$ N/C)

$$v = \frac{E}{B} \qquad 7.8\times10^{5} = \frac{E}{0.220} \qquad E = 1.72\times10^{5}\ N/C$$

5. Positive charged particles travel undeflected through magnetic and electric fields that are perpendicular to each other. The magnetic field strength is $6.50 \times 10^{-1}$ T and the strength of the electric field is $2.10 \times 10^{5}$ N/C. If it is assumed the charged particles are travelling perpendicular to these fields, what is the speed of the particles? ($3.23 \times 10^{5}$ m/s)

$$V = \frac{\bar{E}}{B} = \frac{2.10 \times 10^{5}}{0.65} = \underline{3.23 \times 10^{5}\ m/s}$$

6. Alpha particles travel through a magnetic field of $3.60 \times 10^{-1}$ T and are deflected in an arc with a radius of $8.20 \times 10^{-2}$ m. If it is assumed that the alpha particles are travelling perpendicular to the field, what is the energy of each alpha particle? ($6.71 \times 10^{-15}$ J)

$$\frac{mV}{r} = qB \qquad \frac{(6.65 \times 10^{-27})(V)}{0.082} = (3.20 \times 10^{-19})(0.36)$$

$$V = 1.4 \times 10^{6}\ m/s \qquad KE = \frac{1}{2}(6.65 \times 10^{-27})(1.4 \times 10^{6})^2$$

$$= \underline{6.71 \times 10^{-15}\ J}$$

7. In a CRT (cathode ray tube), electrons are accelerated from rest by a potential difference of $2.50 \times 10^{3}$ V. What is the maximum speed of the electrons? ($2.96 \times 10^{7}$ m/s)

$$\Delta V = \frac{\Delta E}{q} \qquad 2500 = \frac{\Delta E}{1.6 \times 10^{-19}} \qquad \Delta E = \Delta KE = 4.0 \times 10^{-16} = \frac{1}{2}(9.11 \times 10^{-31})(V_f^2 - 0)$$

$$\underline{V = 2.96 \times 10^{7}\ m/s}$$

8. In a CRT, an electron reaches a maximum speed of $4.75 \times 10^{7}$ m/s. If this electron is accelerated from rest, what is the potential difference across the tube? (6423 V)

$$KE = \frac{1}{2}(9.11 \times 10^{-31})(4.75 \times 10^{7})^2 = 1.03 \times 10^{-15}\ J$$

$$\Delta V = \frac{1.03 \times 10^{-15}}{1.6 \times 10^{-19}} \qquad \Delta V = \underline{6423\ V}$$

9. In a CRT, electrons are accelerated from rest by a potential difference of $1.40 \times 10^3$ V. These electrons enter a magnetic field with a strength of $2.20 \times 10^{-2}$ T. If it is assumed that the electrons are travelling perpendicular to the field, what is the radius of the arc of the deflected electrons? ($5.75 \times 10^{-3}$ m)

$$1400 = \frac{\Delta E}{1.6 \times 10^{-19}} \qquad KE = 2.24 \times 10^{-16} J = \frac{1}{2}(9.11 \times 10^{-31})(V_F^2 - 0^2)$$

$$V_F = 2.22 \times 10^7 m/s$$

$$\frac{mV}{r} = qB \qquad \frac{(9.11 \times 10^{-31})(2.22 \times 10^7)}{r} = (1.6 \times 10^{-19})(2.2 \times 10^{-2})$$

$$r = \underline{5.75 \times 10^{-3} m}$$

10. Electrons are accelerated from rest in a CRT. These electrons now pass through a magnetic field of $1.40 \times 10^{-2}$ T and through an electric field of $4.20 \times 10^5$ N/C. The fields are perpendicular to each other, and the electrons are not deflected. If it is assumed the electrons are travelling perpendicular to these fields, what is the potential difference across the CRT? (2562 V)

$$V = \frac{E}{B} = \frac{4.20 \times 10^5}{1.40 \times 10^{-2}} = 3.0 \times 10^7 m/s \qquad \Delta V = \frac{4.1 \times 10^{-16}}{1.6 \times 10^{-19}}$$

$$\Delta KE = \frac{1}{2}(9.11 \times 10^{-31})((3.0 \times 10^7)^2 - 0^2) = 4.1 \times 10^{-16} J \qquad \underline{\Delta V = 2562 V}$$

11. A negatively charged particle with a mass of $8.4 \times 10^{-27}$ kg is travelling at a velocity of $5.6 \times 10^5$ m/s perpendicularly through a magnetic field of $2.8 \times 10^{-1}$ T. If the radius of the path of the particle is 3.5 cm, how many excess electrons does this particle carry? (3 electrons)

$$\frac{mV}{r} = q \cdot B \qquad q = 4.8 \times 10^{-19}$$

$$\frac{q}{e} \quad \frac{4.8 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$$\frac{(8.4 \times 10^{-27})(5.6 \times 10^5)}{0.035} = q \cdot 0.28 \qquad e^- = \underline{3}$$

12. Alpha particles travel at a speed of $3.00 \times 10^6$ m/s through a magnetic field. If the magnetic field strength is $4.2 \times 10^{-2}$ T, what is the radius of the path followed by the alpha particles when the magnetic field is parallel to the direction the alpha particles travel? ($\infty$)

$\infty \rightarrow$ parallel gives no $F_m$ = <u>no deflection</u>

13. A proton moves through a 0.75 T magnetic field in a circle with a radius of 0.30 m. What is the momentum of this proton? ($3.6 \times 10^{-20}$ kg•m/s)

$$\frac{mv}{r} = qB \qquad \frac{(1.67\times10^{-27})v}{0.30} = (1.6\times10^{-19})(0.75) \qquad v = 2.16\times10^{7}\ m/s$$

$$p = m \cdot v = (1.67\times10^{-27})(2.16\times10^{7}) = \underline{3.6\times10^{-20}\ kg\cdot m/s}$$

14. Electrons are accelerated from rest through a potential difference. These electrons are then deflected along an arc of radius 0.77 m when they travel through a $2.2 \times 10^{-4}$ T magnetic field. What is the accelerating voltage? (2528 V – NOTE: will be slightly different depending on rounding)

$$\frac{(9.11\times10^{-31})(v)}{0.77} = (1.6\times10^{-19})(2.2\times10^{-4}) \qquad v = 2.98\times10^{7}\ m/s$$

$$\Delta KE = \frac{1}{2}(9.11\times10^{-31})(2.98\times10^{7})^2 = 4.03\times10^{-16} \qquad \Delta V = \frac{4.03\times10^{-16}}{1.6\times10^{-19}}$$

$$\Delta V = \underline{2528\ V}$$

15. An ion with a charge to mass ratio of $1.10 \times 10^{4}$ C/kg travels perpendicular to a magnetic field ($B = 9.10 \times 10^{-1}$ T) in a circular path ($r = 0.240$ m). How long does it take the ion to complete one revolution? ($6.28 \times 10^{-4}$ s)

$$\frac{q}{m} = \frac{v}{Br} \qquad 1.10\times10^{4} = \frac{v}{(0.910)(0.240)} \qquad v = 2402.4\ m/s$$

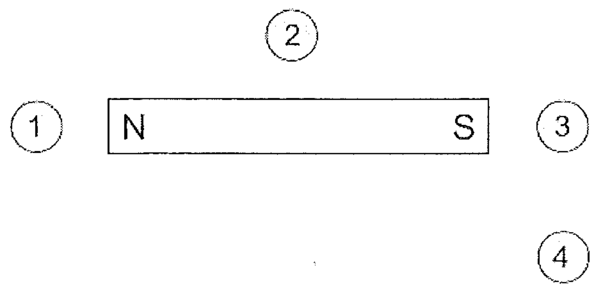
$$v = \frac{2\pi r}{T} \qquad 2402.4 = \frac{2\pi(0.240)}{T}$$

$$T = \underline{6.28\times10^{-4}\ s}$$

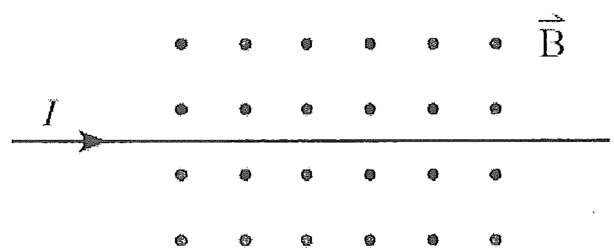
Physics 12 – **Electromagnetism Unit Review**

1. A compass is positioned at each of the following locations near a bar magnet. In which location will the compass needle point to the right-hand side of the page?
   - a. 1
   - b. 2
   - c. 3
   - d. 4

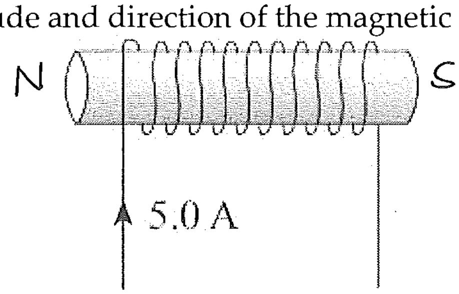
B




2. A current carrying conductor is placed in a uniform magnetic field as shown. What is the direction of the magnetic force on this conductor?
   - a. Into the page
   - b. Out of the page
   - c. Towards the top of the page
   - d. Towards the bottom of the page



