Part I: Basic Electricity

- Prelude
- Atomic Stuff
- Voltage, Resistance, Current, Power, Energy
- DC Series Circuits
- DC Parallel Circuits
- AC Circuits in brief

Announcements (1/28/13)

- 401B and 501B:
  - Laboratory Meeting Tues Jan 29, 4th-5th pm
- Electricity Test in 2 weeks (Feb 11)
- Fill out and hand in 3x5 cards to Lauritz

Prelude: Scale of Measurement

- Deci = $10^{-1}$
- Centi = $10^{-2}$
- Milli = $10^{-3}$
- Micro = $10^{-6}$
- Nano = $10^{-9}$
- Pico = $10^{-12}$
- Fento = $10^{-15}$
- Kilo = $10^3$
- Mega = $10^6$
- Giga = $10^9$
- Tera = $10^{12}$

Foundations:

Basic Electricity
Basic Neurophysiology
Basic Neuroanatomy

What’s a Trillion $ (Tera $)

http://www.pagetutor.com/trillion/index.html
Prelude: 3 Great Forces

- **Nuclear**: Strong, very short (subatomic) distances ...
- **Electrostatic**: Holds all kinds of stuff together in the everyday world
- **Gravitational**: Weakest, but impressive over very large distances and with large masses

**Static Electricity**

- Friction with Poor Conductors
- Electrons displaced from one substance to the other (e.g., Hair to comb, carpet to body)
- Leads to voltage potential (i.e., difference)

**Electrostatic Forces**

- Due to charged subatomic particles
  - Proton
  - Electron
  - but not Neutron
- The Law:
  - Unlike Charges Attract
  - Like Charges Repel

**Basic Electricity by Analogy**

**Free Electrons**

- Some electrons can be easily displaced

**Direction of Electron Movement**
Details

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Term</th>
<th>aka</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>Voltage</td>
<td>Electromotive Force</td>
<td>Volts (V)</td>
</tr>
<tr>
<td>I</td>
<td>Current</td>
<td>Rate of Flow</td>
<td>Amperes (A)</td>
</tr>
<tr>
<td>R</td>
<td>Resistance</td>
<td>--</td>
<td>Ohm (Ω)</td>
</tr>
<tr>
<td>P</td>
<td>Power</td>
<td>Rate of work</td>
<td>Watt (w)</td>
</tr>
<tr>
<td>W</td>
<td>Energy</td>
<td>Ability to do work</td>
<td>Watt-Second (Joule)</td>
</tr>
</tbody>
</table>

Ohm’s Law

\[ I = \frac{E}{R} \]
\[ E = IR \]
\[ R = \frac{E}{I} \]

See also: [http://www.falstad.com/circuit/e-ohms.html](http://www.falstad.com/circuit/e-ohms.html)

Basic Circuit

\[ I = ? \]

Volt-Ohm Meter Demo
### Series Circuit

\[ R_T = R_1 + R_2 \]

\[ I = ? \]

\[ E_{R1} = ? \]

\[ E_{R2} = ? \]

**Java Demo**

### Complex Circuits

Find the current flowing in the circuit, and the voltage drops.

YIKES! Need to reduce. Start at the parallel combination of 20k and 5k resistors; it is replaced with its effective resistance of 4k

\[ \frac{1}{R_{equiv}} = \frac{1}{20} + \frac{1}{5} = \frac{1}{20} + \frac{4}{20} = \frac{5}{20} = \frac{1}{4} \]

This and subsequent slides on this circuit adapted from:

"http://www.physics.udel.edu/~watson/phys345/examples/effective-circuit.html"

### By Analogy: Series Vs Parallel

\[ \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \]

### Slightly less Complex Circuit

Looking Better. The effective resistance of 4k is in series with the actual resistance of 8k, leading to replacement by its effective resistance of 12k.

\[ \frac{1}{R_{equiv}} = 4k + 8k \]

### Parallel Circuit

\[ \frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \]

\[ I_T = ? \]

\[ I_1 = ? \]

\[ I_3 = ? \]

\[ I_2 = ? \]

### Less Complex Still

Better still. Now there is a parallel combination of 12k and 6k resistors; it is replaced with its effective resistance of 4k

\[ \frac{1}{R_{equiv}} = \frac{1}{12} + \frac{1}{6} = \frac{1}{12} + \frac{2}{12} = \frac{3}{12} = \frac{1}{4} \]
Now Series: Almost Simple

Finally, the equivalent resistance for the entire circuit is 9k.
\[ R_{\text{eqiv}} = 4k + 5k \]

Working Back: Voltage Drops and Current

Breaking the 4k resistance into its component parts (in parallel), we find that 2/3 mA of current flows in the 6k resistor and 1/3 mA flows in the effective resistance of 12k.
\[ I = \frac{E}{R} = \frac{4V}{4k} = 1mA \]
\[ I = \frac{E}{R} = \frac{4V}{12k} = 1/3 mA \]

Now Series: Almost Simple

\[ I = \frac{E}{R} = \frac{9V}{9k} = 1mA \]

Working Back: Voltage Drops and Current

Breaking the 12k resistance into its component parts (in series), we find that there is 8/3 V across the 8k resistor and 4/3 V across the effective resistance of 4k.
\[ E = IR = 4k \times \frac{1}{3} mA = \frac{4}{3} V \]
\[ E = IR = 8k \times \frac{1}{3} mA = 8/3 V \]

