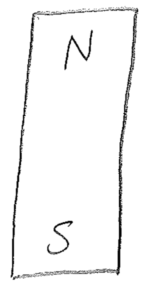
Magnetism

Magnetic Field by a Magnet:

1. Draw the field lines.
2. What is similar about electric and magnetic fields?

<u>electric dipole</u>

<u>magnetic dipole</u>



3. What is the differences between electric and magnetic fields?

4. What did Orsted observe in 1820?

5. What is the right hand rule for electric current?

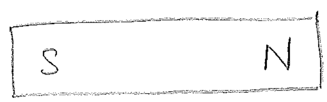
Magnetic Fields

- symbol, B
- Created by moving charges
- Unit, Tesla (T)

Vector Arrows:

Up, Down — Left, Right — Into the Page — Out of the Page

Bar Magnet



Magnitude and direction of the magnetic field around a current carrying wire $B = \frac{\mu_0 I}{2\pi r}$ μ_0 = permeability of free space

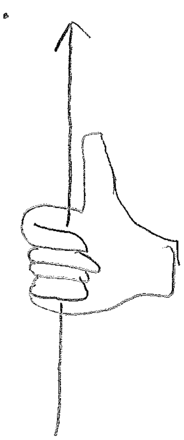
$\mu_0 = 4\pi \times 10^{-7}\ N/A^2$

1st Right Hand Rule (RHR) helps identify the direction of a magnetic field of a current carrying wire.

Similar to the "like" button on facebook.

Thumb: direction of current.

Fingers: curl in the direction of the magnetic field.



Sometimes called "The Fonz"

B by a long straight current. Draw B:

⊙ I ⊗ I ⟶ I

$B \propto \frac{1}{2\pi r}$ $B \propto I$ $\boxed{B \propto \frac{I}{r}}$

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

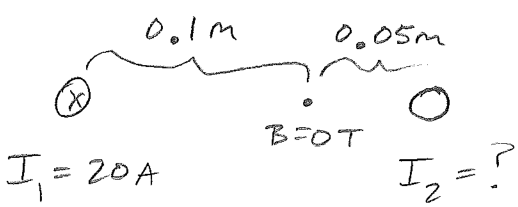
r = distance to the I

$\mu_0 = 4\pi \times 10^{-7} \frac{T \cdot m}{A}$ or permeability of free space.

μ is the magnetic permeability of a material.

For ferromagnetic material (Fe, Co, Ni, etc...) $\mu > \mu_0$.

Two long straight wires are perpendicular to the page. Find the magnitude and direction of I_2.



Different Perspectives

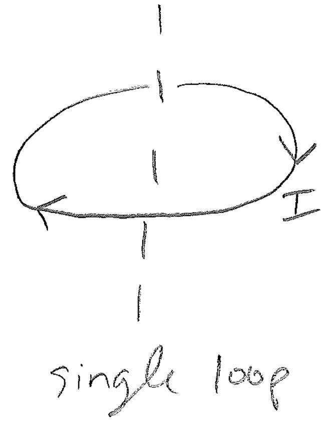
Current going Up View

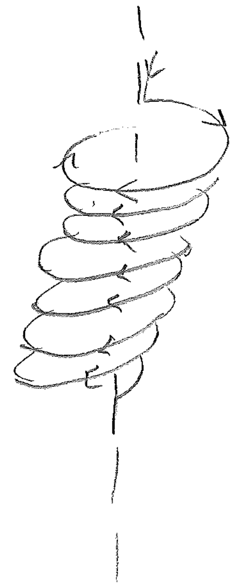
Top View

Current going to the right Views

Another application of the RHR direction of the magnetic field is inside a current carrying loop:

Draw magnetic field lines



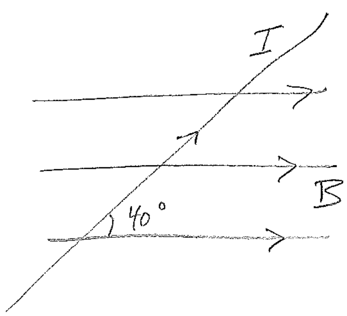


Lorentz Force - the force experienced by charges moving in a magnetic field.

F_B on I

ℓ = length of I in B.

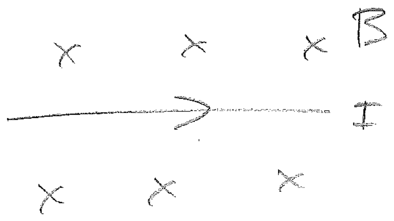
$$F_B = I\vec{\ell} \times \vec{B}$$

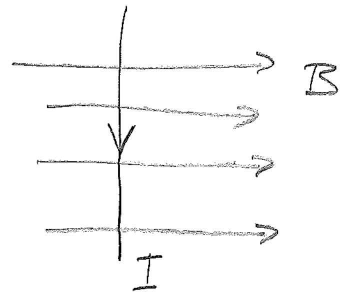


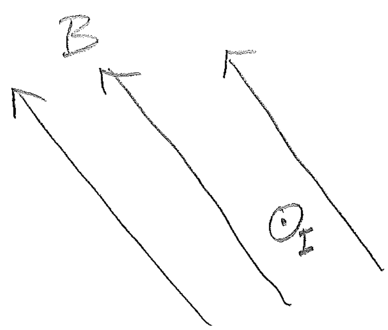
Find $|F_B|$ if $I = 3A$, $\ell = .2m$ & $B = 2T$.

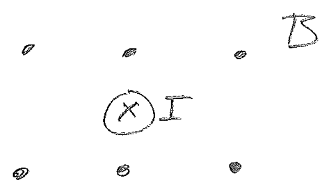
What is the direction of F_B?

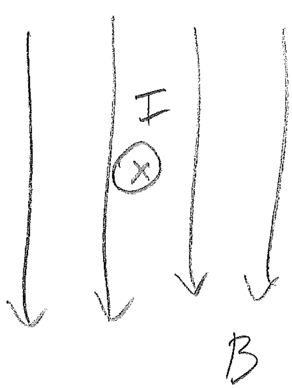
Find the direction of F_B

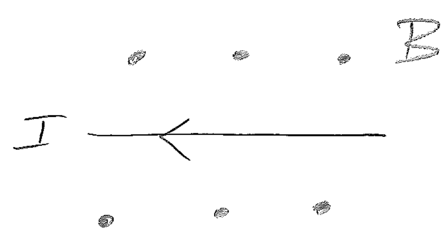






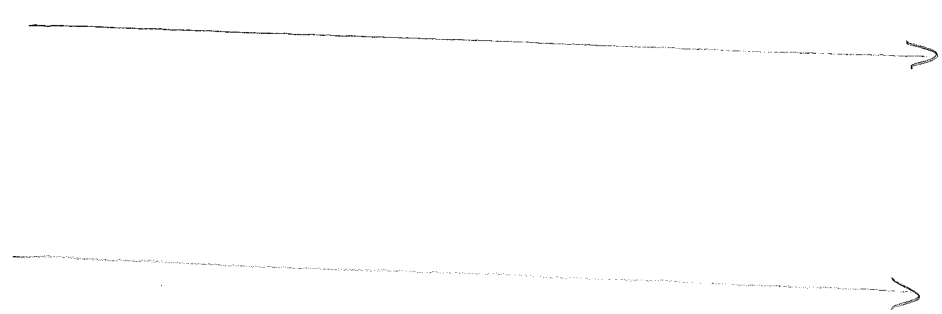


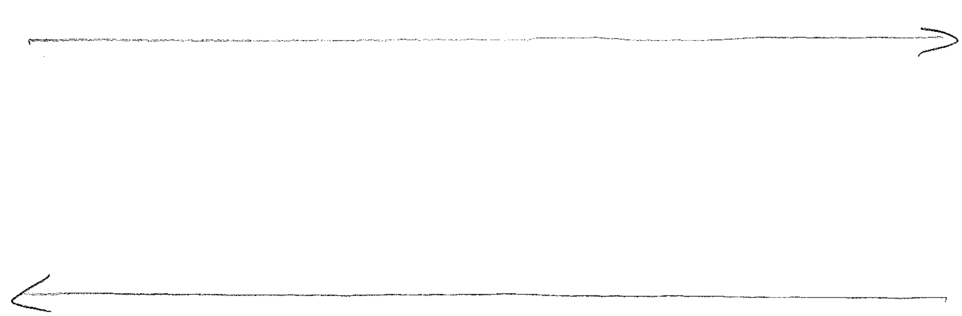




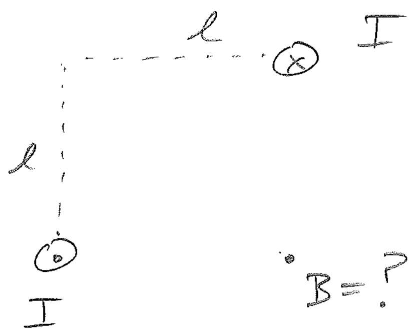
Charges moving near a current carrying wires:

