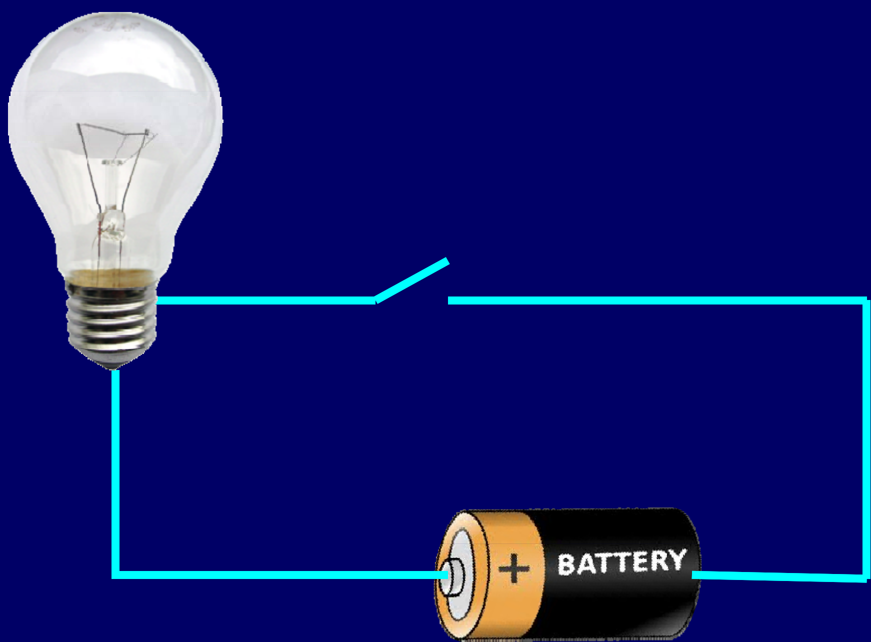
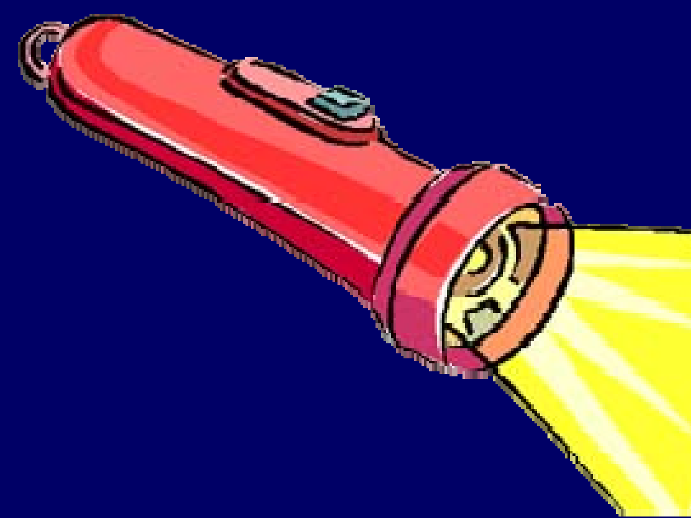
Physics 102: Lecture 05

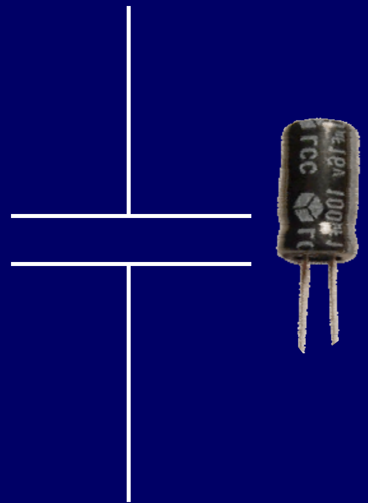
Circuits and Ohm's Law





Summary of Last Time

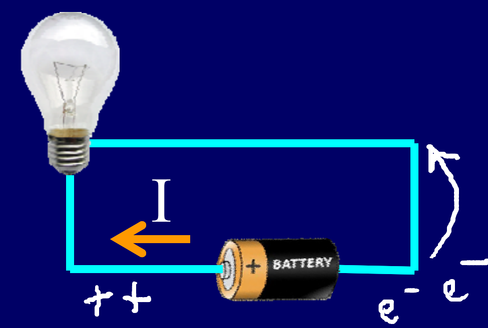
- **Capacitors**
  - Physical $C = \kappa\varepsilon_0 A/d \quad C=Q/V$
  - Series $1/C_{eq} = 1/C_1 + 1/C_2$
  - Parallel $C_{eq} = C_1 + C_2$
  - Energy $U = 1/2\ QV$



