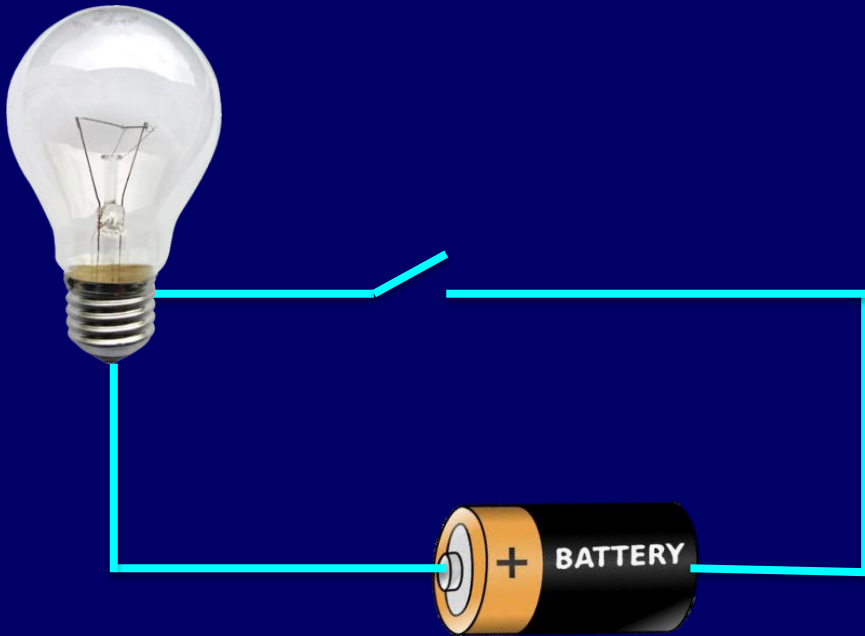


# Physics 102: Lecture 05

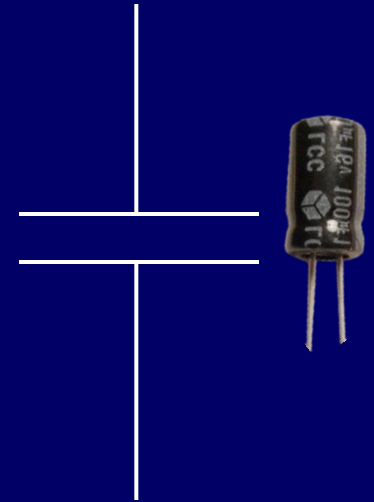
## Circuits and Ohm's Law



# Summary of Last Time

- **Capacitors**

- Physical  $C = \kappa \epsilon_0 A/d$   $C=Q/V$
- Series  $1/C_{eq} = 1/C_1 + 1/C_2$
- Parallel  $C_{eq} = C_1 + C_2$
- Energy  $U = 1/2 QV$



# Summary of Today

- **Resistors**

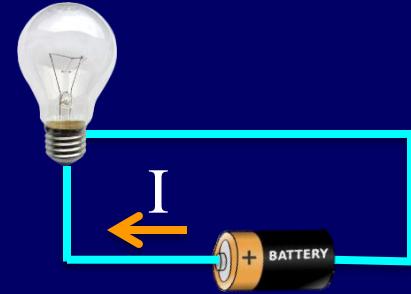
- Physical  $R = \rho L/A$   $V=IR$
- Series  $R_{eq} = R_1 + R_2$
- Parallel  $1/R_{eq} = 1/R_1 + 1/R_2$
- Power  $P = IV$



# Electric Terminology

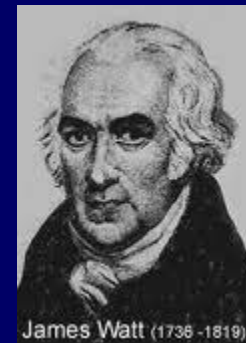
- **Current: Moving Charges**

- Symbol: **I**
- Unit: **Amp**  $\equiv$  Coulomb/second
- Count number of charges which pass point/sec
- Direction of current is direction that + charge flows



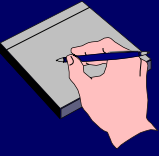
- **Power: Energy/Time**

- Symbol: **P**
- Unit: **Watt**  $\equiv$  Joule/second =  
Volt Coulomb/sec
- $P = VI$



