PHYS 212 Review 2

Exam 2 - 3/30/23-4/2/23

Queue

Exam 2 Overview

9/10) Simple Circuits and Kirchhoff's Laws

11) RC Circuits

12) Magnetic Force

13) Forces and Magnetic Dipoles

14) Biot-Savart Law

15) Ampere’s Law

16) Motional EMF

Current and KCL

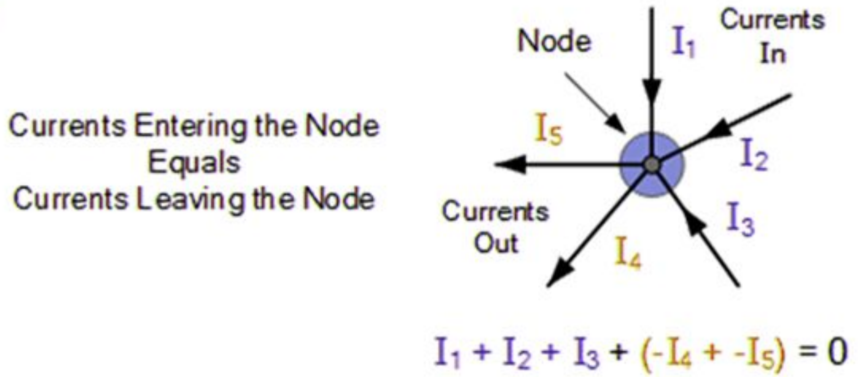
Current (I) is the flow of charge per second

Units: Amperes (A) - Coulombs/second (C/s)

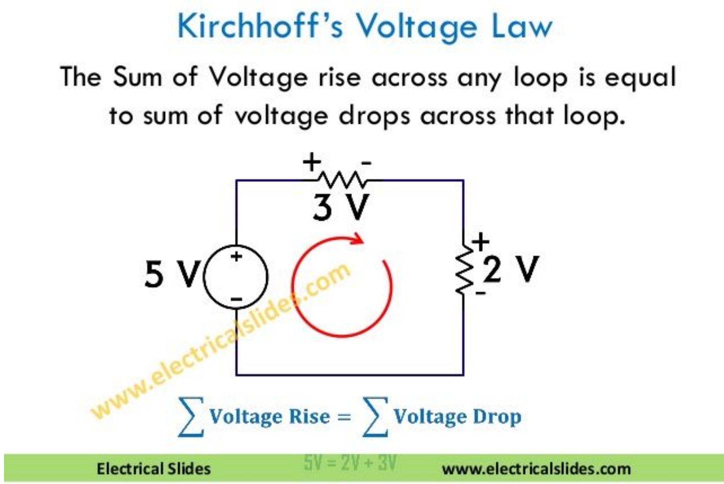
Kirchhoff's Current Law - KCL

- **The amount of current going in is equal to the amount of current coming out**

$$I_{in} = I_{out}$$



Voltage and KVL



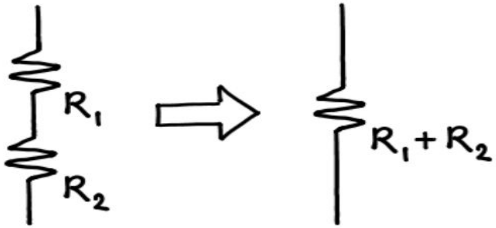
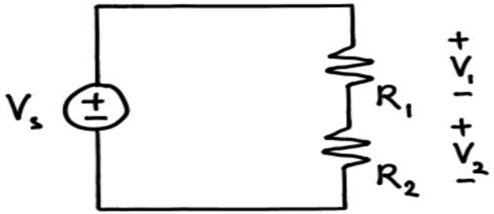
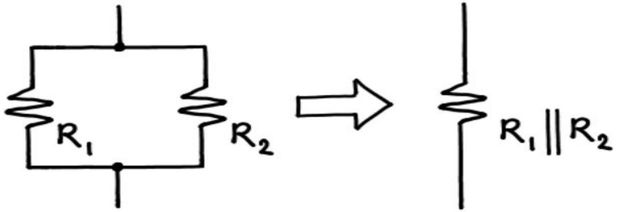
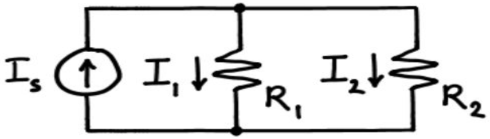
Voltage (V) is the amount of energy per unit charge

