Plan for Lecture 8 (Chapter 28):

1. Direct-current circuits
2. Voltage and resistor circuits
3. Kirchhoff’s rules
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Remember to send in your chapter reading questions...
Comment on Direct current versus Alternating current
http://www.pbs.org/wgbh/amex/edison/sfeature/acdc.html

Example – Li ion rechargeable battery
http://electronics.howstuffworks.com/everyday-tech/lithium-ion-battery1.htm
Switch open, no current flowing, battery storing energy

Switch closed, current flowing, battery discharging
Equivalent circuit for $\mathcal{E}$

$$\mathcal{E} - Ir - IR = 0$$

$$I = \frac{\mathcal{E}}{r + R}$$

$\mathcal{E} = 12\text{V}$, $r = 0.1\Omega$, $R = 9.9\Omega$; what is $\Delta V$?

A. $\Delta V = \mathcal{E}$
B. $\Delta V < \mathcal{E}$
C. $\Delta V > \mathcal{E}$
Resistors in series:

\[ \Delta V - IR_1 - IR_2 = 0 \]

\[ I = \frac{\Delta V}{R_1 + R_2} \]

\[ R_{series} = R_1 + R_2 \]
Resistors in parallel

\[ \Delta V - I_1 R_1 = 0 \]
\[ \Delta V - I_2 R_2 = 0 \]
\[ I = I_1 + I_2 = \frac{\Delta V}{R_1} + \frac{\Delta V}{R_2} \]
\[ \Delta V = I \left( \frac{1}{R_1} + \frac{1}{R_2} \right) \equiv IR_{\text{Parallel}} \]

\[ R_{\text{Parallel}} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} \]
Examples: \( R_1 = 1 \Omega, \; R_2 = 100 \Omega, \; \Delta V = 100V \)

\[
\begin{align*}
\Delta V - IR_1 - IR_2 &= 0 \\
I &= \frac{\Delta V}{R_1 + R_2} = \frac{100}{101} = 0.99A \\
\Delta V_1 &= IR_1 = 0.99V \\
\Delta V_2 &= IR_2 = 99.01V
\end{align*}
\]
Circuit analysis – Kirchhoff’s rules

Conservation of charge (current) at a junction:

\[ \sum I = 0 \]

\[ I_1 - I_2 - I_3 = 0 \]
Circuit analysis – Kirchhoff’s rules

Conservation of potential around a closed circuit:

\[ \sum \Delta V = 0 \]
\[ \Delta V_1 + \Delta V_2 + \Delta V_3 = 0 \]

Sign conventions: \( \Delta V = V_b - V_a \)
Example:

\[ E_1 = 6.0 \text{ V} \]

- \[ R_2 = 10 \Omega \]
- \[ R_1 = 8.0 \Omega \]

\[ E_2 = 12 \text{ V} \]

\[ E_1 - IR_1 - E_2 - IR_2 = 0 \]

Solve for \( I \):

\[ I = \frac{E_1 - E_2}{R_1 + R_2} = \frac{6 - 12}{8 + 10} = -0.33 \text{ A} \]

\( I < 0 \) means:

A. The circuit is wrong (cannot exist or will blow up).

B. The current flows opposite the arrow.
Example:

\[ -14 - 2I_3 - 4I_2 = 0 \]
\[ 10 - 6I_1 - 2I_3 = 0 \]
\[ I_1 + I_2 = I_3 \]

\[ I_1 = 2 \, A \]
\[ I_2 = -3 \, A \]
\[ I_3 = -1 \, A \]
How to measure current

Inside ammeter:

\[ I = I_1 + I_2 \]

\[ R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} \]

\( I_1 \equiv \) "shunt" current; \( R_1 \ll R_2 \)

\( I_2 \equiv \) device current; \( I_2 \ll I_1 \)
Suppose that:

\[ I = 10A, \quad R_1 = 0.01\Omega, \quad R_2 = 100\Omega \]

\[ I_2 = \frac{I}{1 + \frac{R_2}{R_1}} = \frac{10}{10001} A = 0.001A \]

→ Current that drives measurement device.
What if the ammeter were connected in parallel to the wire? (Assume that the wire resistance is \( R_w = 0.001 \Omega \).)

A. The measurement would be identical to series result.
B. The measurement would be less than the series result.
C. The measurement would be greater than the series result.

\[
I_2 = \frac{I}{1 + \frac{R_2}{R_1} + \frac{R_2}{R_w}} = \frac{10}{110001} \quad A = 0.0001A
\]
How to measure voltage

Total equivalent circuit:

\[ I_V R_V = \frac{IR_{eq}}{1 + \frac{R_{eq}}{R_V}} \]

⇒ Works well if

\[ R_V \gg R_{eq} \]
Total equivalent circuit: Suppose $I=10\text{A}, R_{eq}=10\Omega, R_V=100\Omega$

\[
I_V R_V = \frac{10 \times 100}{1+\frac{10}{100}} = 909.1
\]

\[
\frac{I R_{eq} - I_V R_V}{I R_{eq}} = 9\%
\]
3 unknowns ➔ need 3 equations

\[ I_1 = I_2 + I_3 \]
\[ -8I_1 - 6I_2 - 4 = 0 \]
\[ -4I_3 - 12 - 8I_1 = 0 \]
\[ -4I_3 - 12 + 4 + 6I_2 = 0 \]