DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS
IB PHYSICS

TSOKOS LESSON 5-2: HEATING EFFECT OF ELECTRIC CURRENTS

Reading Activity Questions?

Essential Idea:

- One of the earliest uses for electricity was to produce light and heat. This technology continues to have a major impact on the lives of people around the world.

International-Mindedness:

- A set of universal symbols is needed so that physicists in different cultures can readily communicate ideas in science and engineering.

Nature Of Science:

- Peer review: Although Ohm and Barlow published their findings on the nature of electric current around the same time, little credence was given to Ohm. Barlow's incorrect law was not initially criticized or investigated further. This is a reflection of the nature of academia of the time, with physics in Germany being largely non-mathematical and Barlow held in high respect in England. It indicates the need for the publication and peer review of research findings in recognized scientific journals.

Theory Of Knowledge:

- Sense perception in early electrical investigations was key to classifying the effect of various power sources; however, this is fraught with possible irreversible consequences for the scientists involved.
- Can we still ethically and safely use sense perception in science research?

Understandings:

- Circuit diagrams
- Kirchhoff's circuit laws
- Heating effect of current and its consequences
- Resistance expressed as $R\,I = V$
- Ohm's law
- Resistivity
- Power dissipation

Applications And Skills:

- Drawing and interpreting circuit diagrams
- Identifying ohmic and non-ohmic conductors through a consideration of the V/I characteristic graph
- Solving problems involving potential difference, current, charge, Kirchhoff's circuit laws, power, resistance and resistivity

Applications And Skills:

- Investigating combinations of resistors in parallel and series circuits
- Describing ideal and non-ideal ammeters and voltmeters
- Investigating one or more of the factors that affect resistance experimentally

Applications And Skills:

- Describing practical uses of potential divider circuits, including the advantages of a potential divider over a series resistor in controlling a simple circuit

Guidance:

- The filament lamp should be described as a non-ohmic device; a metal wire at a constant temperature is an ohmic device
- The use of non-ideal voltmeters is confined to voltmeters with a constant but finite resistance
- The use of non-ideal ammeters is confined to ammeters with a constant but non-zero resistance
- Application of Kirchhoff's circuit laws will be limited to circuits with a maximum number of two source-carrying loops

Data Booklet Reference:

- *Kirchoff's circuit laws:*
  - $\Sigma V = 0$ (loop)
  - $\Sigma I = 0$ (junction)
- *Refer to electrical symbols on page 4 of the physics data booklet*

$$R = \frac{V}{I}$$

$$P = VI = I^2 R = \frac{V^2}{R}$$

$$R_{total} = R_1 + R_2 + \bullet\bullet\bullet$$

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \bullet\bullet\bullet$$

$$\rho = \frac{RA}{L}$$

Utilization:

- Although there are nearly limitless ways that we use electrical circuits, heating and lighting are two of the most widespread
- Sensitive devices can employ detectors capable of measuring small variations in potential difference and/or current, requiring carefully planned circuits and high precision components

Aims:

- Aim 2: electrical theory and its approach to macro and micro effects characterizes much of the physical approach taken in the analysis of the universe
- Aim 3: electrical techniques, both practical and theoretical, provide a relatively simple opportunity for students to develop a feeling for the arguments of physics

Aims:

- Aim 6: experiments could include (but are not limited to): use of a hot-wire ammeter as an historically important device; comparison of resistivity of a variety of conductors such as a wire at constant temperature, a filament lamp, or a graphite pencil; determination of thickness of a pencil mark on paper; investigation of ohmic and non-ohmic conductor characteristics; using a resistive wire wound and taped around the reservoir of a thermometer to relate wire resistance to current in the wire and temperature of wire

Aims:

- Aim 7: there are many software and online options for constructing simple and complex circuits quickly to investigate the effect of using different components within a circuit

Introductory Video: Resistance 1

Introductory Video: Resistance 2

Introductory Video: Resistance 3

Electron Collisions

- An electric field causes free and loose-living electrons to accelerate
- When electrons collide with lattice atoms, the collisions are inelastic
- *What is the result of an inelastic collision?*

Electron Collisions

- An electric field causes free and loose-living electrons to accelerate
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HEAT

- Electrons give up kinetic energy to the molecules and heat shows up as an increase in the temperature of the conductor

Electric Resistance and Ohm’s Law

- Electric resistance of a conductor is defined as the potential difference across its ends, divided by the current flowing through it:

$$R = \frac{V}{I}$$

- The unit for resistance is the Ohm (**Ω**) and is equal to 1 V/A

Electric Resistance and Ohm's Law

$$R = \frac{V}{I}$$

- When the temperature of a conductor is kept constant, current is proportional to the potential difference across it

- Ohm's Law

$$I \propto V$$

  - This implies resistance is constant

Electric Resistance and Ohm's Law

$$I \propto V$$

$$R = \frac{V}{I}$$

- A conductor with zero electric resistance is known as a perfect conductor
  - Current can flow without a potential difference
  - *Superconductors* can achieve zero resistance at very low temperatures (critical temperature) and are thus perfect conductors

Electric Resistance and Ohm's Law

$$I \propto V$$

$$R = \frac{V}{I}$$

- For metals, increase in temperature results in increased resistance
  - Increased temperature means increased vibration of atoms
  - This increases the number of collisions per unit time
  - This means less time between collisions
  - This means drift speed (current) is reduced

Electric Resistance and Ohm's Law

$$I \propto V$$

$$R = \frac{V}{I}$$

- Assuming the conductor is kept at constant temperature, three factors affect resistance:
  - properties of the material
  - length
  - cross-sectional area.

Electric Resistance and Ohm's Law

$$I \propto V$$

$$R = \frac{V}{I}$$

- **Electric resistance of a wire (at constant temperature) is proportional to its length (L) and inversely proportional to the cross-sectional area**

$$R \propto \frac{L}{A}$$

  - Resistance increases with length
  - Resistance decreases with cross-sectional area

Electric Resistance and Ohm's Law

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- Electric resistance of a wire (at constant temperature) is proportional to its length (L) and inversely proportional to the cross-sectional area

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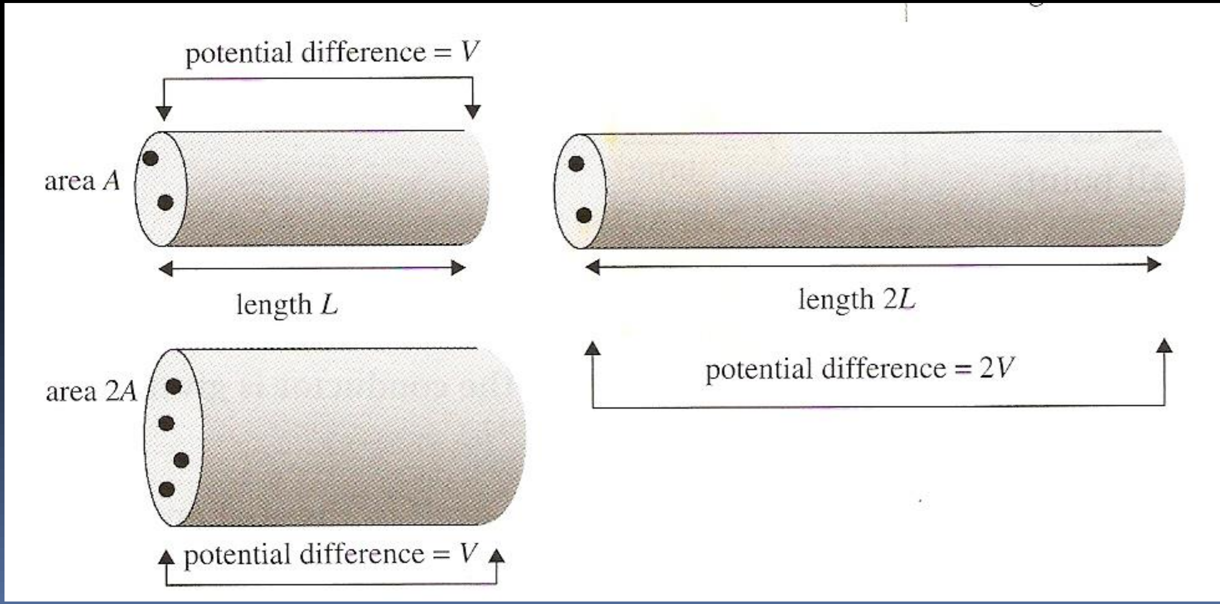


Electric Resistance and Ohm's Law

- The constant of proportionality is *resistivity (ρ)*

$$R = \rho \frac{L}{A}$$

$$\rho = \frac{RA}{L}$$

$$R = \frac{V}{I}$$

$$I \propto V$$

$$R \propto \frac{L}{A}$$

Potential Drop (Voltage)

$$R = \frac{V}{I}$$

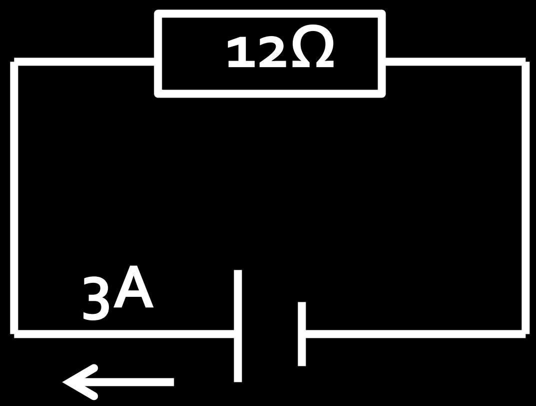
$$V = IR$$

- This derivation tells us that for current to flow through a resistor, there must be a potential difference (V) across the resistor.
- In a circuit, the voltage is said to "drop" across each resistor
- If we assume the resistance of the conductor (wire) is negligible, the total voltage drop and potential difference will be the same

Potential Drop

- **Examples:**

A



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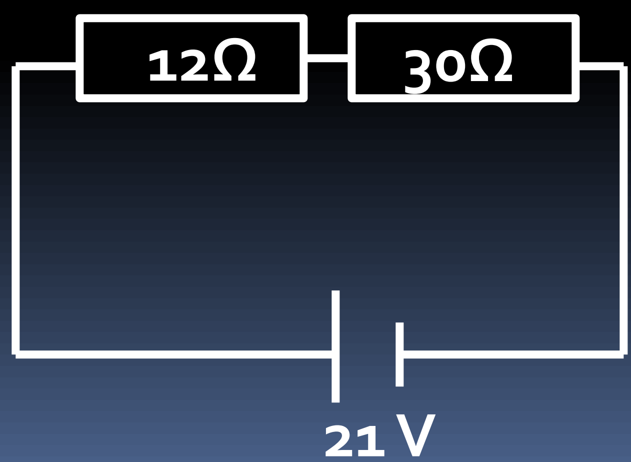