Summary of Today

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

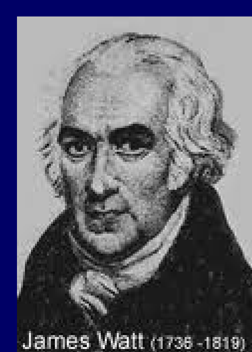
Electric Terminology



- Current: Moving Charges
  - Symbol: I
  - Unit: Amp ≡ Coulomb/second
  - Count number of charges which pass point/sec
  - Direction of current is direction that + charge flows
- Power: Energy/Time
  - Symbol: P

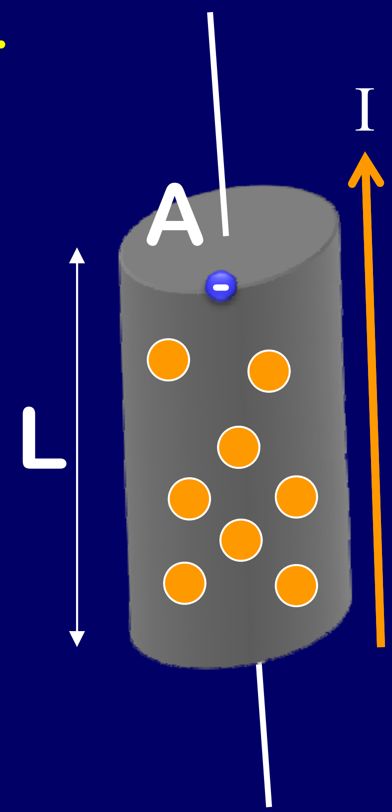
    U = qV
  - Unit: Watt ≡ Joule/second =

    Volt Coulomb/sec
  - P = VI



60 W= 60 J/s

Physical Resistor

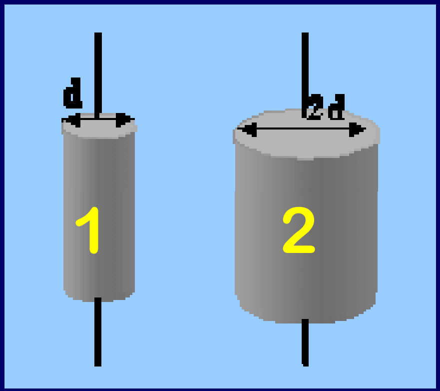


- Resistance: Traveling through a resistor, electrons bump into things which slows them down.

  $R = \rho L / A$ **Units: Ohms Ω**
  - ρ: 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 ⇒ 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.

61% 1. $R_1 > R_2$

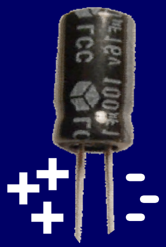
7% 2. $R_1 = R_2$

32% 3. $R_1 < R_2$

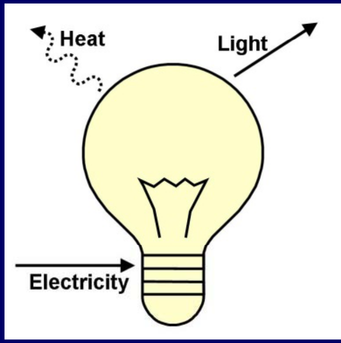
$R = \rho L / A$

Comparison:
Capacitors vs. *Resistors*

- Capacitors *store* energy as separated charge: U=QV/2
  - Capacitance: ability to store separated charge:
    $C = \kappa\varepsilon_0 A/d$
  - 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

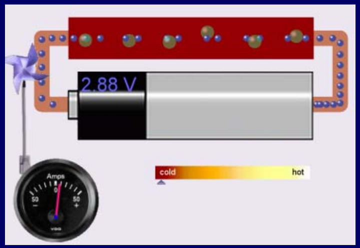


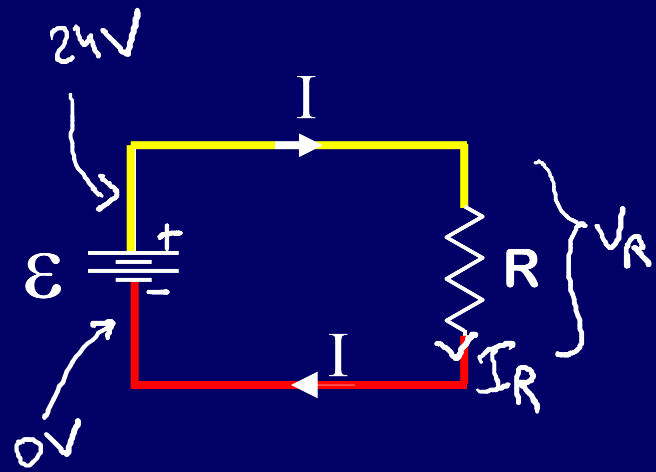
- Don't mix capacitor and resistor equations!

