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ElectromagnetismNotes

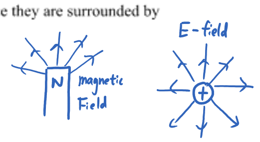
1 – Magnetic Fields

Magnets can attract or repel other magnets.

They are able to exert forces on each other without touching because they are surrounded by magnetic Fields.

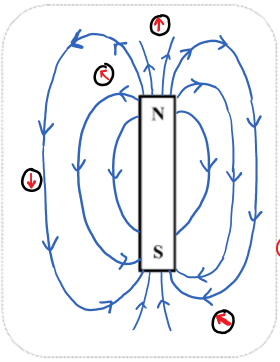
Φ

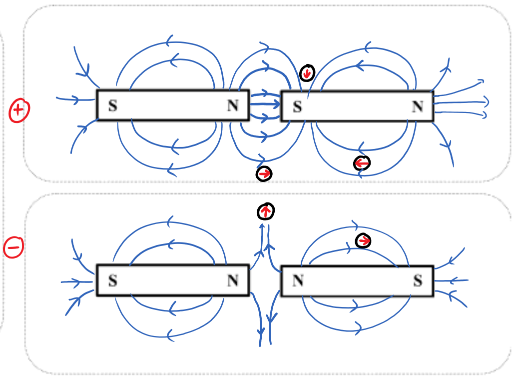
Magnetic Flux refers to… the density of field lines

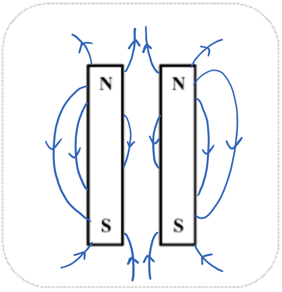


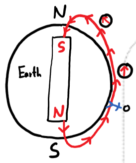
Areas with many lines have strong magnetic field.

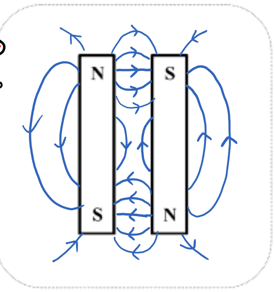
Magnets have two different ends called poles, either as North (+) (N) or South (–) (S).







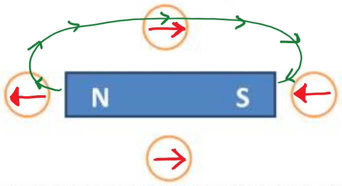




It is important to note that magnetic fields are Vectors and therefore we need to represent the lines as… arrows

[S]

In fact we define the direction of a magnetic field as …the direction that a compass would point



We can sum up the behaviour of interacting magnetic fields:

(1) opposite attract

(2) Likes repel.

This is very much like electric charges; however there is a very important difference between these two. Electric charges can be… Single charges (+ or −)

Whereas magnetic poles… only occur in pairs (N and S)

Consider a compass:

A compass is useful because its needle always points north. This is because the needle is a magnet and so is the Earth.

Yeah fine but WHY does it point north? Line up with Earth's field lines

Well, the north pole of the compass will… (Magnetic "North" is actually the South Pole)

Well that's all very well for magnetism, but where does the electro come in?

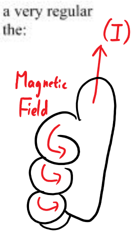
It turns out that any…. Current carrying wire is surrounded by a magnetic field.

In fact a current carrying wire will have a very regular magnetic field around it as predicted by the:

1st Right Hand Rule:

Thumb: Current (I)

Fingers: magnetic field.



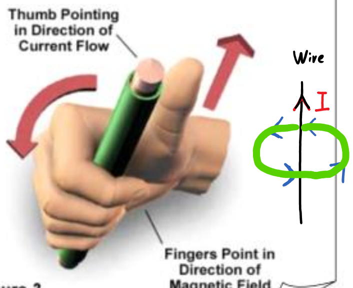
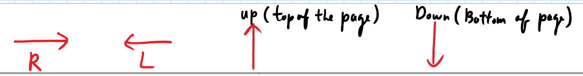


Figure 3



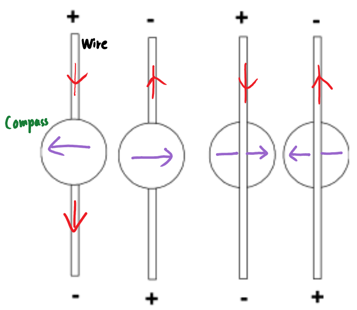
Often we will represent a current carrying wire simply as though you were looking at it end on. In this case we simply draw it as a circle. To indicate the direction of current flow we draw a X if it is in to the page and a ● if it is out of the page.

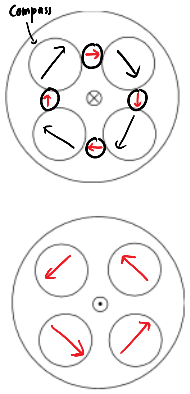
Into the page

Out of the page.

If it helps to remember which is which think of an arrow!

Below shows current carrying wires (lines) and compasses (circles). Draw arrows to show which direction the compasses will point.





Note that the compass always points…

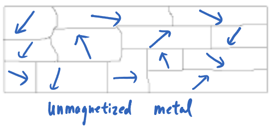
Domains:

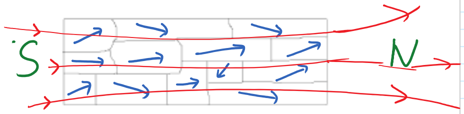
We have seen that the movement of electrons can create a magnetic field, but how does this apply to permanent magnets like bar magnets?
Certain metals (iron, nickel and cobalt) have…

Domains:

We have seen that the movement of electrons can create a magnetic field, but how does this apply to permanent magnets like bar magnets?
Certain metals (iron, nickel and cobalt) have…

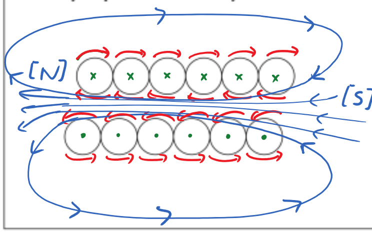
In a piece of these metals the spins of unpaired electrons align in areas called domains. In an unmagnetized piece of metal the domains are lined up randomly. A magnet is created when these domains are aligned in one direction.

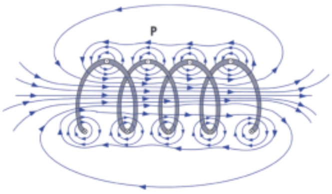




Solenoids: aka electromagnet
A solenoid is simply… a coil of wire

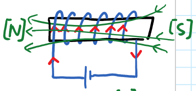
The many loops of wire each carry current and therefore…





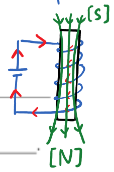
The 2nd Right Hand Rule: (for solenoids)

Fingers: Current   Thumb: points toward North



Note when using any right hand rules that… use conventional current.

Just as with a bar magnet a solenoid has… North and South poles



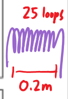
Note from the diagram that the field outside of a solenoid is Weak and non – uniform especially if its Wide is much greater than its length.

However the magnetic field inside the solenoid is strong and uniform.

In a uniform magnetic field INSIDE a solenoid we can calculate the strength of the field using: $\pi \cdot \boxed{4}\ \boxed{Exp}\ \boxed{-7}$

$$\boxed{\vec{B} = \mu_o n I}$$

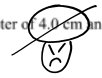
Where :
$\vec{B}$ = Magnetic Field (T)
μ_o = permeability of free space $= 4\pi \times 10^{-7}$
I = current (A)
n = loops / meter $n = \frac{N}{\ell}$ ← total loops, ← length



$n = \frac{25}{0.2} = 125$ loop/m

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 in the solenoid?

0.25m   N



$n = \frac{1000}{0.25} = 4000$ loops/m

$\vec{B} = \mu_o n I = (4\pi \times 10^{-7})(4000 \text{ loop/m})(9 A) = \boxed{0.0452 \text{ T}}$

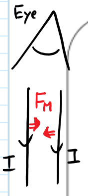
Electromagnetism Notes

2 – Magnetic Forces on Wires and Charges

With permanent magnets opposite poles attract and like poles repel.

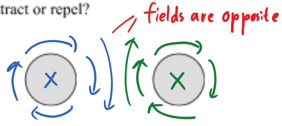
As we have seen magnetic fields surround any… current carrying wire.