**60 W = 60 J/s**

# Physical Resistor



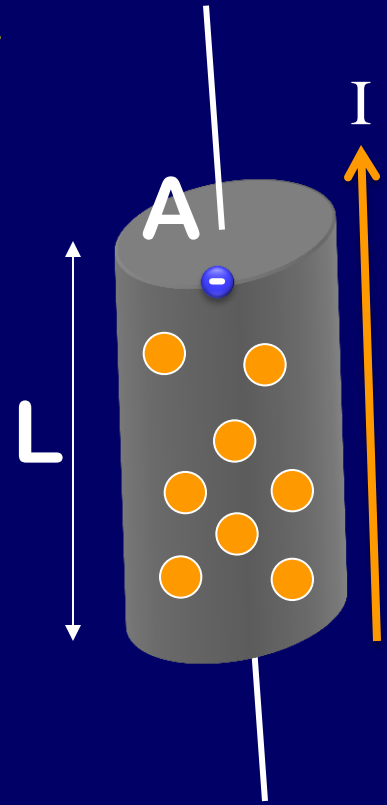
- Resistance: Traveling through a resistor, electrons bump into things which slows them down.

$$R = \rho L / A \quad \text{Units: Ohms } \Omega$$

- $\rho$ : Resistivity: Density of scatterers
- $L$ : Length of resistor
- $A$ : Cross sectional area of resistor

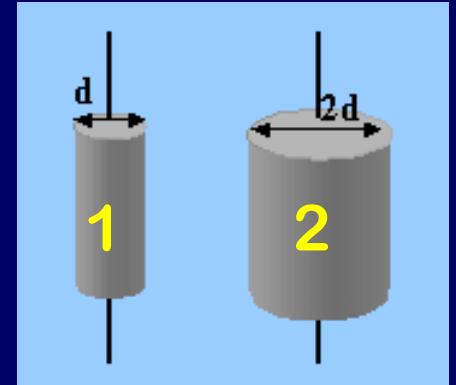
- Ohms Law  $I = V/R$

- Cause and effect (sort of like  $a=F/m$ )
  - potential difference cause current to flow
  - resistance regulate the amount of flow
- Double potential difference  $\Rightarrow$  double current
- $I = (VA) / (\rho L)$



# CheckPoint 1.1

Two cylindrical resistors are made from the same material. They are of equal length but one has twice the diameter of the other.



51% 1.  $R_1 > R_2$

10% 2.  $R_1 = R_2$

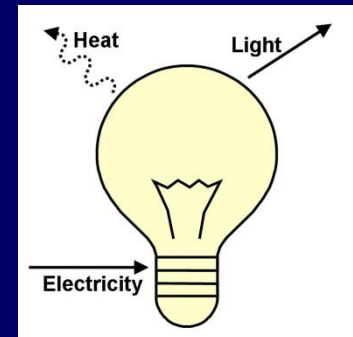
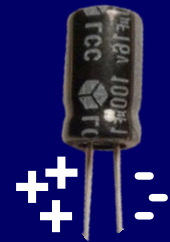
39% 3.  $R_1 < R_2$

$$R = \rho L / A$$

# Comparison:

## *Capacitors vs. Resistors*

- Capacitors *store* energy as separated charge:  $U=QV/2$ 
  - Capacitance: ability to store separated charge:  
 $C = \kappa \epsilon_0 A/d$
  - Voltage drop determines *charge*:  $V=Q/C$
- Resistors *dissipate* energy as power:  $P=VI$ 
  - Resistance: how difficult it is for charges to get through:  
 $R = \rho L / A$
  - Voltage drop determines *current*:  $V=IR$
- Don't mix capacitor and resistor equations!

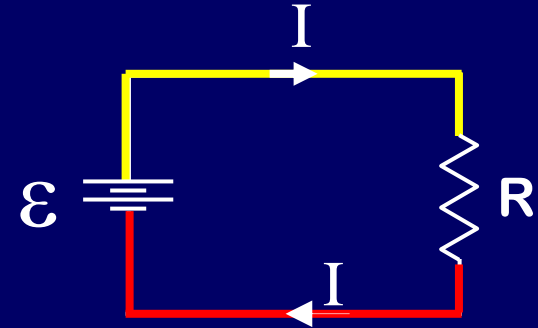
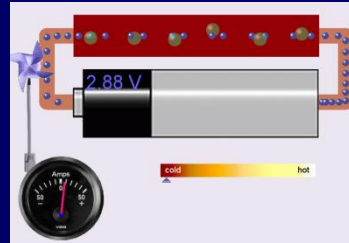


# Example



## Simple Circuit

- Phet Visualization
- Practice...