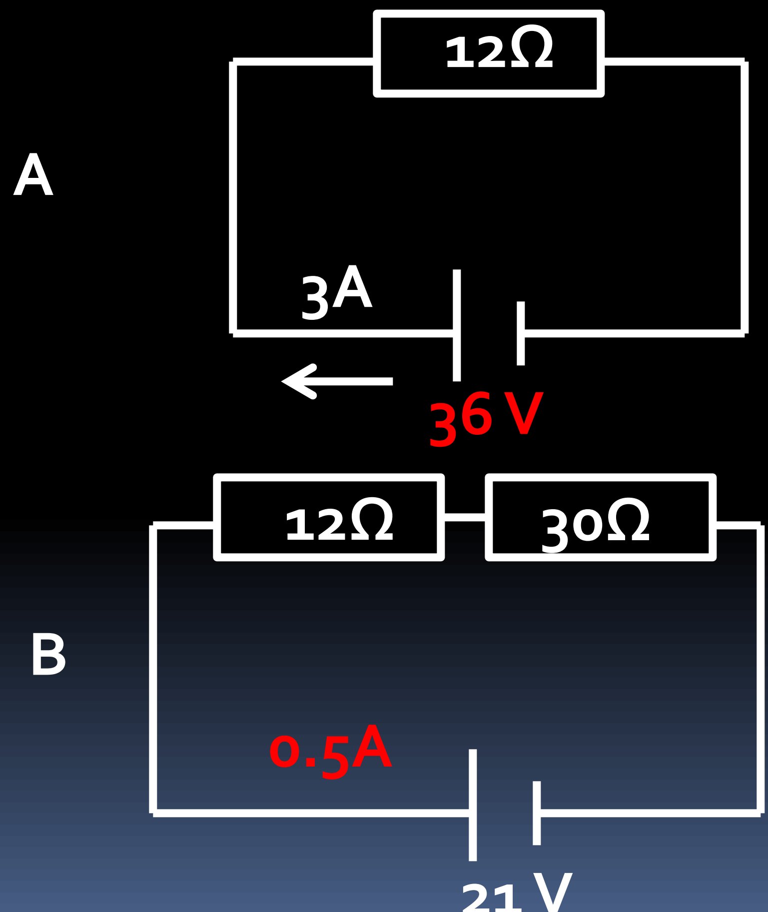
$$R = \frac{V}{I}$$

$$V = IR$$

$$I = \frac{V}{R}$$

Potential Drop

- **Examples:**

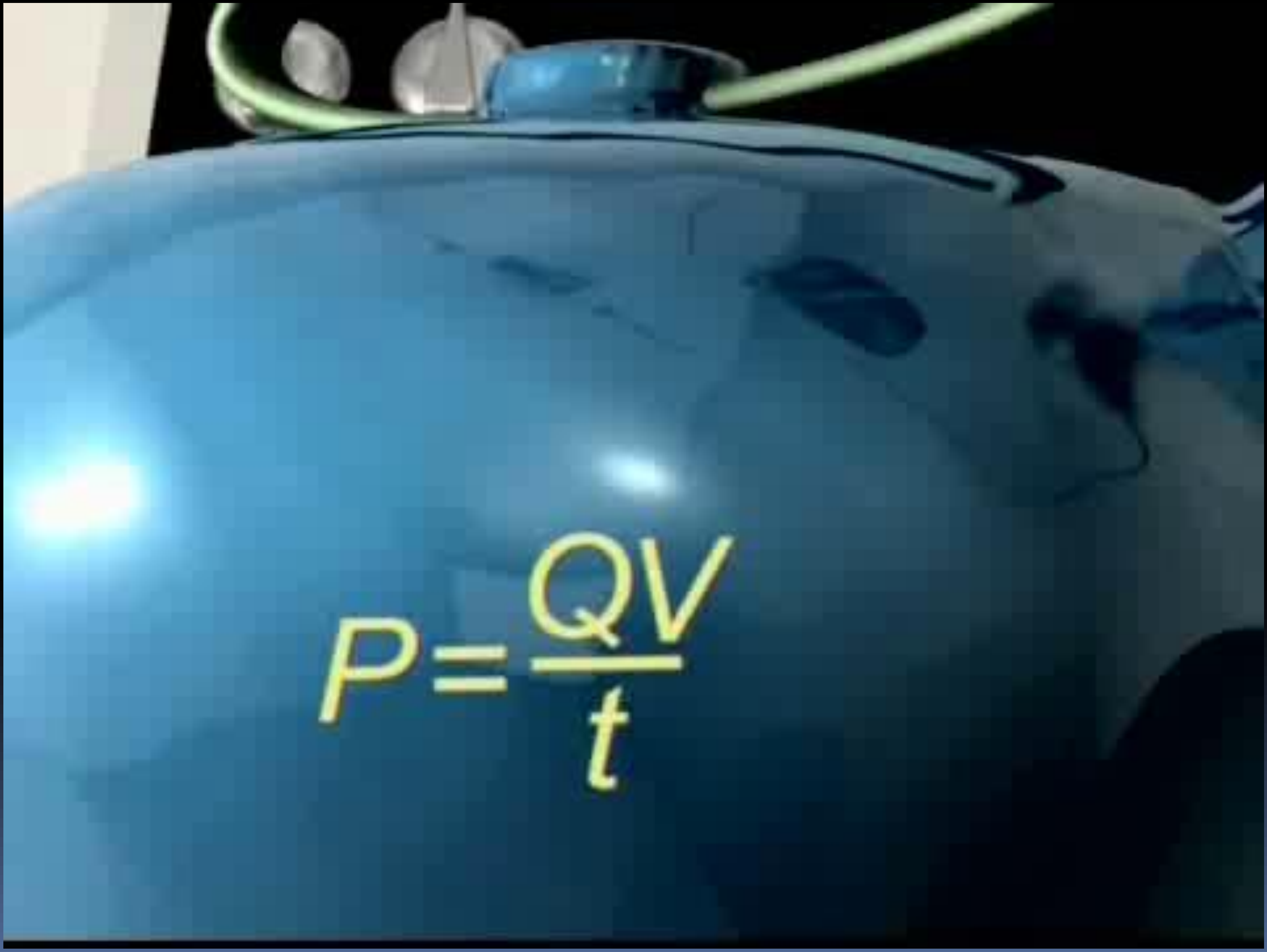


$$R = \frac{V}{I}$$

$$V = IR$$

$$I = \frac{V}{R}$$

Electricity - Measurement of Power



Electric Power

- We have seen that it requires work to move a charge across a potential
- A current is a movement of charge so work is being done, and it is movement per unit time
- Where there is work per unit time, there is POWER

$$P = \frac{Work}{Time}$$

$$W = QV$$

$$P = \frac{QV}{\Delta t}$$

$$I = \frac{\Delta Q}{\Delta t}$$

$$P = VI$$

Electric Power

- This power is translated into mechanical work or thermal energy
- We can re-write the formula for power for devices that obey Ohm's law *(ohmic behavior)*

$$P = VI$$

$$R = \frac{V}{I}$$

$$V = IR$$

$$P = RI^2$$

$$I = \frac{V}{R}$$

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

Electric Power

- This power is translated into mechanical work or thermal energy
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$$P = VI$$

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$$I = \frac{V}{R}$$

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

Electric Power

- **Electrical devices are normally rated in watts (power) and volts (potential)**
- **A light bulb rated as 60W at 220V (normal household voltage) means it will dissipate 60 watts of energy when a potential of 220 V is applied across it**
- ***So, what is the current and resistance?***

Electric Power

- **Electrical devices are normally rated in watts (power) and volts (potential)**
- **A light bulb rated as 60W at 220V (normal household voltage) means it will dissipate 60 watts of energy when a potential of 220 V is applied across it**
- ***So, what is the current and resistance?***

$$P = VI$$

$$\frac{P}{V} = I$$

$$\frac{60}{220} = I = 0.27A$$

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

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

$$R = \frac{220^2}{60} = 807\Omega$$

Emf (ε)

- Emf sources
  - battery - converts stored chemical energy into electrical energy
  - generator – converts mechanical energy into electrical energy
  - thermocouple – converts thermal energy into electrical energy
  - photoelectric material – converts solar energy into electrical energy

Emf (ε)

- Charges will not move in a conductor unless there exists an electric potential created by an *electromotive force (emf)* providing the energy
  - Resistance
  - Superconductors are an exception
- Since the electrons must be ‘pushed’ from the positive terminal to the negative terminal, work must be done on the electrons

Emf (ε)

- Electromotive force (emf, **ε**) is equal to the total work done in moving a unit charge completely around a circuit

$$\varepsilon = \frac{W}{q}$$

- Unit for emf is the volt (V, J/C)

Emf (ε)

- Emf can also be defined as the total power generated by the voltage source per unit current