Therefore it stands to reason that magnetic forces will act on wires carrying moving charges and charged particles moving in magnetic fields.



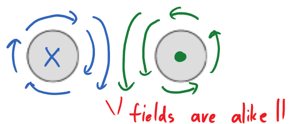
Parallel Current Carrying Wires

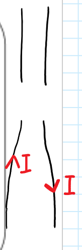
Picture two parallel wires carrying current in the same direction, would the fields produced by these wires attract or repel?



Parallel wires with current flowing in the **same** direction will… Attract !!

The same logic can be used to determine how parallel wires containing currents the flow in the opposite direction interact.





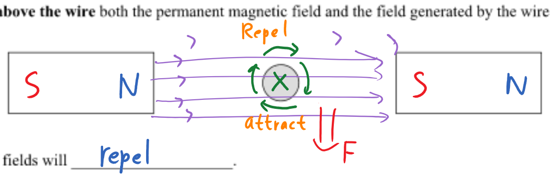
Parallel wires with current flowing in the **opposite** directions will… Repel !!

Current Carrying Wires in Magnetic Fields

A current carrying wire in a magnetic field will also experience…

Imagine a current carrying wire placed between two permanent magnets.

Note that **above the wire** both the permanent magnetic field and the field generated by the wire point… in the same direction.



These two fields will repel.

Also, **below the wire** the permanent magnetic field and the field generated by the wire point… in oppsite direction.

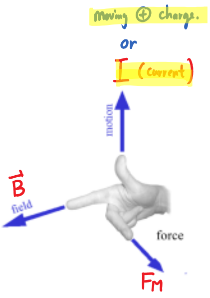
These two fields will attract.

∴ This results in an overall Magnetic Force (F_M) directed down the page.

F_M I ℓ $\vec{B}$

RHR #3 F_M on a current carrying wire inside an external $\vec{B}$

The 3rd Right Hand Rule:



The magnitude of the magnetic force on a conductor can be calculated as:

$$\boxed{\vec{F}_M = \vec{B}\vec{I}\ell(\sin\theta)}$$

Where:

B = mag. Field (T)

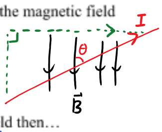
I = current (A)

ℓ = length (m)

θ = orientation

Note that if the conductor is perpendicular to the magnetic field this formula becomes:

$$F_M = \vec{B}\vec{I}\ell$$

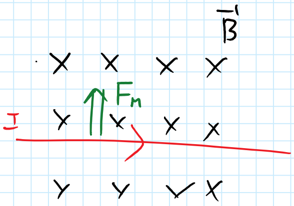


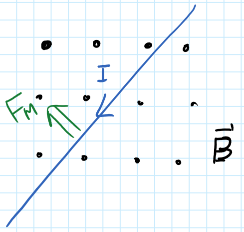
Because… $\sin 90° = 1$

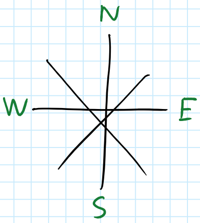
If the conductor is parallel to the magnetic field then…

wire

$F_M = 0$ $\sin 0 = 0$







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.

To determine the direction of the force on such a particle we simply use… the 3rd RHR

NOTE: We use the right hand rules for wires when talking about conventional current (+ → −) and the left hand rules for wires when talking about ______________ ______________.

We follow the same logic when dealing with charged particles:

For **positive** particles use… right hand rules

For **negative** particles use… switch the direction of your thumb

To calculate the magnetic force on the particle we use:

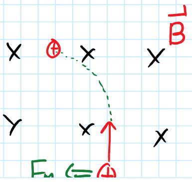
$$\boxed{\vec{F}_M = q\vec{v}\vec{B}(\sin\theta)}$$

Where: q = Chrage (C)

v = velocity (m/s)

B = mag field (T)

θ = Orientation.



$$\vec{F}_M = q\vec{v}\vec{B}\ (\sin\theta)$$

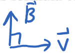
v = velocity (m/s)

B = mag field (T)

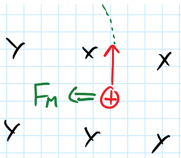
θ = Orientation.

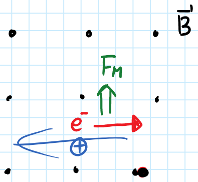
NOTE: Just like the magnetic force on conductors this formula can be reduced to

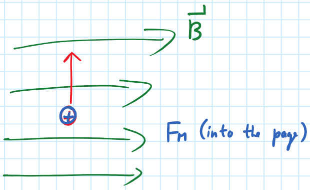
$$\vec{F}_M = q\vec{v}\vec{B}$$



when the particles are moving perpendicular to the magnetic field.

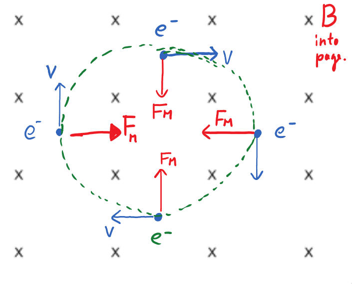






If a charged particle enters a magnetic field traveling perpendicular to the field, it will deflect continuously and travel in a Circle.

Consider an **electron** moving through a magnetic field



Now consider a proton moving through the same magnetic field

Example:

Circular particle accelerators use magnetic fields to bend beams of charged particles. This allows them 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. Note that at these speeds the relativistic mass of a hydrogen anion is 2.524×10^{-27} kg.

What is the outer radius of the cyclotron?

When charged particles travel in a circular path:

$$F_M = F_c$$

$$F_M = F_c$$

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

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

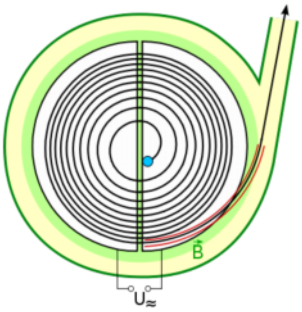
orbital

mass (kg)

speed (m/s)

Charge (C)

mag. Field.



Electromagnetism Notes

3 – Motors, CRT's and Mass Spectrometers

$$F_m = \underset{\perp}{\vec{B}\vec{I}}\,\ell$$

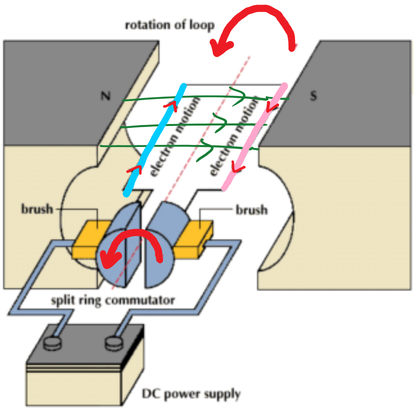
Motors

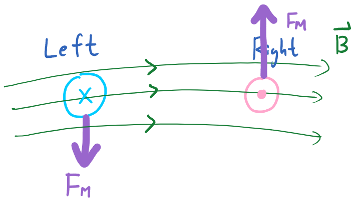
We have seen that a current carrying wire perpendicular to a magnetic field will experience a __Force__________.

This phenomenon is used by an electric motor to transform __electrical_____ energy into __mechanical____ energy.

A simple DC motor consists of a loop of wire that passes through a magnetic field. The ends of the loop are attached to a split ring (__Commutator________) which turns with the loop. Fixed ______brushes___________ connect the commutator to the voltage source.

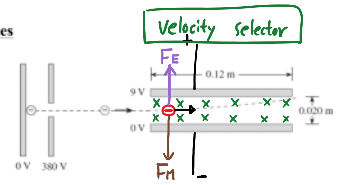
The commutator (split ring) is important because…
it reverse current every half-turn.

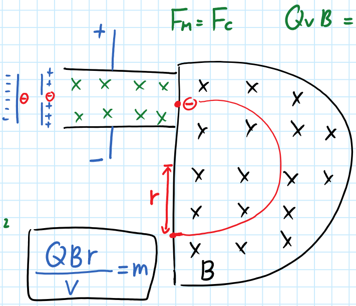




Cathode Ray Tubes

A cathode ray tube is used to accelerate electrons to incredible speeds and then deflect them with electrically charged plates. Consider the following example:





$F_M = F_c$ $\quad QvB = \frac{mv^2}{r}$

$$\boxed{\frac{QBr}{V} = m}$$

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

$\Delta E_p = E_{k\,gain}$ $\quad \Delta V Q = \frac{1}{2} m v^2$

ex,

$380(1.6\times10^{-19}) = \frac{1}{2}(9.11\times10^{-31})V^2$

$V = 1.155\times10^{7}\, m/s$

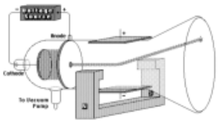
2) What is the electrostatic force on electrons in the region between the horizontal plates when they are connected to a 9.0 V potential difference?