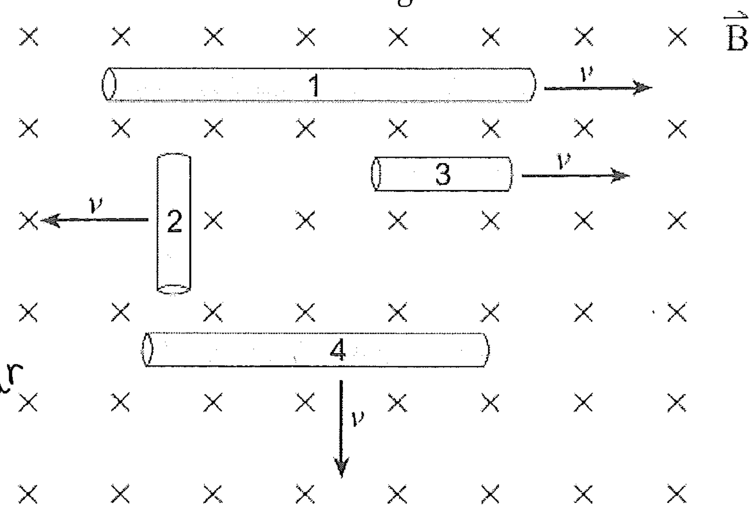

3. A 5.0 A current is flowing through a 0.20 m long solenoid that contains 1500 loops. What are the magnitude and direction of the magnetic field in the center of the solenoid?




$$B = \mu_0\left(\frac{N}{\ell}\right) I$$
$$= \mu_0\left(\frac{1500}{0.20}\right) 5.0$$
$$= 4.7\times10^{-2}\ T$$

| | MAGNITUDE | DIRECTION |
|---|---|---|
| A. | $9.4\times10^{-3}$ T | left |
| B. | $9.4\times10^{-3}$ T | right |
| C. | $4.7\times10^{-2}$ T | left |
| D. | $4.7\times10^{-2}$ T | right |

4. Four conductors of different lengths are moved through a uniform magnetic field at the same speed. Which conductor will induce the greatest EMF?




a. 1

b. 2

c. 3

d. 4

the only conductor moving perpendicular

5. A motor has an armature resistance of 3.5 Ω and is connected to a 12.0 v source. At full speed the current through the armature is 0.18 A. What is the back EMF at full speed?

a. 0 V

b. 0.63 V

c. 11.4 V

d. 12.0 V

$$V_b = \mathcal{E} - Ir$$
$$= 12.0 - (0.18)(3.5)$$
$$= 11.4\ \text{V}$$

6. A **step-down** transformer has a 500 turn primary that operates at 120 V AC. Which of the following sets of conditions best describes the number of secondary turns and secondary voltage of this transformer?

$$\frac{500}{40} = \frac{120}{V_s} \quad V_s = 9.6\text{V}$$

| | SECONDARY TURNS | SECONDARY VOLTAGE |
|---|---|---|
| A. | 40 | 9.6 V ac |
| B. | 40 | 1 500 V ac |
| C. | 2 000 | 30 V ac |
| D. | 2 000 | 480 V ac |

7. A flexible loop of wire of area 4.5 x $10^{-2}$ $m^2$ is positioned in a 0.17 T magnetic field as shown in Figure A. The loop is then stretched until its area is zero in a time of 0.35 s (Figure B). What is the average induced EMF in the circuit and the direction of the current through resistor R?

$\mathcal{E} = -1\left(\frac{0-(0.17)(4.5\times10^{-2})}{0.35}\right) = 2.2\times10^{-2}\,V$

Figure A

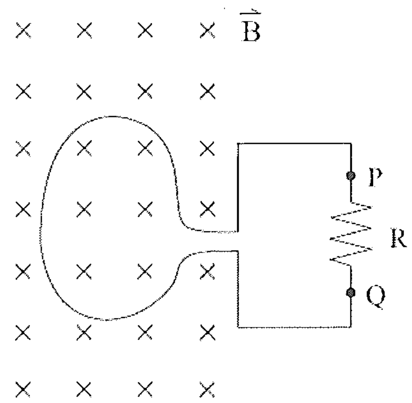
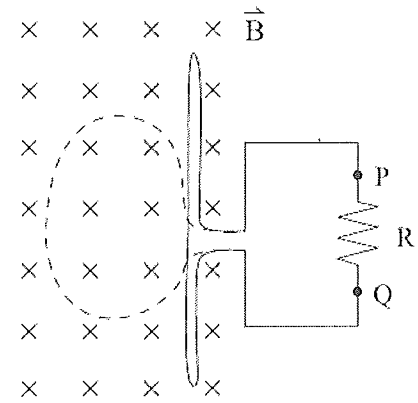
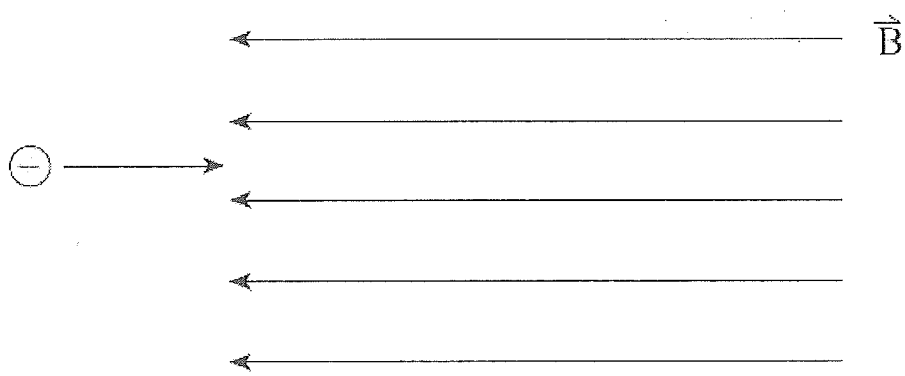



Figure B




| | AVERAGE EMF | DIRECTION OF CURRENT THROUGH R |
|---|---|---|
| A. | $2.2\times10^{-2}$ V | P to Q |
| B. | $2.2\times10^{-2}$ V | Q to P |
| C. | $4.9\times10^{-1}$ V | P to Q |
| D. | $4.9\times10^{-1}$ V | Q to P |

8. An electron enters a uniform magnetic field as shown below.




The path of the electron upon entering the field would be

parallel

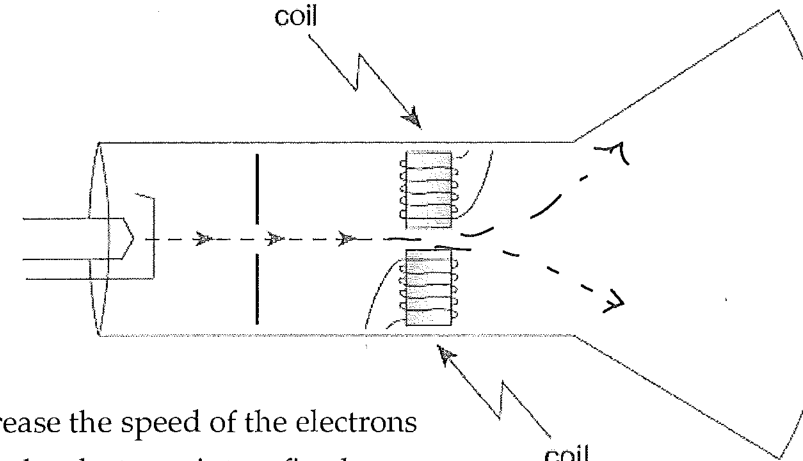
a. Linear

b. Circular

c. Parabolic

d. Hyperbolic

9. The diagram below represents a cross-sectional view from the side of a cathode ray tube. What is the purpose of the coils in a functional cathode ray tube?




a. They increase the speed of the electrons
b. The focus the electrons into a fine beam
c. They deflect the electrons into or out of the page
d. They deflect the electrons toward the top or bottom of the page

10. A solenoid of length 0.35 m and a diameter of 0.040 m carries a current of 5.0 A through its windings. If the magnetic field in the center of the solenoid is $2.8 \times 10^{-2}$ T, what is the number of turns per meter for this solenoid?

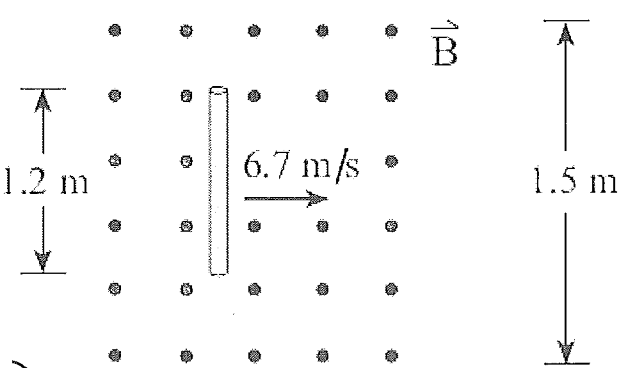
a. $1.8 \times 10^3$ turns/m
b. $7.8 \times 10^3$ turns/m
c. $1.6 \times 10^3$ turns/m
d. $4.5 \times 10^3$ turns/m

$2.8 \times 10^{-2} = \mu_0 \cdot n \cdot 5.0$

$n = 4.5 \times 10^3$ turns/m

11. A 1.2 m length of wire is pulled through a uniform 0.045 T magnetic field at 6.7 m/s as shown. What EMF is generated between the ends of the wire?

a. 0 V
b. 0.090 V
c. 0.36 V
d. 0.45 V




$\mathcal{E} = B \ell v$

$= (0.045)(1.2)(6.7)$

$= \underline{0.36\ V}$

12. A DC motor is connected to a 12.0 V power supply. When the armature is rotating, the current through it is 0.78 A and the back EMF is 10.6 V. What is the resistance of the armature?