$$\varepsilon = \frac{W}{q}$$

$$P = \frac{W}{t}, Pt = W$$

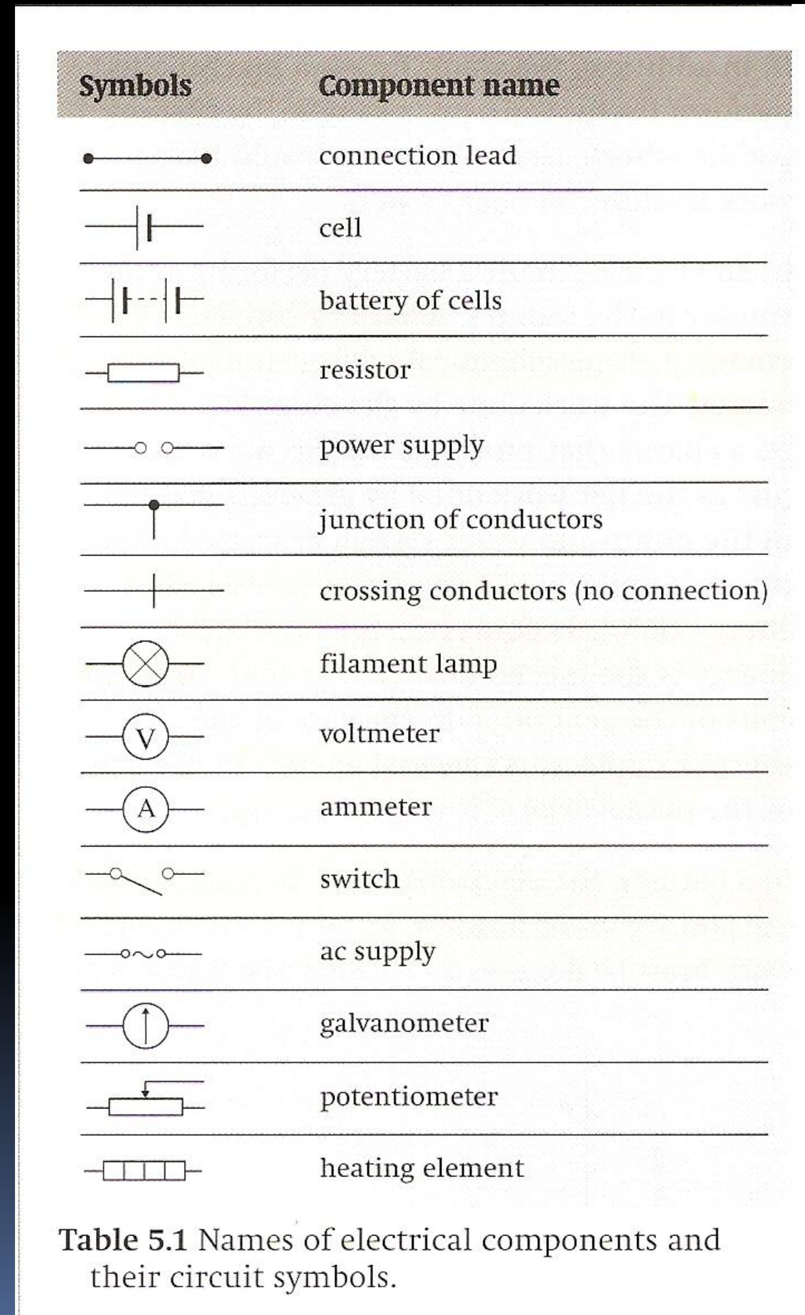
$$\varepsilon = \frac{Pt}{q}$$

$$I = \frac{q}{t}, \frac{1}{I} = \frac{t}{q}$$

$$\varepsilon = \frac{P}{I}$$

Simple DC Circuits

Simple Electric Circuits

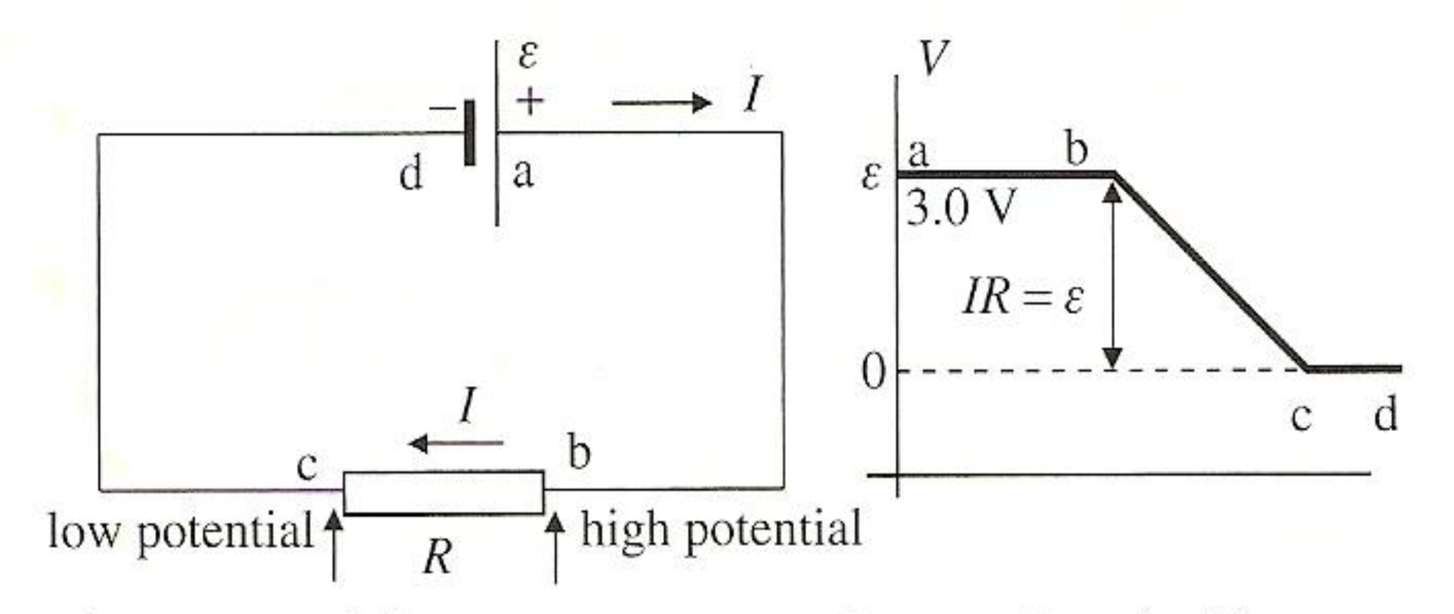


Symbols	Component name
	connection lead
	cell
	battery of cells
	resistor
	power supply
	junction of conductors
	crossing conductors (no connection)
	filament lamp
	voltmeter
	ammeter
	switch
	ac supply
	galvanometer
	potentiometer
	heating element

Table 5.1 Names of electrical components and their circuit symbols.

Simple Electric Circuits

- **Example: Find the current in the simple circuit below with negligible internal resistance, ε = 3.0V, and R = 1.5 Ω.**



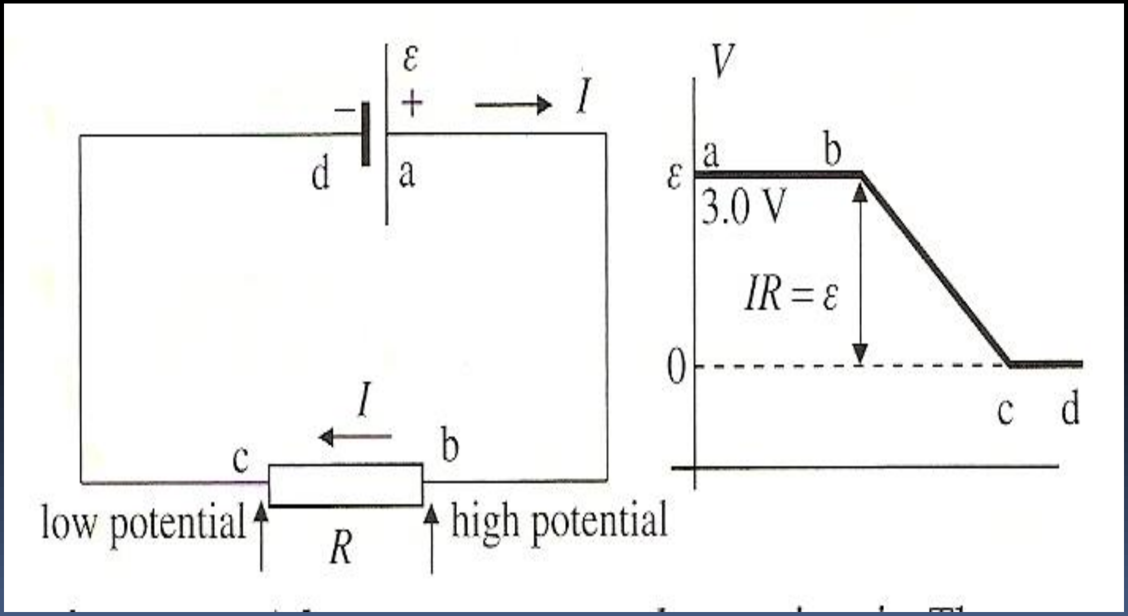
Simple Electric Circuits

- **Example: Find the current in the simple circuit below with negligible internal resistance, ε = 3.0V, and R = 1.5 Ω.**

$$V = IR$$

$$I = \frac{V}{R}$$

$$I = \frac{3.0}{1.5} = 2A$$



Series Circuits

- Circuits are said to be "in series" when the same current runs through them as if they were connected end to end
  - The potential drop across each resistor is, $V_1 = IR_1$, $V_2 = IR_2$, $V_3 = IR_3$

$$V = IR_1 + IR_2 + IR_3$$
$$V = I\left(R_1 + R_2 + R_3\right)$$
$$V = IR_{Total}$$
$$R_{Total} = R_1 + R_2 + R_3$$

Series Circuits

- **For resistors in series, it is the same as replacing all resistors with one that has the total value of all in series.**
- **<u>For resistors in series, the same current flows through all resistors and the potential drop across the resistors is equal to the drop across the series.</u>**

$$R_{Total} = R_1 + R_2 + R_3$$

Series Circuits

- **<u>EXAMPLE:</u> If resistors of 2Ω, 3 Ω, and 7 Ω are connected in series in a circuit with a current of 2.5 amps what will be the emf in a source with negligible resistance?**

$$R_{Total} = R_1 + R_2 + R_3$$

Series Circuits

- **<u>EXAMPLE:</u>** **If resistors of 2Ω, 3 Ω, and 7 Ω are connected in series in a circuit with a current of 2.5 amps what will be the emf in a source with negligible resistance?**

$$R_{Total} = R_1 + R_2 + R_3$$

$$R_{Total} = 3 + 2 + 7 = 12$$

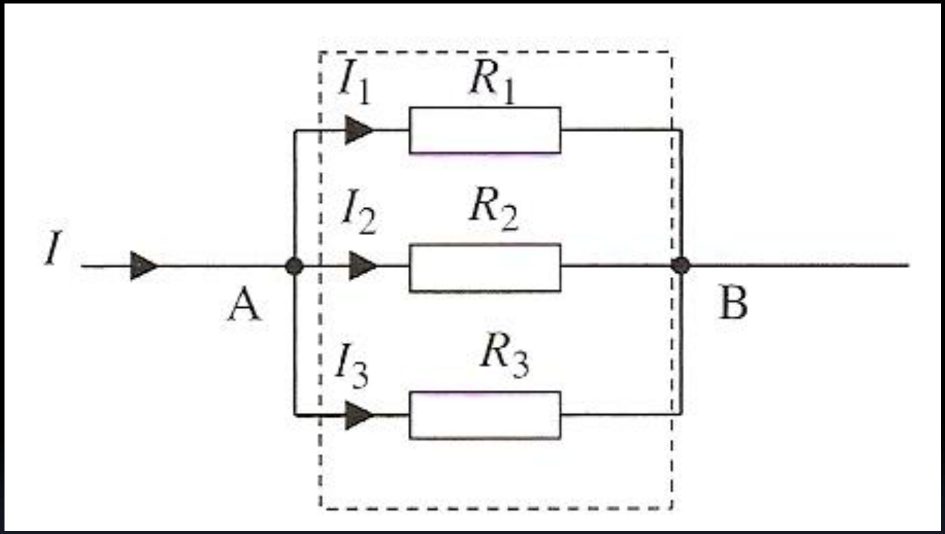
$$V = IR = 2.5x12 = 30V$$

Parallel Circuits

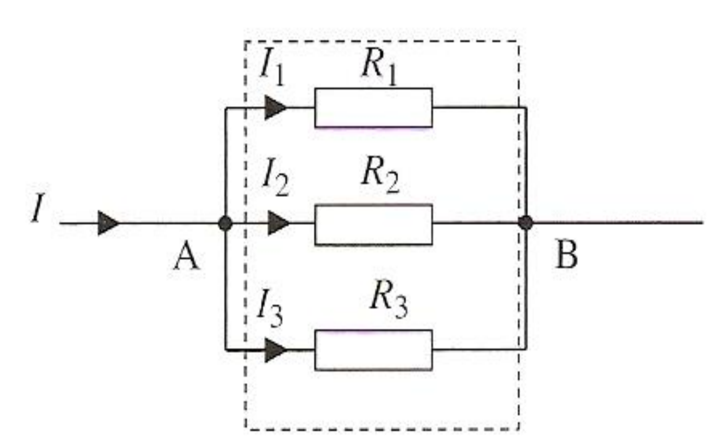
- In parallel circuits, the current splits and flows through two or more resistors
- The current that enters the split must equal the current that exits the split
- The sum of the split currents must equal the current in and out
- The same potential exists across each resistor that is connected in parallel
    - That is what determines the current