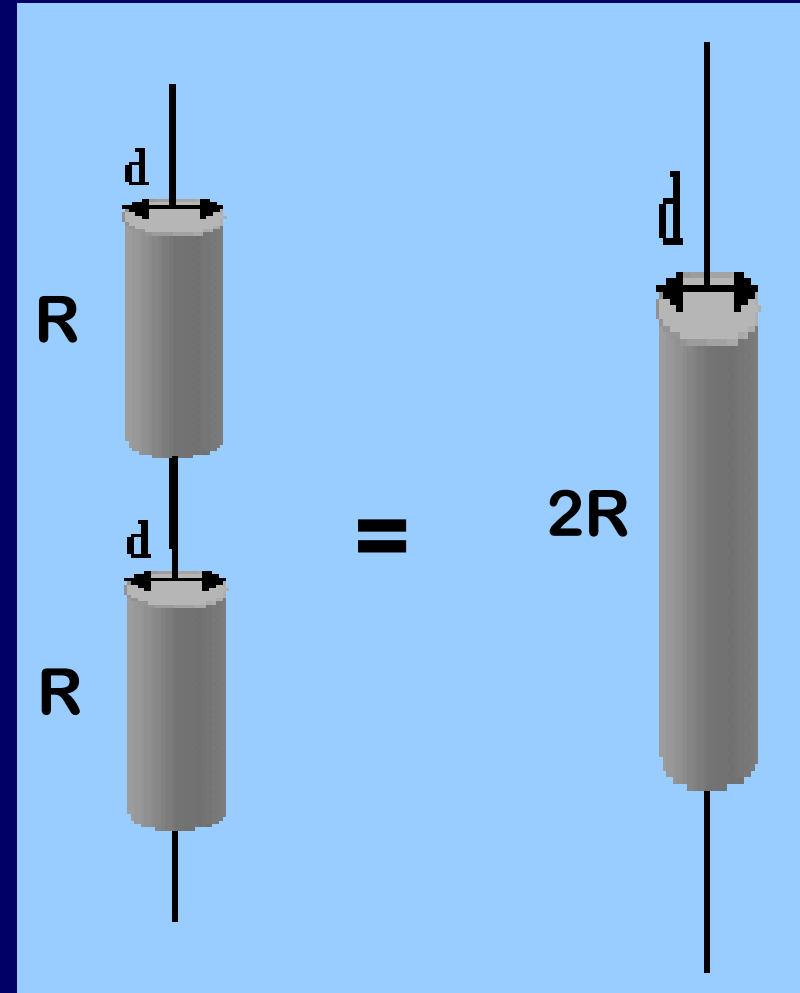
- Calculate  $I$  when  $\mathcal{E}=24$  Volts and  $R = 8 \Omega$
- Ohm's Law:  $V = IR$

$$I = V/R = 3 \text{ Amps}$$

# Resistors in Series

- One wire:
  - Effectively adding lengths:
    - $R_{eq} = \rho(L_1 + L_2)/A$
  - Since  $R \propto L$  add resistance:

$$R_{eq} = R_1 + R_2$$





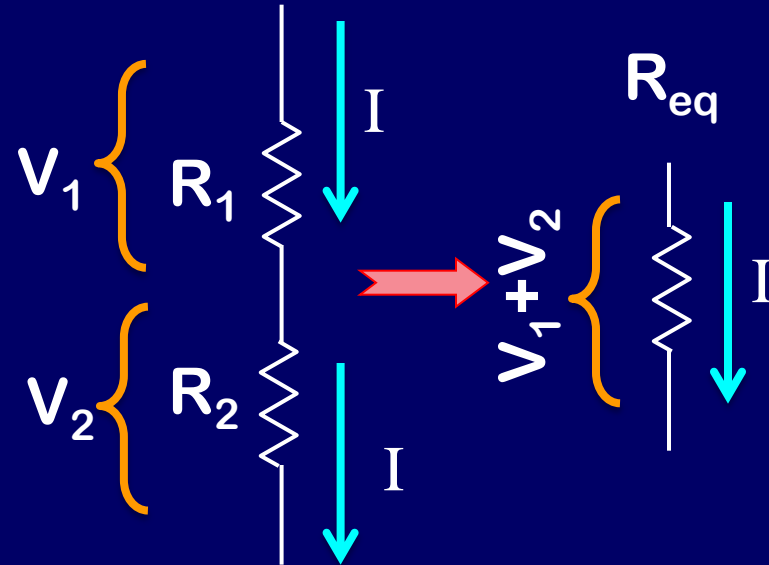
# Resistors in Series

- Resistors connected end-to-end:
  - If charge goes through one resistor, it must go through other.

$$I_1 = I_2 = I_{eq}$$

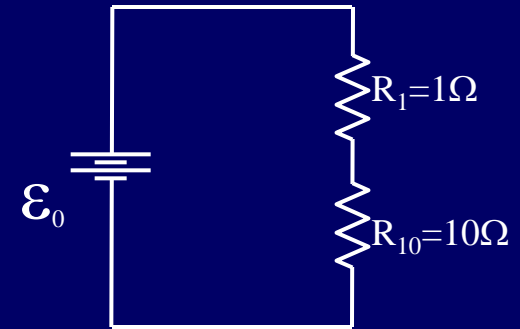
- Both have voltage drops:

$$V_1 + V_2 = V_{eq}$$



# CheckPoint 2.1

Compare  $I_1$  the current through  $R_1$ , with  $I_{10}$  the current through  $R_{10}$ .