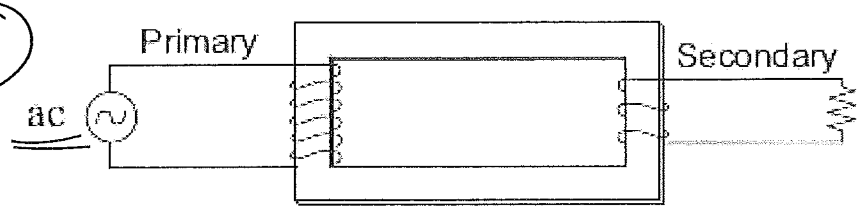
a. 1.4 Ω
b. 1.8 Ω
c. 14 Ω
d. 15 Ω

$10.6 = 12.0 - 0.78r$

$r = 1.8\ \Omega$

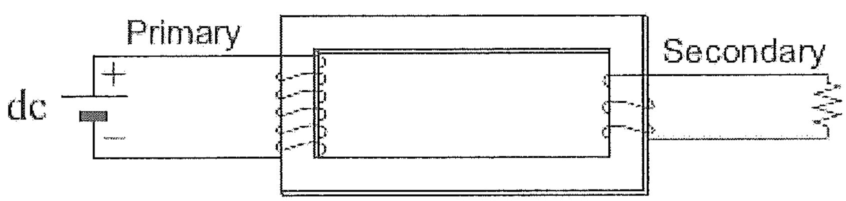
13. In which of the following diagrams is the secondary **current** greater than the primary **current**?

A.

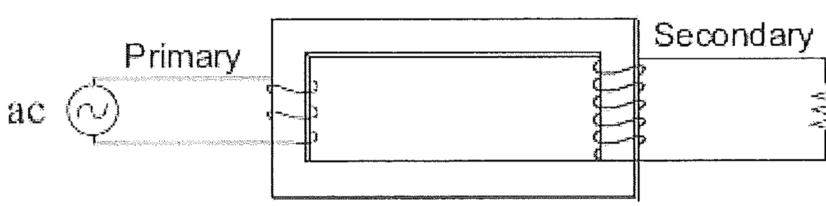



$\downarrow V \uparrow I$

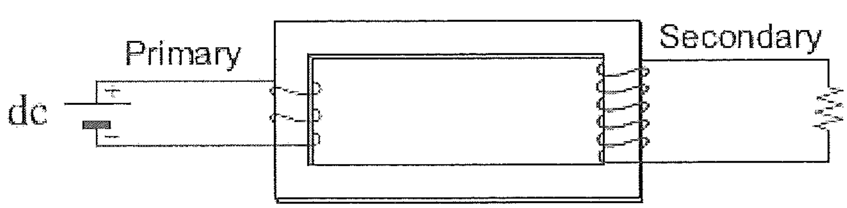
B.



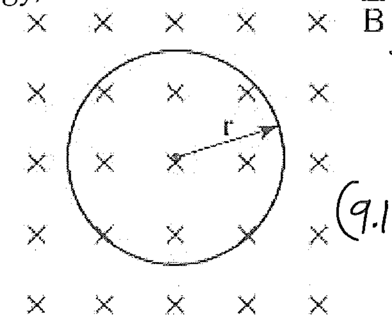

C.




D.



14. An electron circulates in a uniform $5.0 \times 10^{-4}$ T magnetic field as shown. If the electron $3.2 \times 10^{-18}$ J of kinetic energy, what is the radius of orbit, $r$?




a. $2.3 \times 10^{-7}$ m

b. $4.6 \times 10^{-4}$ m

c. $2.5 \times 10^{-3}$ m

d. $3.0 \times 10^{-2}$ m

$3.2 \times 10^{-18} = \frac{1}{2}(9.11 \times 10^{-31})v^2$

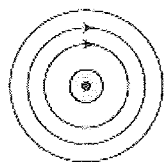
$v = 2.65 \times 10^{6}$ m/s

$\frac{(9.11 \times 10^{-31})(2.65 \times 10^{6})}{r} = 1.6 \times 10^{-19} \cdot 5.0 \times 10^{-4}$

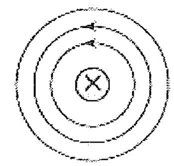
$= 3.0 \times 10^{-2}$ m

15. Which of the following diagrams shown the magnetic field produced by a long current-carrying wire?

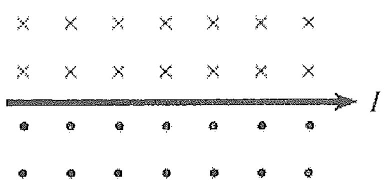
A.



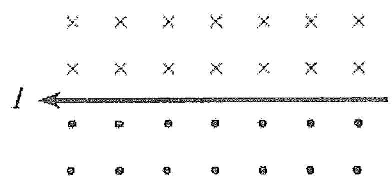
B.



C.




D.




16. Which of the following devices has commonly used a cathode ray tube?

a. Kettle

b. Televisions

c. Battery

d. Incandescent bulb

17. An electric motor is connected to a constant source of potential. Considering back EMF, which of the following observations is correct?

a. At full speed the applied voltage increases

b. At full speed the armature resistance increases

c. If the motor is kept from rotating at full speed, the armature heats up

d. If the motor is kept from rotating at full speed, the armature temperature decreases.

↑I = ↑friction

18. Which of the following are correct units for magnetic flux?

a. T

b. Wb

c. V/m

d. N•m$^2$

19. In a step-up transformer, how does the secondary voltage $V_S$ compare with the primary voltage $V_P$, and the number of turns in the secondary $N_S$ compare with the number of turns in the primary $N_P$?

| | VOLTAGE | NUMBER OF TURNS |
|---|---|---|
| A. | $V_s < V_p$ | $N_s > N_p$ |
| B. | $V_s > V_p$ | $N_s > N_p$ |
| C. | $V_s < V_p$ | $N_s < N_p$ |
| D. | $V_s > V_p$ | $N_s < N_p$ |

20. An ideal transformer has a potential difference of 130 V AC across the primary windings and a potential difference of 780 V AC across the secondary windings. There are 390 turns in the secondary. The secondary current is

a. Twice the primary current

b. One half the primary current

c. Six times the primary current

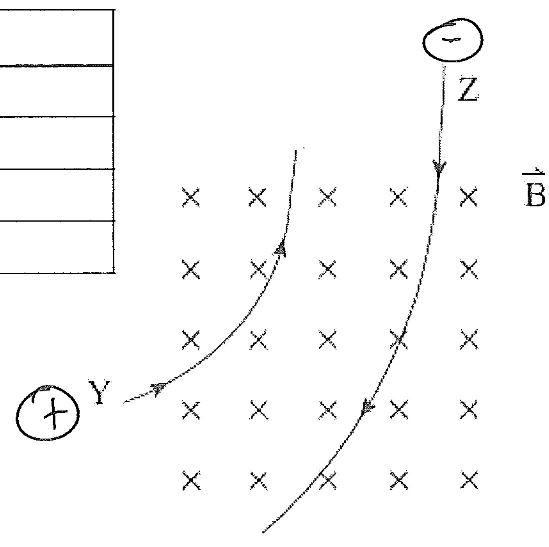
d. One-sixth the primary current

$\frac{130}{780} = \frac{65}{390} \rightarrow \boxed{\frac{1}{6}}$

21. Two particles Y and Z with equal mass and speed enter a uniform magnetic field and follow the paths as shown. How do their magnitude and polarity of charge compare?

| | MAGNITUDE OF CHARGE | POLARITY |
|---|---|---|
| A. | Y < Z | same charge |
| B. | Y < Z | opposite charge |
| C. | Y > Z | same charge |
| D. | Y > Z | opposite charge |

Y bends more $= \uparrow q = \uparrow F_m/F_c$



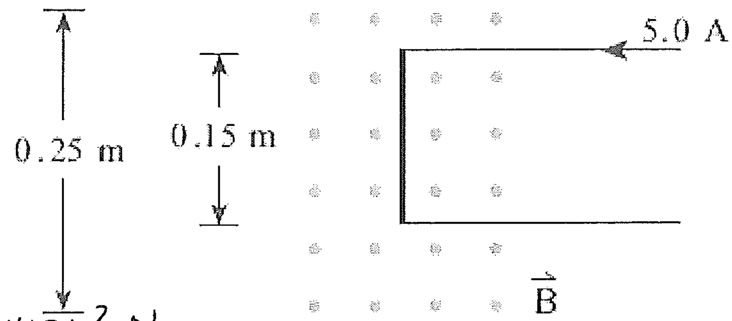
22. A wire carrying a current of 5.0 A is in a uniform $3.2 \times 10^{-2}$ T magnetic field as shown. What is the force on the 0.15 m length of wire?