$F_E = F_M$ $\quad E\cancel{Q} = \cancel{Q}vB$ $\quad \boxed{V = \frac{E}{B}}$

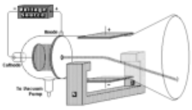
for zero deflection

Determining the Mass and Charge of the Electron

Famed physicist J.J. Thompson took the cathode ray a step further. First he set up a cathode ray tube that deflected the electron ray using a second set of electrically charged plates (aka yoke), similar to the example above.



As expected the ray deflected towards the positive plate.



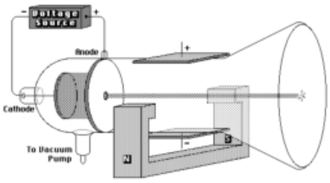
He then disconnected the current from the electric yoke and instead sent current through an electromagnet flanking the cathode ray. He was intrigued to note that the ray of electrons deflected downwards.

Since r and B can both be easily measured we could simply determine the speed of the electron by

Unfortunately for good old J. J., nobody knew the mass or charge of an electron. Both of which would be needed to determine the velocity of the electron ray.

But then, he weren't no genius for nothin'. He set up another cathode ray that had both electromagnetic and electrostatic yokes working in opposition to each other.

By gently calibrating the electric field between the plates, he was able to obtain an undeflected beam as shown:



In this case where the electrons are undeflected, we know that the electrostatic and magnetic forces are Equal and opposite

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

Or simply, $F_E = F_M$ .This can be used to solve for the velocity of the electrons, which in turn allowed Thompson to determine the charge to mass ratio of the electron long before either quantities were understood.

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

$\uparrow F_M = QvB$

$\downarrow F_E = QE$

$QvB = QE$

$V = \frac{E}{B} = \frac{6.3 \times 10^3}{7.11 \times 10^{-3}}$

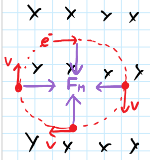
$V = 8.86 \times 10^5 \, m/s$

Example: Charged particles traveling horizontally at 3.60×10^6 m/s when they enter a vertical magnetic field of 0.710 T. If the radius of their arc is 9.50×10^{-2} m, what is the **charge to mass** ratio of the particles?

$F_M = F_c$

$QvB = \frac{mv^2}{r}$

$\frac{Q}{m} = \boxed{\frac{V}{Br}} = 5.34 \times 10^7 \, C/kg$

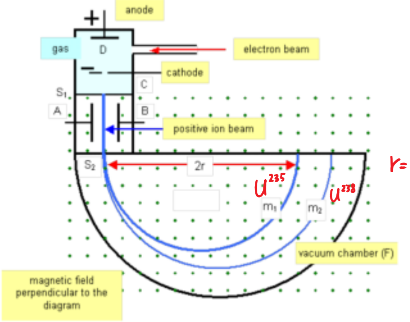


Mass Spectrometers

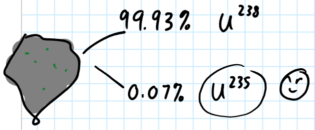
Mass spectrometers can be used to determine the mass of unknown substance or to separate similar compounds of slightly different mass. First the sample is vaporized and then it is bombarded with electrons. These high energy electrons ionize the sample by knocking loose electrons. These cations are then accelerated by a potential difference and then fired into a perpendicular magnetic field. This field causes them to bend until they strike a detector.

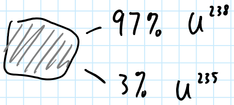
How can this be used to determine the mass of an unknown sample?

$$\boxed{m = \frac{QBr}{V}}$$



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





In practice even a pure substance will strike the detector at multiple locations. Explain why this might occur.

- It is possible to have different charges $[Fe^{2+}, Fe^{3+}]$
- Isotopes !! – Same # proton
  – different # neutron → masses !!

Mass spectrometers can also be used to separate substances into individual isotopes. For example uranium naturally exists as a mixture of Uranium-238 and Uranium-235. Describe how this is done. On the diagram above, which paths (m_1 or m_2) would represent U-235 and U-238?

↑ Larger mass.

- Larger mass travel in larger radius.
- Collectors are placed at the appropriate locations.

Electromagnetism Notes
4 – Electromagnetic Induction

After scientists had discovered that an electric current can generate a magnetic field the logical question followed: *"If an electric current can generate a magnetic field, can a magnetic field generate an electric current?"* Michael Faraday and Joseph Henry independently discovered they could.

Electromagnetic Induction:

Generation of an EMF (Voltage) from changing of Magnetic Fields.

Faraday discovered many ways to induce a current. For example in the induction coil shown below.

What was most interesting to note was that… it doesn't matte which way the coil or magnet moved.

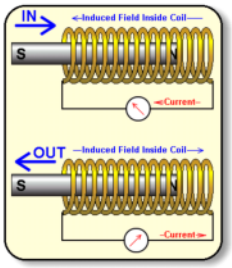
This showed that magnetic fields do not simply create electric currents, rather they are only generated by… a change in magnetic fields

Another example of this comes when you move a bar magnet into or out of a hollow solenoid.

When the magnet is moved one way the current is in one direction and when it is moved the other way the current reverses.

To predict the direction of the induced current we use Lenz's Law:

Induced magnetic Field work against the applied force (change in field)



Lenz's Law is really an application of… The Laws of Conservation of Energy.

Remember that we can use the 2nd **Right Hand Rule** to relate the poles of an electromagnet and the direction of current flow.

Thumb: North

Fingers: Current

As we said the electric current is generated by a… a change in $\vec{B}$

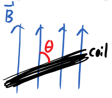
Voltage

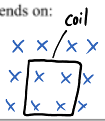
In order to calculate the EMF generated we need to use the idea of magnetic flux.

Magnetic Flux: # of field lines that pass through a coil

For a loop of wire in a magnetic field the magnetic flux depends on:

(1) Mag Field (B)
(2) Area of Loop (A)
(3) Orientation to field (θ)

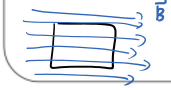




Note that magnetic flux is at a **maximum** when the loop is… perpendicular

0

And at a **minimum** when the loop is… parallel



Magnetic flux can be calculated by:

Where:

$$\boxed{\Phi = BA\,(\sin\theta)}$$

Φ = flux (Wb)

B = Mag Field (T)

A = Area (m^2)

θ = angle

The units of flux are Tm^2 or the Weber (Wb)

As we said before an EMF is produced by a changing magnetic field, specifically by a changing flux. In fact, Induced Voltage $\Delta(BA)$

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

drop it in actual calculation

Where: N = # of loops

And the "–" sign relates to… Lenz's Law

Example:
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?

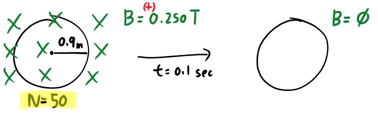
$$\Phi = BA = (1.5T)(4.41\times10^{-4}m^2)$$

$$\Phi = 6.6\times10^{-4}\ Wb$$

$A = (0.021)^2$

$A = 4.41\times10^{-4}m^2$

Example:
A 1.80 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 0.100s what is the average induced EMF in the coil?

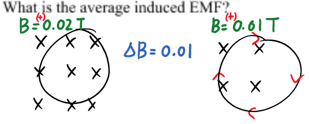


$$\text{Area} = \pi r^2 = \pi(0.9)^2 = 2.5447\,m^2$$

$$\mathcal{E}_{\text{induced}} = \frac{N\Delta\Phi}{t} = \frac{50\,\Delta B\cdot A}{0.1} = \frac{50(0.25T)(2.5447)}{0.1} = \boxed{318V}$$

$V = IR$

Example:
A circular loop of wire radius 2.5 cm is placed in a magnetic field B = 0.020 T into the page. The field is then reduced to 0.010 T into the page in 0.10 s.
a. What is the average induced EMF?



