ELECTRICITY

IB PHYSICS | COMPLETED NOTES

Electrical Properties

IB PHYSICS | ELECTRICITY

Remember back...

What is potential energy?

Stored Energy

Voltage

Voltage is the Potential Energy __Difference__ between two locations

Voltage = Potential Difference
p.d.

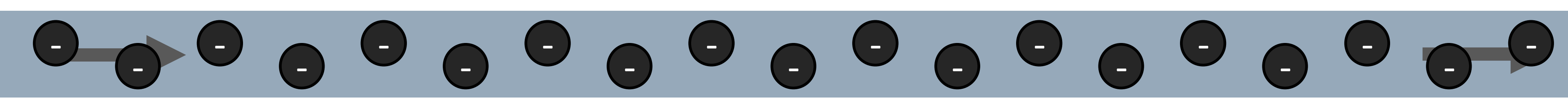
Symbol: V	Unit: Volts [V]

Current

The rate at which charges move through a conductor

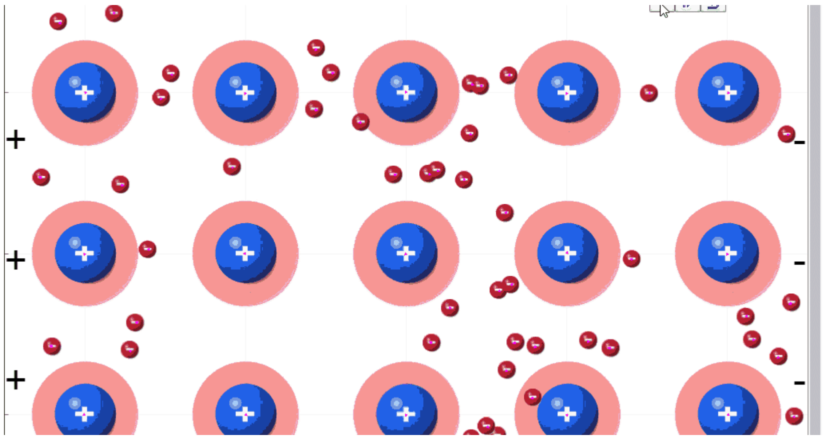
Flow of Electrons

Symbol: I	Unit: Amperes [A]

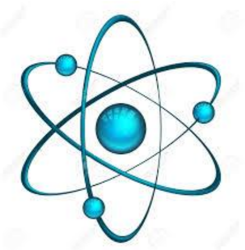


Current

Why do the electrons flow instead of protons or neutrons?



Outside of the atom so they are more easily transferred



Resistance

How difficult it is for electrons to flow

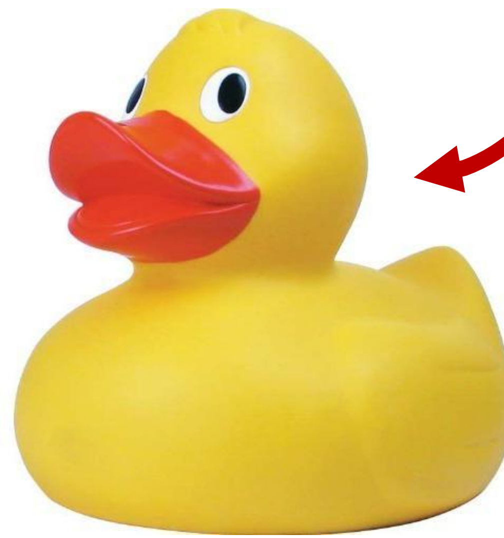
Symbol: R	Unit: Ohms [Ω]

Which one has more resistance for water flow?

Conductors and Insulators

Conductors have a ____low____ resistance

Insulators have a ____high____ resistance



Electrical Properties

Property	What is it?	Symbol	Unit
Voltage	Potential Difference	V	Volts [V]
Current	The rate at which the charges move through wire	I	Amps [A]
Resistance	How hard it is for current to flow through a conductor	R	Ohms [Ω]

How are they Related?

Voltage

Current

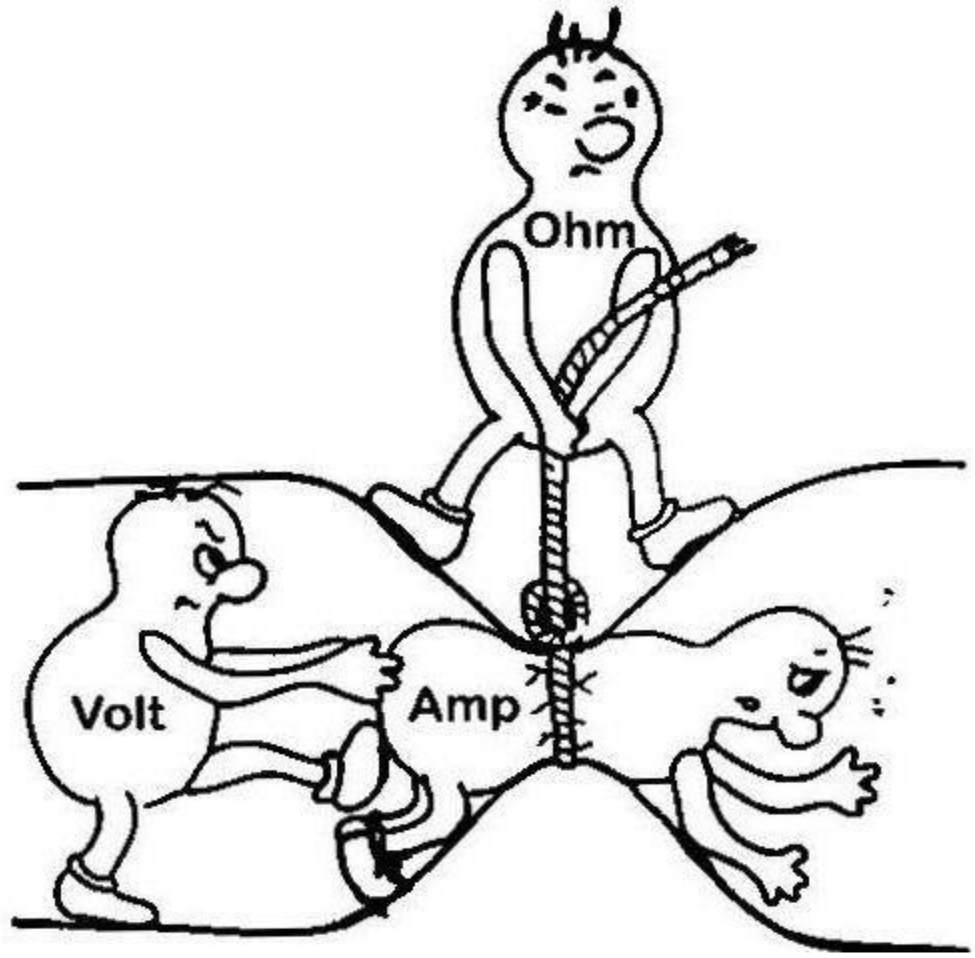
$$V \propto I$$

Resistance

Current

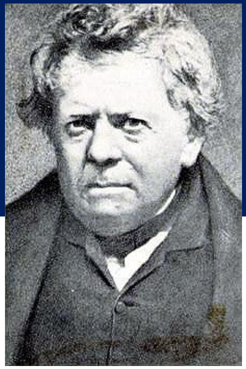
$$R \propto {}^{1}/_{I}$$

How are they Related?

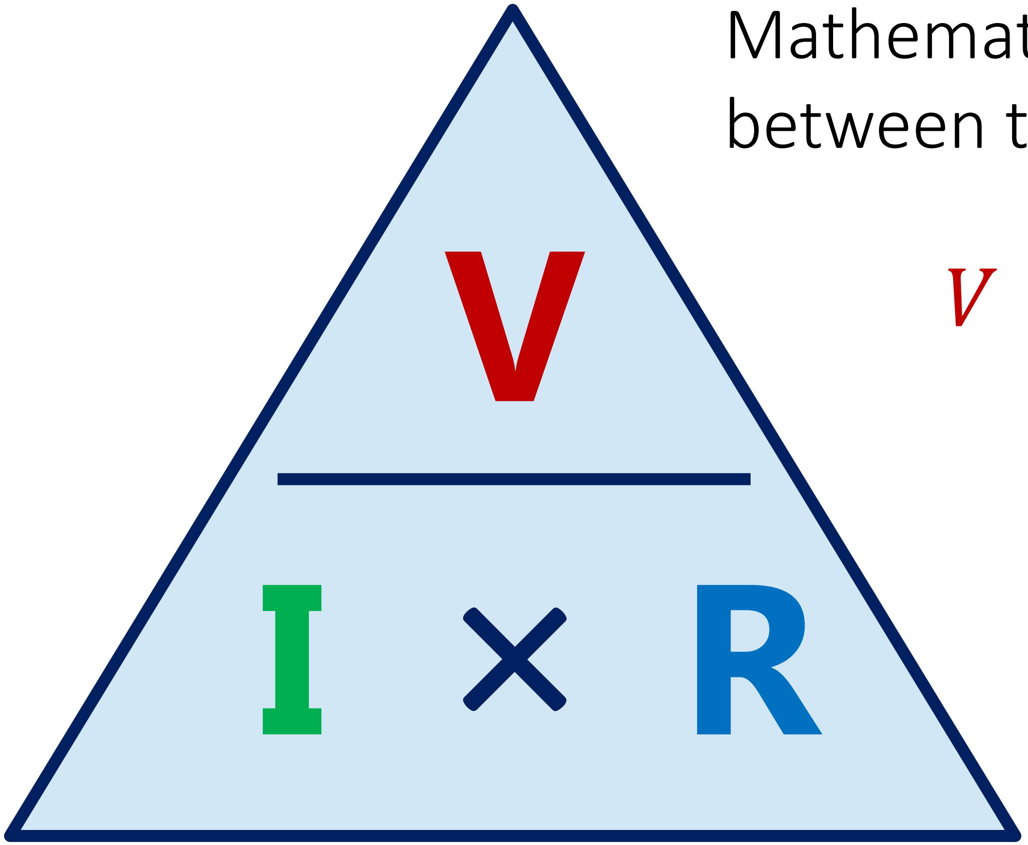


Memorize

Ohm's Law



Mathematical relationship between the electrical properties



$$V = I \times R$$

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

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

IB Physics Data Booklet

Sub-topic 5.1 – Electric fields	Sub-topic 5.2 – Heating effect of electric currents
$I = \frac{\Delta q}{\Delta t}$ $F = k\frac{q_1 q_2}{r^2}$ $k = \frac{1}{4\pi\varepsilon_0}$ $V = \frac{W}{q}$ $E = \frac{F}{q}$ $I = nAvq$	Kirchhoff's circuit laws: $\Sigma V = 0$ (loop) $\Sigma I = 0$ (junction) $R = \frac{V}{I}$ $P = VI = I^2 R = \frac{V^2}{R}$ $R_{\text{total}} = R_1 + R_2 + \cdots$ $\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$ $\rho = \frac{RA}{L}$
Sub-topic 5.3 – Electric cells	**Sub-topic 5.4 – Magnetic effects of electric currents**
$\varepsilon = I(R + r)$	$F = qvB\sin\theta$ $F = BIL\sin\theta$

Voltage Current Resistance Power

Try this... $R = \frac{V}{I}$

What is the voltage of a battery that produces a current of 1.5 amps through a 3 ohm resistor?

$I = 1.5\ \mathrm{A}$

$R = 3\ \Omega$

$V = ??$

$$V = I \times R = 1.5 \times 3 = 4.5\ \mathrm{V}$$

What resistance would produce a current of 5 amps from a 120-volt power source?

$I = 5\ \mathrm{A}$

$V = 120\ \mathrm{V}$

$R = ??$

$$R = \frac{V}{I} = \frac{120}{5} = 24\ \Omega$$

Remember Power?

Symbol: P	Unit: Watts [W]

New Equations:

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

$$V = IR$$

$$P = VI$$

$$P = I^2R$$

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

IB Physics Data Booklet

Sub-topic 5.1 – Electric fields	Sub-topic 5.2 – Heating effect of electric currents
$I = \frac{\Delta q}{\Delta t}$ $F = k\frac{q_1 q_2}{r^2}$ $k = \frac{1}{4\pi\varepsilon_0}$ $V = \frac{W}{q}$ $E = \frac{F}{q}$ $I = nAvq$	Kirchhoff's circuit laws: $\Sigma V = 0$ (loop) $\Sigma I = 0$ (junction) $R = \frac{V}{I}$ $P = VI = I^2R = \frac{V^2}{R}$ $R_{\text{total}} = R_1 + R_2 + \cdots$ $\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$ $\rho = \frac{RA}{L}$
Sub-topic 5.3 – Electric cells	**Sub-topic 5.4 – Magnetic effects of electric currents**
$\varepsilon = I(R + r)$	$F = qvB\sin\theta$ $F = BIL\sin\theta$

Voltage | Current | Resistance | Power

Calculating Power

A blender runs on 5 amps of current on a 120 V. How much power is it drawing?

$I = 5\ \text{A}$

$V = 120\ \text{V}$

$$P = VI = (120)(5)$$

$$= \mathbf{600\ W}$$

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

Different Devices… Different Power

Common Appliances	Estimated Watts
Blender	300-1000
Microwave	1000-2000
Waffle Iron	800-1500
Toaster	800-1500
Hair Dryer	1000-1875
TV 32" LED/LCD	50
TV 42" Plasma	240
Blu-Ray or DVD Player	15
Video Game Console (Xbox / PS4 / Wii)	40-140

What do you notice?

Heat

Lesson Takeaways

- ❑ I can describe the properties of Voltage, Current, Resistance, and Power
- ❑ I can use Ohm's Law to mathematically relate these electrical properties and solve for an unknown

Circuits

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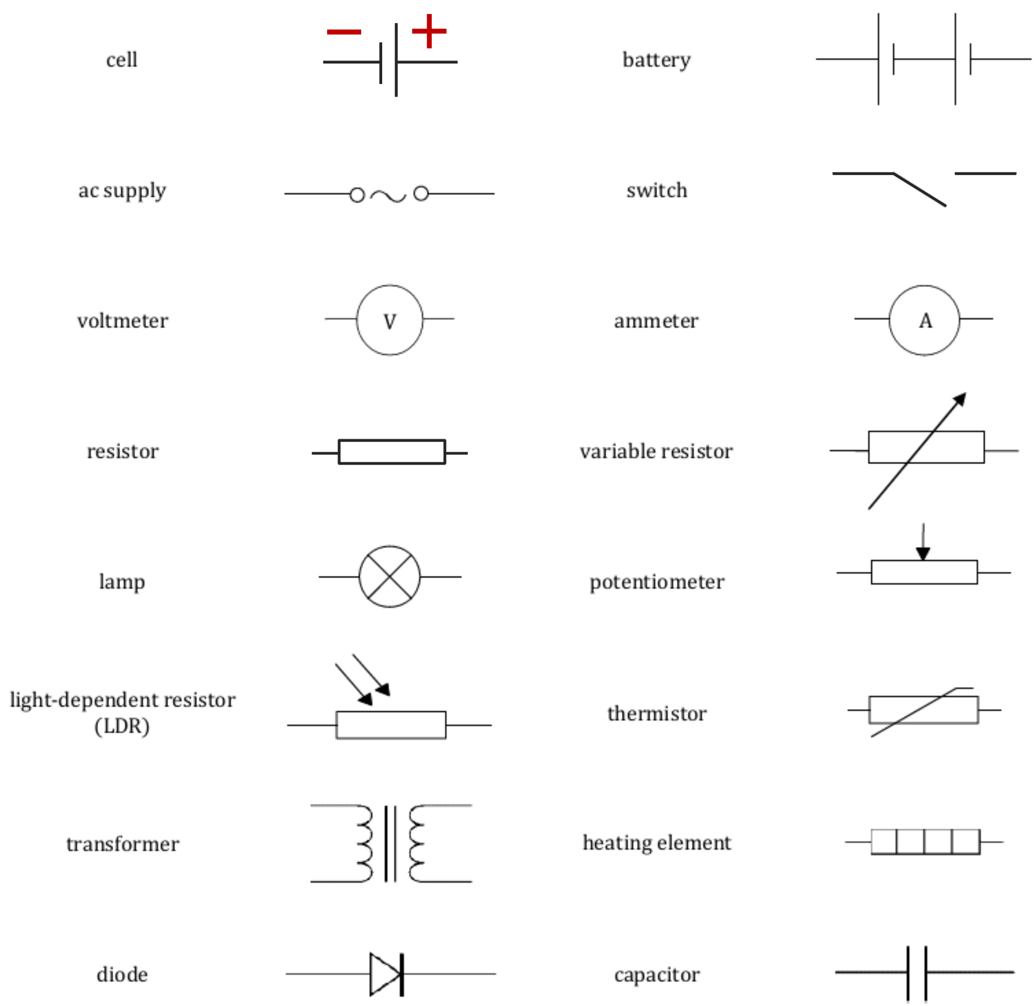
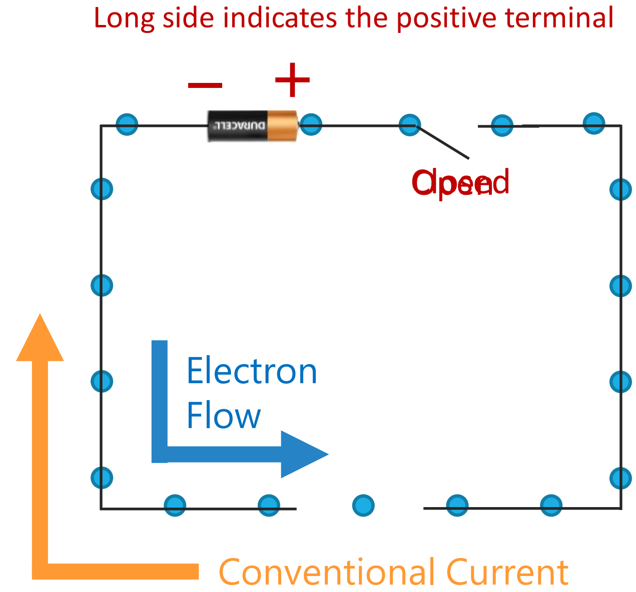
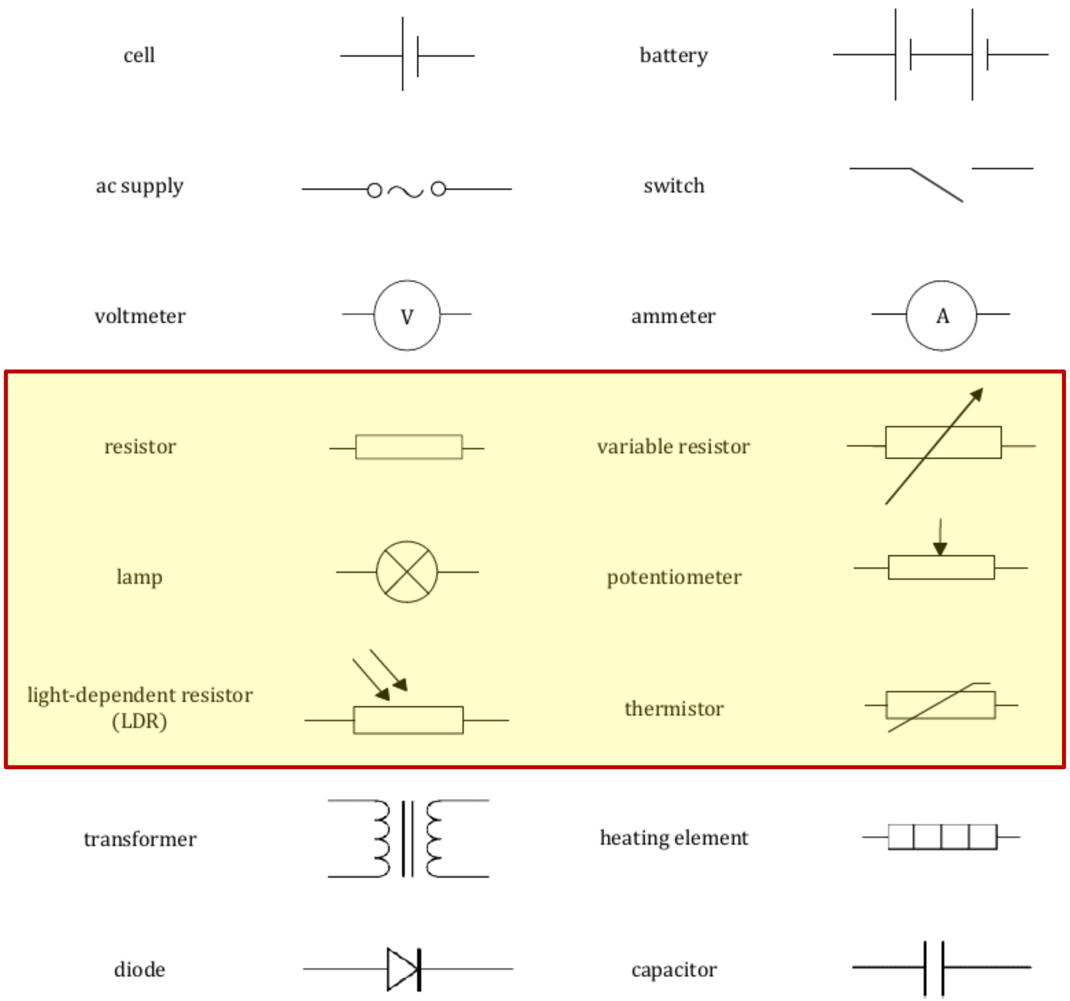
Circuits





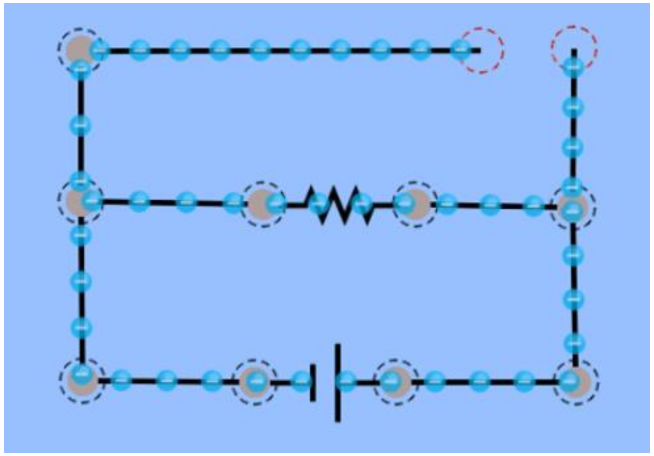
*Ben Franklin defined current as the flow of positive charges

Resistance in a Circuit



There are many different components that act as resistors when placed in a circuit