Parallel Circuits

- Consider the circuit below



Parallel Circuits



$$V = IR$$

$$I = \frac{V}{R}$$

$$I_{Total} = I_1 + I_2 + I_3$$

$$I_{Total} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$I_{Total} = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$\frac{I_{Total}}{V} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$R_{Total} = \frac{V}{I_{Total}}$$

$$\frac{1}{R_{Total}} = \frac{I_{Total}}{V} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Series Circuits

$$R_{Total} = R_1 + R_2 + R_3 + \bullet\bullet\bullet$$

Parallel Circuits

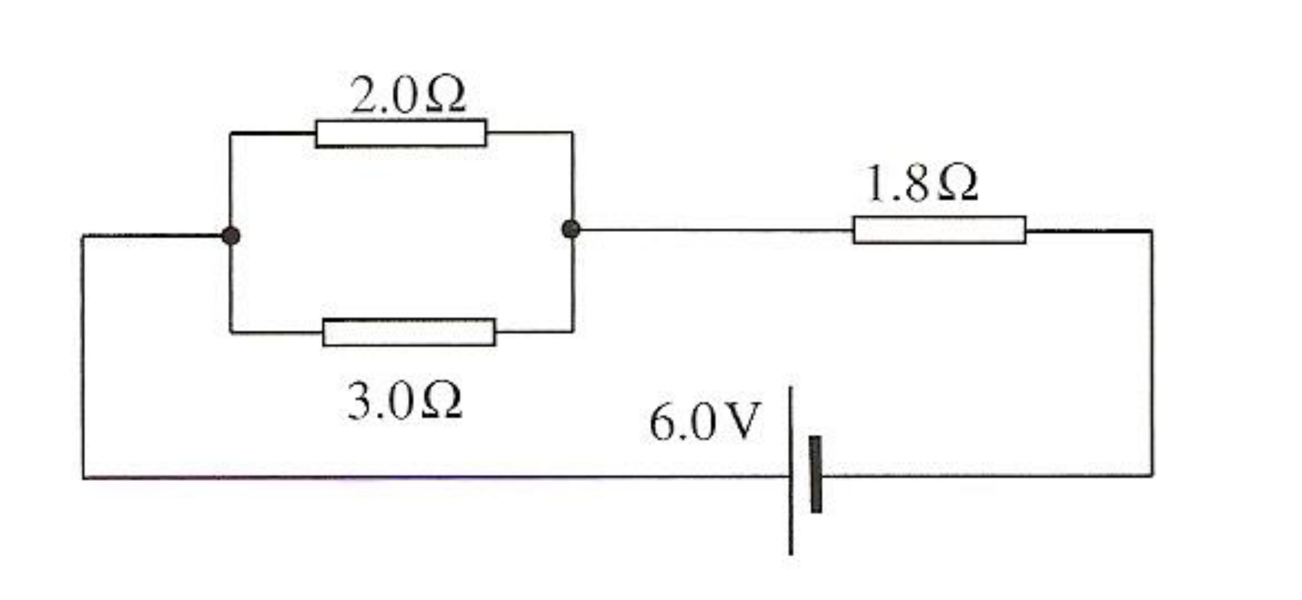
$$\frac{1}{R_{Total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \bullet\bullet\bullet$$

Analyzing Circuits

- The reason we have learned how to combine resistors that are in series or in parallel is that it gives us a means for analyzing circuits

Analyzing Circuits

- **EXAMPLE: Find the current through each resistor and the potential difference across each resistor in the circuit below:**



- *In series resistors, the current through each resistor is the same and the potential difference (drop) is different.*

- *In parallel resistors, the potential difference (drop) is the same and the current through each resistor is different.*

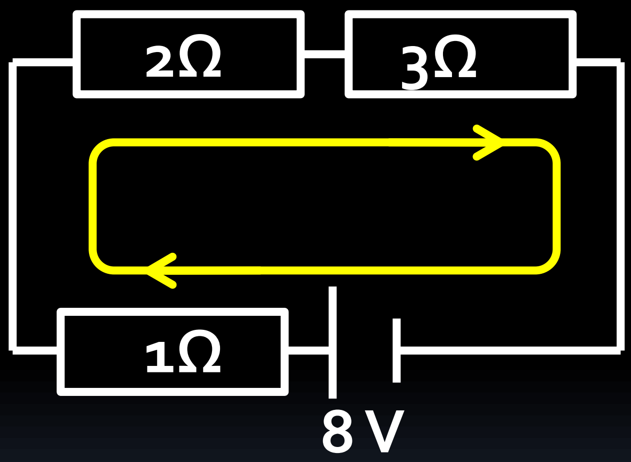
Kirchhoff’s Second Law

- AKA Voltage Law, AKA Loop Law
- The sum of the voltages around a circuit equal zero
  - Voltage across power sources are positive
  - Voltage drops across resisters are negative

$$\Sigma V = 0$$

Kirchhoff's Second Law

- AKA Voltage Law, AKA Loop Law
- The sum of the voltages around a circuit equal zero



$$\Sigma V = 0$$

$$V = IR$$

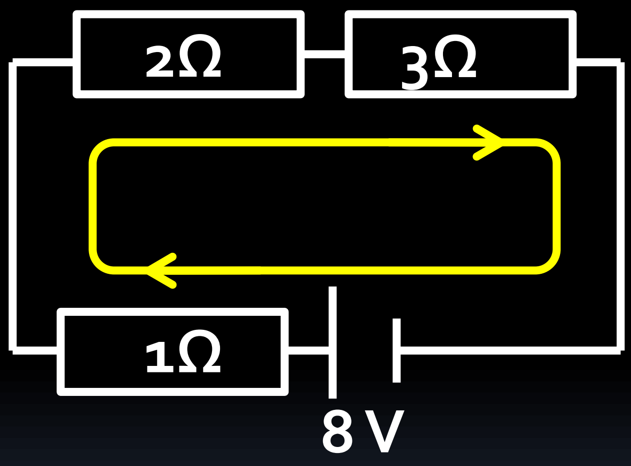
$$\Sigma V = +8 - 1I - 2I - 3I = 0$$

$$8 = 6I$$

$$1.3A = I$$

Kirchhoff's Second Law

- This example illustrates the fact that series resistors can be added.



$$\Sigma V = +8 - 1I - 2I - 3I = 0$$

$$8 = 6I$$

$$R_{total} = 1 + 2 + 3 = 6\Omega$$

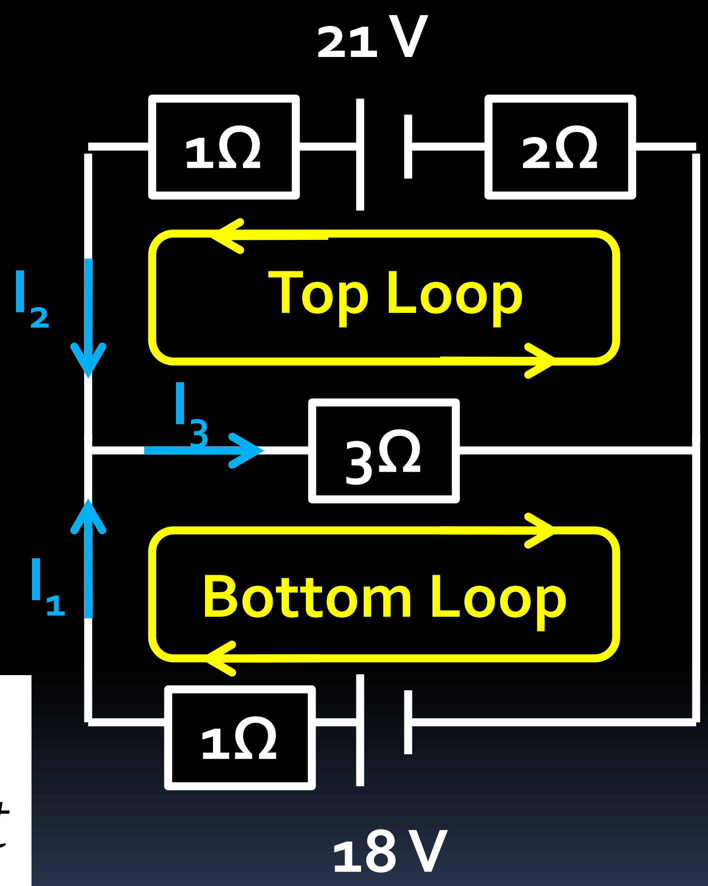
$$V = IR_{total}$$

$$8 = 6I$$

$$1.3 = I$$

Kirchhoff's First Law

- AKA Current Law, AKA Junction Law
- The sum of the currents going into a junction will equal the sum of the currents flowing out of a junction.