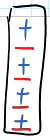
$$\mathcal{E} = \frac{N\Delta\Phi}{t} = \frac{N\cdot\Delta B\cdot A}{t}$$

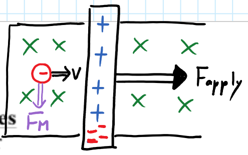
$$= \frac{1\times0.01\times(\pi\,0.025^2)}{0.1\,\text{sec}}$$

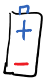
$$= \boxed{1.96\times10^{-4}\ V}$$

b. Which direction does the current flow?

I_{induced} = Clockwise.







Electromagnetism Notes

5 – Moving Conductor

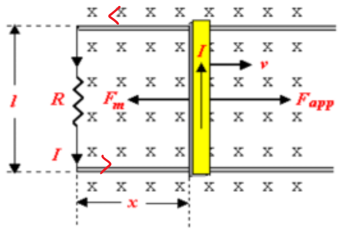
We have already seen that a loop rotating in a magnetic field will generate an EMF according to Faraday's Law ($\mathcal{E} = \frac{-N\Delta\Phi}{t}$)

However when considering a conductor moving in a magnetic field it is better to consider a different form of this equation.

For Moving Conductors:

$$\boxed{\mathcal{E} = Bl v}$$

Where:
ε = EMF (Voltage)
B = Field (T)
l = length (m)
v = Velocity (m/s)



Derivation:

$$\mathcal{E} = \frac{\cancel{N}\Delta\Phi}{t} = \frac{B\cdot\Delta A}{t} = \frac{B\cdot l\,\Delta x}{t} = Blv$$

B·A

Velocity

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

0.25m

$$\mathcal{E} = Blv = (0.2)(0.25)(1\,m/s)$$

$$= \boxed{0.05\,V}$$

Example:
A conducting rod 15 cm long moves at a speed of 2.0 m/s perpendicular to a 0.30 T magnetic field. If the resistance of the circuit is 4.0 ohms, what is the magnitude of the current through the circuit?

0.15m B R v

$$\mathcal{E} = Blv = (0.3)(0.15)(2) = 0.09\ V$$

$$V = IR \quad I = \frac{V}{R} = \frac{0.09}{4} = \boxed{0.0225A}$$

Example: A 0.75 m conducting rod is moved at 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?

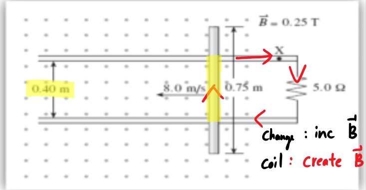
$$\mathcal{E} = Blv = (0.25\,T)(0.4m)(8\,m/s)$$

Example: A 0.75 m conducting rod is moved at 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?

$$\varepsilon = B l v = (0.25\,T)(0.4\,m)(8\,m/s)$$

$$= 0.80\,V$$

$$V = IR \quad I = \frac{V}{R} = \frac{0.8}{5} = \boxed{0.16\,A \text{ to Right}}$$



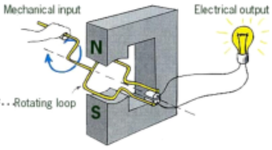
Change: inc $\vec{B}$ out of page

coil: create $\vec{B}$ into the page.

Electromagnetism Notes

6 – Back EMF

Devices that use mechanical energy to induce an electric current are called generators.
Many kinds of mechanical energy can therefore by converted into electrical energy such as in:
hydrelectric dams and wind turbines.



Note that this works in the exact opposite manner as an electric motor.
Motor: electrical energy to mechanical energy
Generator: mechanical energy to electrical energy

Notice that these generators produce alternating current because…
the coils are reversed every half turn.

Remember that to determine the direction of the current through a loop we can use Faraday's Law $\varepsilon = -N\frac{\Delta\Phi}{t}$ and to determine the EMF produced by a loop we can use Lenz's Law (RHR).

This brings up an inherent problem with all electric motors. As we said, electric motors are basically Coils of wire rotating in a magnetic Field.

However, we know that whenever we rotated wires in a magnetic field we generate an induced EMF.

We also know from Lenz's Law that the induced EMF works in the direction opposite to motion.

This is called: Back EMF!!

And it always works… against the Apply Voltage.

Back EMF can be calculated using:

@ full speed

$$\boxed{V_{back} = \varepsilon - I_{min}\, r}$$

@ start / stop

$$\boxed{\varepsilon = I_{max} r}$$

Where: V_{back} = Back EMF
ε = Apply Voltage
I = current
r = resistance

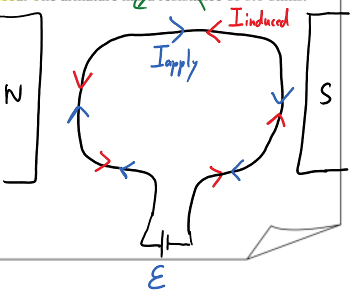
Example: A 120 V motor draws 12 A when operating at full speed. The armature has a resistance of 6.0 ohms.

ε (120 V), I_{min} (12 A)

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

$$\varepsilon = I_{max} \cdot r \qquad 120 = I_{max}(6\,\Omega)$$

$$I_{max} = 20\,A$$



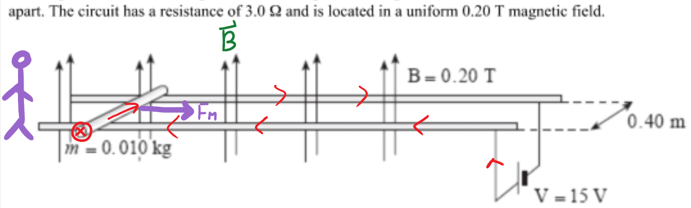
b) Find the back EMF when the motor reaches full speed.

$$V_{back} = \overset{120V}{\varepsilon} - \overset{(12A)(6\Omega)}{I_{min}\, r}$$

$$= \boxed{48\,V}$$

Railgun

Example:
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.



a) What is the initial acceleration of the bar?

$V = IR$ $\boxed{I = 5A}$

$15 = I(3\Omega)$

$F_M = BIl$

$= (0.2T)(5)(0.4m)$

$= \boxed{0.4\ N}$

$F_{net} = ma$

$0.4 = (0.01)a$

$\boxed{a = 40\ m/s^2}$

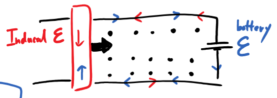
b) What is its top speed?

Induced $\mathcal{E}$ = 15 V

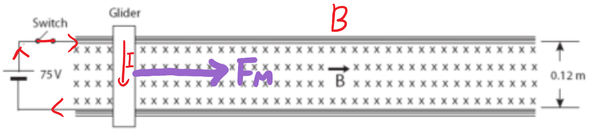
$\boxed{\mathcal{E}_{induced} = Blv}$

$15 = (0.2)(0.4)v$

$\boxed{V = 187.5\ m/s}$



Example:
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 9.5x10^{-2} kg across the rails. The internal resistance of the 75 V power supply is 0.30 ohms and the electrical resistance of the rails and the glider is negligible. Assume friction is also negligible.



a) What is the initial acceleration of the glider?

$F_M = BIl$

$= (0.055)(250)(0.12)$

$F_{net} = ma$

$I = 250\ A$

$F_M = 1.65\ N$

$\boxed{a = 17.4\ m/s^2}$

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

$\mathcal{E}_{induced} = \mathcal{E}_{battery}$

$\mathcal{E} = Blv$

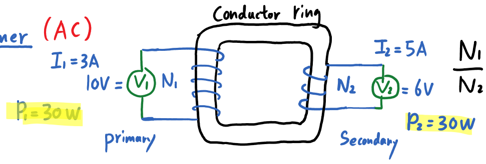
11.4 km/s

$\mathcal{E}_{ind} = 75\ V$

$V = 11400\ m/s$

$V_{esp} = 11.2\ km/s$

Transformer (AC)



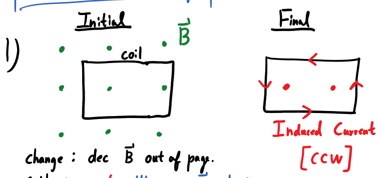
$$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$$

Example:
A step-down transformer reduces the voltage from a 120 V to 12.0 V. If the primary coil has 500 turns and draws $3.00\text{x}10^{-2}$ A,

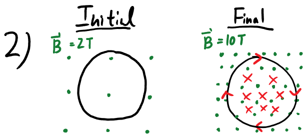
a) What is the power delivered to the secondary coil?

b) What is the current in the secondary coil?

