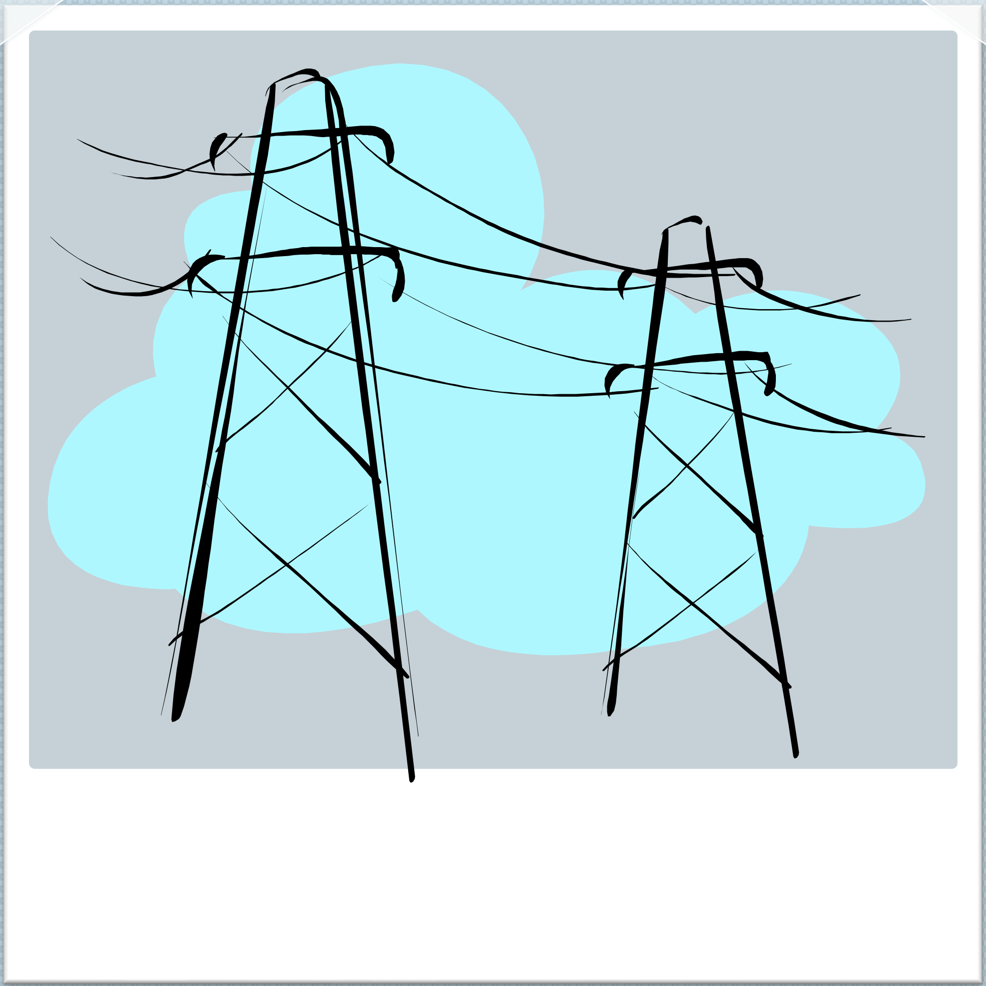


Voltage

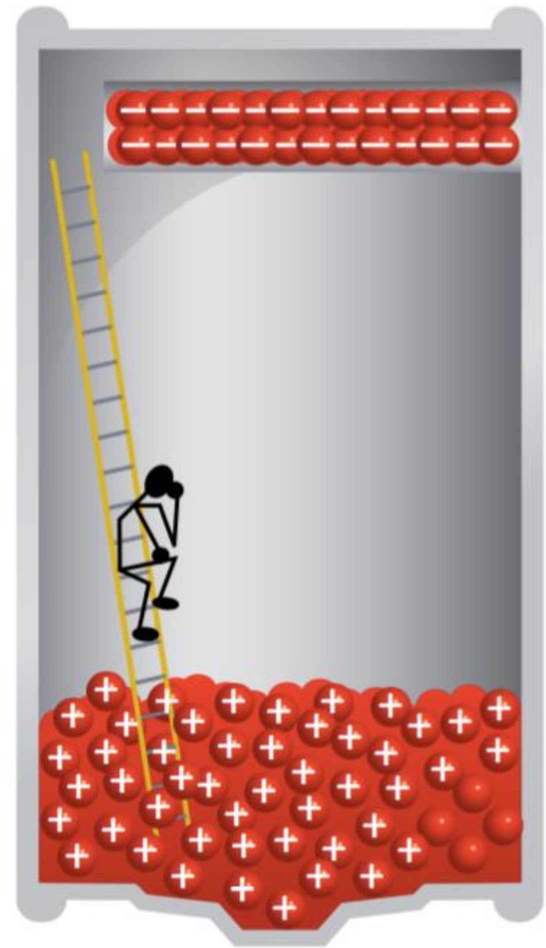
Energy is Required to do Work

- In science, energy is measured in **"Joules" (J)**
  - Your phone battery holds **~40,000 J** of energy!
  - Fun fact: a food "Calorie" is equal to 4184 J, so an egg holds **650,000 J** of energy!
- Energy sources provide electrons with energy to do **work** (e.g. lighting up a bulb, heating up a stove).

Understanding Potential Energy

Voltage Gain

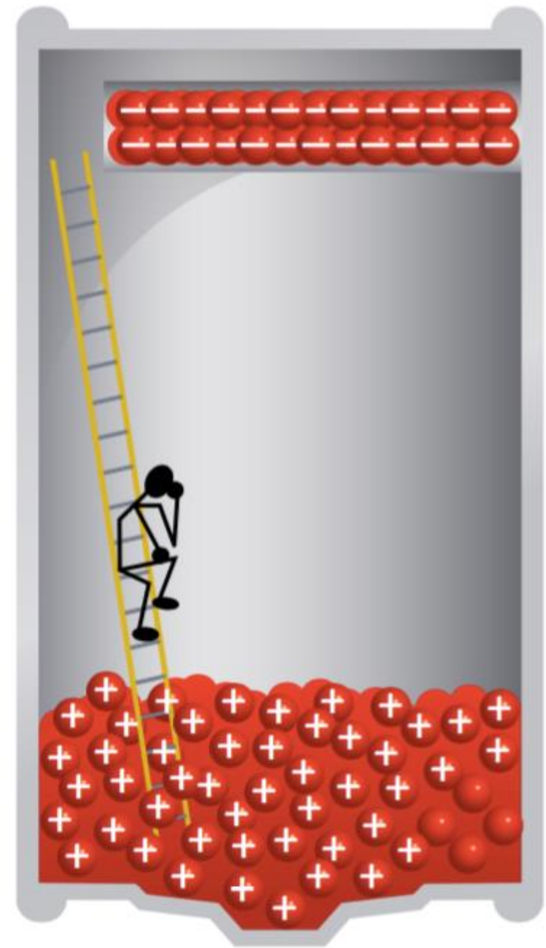