Working Back: Voltage Drops and Current

Breaking the 20k resistance into its component parts (in parallel), we find that 1/15 mA of current flows in the 5k resistor and 4/15 mA flows in the effective resistance of 12k.
\[ I = \frac{E}{R} = \frac{4/3V}{20k} = 4/60 mA = 1/15 mA \]
\[ I = \frac{E}{R} = \frac{4/3V}{5k} = 4/15 mA \]

The real 5k resistor and the effective 4k resistance each have 1 mA of current since they are in series. Thus the 4k resistance has 4V of voltage difference across it (by Ohm's law).
Working Back: Voltage Drops and Current

Summarizing:
1. Current through the battery?  1 mA
2. Current through the 8k resistor?  1/3 mA
3. Voltage difference across the 20k resistor?  4/3 V
4. Rate of energy dissipated by the 6k resistor? $P = \frac{2}{3} \text{ mA} \times 4 \text{ V} = \frac{8}{3} \text{ mW}$

In Real Life…

Capacitance

- Two closely spaced plates – offer essentially no resistance
- As negative charge built up on first plate due to flow of electrons, a positive charge would build up on second plate
- The current charges the plates of the capacitor, but does not flow through the capacitor, itself.

Capacitance – Size Matters

- Which has more capacity?
- More capacity, more current flows before capacitor is fully charged

Capacitance

Capacitor = two conductors separated by a dielectric.
Dielectric = material that is a good insulator (incapable of passing electrical current), but is capable of passing electrical fields of force. Examples include glass, porcelain.
Capacitor Time Constants

Over time...
Capacitor's voltage increases
Current flow grinds to a halt

The capacitor’s time constant $T_C$:
- The time in seconds for it to become 63.2% charged
- The time in seconds for current flow have slowed by 63.2% from its starting value

AC Circuits

DC Circuit: Current Flow is unidirectional, from $-$ to $+$

AC Circuit: Current Flow switches direction periodically (at a given frequency in Hz)

AC Circuits and Capacitance

- Slowly alternating signals
  - will fully charge capacitor, and signal will be impeded
- Rapidly alternating signals
  - will not fully charge the capacitor before the direction of flow reverses, allowing signals to pass unimpeded

Using Capacitors to make Low Pass Filters

Using Capacitors to make High Pass Filters

http://micro.magnet.fsu.edu/electromag/java/capacitor/
Part II: Basic Neurophysiology

- Three basic units inside the brain
  - Glial cells
  - Extracellular space: not really space
  - The neuron
    - Three types:
      - Sensory
      - Motor
      - Interneuron

The Common Household Neuron

- Vary widely, but all have:
  - Cell body (soma)
  - Dendrites
  - Axon
    - Myelin sheath
    - Nodes of Ranvier
    - Microtubules
    - Terminal buttons (AKA synaptic knob)
- Nerve = a bundle of axons
Neural Communication

- Axonal Conduction (electro-chemical)
- Synaptic Transmission (chemico-electrical)

Axonal Conduction

- Resting potential
  - Inside of cell slightly negative
  - Two forces act upon these ions
    - Concentration gradient—osmotic force
    - Electromotive force
  - Equilibrium potential:
    \[
    E_{\text{ion}} = \frac{(R \cdot T \cdot z \cdot F)}{z} \ln\left(\frac{\text{Conc}_{\text{ex}}}{\text{Conc}_{\text{in}}}\right)
    \]
    where R is gas constant, T is temperature, z is ionic valence, and F is Faraday’s constant.
  - The Hodgkin & Huxley Model

- Depolarization
  - Threshold
  - Axon Hillock
  - Na ions rush in resulting in:
    - Action potential:
      - All or none phenomenon, high frequency
      - Afterpotentials; hyperpolarizing, depolarizing; slow frequency
    - Changes in membrane permeabilities
  - Propagation

- Refractory period
Synaptic Transmission

- Not an all-or-none phenomenon
- Synaptic gap or cleft at the synaptic junction
- Single axon splits near end—terminal arborization
- As action potential arrives
  - Synaptic vesicles migrate to cell membrane fuse and release
  - Neurotransmitters diffuse across the synaptic cleft
  - combine with post-synaptic receptors
  - When neurotransmitter binds to a receptor on the post-synaptic cell, a slow electrical potential (post-synaptic potential) is generated:
    - 5 to 20 mV at peak amplitude
    - 20-150 msec in duration (50 to 6 Hz)
Synaptic Transmission

- Post-synaptic potentials (PSPs);
  - Excitatory
  - Inhibitory
  - Interaction
- Summation/Integration
  - temporal
  - spatial
  - decremental conduction on dendrites and soma
- Axon hillock is critical area at which threshold must be reached
- After release of neurotransmitter,
  - reuptake
  - degradation
- Functional Synaptic Units

Fig. 3-11. Inhibitory post-synaptic potentials. Experimental arrangement as in Fig. 3-10, except that here an antagonist nerve is stimulated.

Fig. 3-14. The effect of an IPSP on the action potential; experimental arrangement as in Fig. 3-13. The homonymous nerve is stimulated strongly enough to produce a superthreshold EPSP (left). On the right, the antagonist nerve is stimulated about 5 ms before the homonymous nerve. The equilibrium potentials of Na⁺, K⁺, Cl⁻, EPSP, and IPSP are shown.
Temporal Summation, Figure 5.11

Temporal summation

A. Event
B. Event