Two current carrying wires:

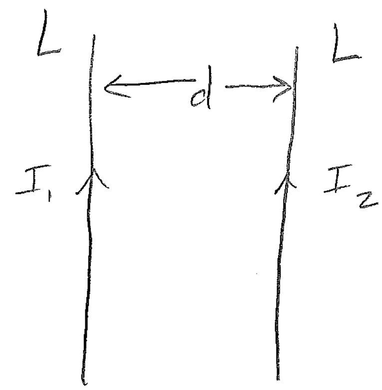




There are 2 long straight wires each with current I:



Two parallel currents exist:



Find a.) the F_e

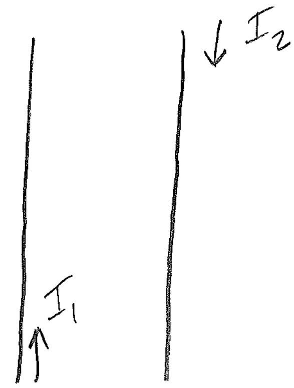
b.) the F_B on I_2 by I_1

Parallel Wires with Current Opposite Directions

$I_1 = 3.5\ A$ $I_2 = 4.0\ A$

$\ell = 50\,cm$ $d = 3.\ mm$

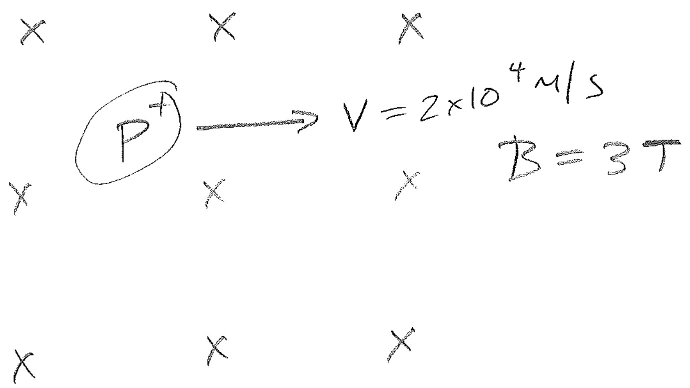
$F_2 = ?$



F_B on moving q: $\quad \vec{F}_B = I\vec{\ell} \times \vec{B}$

$$\frac{\ell}{t} = v \qquad F_B = \frac{q}{t} \cdot \frac{\ell}{1} \times \vec{B} = q\left(\frac{\ell}{t}\right) \times \vec{B}$$

$$F_B = q\,v \cdot B \sin \angle^{v}_{B}$$



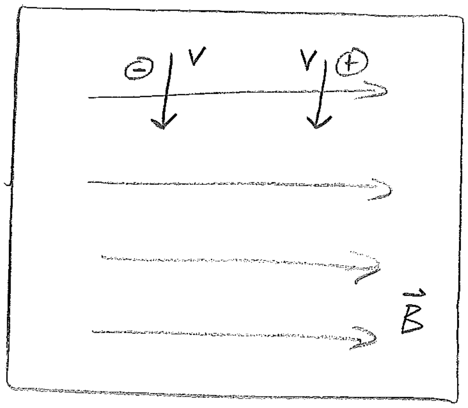
What is the $|F_B|$ on the p^+?

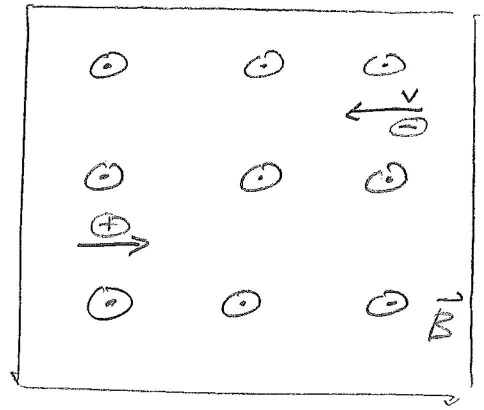
What is the direction of F_B?

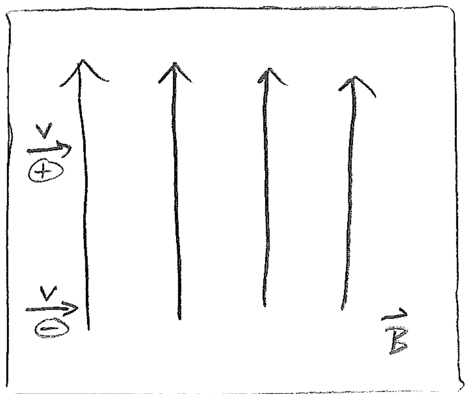
Does a force that is always perpendicular to the velocity remind you of anything? What shape path do you think this proton in the magnetic field will follow?

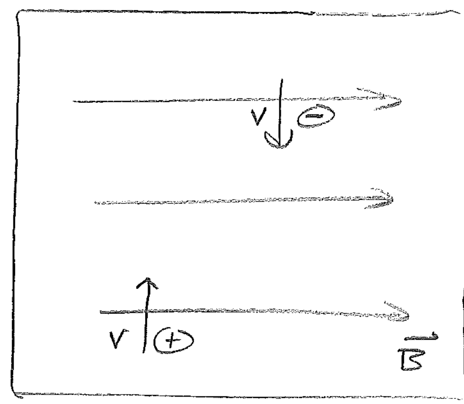
How much work is done on the p^+ by the magnetic field?

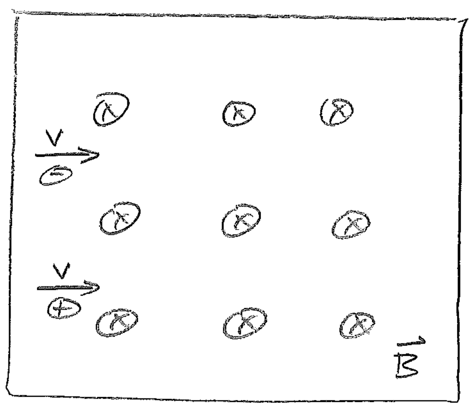
Determine the direction of force on each particle :

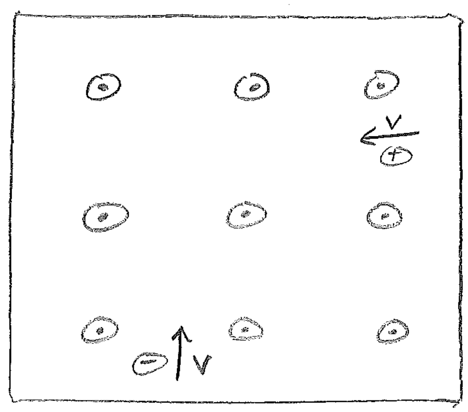


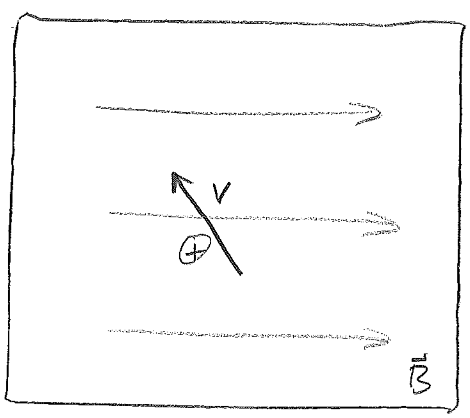


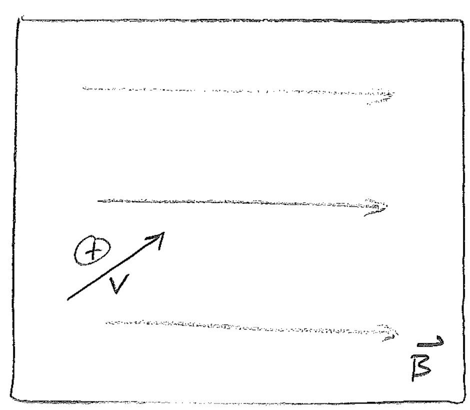








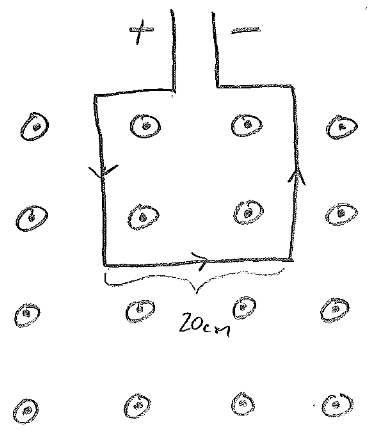




Force on a Current Carrying Wire

Derive the equation for force on a current carrying wire using the following: $F = qvB\sin\theta$ $\quad v = \frac{l}{t}$

There is a 20 cm long wire with a current of 15 A flowing right. The wire is in a magnetic field that is directed into the page with strength of 1.2 T. The angle between the wire and the magnetic field is 90°. What is the direction and magnitude of the force on the wire?