- Batteries give electrons a certain amount of **potential energy,** also known as **voltage (V)**.
- E.g. an AA or AAA battery has a potential energy difference of 1.5 V between its two terminals, so we call it a 1.5 V battery.



Understanding Potential Energy

Voltage Drop

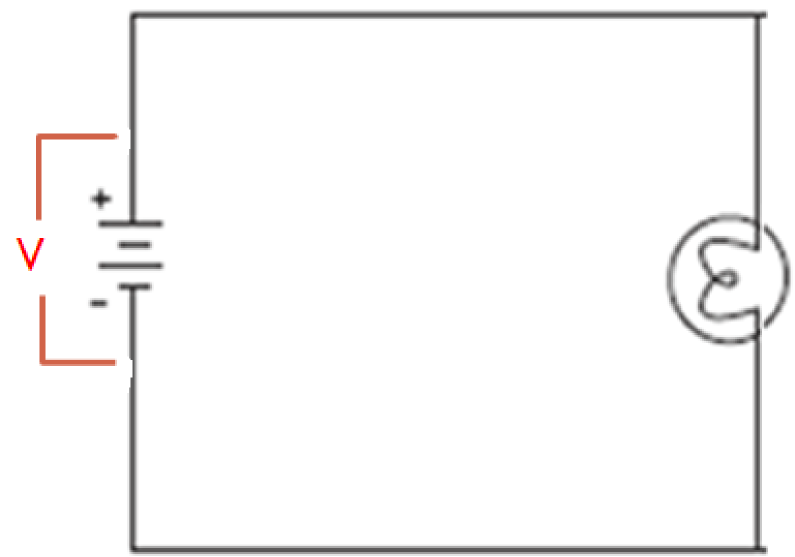
- When electrons go through a **load** (e.g. resistor, light bulb), they **lose energy**. Some loads may use more energy than others.
- On its journey around the circuit, an electron must use **all of its potential energy** before it returns to the positive terminal of the battery.