18% 1.  $I_1 < I_{10}$

51% 2.  $I_1 = I_{10}$  "charge goes through one resistor, it must go through the other, making the I's equal."

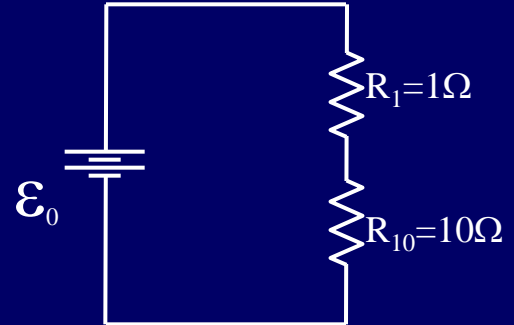
31% 3.  $I_1 > I_{10}$

Note:  $I$  is the same everywhere in this circuit!



# ACT: Series Circuit

Compare  $V_1$  the voltage across  $R_1$ , with  $V_{10}$  the voltage across  $R_{10}$ .



1.  $V_1 > V_{10}$

2.  $V_1 = V_{10}$

3.  $V_1 < V_{10}$

$$V_1 = I_1 R_1 = I \times 1$$

$$V_{10} = I_{10} R_{10} = I \times 10$$

# Example

## Practice: Resistors in Series

Calculate the voltage across each resistor if the battery has potential  $\varepsilon_0 = 22$  volts.

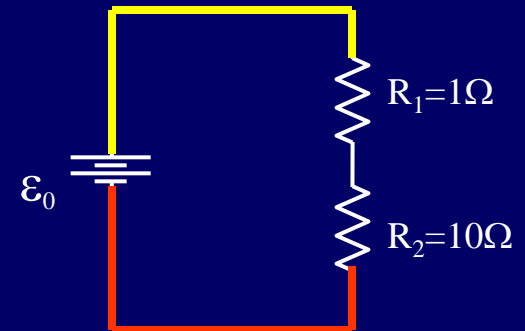
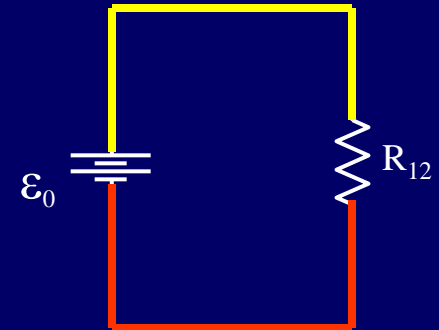
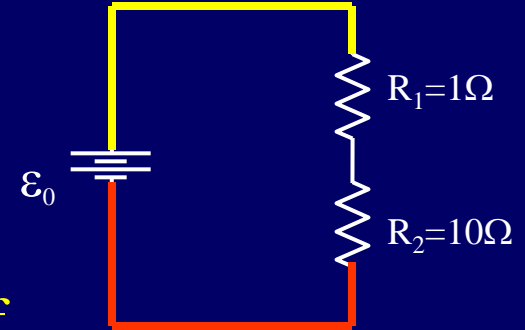
Simplify ( $R_1$  and  $R_2$  in series):

- $R_{12} = R_1 + R_2 = 11 \Omega$
- $V_{12} = V_1 + V_2 = \varepsilon_0 = 22 \text{ Volts}$
- $I_{12} = I_1 = I_2 = V_{12}/R_{12} = 2 \text{ Amps}$

Expand:

- $V_1 = I_1 R_1 = 2 \times 1 = 2 \text{ Volts}$
- $V_2 = I_2 R_2 = 2 \times 10 = 20 \text{ Volts}$