a. 0 N

b. $1.6 \times 10^{-2}$ N

c. $2.4 \times 10^{-2}$ N

d. $4.0 \times 10^{-2}$ N




$F_m = BlI$

$= (3.2\times10^{-2})(0.15)(5.0) = 2.4\times10^{-2}$ N

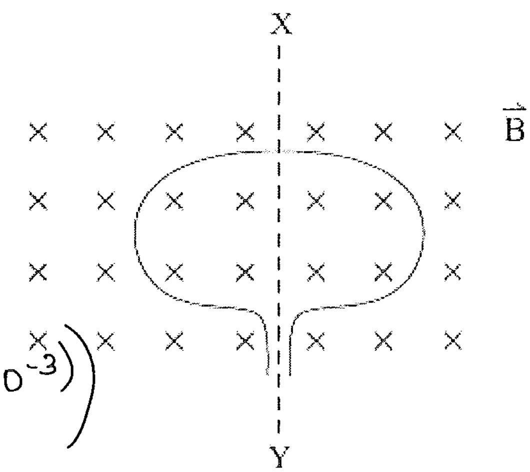
23. A single coil of wire of area $6.0 \times 10^{-3}$ m² is positioned in a uniform 0.18 T magnetic field as shown. The coil is rotated 90° about axis XY in 0.0042 s. What average EMF is induced by the coil?

a. 0 V

b. 0.13 V

c. 0.26 V

d. 43 V




$\mathcal{E} = -1\left(\dfrac{0 - (0.18)(6.0\times10^{-3})}{4.2\times10^{-3}}\right)$

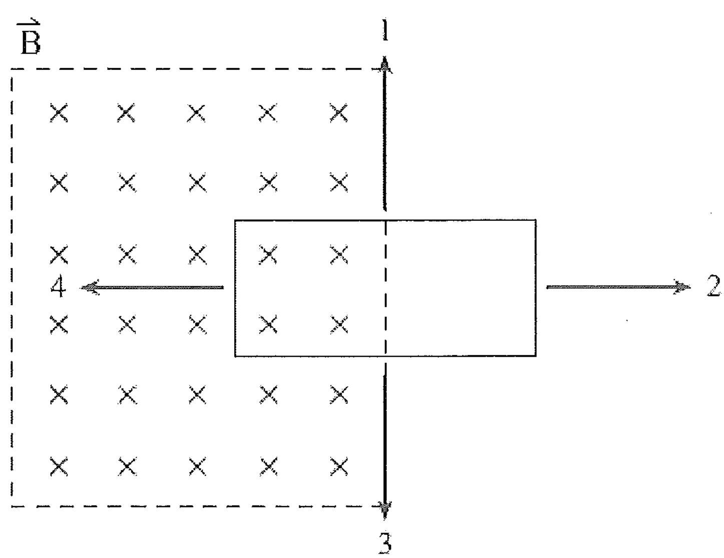
24. A part of a coil of wire is placed in a uniform magnetic field as shown. Which two directions of motion would immediately induce an EMF in the coil?

a. 1 and 2

b. 1 and 3

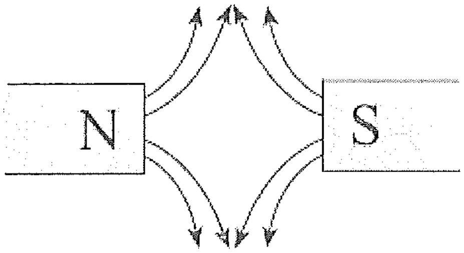
c. 2 and 3

d. 2 and 4

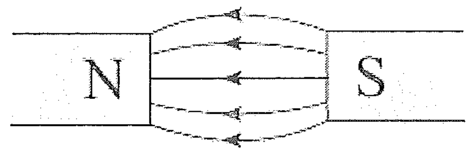


25. Which of the following diagrams best shows the magnetic field lines between the poles of two permanent magnets?

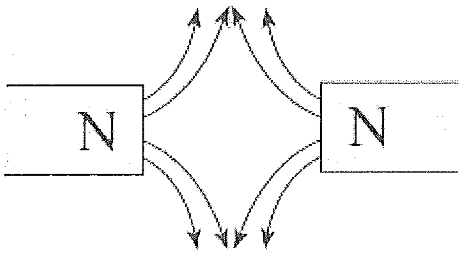
A.



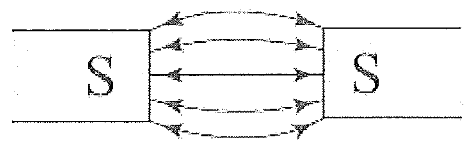

B.



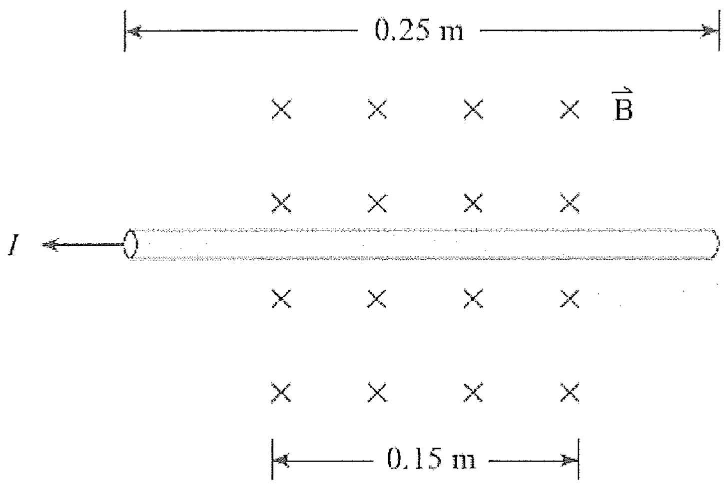

C.




D.




26. A wire carrying 12 A of current is placed in a magnetic field of strength 0.63 T. What are the magnitude and direction of the magnetic force acting on the wire?




$F_m = BlI$
$= (0.63)(0.15)(12)$
$= 1.1\text{ N} \downarrow$

| | FORCE | DIRECTION |
|---|---|---|
| A. | 1.1 N | down the page |
| B. | 1.1 N | up the page |
| C. | 1.9 N | down the page |
| D. | 1.9 N | up the page |

27. A particle having a charge of $3.2 \times 10^{-19}$ C follows a circular path of 0.45 m radius while travelling at a speed of $1.2 \times 10^{4}$ m/s in a 0.78 T magnetic field. What is the mass of the particle?

a. $7.8 \times 10^{-28}$ kg
b. $9.4 \times 10^{-24}$ kg
c. $1.1 \times 10^{-19}$ kg
d. $3.0 \times 10^{-15}$ kg

$$\frac{m(1.2\times10^{4})}{(0.45)} = (3.2\times10^{-19})(0.78)$$

$$m = 9.4\times10^{-24}\ \text{kg}$$

28. A 460-turn solenoid having a diameter of 0.024 m is 0.14 m long. What is the magnetic field at the center of the solenoid when a 13 A current flows through it?

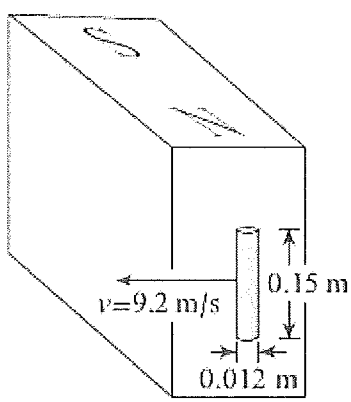
a. 0 T
b. $5.3 \times 10^{-2}$ T
c. $3.1 \times 10^{-1}$ T
d. $6.3 \times 10^{-1}$ T

$$B = \mu_0\left(\frac{460}{0.14}\right)(13)$$

$$\approx 5.3\times10^{-2}\ T$$

29. A conducting rod is moving perpendicular to a uniform magnetic field of 0.23 T at a velocity of 9.2 m/s. What EMF is generated during this motion?

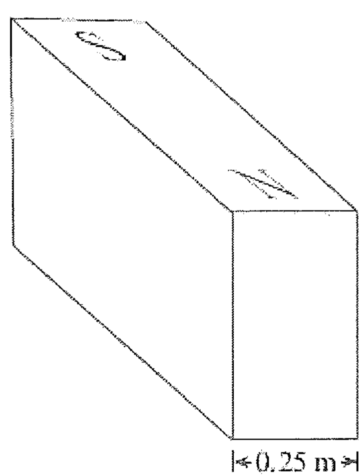
a. 0 V
b. ~~0.025 V~~
c. 0.32 V
d. 0.53 V




$$\mathcal{E} = B\ell v$$

$$= (0.23)(0.15)(9.2)$$

$$= 0.32\ V$$



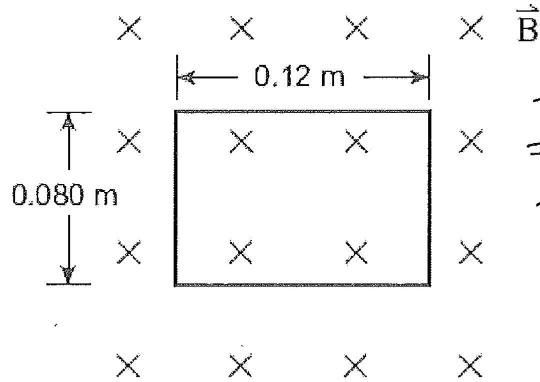
30. A rectangular coil measuring 0.12 m by 0.080 m is placed perpendicular to a 0.85 T magnetic field as shown. What is the magnetic flux through the coil?