Example

Simple Circuit

- Phet Visualization





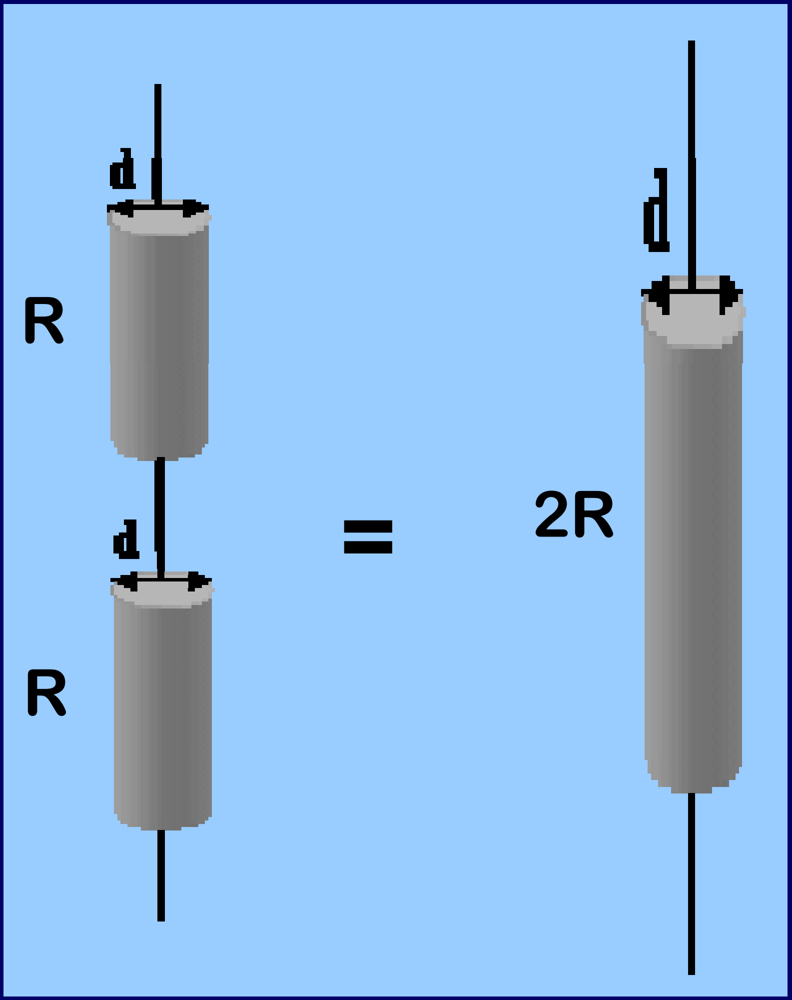
- Practice…
  - Calculate I when ε=24 Volts and R = 8 Ω
  - Ohm's Law: $V_R = I_R R$

I = V/R = 3 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.

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

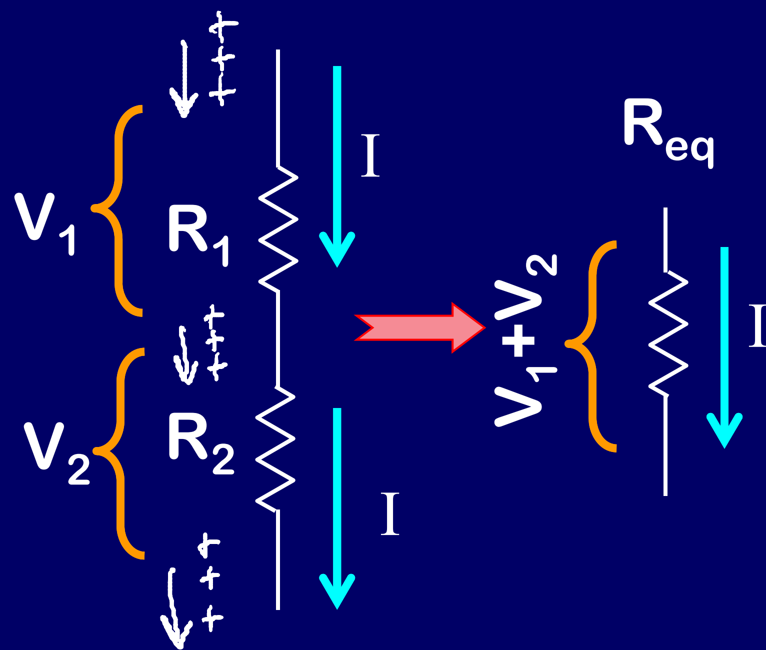
  - Both have voltage drops:

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

$R = V/I$

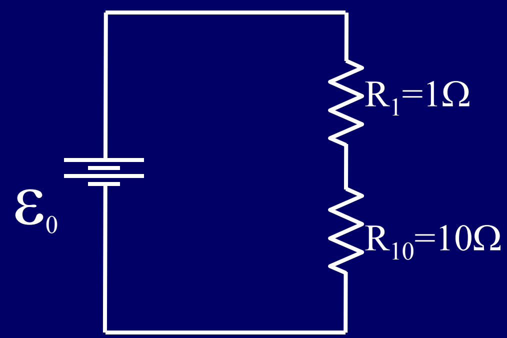
$$\frac{V_1}{I_1} + \frac{V_2}{I_2} = \frac{V_{eq}}{I_{eq}}$$

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



CheckPoint 2.1

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



13% 1. $I_1 < I_{10}$

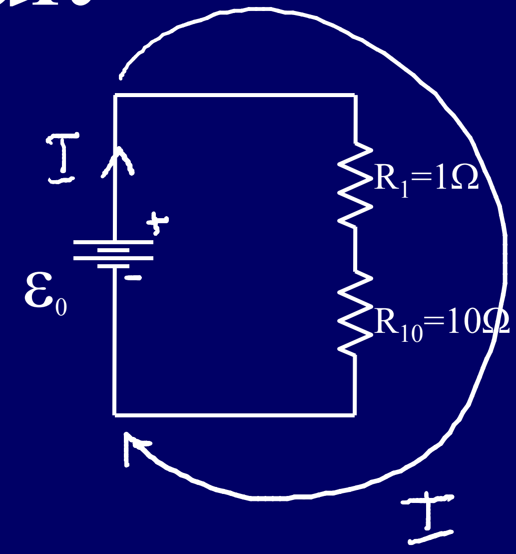
51% 2. $I_1 = I_{10}$

36% 3. $I_1 > I_{10}$

"Since they are connected in series, the current is the same for every resistor. If charge goes through one resistor, it must go through other."

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}.

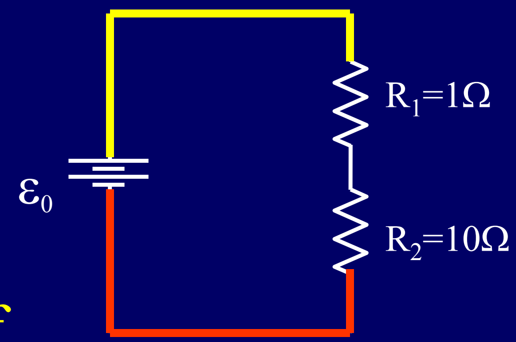
1. $V_1 > V_{10}$
2. $V_1 = V_{10}$
3. $V_1 < V_{10}$

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

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

Example

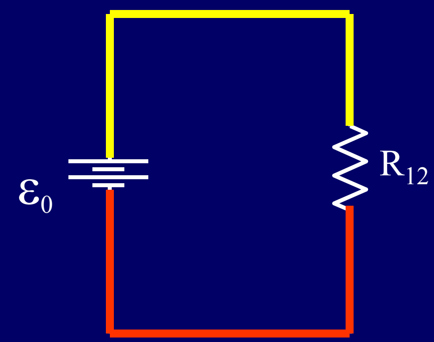
Practice: Resistors in Series



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

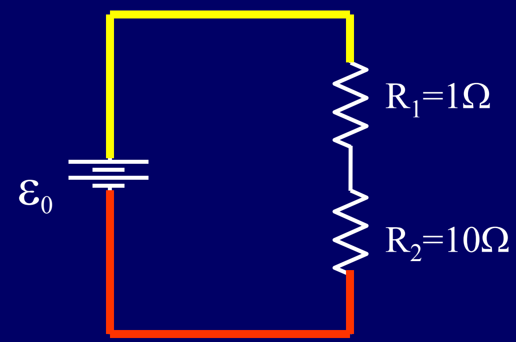
Simplify (R_1 and R_2 in series):

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



Expand:

- $V_1 = I_1R_1 \quad = 2 \times 1 = 2$ Volts
- $V_2 = I_2R_2 \quad = 2 \times 10 = 20$ Volts