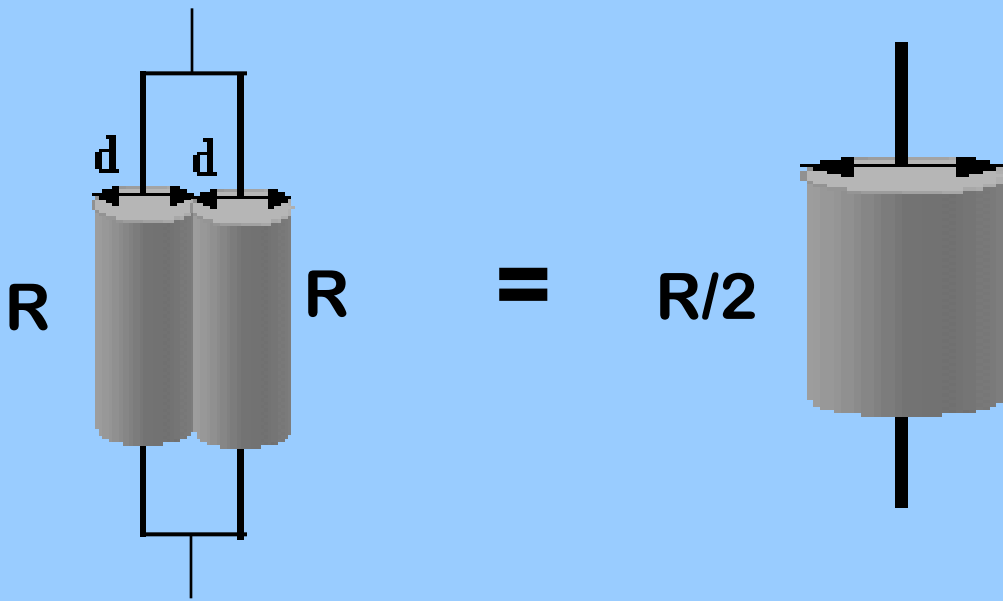
Check:  $V_1 + V_2 = V_{12} ?$



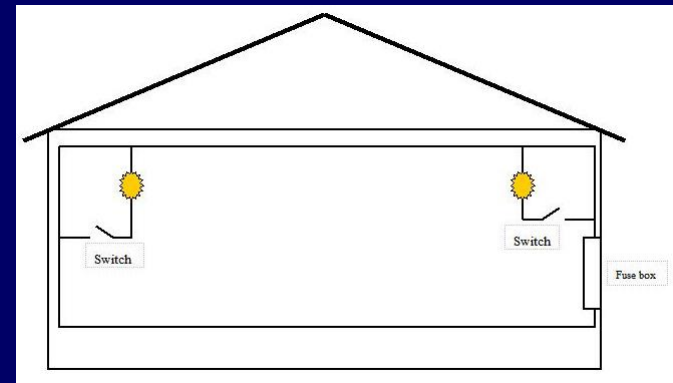
# Resistors in Parallel

- Two wires:
  - Effectively adding the Area
  - Since  $R \propto 1/A$  add  $1/R$ :

$$1/R_{eq} = 1/R_1 + 1/R_2$$



Used in your house!



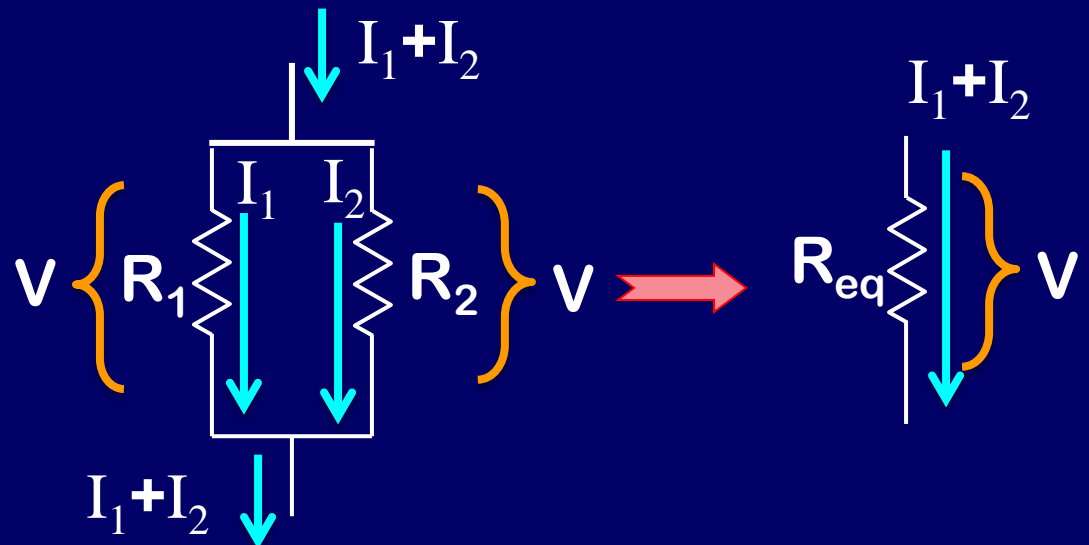
# Resistors in Parallel

- Both ends of resistor are connected:
  - Current is split between two wires:

$$I_1 + I_2 = I_{eq}$$

- Voltage is same across each:

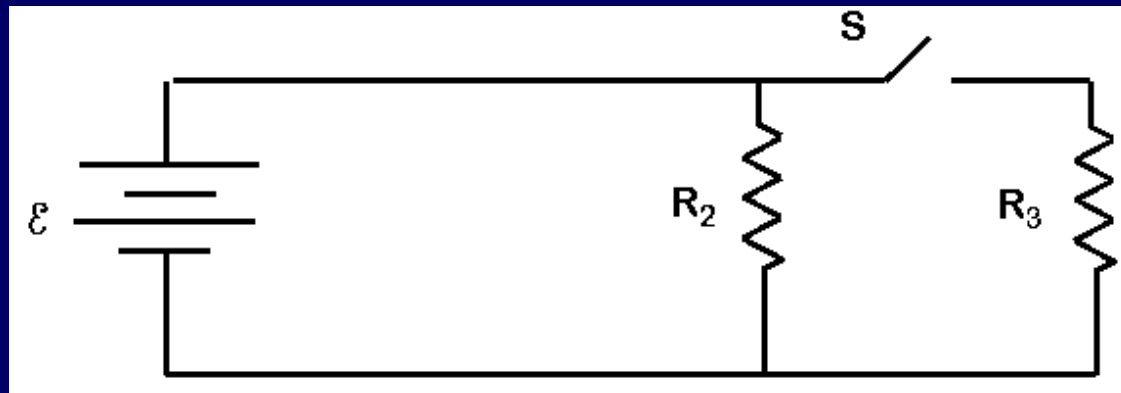
$$V_1 = V_2 = V_{eq}$$



# CheckPoint 3.1

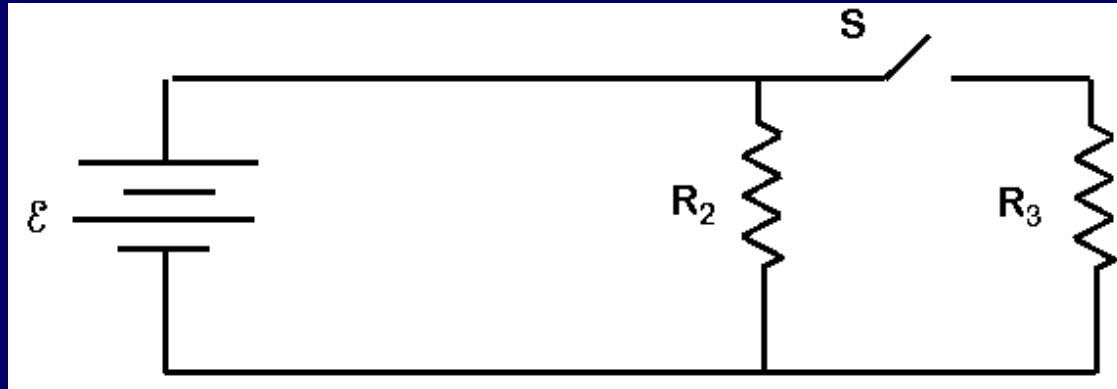
What happens to the current through  $R_2$  when the switch is closed?

- 29% • Increases
- 32% • Remains Same
- 39% • Decreases





# ACT: Parallel Circuit



What happens to the current through the battery when the switch is closed?

- (A) Increases
- (B) Remains Same
- (C) Decreases

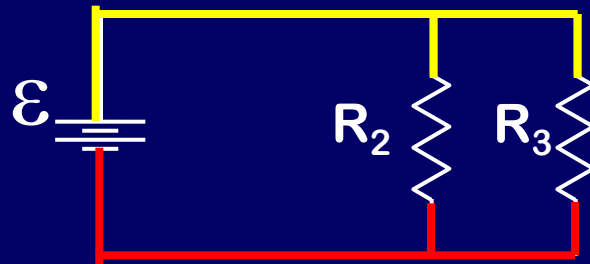
$$I_{\text{battery}} = I_2 + I_3$$



# Example



## Practice: Resistors in Parallel



Determine the current through the battery.

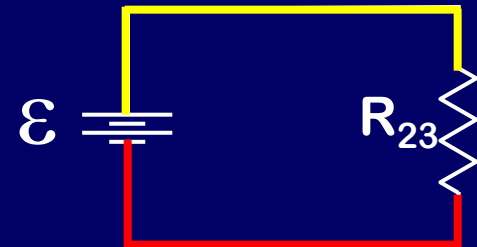
Let  $\mathcal{E} = 60$  Volts,  $R_2 = 20\ \Omega$  and  $R_3 = 30\ \Omega$ .