Resistance and Electron Flow

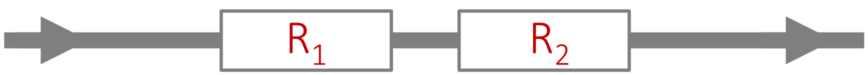


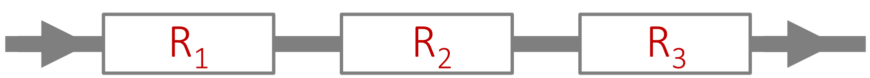
short circuit

Electrons will follow the path of <u>least resistance</u>

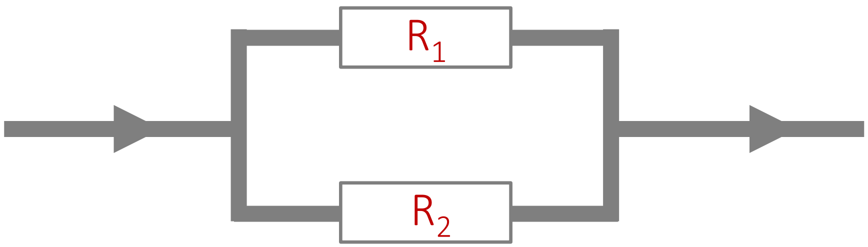
Combining Components

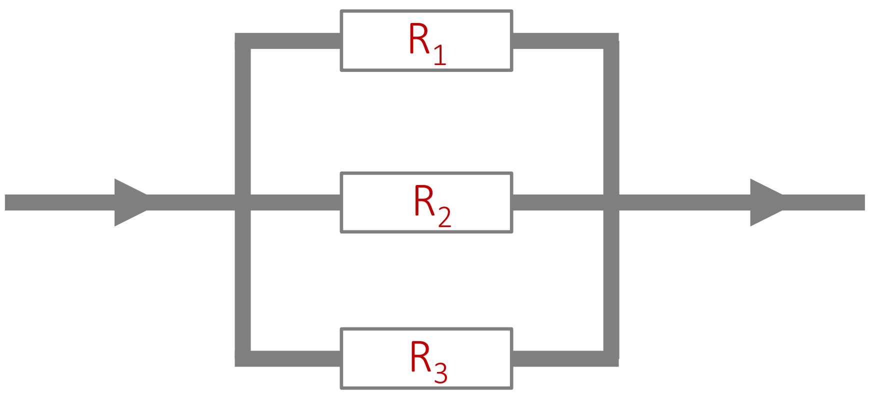
Series





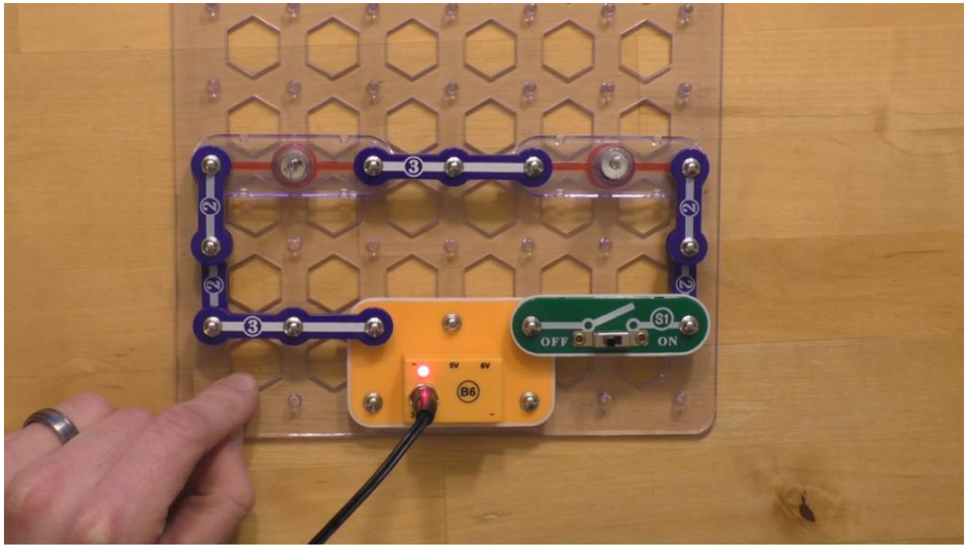
Parallel





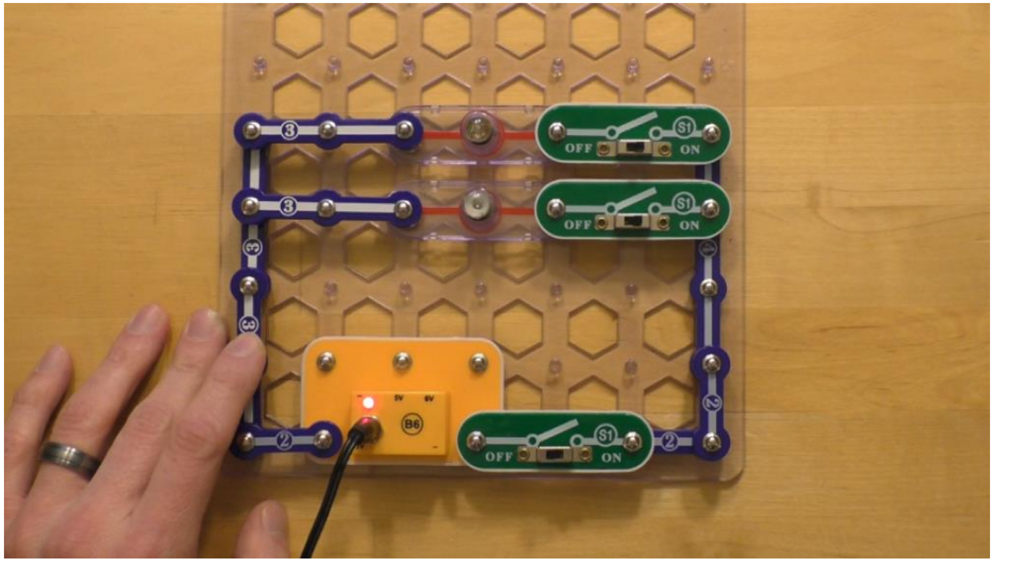
Connecting in Series

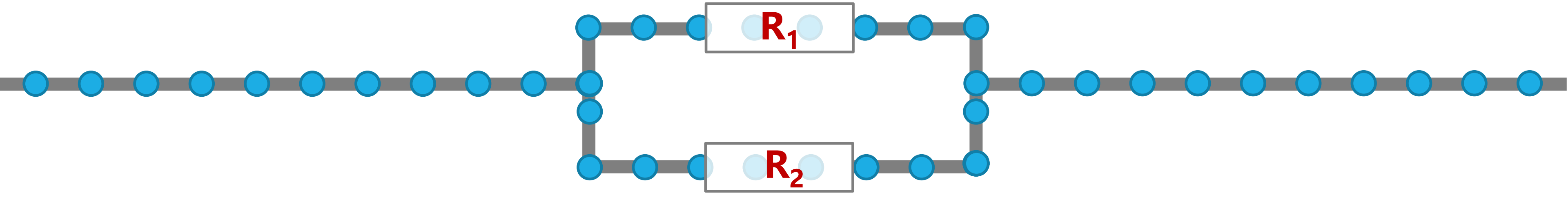
- Components in one single pathway
- Current flows the same through everything



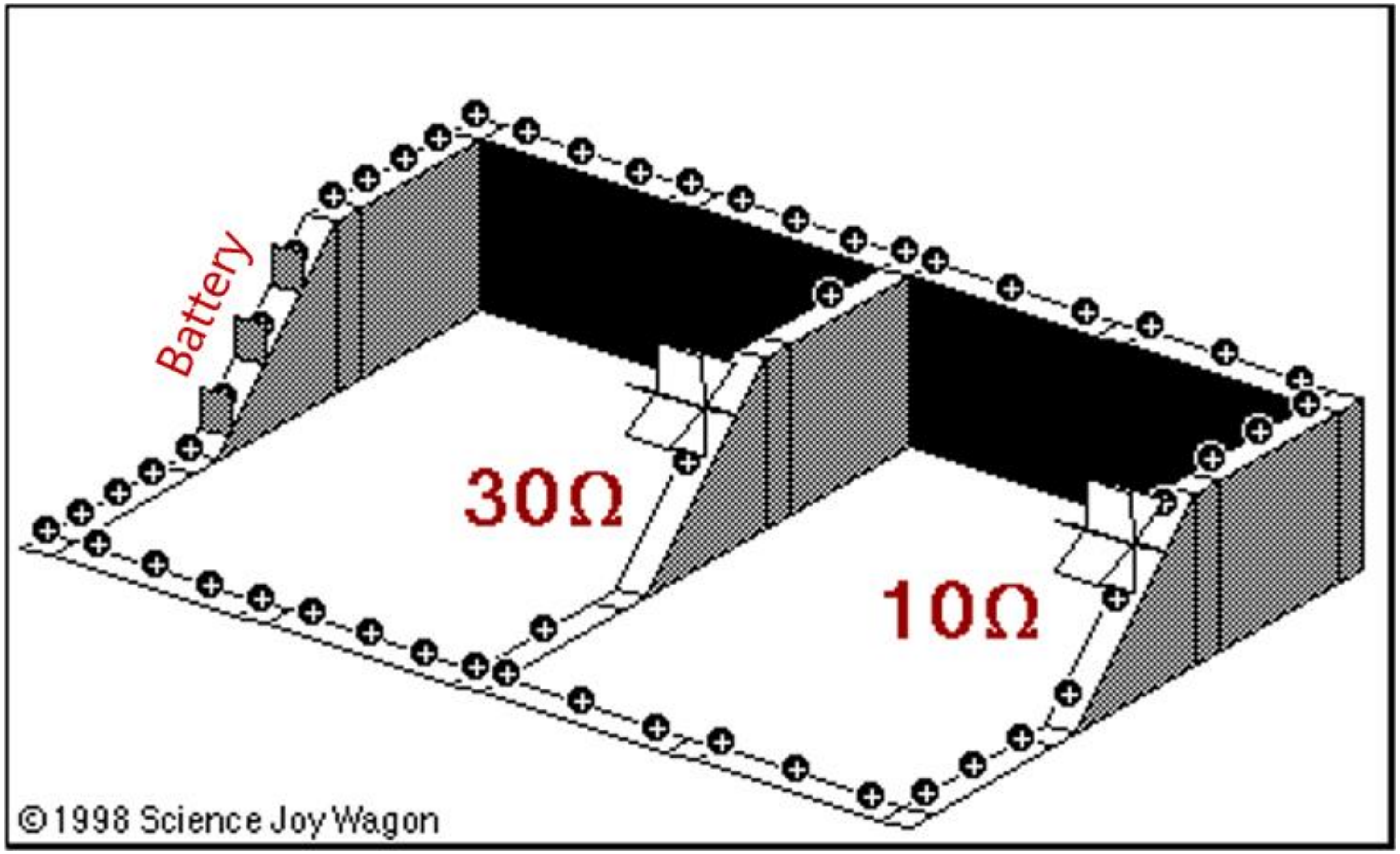
Connecting in Parallel

- Separate branches
- Current splits up between the different pathways





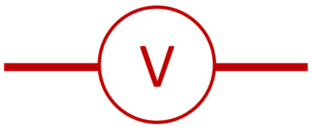
Water Flow Model



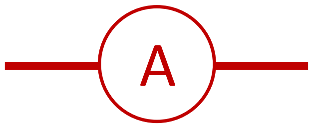
Measuring Circuits

When we measure **voltage** or **current** in a circuit, we need to connect our instrumentation in the right way

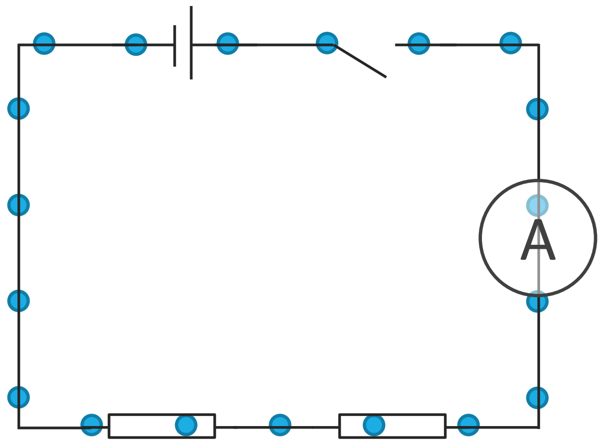
Voltmeter



Ammeter



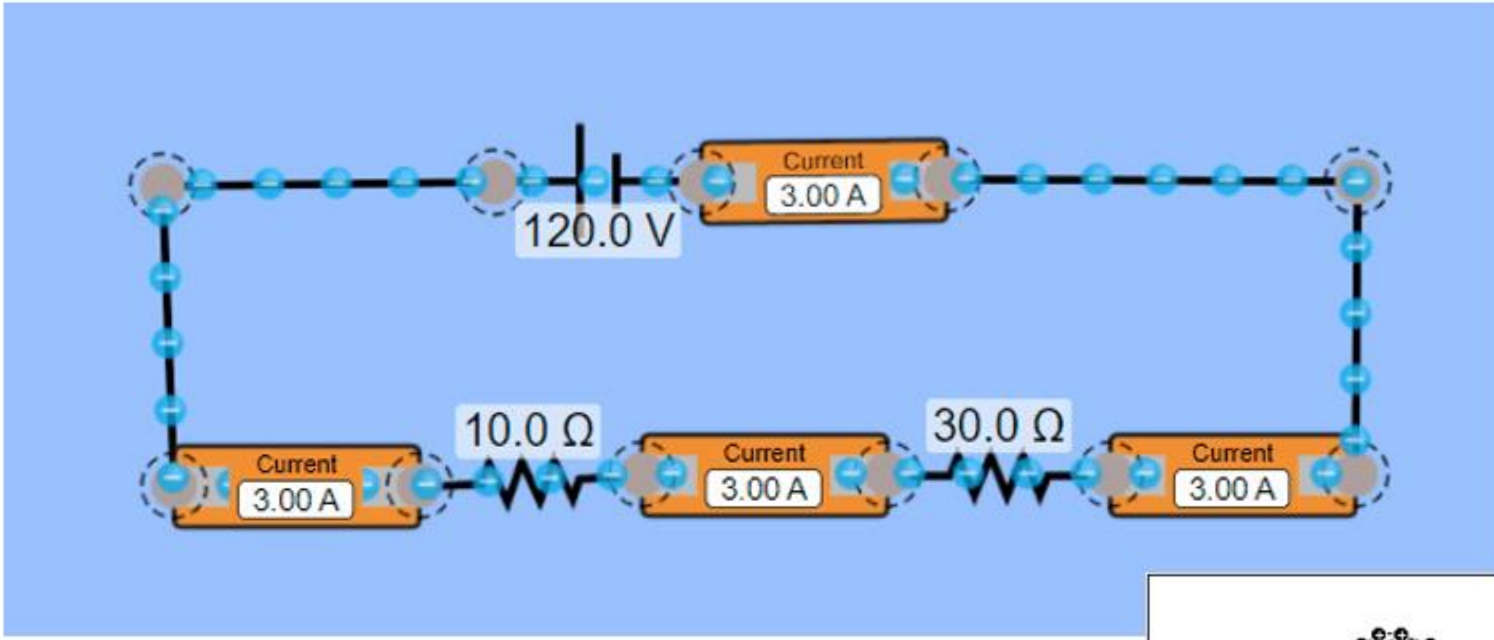
Ammeter

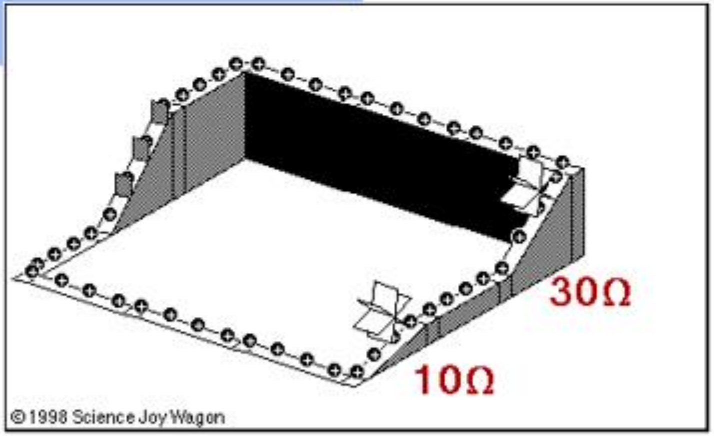


Hooked up in ___series___ with the component being measured

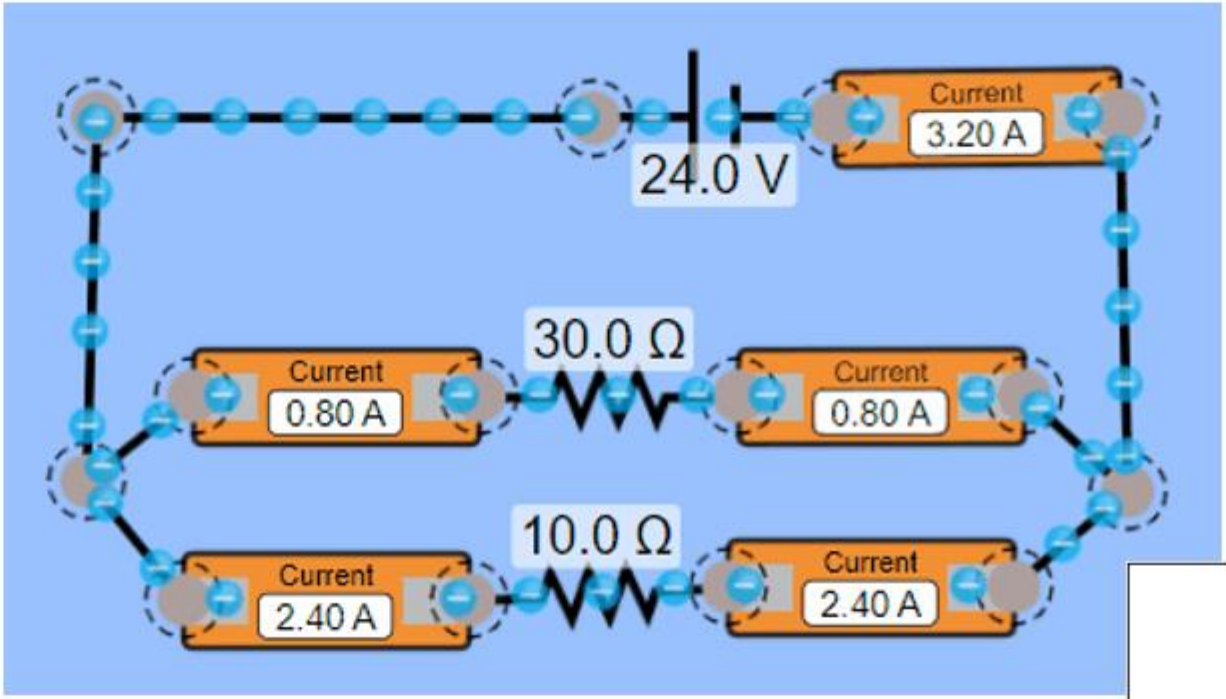
To measure the current, the current must flow through the ammeter

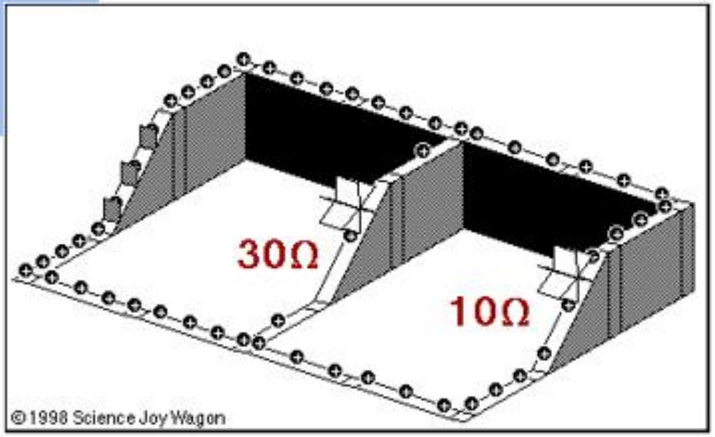
Measuring Current



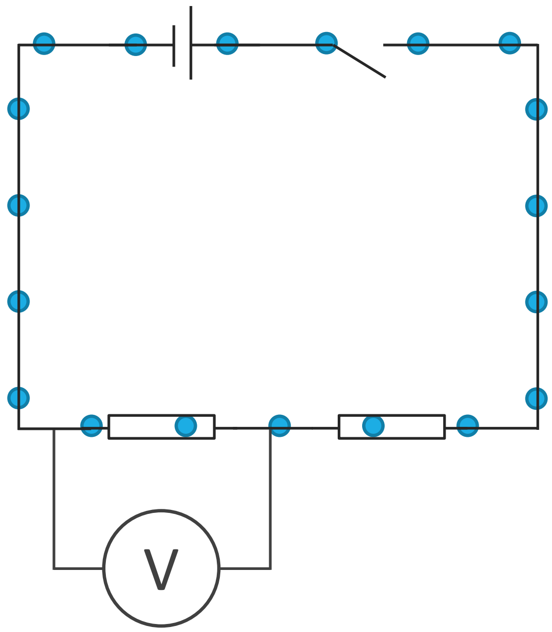


Measuring Current





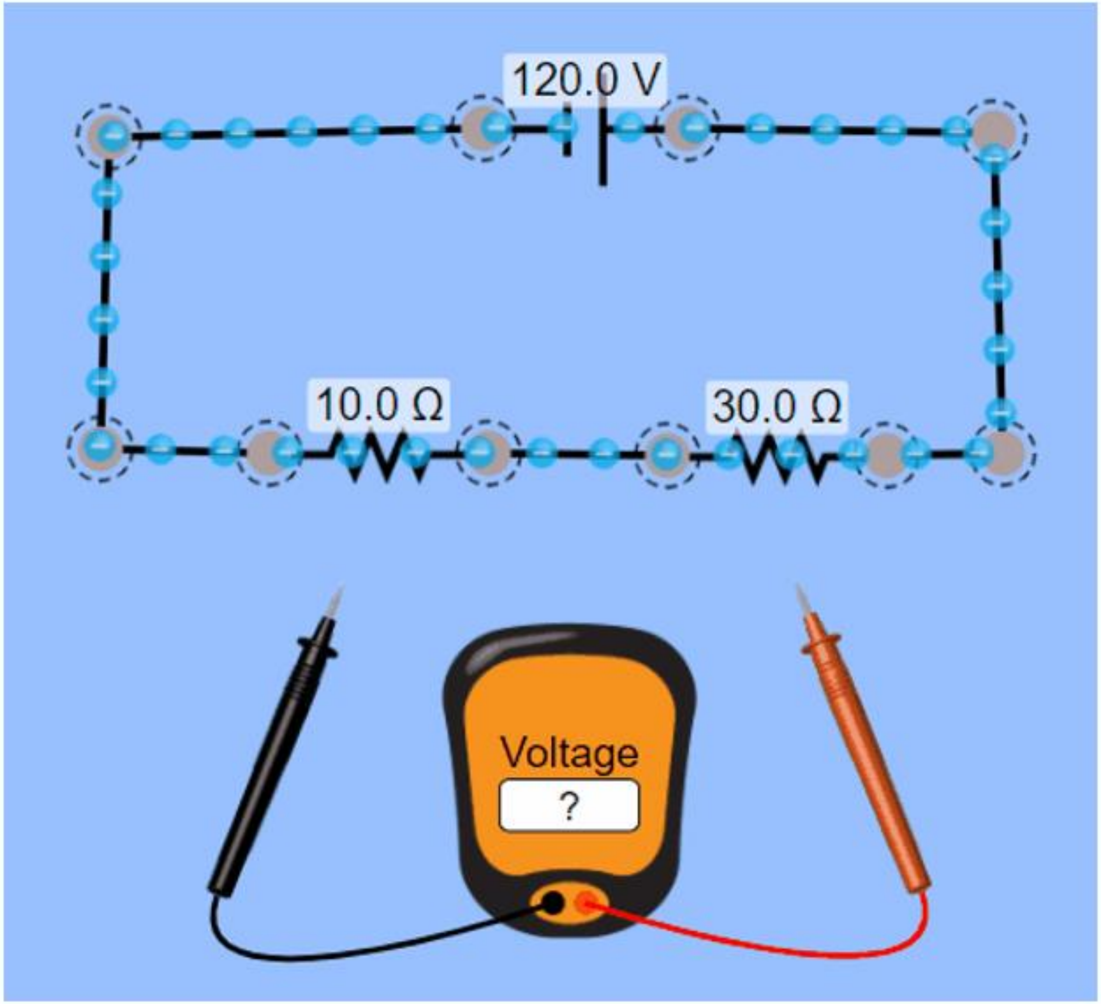
Voltmeter

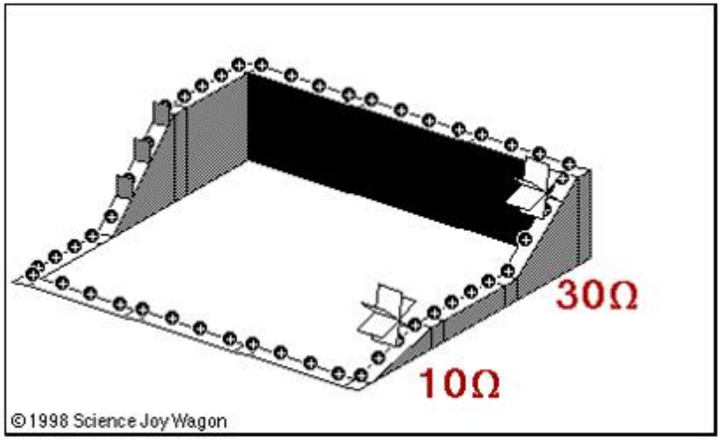


Hooked up in ___parallel___ with the component being measured

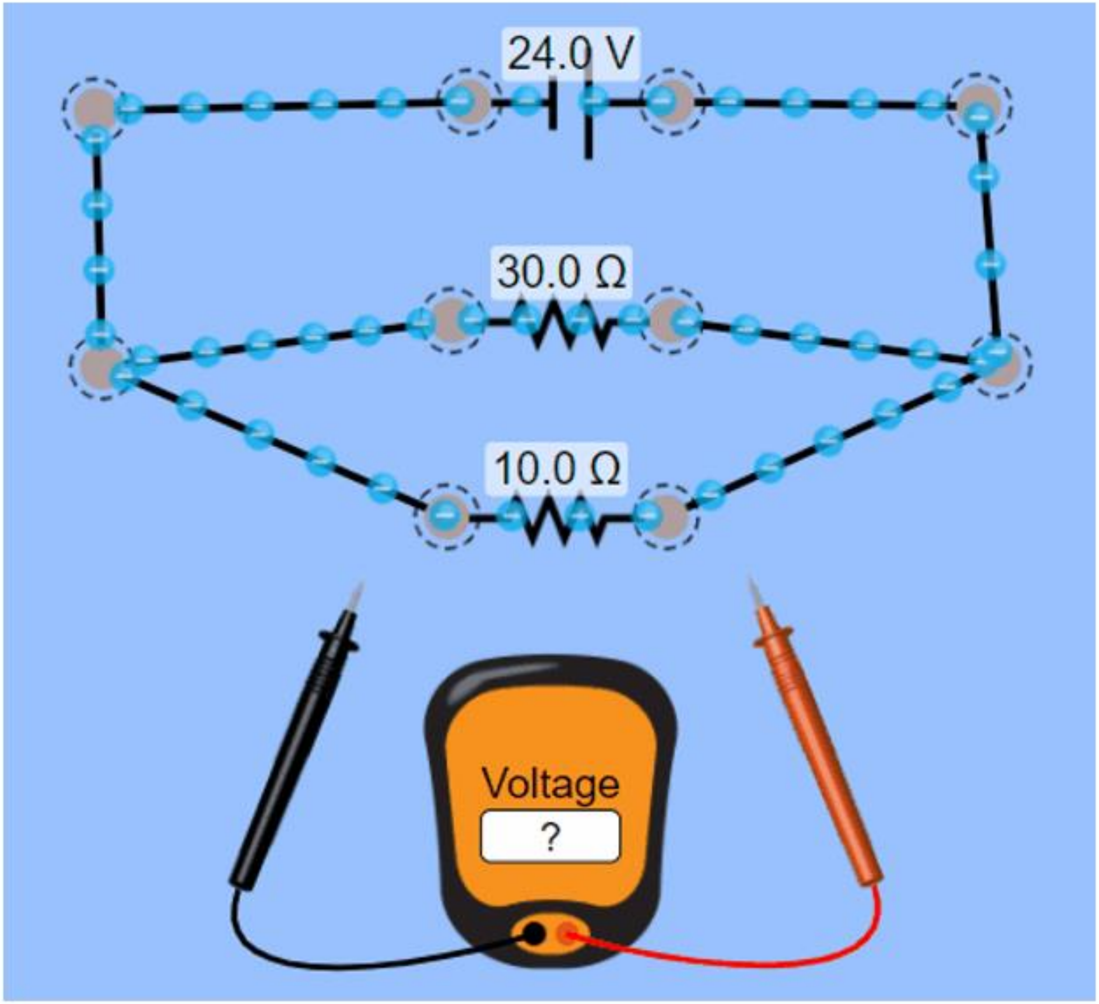
To measure the potential difference (voltage) a voltmeter needs to connect to two locations

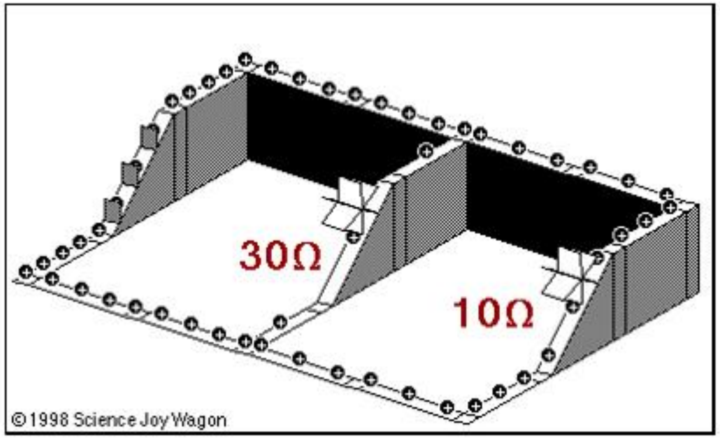
Measuring Voltage





Measuring Voltage





Lesson Takeaways

- ❑ I can describe the direction of conventional current compared to the movement of charges through a circuit
- ❑ I can identify component combinations as parallel or series
- ❑ I can describe how current flows through parallel and series resistors
- ❑ I can describe the set up to measure current and voltage in a circuit

Resistivity

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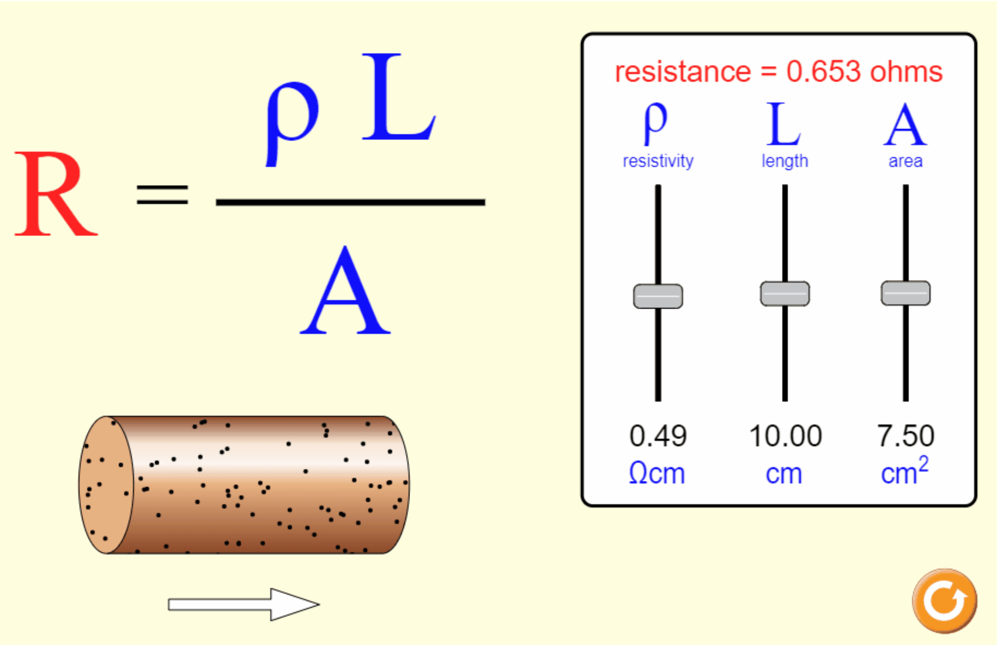
Resistance

What factors affect the resistance of a wire?