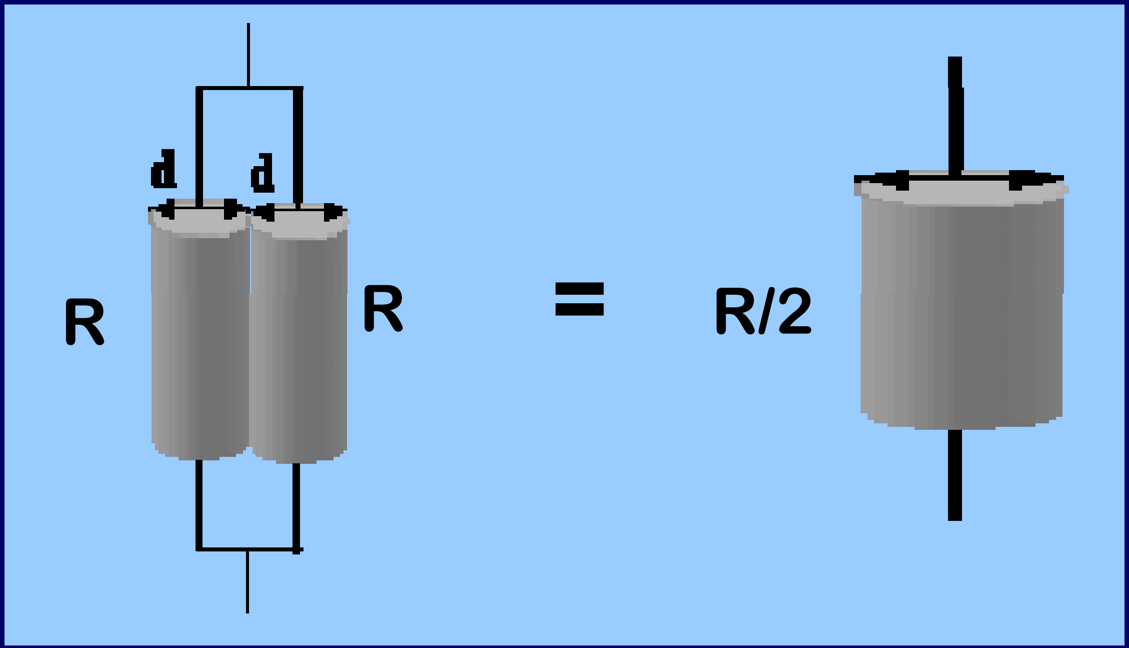


Check: $V_1 + V_2 = V_{12}$? ✓

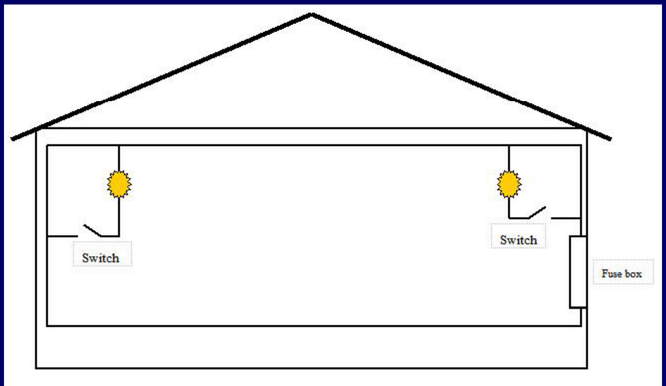
Resistors in Parallel

- 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!