Simplify:  $R_2$  and  $R_3$  are in parallel

$$1/R_{23} = 1/R_2 + 1/R_3 \quad R_{23} = 12\ \Omega$$

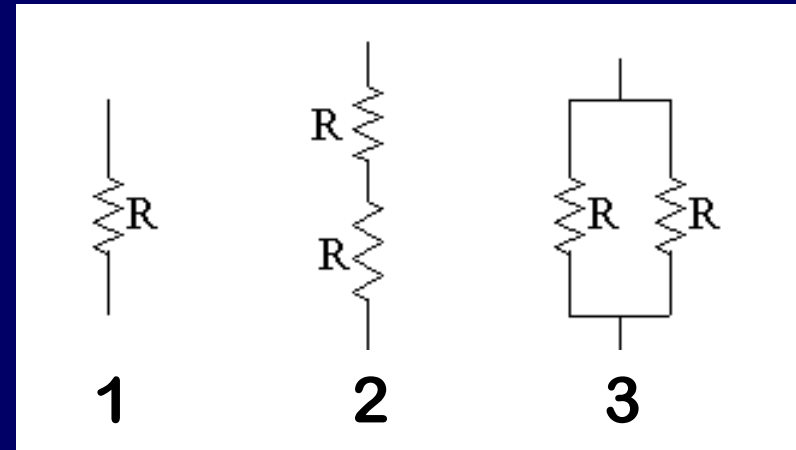
$$V_{23} = V_2 = V_3 = 60\text{ Volts}$$

$$I_{23} = I_2 + I_3 = V_{23} / R_{23} = 5\text{ Amps}$$





# ACT / CheckPoint 4.1,4.2



$R$

$2R$

$R/2$

Which configuration has the **smallest** resistance?

42% A. 1

5% B. 2

52% C. 3

Which configuration has the **largest** resistance?

B. 2

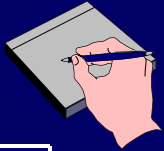
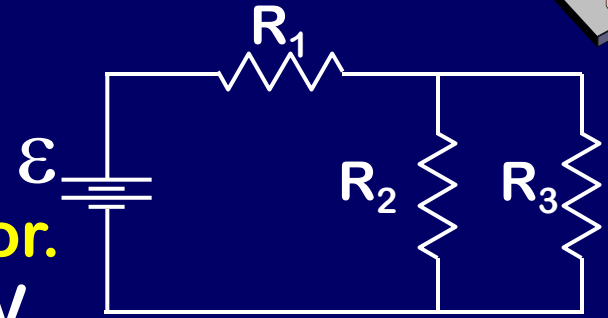
69%

# Example

## Try it!

Calculate current through each resistor.

$R_1 = 10 \Omega$ ,  $R_2 = 20 \Omega$ ,  $R_3 = 30 \Omega$ ,  $\mathcal{E} = 44 \text{ V}$

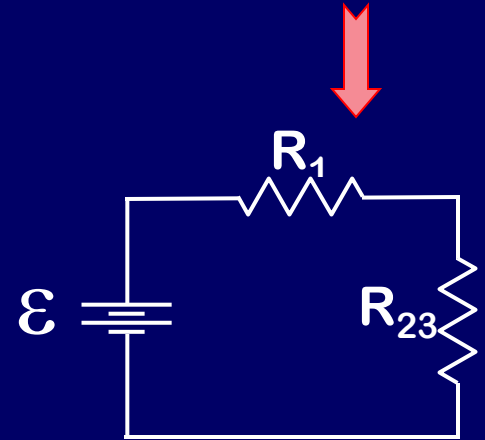


Simplify:  $R_2$  and  $R_3$  are in parallel

$$1/R_{23} = 1/R_2 + 1/R_3 \quad : R_{23} = 12 \Omega$$

$$V_{23} = V_2 = V_3$$

$$I_{23} = I_2 + I_3$$

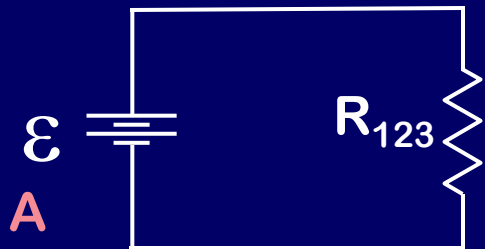


Simplify:  $R_1$  and  $R_{23}$  are in series

$$R_{123} = R_1 + R_{23} \quad : R_{123} = 22 \Omega$$

$$V_{123} = V_1 + V_{23} = \mathcal{E}$$

$$I_{123} = I_1 = I_{23} = I_{\text{battery}} \quad : I_{123} = 44 \text{ V} / 22 \Omega = 2 \text{ A}$$