a. 0 Wb

b. $8.2 \times 10^{-3}$ Wb

c. $6.8 \times 10^{-2}$ Wb

d. $1.0 \times 10^{-1}$ Wb




$\Phi = BA$
$= (0.85)(0.12 \cdot 0.08)$
$= 8.2 \times 10^{-3}$ Wb

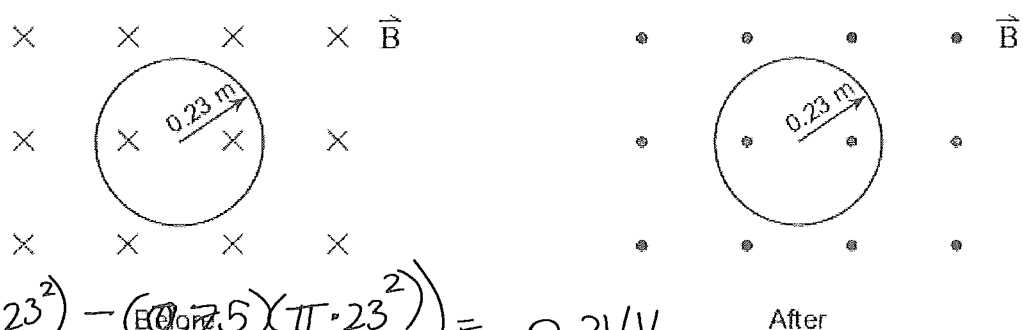
31. A single loop of wire of radius 0.23 m is placed in a single 0.75 T magnetic field as shown. The magnetic field is changed to a strength of 0.50 T in the opposite direction in 0.61 s. What is the average EMF induced in the coil?

a. 0.068 V

b. 0.094 V

c. 0.34 V

d. 0.47 V




$\mathcal{E} = -1\left(\dfrac{(-0.50)(\pi \cdot 0.23^2) - (0.75)(\pi \cdot 0.23^2)}{0.61}\right) = 0.34\text{V}$

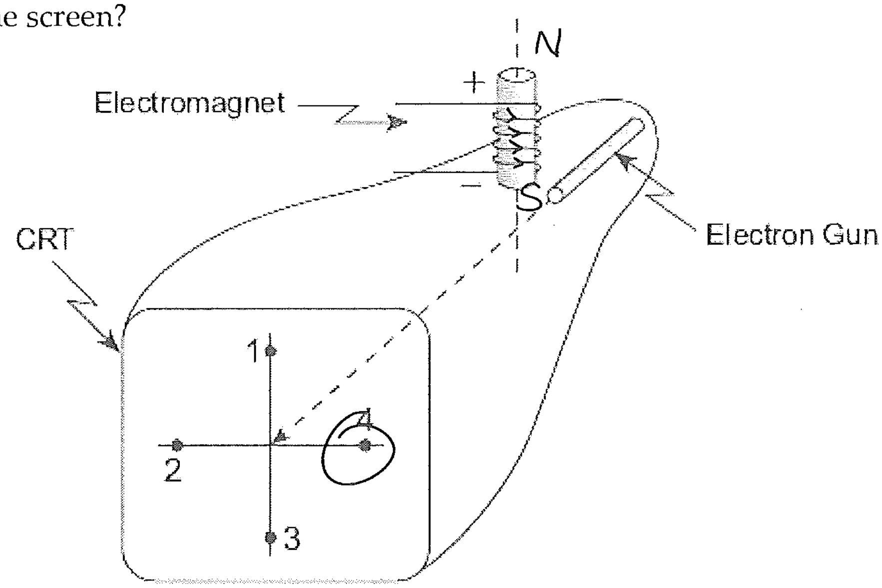
32. With the electromagnet turned off, electrons in the cathode ray tube strike the center of the screen as shown. When the electromagnet is turned on, where will the electron beam now hit the screen?

a. 1

b. 2

c. 3

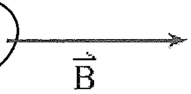
d. 4

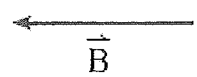


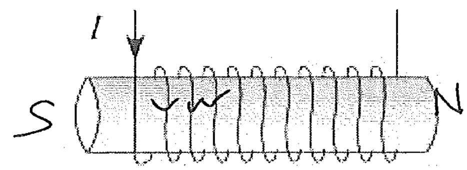

$e^- = \ominus$

LHR

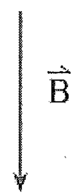
33. An electric current flows through a solenoid as shown below. What is the direction of the magnetic field inside the solenoid?

A. 


B. 

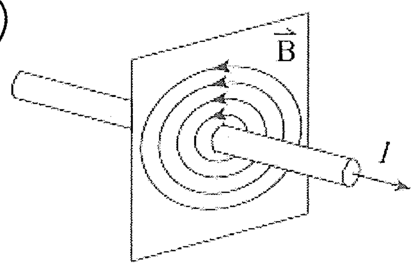



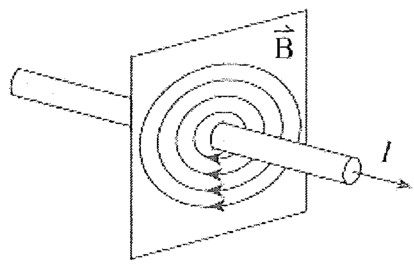

C. 

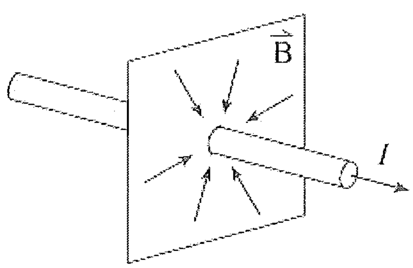

D. 

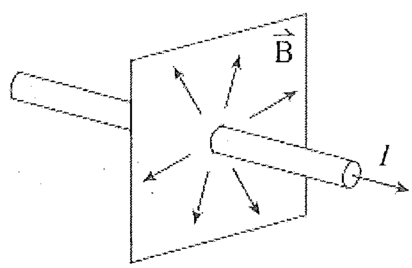

RHR

34. Which of the following diagrams best show the magnetic field due to a long straight wire carrying a conventional current I as shown?

A. 


B. 


C. 


D. 


35. A proton is traveling at $2.3 \times 10^6$ m/s in a circular path in a 0.75 T magnetic field. What is the magnitude of the force on the proton?

a. $1.6 \times 10^{-24}$ N

b. $2.9 \times 10^{-21}$ N

c. $2.8 \times 10^{-13}$ N

d. 1.7 N

$F_m = qvB$

$= (1.6 \times 10^{-19})(2.3 \times 10^6)(0.75)$

$= 2.8 \times 10^{-13}$ N

36. A solenoid of length 0.75 m has a radius 0.092 m. A current of 25 A flows through its 4700 turns. Within this solenoid a 0.10 m long conductor moves at 4.3 m/s perpendicular to the field in the solenoid. What EMF is induced between the ends of the conductor?

a. 0.085 V

b. 0.197 V

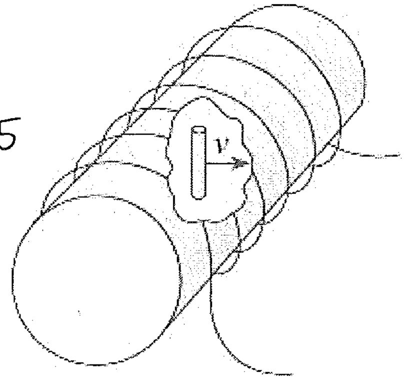
c. 0.430 V

d. 4.80 V

$B = \mu_0 n I$

$= \mu_0 \left(\frac{4700}{0.75}\right) 25$

$= 0.198\ T$



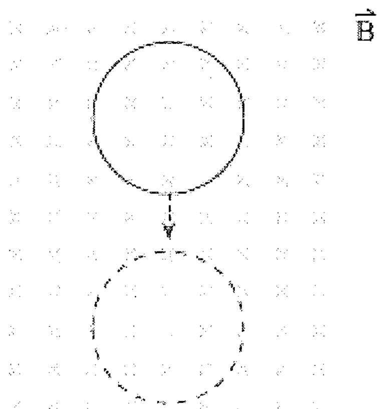

$\mathcal{E} = B l v$

$= (0.198)(0.10)(4.3)$

$= 0.085\ V$

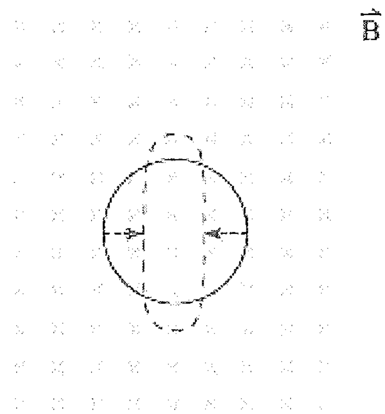
37. In which of the following situations would the greatest EMF be induced in the coil? All changes occur in the same time interval.

A.



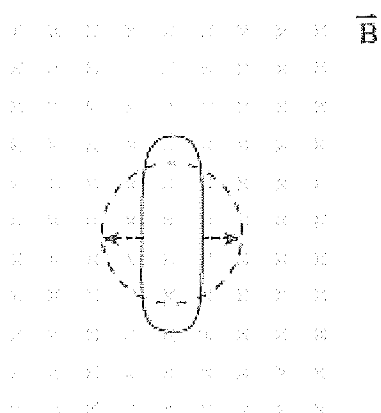

coil moves

B.



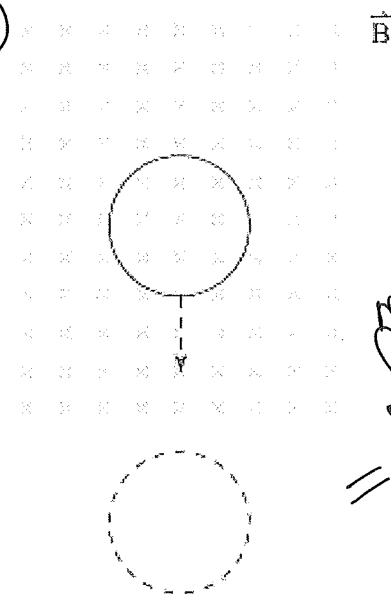

coil changes shape

C.




coil changes shape

D.




coil moves

moved right out of B $= \Delta\Phi$

38. A motor is connected to a 12 V DC supply and draws 5.0 A when it firsts starts up. What will be the back EMF when the motor is operating at full speed and drawing 1.2 A?