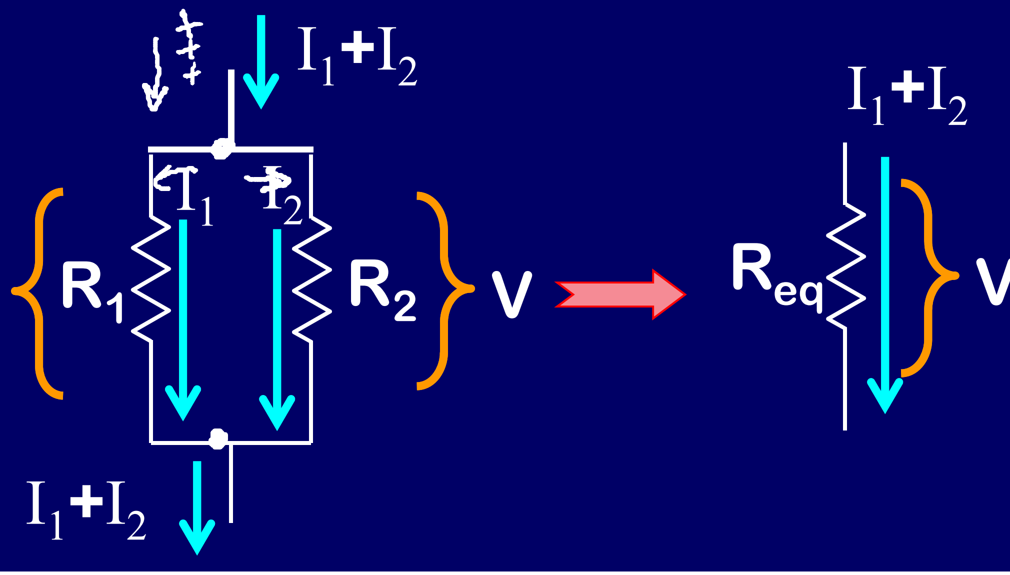
Resistors in Parallel

- 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?