Induction Example

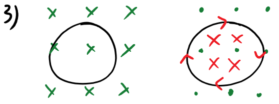


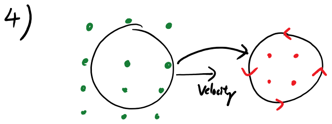
change : dec $\vec{B}$ out of page.
Coil : create it's own $\vec{B}$ out of page

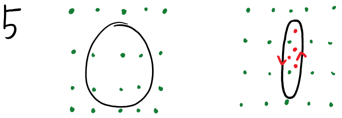


Change : inc $\vec{B}$ out of page
Coil : Create $\vec{B}$ into the page.

I = [CW]





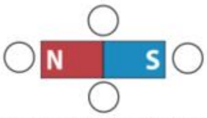


Change : dec B out of page.
coil : Create $\vec{B}$ out of page I_{ind} = [CCW]

Worksheet 8.1 - Magnetic Fields

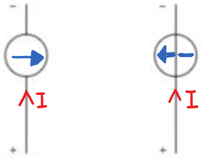
1. You are experimenting with two identical permanent magnets. One magnet is coloured blue, and the other is coloured red. If the blue magnet attracts the red magnet with the force of 75.0 N, what is the force of attraction between the red and the blue magnet?

2. If four compasses are arranged around a magnet as shown in the diagram below, in what direction will the north end of each compass needle point? Draw the needles in the diagram.



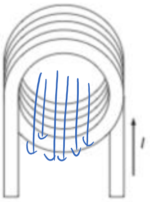
3. What will happen to the suspended magnet as a second magnet is brought close?

4. Draw the direction the compass needle will point when the compass is placed on the current-carrying conductor in each diagram below.



(a) (b)

5. Draw the direction of the magnetic field inside the loops and outside the loops in the figure below.



$n = \frac{N}{l} = \frac{1800}{0.25 m}$

$n = 7200$ loops/m

$\vec{B}$ [out of page]

6. 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.

$\vec{B} = \mu_0 n I = 4\pi \times 10^{-7} (7200)(1.25 A)$

$= \boxed{0.0113\ T}$

$\boxed{4}\ \boxed{Exp}\ \boxed{-7}\ \boxed{\times}\ \boxed{\pi}$

$\boxed{\times}\ \boxed{10}\ \boxed{\wedge}$

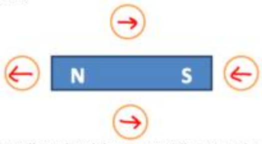
7. An air core solenoid is 25 cm long and carries a current of 0.72 A If the magnetic field in the core is 2.1×10^{-3}T how many turns does this solenoid have?

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

9. What is the magnetic field near the centre of a .30m long solenoid that has 800 turns of wire if it carries a electric current of 2.0 A?

Answers:

1. 75 N



2.
3. It will repel, and the magnet will move to the right and up (due to tension in the rope)
4. a. Since the reading is ABOVE the wire = → b. Since the reading is BELOW the wire ←
5. Inside the loop coming out of the page; outside the loop into the page
6. (1.13×10^{-2}T)
7. (580)
8. (31 A)
9. (6.7×10^{-3}T)

Quiz next Class Day 1 - 2 (RHR 1,2,3)

Worksheet 8.2 - Magnetic Forces on Wires and Charges

1. A particle carrying a charge of 0.50 μC enters a magnetic field of strength 0.045 T, with a velocity of 350 m/s. The velocity is perpendicular to the magnetic field. What is the magnetic force acting on the charged particle?

2. A segment of conducting wire 5.0 cm long carrying 5.0 A of current is perpendicular to a magnetic field of 12 T. What magnetic force acts on the segment?

3. A wire is 0.75 m long carries a current of 10.0 A is at a right angle to a uniform magnetic field. The force on the wire is 0.50 N. What is the strength of the magnetic field

4. What is the magnitude of force on a wire that is 30 cm long and positioned at a right angle to a 0.40 T uniform magnetic field? The current through the wire is 5.0 A.

5. A half-kilometre length of wire is positioned perpendicular to a 0.40 T magnetic field. What is the current carried in the wire if a force of 2.0 N acts on the wire?

6. What magnetic field strength is needed to exert a force of 1.0×10^{-15} N on an electron traveling 2.0×10^{7} m/s?

7. A solenoid 0.20 m long has 600 turns of wire. What current must be passed through the solenoid to produce a magnetic field of 2.0×10^{-2} T?

8. A magnetic resonance imaging machine (MRI) is used to take medical diagnostic images of the body. To create these images, a large solenoid is used and the person is placed in the centre of the solenoid. A current of 1500 A is carried through a 2.00 m long solenoid that has 2500 loops. What is the magnetic field strength inside the solenoid?

9. A 61 mg mass just balanced the balance arm of a current balance when the strip current is 3.0 A. If the strip is 2.2 cm long, what is the magnetic field strength inside the solenoid in which the current balance is located?

Answers:

1. 7.9×10^{-6} N
2. 3.0 N
3. 0.0067 T
4. 0.60 N
5. 0.01 A
6. 3.1×10^{-6} T
7. 5.3 A
8. 2.36 T
9. 9.1×10^{-3} T

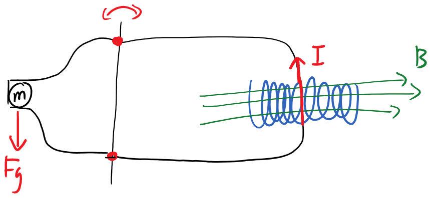
⑨,

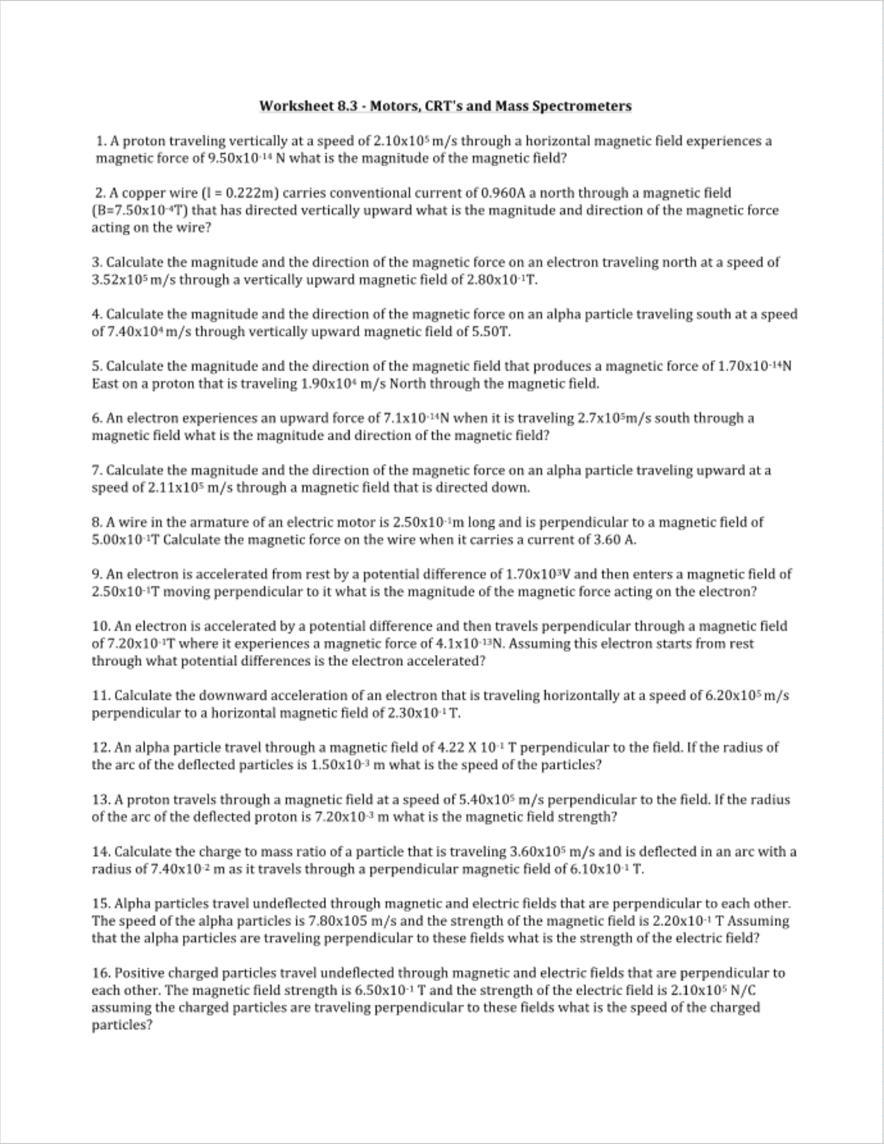
$$F_m = F_g$$

$$BI\ell = mg$$

$$B(3)(0.022\text{m}) = (61\,\cancel{\text{mg}})\left(\frac{1\,\cancel{\text{g}}}{1000\,\cancel{\text{mg}}}\right)\left(\frac{1\,\text{kg}}{1600\,\cancel{\text{g}}}\right)(9.8)$$

$$\vec{B} = 9.06 \times 10^{-3}\ \text{T}$$





Worksheet 8.3 - Motors, CRT's and Mass Spectrometers

1. A proton traveling vertically at a speed of $2.10x10^5$ m/s through a horizontal magnetic field experiences a magnetic force of $9.50x10^{-14}$ N what is the magnitude of the magnetic field?