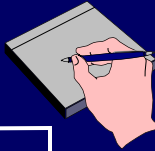
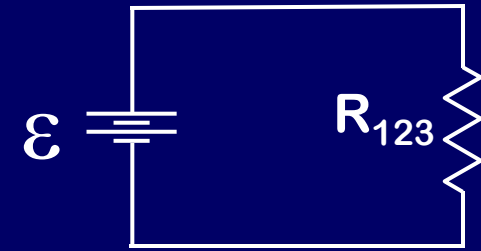
Power delivered by battery?  $P = IV = 2 \times 44 = 88 \text{ W}$

# Example

## Try it! (cont.)

**Calculate current through each resistor.**

$$R_1 = 10 \, \Omega, R_2 = 20 \, \Omega, R_3 = 30 \, \Omega, \mathcal{E} = 44 \, \text{V}$$



**Expand:  $R_1$  and  $R_{23}$  are in series**

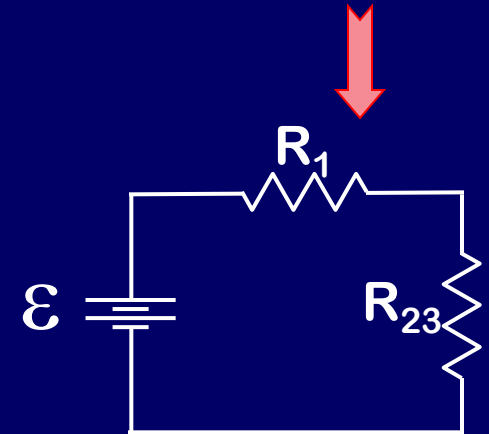
$$R_{123} = R_1 + R_{23}$$

$$: I_{23} = 2 \, \text{A}$$

$$V_{123} = V_1 + V_{23} = \mathcal{E}$$

$$: V_{23} = I_{23} R_{23} = 24 \, \text{V}$$

$$I_{123} = I_1 = I_{23} = I_{\text{battery}}$$



**Expand:  $R_2$  and  $R_3$  are in parallel**

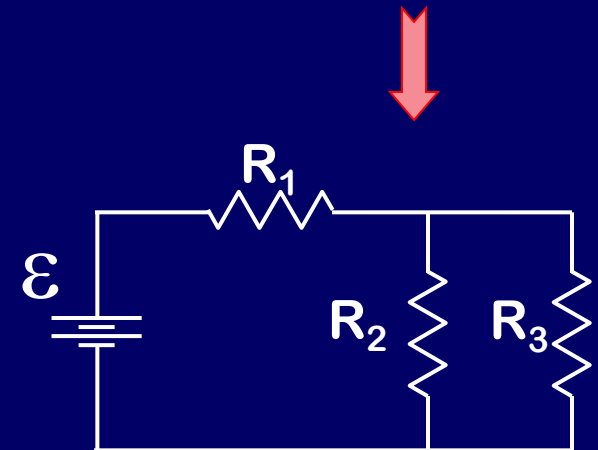
$$1/R_{23} = 1/R_2 + 1/R_3$$

$$V_{23} = V_2 = V_3$$

$$I_{23} = I_2 + I_3$$

$$I_2 = V_2/R_2 = 24/20 = 1.2 \, \text{A}$$

$$I_3 = V_3/R_3 = 24/30 = 0.8 \, \text{A}$$

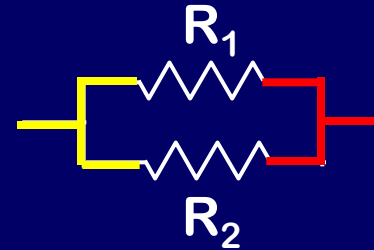


# Summary

## Series



## Parallel



### Wiring

Each resistor on the same wire.

Each resistor on a different wire.

### Voltage

Different for each resistor.

$$V_{\text{total}} = V_1 + V_2$$

Same for each resistor.

$$V_{\text{total}} = V_1 = V_2$$

### Current

Same for each resistor

$$I_{\text{total}} = I_1 = I_2$$

Different for each resistor

$$I_{\text{total}} = I_1 + I_2$$

### Resistance

Increases

$$R_{\text{eq}} = R_1 + R_2$$

Decreases

$$1/R_{\text{eq}} = 1/R_1 + 1/R_2$$