- 23% • Increases
- 30% • Remains Same
- 47% • Decreases

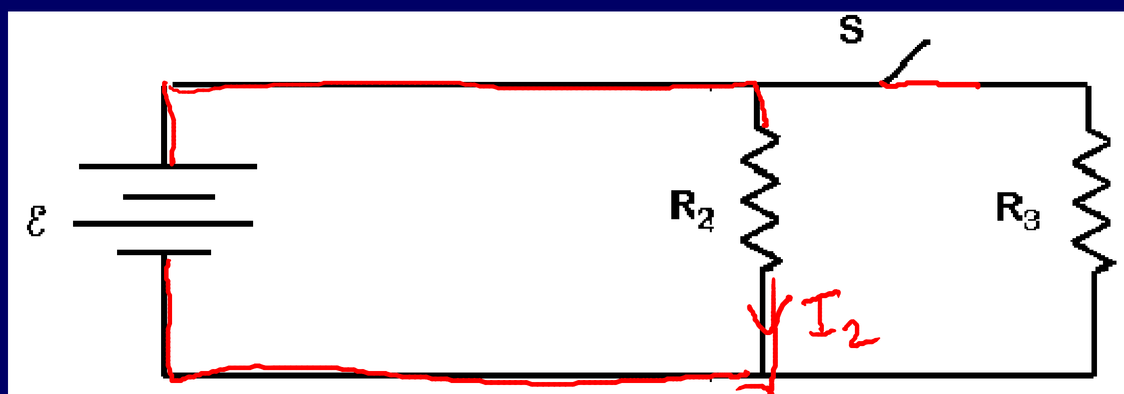
Before

$V_2 = \varepsilon$

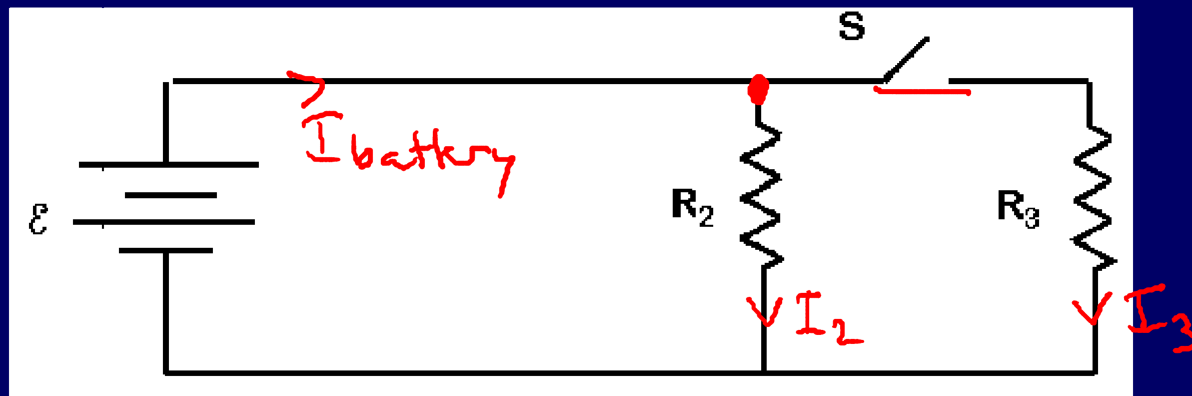
$I_2 = \varepsilon / R_2$

After

$V_2 = \varepsilon$



ACT: Parallel Circuit



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

(A) Increases

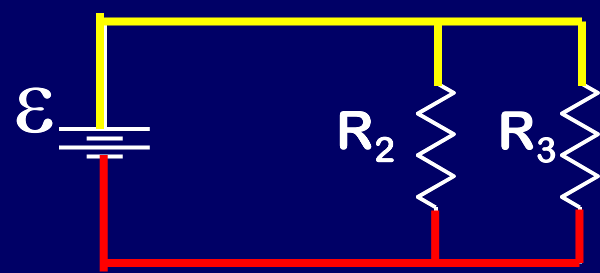
(B) Remains Same

(C) Decreases

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

Example

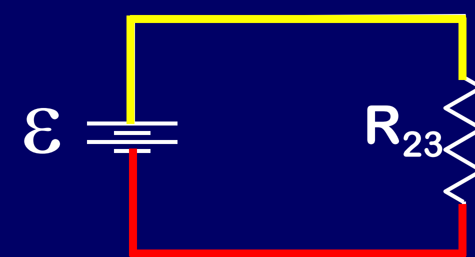
Practice: Resistors in Parallel



Determine the current through the battery.

Let ε = 60 Volts, R_2 = 20 Ω and R_3=30 Ω.

Simplify: R_2 and R_3 are in parallel

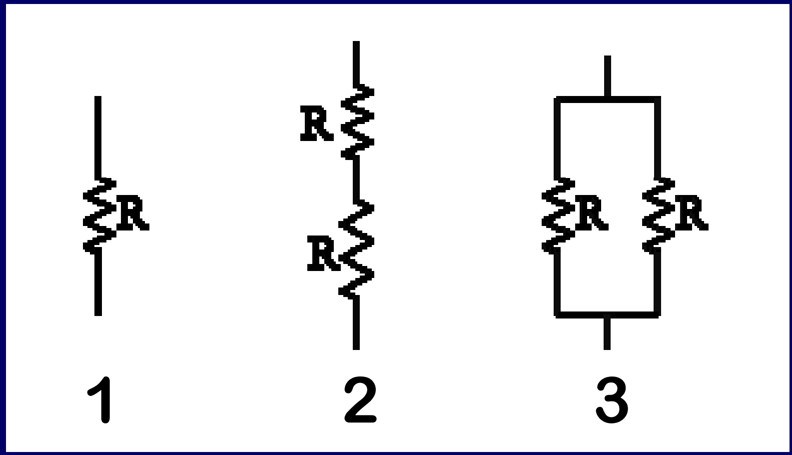


$1/R_{23} = 1/R_2 + 1/R_3$ $\quad R_{23} = 12\ \Omega$

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

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

ACT / CheckPoint 4.1,4.2



R 2R R/2

Which configuration has the smallest resistance?

36% A. 1

5% B. 2

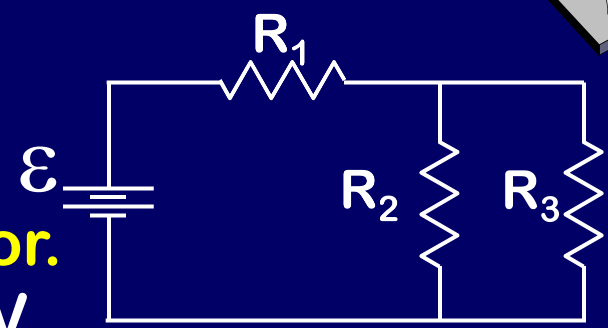
59% C. 3

Which configuration has the largest resistance?

B. 2 70%

Example

Try it!



Calculate current through each resistor.

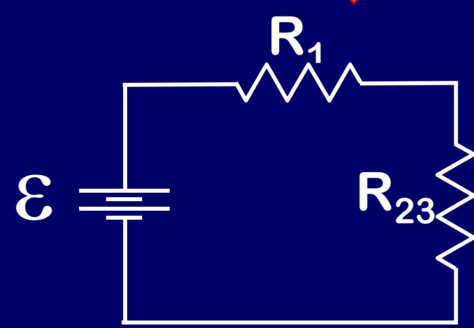
$R_1 = 10\ \Omega$, $R_2 = 20\ \Omega$, $R_3 = 30\ \Omega$, $\mathcal{E} = 44$ V

Simplify: R_2 and R_3 are in parallel

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

$V_{23} = V_2 = V_3$

$I_{23} = I_2 + I_3$

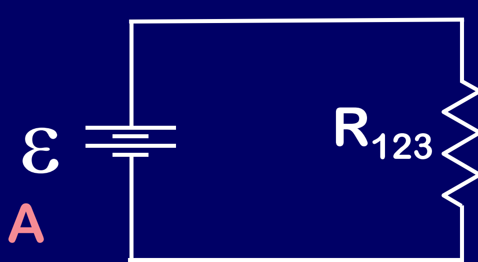


Simplify: R_1 and R_{23} are in series

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

$V_{123} = V_1 + V_{23} = \varepsilon$

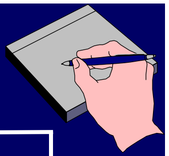
$I_{123} = I_1 = I_{23} = I_{battery}$: $I_{123} = 44\text{ V}/22\ \Omega = 2$ A