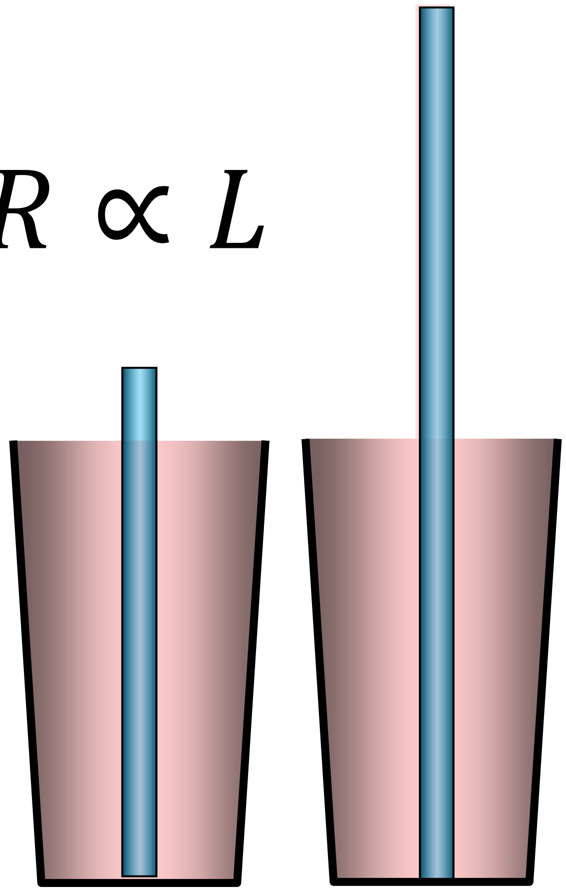
- Cross-sectional Area
- Length
- Material

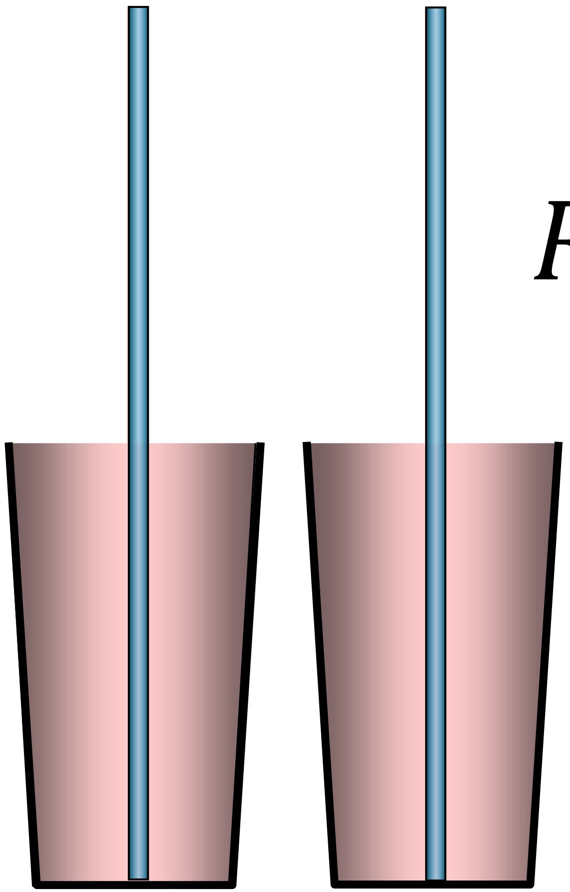


Resistance

Imagine that you are testing the resistance of a straw while drinking a milkshake…

$$R \propto L$$





$$R \propto \frac{1}{A}$$

Calculating Resistance

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

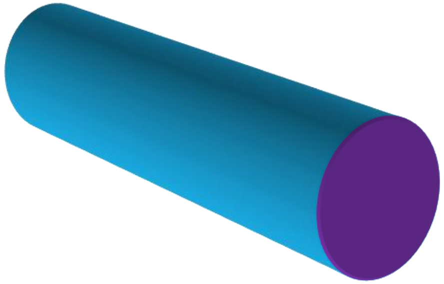
R → Resistance [Ω]

L → Length [m]

A → Area [m^2]

ρ → Resistivity [Ωm]

$$A = \pi r^2$$



IB Physics Data Booklet

Sub-topic 5.1 – Electric fields	Sub-topic 5.2 – Heating effect of electric currents
$I = \frac{\Delta q}{\Delta t}$ $F = k\frac{q_1 q_2}{r^2}$ $k = \frac{1}{4\pi\varepsilon_0}$ $V = \frac{W}{q}$ $E = \frac{F}{q}$ $I = nAvq$	Kirchhoff's circuit laws: $\Sigma V = 0$ (loop) $\Sigma I = 0$ (junction) $R = \frac{V}{I}$ $P = VI = I^2R = \frac{V^2}{R}$ $R_{\text{total}} = R_1 + R_2 + \cdots$ $\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$ $\rho = \frac{RA}{L}$
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$\varepsilon = I(R + r)$	$F = qvB\sin\theta$ $F = BIL\sin\theta$

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

Resistivity

Resistivity ρ changes depending on the material used.

Conductor Material	Resistivity (Ohm meters @ 20 °C)
Silver	1.64×10^{-8}
Copper	1.72×10^{-8}
Aluminum	2.83×10^{-8}
Tungsten	5.50×10^{-8}
Nickel	7.80×10^{-8}
Iron	12.0×10^{-8}
Constantan	49.0×10^{-8}
Nichrome II	110×10^{-8}

Lower Resistivity → Better Conductor

Resistivity – Try This #1

Conductor Material	Resistivity (Ohm meters @ 20 °C)
Silver	1.64×10^{-8}
Copper	1.72×10^{-8}
Aluminum	2.83×10^{-8}
Tungsten	5.50×10^{-8}
Nickel	7.80×10^{-8}
Iron	12.0×10^{-8}
Constantan	49.0×10^{-8}
Nichrome II	110×10^{-8}

Calculate the resistance of a 1.8 m length of iron wire of with a diameter of 3 mm

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

L = 1.8 m

$\rho = 12.0 \times 10^{-8}\ \Omega m$

$A = \pi(0.003/2)^2 = 7.07 \times 10^{-6}\ m^2$

$$R = (12.0 \times 10^{-8}) \frac{(1.8)}{(7.07 \times 10^{-6})}$$

$$R = 0.0306\ \Omega$$

Resistivity – Try This #2

A current of 4 A flowed through a 75 m length of metal alloy wire of area 2.4 mm^2 when a p.d. of 12 V was applied across its ends. What was the resistivity of the alloy?

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

$$R = \frac{V}{I} = \frac{12}{4} = 3\ \Omega$$

$$L = 75\ \mathrm{m}$$

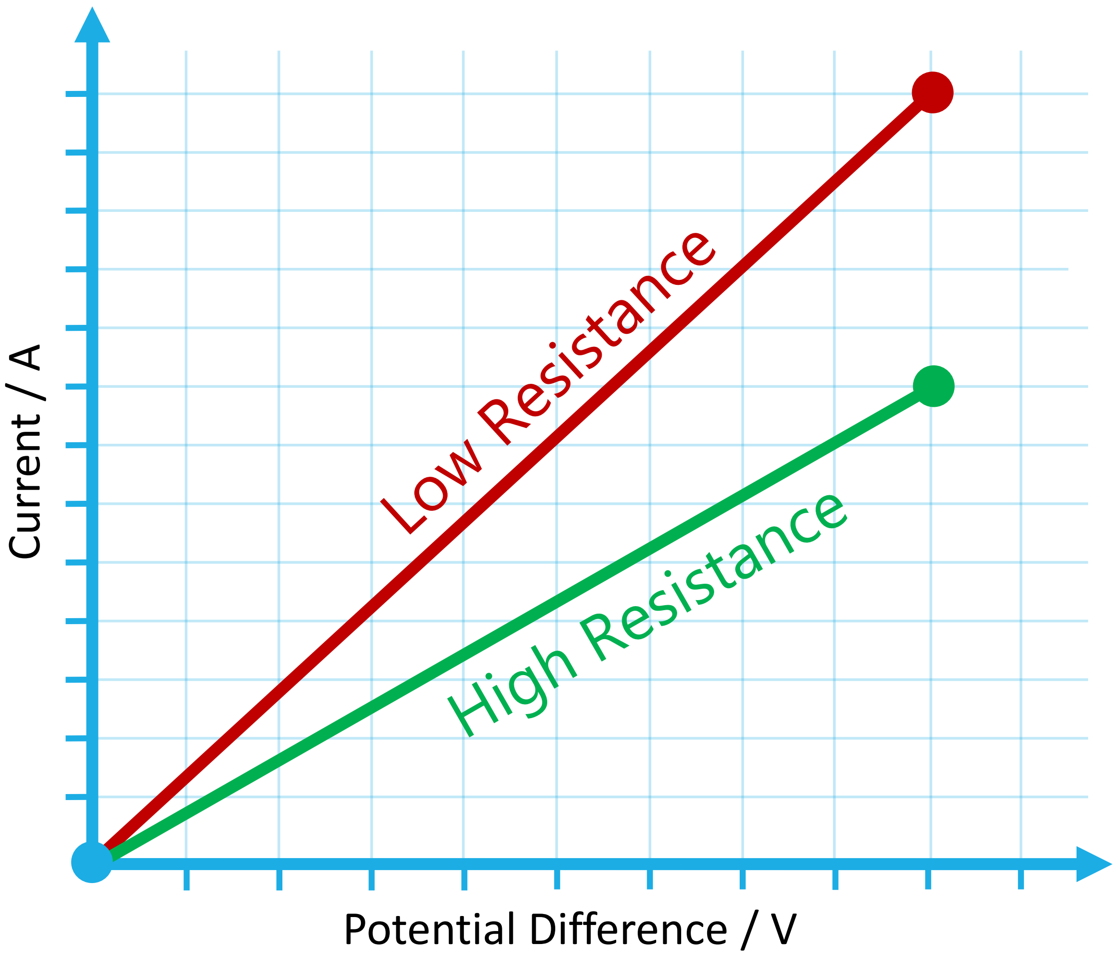
$$A = 2.4\ \mathrm{mm}^2 \times \left(\frac{1\ \mathrm{m}}{1000\ \mathrm{mm}}\right)^2$$

$$A = 2.4 \times 10^{-6}\ \mathrm{m}^2$$

$$\rho = \frac{(3)(2.4 \times 10^{-6})}{(75)}$$

$$= \mathbf{9.6 \times 10^{-8}\ \Omega m}$$

Graphing Ohm's Law

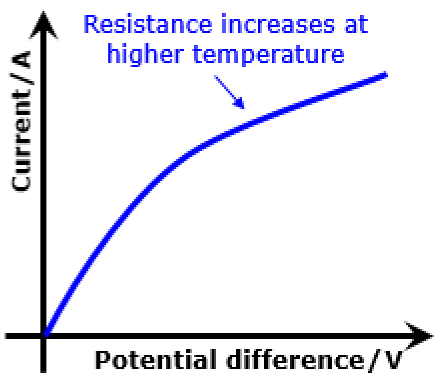


Linear Relationship means that our component is _____Ohmic_____

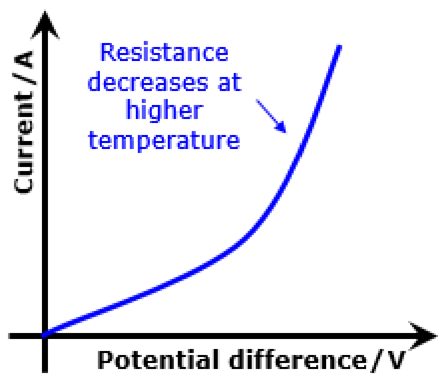
Resistance is constant

Graphing Ohm's Law

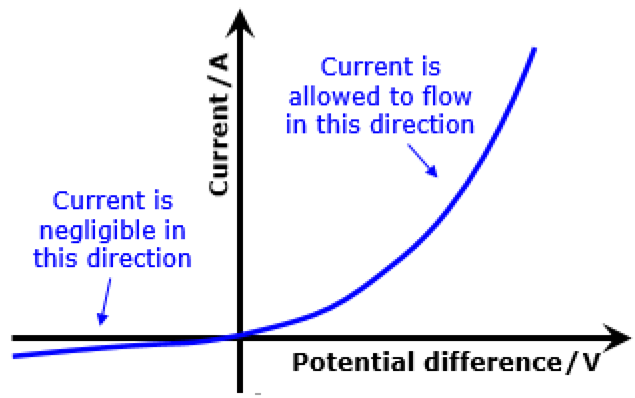
Many/most electrical resistors don't follow Ohm's Law all of the time… For example, incandescent light bulbs have much more resistance as they heat up



***I-V* Graph For A Filament Lamp**



***I-V* Graph For A Thermistor**



***I-V* Graph For A Semiconductor Diode**

Non-linear Relationship means that our component is _Non-ohmic_

Graphing Ohm's Law

Find V and R for the resistors X and Y when the current is 2A

X

V	4 V
I	2 A
R	2 Ω

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

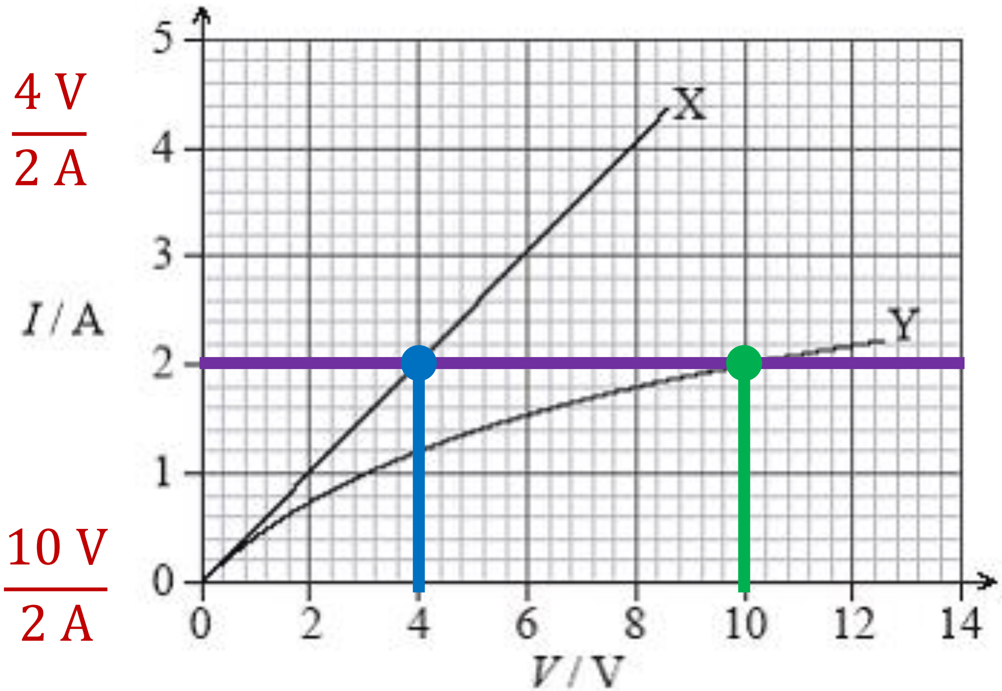
$$R = \frac{4\ V}{2\ A}$$

Y

V	10 V
I	2 A
R	5 Ω

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

$$R = \frac{10\ V}{2\ A}$$



Equivalent Resistance

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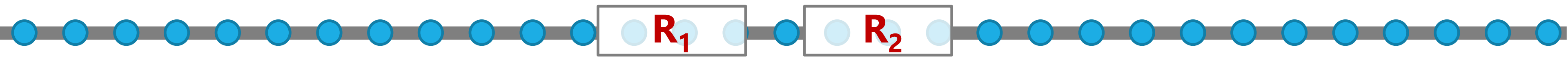
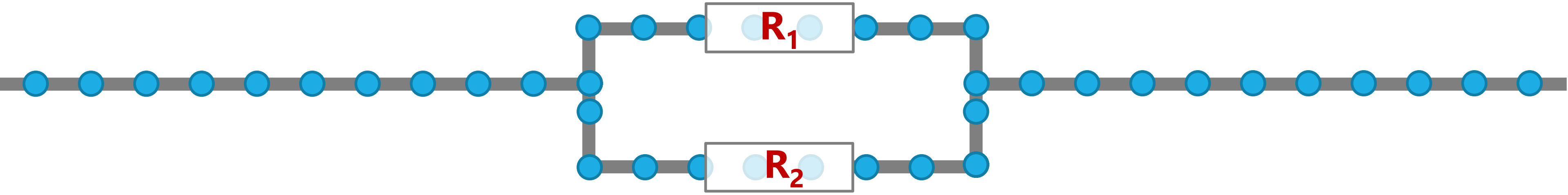
Series and Parallel

Series

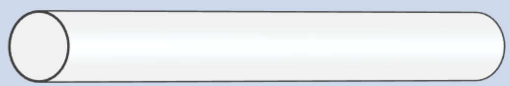
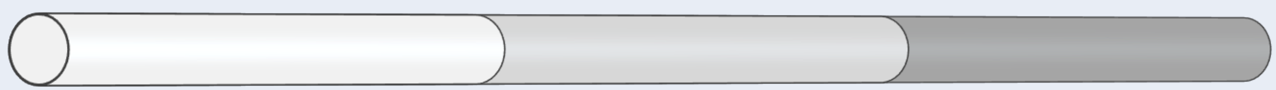
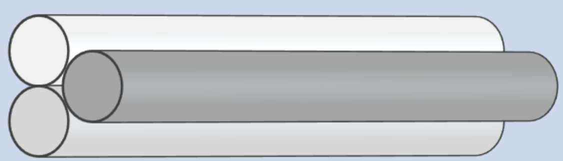


Parallel



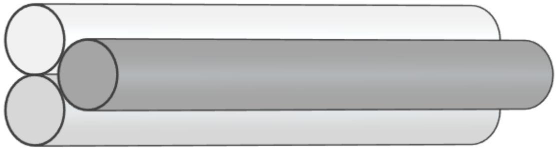
Straw “Resistor”

A good physical model for current travelling through resistors is blowing through a straw.

1 resistor	
3 resistors in series	
3 resistors in parallel	

Combining Resistors

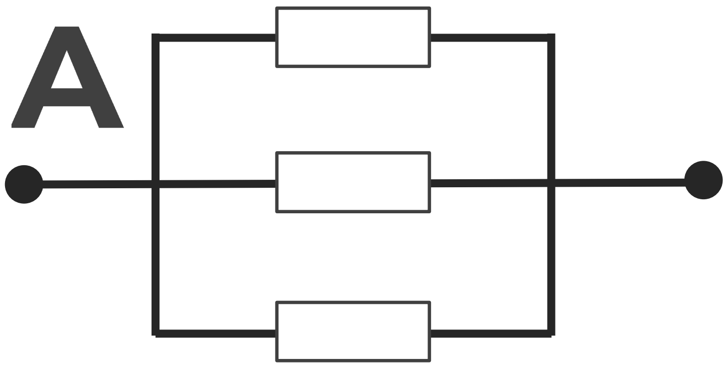
Adding resistors in series **increases** overall resistance

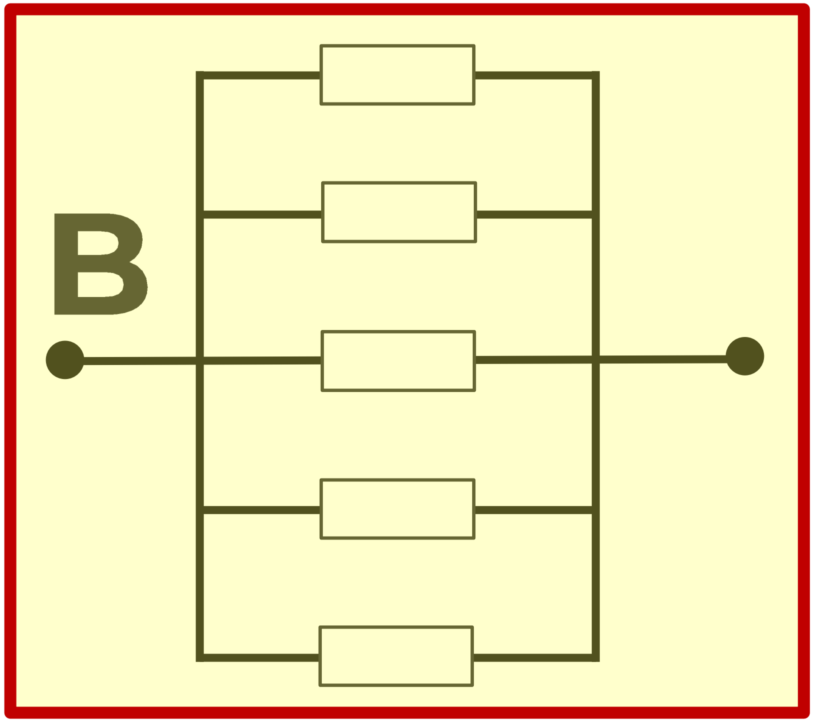


Adding resistors in parallel **decreases** overall resistance

Compare these Combos…

Which example has the lowest overall resistance?
Assume that every resistor is the same.