- Units: Volts (V) = Joules/Coulomb (J/C)

Kirchhoff's Voltage Law - KVL

- **The total voltage in a loop is the sum of all the voltage drops and rises**
  - Voltage drop - “+” to “-”
  - Voltage rise - “-” to “+”

You can solve all the circuit problems you will see in this course by applying KCL and KVL

<table>
<tr><th>Name</th><th>Diagram</th><th>Formulas</th></tr>
<tr><td>Series Resistors</td><td>
</td><td>$$\text{Equivalent resistance} = R_1 + R_2$$</td></tr>
<tr><td>Voltage Divider</td><td>
</td><td>$$V_1 = \frac{R_1}{R_1 + R_2} V_s \qquad V_2 = \frac{R_2}{R_1 + R_2} V_s$$</td></tr>
<tr><td>Parallel Resistors</td><td>
</td><td>$$\text{Equivalent resistance} = R_1 \| R_2 = \frac{R_1 R_2}{R_1 + R_2}$$</td></tr>
<tr><td>Current Divider</td><td>
</td><td>$$I_1 = \frac{R_2}{R_1 + R_2} I_s \qquad I_2 = \frac{R_1}{R_1 + R_2} I_s$$</td></tr>
</table>

Power

Power is the amount of energy per second being delivered/absorbed

- Units: Watts (W) = Joules/second (J / s) ==> amount of energy per second
- **$P_{resistor}$ = IV = V^2/R = I^2R (These last 2 equations are for resistors ONLY)**

The sign (“+” or “-”) is very important when it comes to power **(Not on your test)**

- Negative power means that circuit element is delivering energy to the circuit (sources, capacitors, inductors)
- Positive power means that the circuit element is absorbing energy from the circuit (resistors, capacitors, inductors)

RC Circuits

Time Constant

$$\tau = RC$$

τ - tau is the time constant which affects the rate of growth/decay

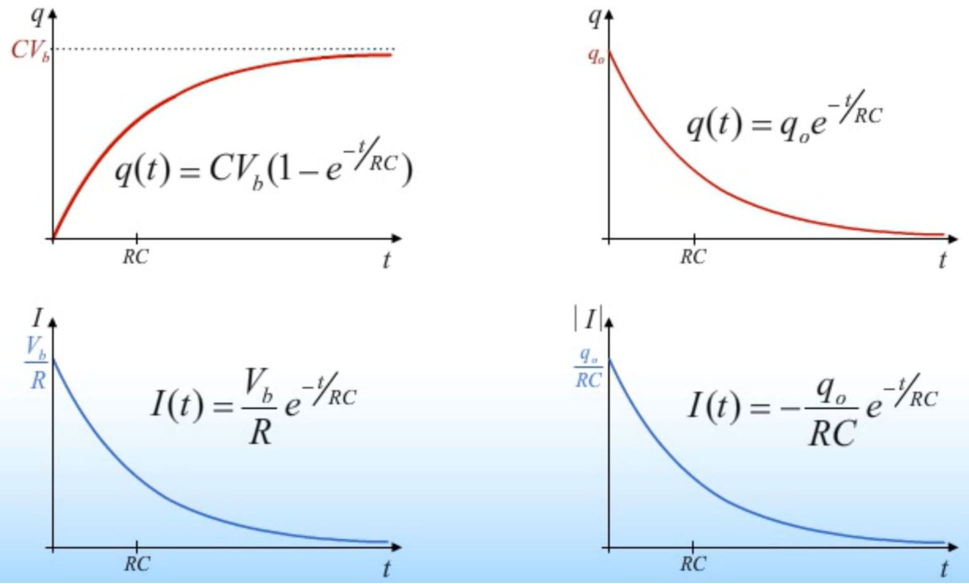
Charging and Discharging Equations

Charging

Discharging

$$Q(t) = Q(\infty)\left(1 - e^{-t/\tau}\right)$$

$$Q(t) = Q(0)e^{-t/\tau}$$



RC Circuits cont.