Measuring Changes in Potential Energy

- The voltage **difference** between two points on a circuit can be measured using a voltmeter.

- A voltmeter is always connected across the device, in **parallel.**



Voltage Calculations

- Voltage is measured in volts (V).
- Voltage is defined as the amount of Energy (J) carried by 1 Coulomb of electrons in a circuit.

$$V = \frac{E}{Q}$$

V = voltage in Volts (V)

E = energy in Joules (J)

Q = charge in Coulombs (C)

Voltage Calculations

Example 1: A light bulb is powered by 3 AA batteries. How much energy is delivered to the bulb if 20 C of charge is used?

$$V = \frac{E}{Q}$$

$$E = V \times Q$$

$$E = 4.5\ V \times 20\ C$$

$$E = 90\ J$$

Remember: each AA or AAA battery is 1.5V.
So 3 batteries is:
1.5 V x 3 = 4.5 V

Voltage Calculations

Example 2: A car battery is 12 V and sends out 28 kJ of energy. How much electric charge does the battery hold?

$$V = \frac{E}{Q}$$

$$Q = \frac{E}{V}$$

$$Q = \frac{28{,}000\ J}{12\ V}$$

$$Q = 2333\ C$$

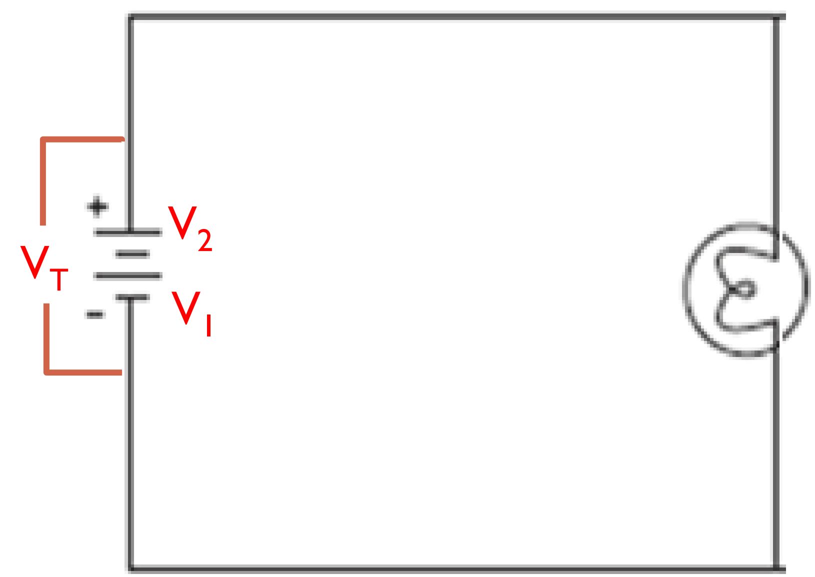
Remember: 'kilo-' in the metric system means 1000.
So 1kJ=1000J.

CIRCUITS AND VOLTAGE

Cells in SERIES

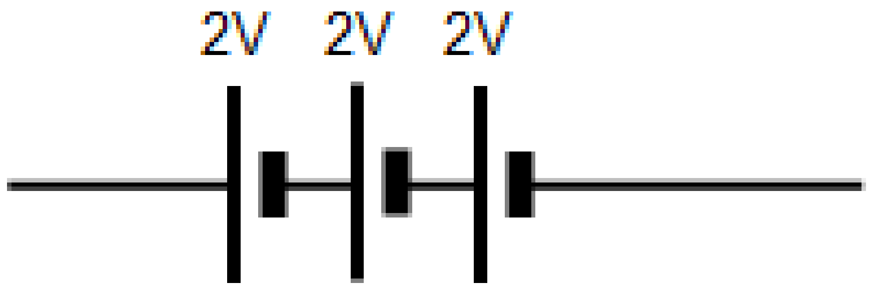
- When cells are connected in series, we can find the total amount of voltage by just adding them together.