$0 = 12 - 5.0r \quad r = 2.4\,\Omega$

$V_b = 12 - 1.2(2.4) \quad V_b = 9.1\ V$

a. 7.0 V
b. 7.8 V
c. 9.1 V
d. 10.8 V

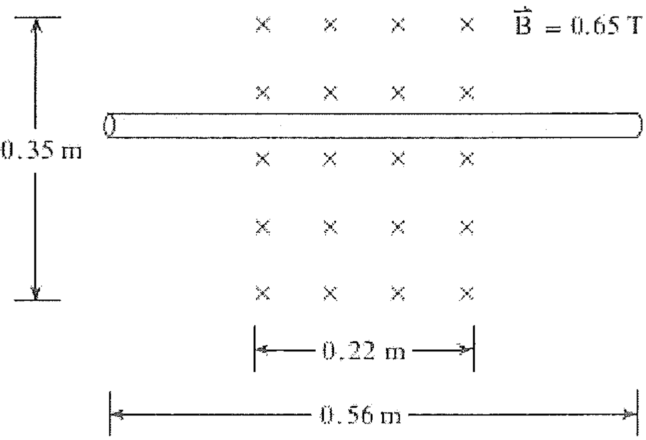
39. A long conductor is placed in a 0.65 T magnetic field as shown below. What are the magnitude and direction of the current that produces a 1.6 N force on the wire directed up the page?

$F_m = BlI$

$1.6 = 0.65(0.22)I$

$I = 11\ A$

$\longrightarrow$




| | MAGNITUDE OF CURRENT | DIRECTION OF CURRENT |
|---|---|---|
| A. | 4.4 A | Right |
| B. | 4.4 A | Left |
| C. | 11 A | Right |
| D. | 11 A | Left |

40. A proton has a speed of $5.0 \times 10^{6}$ m/s while travelling perpendicular to a 0.14 T magnetic field. What is the magnetic force on the proton?

a. $1.6 \times 10^{-26}$ N
b. $8.4 \times 10^{-21}$ N
c. $2.2 \times 10^{-20}$ N
d. $1.1 \times 10^{-13}$ N

$F_m = qvB$

$= (1.6 \times 10^{-19})(5.0 \times 10^{6})(0.14)$

$= 1.12 \times 10^{-13}\ N$

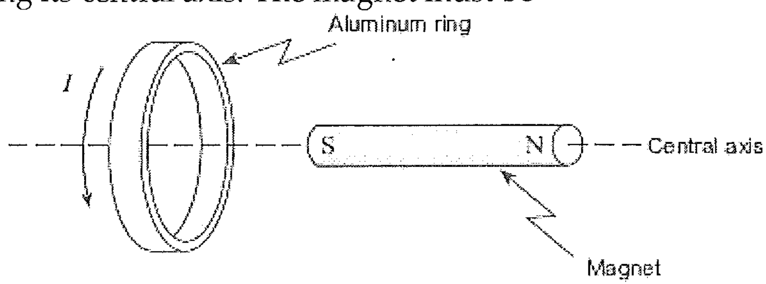
41. The flux through a circular coil with a radius of 0.075 m is 0.013 Wb when placed perpendicular to a magnetic field. What is the strength of the magnetic field?

$0.013 = B(\pi(0.075)^2)$   $B = 0.74\,T$

a. 0 T
b. 0.17 T
c. 0.74 T
d. 2.3 T

42. The diagram below shows an aluminum ring and the current induced in it by the nearby magnet that is free to move along its central axis. The magnet must be

a. Stationary
b. Moving to the left
c. Moving to the right
d. Spinning about its central axis




43. A computer adaptor contains a transformer that converts 120 V AC across its primary windings to 24 V AC across its secondary windings. The primary current is 1.2 A. What is the secondary current and what is the type of the transformer?

$\frac{120}{24} = \frac{I_s}{1.2}$

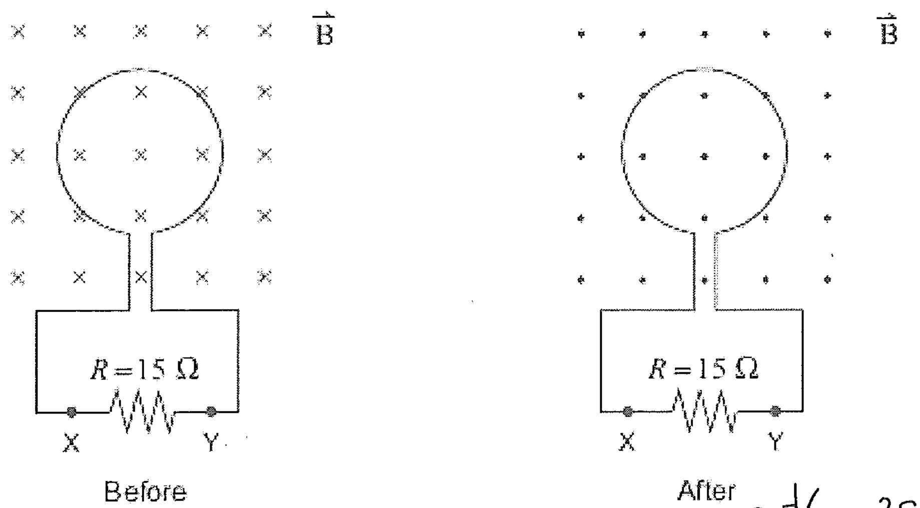
$I_s = 6.0A$

| | MAGNITUDE OF CURRENT | DIRECTION OF CURRENT |
|---|---|---|
| A. | 0.24 A | Step-up |
| B. | 0.24 A | Step-down |
| C. | 6.0 A | Step-up |
| D. | 6.0 A | Step-down |

44. A charged particle travels in a circular path in a magnetic field. What changes to the magnetic field and to the velocity of the particle would both cause the radius of its path to decrease?

| | CHANGE TO THE MAGNETIC FIELD | CHANGE TO THE VELOCITY |
|---|---|---|
| A. | increase | increase |
| B. | increase | decrease |
| C. | decrease | increase |
| D. | decrease | decrease |

45. A loop of wire of area 0.32 $m^2$ is placed in a 0.75 T magnetic field as shown. The magnetic field is changed to 0.35 T in the opposite direction in 0.45 s. What are the magnitude and direction of current through the 15 Ω resistor?




$\mathcal{E} = \frac{-(-0.35 \cdot 0.32) - (0.75 \cdot 0.3}{0.45}$

$\mathcal{E} \approx 0.782\ V$

$0.782 = I(15)$

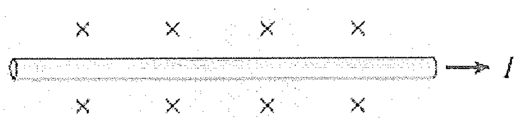
$I = 0.052\ A$

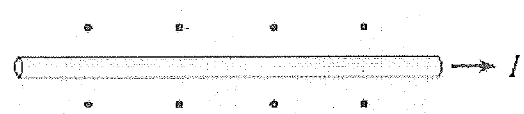
| | MAGNITUDE OF CURRENT | DIRECTION OF CURRENT |
|---|---|---|
| A. | 0.019 A | X to Y |
| B. | 0.019 A | Y to X |
| C. | 0.052 A | X to Y |
| D. | 0.052 A | Y to X |

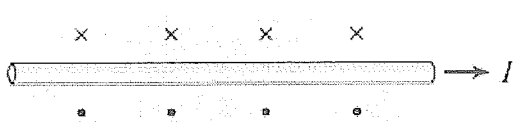
46. The direction of a magnetic field is determined to be the direction in which

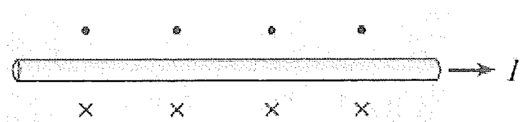
a. A positive charge would tend to move
b. A negative charge would tend to move
c. The north end of a compass needle would point
d. The south end of a compass needle would point

47. Which diagram shows the magnetic field created near a conductor carrying current towards the right?

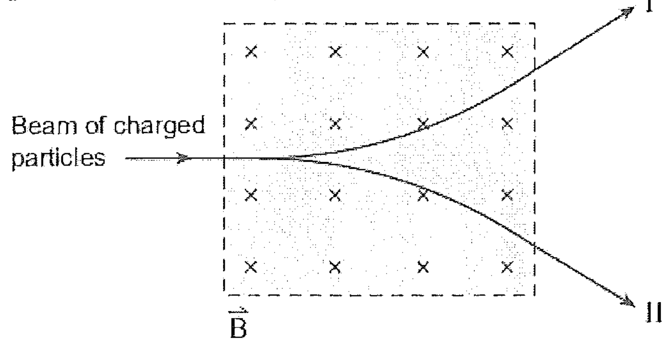
A.



B.



C.



D.