$I = .35\ A$ $\quad F = 3.75 \times 10^{-2}\ N$ $\quad B = ?$

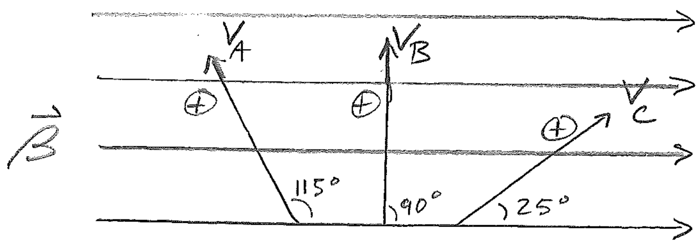
If the velocity is not perpendicular to the magnetic field : $F = qvB \cdot \sin\theta$

θ is the angle between velocity and the B field.

$\sin 90° = 1$	$\sin 0° = 0$	$\sin 180° = 0$
perpendicular	parallel	parallel

The particle must be in motion to experience a Lorentz force.

Find the force magnitude on A, B & C :



$q = 9.5\,\mu C$

$V_{A,B,C} = 37.5$ m/s

$B = .6$ T

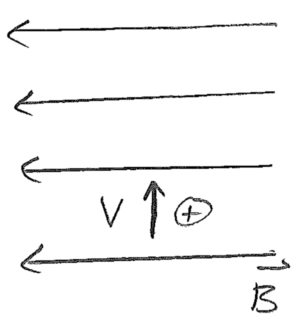
A

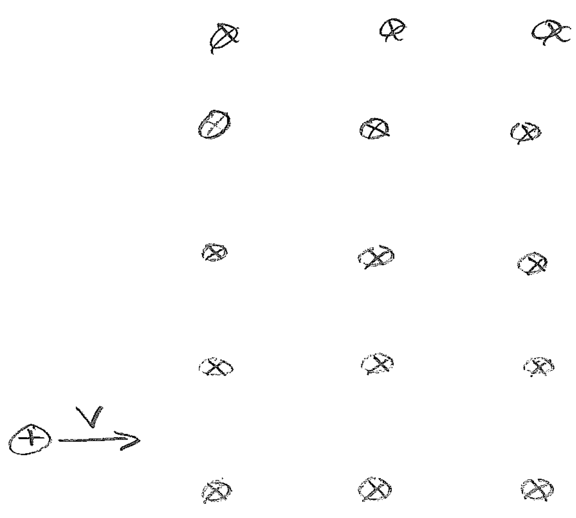
B

C

A proton is moving through a magnetic field to the north.

$V_{\oplus} = 4.5 \times 10^{6}$ m/s $\quad F_B = 7 \times 10^{-14}$ N $\quad q_{\oplus} = 1.6 \times 10^{-19}$ C $\quad B = ?$





1. Sketh the path of the positively charged particle through the magnetic field.

2. Create a literal equation for the radius of curvature for its path using the following:

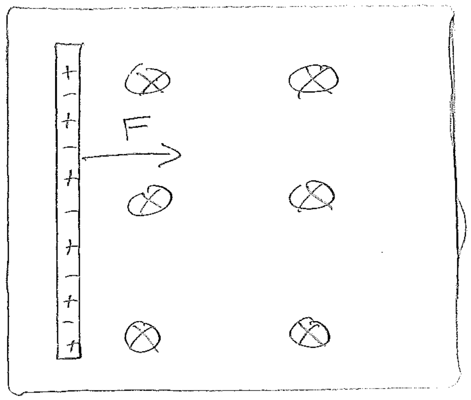
$\Sigma F = m \cdot a$ $\quad F = q V_{\perp} B$ $\quad F_c = \frac{mV^2}{r}$

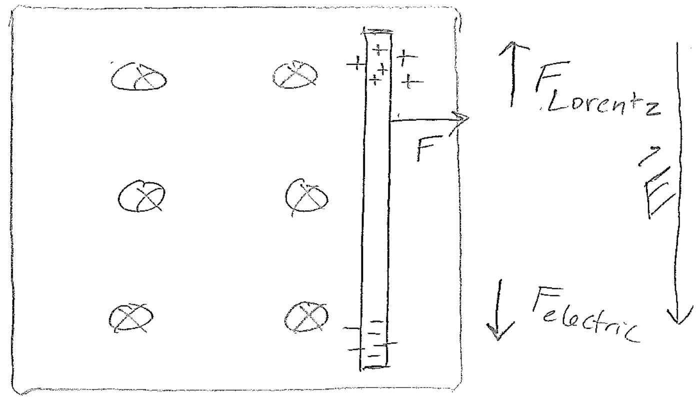
3. $q = +5 \times 10^{-4}\,C$ $\quad V = 1.0 \times 10^{3}\,m/s$ $\quad m = 2.0 \times 10^{-9}\,kg$ $\quad B = .2\,T$

Find the radius of curvature.

Motional EMF $\mathcal{E} = B l v$

Induced Voltage





$V = \vec{E} d$

$\vec{E} = \frac{V}{d}$

Equilibrium

$F_{Lorentz} = F_{electric}$

$q (vel.) B = q \vec{E}$

$(vel.) B = \vec{E}$

$(vel.) B = \vec{E}$

$(vel) B = V/d$

Voltage $= B (vel.)(d)$

$\mathcal{E} = B v l$

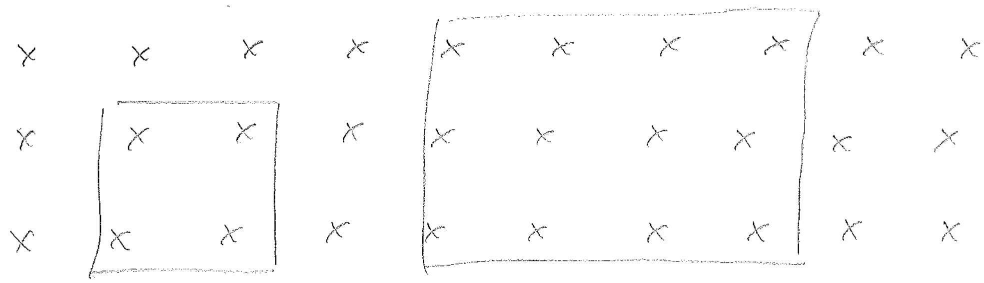
A wire with a length $l = 12$ cm is moving with constant velocity $v = 1.5$ m/s through a homogeneous magnetic field of strength $B = .5$ mT. Determine the potential difference in the wire.