- $V_T = V_1 + V_2 + \ldots$



Cells in SERIES

Example: Calculate the total voltage of this battery made of three, 2-volt cells.



$V_T = V_1 + V_2 + V_3$

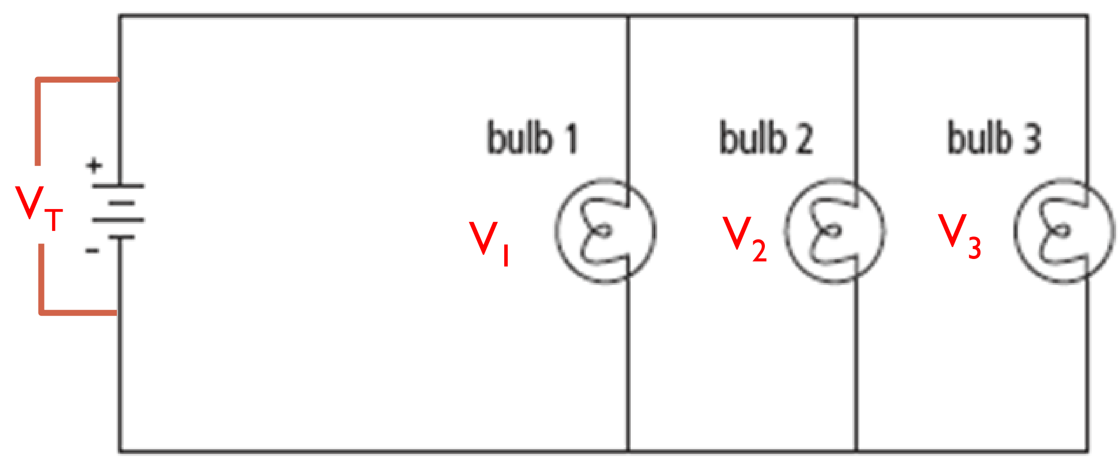
$V_T = 2V + 2V + 2V$

$V_T = 6V$

This is a 6 Volt battery!

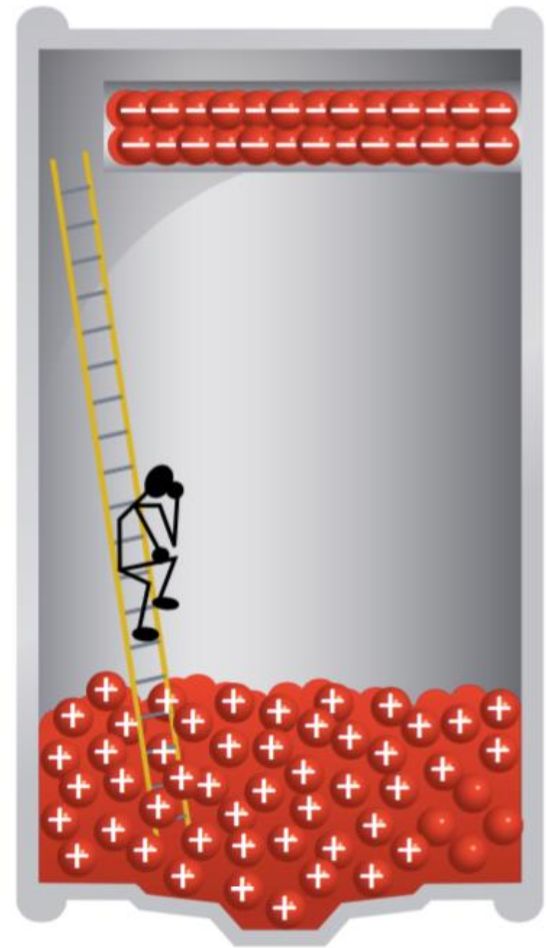
Cells in PARALLEL

- When cells are combined in parallel, the voltage does not increase but the amount of charge (current) does
- **Advantages**: greater current or longer battery life
- $V_T = V_1 = V_2 = V_3$