Charging

t = 0 → capacitor acts like a wire (short circuit)

- V = 0 V, but there is a current

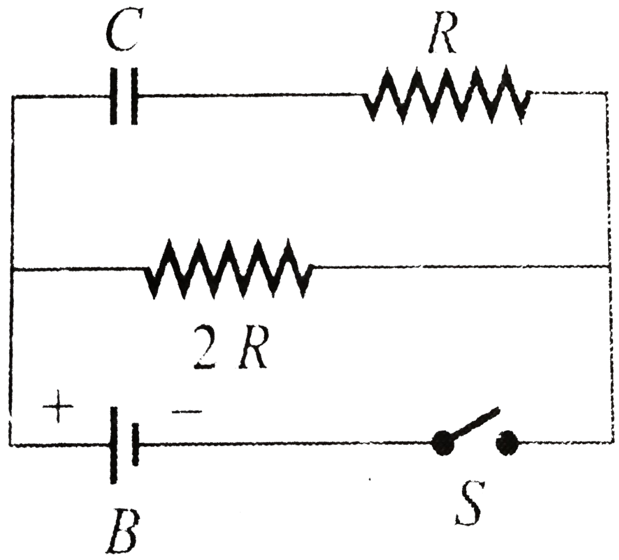
t = ∞ → no current thru capacitor (open circuit)

- I = 0 A, but there is a voltage

Discharging

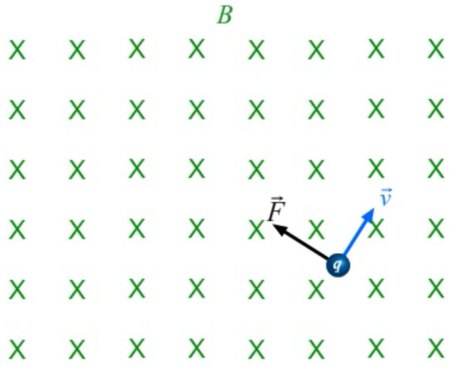
t = 0 → capacitor acts like a battery (C = Q/V where V is found when charging up)

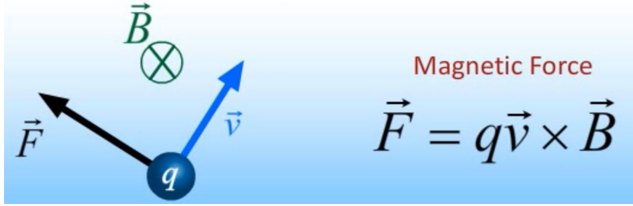
t = ∞ → capacitor acts like a wire (all the charge is dissipated aka gone)



Magnetic Force on Charges

- F_m = **qv X B**
    - we know that **F = ma**
    - and for these problems **$a = a_c = v^2/r$**
    - If we substitute in for F we get **mv^2/r = qv X B**
    - We use this to solve for any missing variable





Right-Hand Rule (1st RHR)

- Point fingers or hand along the direction of v
- Curl fingers in the direction of B
- Thumb points in the direction of the force*

***This works for positive charges, flip your thumb 180° for a negative charge**

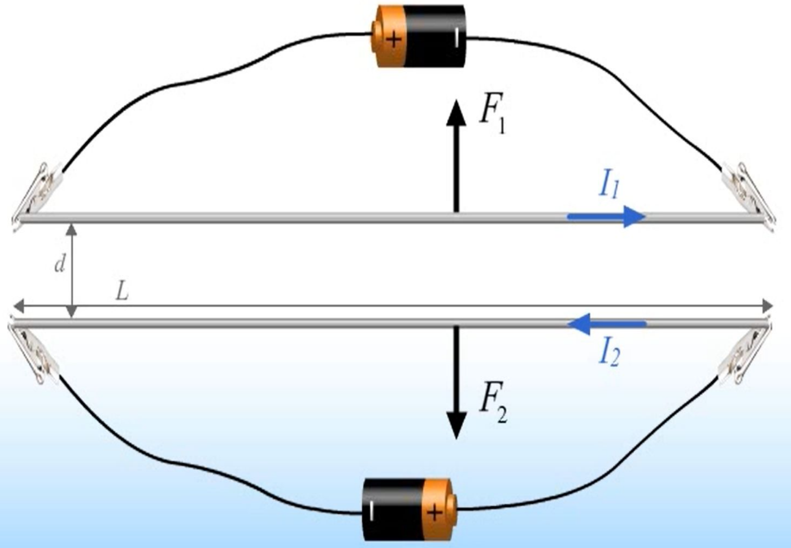
Forces on Current Wires and Loops

$F_{wire} = I\ L \times B$ (1st RHR)

