Plan for Lecture 9 (Chapter 28):

1. Direct-current circuits continued
2. Voltage, resistor, and capacitor circuits
<table>
<thead>
<tr>
<th>Week</th>
<th>Date</th>
<th>Topic</th>
<th>Sections</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>02/02/2012</td>
<td>Electric potential</td>
<td>25.5-25.8</td>
<td>(Review for exam)</td>
</tr>
<tr>
<td></td>
<td>02/07/2012</td>
<td>Exam</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>02/14/2012</td>
<td>Current and resistance</td>
<td>27.1-27.6, 27.3-27.12, 27.29</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>02/21/2012</td>
<td>Direct current circuits</td>
<td>28.3-28.5, 28.23-28.25, 28.34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>02/23/2012</td>
<td>Review</td>
<td>26.1-28.5</td>
<td>(Review for exam)</td>
</tr>
<tr>
<td></td>
<td>02/28/2012</td>
<td>Exam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>03/01/2012</td>
<td>Magnetic fields</td>
<td>29.1-29.6, 29.5-29.12, 29.47</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>03/06/2012</td>
<td>Magnetic field sources</td>
<td>30.1-30.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>03/08/2012</td>
<td>Faraday's law</td>
<td>31.1-31.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>03/13/2012</td>
<td>No class (Spring Break)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>03/15/2012</td>
<td>No class (Spring Break)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>03/20/2012</td>
<td>Induction and AC circuits</td>
<td>32.1-32.6</td>
<td></td>
</tr>
</tbody>
</table>

Remember to send in your chapter reading questions...
Professor George Holzwarth (gholz@wfu.edu) will administer the exam on 2/28/2012 and will lecture on magnetic fields, electric motors, etc. on 3/1/2012.
Circuit diagram:

Example project from web page
http://www.kpsec.freeuk.com/projects/dummy.htm
From webassign:

Consider the circuit shown in the figure below. (Let $R_1 = 3.00 \, \Omega$, $R_2 = 4.00 \, \Omega$, and $\mathcal{E} = 6.00 \, \text{V}$.)

\[ \mathcal{E} - 2I - R_1 I_1 = 0 \]

\[ \Delta V_1 = R_1 I_1 = \mathcal{E} - 2I \]

among the many ways to find $I$:

\[ I = \frac{\mathcal{E}}{R_{eq}} \]

(a) Find the voltage across $R_1$.

\[ \text{V} \]

(b) Find the current in $R_1$.

\[ \text{A} \]
Circuits involving Voltage, Capacitance, and Resistance

Open switch ➞ no charge or current

Switch closed ➞ VCR circuit

Switch closed ➞ RC circuit
\[
I = \frac{dQ}{dt}
\]

\[
- \frac{Q}{C} - IR = 0
\]

\[
- \frac{Q}{C} - \frac{dQ}{dt} R = 0
\]

\[
\frac{dQ}{dt} = -\frac{1}{RC} Q
\]
What are the units of RC?
A. Seconds
B. Cycles per second
C. Meters
D. Coulombs
E. Volts
Simple rate equation for growth:

\[
\frac{dM}{dt} = rM
\]

\[
\frac{dM}{dt} = \text{rate of accumulation of money}
\]

\[
r = \text{rate of increase}
\]

\[
M = M(t) = \text{money at time } t
\]

Analysis:

\[
\frac{dM}{dt} = rM \quad \Rightarrow \quad \frac{dM}{M} = d \ln(M) = r dt
\]

\[
\ln(M) \bigg|_{M_0}^{M} = rt \bigg|_{t_0}^{t} \quad \Rightarrow \quad M(t) = M_0 e^{rt(t-t_0)}
\]
Simple rate equation for decrease:

\[ \frac{dM}{dt} = -rM \]

\[ \frac{dM}{dt} \] = rate of accumulation of money

\[ r \] = rate of decrease

\[ M = M(t) \] = money at time \( t \)