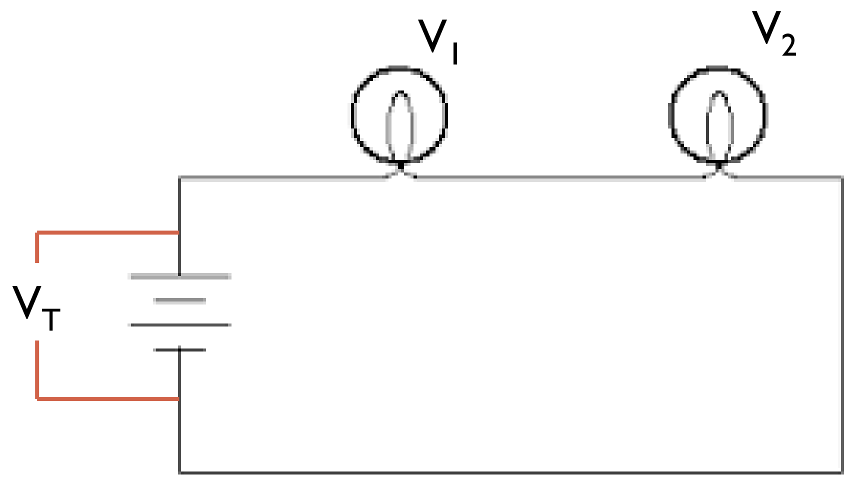
Review:
Understanding Potential Energy

- On its journey around the circuit, an electron must use **all of its potential energy** before it gets back to the positive terminal of the battery.
- Some parts of the journey take up more energy than others.

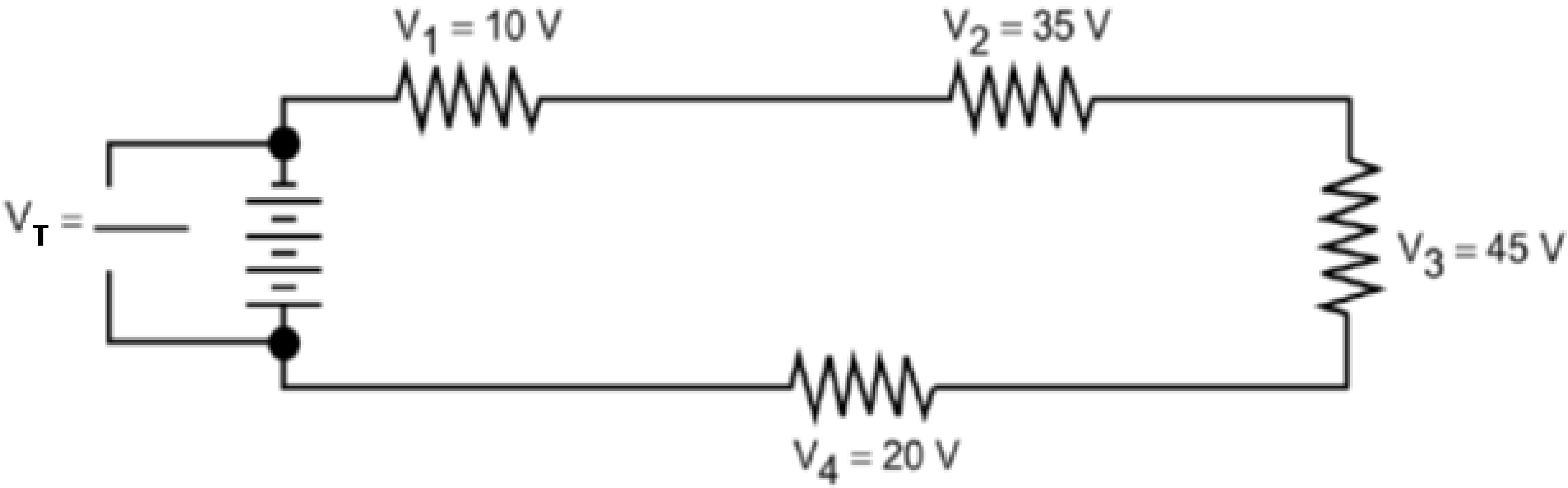


Loads Connected in Series

- The total voltage gained from the battery should be equal to the total voltage dropped from all the loads combined.
- $V_T = V_1 + V_2 + \ldots$