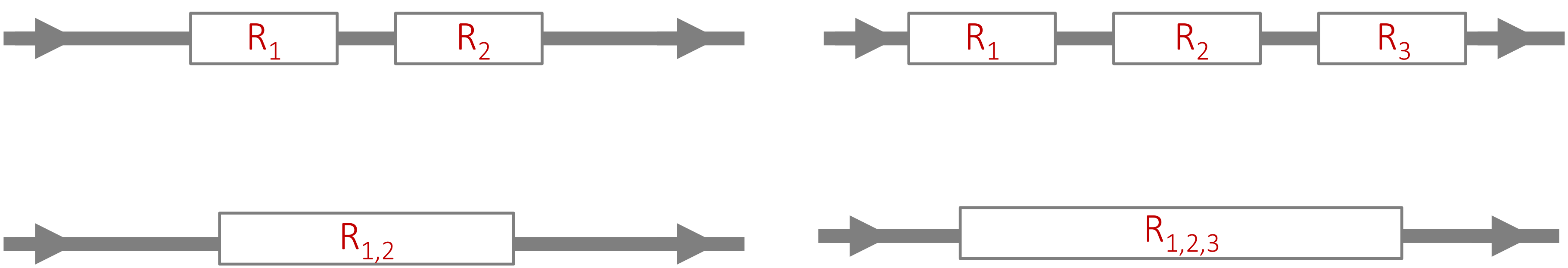




Combining Resistors | Series

When combining resistors in series, the resistances are simply added up as if they were one large resistor

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



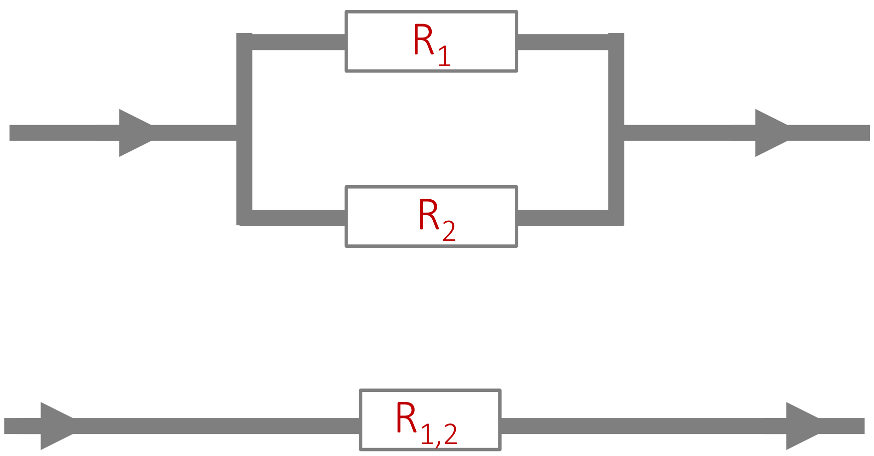
Combining Resistors | Parallel

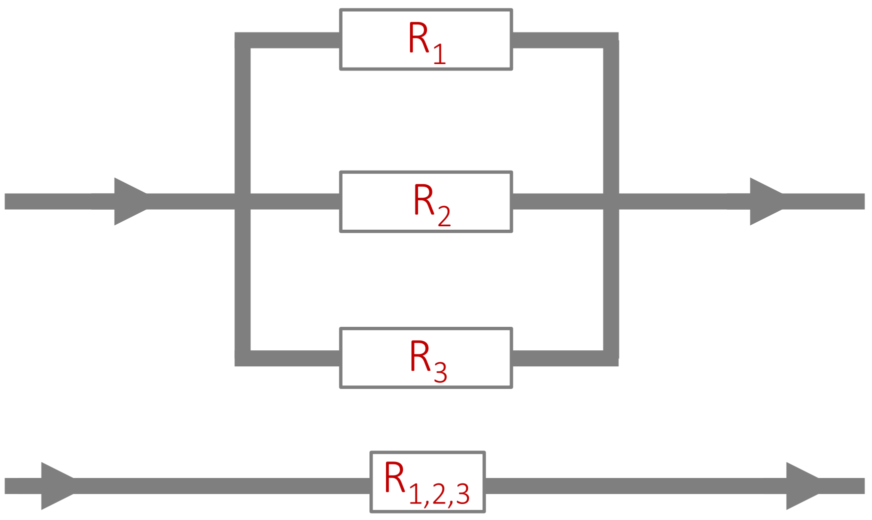
When combining resistors in parallel, the overall resistance decreases to produce a smaller equivalent resistance

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

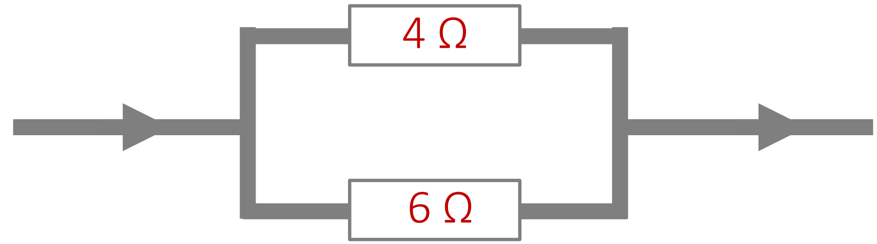
$$R_{total}{}^{-1} = \left(R_1{}^{-1} + R_2{}^{-1} + \cdots\right)$$

$$R_{total} = \left(R_1{}^{-1} + R_2{}^{-1} + \cdots\right)^{-1}$$





Combining Resistors – Try This



$$R_T = 4 + 6 + 8 = 18\ \Omega$$

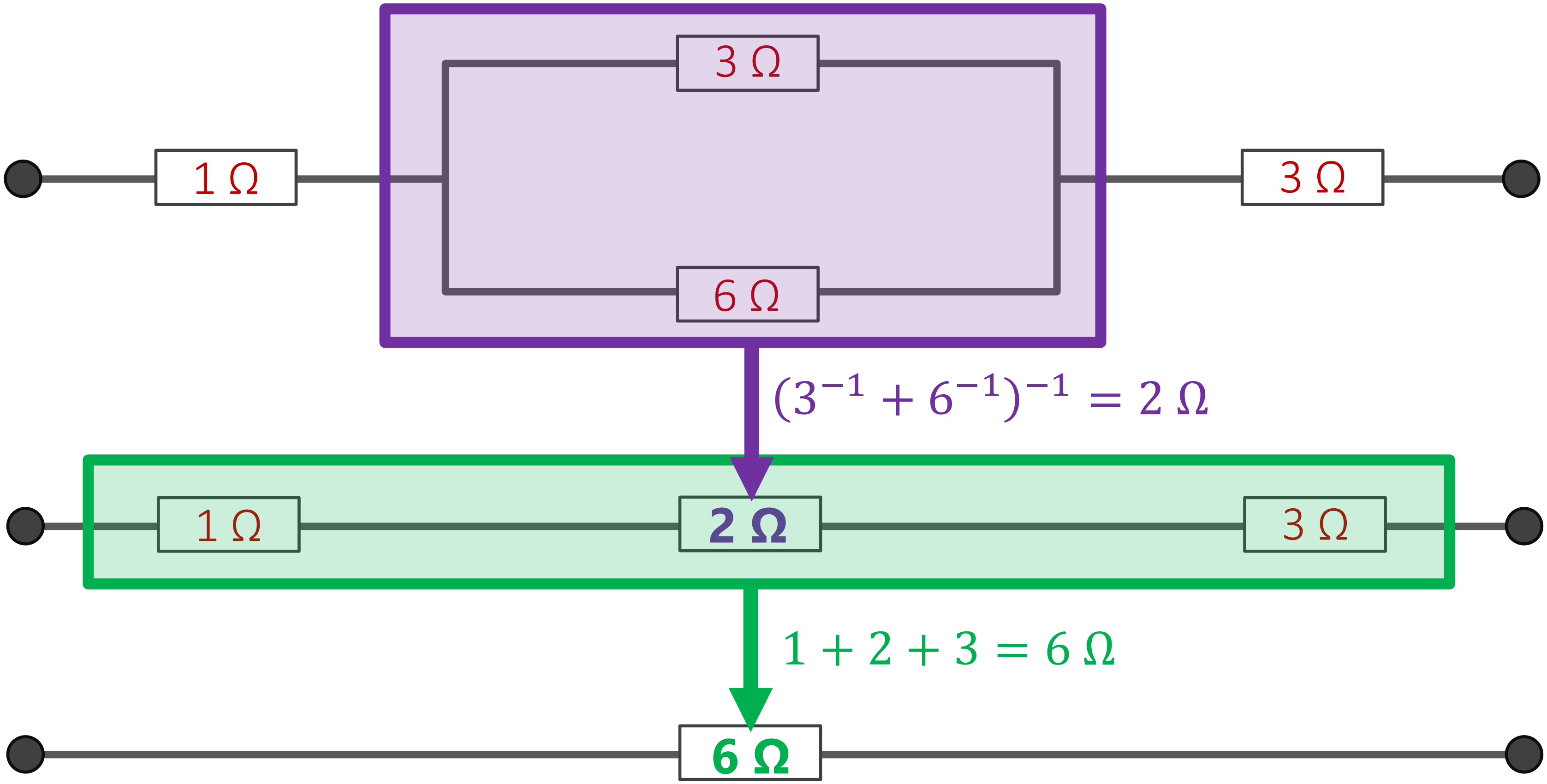
$$\frac{1}{R_T} = \frac{1}{4} + \frac{1}{6} \Rightarrow R_T = \frac{1}{\frac{1}{4} + \frac{1}{6}}$$

$$R_T = (4^{-1} + 6^{-1})^{-1} = 2.4\ \Omega$$

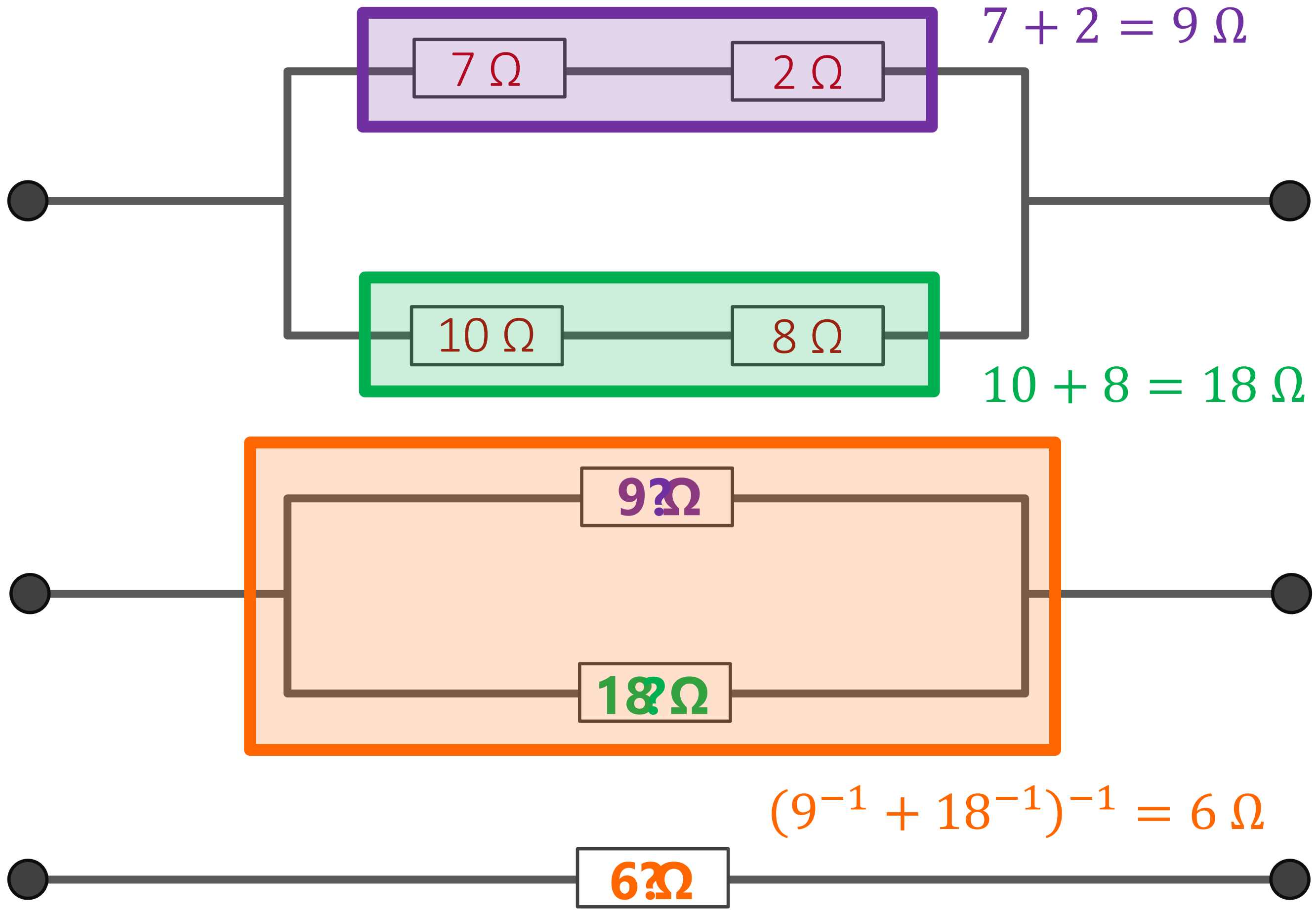
IB Physics Data Booklet

Sub-topic 5.1 – Electric fields	Sub-topic 5.2 – Heating effect of electric currents
$I = \frac{\Delta q}{\Delta t}$ $F = k\frac{q_1 q_2}{r^2}$ $k = \frac{1}{4\pi\varepsilon_0}$ $V = \frac{W}{q}$ $E = \frac{F}{q}$ $I = nAvq$	Kirchhoff's circuit laws: $\Sigma V = 0$ (loop) $\Sigma I = 0$ (junction) $R = \frac{V}{I}$ $P = VI = I^2R = \frac{V^2}{R}$ $R_{\text{total}} = R_1 + R_2 + \cdots$ $\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$ $\rho = \frac{RA}{L}$
Sub-topic 5.3 – Electric cells	**Sub-topic 5.4 – Magnetic effects of electric currents**
$\varepsilon = I(R + r)$	$F = qvB\sin\theta$ $F = BIL\sin\theta$

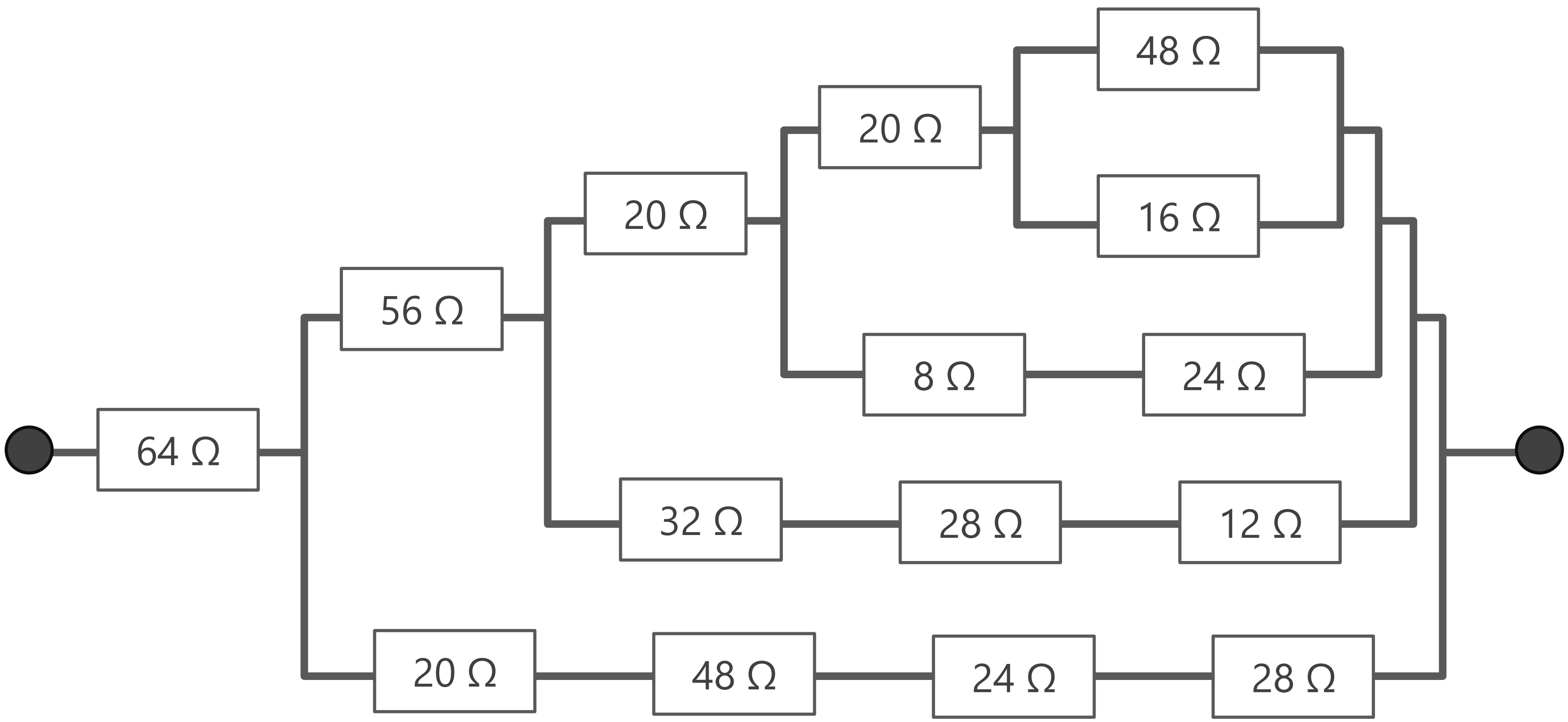
Equivalent Resistance



Try This | Equivalent Resistance



This could be bigger…



Lesson Takeaways

- ❑ I can calculate the equivalent resistance for combinations of resistors in series and parallel
- ❑ I can systematically step through the calculation of the equivalent resistance for a complex combination

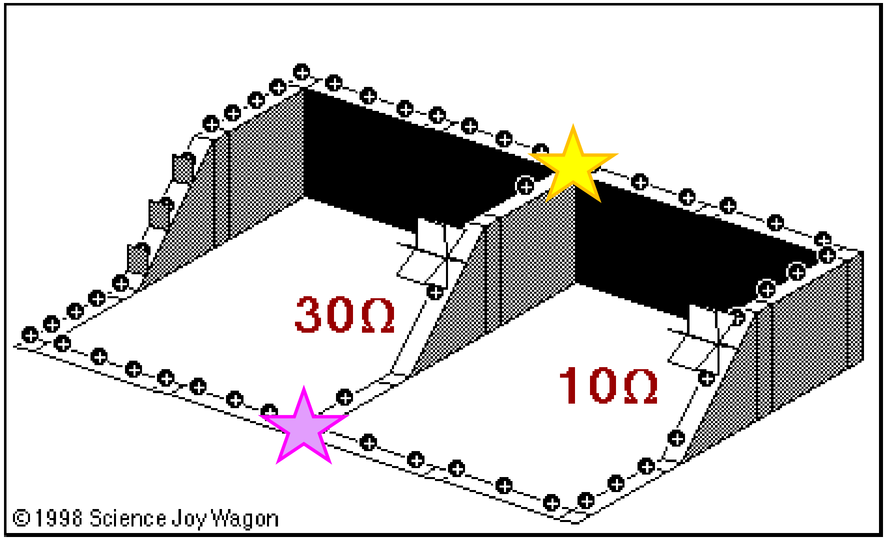
Circuit Analysis

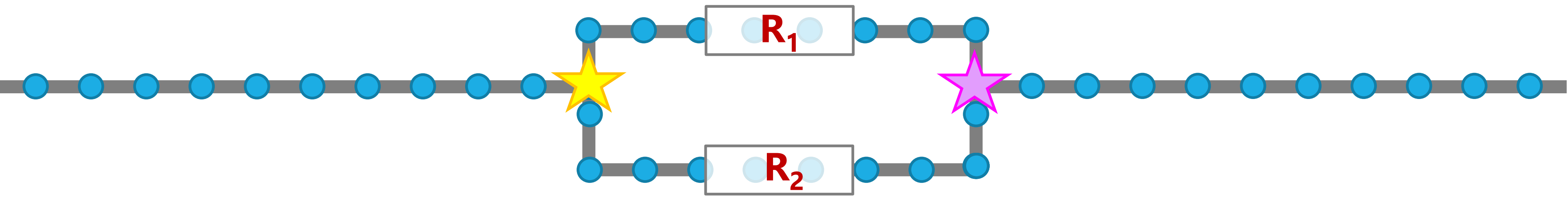
IB PHYSICS | ELECTRICITY

Review of Parallel Circuits

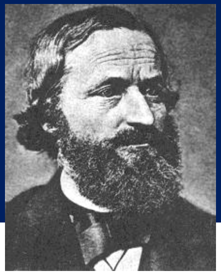
- Separate branches
- Current splits up between the different pathways

Junctions

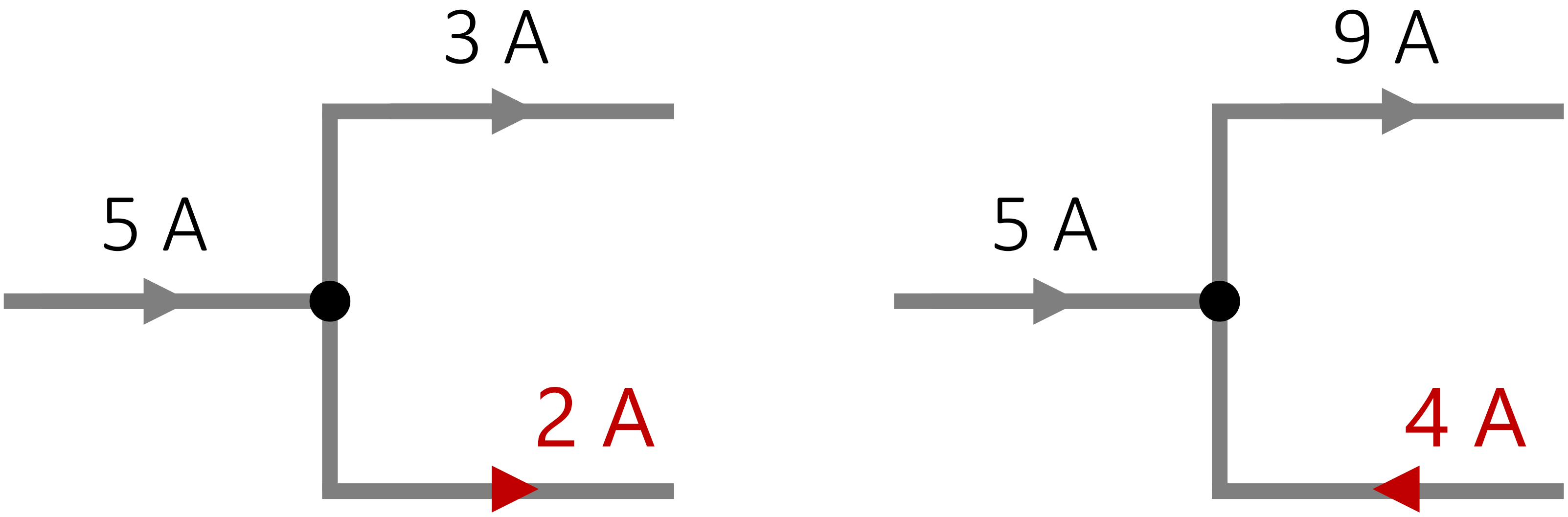




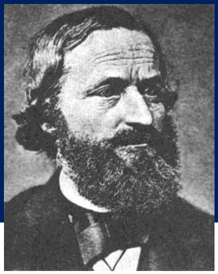
Kirchhoff's First Law



The total current coming into a junction must equal the total current leaving the same junction



