Chapter 22: Current and Resistance

Section 22.1: A Model of Current

Pith Balls Are Parlor Tricks

- Grounding shows how to move charge, but it's a finite, one-off event
- How to keep them moving? You can't really do much just by discharging a sphere
- Unless it's the 19th century and you're a rogue and a charlatan separating people from their money

Fluid Flow and Charge Flow

- This is a flawed analogy, but not a bad place to start
- Fluid flows from higher pressure to lower, flow stops when pressure equalizes
- Charge flows from higher potential to lower potential, stops when potential equalizes

A Battery = A Pump

- Decorative fountains: you need a pump to force the water back to the top to keep flowing
- A battery will maintain a potential difference to "pump" charge through a circuit
- Guess what! We still don't know how a battery works!

Conservation of Current

- Current is the same everywhere through a wire; it does not increase or decrease
- Different wire? Sure, that can be a different current

Section 22.2: Defining and Describing Current

Electric Current

- Electron flow: you are not pulling protons out of nuclei!
- Electrons move in the direction of higher potential
- To keep the process continuous you need a complete circuit (unbroken path)
- Flowing water analogy breaks right here: the e- do not pour out of the negative terminal of a battery, race completely through the entire length of wire, and pour back in to the positive terminal of the battery

Electrons In Motion

- Focus on conducting materials in general, metals in specific
- Valence electrons are "free:" they are easy to strip away from their respective nuclei
- Mostly, the motion is completely random: not a current
- Apply an electric field: motion becomes directed, less random
- Drift velocity: All the e^- do not have the same velocity vector; there is still some randomness due to collisions, but overall motion is in the direction opposite the applied E field

Definition and Sign Convention

- Current = $I = \frac{q}{t}$ = charge/time = $\frac{C}{s}$ = amp (or ampere)
- This is not the speed! Not even a little bit!
- Sign convention: direction that a (+) charge would move (underline this in your notes: you are not pulling protons out of nuclei!)
- Current flows from (+) to (–) means that the direction of travel for the e^- is opposite the current
- Don't fight it; it's an historical artifact pre-dating the discovery of the electron

Conservation of Current at a Junction

- What goes in must come back out
- No losses
- Total I in = total I out: $\sum I_{in} = \sum I_{out}$

Section 22.3: Batteries and EMF

Vocabulary, Not Physics

- EMF = electro-motive force
- This is not a force
- EMF = voltage, and we still have no clue how batteries work!

Beware the Charge Escalator

- Seriously, you are not moving positive charges
- YOU
- ARE
- NOT
- MOVING
- POSITIVE
- CHARGES

Batteries in Series

- Ever notice that nothing takes just one battery? (Ok, a few things do)
- Add the battery voltages to get the total voltage, or total emf, or total potential difference
- $V = V_1 + V_2 + \cdots + V_n$

Section 22.4: Connecting Potential and Current

Hannibal Crossing the Alps

- Imagine voltage like rations: a packet of calories—or literally, energy per packet
- You have a very specific number of rations, so how many troops (charges) can you take on your campaign to destroy the Roman Empire?
- If you pick an easy path (low resistance), each soldier (charge) can get by on fewer calories. You can take more men and the rations go farther (but you lose the element of surprise).
- If you pick the hardest possible path (like crossing the Alps at the onset of winter), each soldier (charge) needs a lot more food to keep functioning. So you can't take as many men (not to mention the war elephants you're desperately trying to keep alive—history is horrible because it's true)
- This is essentially how voltage, current, and resistance are related

Resistance

- Measures how difficult it is to move charge through a medium
- Low resistance R = high conductance (G) = easy to move charge
- High resistance R = low conductance (G) = hard to move charge

Other Factors Affect Resistance

- Length: longer wire = more resistance
- Cross-section: smaller area = more resistance
- Temperature: higher temp = more resistance
- $R = \frac{\rho L}{A}$ where ρ= resistivity = material property
- $R = R_0(1 + \alpha\Delta T)$ where α is the temperature coefficient for the material

Section 22.5: Ohm's Law and Resistor Circuits

Ohm's Law

- $V = IR$: How much work must be done (V) to push a specific quantity of charge (I) across a particular obstacle (R)
- $I = \frac{V}{R}$: How much current (I) can you push across a particular obstacle (R) if you only have so much energy (V)?
- Ohmic: Material or device behaves linearly according to Ohm's law

A Word About Dependent and Independent Variables

- We saw this with Snell's Law (at least, we tried to)
- The book is pretty explicit here in showing you that voltage is the independent and current is the dependent variable
- This graphs as a line with slope = $\frac{1}{R}$
- Literally nobody does this; every graph will be V (y-axis) vs I (x-axis), with a slope of R

Non-Ohmic Behavior

- Non-ohmic: Material or device does not follow a linear relationship
- Incandescent light bulbs are non-ohmic
- Increasing the voltage increases the current, but the resistance does not remain constant
- As a bulb filament heats up, its resistance increases

Symbols for Electric Circuits

- Standard symbols are useful for wiring diagrams
- Wiring diagrams are necessary for designing and building
- Everybody agrees on the symbols, everybody builds the same circuit

Analyzing a Simple Circuit

- A circuit requires a complete closed path containing a voltage source and whatever additional devices
- You can have multiple voltage sources and multiple devices
- Assume that the wire does not dissipate any of the energy
- This means the only voltage drops will occur at the resistors

Section 22.6: Energy and Power

Electric Power

- Power =(work/time) = $P = \frac{(qV)}{t} = (\frac{q}{t})(V) = IV$
- Or $P = IR^2$ or $P = \frac{V^2}{R}$
- As long as current flows, the electric potential energy will be continuously transformed
- Literally, this transformation is thermal (recall that anything "thermal" is all about making atoms move; as the e- jump around, they transfer kinetic energy to/from atom to atom, which manifests as increased vibrational energy—heat)

Light Bulbs Are Power-Rated, Not Current-Rated

- You know when you shop for light bulbs that a 100W bulb will be brighter than a 60W bulb
- What, then, actually is brightness?

- Literally, we would define it as an intensity: (energy/time)/area
- (energy/time) = power (by definition), which simply means the bulb keeps glowing
- /area = per area means that the (energy/time) gets spread out as you get further from the source