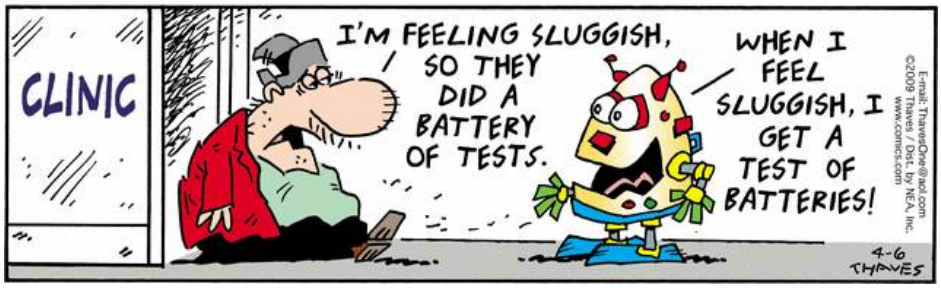
March 13, 2017 Physics 132 Prof. E. F. Redish

- **Theme Music:** **The Blue Man Group**
  Current
- **Cartoon:** **Bob Thaves**
  Frank & Ernest



3/13/17 Physics 132 **1**

Outline

- Quiz 6
- Electric current
  - Model of current flow
- Ohm's law
- Basic current elements
- Kirchhoff's laws
- Current analogies

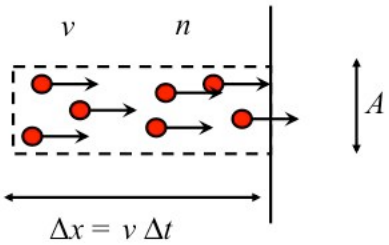
3/13/17 Physics 132 **2**

Foothold Ideas: Electric Current

- Current is a measure of the motion of charge.
- The current is defined as the rate at which charge crosses a given surface. $I = \frac{\Delta q}{\Delta t}$
- You can have current even in neutral matter if one kind of the charge is moving differently from the other.
- Unit of current: Ampere = Coulomb/second.
- Sign of current: We choose a direction as +. Current is + when + charges cross in the + direction.

Foothold Ideas: Current Density

- How much charge crosses an area A in a time Δt?
  - each moving charge has a charge, q
  - the density of moving charge per unit volume is n
  - the speed of the moving charges are v



- J = current density (current/unit area)

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Moving Charges in a Neutral Conductor

- What happens if we arrange charges to put an electric force on a neutral conductor?
  - Positive ions are fixed in a lattice
  - Some negative charges (shared electrons) are free to move

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3/13/17 Physics 132 **5**

Reading questions

- We are told that since there's a constant electric field, there's a constant force pushing electrons. How come there isn't any charge imbalance observed? Do we use the entropy argument again here (more possible microstates if the charges are spread out)?
- Does charge move through a wire in a current in 3D? Is it similar to water molecules in a pipe, or is it more like ping pong balls in a garden hose, where you put one in and another pops out the other end?

3/13/17 Physics 132 **6**

Reading question

- I don't really get how the plus/minus system of current works. If negative charge flows in our direction of interest, the current is negative, whereas the current is positive if positive charges move in the positive direction. However, positive charges don't move in currents, and we typically describe currents with the flow of electrons, and the current (in amps) is written as positive. How do I keep all of this straight?

WE WERE GOING TO USE THE TIME MACHINE TO PREVENT THE ROBOT APOCALYPSE, BUT THE GUY WHO BUILT IT WAS AN ELECTRICAL ENGINEER.

Reading question

- How does moving charge tend to maintain its volume like an incompressible fluid? Aren't the electrons always repelling each other and scattering around, therefore leading to a lack of defined volume?

Foothold Idea: Local Neutrality

- Most matter is made of of an equal balance of two kinds of charges: positive and negative.
- Since the electric force is very strong, mostly the + and - charges overlap closely and cancel each other. (Large energy in BF!)
- Small imbalances in the cancellation leads to:
  - polarization forces
  - potential drop across a resistance
  - observed electric forces.

Foothold ideas: Currents

- Charge is moving: How much?
- How does this relate to the individual charges?
- Constant flow means pushing force balances the drag force
- What pushes the charges through resistance? Electric force implies a drop in V!

$$I = \frac{\Delta q}{\Delta t}$$

$$I = q\,n\,A\,v$$

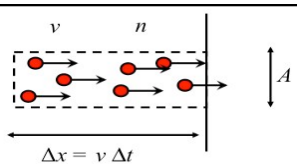
$$ma = F_e - bv$$

$$a = 0 \quad \Rightarrow \quad v = F_e/b$$

$$F_e = qE$$

$$\Delta V = -\frac{E}{L}$$

3/13/17 Physics 132 **11**



Ohm's Law

- Current proportional to velocity
- Due to resistance, Electric force proportional to velocity.
- Force proportional to "electric pressure drop" = "electric PE"
- Therefore, current proportional to "electric PE"

$$\Delta V = IR$$

$$I = qnAv \quad \Rightarrow \quad v = \frac{I}{qnA}$$

$$qE = bv$$

$$\Delta V = EL \quad \Rightarrow \quad E = \frac{\Delta V}{L}$$

$$\Rightarrow \quad \frac{q\Delta V}{L} = \frac{bI}{qnA}$$

$$\Delta V = I\left(\frac{bL}{q^2 nA}\right) \equiv IR$$

3/13/17 Physics 132 **14**

This is like the Hagen-Poiseuille equation!

- $\Delta p = JZ$

  Pressure drop =
  Rate of fluid flow
  ×Resistance to flow

- $\Delta V = IR$

  Voltage drop =
  Rate of charge flow
  ×Electrical resistance

Resistivity and Conductance

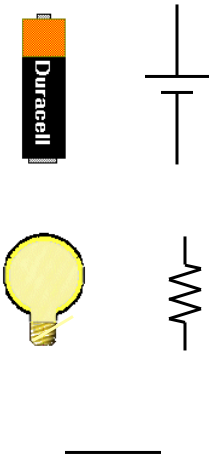
- The resistance factor in Ohm's Law separates into a geometrical part (L/A) times a part independent of the size and shape but dependent on the material.
- This coefficient is called the *resistivity* of the material (ρ). Its reciprocal (g) is called *conductivity*. The reciprocal of the resistance is called the *conductance* (G).

$$R = \left(\frac{bL}{q^2 nA}\right) = \rho\frac{L}{A} = \frac{1}{g}\frac{L}{A} = \frac{1}{G}$$

3/13/17 **16**

Electric circuit elements

- *Batteries* —devices that maintain a constant electrical pressure difference across their terminals (like a water pump that raises water to a certain height).
- *Resistances* —devices that have significant drag and oppose current. Pressure will drop across them.
- *Wires* — have very little resistance. We can ignore the drag in them (mostly – as long as there are other resistances present).



Foothold ideas: Kirchhoff's principles

1. ***Flow rule***: The total amount of current flowing into any volume in an electrical network equals the amount flowing out.
2. ***Ohm's law***: in a resistor, $\Delta V = IR$
3. ***Loop rule***: Following around any loop in an electrical network the potential has to come back to the same value (sum of drops = sum of rises).

Very useful heuristic

- The Constant Potential Trick (CPT)
  (Or, if you like, "Kirchhoff's 0th law")
  - Along any part of a circuit with 0 resistance, then $\Delta V = 0$, i.e., the voltage is constant since in any circuit element

$$\Delta V = IR$$