2. A copper wire (l = 0.222m) carries conventional current of 0.960A a north through a magnetic field ($B=7.50x10^{-4}T$) that has directed vertically upward what is the magnitude and direction of the magnetic force acting on the wire?

3. Calculate the magnitude and the direction of the magnetic force on an electron traveling north at a speed of $3.52x10^5$ m/s through a vertically upward magnetic field of $2.80x10^{-1}$T.

4. Calculate the magnitude and the direction of the magnetic force on an alpha particle traveling south at a speed of $7.40x10^4$ m/s through vertically upward magnetic field of 5.50T.

5. Calculate the magnitude and the direction of the magnetic field that produces a magnetic force of $1.70x10^{-14}$N East on a proton that is traveling $1.90x10^4$ m/s North through the magnetic field.

6. An electron experiences an upward force of $7.1x10^{-14}$N when it is traveling $2.7x10^5$m/s south through a magnetic field what is the magnitude and direction of the magnetic field?

7. Calculate the magnitude and the direction of the magnetic force on an alpha particle traveling upward at a speed of $2.11x10^5$ m/s through a magnetic field that is directed down.

8. A wire in the armature of an electric motor is $2.50x10^{-1}$m long and is perpendicular to a magnetic field of $5.00x10^{-1}$T Calculate the magnetic force on the wire when it carries a current of 3.60 A.

9. An electron is accelerated from rest by a potential difference of $1.70x10^3$V and then enters a magnetic field of $2.50x10^{-1}$T moving perpendicular to it what is the magnitude of the magnetic force acting on the electron?

10. An electron is accelerated by a potential difference and then travels perpendicular through a magnetic field of $7.20x10^{-1}$T where it experiences a magnetic force of $4.1x10^{-13}$N. Assuming this electron starts from rest through what potential differences is the electron accelerated?

11. Calculate the downward acceleration of an electron that is traveling horizontally at a speed of $6.20x10^5$ m/s perpendicular to a horizontal magnetic field of $2.30x10^{-1}$ T.

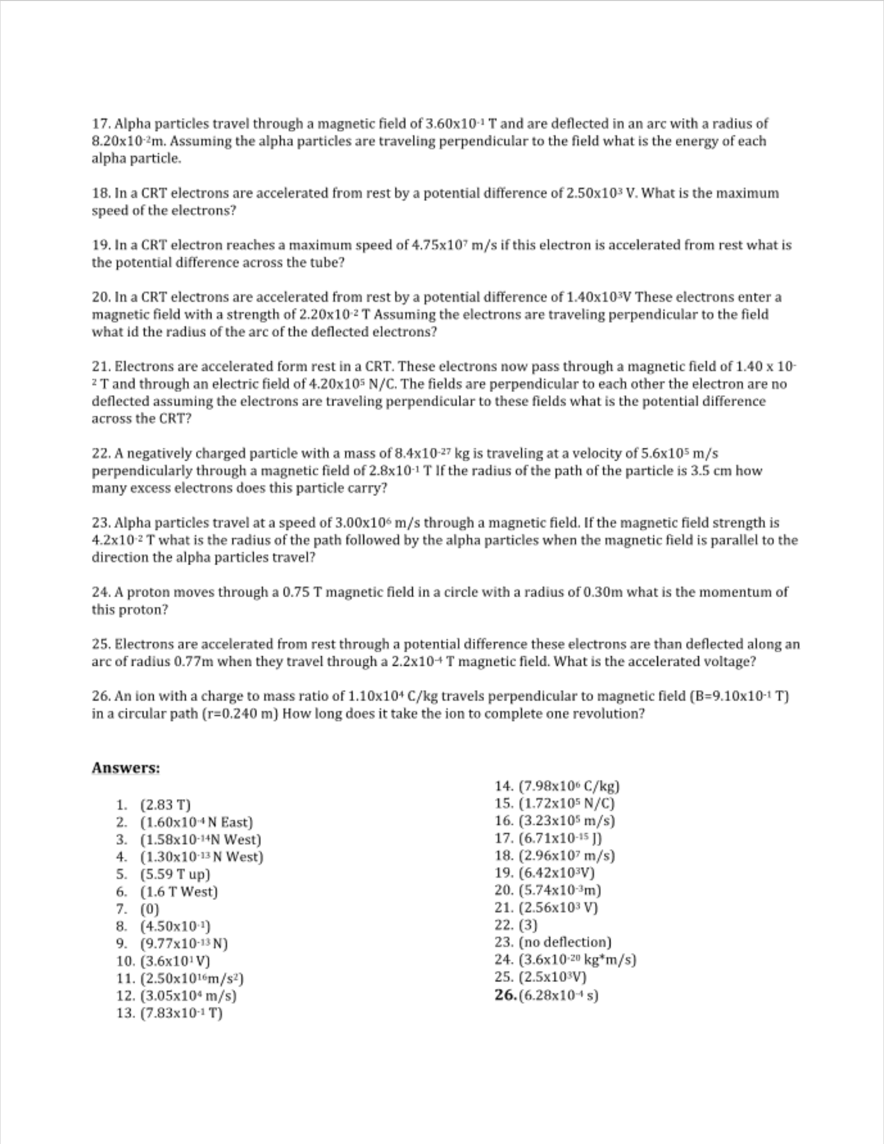
12. An alpha particle travel through a magnetic field of $4.22 X 10^{-1}$ T perpendicular to the field. If the radius of the arc of the deflected particles is $1.50x10^{-3}$ m what is the speed of the particles?

13. A proton travels through a magnetic field at a speed of $5.40x10^5$ m/s perpendicular to the field. If the radius of the arc of the deflected proton is $7.20x10^{-3}$ m what is the magnetic field strength?

14. Calculate the charge to mass ratio of a particle that is traveling $3.60x10^5$ m/s and is deflected in an arc with a radius of $7.40x10^{-2}$ m as it travels through a perpendicular magnetic field of $6.10x10^{-1}$ T.

15. Alpha particles travel undeflected through magnetic and electric fields that are perpendicular to each other. The speed of the alpha particles is 7.80x105 m/s and the strength of the magnetic field is $2.20x10^{-1}$ T Assuming that the alpha particles are traveling perpendicular to these fields what is the strength of the electric field?

16. Positive charged particles travel undeflected through magnetic and electric fields that are perpendicular to each other. The magnetic field strength is $6.50x10^{-1}$ T and the strength of the electric field is $2.10x10^5$ N/C assuming the charged particles are traveling perpendicular to these fields what is the speed of the charged particles?



17. Alpha particles travel through a magnetic field of $3.60x10^{-1}$ T and are deflected in an arc with a radius of $8.20x10^{-2}$m. Assuming the alpha particles are traveling perpendicular to the field what is the energy of each alpha particle.

18. In a CRT electrons are accelerated from rest by a potential difference of $2.50x10^{3}$ V. What is the maximum speed of the electrons?

19. In a CRT electron reaches a maximum speed of $4.75x10^{7}$ m/s if this electron is accelerated from rest what is the potential difference across the tube?

20. In a CRT electrons are accelerated from rest by a potential difference of $1.40x10^{3}$V These electrons enter a magnetic field with a strength of $2.20x10^{-2}$ T Assuming the electrons are traveling perpendicular to the field what id the radius of the arc of the deflected electrons?