- The force around an entire loop of current is always zero (assuming B is constant) but be careful because it may not be zero at a segment of the loop

Currents traveling in the same direction - attract

Currents traveling in opposite directions - repel



Torques and Energy on Current Loops

Remember sin(θ) goes with cross products and cos(θ) goes with dot products

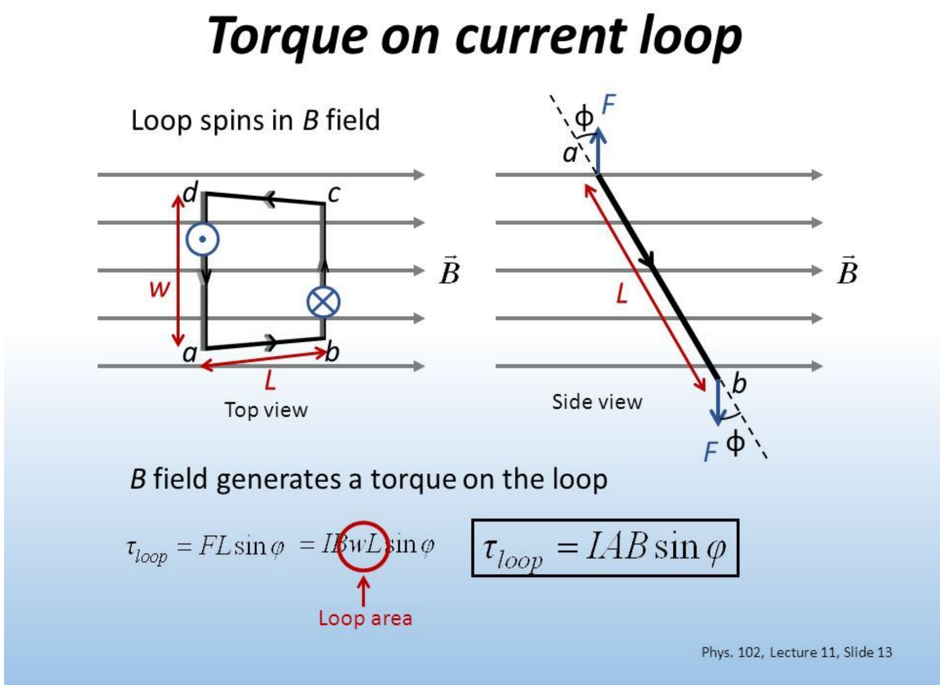
Magnetic Dipole: **μ = n * I * A (2nd RHR)**

- **n = # of turns**
- **I = current through loop**
- **A = area of the loop**

Torque: **τ = μ x B = |μ||B|sin(θ) (1st RHR)**

Potential Energy: **U = -μ · B = -|μ||B|cos(θ)**

Work: **W = -U**



Torques and Energy Cont.

Remember sin(θ) goes with cross products and cos(θ) goes with dot products

Torque: $\boldsymbol{\tau}$ **= μ x B = |μ||B|sin(θ)**

Max when sin(θ) = 1 → θ = 90 → when μ and B are perpendicular

Potential Energy: **U = μ · B = |μ||B|cos(θ)**

Max when cos(θ) = 1 → θ = 0° → when μ and B are parallel in the same direction

Min when cos(θ) = -1 → θ = 180° → μ and B are parallel in opposite directions

Work: **W = -U**

Biot-Savart Law

By using the Biot-Savart Law, we were able to derive the equation for the **magnetic field produced by a current carrying wire (in orange)**

Direction of B is always tangent to the circle (3rd RHR)