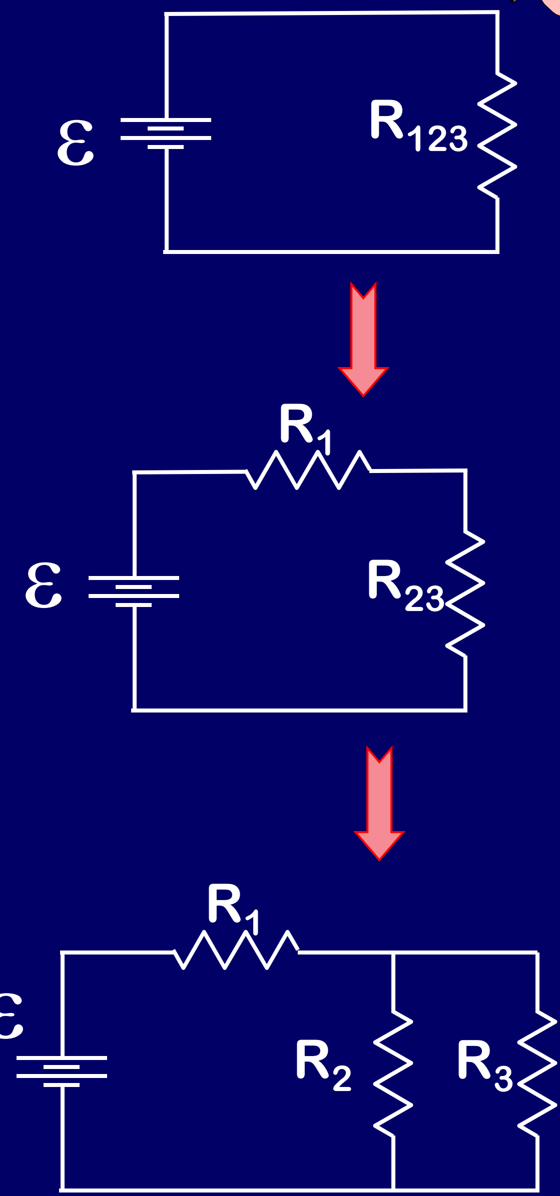


Power delivered by battery? **$P=IV = 2 \times 44 = 88$W**

Example

Try it! (cont.)





Calculate current through each resistor.

$R_1 = 10\ \Omega$, $R_2 = 20\ \Omega$, $R_3 = 30\ \Omega$, $\varepsilon = 44$ V

Expand: R_1 and R_{23} are in series

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

$V_{123} = V_1 + V_{23} = \varepsilon$

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

: $I_{23} = 2$ A

: $V_{23} = I_{23} R_{23} = 24$ V

Expand: R_2 and R_3 are in parallel

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

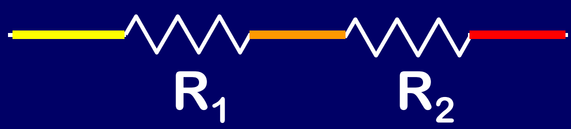
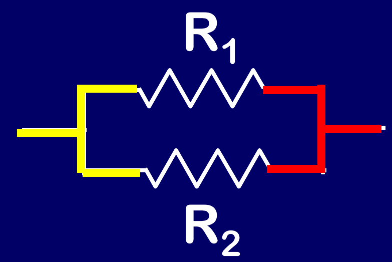
$V_{23} = V_2 = V_3$

$I_{23} = I_2 + I_3$

$I_2 = V_2/R_2 = 24/20 = 1.2$A

$I_3 = V_3/R_3 = 24/30 = 0.8$A

Summary

	Series	Parallel
		
Wiring	Each resistor on the **same** wire.	Each resistor on a **different** wire.
Voltage	**Different** for each resistor. $V_{total} = V_1 + V_2$	**Same** for each resistor. $V_{total} = V_1 = V_2$
Current	**Same** for each resistor $I_{total} = I_1 = I_2$	**Different** for each resistor $I_{total} = I_1 + I_2$
Resistance	**Increases** $R_{eq} = R_1 + R_2$	**Decreases** $1/R_{eq} = 1/R_1 + 1/R_2$