Analysis:

\[ \frac{dM}{dt} = -rM \quad \Rightarrow \quad \frac{dM}{M} = d \ln(M) = -rdt \]

\[ \ln(M) \bigg|_{M_0}^M = -rt \bigg|^{t}_{t_0} \quad \Rightarrow \quad M(t) = M_0 e^{-r(t-t_0)} \]
\[
\frac{dQ}{dt} = -\frac{1}{RC} Q = -\frac{1}{\tau} Q
\]

\[
Q(t) = Q_0 e^{-\left(\frac{t-t_0}{\tau}\right)}
\]

\[
e^{-1}=0.37 \\
e^{-2}=0.14 \\
e^{-3}=0.05
\]
Charging capacitor:

Switch closed at \( t=0; \ Q(t=0)=0 \)

\[ \mathcal{E} - \frac{Q}{C} - IR = 0 = \mathcal{E} - \frac{Q}{C} - \frac{dQ}{dt} R \]

\[ \frac{dQ}{dt} = - \frac{1}{RC} \left( Q - C \mathcal{E} \right) \equiv - \frac{1}{\tau} \left( Q - C \mathcal{E} \right) \]
Charging capacitor:

Switch closed at $t=0$; $Q(t=0)=0$

\[
\frac{dQ}{dt} = -\frac{1}{RC} (Q - C\mathcal{E}) \equiv -\frac{1}{\tau} (Q - C\mathcal{E})
\]

\[
Q(t) = C\mathcal{E} \left( 1 - e^{-t/\tau} \right)
\]
Discharging capacitor

When switch closed $Q(t_c) = CE$

\[ \frac{dQ}{dt} = -\frac{1}{RC}Q = -\frac{1}{\tau}Q \]

\[ Q(t) = C\mathcal{E}e^{-(t-t_c)/\tau} \]
\[ \frac{Q}{CE\varepsilon} \]
\[ \frac{Q}{CE} \]

\[ \frac{I}{\varepsilon/R} \]

\[ \Rightarrow t \]

\[ \Rightarrow \]
Example 28.5:
Assume the capacitor is initially uncharged.

What is the current $I$ flowing through the battery just when the switch is closed?
A. 0
B. $\varepsilon/2R$
C. $\varepsilon/R$
D. $2\varepsilon/R$

What is the current $I$ flowing through the battery after the switch has been closed for a long time?
A. 0
B. $\varepsilon/2R$
C. $\varepsilon/R$
D. $2\varepsilon/R$
When switch is open:

\[ \mathcal{E} - I R_1 - \frac{Q}{C} - I R_2 = 0 \]

\[ I(R_1 + R_2) = \mathcal{E} - \frac{Q}{C} \]

\[ \frac{dQ}{dt}(R_1 + R_2) = \mathcal{E} - \frac{Q}{C} \]

\[ \frac{dQ}{dt} = -\frac{1}{(R_1 + R_2)C}(Q - C\mathcal{E}) \]

\[ Q(t) = C\mathcal{E}\left(1 - e^{-t/\tau}\right) \quad \text{where} \quad \tau \equiv (R_1 + R_2)C \]

For \( t \gg \tau \):
\[ Q(t \to \infty) = C\mathcal{E} \]

\[ I(t \to \infty) = \frac{C\mathcal{E}}{\tau} e^{-t/\tau} \bigg|_{t \to \infty} = 0 \]
When switch is closed (reset $t=0$):

$$\mathcal{E} - I_1 R_1 = 0$$

$$-\frac{Q}{C} - I_2 R_2 = 0$$

$$I_2 = \frac{dQ}{dt} \quad \Rightarrow \quad Q(t) = Q_0 e^{-t/\tau}$$

$$\tau \equiv R_2 C \quad \text{and} \quad Q_0 \equiv C \mathcal{E}$$

$$I_2 = \frac{dQ}{dt} = -\frac{C \mathcal{E}}{\tau} e^{-t/\tau} = -\frac{\mathcal{E}}{R_2} e^{-t/\tau}$$

Current through switch:

$$I_1 = I_2 + I_s = 0$$

$$I_s = I_1 - I_2 = \frac{\mathcal{E}}{R_1} + \frac{\mathcal{E}}{R_2} e^{-t/\tau}$$