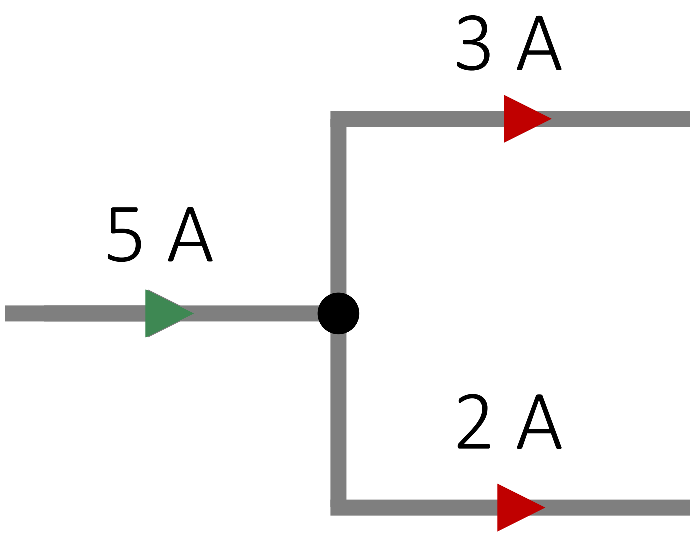
Kirchhoff’s First Law



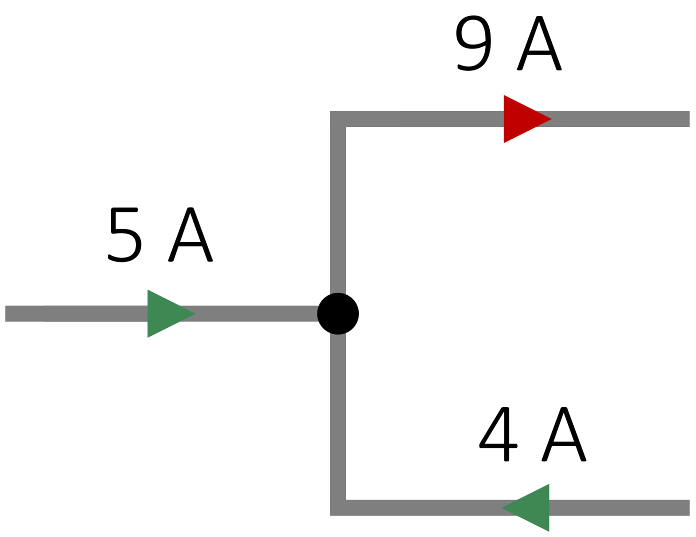
$$\Sigma I = 0 \ \ (junction)$$

Entering Junction	→●	Positive
Exiting Junction	●→	Negative

$(+5) + (-3) + (-2) = 0$



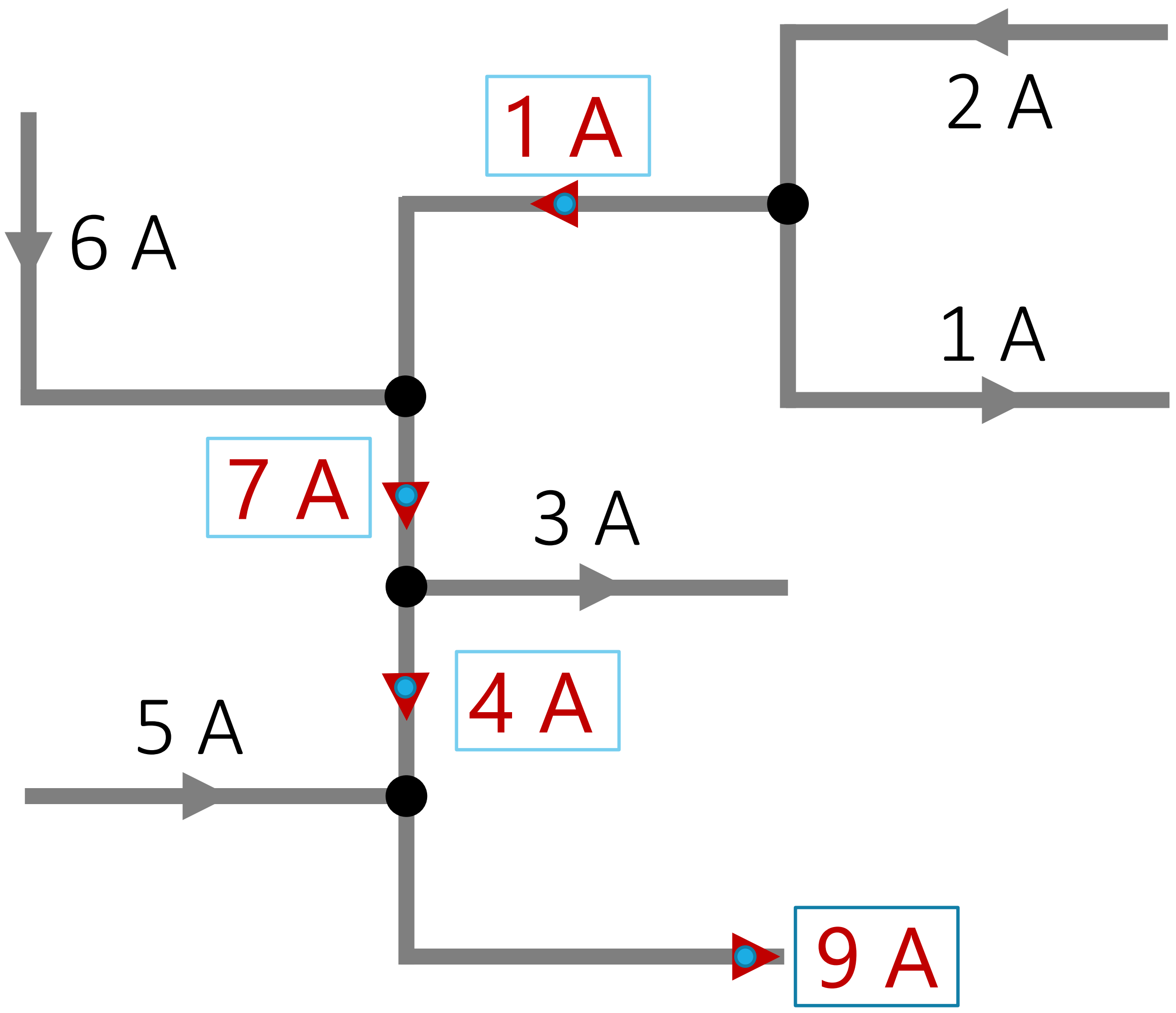
$(+5) + (-9) + (+4) = 0$



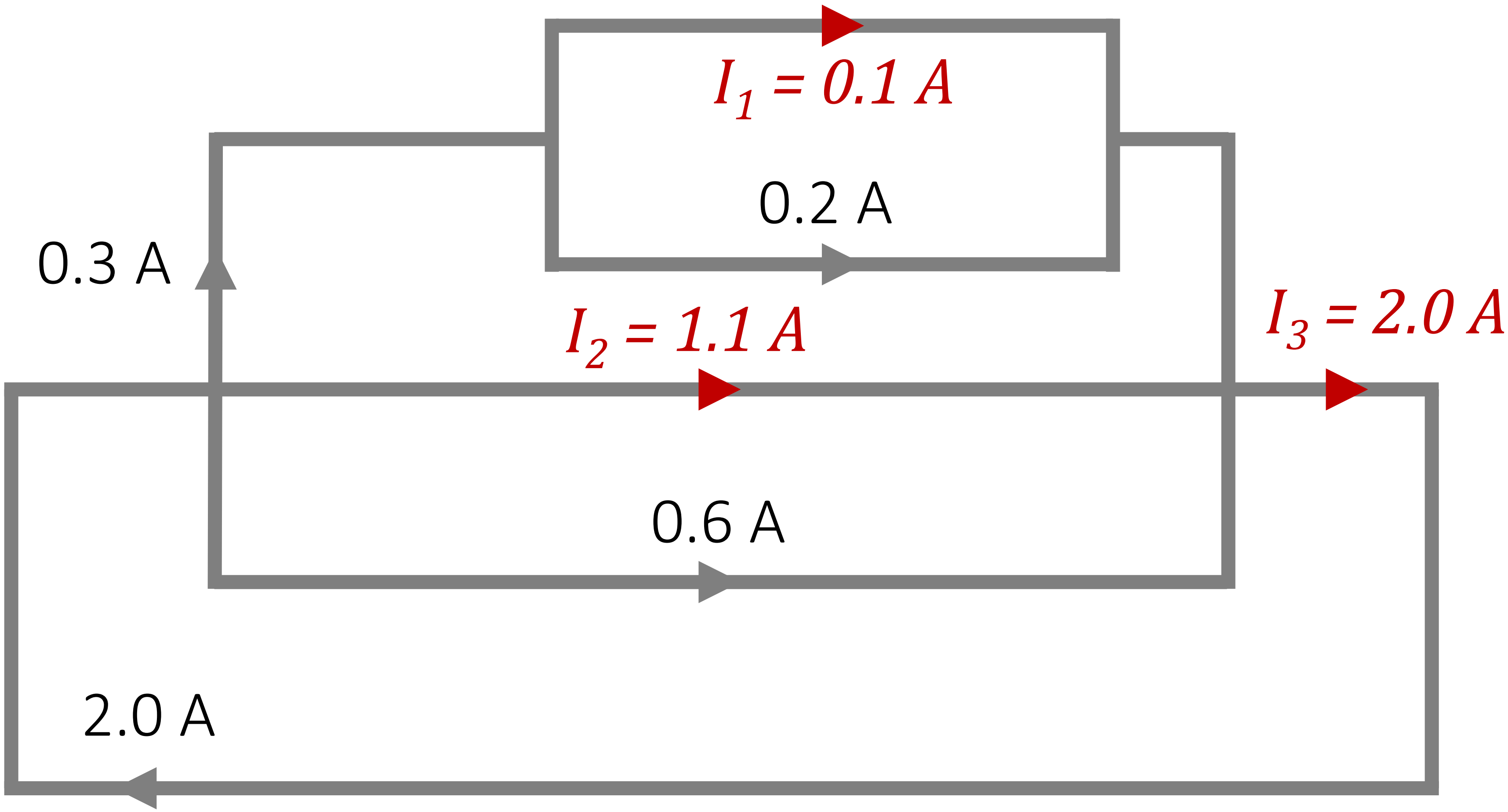
IB Physics Data Booklet

Sub-topic 5.1 – Electric fields	Sub-topic 5.2 – Heating effect of electric currents
$I = \frac{\Delta q}{\Delta t}$ $F = k\frac{q_1 q_2}{r^2}$ $k = \frac{1}{4\pi\varepsilon_0}$ $V = \frac{W}{q}$ $E = \frac{F}{q}$ $I = nAvq$	Kirchhoff's circuit laws: $\Sigma V = 0$ (loop) $\Sigma I = 0$ (junction) $R = \frac{V}{I}$ $P = VI = I^2 R = \frac{V^2}{R}$ $R_{\text{total}} = R_1 + R_2 + \cdots$ $\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$ $\rho = \frac{RA}{L}$
Sub-topic 5.3 – Electric cells	**Sub-topic 5.4 – Magnetic effects of electric currents**
$\varepsilon = I(R + r)$	$F = qvB\sin\theta$ $F = BIL\sin\theta$

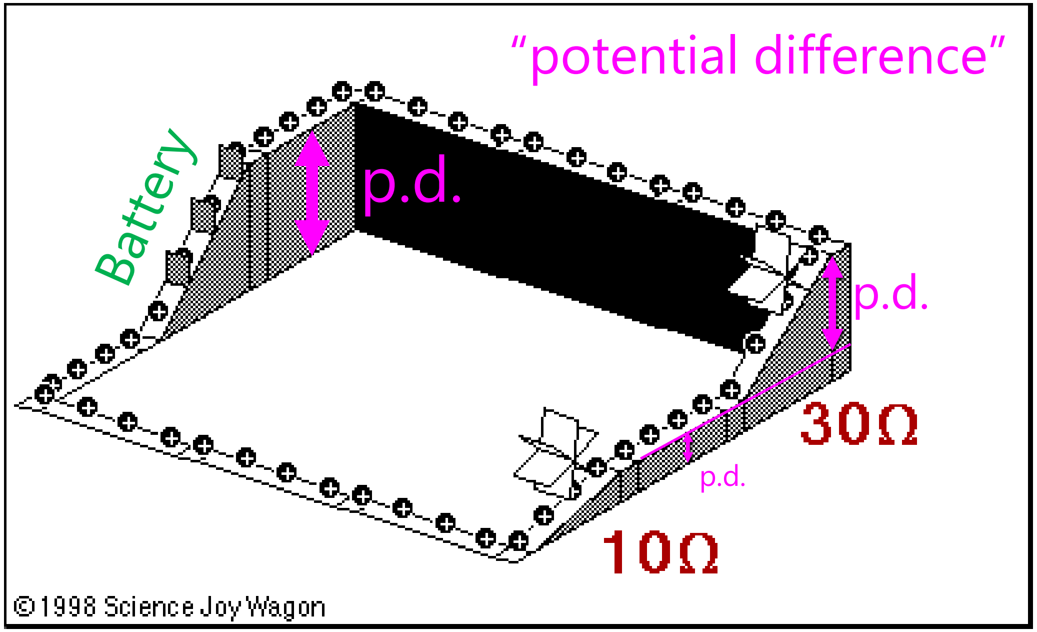
Follow the Current…



Try This

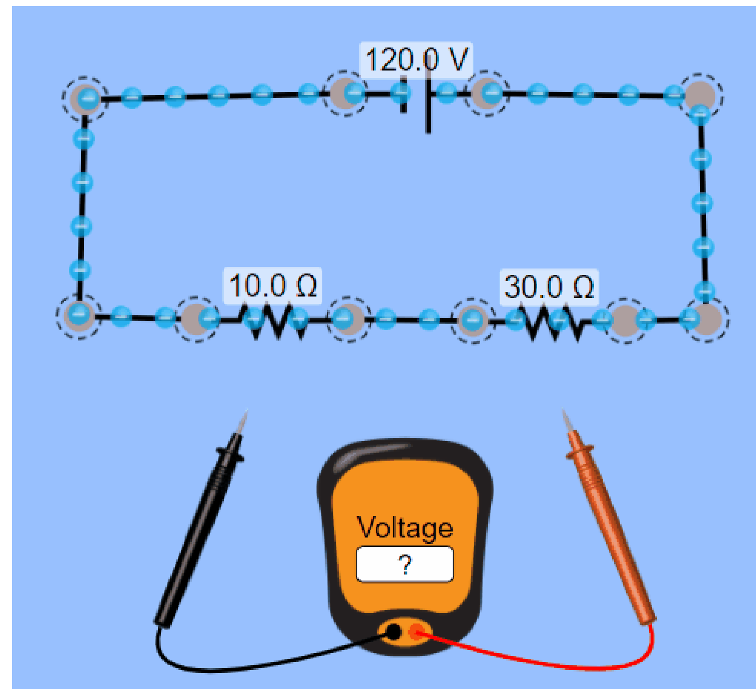


Review of the Water Flow Model

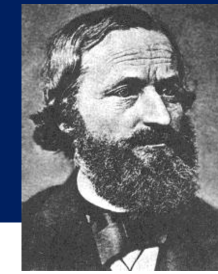


The voltage used by the resistors equals the voltage supplied by the battery

Each resistor has a "voltage drop"



Kirchhoff's Second Law



The sum of the voltages (potential differences) provided must equal the voltages dissipated across components

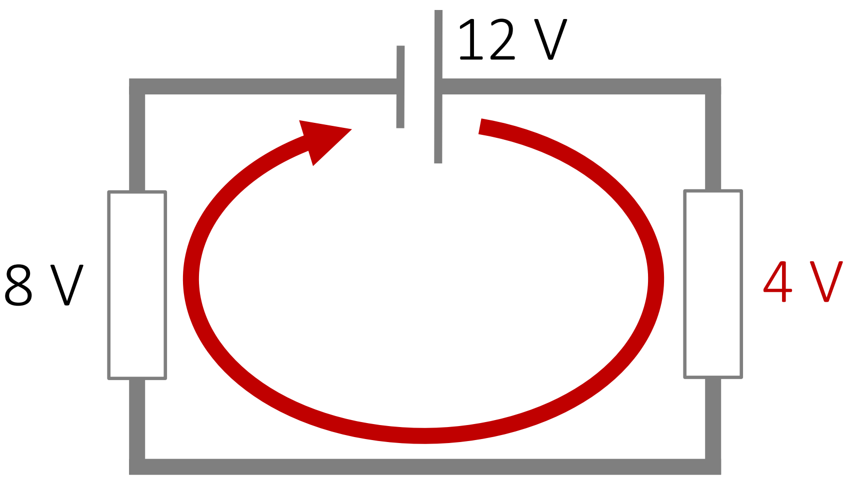
$$\Sigma V = 0 \ \ (loop)$$

Across Batteries

Negative to Positive	→	Positive
Positive to Negative	→	Negative

Over Resistors:

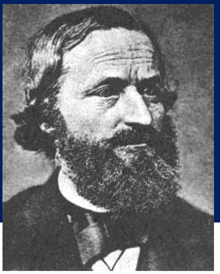
Always Negative



$$(+12) + (-4) + (-8) = 0$$

Resistor

Kirchhoff's Second Law



$$\Sigma V = 0 \ \ (loop)$$

Across Batteries

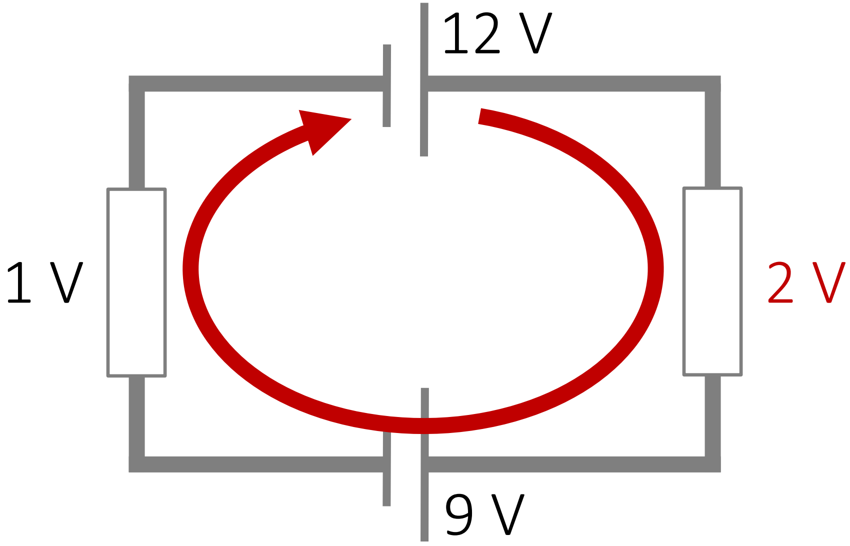
Negative to Positive	→	Positive
Positive to Negative	→	Negative

Over Resistors:

Always Negative

$$(+12) + (-2) + (-9) + (-1) = 0$$

Resistor



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Sub-topic 5.3 – Electric cells	**Sub-topic 5.4 – Magnetic effects of electric currents**
$\varepsilon = I(R + r)$	$F = qvB\sin\theta$ $F = BIL\sin\theta$

The Big Three

Ohm's Law: If you know two of the three electrical properties: V, I, or R

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

Kirchhoff's Voltage Law

$$\Sigma V = 0 \ \ (loop)$$

- Draw a loop
- The voltage provided must equal the voltage dissipated
- Useful if you have parallel branches to solve for

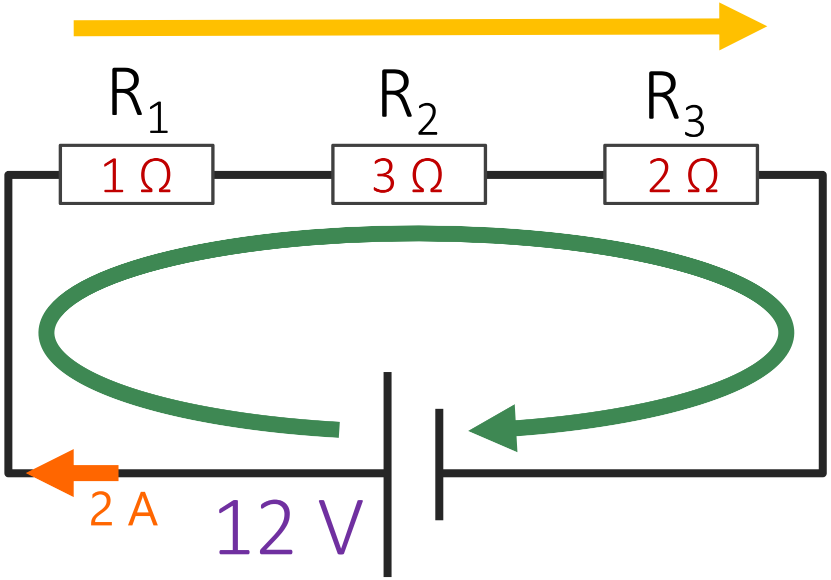
Kirchhoff's Current Law

$$\Sigma I = 0 \ \ (junction)$$

- Calculate the current coming out of the battery (total current)
- If this splits into parallel branches, the total should still add up

Calculating Circuits - Series

No Junction: Current is the same throughout



Loop: Voltage supplied equals voltage dissipated

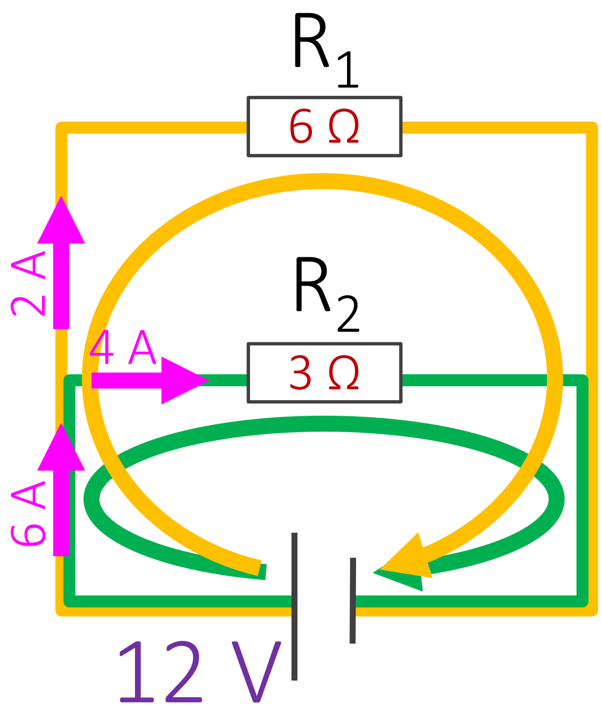
	V	I	R
R_1	2 V	2 A	1 Ω
R_2	6 V	2 A	3 Ω
R_3	4 V	2 A	2 Ω
Total	12 V	2 A	6 Ω

$R_T = 1 + 3 + 2 = 6\ \Omega$

$I_T = \frac{V}{R} = \frac{12}{6} = 2\ A$

$V = I \times R =$

Calculating Circuits - Parallel



	V	I	R
R_1	12 V	2 A	6 Ω
R_2	12 V	4 A	3 Ω
Total	12 V	6 A	2 Ω

$$R_T = (6^{-1} + 3^{-1})^{-1} = 2\ \Omega$$

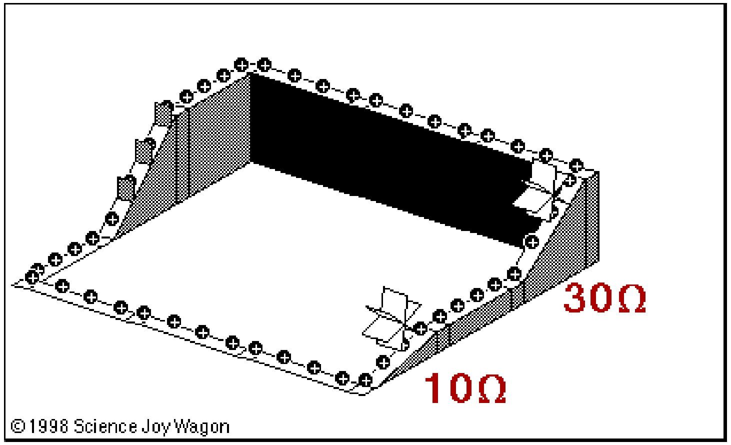
Loop: Voltage supplied equals voltage dissipated

$$I_T = \frac{V}{R} = \frac{12}{2} = 6\text{ A}$$

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

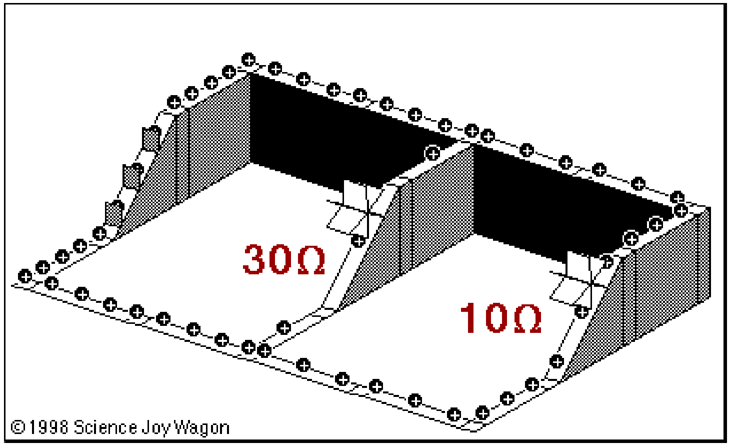
Junction: Current in = Current out

Patterns



Series Circuit

- Voltage is divided between components
- Current is the same for all components



Parallel Circuit

- Voltage is the same for each branch
- Current splits at each junction

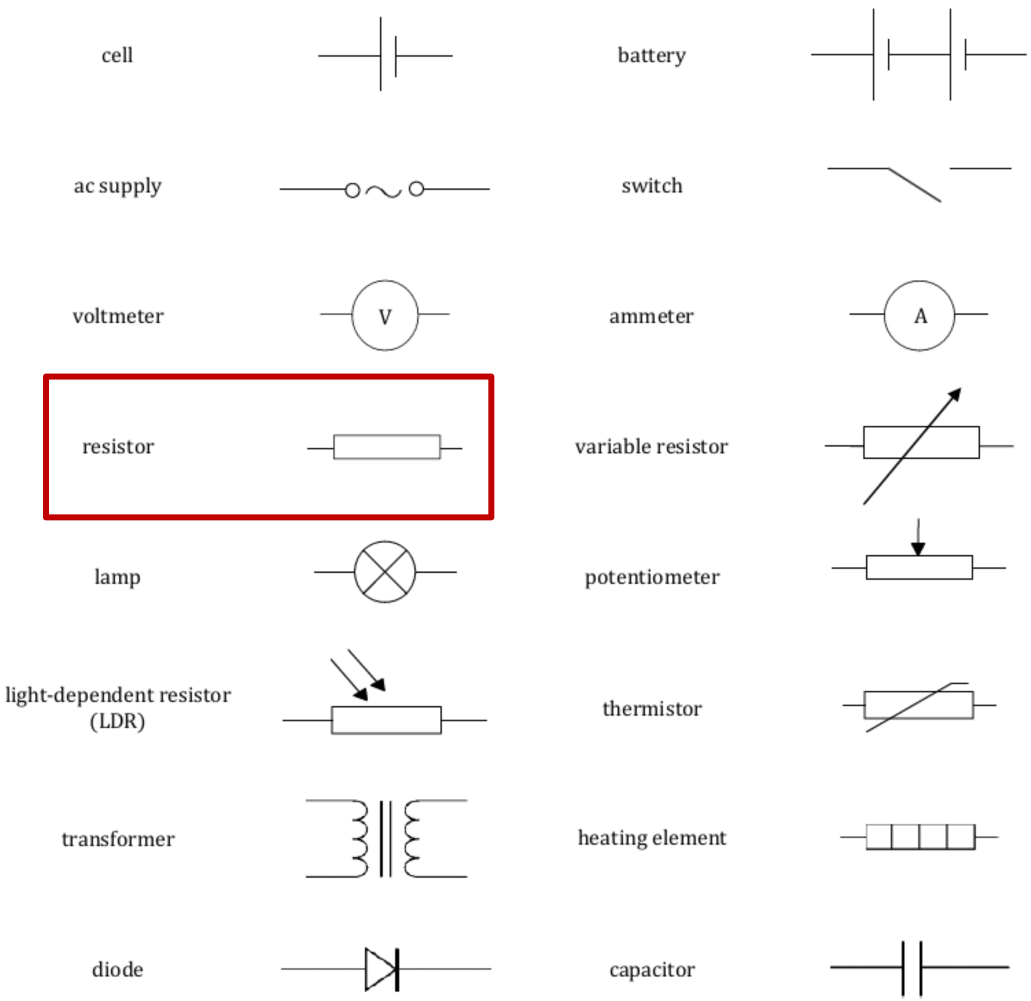
Lesson Takeaways

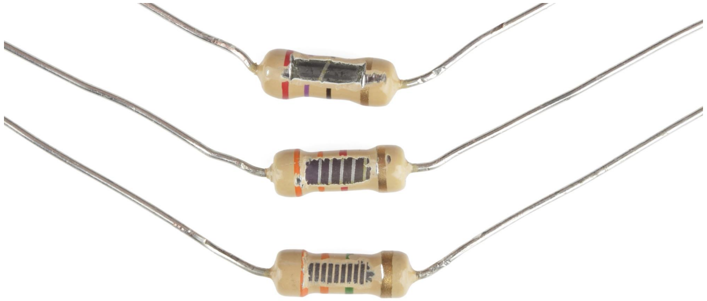
- ❑ I can use Kirchhoff's First Law to determine an unknown current at a junction
- ❑ I can use Kirchhoff's Second Law to determine an unknown current at a junction
- ❑ I can calculate voltage, current, and resistance for every component in a simple series or parallel circuit
- ❑ I can compare and contrast the properties for simple series and parallel circuits