An airplane flies through the earth's magnetic field. $\mathcal{E} = ?$
$B = 5 \times 10^{-5}$ T $l = 70$ velocity $= 280$ m/s

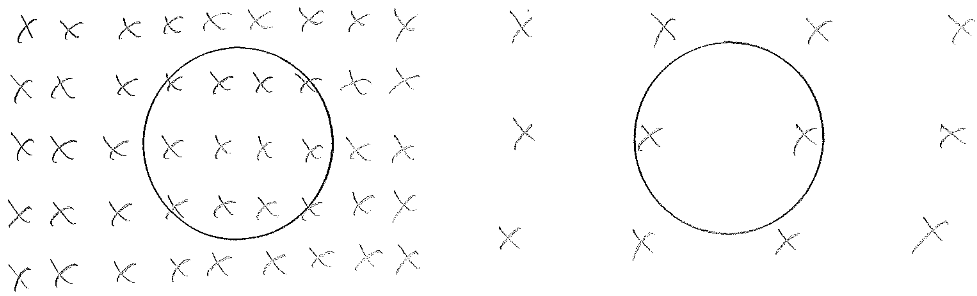
Magnetic Flux is the amount of magnetic field passing through a loop of wire. $\Phi = A \cdot B \cos\theta$

The unit of magnetic flux is the Weber (Wb)

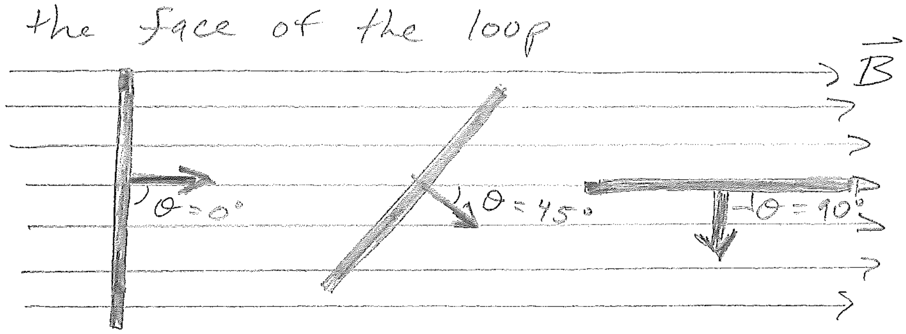
A = area of the loop



B = magnetic field strength



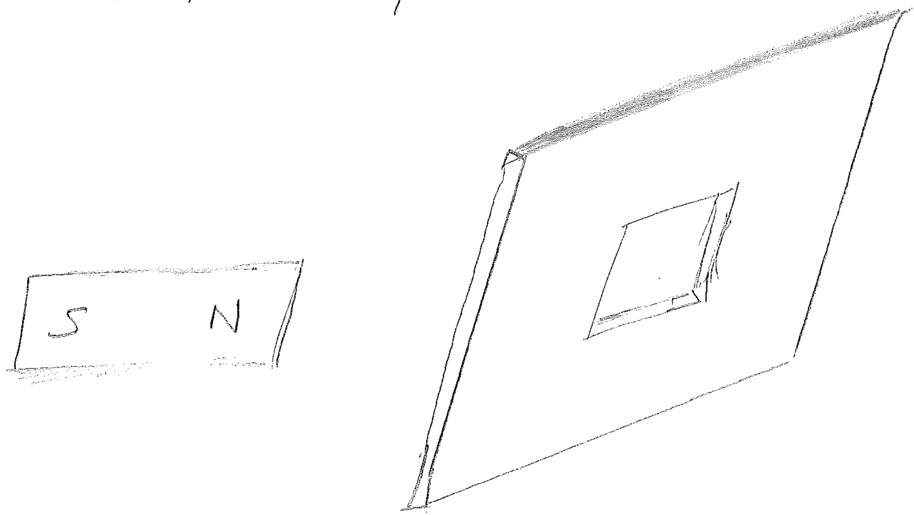
θ = angle between B and a line perpendicular to the face of the loop



Determine the magnetic flux through a square coil with sides 35 cm in a magnetic field $B = 2.65\,T$ & $\theta = 90°$.

Determine the magnetic flux through a coil loop of area $75\,cm^2$ in a magnetic field $B = 5.95\,T$ and $\theta = 55°$.

Magnetic Flux, Faradays Law, Induced Current, Lenz's Law



Faraday's Law: changing the magnetic flux in a certain amount of time generates an electric potential: $\mathcal{E} = \frac{-\Delta \Phi_B}{\Delta t} = \frac{-\Delta(BA)}{\Delta t}$

where $\mathcal{E}$ is the electromotive force. Measured in Volts. The same volts in Ohm's Law. Which means $\mathcal{E}$ can induce currents. $\mathcal{E} = IR = V$

Methods to change flux:

1. Increase or decrease the magnetic field strength B within the Area by ...
   a. moving the Area closer to or farther from the B_{field}
   b. moving a magnet closer to or farther from the Area.
2. Move the Area into or out of the magnetic field
3. Rotate the Area so the perpendicular component changes.

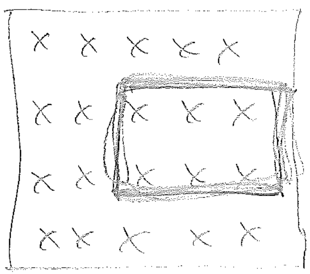
galvanometer – an instrument for detecting and measuring small electrical currents.

Coils and Faraday's Law

A voltage will be induced in the coil when the magnetic flux through the coil changes over time.

$$\mathcal{E} = V_{induced} = -N\frac{\Delta \Phi_B}{\Delta t} = -N\frac{\Delta(A \cdot B)}{\Delta t}$$

A = area B = magnetic field N = # of windings t = time



$B = 4\,mT$ $A_i = 0\,m^2$ $A_f = 6 \cdot 10^{-4}\,m^2$ $t = 3\,s$

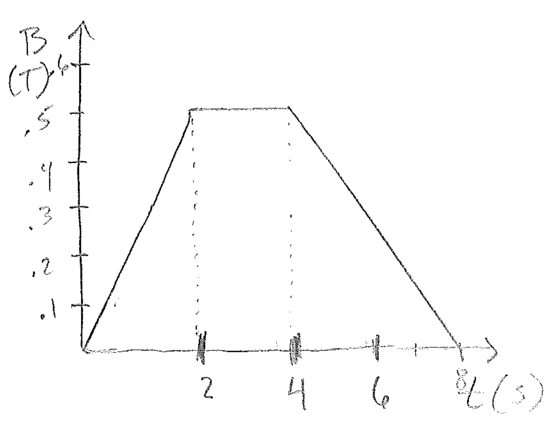
$N = 50$ windings $V_{induced} = \mathcal{E} = ?$

If the # of windings or turns is not mentioned, assume $N = 1$.

1. A circular loop of wire with a diameter of 12 cm is in a 1.8 T magnetic field. The loop is removed from the magnetic field over a time of .25 sec. What is the induced emf?

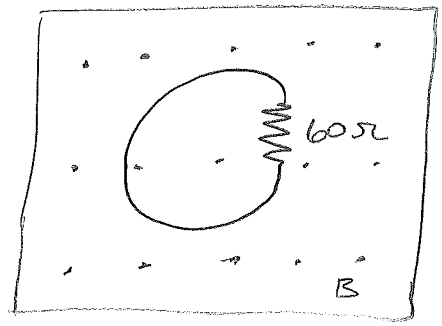
2. A rectangular coil with 100 windings and a length 20 cm and a width 12 cm is initially held so that its plane is parallel to a 1.5 T magnetic field. The loop is then rotated in .2 sec. so that is perpendicular to the magnetic field. What is the induced emf in the loop?

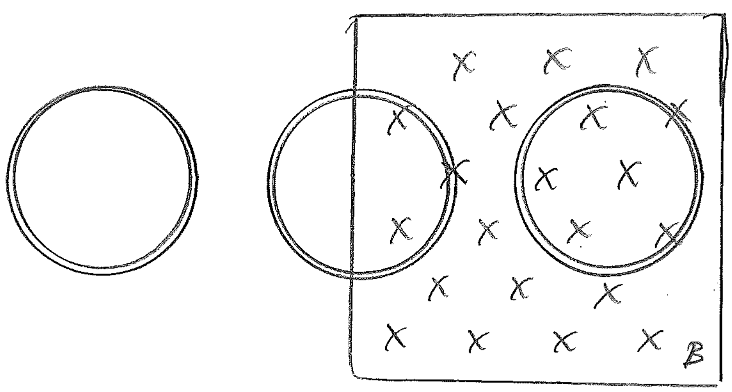
3. The magnetic field through a single loop of wire, 10 cm in radius and with a resistance of 7.5 Ω, changes with time as shown. Determine the induced emf in the loop as a function of time.



$B_i = 3.2\ T \quad B_f = 1.2\ T \quad \Delta t = 5\ sec. \quad A = 7.5 m^2 \quad \mathcal{E} = ?$

A loop moves in a magnetic field such that $B_i = 3.2T$ and $B_f = 1.2\ T$. The loop contains a resistor of $60\ \Omega$ and has area of $7.5\ m^2$. $\Delta t = 5 sec.$ What is the $\mathcal{E}$ produced in the loop?