48. A beam of positively and negatively charged particles enters a magnetic field as shown. Which paths illustrate the positive and negative charges leaving the magnetic field region?




| | PATH OF POSITIVE CHARGES | PATH OF NEGATIVE CHARGES |
|---|---|---|
| A. | I | I |
| B. | I | II |
| C. | II | I |
| D. | II | II |

49. A solenoid has a length of 0.30 m, a diameter of 0.040 m and 500 windings. The magnetic field at its center is 0.045 T. What is the current in the windings?

a. 2.9 A
b. 3.0 A
c. 21 A
d. 170 A

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

$0.045 = \mu_0 \left(\frac{500}{0.30}\right) I$

$I = 21A$

50. An aircraft with a wingspan of 24 m flies at 85 m/s perpendicular to a magnetic field. An EMF of 0.19 V is induced across the wings of the aircraft. What is the magnitude of the magnetic field?

a. $9.3 \times 10^{-5}$ T
b. $5.4 \times 10^{-2}$ T
c. $6.7 \times 10^{-1}$ T
d. $3.9 \times 10^{2}$ T

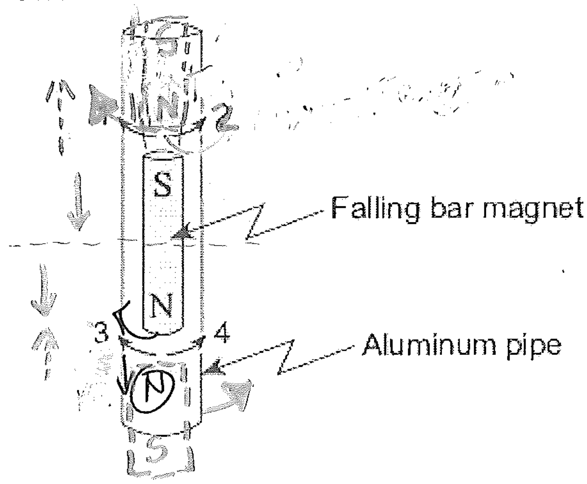
$\mathcal{E} = B l v$

$0.19 = B(24)(85)$ $\quad B = 9.3 \times 10^{-5}$ T

51. As a carpenter drills into a beam, friction on the drill bit causes the armature of the drill to slow down. How will the back EMF and current through the armature change as the drill slows down? $V_b = \mathcal{E} - Ir$

| | BACK EMF ↓ | ↑ CURRENT |
|---|---|---|
| A. | Increase | Increase |
| B. | Increase | Decrease |
| C. | Decrease | Increase |
| D. | Decrease | Decrease |

52. The diagram shows a bar magnet falling through an aluminum pipe. Electric currents are induced in the pipe immediately above and below the falling magnet. In which direction do these currents flow?




RHR

| | ABOVE THE MAGNET | BELOW THE MAGNET |
|---|---|---|
| A. | 1 | 3 |
| B. | 1 | 4 |
| C. | 2 | 3 |
| D. | 2 | 4 |

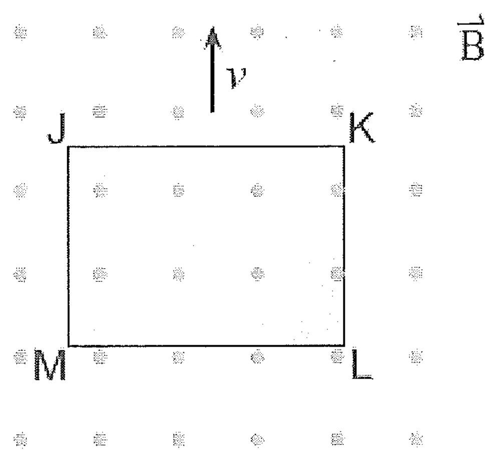
53. A metal block moves with a constant speed in a uniform magnetic field. Which side of the block is positive?

a. JK

b. KL

c. LM

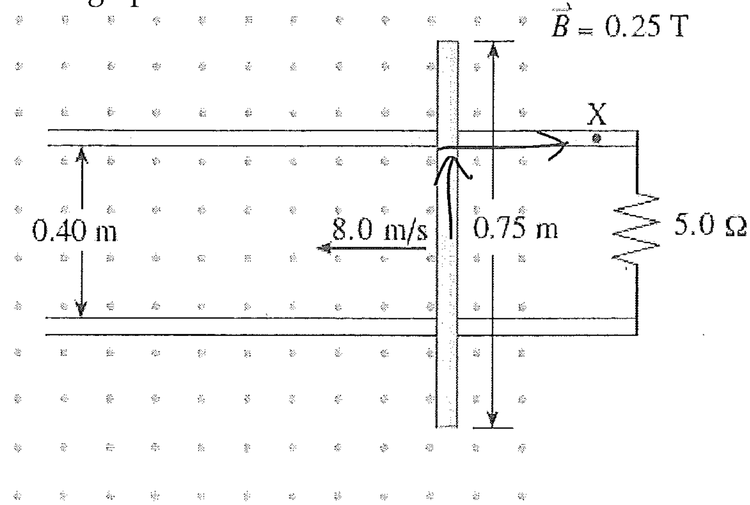
d. MJ



54. A 0.75 m conducting rod is moved 8.0 m/s across a 0.25 T magnetic field along metal rails. The electrical resistance of the system is 5.0 Ω. What are the magnitude and direction of the current through point X?

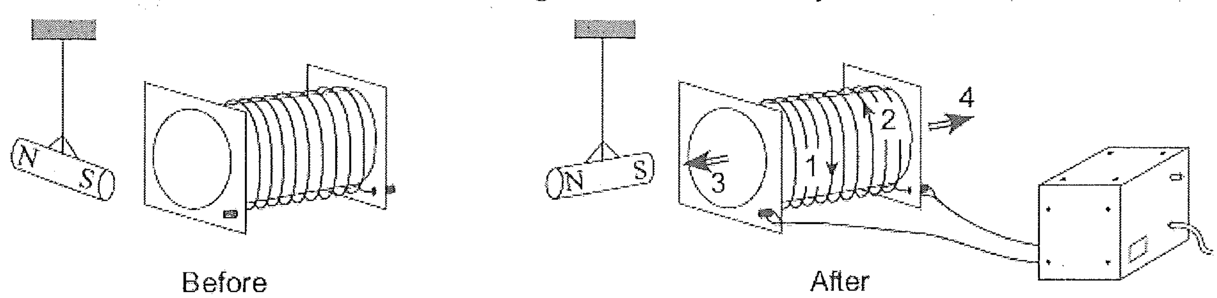
$$\mathcal{E} = B\ell v$$
$$= (0.25)(0.40)(8.0)$$
$$= 0.80$$

$$0.80 = I(5.0)$$
$$I = \underline{0.16\ A}$$




| | MAGNITUDE OF CURRENT | DIRECTION OF CURRENT THROUGH X |
|---|---|---|
| A. | 0.16 A | Left |
| B. | 0.16 A | Right |
| C. | 0.30 A | Left |
| D. | 0.30 A | Right |

55. The diagram shows a magnet suspended near a solenoid. After the solenoid has been connected to a power supply, the magnet rotates to a new position with its south pole pointing towards the solenoid. Which arrows show the direction of the current in the solenoid and the direction of the magnetic field caused by this current?




| | DIRECTION OF CURRENT | DIRECTION OF MAGNETIC FIELD |
|---|---|---|
| A. | 1 | 3 |
| B. | 1 | 4 |
| C. | 2 | 3 |
| D. | 2 | 4 |

$0.40=(0.01)\vec{a}$  $\vec{a}=40\,m/s^2$

56. The diagram shows a 0.010 kg metal rod resting on two long horizontal frictionless rails which remain 0.40 m apart. The circuit has a resistance of 3.0 Ω and is located in a uniform 0.20 T magnetic field. Find the initial acceleration and maximum velocity for the rod.

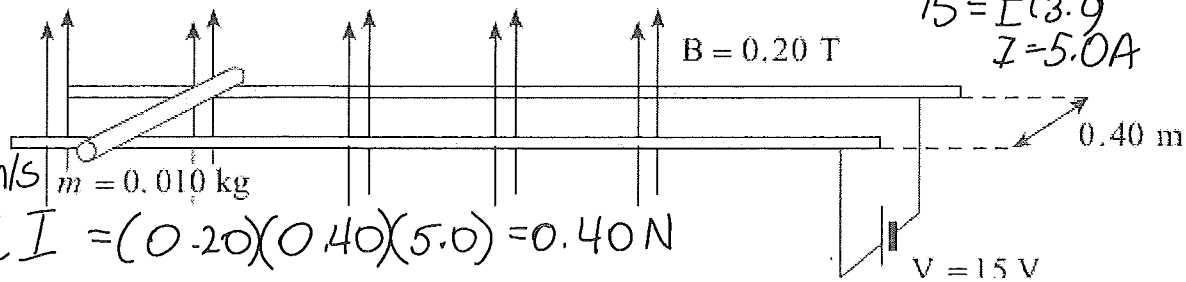
$15=I(3.0)$

$I=5.0A$

$\mathcal{E}=BlV$

$15=(0.20)(0.40)V$

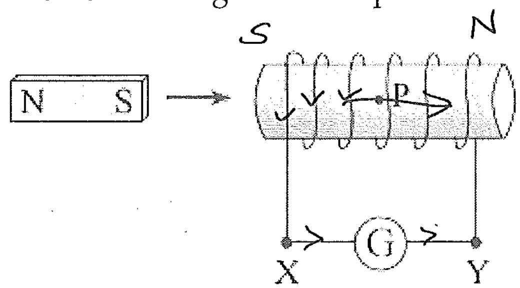
$V=190\,m/s$




$F_m=BlI=(0.20)(0.40)(5.0)=0.40\,N$

| | INITIAL ACCELERATION | MAXIMUM VELOCITY |
|---|---|---|
| A. | 40 $m/s^2$ | 190 m/s |
| B. | 40 $m/s^2$ | 300 m/s |
| C. | 120 $m/s^2$ | 190 m/s |
| D. | 120 $m/s^2$ | 300 m/s |

57. A bar magnet is moving toward a solenoid. What is the direction of the current through the galvanometer and what is the direction of the magnetic field produced by this current at location P inside the solenoid?




| | DIRECTION OF THE CURRENT THROUGH THE GALVANOMETER | DIRECTION OF THE MAGNETIC FIELD AT P |
|---|---|---|
| A. | From X to Y | Right |
| B. | From X to Y | Left |
| C. | From Y to X | Right |
| D. | From Y to X | Left |

WRITTEN PRACTICE QUESTIONS

1. A single loop of wire of area 5.0 x $10^{-3}$ $m^2$ and resistance 1.8 Ω is perpendicular to a uniform magnetic field B The field then decreases to zero in 0.0012 s inducing an average current of 0.083 A in the loop. What was the initial value of the magnetic field B?