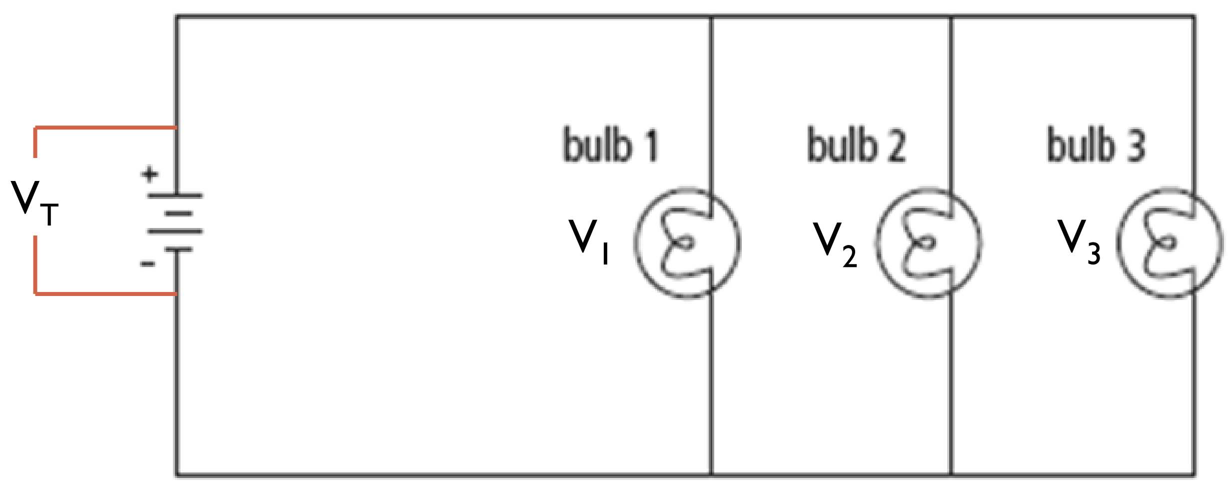
Example #1



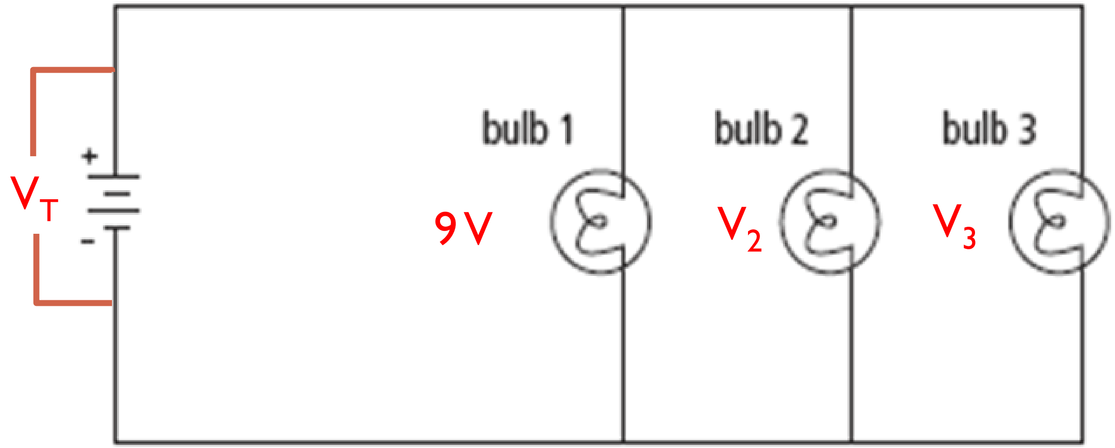
- What is V_T?
- $V_T = V_1 + V_2 + V_3 + V_4$
- $V_T = 10 + 35 + 45 + 20$
- $V_T = 110 V$