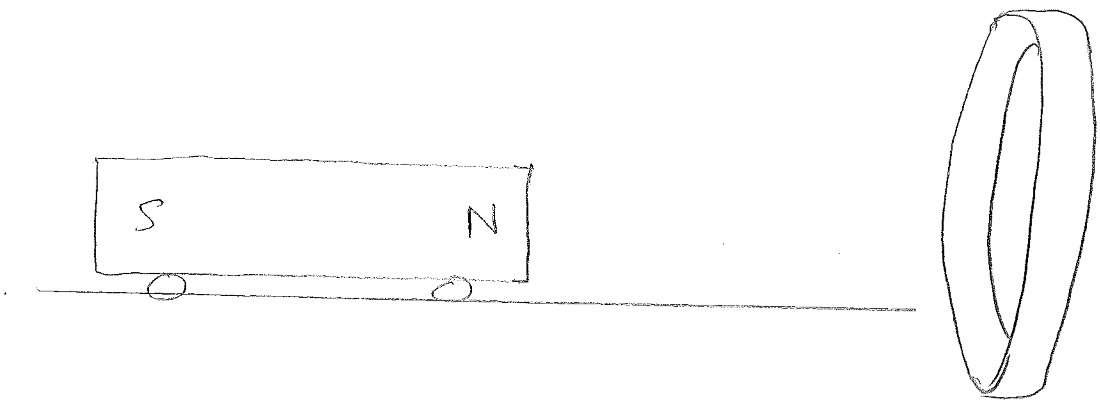




Determine the direction of the induced current as the loop passes into the magnetic field and then find the current as the loop passes out of the magnetic field.

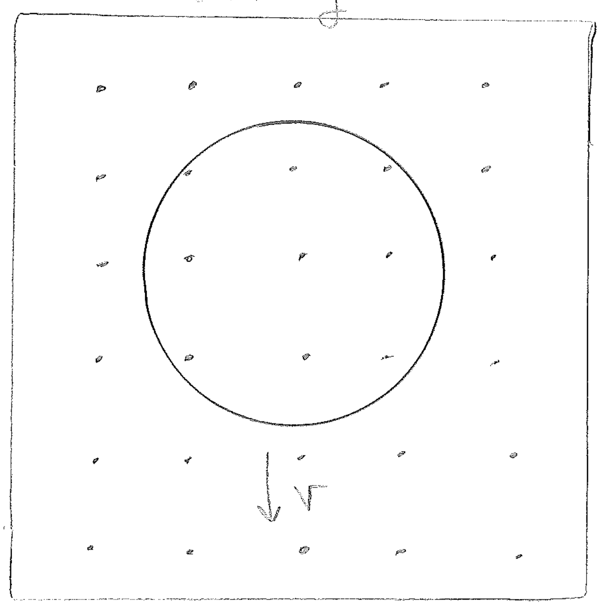
Lenz's Law: the current that is created by the change in magnetic flux (from Faraday's Law) generates its own magnetic field that opposes the original change in Flux.

Lenz's Law

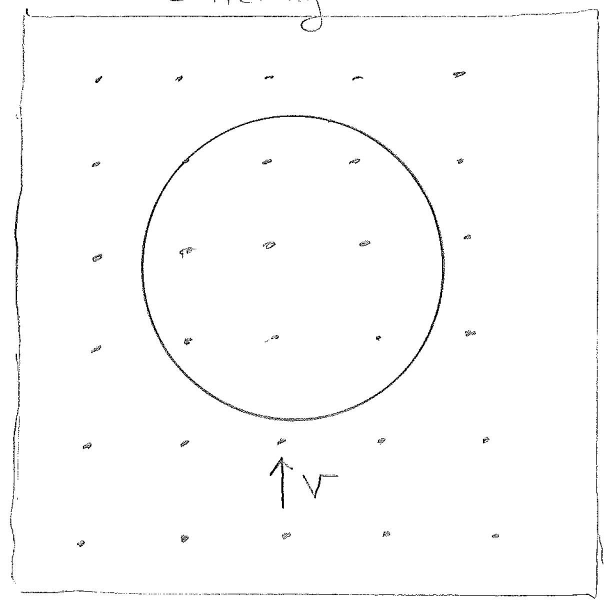


Lenz's Law

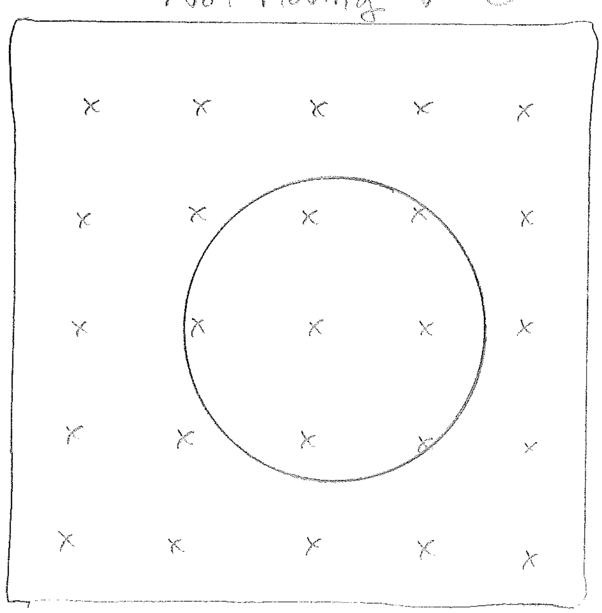
Leaving



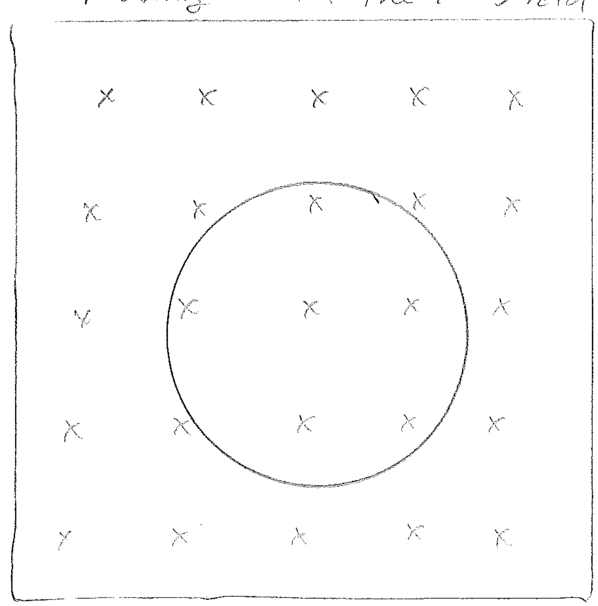
Entering



Not moving $v = 0$

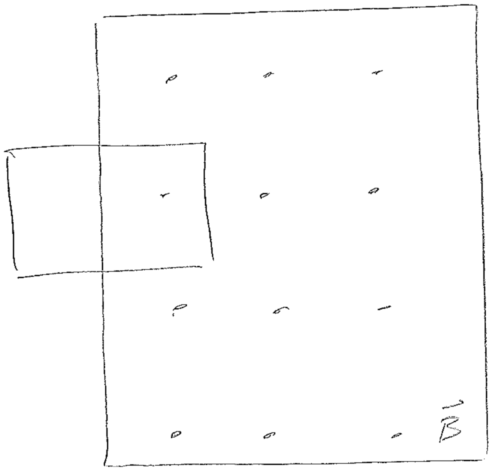


Moving within the B-field

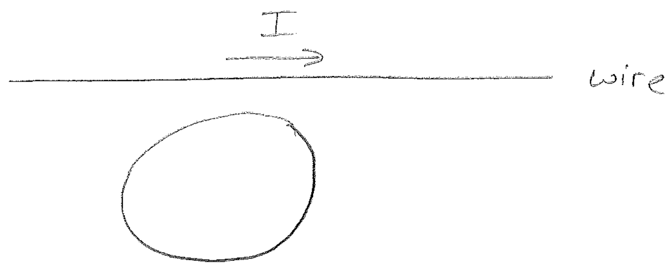


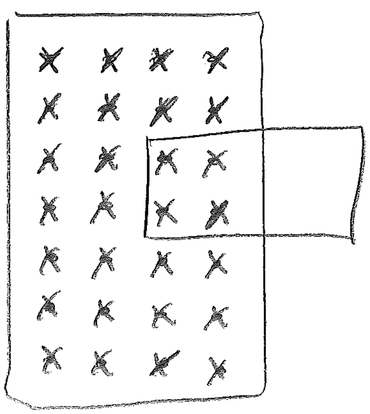
Lenz's Law

For the following determine the direction of induced current.