$\mathcal{E} = IR$
$= (0.083)(1.8)$
$\mathcal{E} = 0.1494\ V$

$$0.1494 = -1\left(\frac{0 - (B_0)(5.0\times10^{-3})}{0.0012}\right)$$

$B_0 = \underline{0.036\ T}$

2. An electron is accelerated from rest through a potential difference of 750 V. It then enters a uniform 0.0023 T magnetic field at right angles to the field.
   a. What is the speed of the electron?

$-750 = \frac{\Delta KE}{-1.6\times10^{-19}}$   $\Delta KE = 1.2\times10^{-16} = \frac{1}{2}(9.11\times10^{-31})v_f^2$

$\underline{v_F = 1.62\times10^{7}\ m/s}$

   b. What is the radius of its path in the magnetic field?

$\frac{(9.11\times10^{-31})(1.62\times10^{7})}{r} = (1.6\times10^{-19})(0.0023)$   $\underline{r = 0.040\ m}$

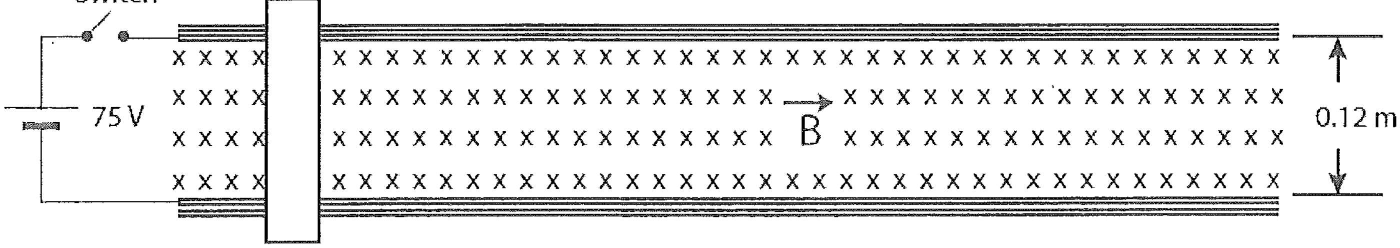
3. An electric device operates on 9.0 V AC and has a total resistance of 21 Ω. An ideal transformer is used to change the incoming line voltage of 120 V to the operating voltage of 9.0 V AC.
   a. Is the transformer a step-up or step-down transformer?
   b. What is the current in the primary side?

a) <u>step down</u>

b) $V = IR$   $9.0 = I(21)$   $I_s = 0.429\ A$

$\frac{120}{9.0} = \frac{0.429}{I_p}$   $I_p = \underline{0.032\ A}$

4. The diagram below shows a pair of horizontal parallel rails 0.12 m apart with a uniform magnetic field of 0.055 T directed vertically downward between the rails. There is a glider of mass 9.5 x $10^{-2}$ kg across the rails. The internal resistance of the 75 V power supply is 0.30 Ω and the electrical resistance of the rails and glider is negligible. Assume friction is also negligible.




a) When the switch is closed, what is the initial acceleration of the glider?

$75 = I(0.30)$

$I = 250 A$

$F_m = BlI$

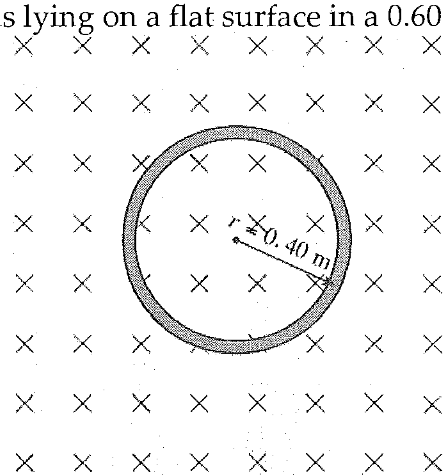
$= (0.055)(0.12)(250)$

$F_m = 1.65 N = (9.5 \times 10^{-2})\vec{a}$  $\vec{a} = 17.4 m/s^2$

b) What is the value of the terminal velocity as limited by the back EMF produced by the moving glider? $\mathcal{E} = Blv$

$75 = (0.055)(0.12)v$  $v = 1.14 \times 10^4 m/s$

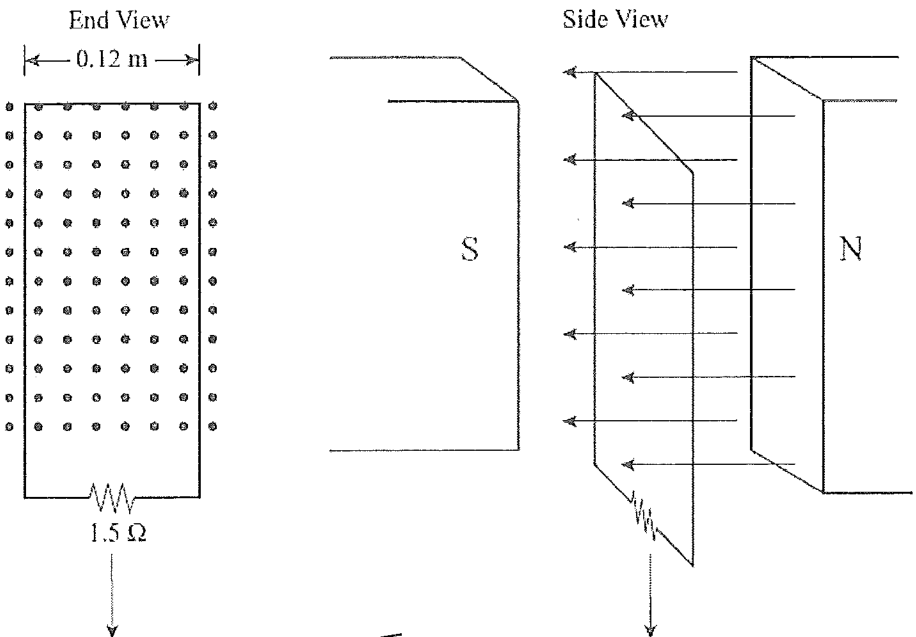
5. A coil of wire containing 50 loops is lying on a flat surface in a 0.60 T magnetic field pointing directly into the surface.




The magnetic field then changes to a value of 0.10 T in the opposite direction in 2.10 s. What is the average EMF induced in the coil during the time that the magnetic field was changing?

$$\mathcal{E} = -50 \cdot \left( \frac{(0.40^2 \cdot \pi)(-0.10 - 0.60)}{2.10} \right) = 8.4 V$$

6. A rectangular conducting loop of mass 0.045 kg and resistance 1.5 Ω is dropped in the direction shown through a uniform horizontal magnetic field of 1.8 T. At what speed will this loop be falling through the magnetic field when it stops accelerating?




$a = 0 \rightarrow F_g = F_m$

$mg = B\ell I$

$(0.045)(9.8) = (1.8)(0.12) I$

$I = 2.04\ A$

$\mathcal{E} = IR$
$= (2.04)(1.5)$

$\mathcal{E} = 3.0625 = B\ell v$

$3.0625 = (1.8)(0.12) v$

$v = \underline{14.2\ m/s}$

7. Suppose a coil and a magnet were each moving with the same velocity relative to the earth. Would there be an induced current in the coil? Explain. (same speed and direction)

→ no relative motion between the coil & magnet
= no change in magnetic flux
= no induced current

8. Does a bolt of lightning contain moving charges as it strikes the ground?

**Multiple Choice Questions:**

1. B
2. D
3. C
4. D
5. C
6. A
7. A
8. A
9. D
10. D
11. C
12. B
13. A
14. D
15. D
16. B
17. C
18. B
19. B
20. D
21. D
22. C
23. C
24. D
25. C
26. A
27. B
28. B
29. C
30. B
31. C
32. D
33. A
34. A
35. C
36. A
37. D
38. C
39. C
40. D
41. C
42. C
43. D
44. B
45. D
46. C
47. D
48. B
49. C
50. A
51. C
52. C
53. B
54. B
55. C
56. A
57. A

**Written Questions:**

1. 0.036 T
2. A) $1.62 \times 10^7$ m/s
   B) 0.040 m
3. A) step down
   B) 0.032 A
4. A) 17.4 $m/s^2$
   B) $1.14 \times 10^4$ m/s
5. 8.4 V
6. 14.2 m/s
7. check solutions
8. look it up!