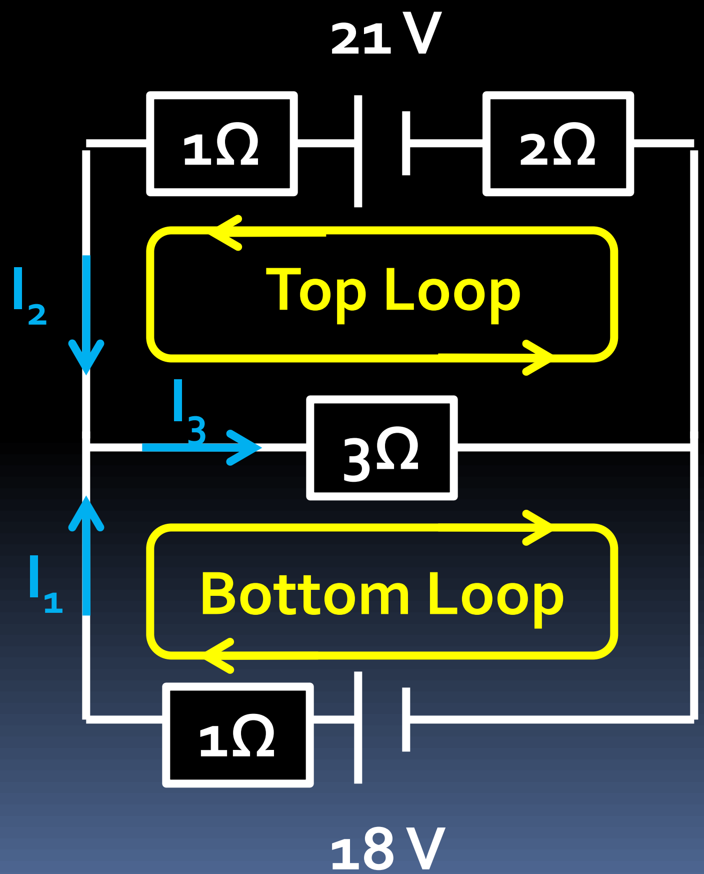
$$\Sigma I_{in} = \Sigma I_{out}$$

$$I_1 + I_2 = I_3$$

Kirchhoff's First Law

$$\Sigma I_{in} = \Sigma I_{out}$$

$$\Sigma V = 0$$

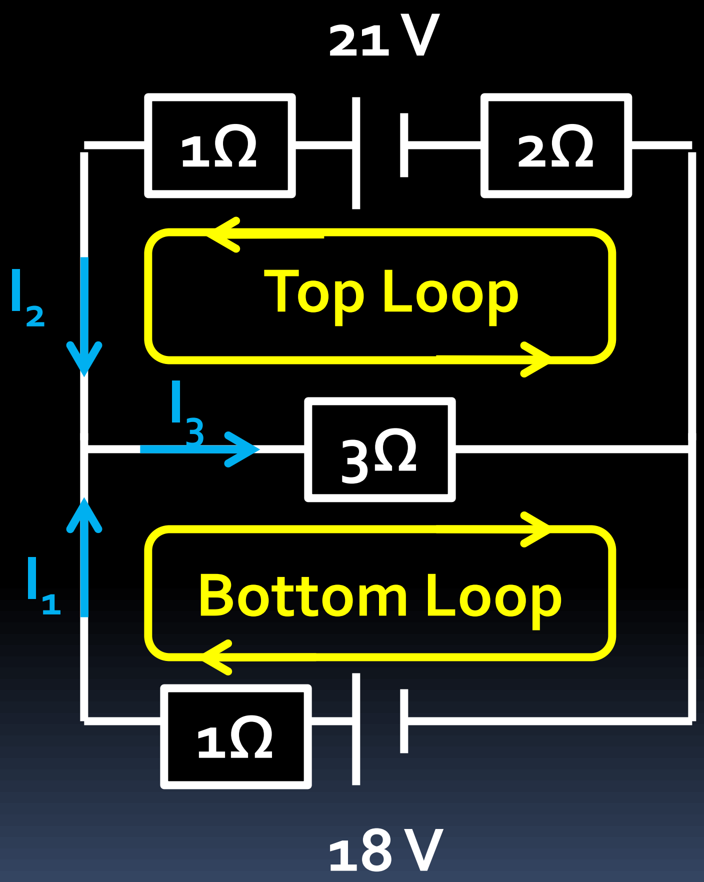


$$I_1 + I_2 = I_3$$

$$21V = 2I_2 + 1I_2 + 3I_3$$

$$18V = 1I_1 + 3I_3$$

Kirchhoff's First Law



$$I_1 + I_2 = I_3$$

$$21V = 2I_2 + 1I_2 + 3I_3$$

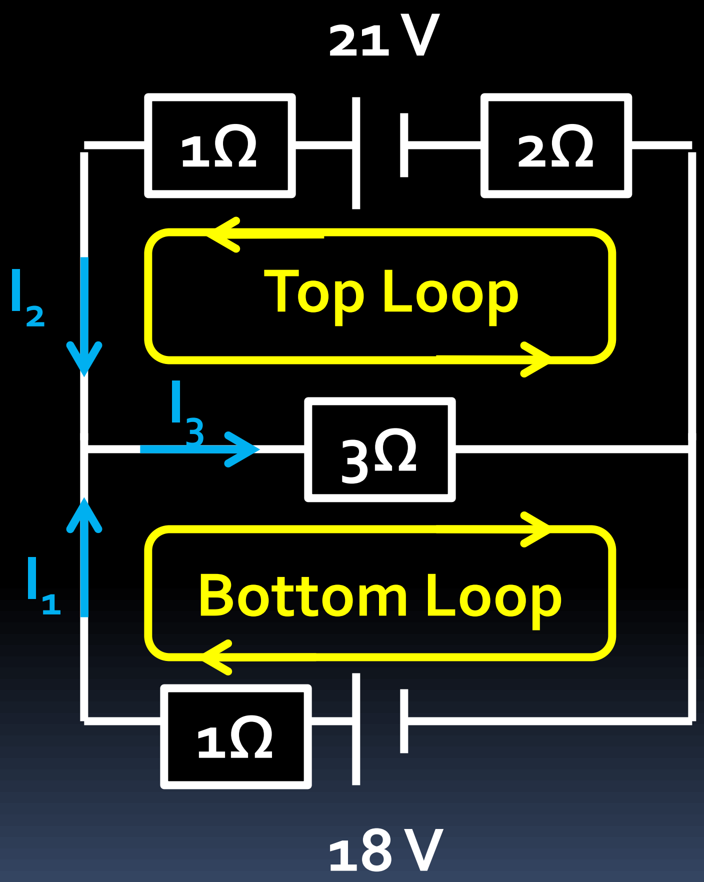
$$21V = 3I_2 + 3(I_1 + I_2)$$

$$21V = 3I_2 + 3I_1 + 3I_2$$

$$21V - 6I_2 = 3I_1$$

$$7V - 2I_2 = I_1$$

Kirchhoff's First Law



$$I_1 + I_2 = I_3$$

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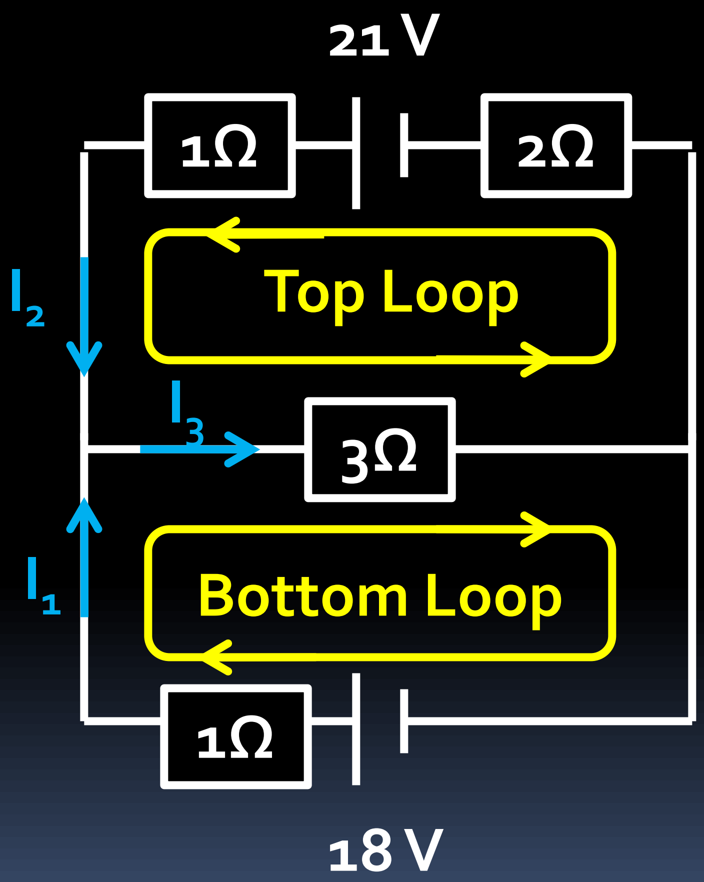
Kirchhoff's First Law