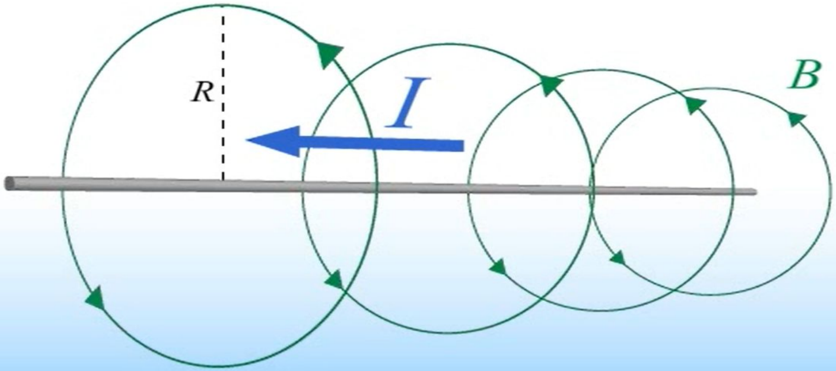
(Not used often, painful to integrate)

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

Right Hand Rule

1. Place thumb in direction of I
2. Fingers curl in direction of B

$$B_z = \frac{\mu_0 I R^2}{2(z^2 + R^2)^{3/2}}$$



Right-Hand Rules (3 Total)

1st RHR - Cross Products

- Place your fingers along the first vector, curl your fingers in the direction of the second vector, your thumb gives you the direction of the force, torque, etc.

2nd RHR - Magnetic Dipole

- Curl your fingers along the direction in which the current is flowing, your thumb gives you the direction of the magnetic dipole

3rd RHR - Magnetic Fields

- Place your thumb along the direction of current, curl your fingers to give you the direction of the “circular path”, B is tangent to the “circular path”

Ampere's Law

Think of it as the 2D version of Gauss's Law, but for magnetic fields now

By convention for line integrals, **traversing a closed loop counter-clockwise (CCW) is positive and traversing it clockwise (CW) is negative**

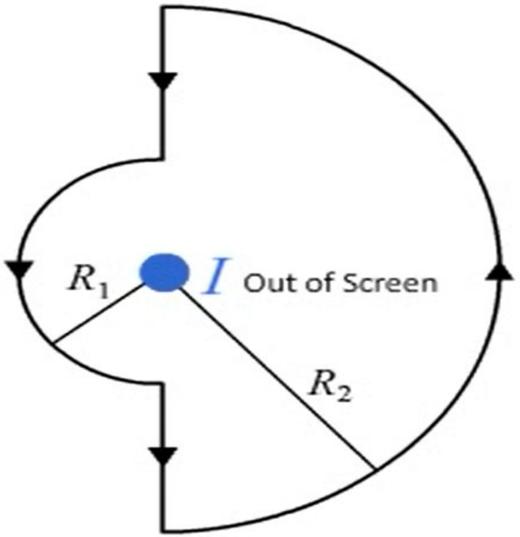
Current density: J = I / A

Units: (A/m^2)

I - Current

A - Area

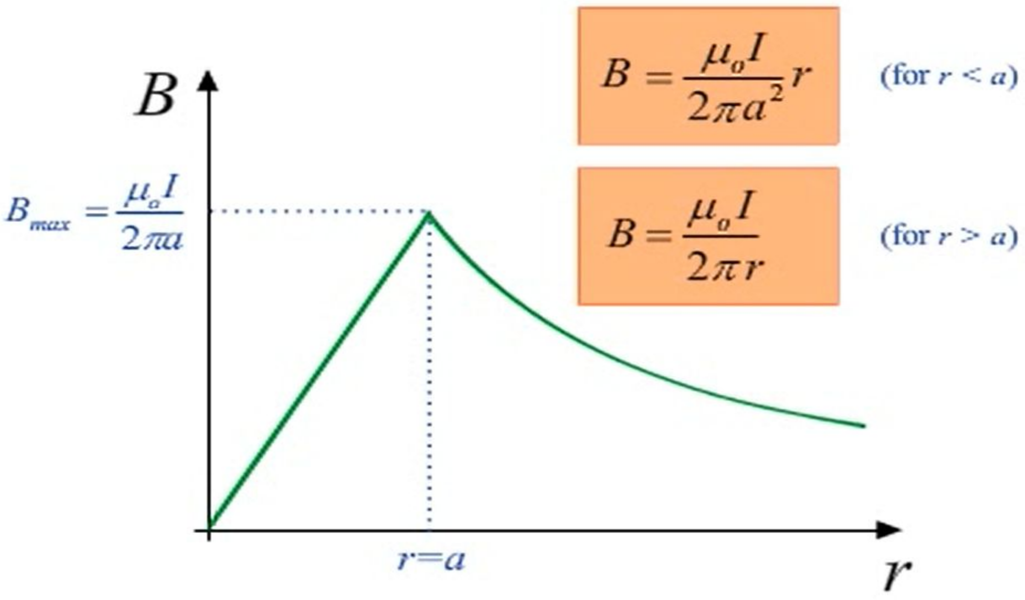
$$\oint_{loop} \vec{B} \cdot d\vec{l} = \mu_o I_{enclosed}$$