21. Electrons are accelerated form rest in a CRT. These electrons now pass through a magnetic field of $1.40 \text{ x } 10^{-2}$ T and through an electric field of $4.20x10^{5}$ N/C. The fields are perpendicular to each other the electron are no deflected assuming the electrons are traveling perpendicular to these fields what is the potential difference across the CRT?

22. A negatively charged particle with a mass of $8.4x10^{-27}$ kg is traveling at a velocity of $5.6x10^{5}$ m/s perpendicularly through a magnetic field of $2.8x10^{-1}$ T If the radius of the path of the particle is 3.5 cm how many excess electrons does this particle carry?

23. Alpha particles travel at a speed of $3.00x10^{6}$ m/s through a magnetic field. If the magnetic field strength is $4.2x10^{-2}$ 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?

24. A proton moves through a 0.75 T magnetic field in a circle with a radius of 0.30m what is the momentum of this proton?

25. Electrons are accelerated from rest through a potential difference these electrons are than deflected along an arc of radius 0.77m when they travel through a $2.2x10^{-4}$ T magnetic field. What is the accelerated voltage?

26. An ion with a charge to mass ratio of $1.10x10^{4}$ C/kg travels perpendicular to magnetic field ($B=9.10x10^{-1}$ T) in a circular path ($r=0.240$ m) How long does it take the ion to complete one revolution?

Answers:

1. (2.83 T)
2. ($1.60x10^{-4}$ N East)
3. ($1.58x10^{-14}$N West)
4. ($1.30x10^{-13}$ N West)
5. (5.59 T up)
6. (1.6 T West)
7. (0)
8. ($4.50x10^{-1}$)
9. ($9.77x10^{-13}$ N)
10. ($3.6x10^{1}$ V)
11. ($2.50x10^{16}$m/s^{2})
12. ($3.05x10^{4}$ m/s)
13. ($7.83x10^{-1}$ T)
14. ($7.98x10^{6}$ C/kg)
15. ($1.72x10^{5}$ N/C)
16. ($3.23x10^{5}$ m/s)
17. ($6.71x10^{-15}$ J)
18. ($2.96x10^{7}$ m/s)
19. ($6.42x10^{3}$V)
20. ($5.74x10^{-3}$m)
21. ($2.56x10^{3}$ V)
22. (3)
23. (no deflection)
24. ($3.6x10^{-20}$ kg*m/s)
25. ($2.5x10^{3}$V)
26. ($6.28x10^{-4}$ s)

Worksheet 8.4 - Electromagnetic Induction

1. A magnetic field (B=3.2x10^{-3} T) passes perpendicular through a circular loop of wire (radius = 5.0 cm). What is the magnetic flux through the loop?

2. A circular coil (200 turn radius of 6.0 cm) is rotated in a uniform magnetic field (B = 3.6x10^{-4} T) At t = 0 the coil is perpendicular to the field and at t = 0.015s the coil is parallel to the field what is the average emf induced in the coil?

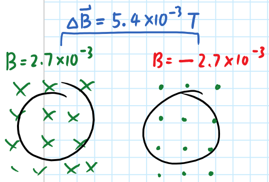
3. A square loop of wire with an area of 2.5x10^{-3} m^2 is perpendicular to a uniform magnetic field (B = 2.2x10^{-2} T). If the square collapsed to an area of essentially 0 m^2 in a time of 0.100 s as shown in the diagram what is the average induced emf as it is collapsed and what is the direction of the induced current? (Remember to use conventional current)

4. Find the average emf induced in a circular coil (50 turns radius of 0.050 m) if the magnetic flux through the loops is changing at a rate of 15.0 Wb/s?

5. A square coil (100 turns area of each square loop = 4.0x10^{-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?

N $A = \pi r^2 = \pi(0.125)^2 = 0.049\,m^2$

6. A circular coil (10 turns, diameter = 25 cm) is placed perpendicular to a uniform magnetic field (B = 2.7 x 10^{-3} T). If the direction of the magnetic field is reversed in 0.30s, what is the average emf induced in the coil?



$$\mathcal{E} = \frac{N\Delta\Phi}{t} = \frac{N\Delta B\cdot A}{t} = \frac{10(5.4\times10^{-3})(0.049)}{0.3}$$

$$\boxed{\mathcal{E} = 8.82\times10^{-3}\ V}$$

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

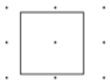
8. A square loop of wire (area= 7.2 x 10^{-3} m^2) has a resistance of 12.0Ω. Assume that the magnetic field drops uniformly from 1.6 T to zero in 0.050 s as the loop is pulled from the magnetic field.

a) What is the average emf induced in the loop?
b) What is the current induced in the loop?
c) What is the direction of the electron flow in the loop?

Current [CCW]

electron [CW]

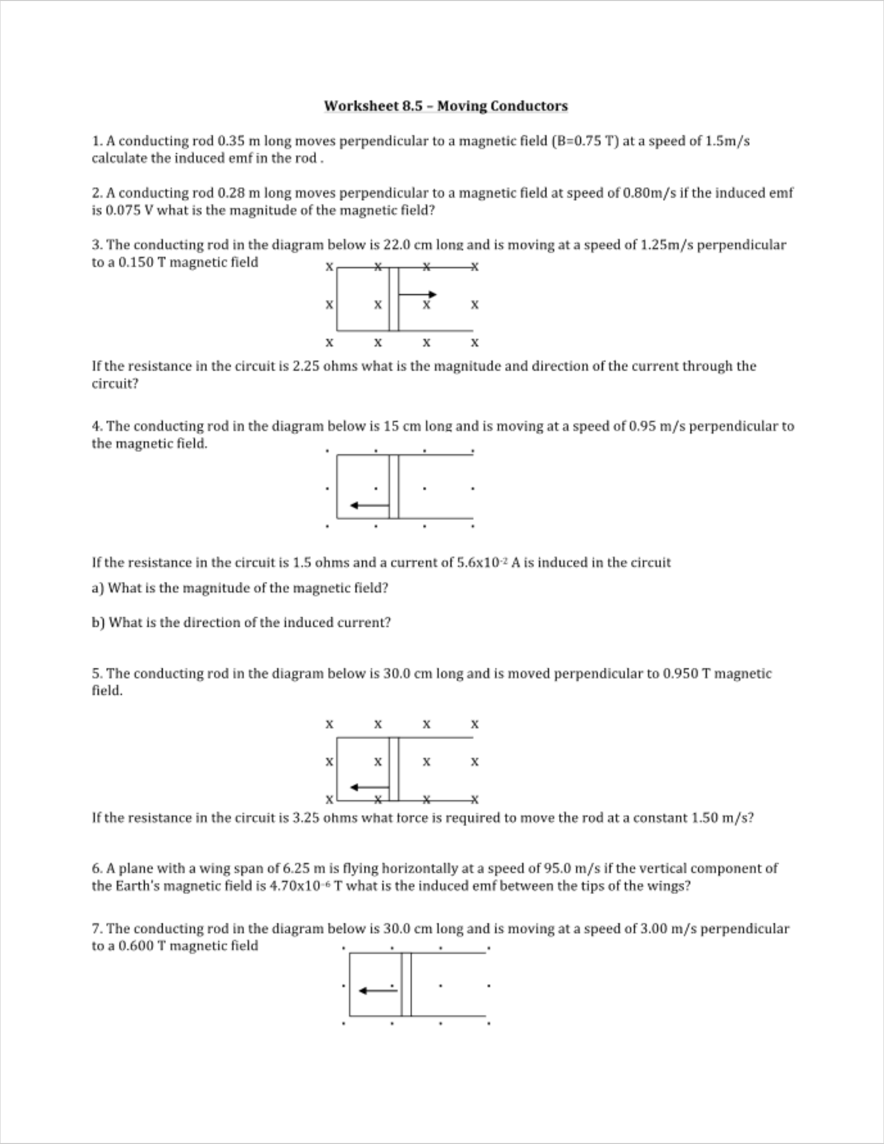
9., A square loop of wire (4.0 cm per side) is placed in a magnetic field ($B = 0.20$ T). The magnetic field is increased to 0.50 T in 0.30 s.



a. Find the current through the loop if the resistance of the loop is 2.0 Ω.
b. Find the direction of the **electron flow** through the loop.

