Announcements

- Homework
  - Webwork 15 is due tonight
  - Will be an Webwork due Friday, but not over break
- Test 2 is postponed
  - Chapters 16 – 19
  - Probably have it Wednesday or Friday after break
- Polling: `rembold-class.ddns.net`

Adding Resistors

In Series

- By loop law:

$$\mathcal{E} - R_1\mathrm{I} - R_2\mathrm{I} - R_3\mathrm{I} = 0$$

- Current same through series

$$\mathcal{E} - \underbrace{(R_1 + R_2 + R_3)}_{R_{eq}}\mathrm{I} = 0$$

- So in series:

$$R_{eq} = R_1 + R_2 + R_3 + \cdots$$

In parallel

- Same loop law
- $\mathcal{E}$ the same in parallel

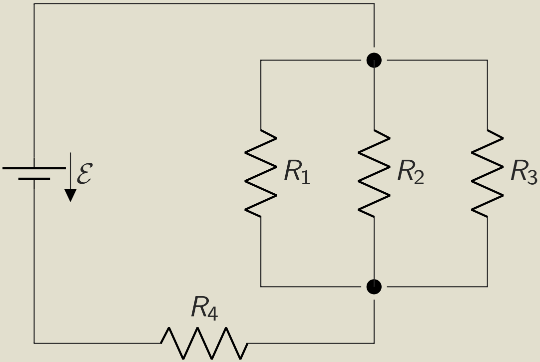
$$\mathrm{I} - \mathcal{E}\underbrace{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)}_{1/R_{eq}} = 0$$

- So in parallel:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$

Simplifying Circuits

Reduce the below circuit to a single resistor and determine its equivalent resistance.



$$R_1 = 50\,\Omega$$
$$R_2 = 75\,\Omega$$
$$R_3 = 100\,\Omega$$
$$R_4 = 25\,\Omega$$

Solution: $48.1\,\Omega$

Understanding Check!

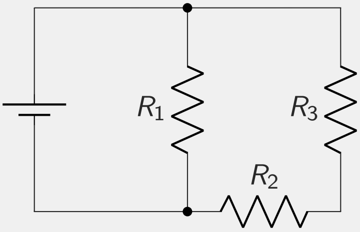
Given the circuit to the right, what is the equivalent resistance?

A. $5\,\Omega$

B. $8.86\,\Omega$

C. $12\,\Omega$

D. $20\,\Omega$



$$R_1 = 10\,\Omega$$
$$R_2 = 6\,\Omega$$
$$R_3 = 4\,\Omega$$

Solution: $5\,\Omega$

Ultimate Power in the Universe...

- Lightbulbs (or any resistor) don't use up current
  - But they do transform energy to light and heat
  - Rate at which they do so determines brightness
- Mathematically:

$$\text{Power} = \frac{\Delta U}{\Delta t} = \frac{\Delta q \Delta V}{\Delta t} = \mathrm{I}\Delta V$$

- Can also be related to the resistance:

$$\text{Power} = \mathrm{I}\Delta V = \mathrm{I}^2 R = \frac{(\Delta V)^2}{R}$$

- Energy dissipated through a circuit component will depend on both the current and the potential difference across that circuit element

Lightbulb!

Suppose you have three equivalent lightbulbs. How can you hook them up to a battery to ensure the greatest possible output of total light?

Solution: All in parallel

Back to Batteries

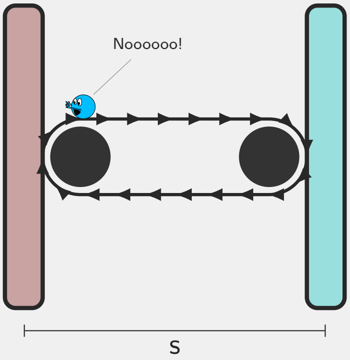
- Have been assuming perfect batteries
  - only force felt would be from the conveyor belt
  - What about the electrostatic forces from charges already moved?
- Would give opposing force:

$$\vec{\mathbf{F}}_{net} = \vec{\mathbf{F}}_{batt} - e\vec{\mathbf{E}}_{batt}$$

- Finding the change in potential:

$$\Delta V = (F_{batt} - eE_{batt})\,\frac{s}{e}$$

$$\Delta V = \mathcal{E} - E_{batt}s = \mathcal{E} - r_{int}\mathrm{I}$$



Ideal Battery

Suppose you have a $9\,\mathrm{V}$ battery which, when hooked up to a $100\,\Omega$ resistor only creates a current of only $75\,\mathrm{mA}$. What is the internal resistance of the battery?

Solution: $20\,\Omega$

When does it matter?

Take the same battery and compare its ideal and real currents for a selection of resistances:

Circuit Resistor	Ideal ($r_{int} = 0$)	Real ($r_{int} = 20\,\Omega$)
$100\,\Omega$	$90\,\text{mA}$	$75\,\text{mA}$
$1000\,\Omega$	$9\,\text{mA}$	$8.8\,\text{mA}$
$10\,\text{k}\Omega$	$0.9\,\text{mA}$	$0.898\,\text{A}$

When does it matter?

Take the same battery and compare its ideal and real currents for a selection of resistances:

Circuit Resistor	Ideal ($r_{int} = 0$)	Real ($r_{int} = 20\,\Omega$)
$10\,\Omega$	$0.9\,\mathrm{A}$	$0.3\,\mathrm{A}$
$100\,\Omega$	$90\,\mathrm{mA}$	$75\,\mathrm{mA}$
$1000\,\Omega$	$9\,\mathrm{mA}$	$8.8\,\mathrm{mA}$
$10\,\mathrm{k}\Omega$	$0.9\,\mathrm{mA}$	$0.898\,\mathrm{A}$

Internal resistance can make a huge difference when the resistances are small!