Potential Dividers

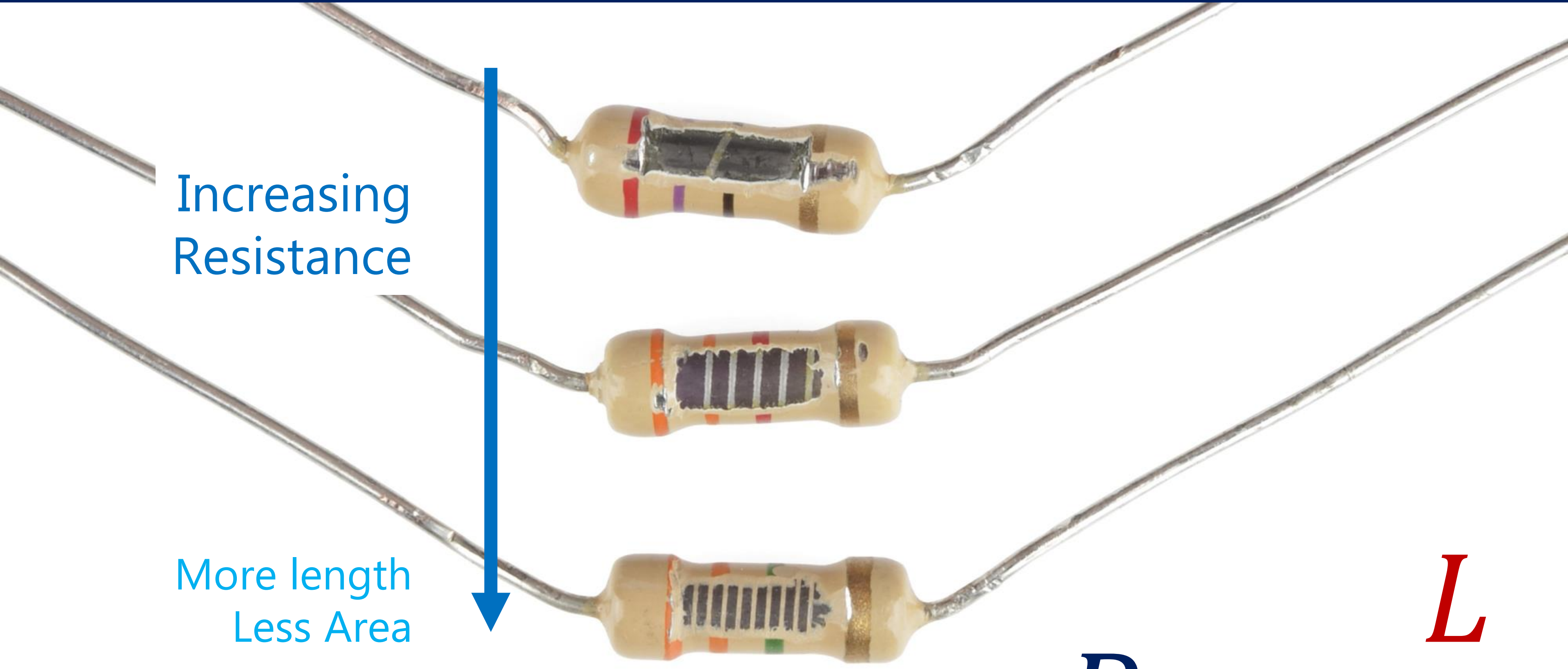
IB PHYSICS | ELECTRICITY

Types of Resistors





Resistor

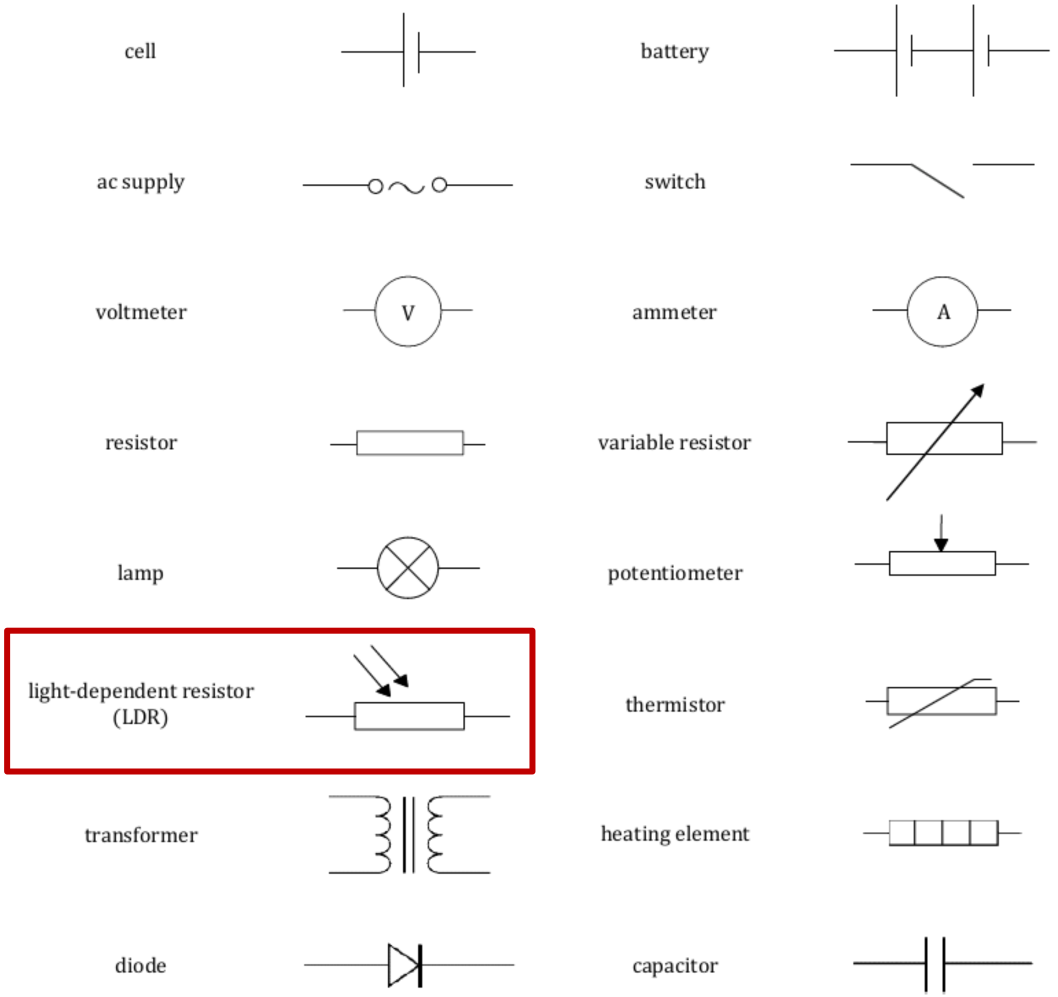


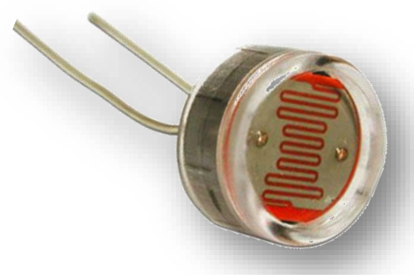
Increasing Resistance

More length
Less Area

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

Types of Resistors



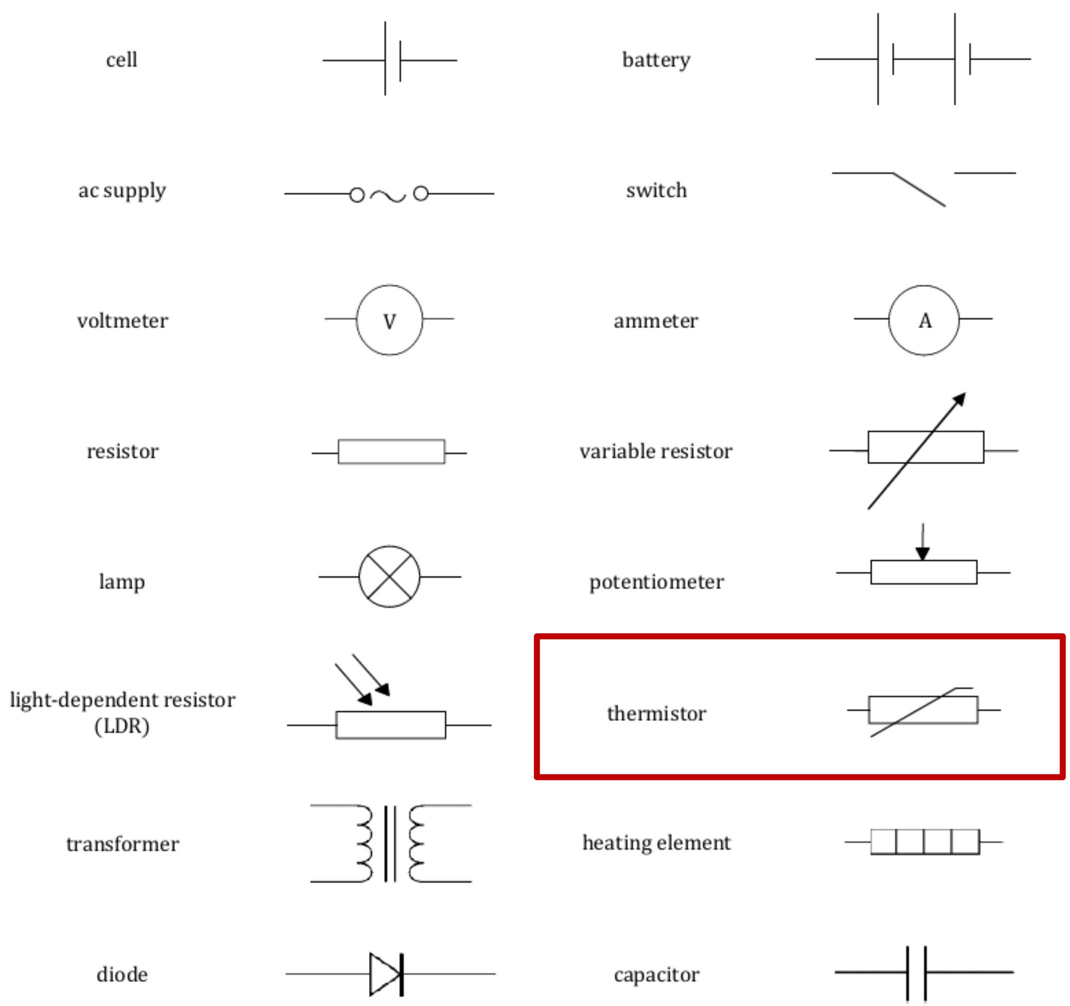


Light

Resistance

Inverse Relationship

Types of Resistors

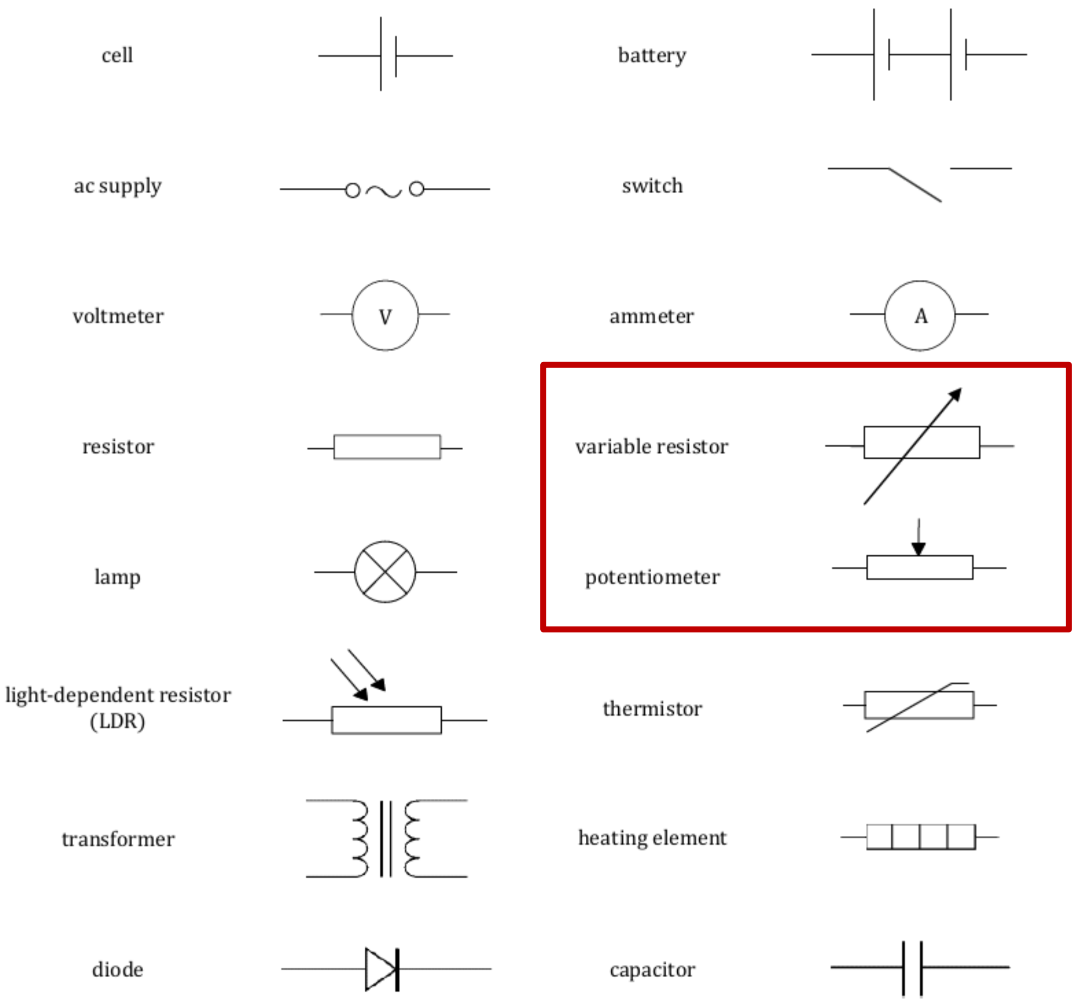


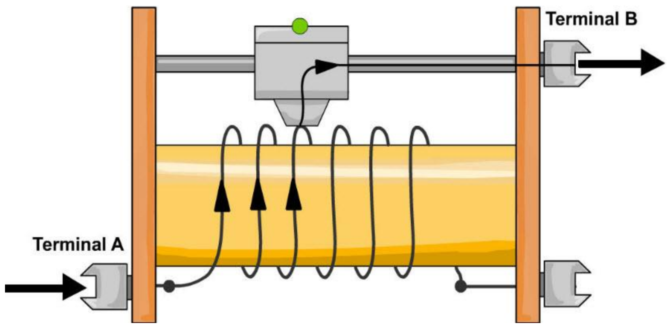
Heat

Resistance

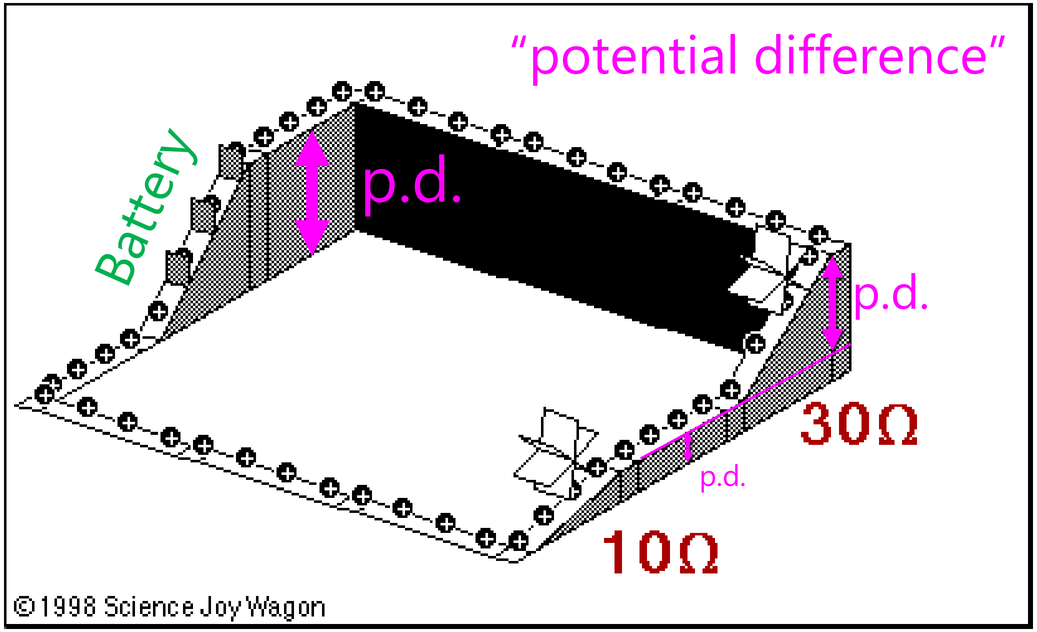
Inverse Relationship

Types of Resistors

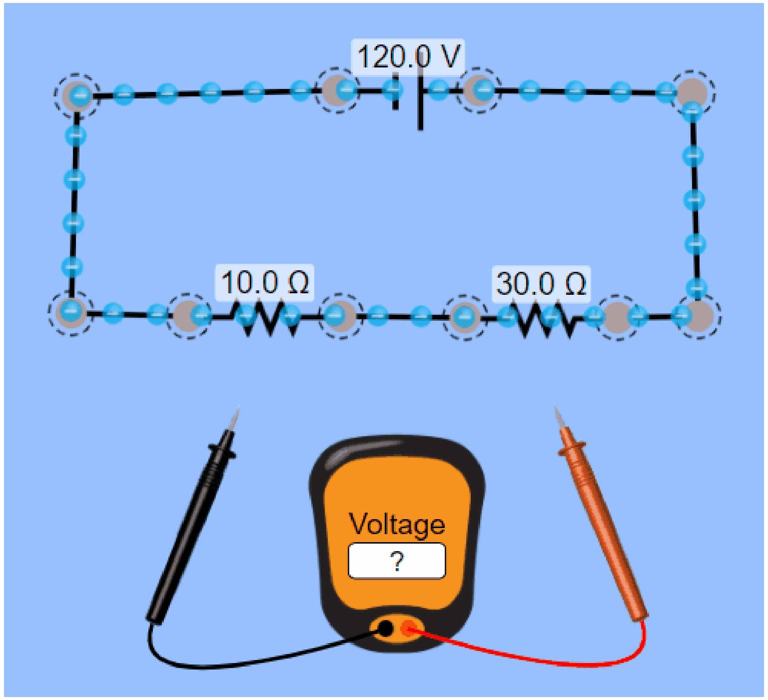




Potential Divider

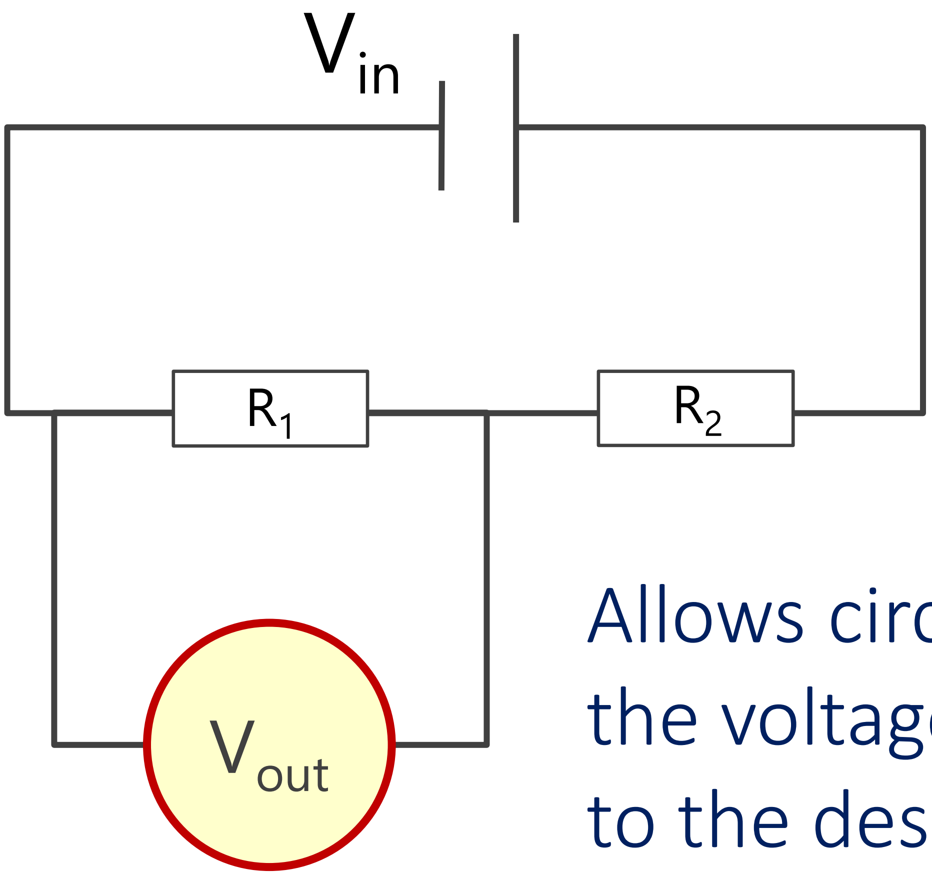


Each resistor has a "voltage drop"



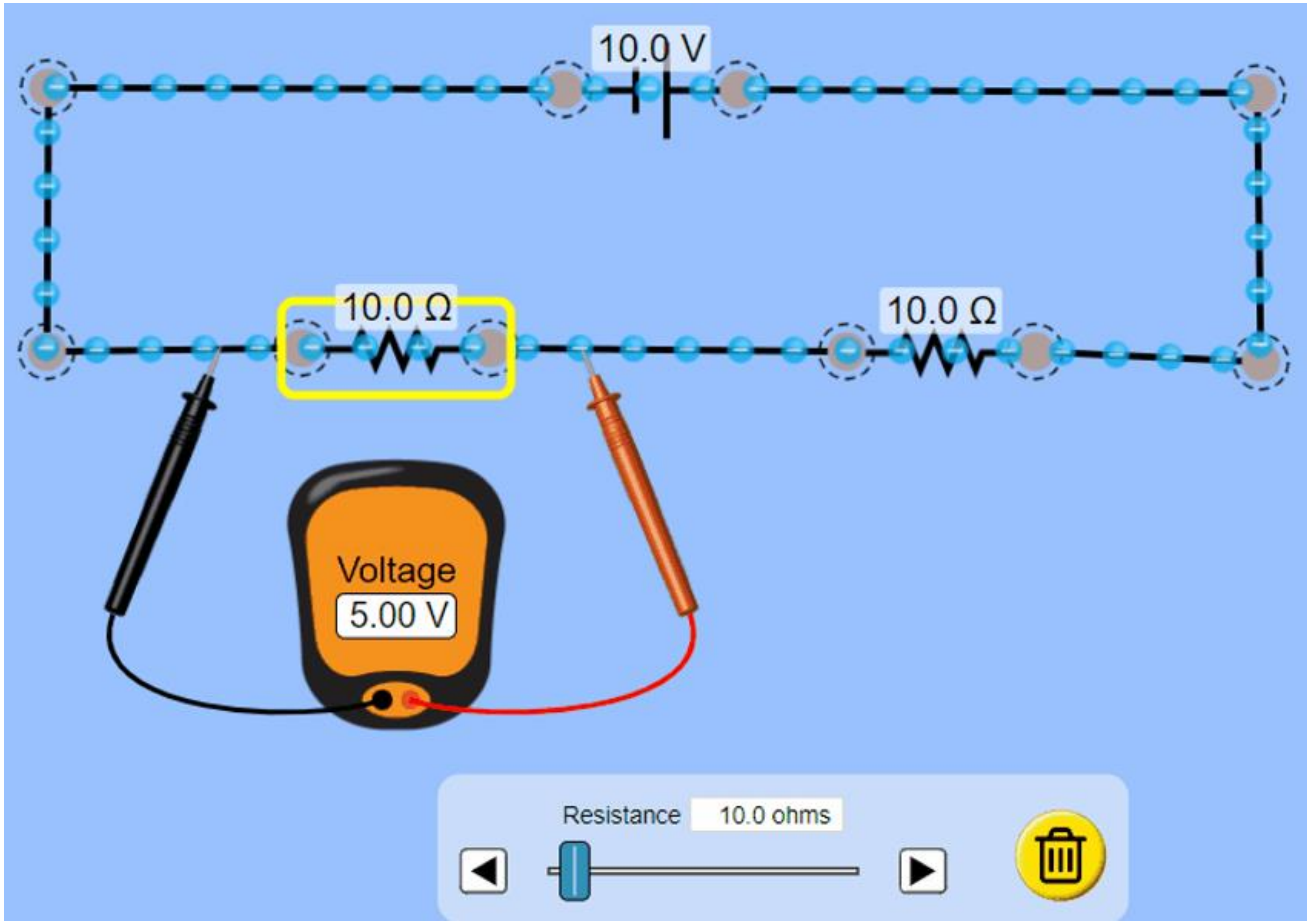
The total voltage supplied by the battery is "divided" across the different resistors

Potential Divider

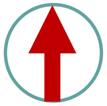


Allows circuit designers to tune the voltage that is being delivered to the desired components