Answers:

1. (2.5×10^{-5} Wb)`
2. (5.4×10^{-2} V)
3. (5.5×10^{-4} V clockwise)
4. (750 V)
5. (2.8×10^{-1} T)
6. (8.8×10^{-3} V)
7. (5.0×10^{-2} V)
8. a. (2.3×10^{-1} V) b. (1.9×10^{-2} A) c. (clockwise)
9. a. (8.0×10^{-4} A) b. (counter-clockwise)



Worksheet 8.5 – Moving Conductors

1. A conducting rod 0.35 m long moves perpendicular to a magnetic field (B=0.75 T) at a speed of 1.5m/s calculate the induced emf in the rod .

2. A conducting rod 0.28 m long moves perpendicular to a magnetic field at speed of 0.80m/s if the induced emf is 0.075 V what is the magnitude of the magnetic field?

3. The conducting rod in the diagram below is 22.0 cm long and is moving at a speed of 1.25m/s perpendicular to a 0.150 T magnetic field

If the resistance in the circuit is 2.25 ohms what is the magnitude and direction of the current through the circuit?

4. 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 ohms and a current of $5.6x10^{-2}$ A is induced in the circuit

a) What is the magnitude of the magnetic field?

b) What is the direction of the induced current?

5. The conducting rod in the diagram below is 30.0 cm long and is moved perpendicular to 0.950 T magnetic field.

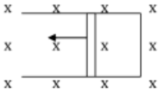
If the resistance in the circuit is 3.25 ohms what force is required to move the rod at a constant 1.50 m/s?

6. A plane with a wing span of 6.25 m is flying horizontally at a speed of 95.0 m/s if the vertical component of the Earth's magnetic field is $4.70x10^{-6}$ T what is the induced emf between the tips of the wings?

7. 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 ohms what is the electric energy dissipated in the resistor in 15.0s?

8. The conducting rod in the diagram below is 1.2 m long and is moving at a speed of 2.5m/s perpendicular to a 0.75 T magnetic field



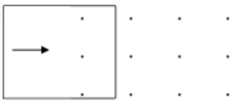
If the current in the circuit is 0.45 A what is the resistance in the circuit?

9. A conducting rod is 1.0 m long and is moved at a speed of 3.0m/s perpendicular to a 0.95 T magnetic field directed into the page. If the resistance in the circuit is 45.0 ohms how much work is done against the magnetic field in 10s s?

10. A conducting rod is 0.50m long and is moved at a constant speed perpendicular to a 0.65 T magnetic field. If the resistance in the circuit is 2.9 ohms and the induced current is 5.2×10^{-2} A what is the speed of the conducting rod?

11. A rectangle loop of wire is moved at a speed of 1.80m/s perpendicular to a 1.30 T magnetic field as shown below

If the length of the side moving perpendicular to the field is 0.625 m and the resistance in the circuit is 1.50 ohms

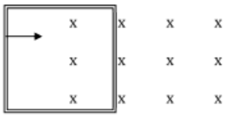


a) What is the induced current?

b) What is the direction of the current?

12. A rectangle coil of wire containing 5 loops is moved at a speed of 2.7m/s perpendicular to a 1.1 T magnetic field as shown below

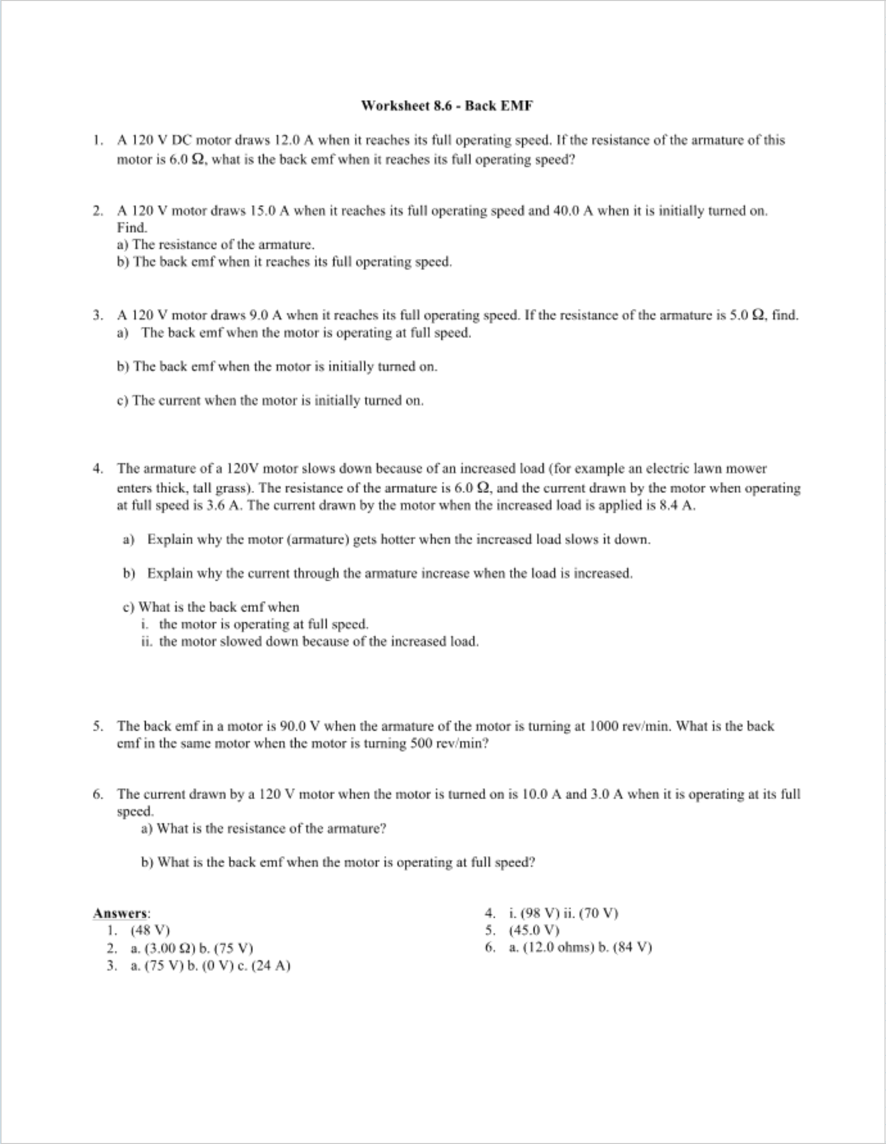
If the length of the side of the coil moving perpendicular to the field is 0.18m and the resistance in the circuit is 3.5 ohms



a) What is the induced current?
b) What is the direction of the current?

Answers:

1. (0.39 V)
2. (0.33 T)
3. (1.83×10^{-2}A counter clockwise)
4. a. (0.59 T) b. (counterclockwise)
5. (3.75×10^{-2} N)
6. (2.79×10^{-3} V)
7. (1.94 J)
8. (5.0 ohms)
9. (1.8 J)
10. (0.46m/s)
11. (0.975A) (clockwise)
12. (0.76A) (counter-clockwise)



Worksheet 8.6 - Back EMF

1. A 120 V DC motor draws 12.0 A when it reaches its full operating speed. If the resistance of the armature of this motor is 6.0 Ω, what is the back emf when it reaches its full operating speed?

2. A 120 V motor draws 15.0 A when it reaches its full operating speed and 40.0 A when it is initially turned on. Find.
   a) The resistance of the armature.
   b) The back emf when it reaches its full operating speed.

3. A 120 V motor draws 9.0 A when it reaches its full operating speed. If the resistance of the armature is 5.0 Ω, find.
   a) The back emf when the motor is operating at full speed.

   b) The back emf when the motor is initially turned on.

   c) The current when the motor is initially turned on.

4. The armature of a 120V motor slows down because of an increased load (for example an electric lawn mower 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 increase when the load is increased.

   c) What is the back emf when
      i. the motor is operating at full speed.
      ii. the motor slowed down because of the increased load.

5. The back emf in a motor is 90.0 V when the armature of the motor is turning at 1000 rev/min. What is the back emf in the same motor when the motor is turning 500 rev/min?

6. 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 operating at its full speed.
   a) What is the resistance of the armature?

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

Answers:
1. (48 V)
2. a. (3.00 Ω) b. (75 V)
3. a. (75 V) b. (0 V) c. (24 A)
4. i. (98 V) ii. (70 V)
5. (45.0 V)
6. a. (12.0 ohms) b. (84 V)