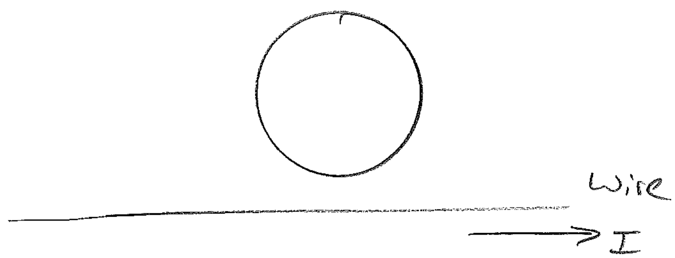


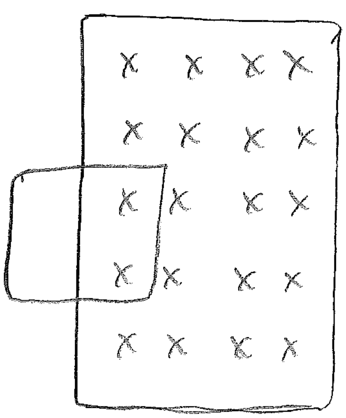
Coil of wire enters the magnetic field



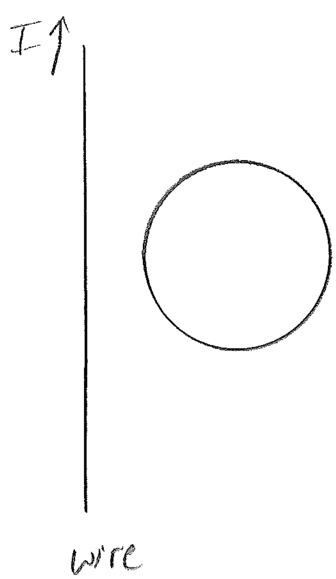


Coil of wire leave the magnetic field



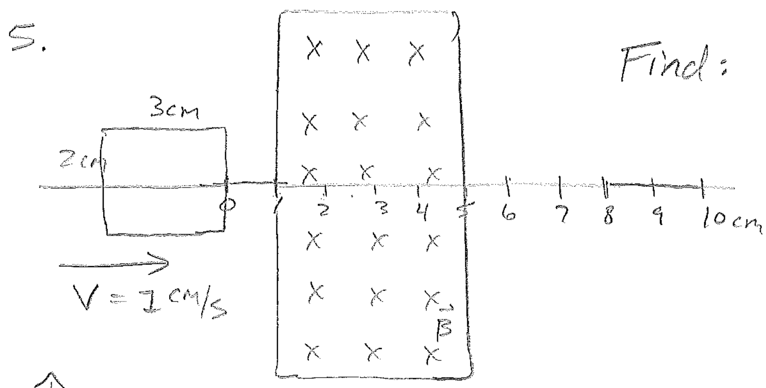


Coil of wire enters the magnetic field

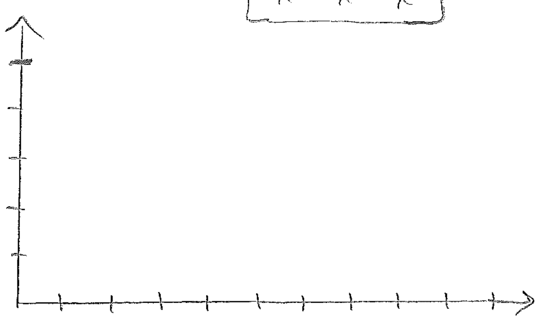


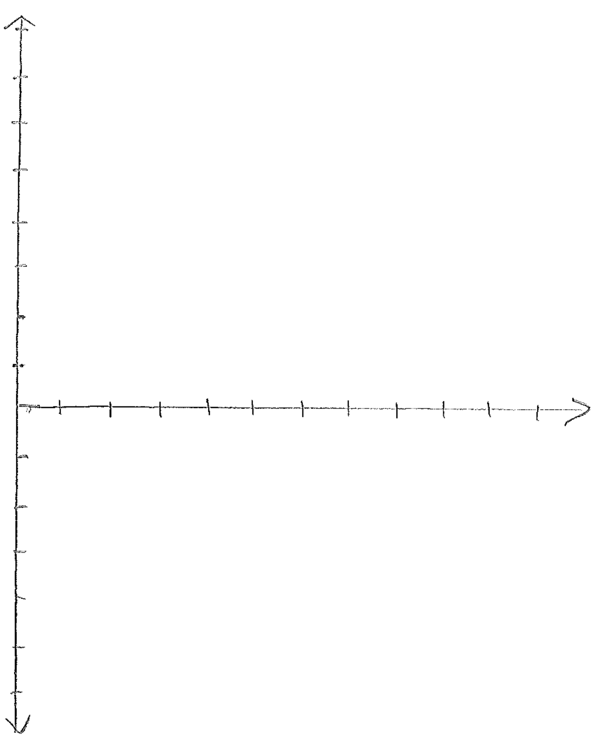
4. A coil of wire with 5 loops is 20 cm on each side. A magnetic field of .6 T passes through the coil. The plane of the coil is perpendicular to the magnetic field. The field increases 1.8 T in .75 sec. What is the ε?

5.



Find:
1. Change in Φ for 0 s to 10 s.
2. Induced Emf for 0 s to 10 s.
3. Graph the change in Φ for 0 to 10 s.
4. Graph the induced Emf for 0 to 10 s.
5. Direction of the induced current.





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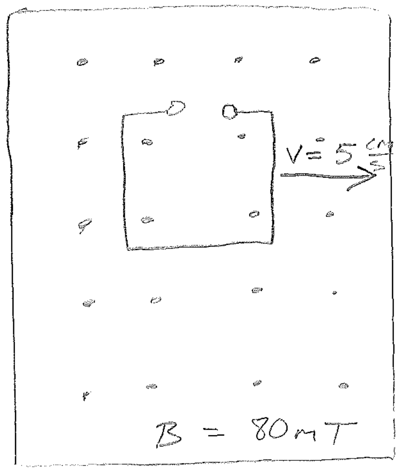
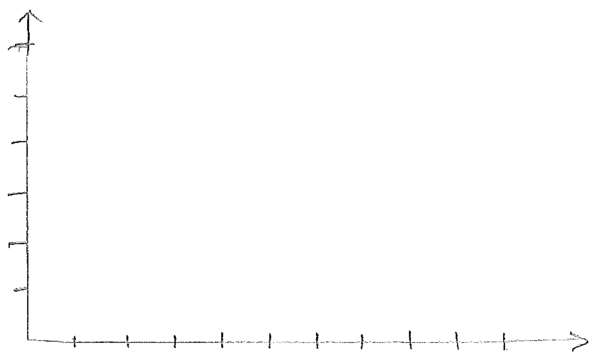
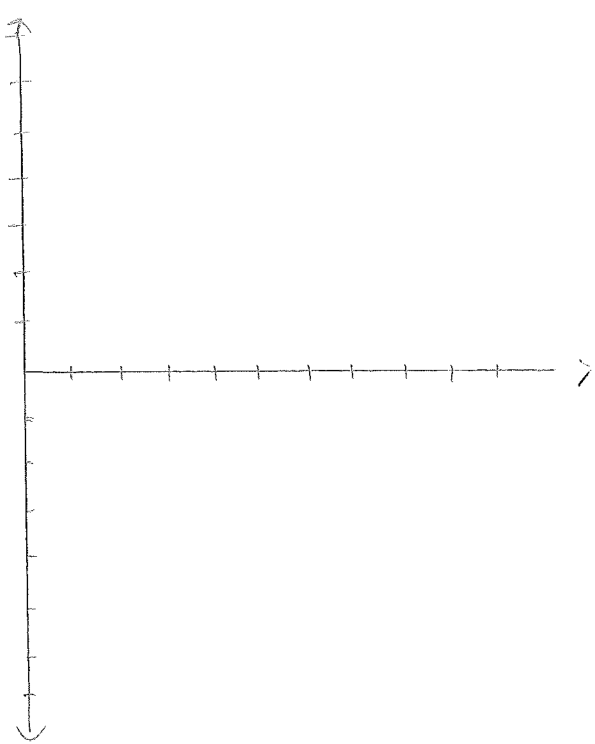
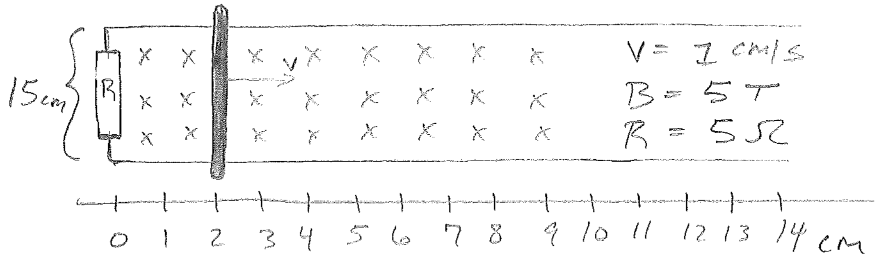