Loads Connected in Parallel

- When electrons go through devices in parallel, they split at junction points.
- Each load in parallel will receive the same amount of energy/Voltage.
- $\mathbf{V_T = V_1 = V_2 = V_3 \ldots}$



Example #2



Calculate V_T , V_2 , V_3

$V_T = V_1 = V_2 = V_3$

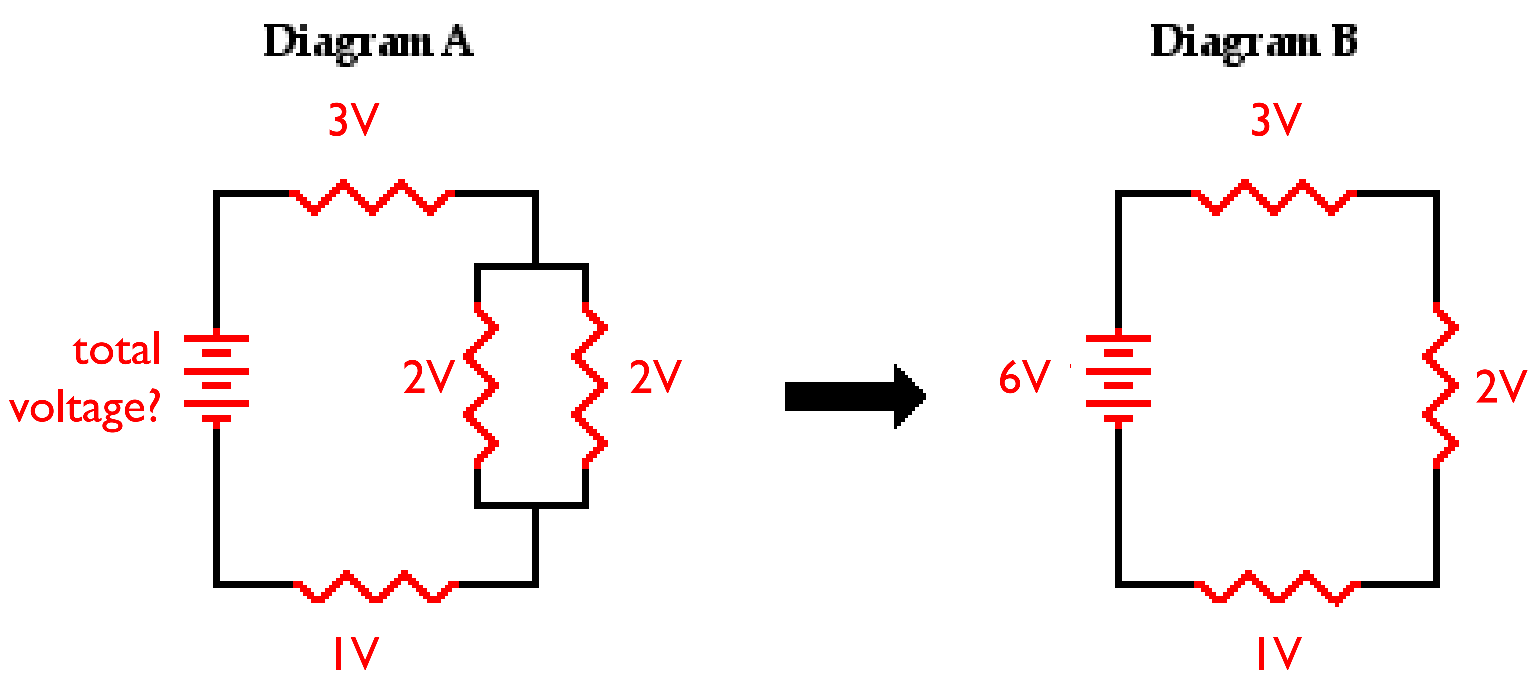
$= 9\,V$

Summary

Type of Circuit	Series	Parallel
Total Current (I_T)	$I_T = I_1 = I_2 = I_3$	$I_T = I_1 + I_2 + I_3$
Total Voltage (V_T)	$V_T = V_1 + V_2 + V_3$	$V_T = V_1 = V_2 = V_3$

Loads Connected in Series *and* Parallel (just for fun)

- Treat the parallel component as a single component of the larger series.



$V_t = 3V + 2V + 1V = 6V$