$$I_1 + I_2 = I_3$$

$$7V - 2I_2 = I_1$$

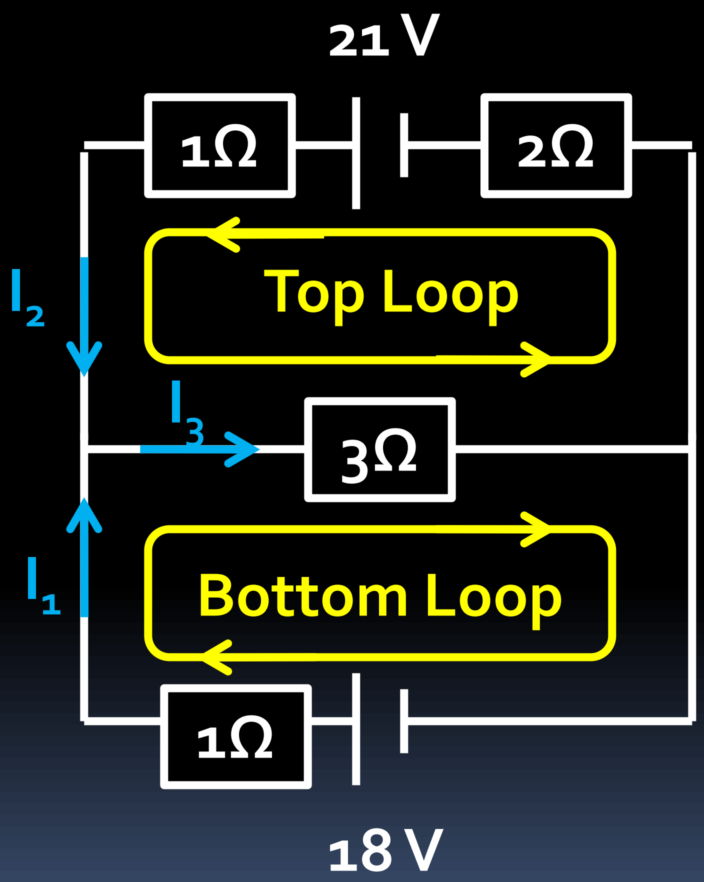
$$18V = 1I_1 + 3I_3$$

$$18V = (7V - 2I_2) + 3(I_1 + I_2)$$

$$18V = 7V - 2I_2 + 3I_1 + 3I_2$$

$$11V = I_2 + 3I_1$$

Kirchhoff's First Law



$$I_1 + I_2 = I_3$$

$$7V - 2I_2 = I_1$$

$$11V = I_2 + 3I_1$$

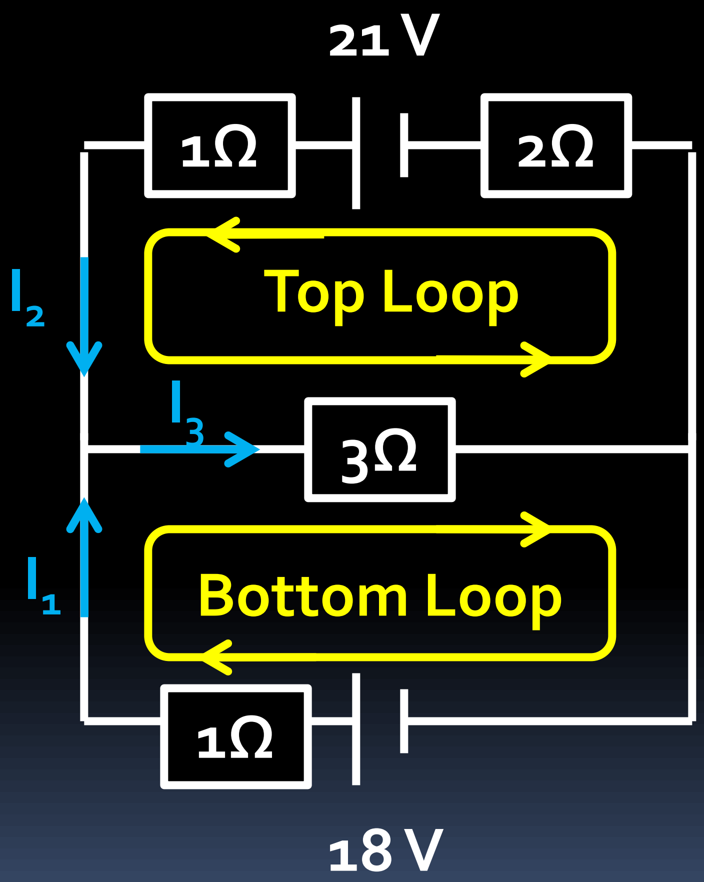
$$11V = I_2 + 3(7V - 2I_2)$$

$$11V = I_2 + 21V - 6I_2$$

$$-10V = -5I_2$$

$$2A = I_2$$

Kirchhoff's First Law



$$I_1 + I_2 = I_3$$

$$7V - 2I_2 = I_1$$

$$2A = I_2$$

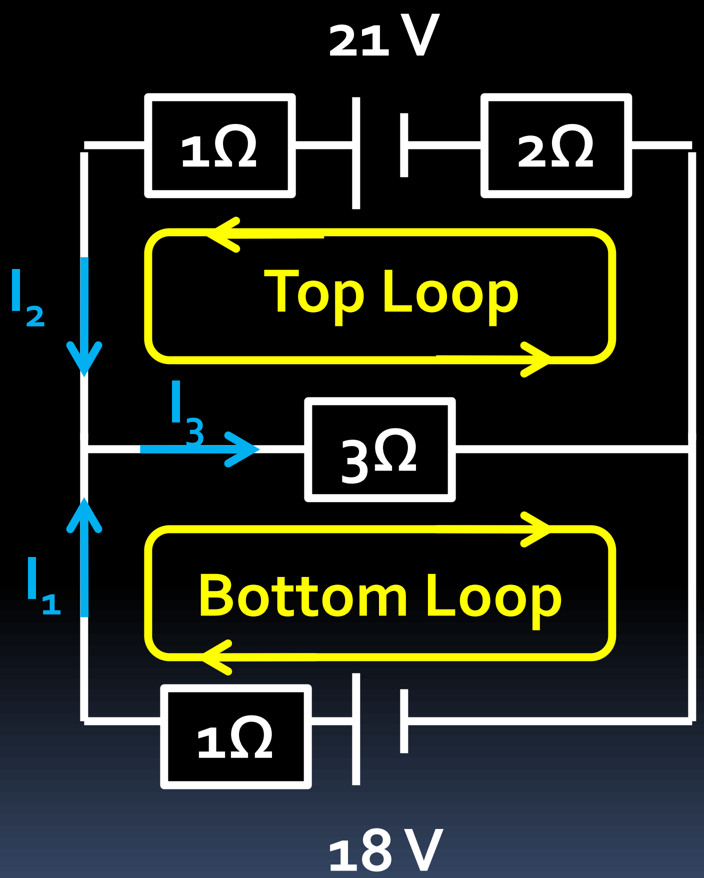
$$7V - 2(2) = I_1$$

$$3A = I_1$$

$$I_1 + I_2 = I_3$$

$$(2) + (3) = I_3 = 5A$$

Kirchhoff's First Law



$$I_1 + I_2 = I_3$$

$$7V - 2I_2 = I_1$$

$$2A = I_2$$

$$7V - 2(2) = I_1$$

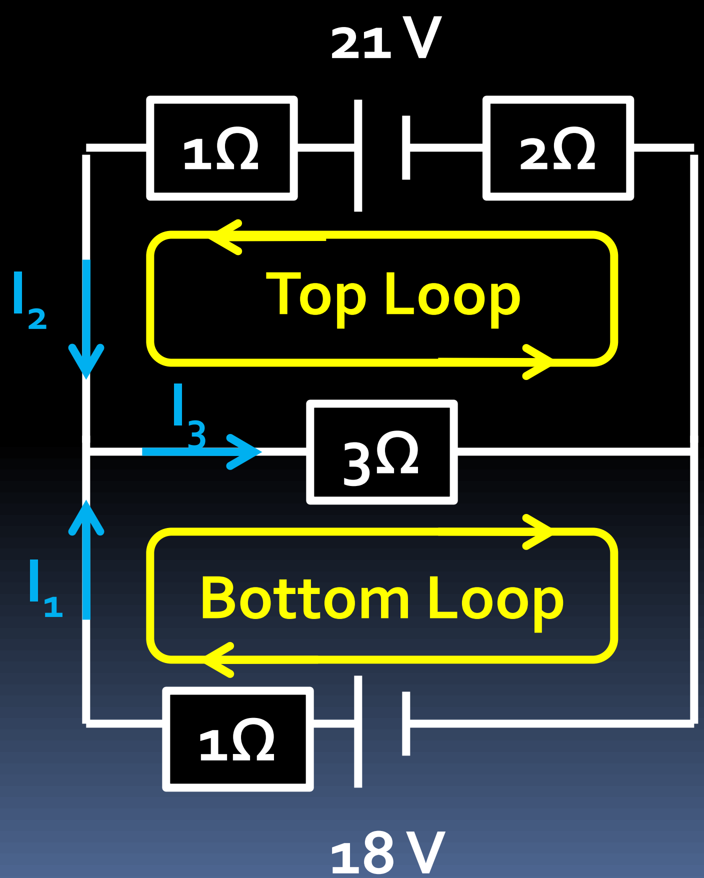
$$3A = I_1$$

$$I_1 + I_2 = I_3$$

$$(2) + (3) = I_3 = 5A$$

Kirchhoff's First Law

- ***Does it check?***



$$I_1 = 3, I_2 = 2, I_3 = 5$$

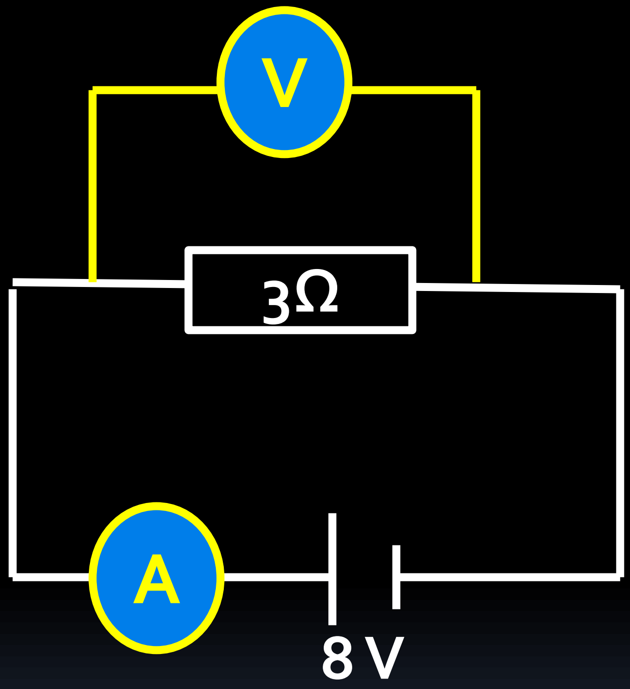
$$I_1 + I_2 = I_3$$

$$21V = 2I_2 + 1I_2 + 3I_3$$

$$18V = 1I_1 + 3I_3$$

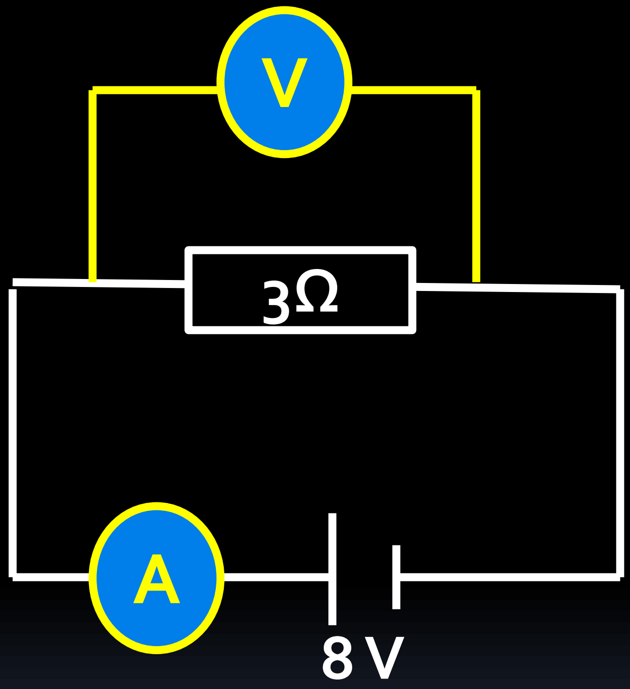
Ammeters and Voltmeters

- Ammeters measure amps which is short for amperes which is the unit of current
- ***Ammeters must be installed in series with the circuit***
- ***An ideal ammeter will have zero resistance***
  - *Otherwise, there would be a voltage drop across the ammeter which would change the current*