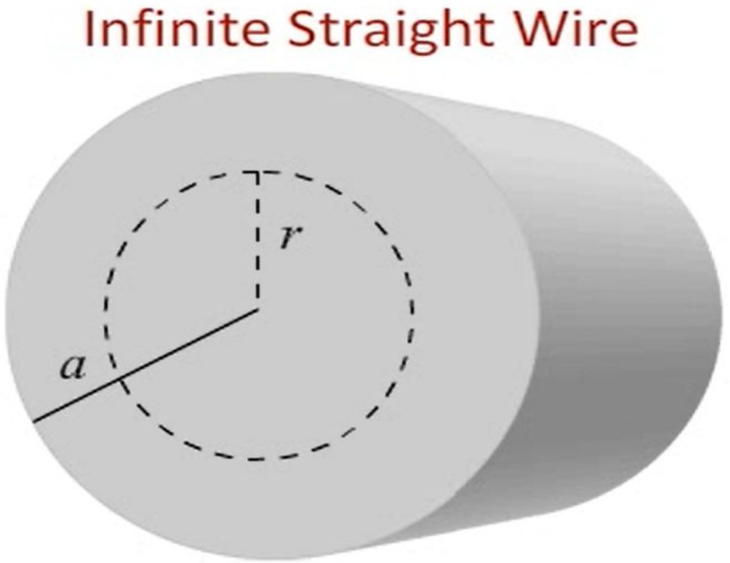


Ampere's Law Cont.

Magnetic field equations inside and outside a current-carrying wire

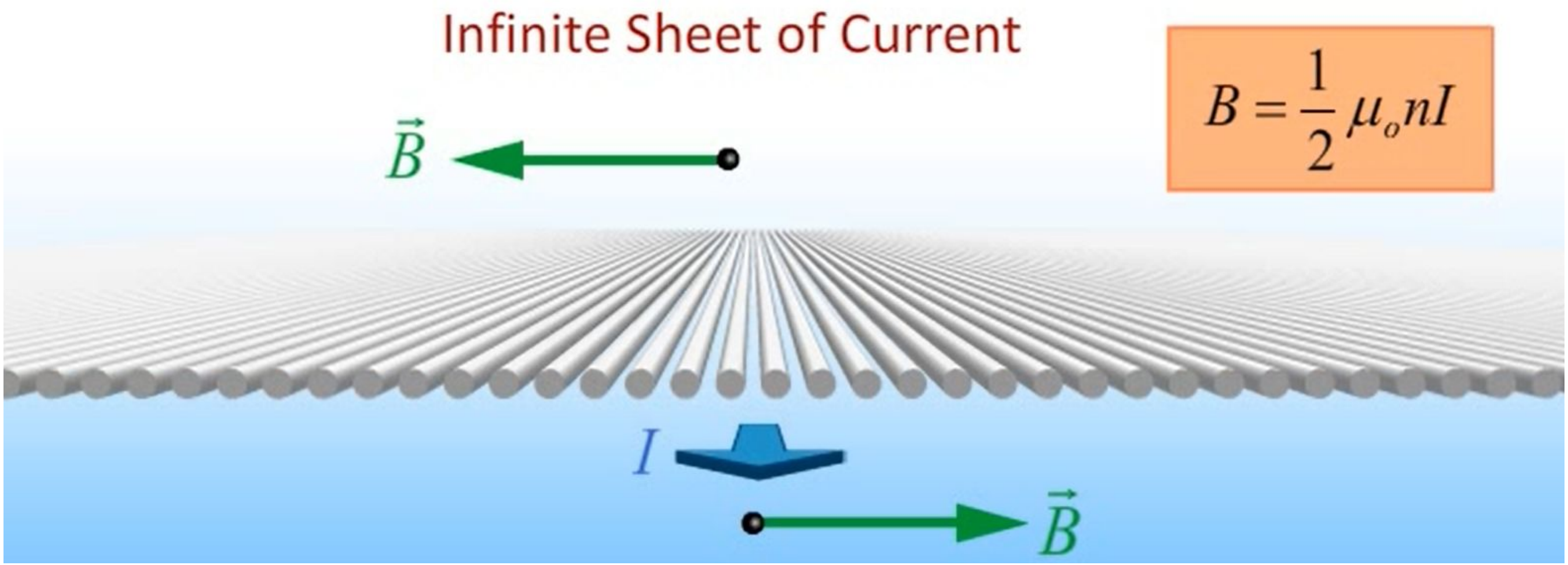
Memorize inside equation (#1), it will save you time from deriving it on the exam