1. Calculate Φ at $t = 0$ sec.
2. Graph the change in Φ for 0s to 10s
3. Induced Emf (V) for 0s to 10s
4. Graph the induced Emf for 0s to 10s
5. Direction of the induced current

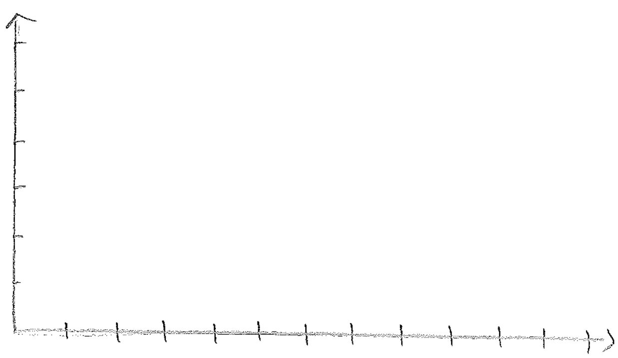


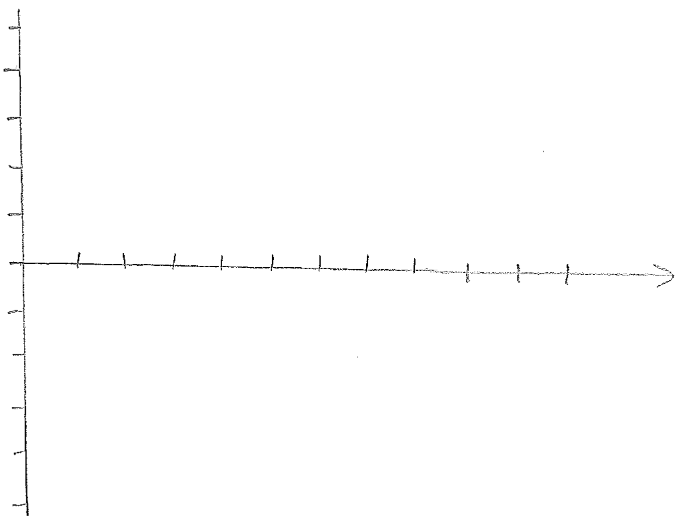


7.



1. Calculate Φ for 0s to 10s
2. Graph the change in Φ for 0s to 10s
3. Calculate the induced emf (V) for 0s to 10s
4. Graph the induced emf (V) for 0s to 10s

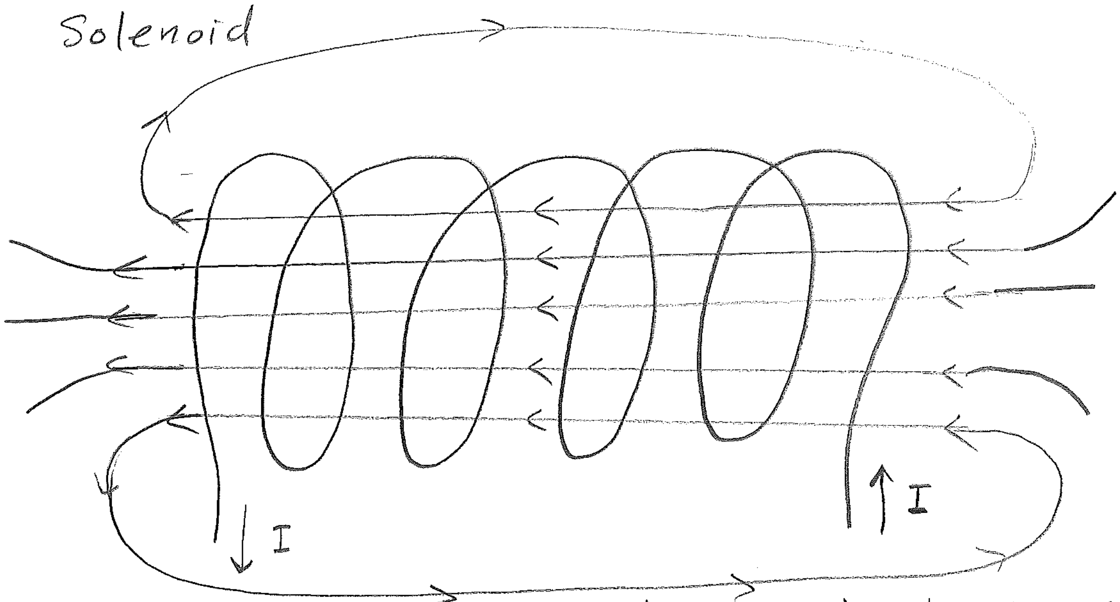




7. continued

5. Determine magnitude and direction of the induced current.
6. Determine the force needed to move the bar right.

Solenoid



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

turns (N)
coil length (l)
current (I)

Magnetic field runs parallel to the length of the wire.
The magnetic field is concentrated into a nearly uniform field in the center of a long solenoid.
The field outside is weak and divergent.

If you place material inside the coil: $B = \mu_0 \mu_r \frac{N}{l} \cdot I$

μ_r is relative permeability and is the factor by which the magnetic field strength is increased or decreased.

$I = 6A$ $N = 320$ turns $l = 40cm$ $\mu_0 = 4\pi \cdot 10^{-7} \frac{T \cdot m}{A}$ $\mu_r = 1$

Find B:

If $\mu_{r\,(iron)} = 200$, Find the new B:

$\mu_r = 1$

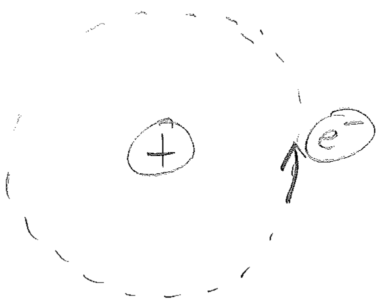
$I = 3.7A$ $N = 250$ turns $B = 5.5\ mT$ $\ell = ?$

$\ell = 35\ cm$ $N = 370$ turns $B = 1.2\ mT$ $I = ?$

$I = 4.2A$ $N = 301$ turns $B = 2.1\ mT$ $\ell = ?$

$\ell = 60\ cm$ $B = 4.1\ mT$ $I = 5.6\ A$ $N = ?$

Magnetic Dipole Moment



e^- have orbital magnetic dipole moments

e^- also have spin magnetic dipole moments.

When you add all the dipole moments in an atom you get a sum or net dipole.

3 types of materials:

para<u>magnetic material</u> - each individual atom has net magnetic dipole moment $\neq 0$. Without an external magnetic field the material has zero net magnetic moment. In the presence of an external magnetic field, atomic magnetic moments align slightly with the external magnetic field. (eg. Al, tungsten)

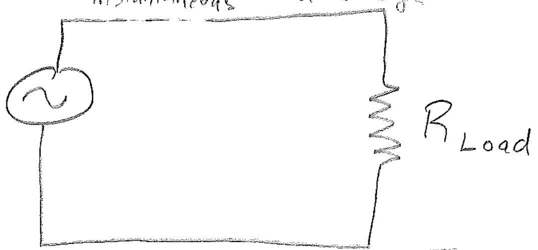
<u>ferromagnetic material</u> - has permanent atomic magnetic dipole moments. They tend to align parallel with each other and make up domains. (e.g. iron, cobalt, nickel)

dia<u>magnetic</u> material - no net dipole moment by itself. (e.g. pyrolytic carbon, water) In the presence of an external magnetic field, can obtain a very weak induced net magnetic moment <u>opposite</u> to the external magnetic field. This material is repelled by the magnet. When the external magnetic field is removed, the net magnetic moment and repulsive force go to zero.