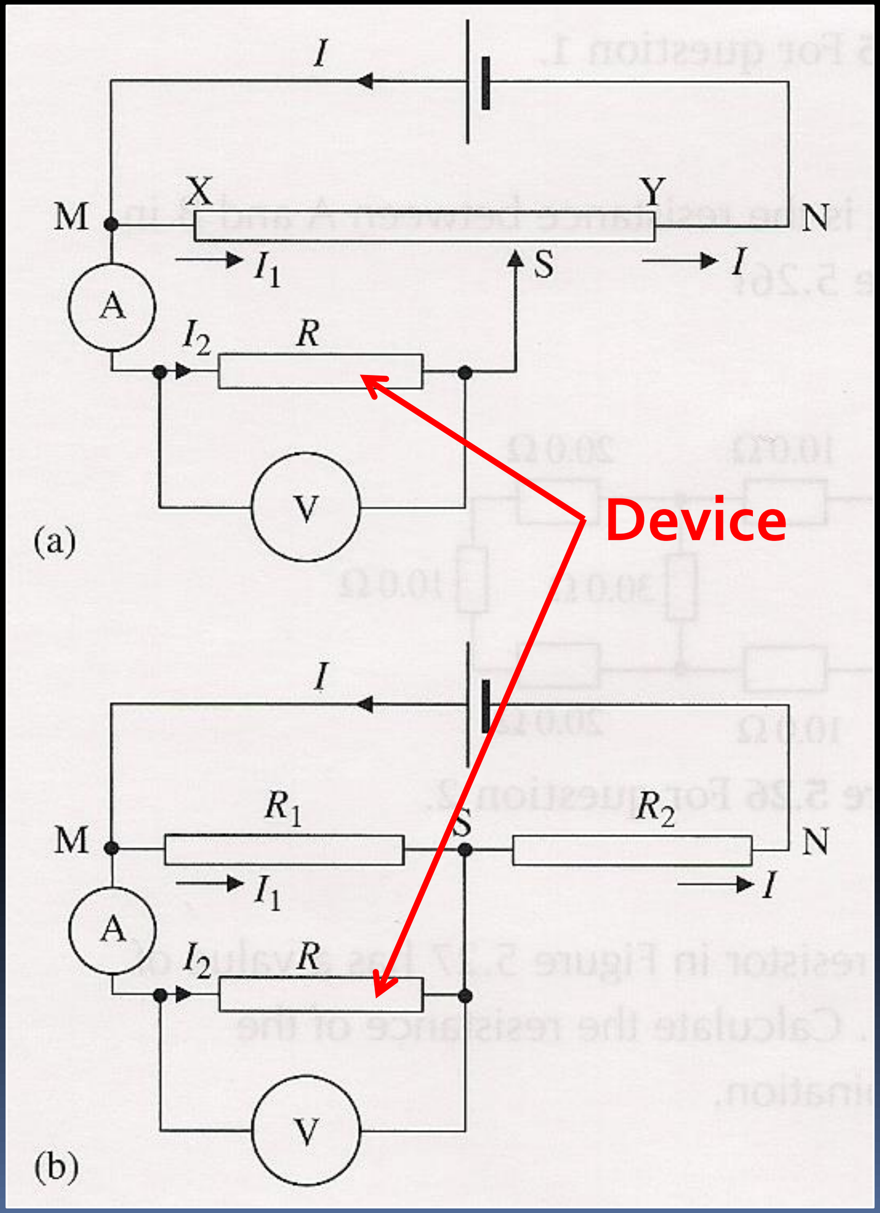
Ammeters and Voltmeters

- Voltmeters measure volts which is the unit for potential difference
- ***Voltmeters must be installed in parallel with the circuit***
- ***An ideal voltmeter will have infinite resistance***
  - *Otherwise, there would be current through it and would give a lower voltage reading than actual*



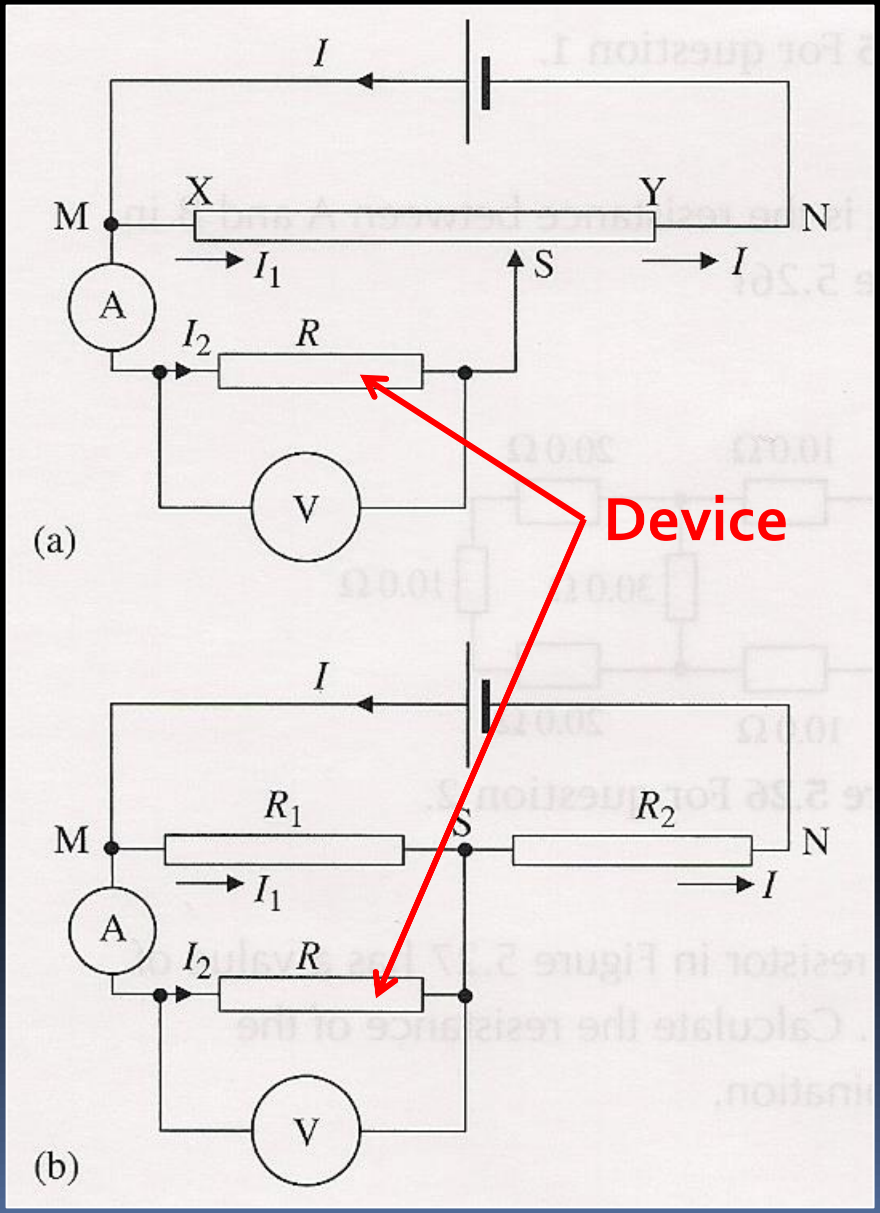
Potential Divider

- The XY bar is a resistor, but the connection at S splits the XY resistor into two pieces, one in parallel to the device and one in series with the circuit.



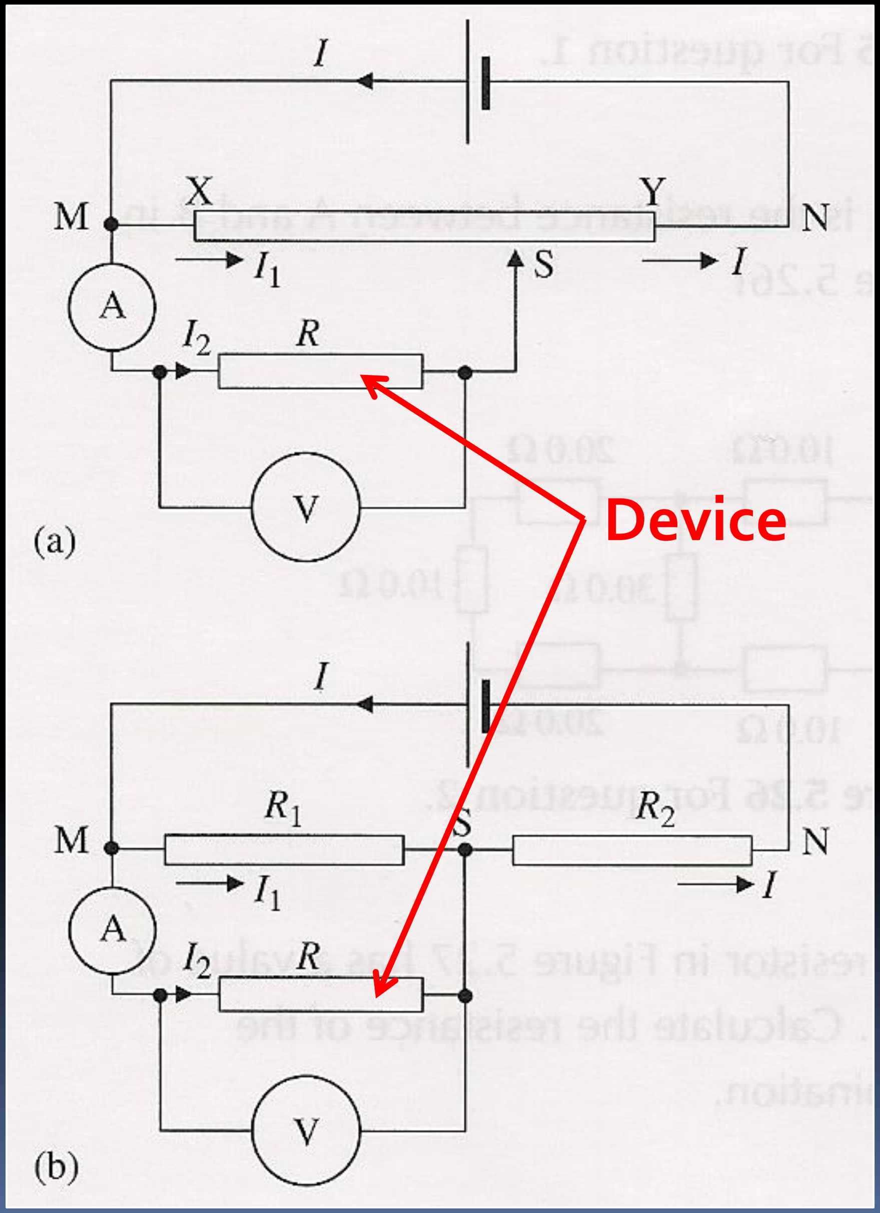
Potential Divider

- Diagram (b) illustrates how the XY resistor is effectively split in two
  - The resistance of R_1 and R_2 add to the total resistance of XY
  - R_1 is the portion in parallel with the device
  - R_2 is in series with the parallel circuit