Ampere's Law Cont.

Magnetic field equation for an infinite sheet of current



Motional EMF

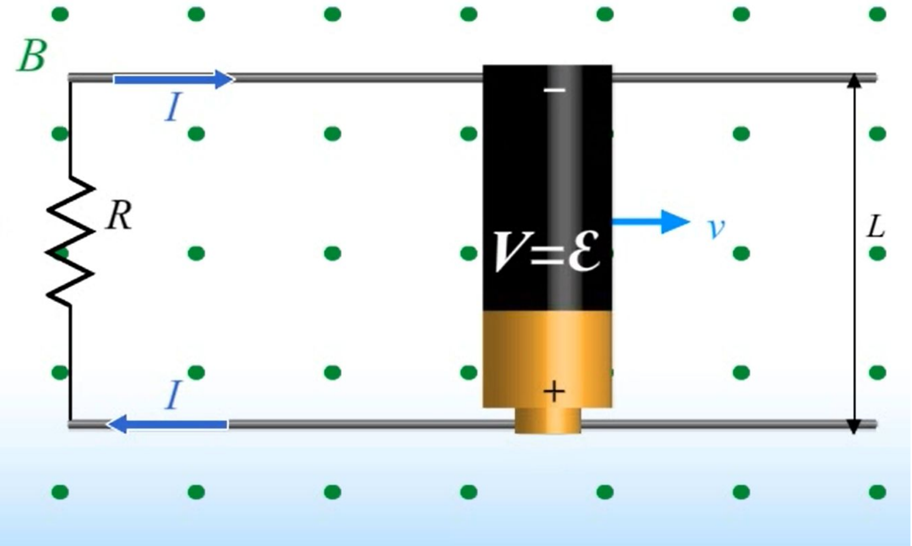
Potential difference = Voltage = Electromagnetic Force (EMF)

$$\boxed{\mathcal{E} = vBL}$$

v - velocity

B - magnetic field

L - length of the loop



To find direction of current: 1st RHR

- RHR wrt the magnet: **F = qv x B**
- **Your thumb gives you the direction of the current**

Faraday's Law

$$\varepsilon_{induced} = -\frac{d\Phi_B}{dt}$$

Main Idea: A changing magnetic flux creates an electric field

The induced EMF (voltage) always opposes the change in magnetic flux

The induced EMF gets **multiplied by N turns** if the loop has N turns in it

3 ways to change the magnetic flux

- **Making the area of the loop smaller or larger**
- **Moving the loop around in a constant magnetic field**
- **Having a time-varying magnetic field (i.e. B is not constant with time)**

Faraday's Law cont.

$$\Phi_B = \int \vec{B} \cdot d\vec{A}$$

$$\mathcal{E}_{induced} = -\frac{d\Phi_B}{dt}$$

Steps for solving Faraday's Law problems (2 types)

Type 1: (Usually given B as a function of time or on a graph)

1) Find the magnetic flux **(B · A)**
2) Solve for the induced EMF by take the negative derivative of the magnetic flux with respect to time **(-d/dt of the magnetic flux)**

Type 2: (Usually a picture with one or "N" conducting loops)

1) **Determine the change in magnetic flux, $B_{induced}$ will always point in the opposite direction** to the change in magnetic flux
2) **Use the 3rd RHR:** Point your fingers in the direction of $B_{induced}$ and curl your fingers to give you the direction of the induced current