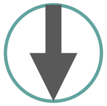
Relationship between R_1 and V_{out}



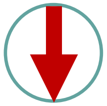
R_1



V_{out}

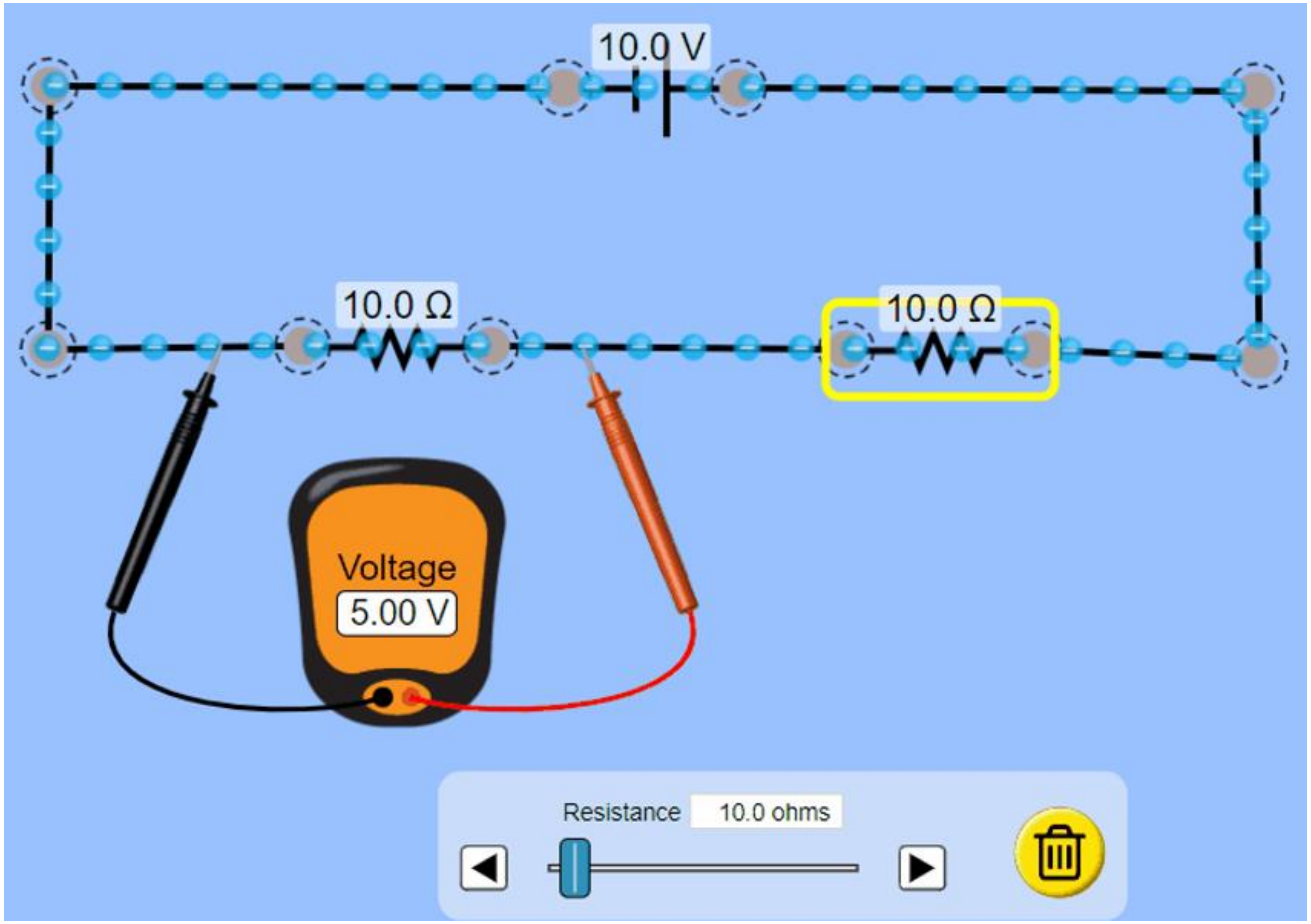


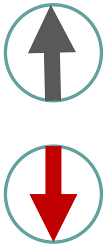
R_1



V_{out}

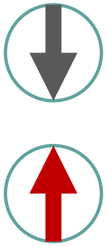
Relationship between R_2 and V_{out}





R_2 ↑

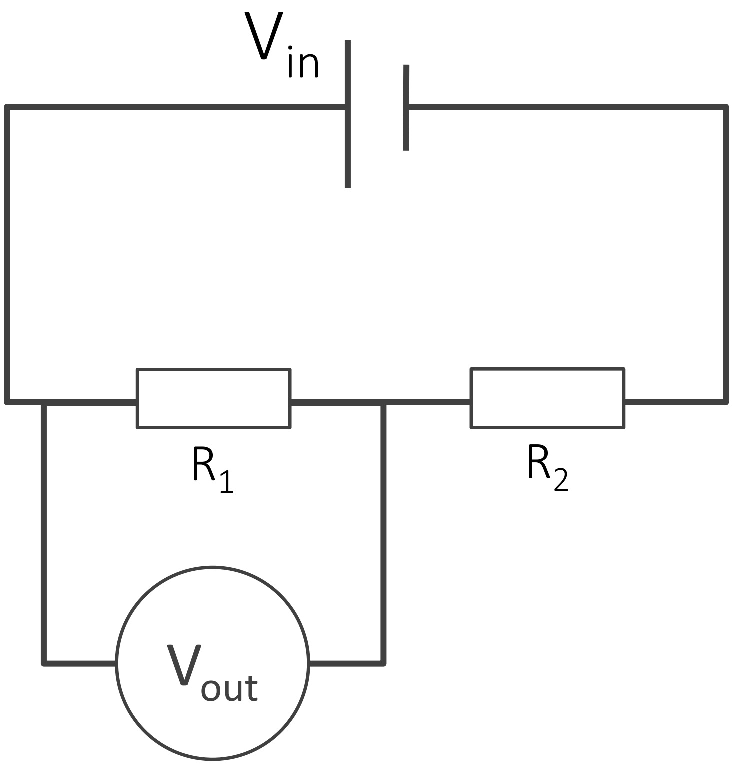
V_{out} ↓



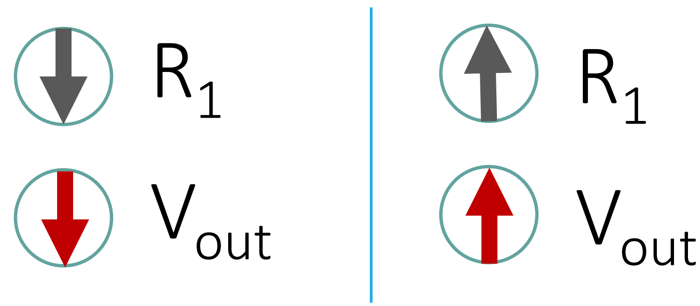
R_2 ↓

V_{out} ↑

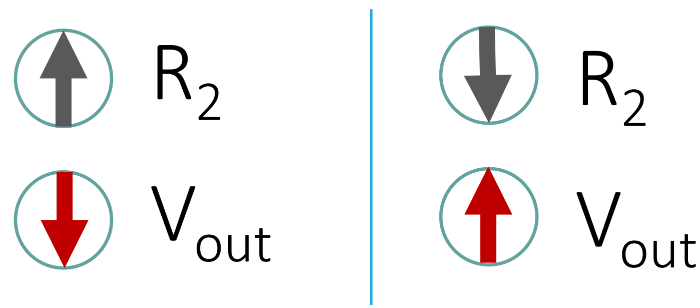
Potential Divider



Relationship between R_1 and V?



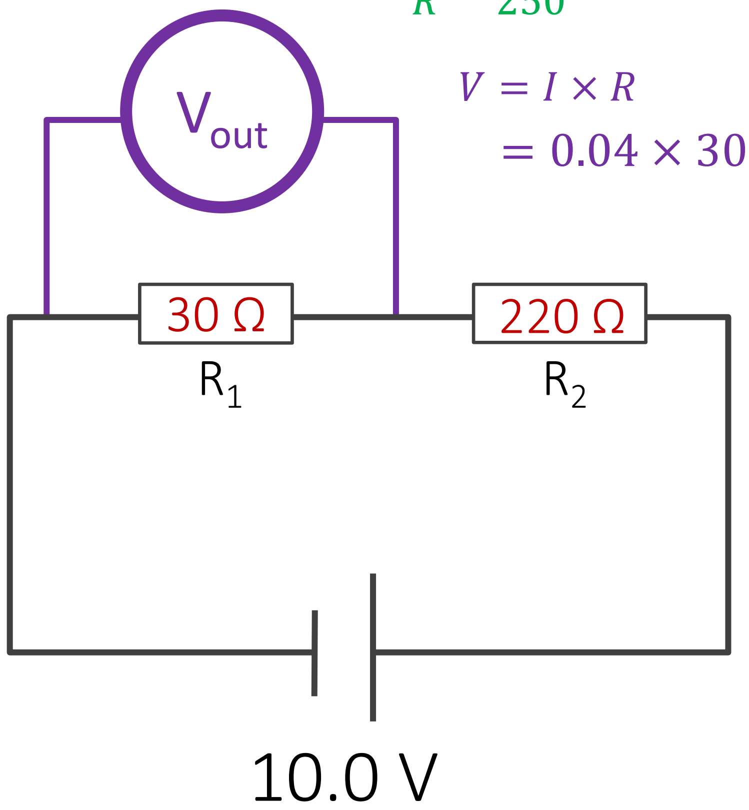
Relationship between R_2 and V?



Potential Divider

$$I_T = \frac{V}{R} = \frac{10}{250} = 0.04 \text{ A}$$

$$V = I \times R$$
$$= 0.04 \times 30$$



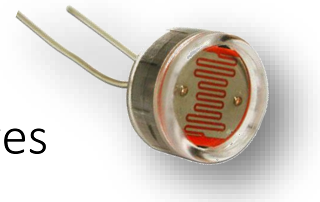
Find the Output Voltage:

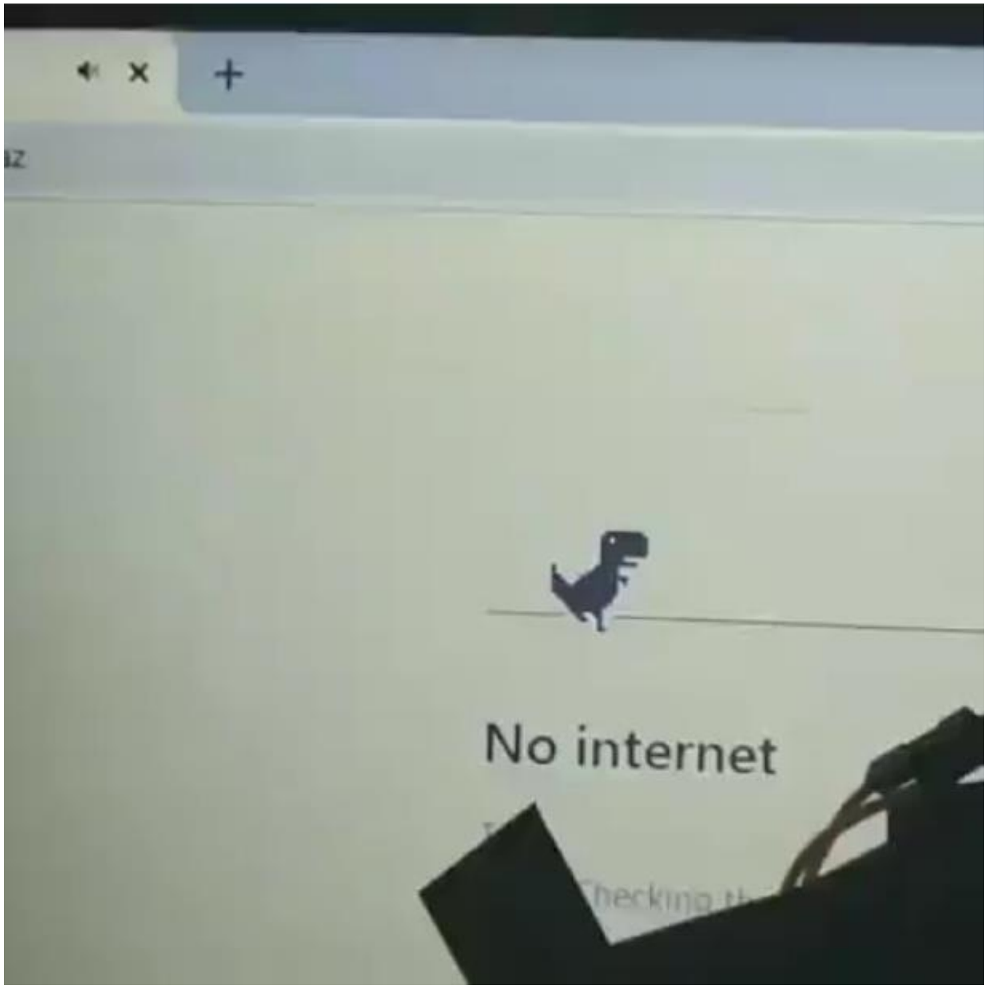
	V	I	R
R_1	**1.2 V**	0.04 A	30 Ω
R_2		0.04 A	220 Ω
Total	10 V	0.04 A	250 Ω

1. Calculate total resistance and current
2. Current is the same for each resistor
3. Calculate voltage across R_1

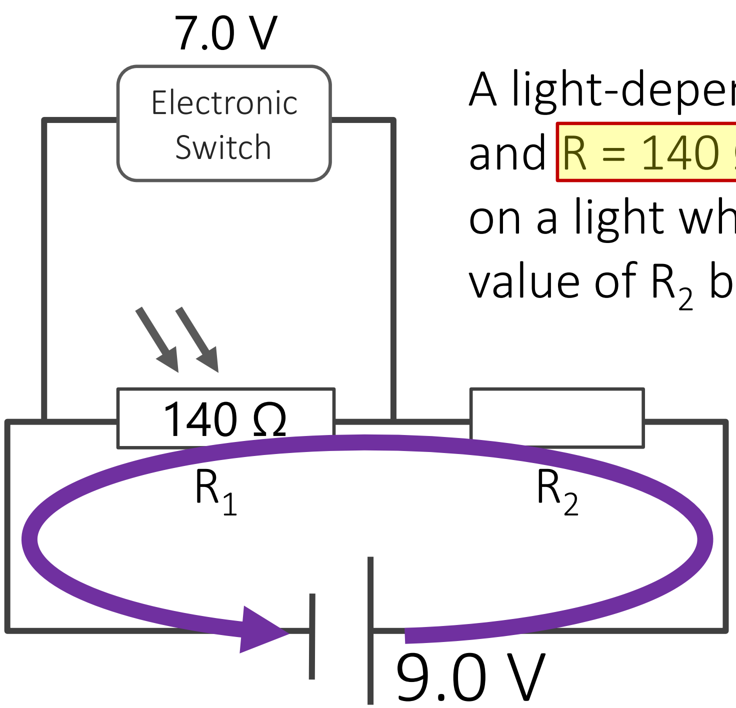
Applications of LDRs

Designed to perform function when the amount of light changes





Potential Divider | Night Light



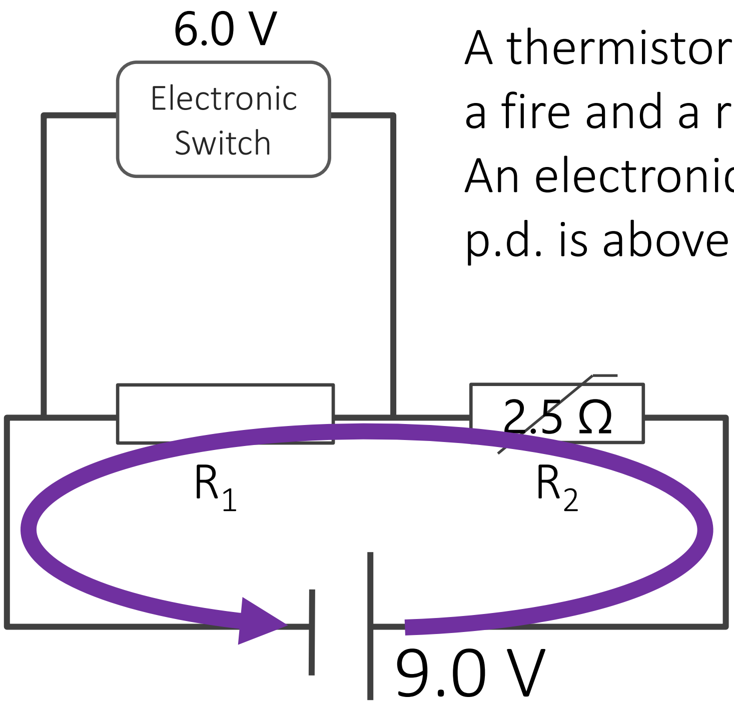
A light-dependent resistor (LDR) has R = 8 Ω in bright light and R = 140 Ω in low light. An electronic switch will turn on a light when its p.d. is above 7.0 V. What should the value of R_2 be?

*Night light should turn on in low light

	V	I	R
R_1	7.0 V	0.05 A	140 Ω
R_2	2.0 V	0.05 A	40 Ω
Total	9.0 V	0.05 A	

1. Calculate current through R_1
2. Current is the same throughout circuit (no current through switch)
3. Use voltage loop to find voltage across R_2
4. Calculate resistance of R_2

Potential Divider | Sprinkler System



A thermistor has a resistance of 2.5 Ω when it is in the heat of a fire and a resistance of 650 Ω in when at room temperature. An electronic switch will turn on a sprinkler system when its p.d. is above 6.0 V. What should the value of R_1 be?

*Sprinkler should activate when hot

	V	I	R
R_1	6.0 V	1.2 A	5 Ω
R_2	3.0 V	1.2 A	2.5 Ω
Total	9.0 V	1.2 A	

1. Use voltage loop to find voltage across R_2
2. Calculate current through R_2
3. Current is the same throughout circuit (no current through switch)
4. Calculate resistance of R_1

Lesson Takeaways

- ❑ I can identify the different circuit diagram symbols for different types of resistors
- ❑ I can describe how environmental changes can affect the resistance of LDRs and Thermistors
- ❑ I can describe how changing resistor values can affect the voltage drop in a potential divider circuit
- ❑ I can design a potential divider circuit to perform a certain task

Non-Ideal Meters

IB PHYSICS | ELECTRICITY

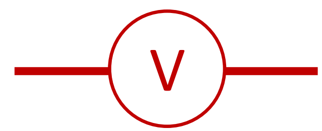
The Observer Effect

When taking any scientific measurement, there is always the possibility that the act of taking the measurement will change what is being measured

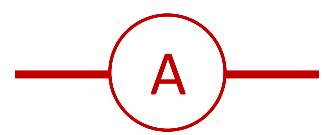
The Observer Effect

When we measure **voltage** or **current** in a circuit, we want to make sure to minimize an effect that our tool has on the circuit so that we get the most accurate results

Voltmeter

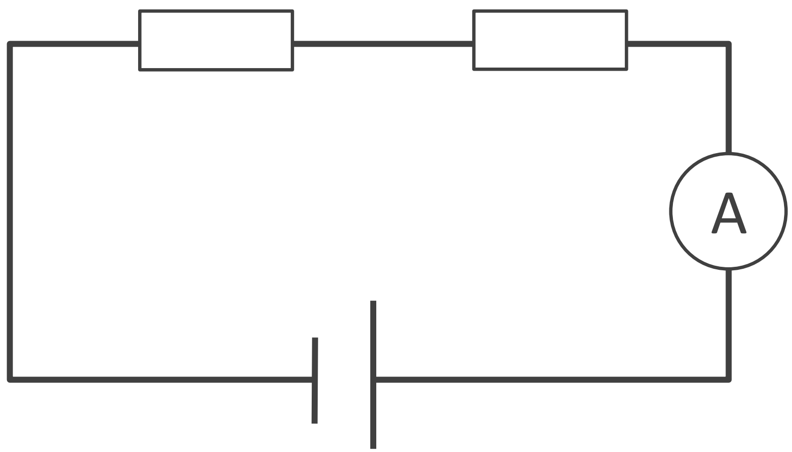


Ammeter



Ammeter

Hooked up in **series** with the component being measured

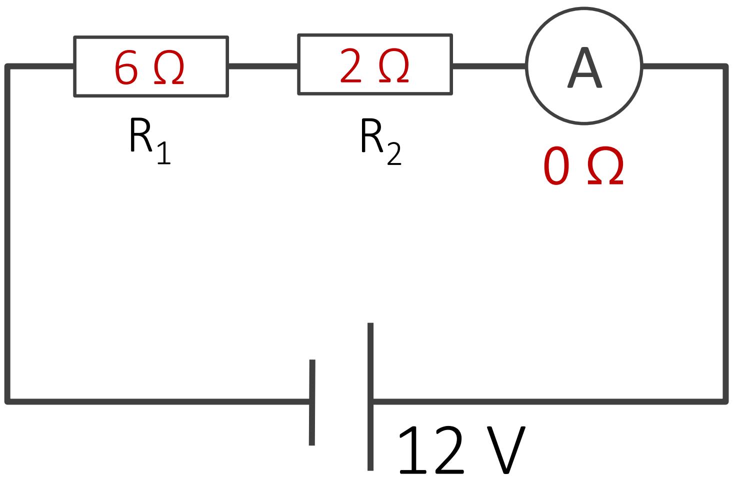


Ideal Ammeter:

$$[R = 0\ \Omega]$$

Measuring the Current

What is the reading for the current flowing through this ideal ammeter?



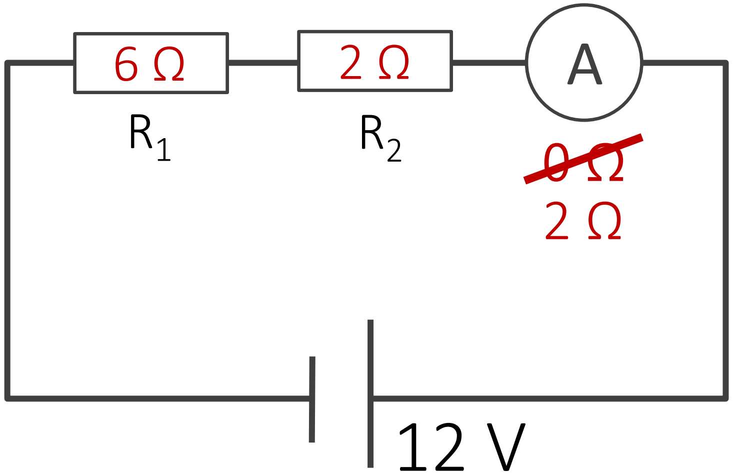
$$R_T = 8\ \Omega$$

$$I = \frac{V}{R} = \frac{12}{8} = \mathbf{1.5\ A}$$

The ammeter has no effect on the current that it's measuring

What if Ammeter isn't ideal?

What is the reading for the current flowing through this ~~ideal~~ 2 Ω ammeter?

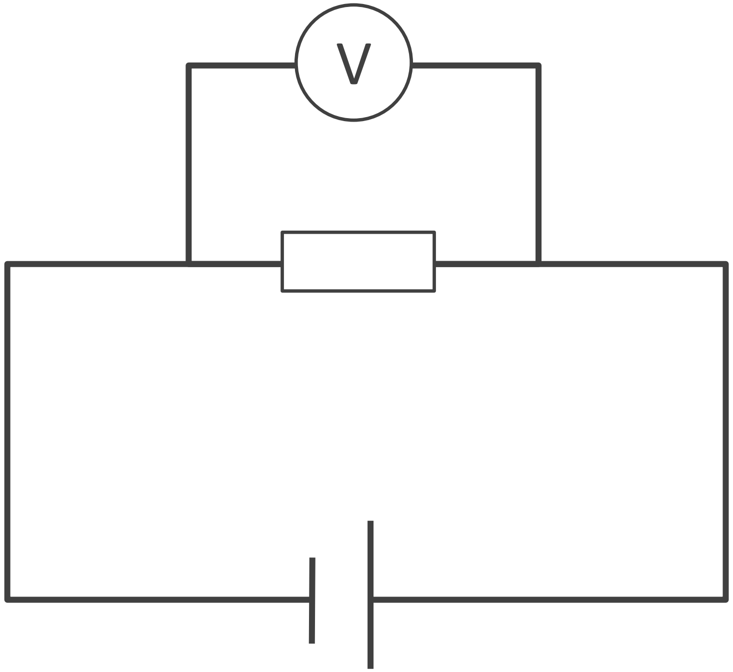


$R_T = \cancel{8\ \Omega}$ **10 Ω**

$I = \frac{V}{R} = \frac{12}{\cancel{8}\ 10} = \cancel{\mathbf{1.5\ A}}\ \mathbf{1.2\ A}$

The non-ideal ammeter's resistance slows down the current that it's measuring

Voltmeter

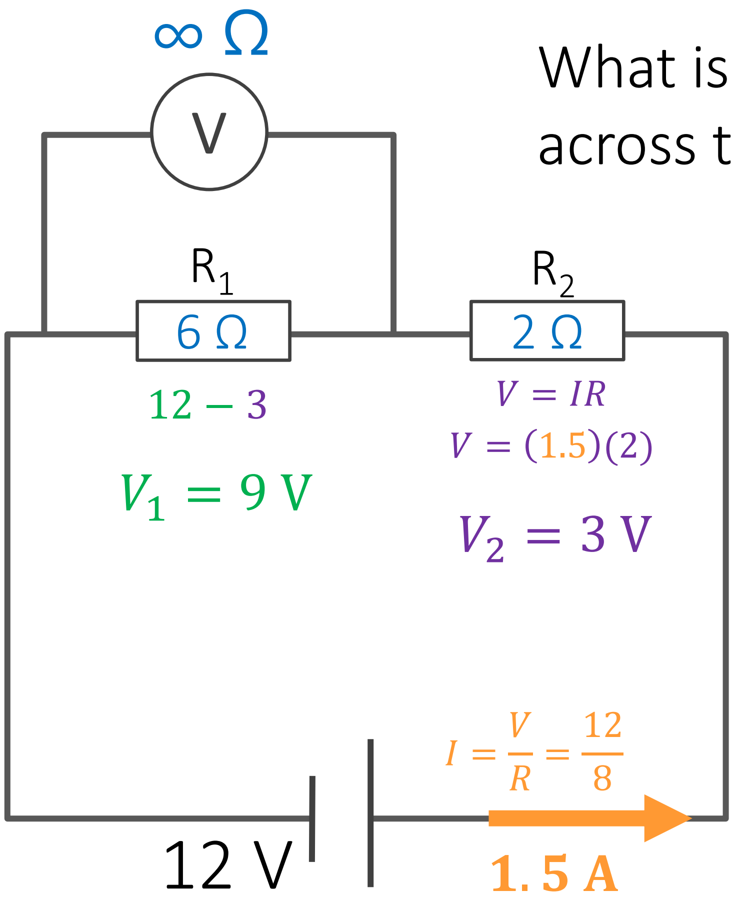


Hooked up in **parallel** with the component being measured

Ideal Voltmeter:

$$[R = \infty\ \Omega]$$

Measuring the Voltage



What is the reading for the ideal voltmeter across the resistor R_1?