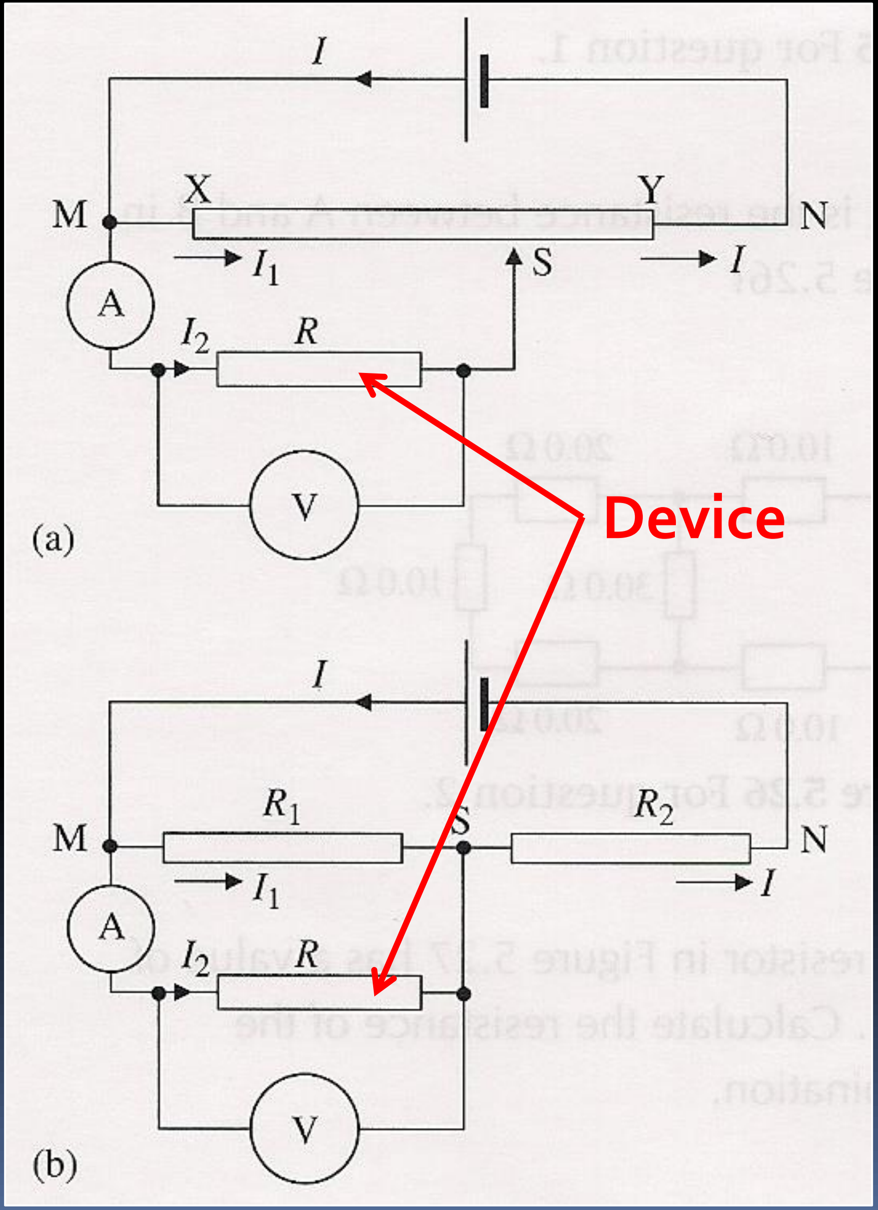
Potential Divider

- By changing the amount of resistance in parallel to the device, we can create different currents and voltage drops in the device
  - The voltage across the device drops to zero when the S slider is at position X



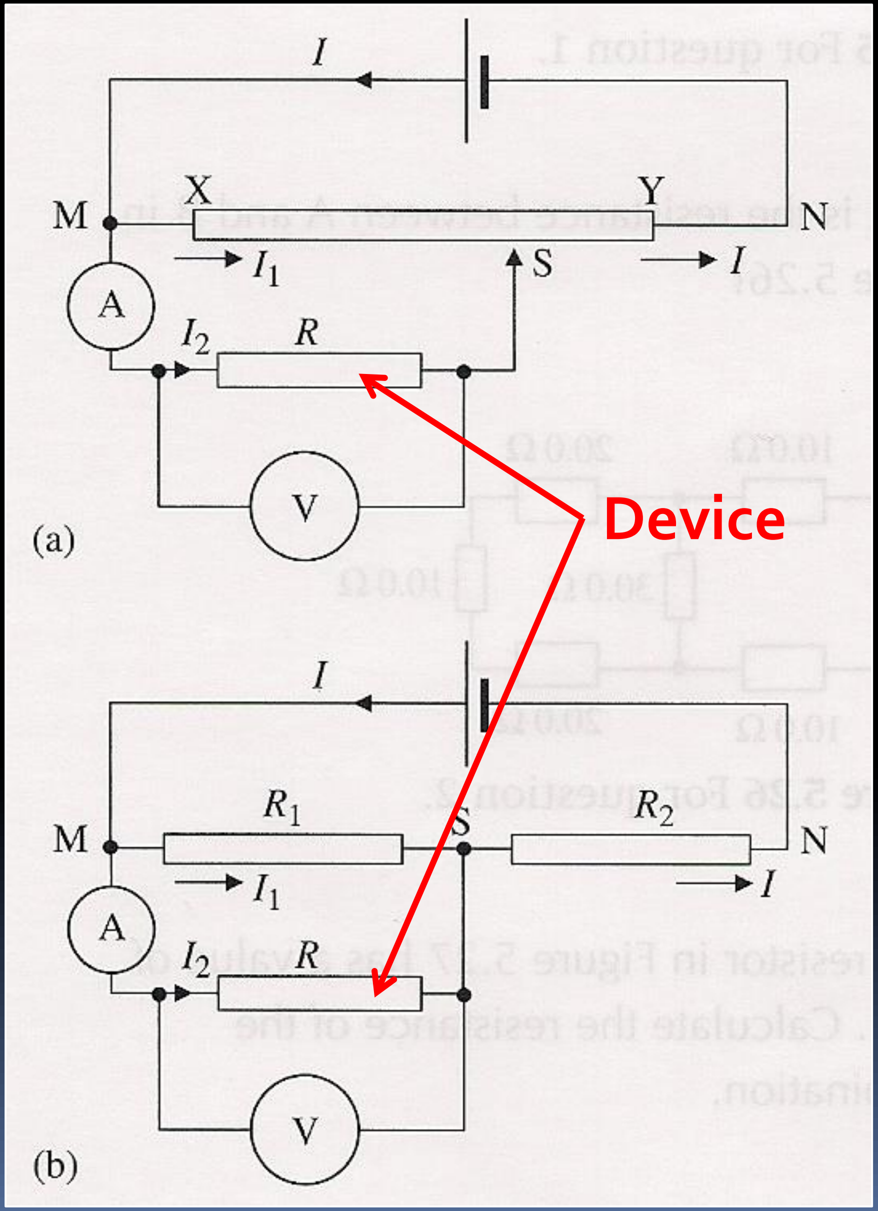
Potential Divider

- By changing the amount of resistance in parallel to the device, we can create different currents and voltage drops in the device
  - The voltage across the device increases to maximum (equal to the emf of the power source) when the S slider is at position Y

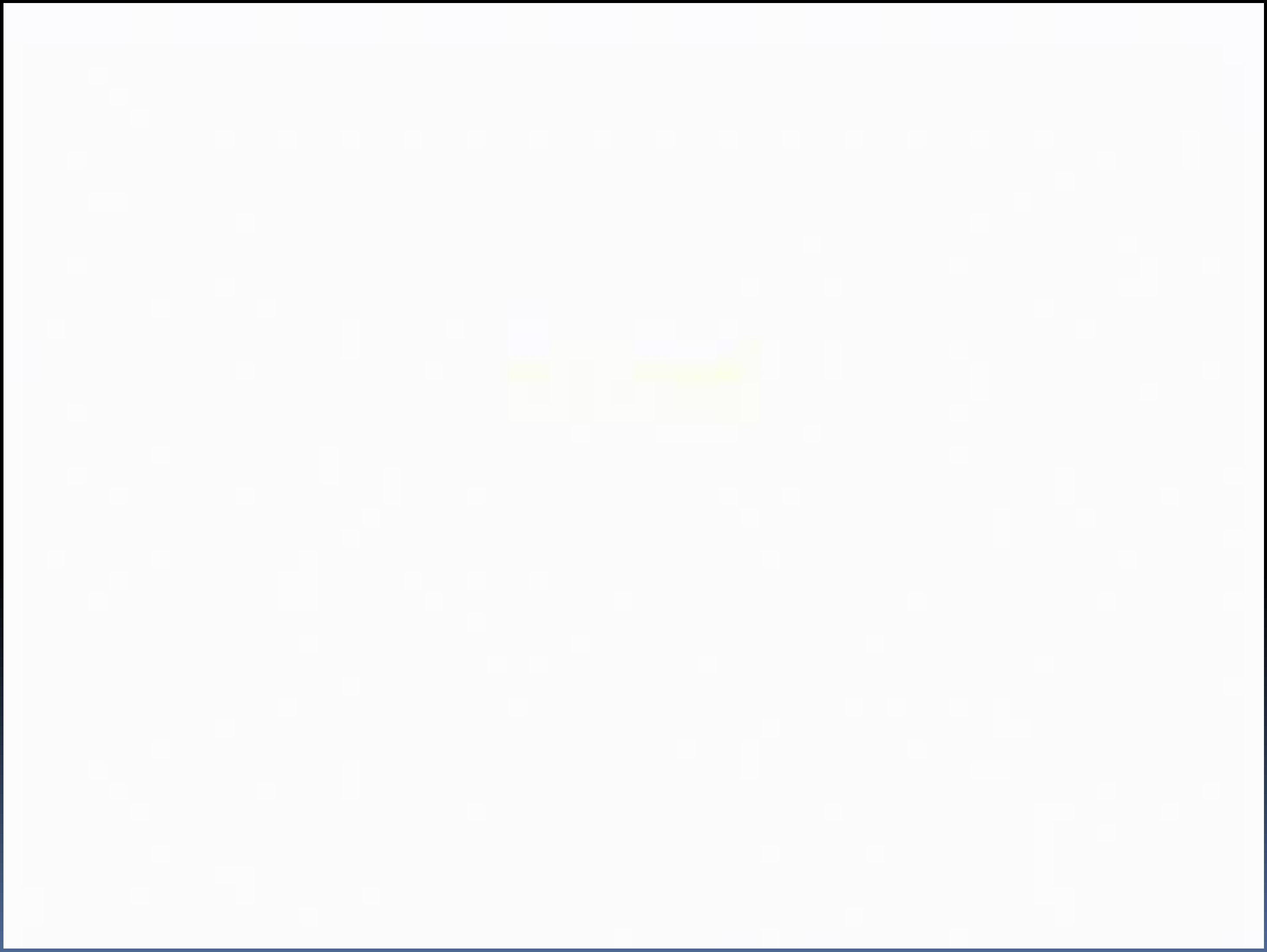


Potential Divider

- ***You will have a graded exercise on potential dividers in the near future!!!***



Electrical Circuits - Ohm's Law - Summary



Understandings:

- Circuit diagrams
- Kirchhoff's circuit laws
- Heating effect of current and its consequences
- Resistance expressed as $R\ I = V$
- Ohm's law
- Resistivity
- Power dissipation

Applications And Skills:

- Drawing and interpreting circuit diagrams
- Identifying ohmic and non-ohmic conductors through a consideration of the V/I characteristic graph
- Solving problems involving potential difference, current, charge, Kirchhoff's circuit laws, power, resistance and resistivity

Applications And Skills:

- Investigating combinations of resistors in parallel and series circuits
- Describing ideal and non-ideal ammeters and voltmeters
- Investigating one or more of the factors that affect resistance experimentally

Applications And Skills:

- Describing practical uses of potential divider circuits, including the advantages of a potential divider over a series resistor in controlling a simple circuit

Essential Idea:

- One of the earliest uses for electricity was to produce light and heat. This technology continues to have a major impact on the lives of people around the world.

QUESTIONS?

Homework

#1-20

STOPPED HERE 4/21/15