Peak v. RMS (root mean square)

Alternating Current (AC)

$P_{instantaneous} \neq P_{average}$



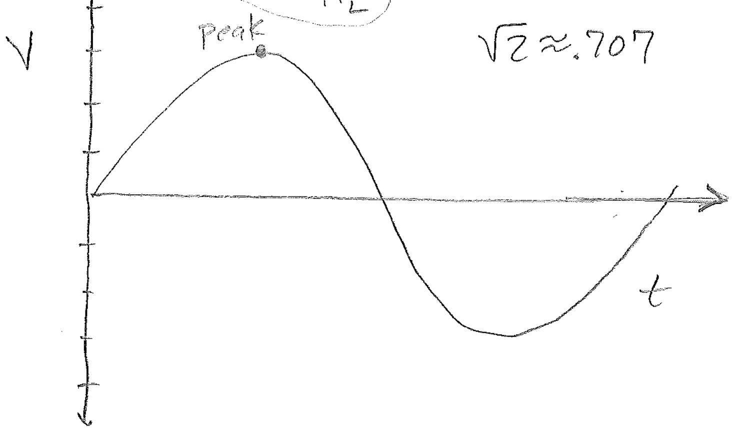
$P_{ave} = I_{RMS} V_{RMS}$

$$P_{ave} = \frac{V_{RMS}^2}{R_L}$$

$I_{rms} = I_{peak} \cdot \frac{1}{\sqrt{2}}$

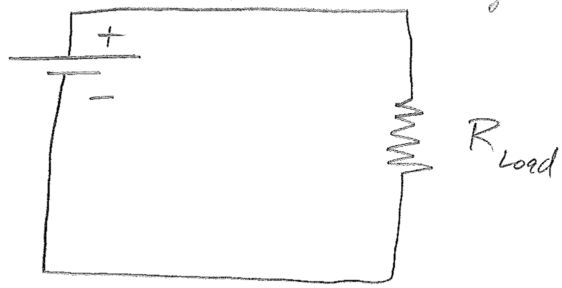
$V_{rms} = V_{peak} \cdot \frac{1}{\sqrt{2}}$

$\sqrt{2} \approx .707$



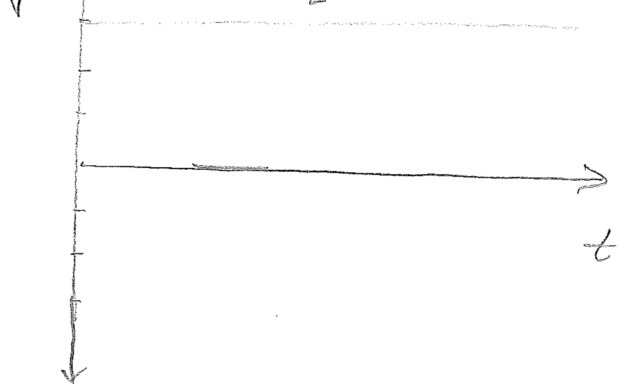
Direct Current (DC)

$P_{instantaneous} = P_{average}$



$P = I \cdot V$

$$P = \frac{V^2}{R_L}$$



V_{rms} allows us to find the average power in an AC circuit.

"House Voltage" refers to 120 VAC (e.g. V_{rms}) that comes from the wall outlets in your house.

1. A hair dryer is plugged into the 120 VAC outlet and consumes 1275 W of AC Power. How much AC current goes through the dryer?

2. What is the resistance of the hair dryer?

3. What is the peak voltage for 120 VAC?

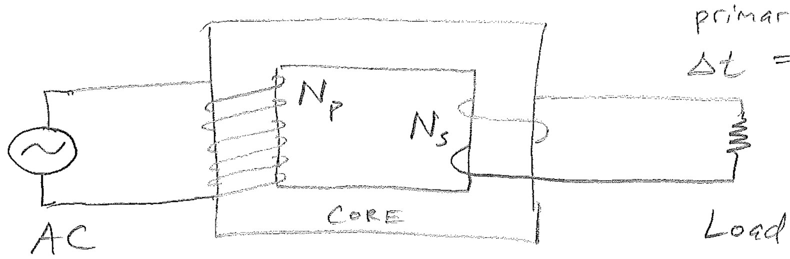
Transformers

Matching load requirements to power sources is important. Voltage dividers (e.g. resistors) can be used for DC circuits. For AC circuits, a device known as a transformer can be used. A transformer consists of two coils sharing the same magnetic flux.

$\Delta\Phi$ = common flux

N_p & N_s are the number of primary and secondary turns.

Δt = time interval.



$$V_p = -N_p \frac{\Delta\Phi}{\Delta t}$$

Divide these two to get:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$V_s = -N_s \frac{\Delta\Phi}{\Delta t}$$

Power going into the transformer equals the power leaving.

$$P_{in} = P_{out}$$

$$P_{IN} = V_p I_p = V_s I_s = P_{OUT}$$

There is a trade off between voltage and current.

$$\frac{V_p}{V_s} = \frac{I_s}{I_p} \qquad \frac{N_p}{N_s} = \frac{I_s}{I_s}$$

<u>Step Up</u> transformers are used to multiply the voltage in the primary to produce a higher voltage with less current. <u>Step down</u> transformers are used to produce lower voltages with higher currents.

A neon sign transformer steps up the voltage from the power line (115 VAC) to 15,000 Volts. What is the turns ratio (N_s/N_p)?

A model train has a power supply that plugs into a wall (117 VAC). The train runs with a maximum voltage of 15 Volts. At this voltage it draws 4A.

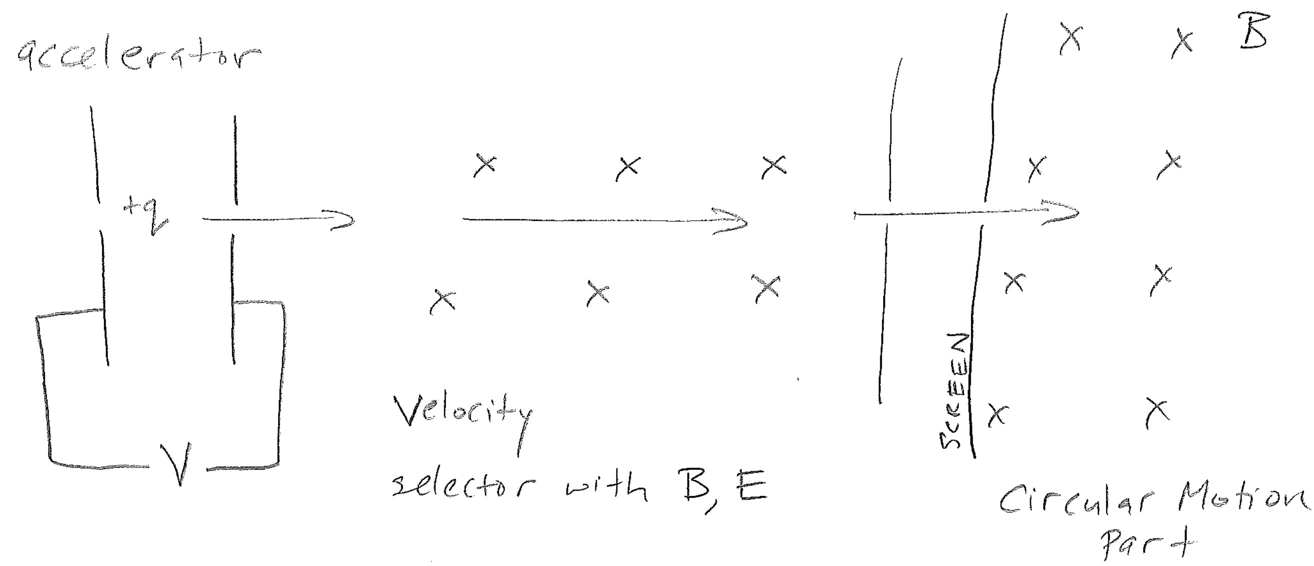
a.) What is the power used by the train?

b.) What is the current drawn by the primary?

What is the turns ratio of a step-down transformer designed to convert 200,000 VAC to 120 VAC?

If the transformer secondary supplies a neighborhood with a maximum of 10,000 A, how much current does this cause to flow in the primary?

Mass Spectrometer



After a p^+ is accelerated by 1000 V it enters $B = .05\,T$

a.) what magnitude and direction of E is needed to make p^+ go undeflected?

b.) Turn off E, find r of p^+'s circular motion. ($m_{p+} = 1.67 \times 10^{-27}$ kg)