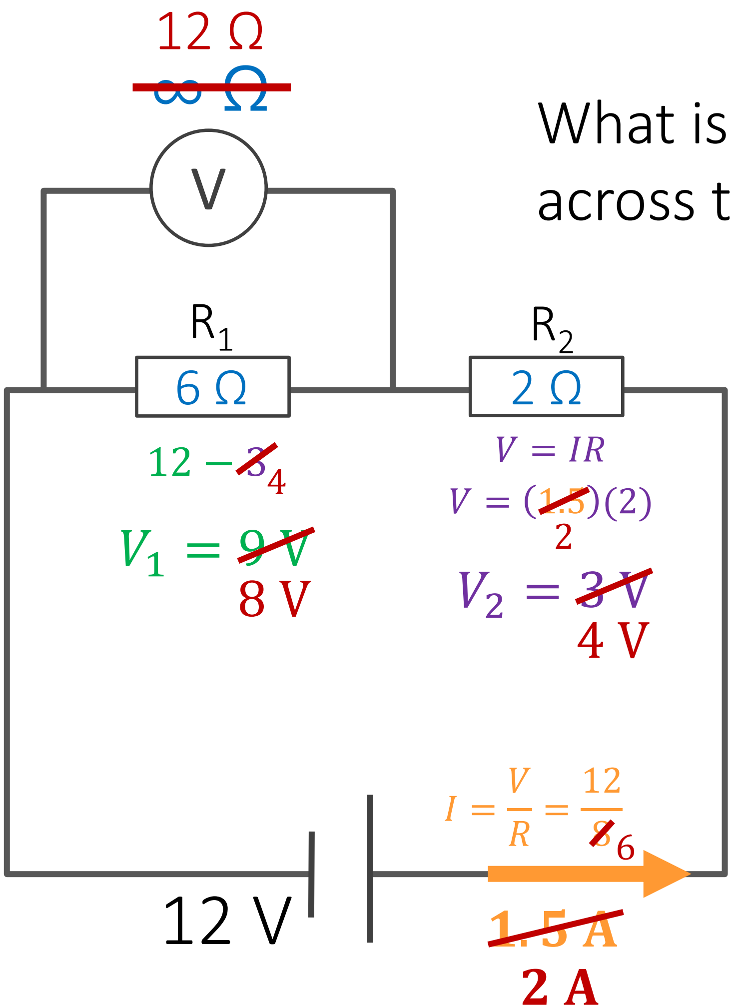
$$R_T = \frac{1}{\frac{1}{6} + \frac{1}{\infty}} + 2$$

$\frac{1}{\infty}$ → **0**

$$R_T = 6 + 2 = \mathbf{8\ \Omega}$$

Measuring the Voltage

What is the reading for the ~~ideal~~ 12 Ω voltmeter across the resistor R_1?



$$R_T = \frac{1}{\frac{1}{6} + \frac{1}{\cancel{\infty}\ 12}} + 2$$

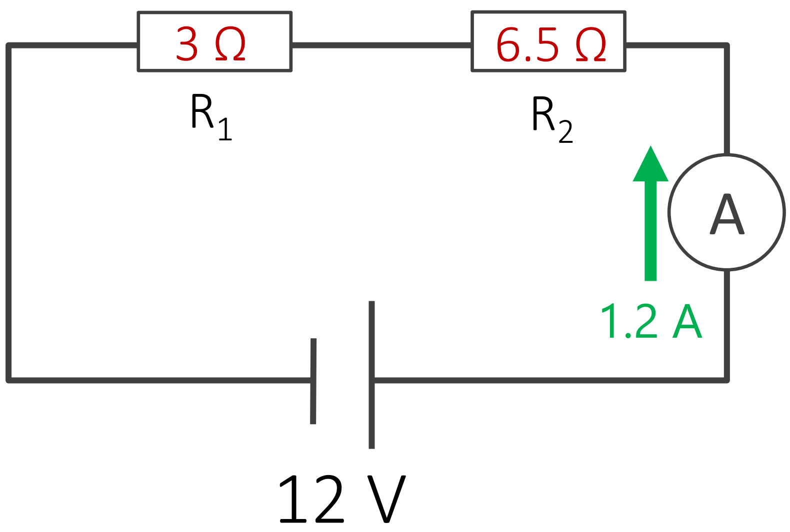
$$R_T = \cancel{6}\ 4 + 2 = \cancel{8\ \Omega}\ \mathbf{6\ \Omega}$$

Try This

Calculate the resistance of this non-ideal meter:

Ammeter Reading	1.2 A

- Current is the same for all components
- Calculate total resistance from voltage and current
- Calculate ammeter resistance



$$R = \frac{V}{I} = \frac{12}{1.2} = 10\ \Omega$$

$$R_T = 10\ \Omega = 3 + 6.5 + A$$

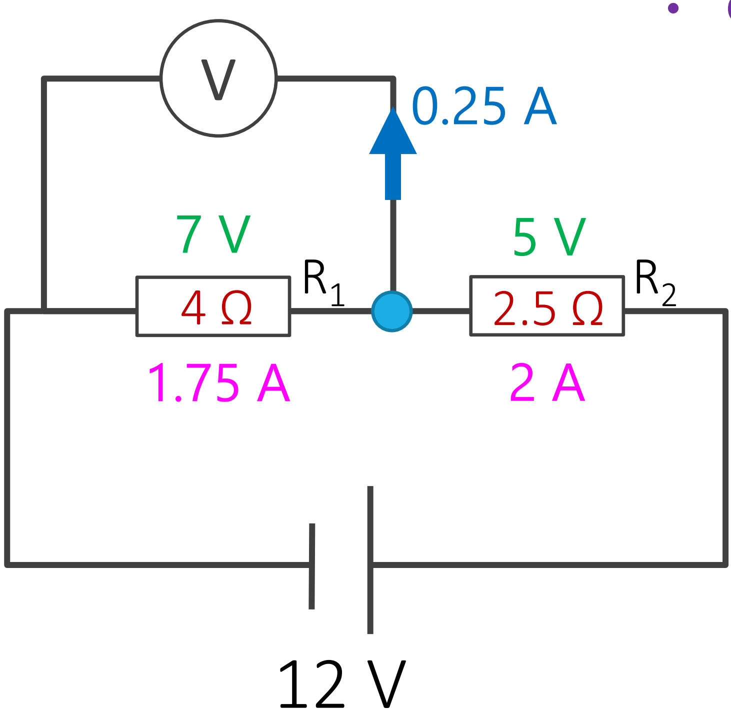
$$A = \mathbf{0.5\ \Omega}$$

Try This

Calculate the resistance of this non-ideal meter:

Voltmeter Reading	7 V

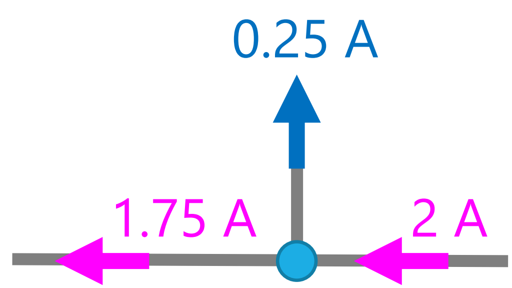
- Use voltage loops to calculate voltage for R_1 and R_2
- Calculate current for R_1 and R_2
- Use current junction to find current through meter
- Calculate resistance of voltmeter



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

$$R = \frac{V}{I} = \frac{7}{0.25}$$

$$R = \mathbf{28\ \Omega}$$



Lesson Takeaways

- ❑ I can connect a meter to measure current or voltage
- ❑ I can describe the conditions required for an ideal ammeter or voltmeter
- ❑ I can calculate for a situation when the meter isn't ideal

Batteries

IB PHYSICS | ELECTRICITY

Batteries

Primary Cells

One time use

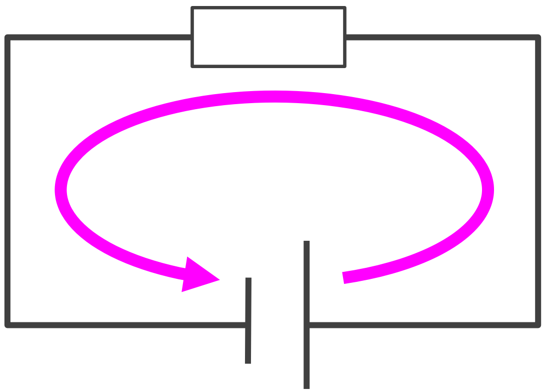
Secondary Cells

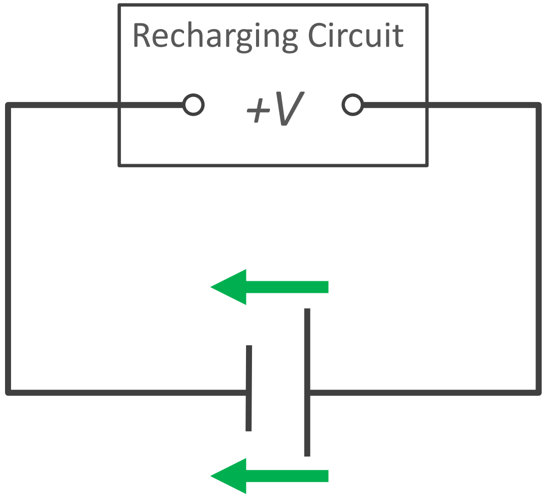
Rechargeable

Battery Shape	Chemistry	Nominal Voltage	Rechargable?
AA, AAA, C, and D	Alkaline or Zinc-carbon	1.5V	No
9V	Alkaline or Zinc-carbon	9V	No
Coin cell	Lithium	3V	No
Silver Flat Pack	Lithium Polymer (LiPo)	3.7V	Yes
AA, AAA, C, D (Rechargeable)	NiMH or NiCd	1.2V	Yes
Car battery	Six-cell lead-acid	12.6V	Yes

Recharging?

Some batteries can reverse the chemical reaction that produces the potential difference by passing a current through the battery in the opposite direction as it would normally travel



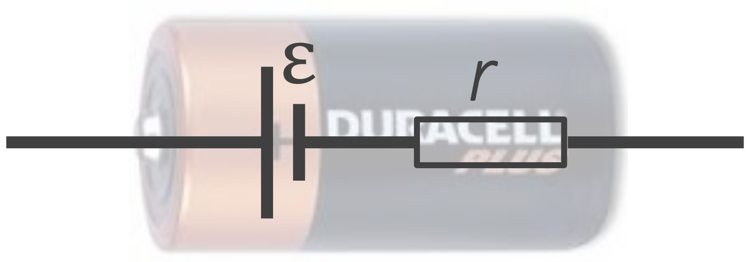


Batteries | emf

We've been describing batteries so far as the voltage that they provide to the circuit, but that's not the whole story…

Electromotive Force (emf)
The total energy transferred in the source per unit charge passing through it

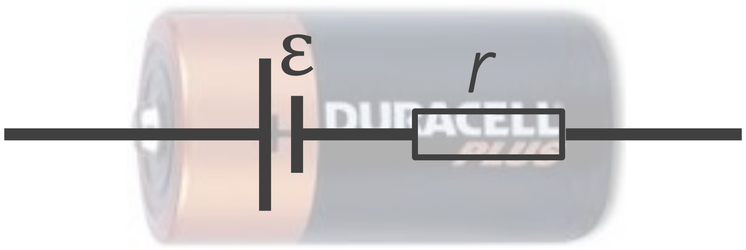
Symbol
ε



Unit
Volts [V]

Batteries | Internal Resistance

All batteries have some amount of internal resistance



Symbol
r

Unit
Ohms [Ω]

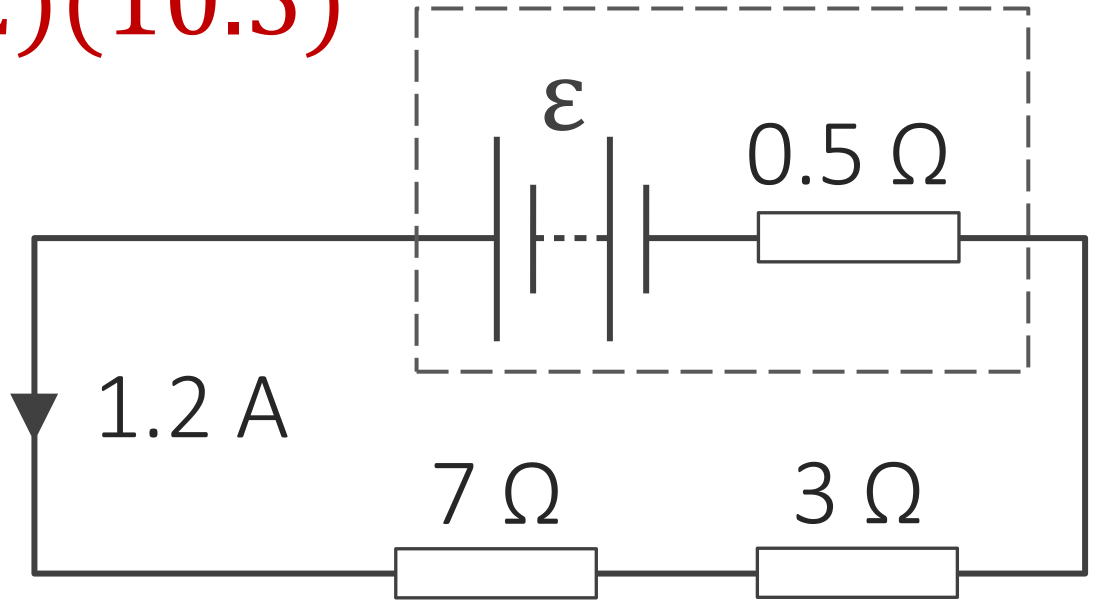
Batteries | emf

What is the emf for a battery shown below?

$$R_T = 7 + 3 + 0.5 = \mathbf{10.5\ \Omega}$$

$$\varepsilon = IR_T = (1.2)(10.5)$$

$$\varepsilon = \mathbf{12.6\ V}$$



IB Physics Data Booklet

Sub-topic 5.1 – Electric fields	Sub-topic 5.2 – Heating effect of electric currents
$I = \frac{\Delta q}{\Delta t}$ $F = k\frac{q_1 q_2}{r^2}$ $k = \frac{1}{4\pi\varepsilon_0}$ $V = \frac{W}{q}$ $E = \frac{F}{q}$ $I = nAvq$	Kirchhoff's circuit laws: $\Sigma V = 0$ (loop) $\Sigma I = 0$ (junction) $R = \frac{V}{I}$ $P = VI = I^2R = \frac{V^2}{R}$ $R_{\text{total}} = R_1 + R_2 + \cdots$ $\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$ $\rho = \frac{RA}{L}$
Sub-topic 5.3 – Electric cells	**Sub-topic 5.4 – Magnetic effects of electric currents**
$\varepsilon = I(R + r)$ Essentially the same as V = IR	$F = qvB\sin\theta$ $F = BIL\sin\theta$

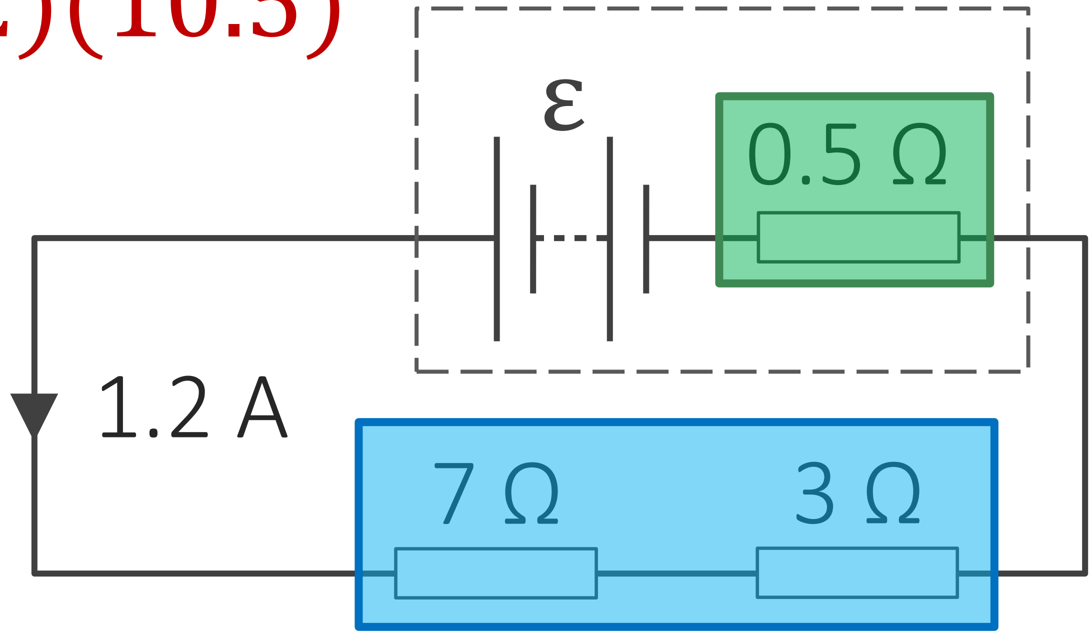
Batteries | emf

What is the emf for a battery shown below?

$$R_T = \underbrace{7 + 3}_{R} + \underbrace{0.5}_{r} = \mathbf{10.5\ \Omega}$$

$$\varepsilon = IR_T = (1.2)(10.5)$$

$$\boxed{\varepsilon = \mathbf{12.6\ V}}$$



Batteries | Terminal Voltage

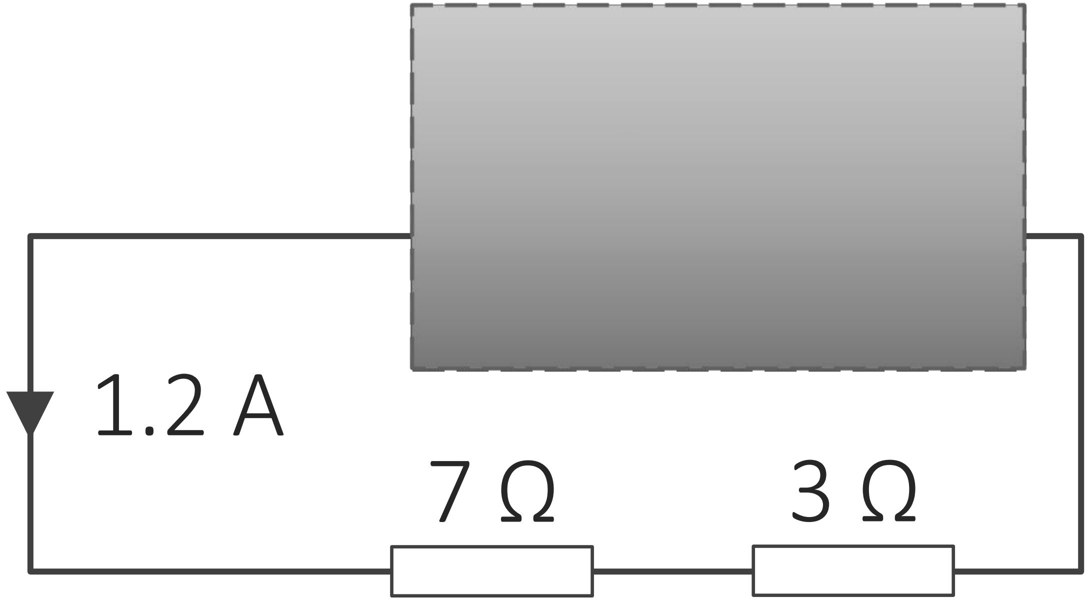
What is the terminal voltage for a battery shown below?

$$V_1 = IR = (1.2)(7) = 8.4 \text{ V}$$

$$V_2 = IR = (1.2)(3) = 3.6 \text{ V}$$

$$V_T = 8.4 \text{ V} + 3.6 \text{ V}$$

$$V_T = 12 \text{ V}$$



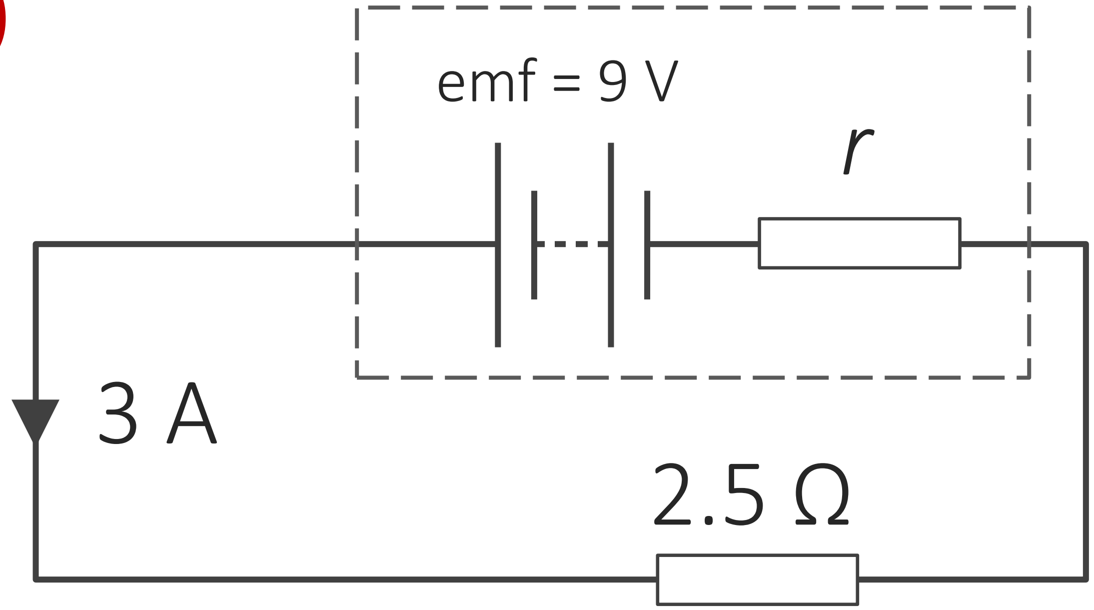
Batteries | Internal Resistance

What is the internal resistance of this battery as shown below?

$$\varepsilon = I(R + r)$$

$$9 = 3(2.5 + r)$$

$$\boldsymbol{r = 0.5\ \Omega}$$



Graphing Internal Resistance

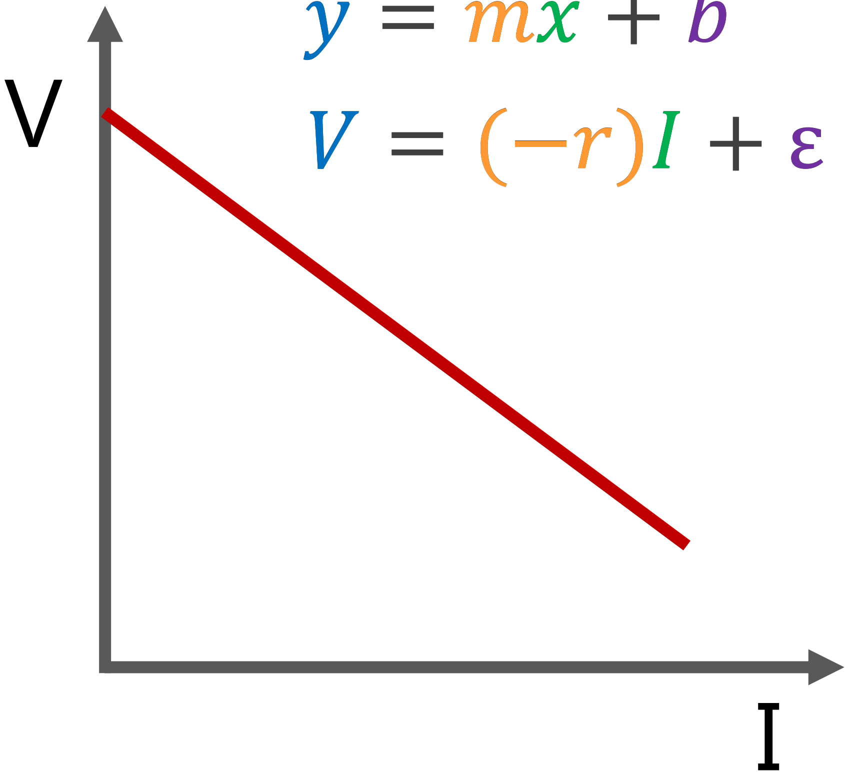
$$\varepsilon = I(R + r)$$

$$\varepsilon = IR + Ir$$

$$V = IR$$

$$\varepsilon = V + Ir$$

$$V = \varepsilon - Ir$$



$$y = mx + b$$

$$V = (-r)I + \varepsilon$$

Lesson Takeaways

- I can describe the difference between primary and secondary cells
- I can define the electromotive force and describe how is it is different than the battery's terminal voltage
- I can solve for a circuit that includes a battery with internal resistance
- I can describe how