Electrostatics vs. Circuits

- Thus far, we've focused on electrostatics and electric fields and potentials: the behavior of individual charges, stationary or in an electric field, and the principles behind those behaviors
- We have <u>not</u> yet talked about electric **current**, or the behavior of charges in **circuits**
- The best way to begin thinking about electrical current in circuits is by thinking about water in a pipe system…like this…

Water circuit analogy

- Consider the picture to the right.
  - What is flowing through the pipes?

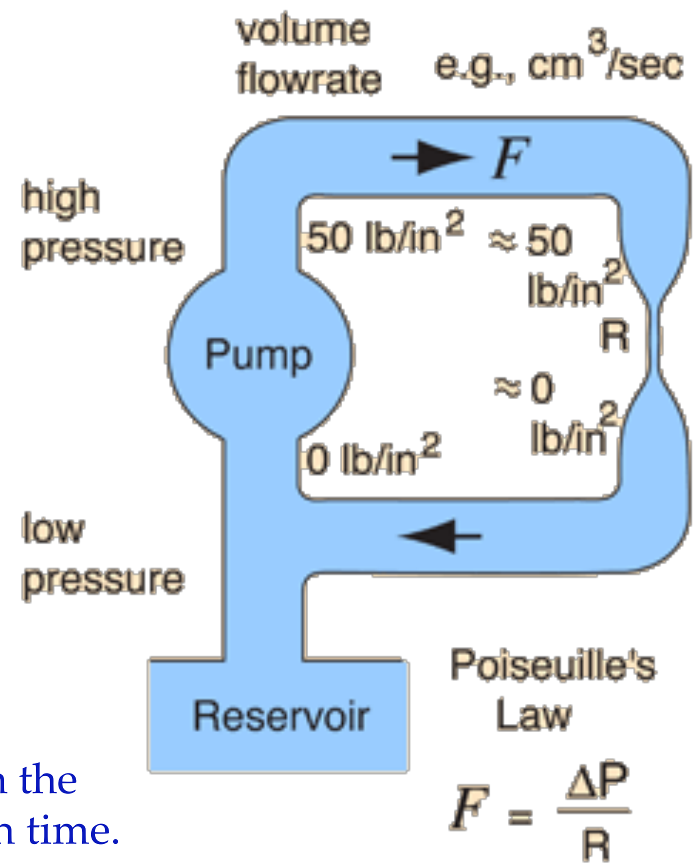
    Water (duh)
  - What causes it to flow?

    The pump, which provides high pressure to force water to move.
  - Which way does it flow?

    From the high pressure side to the low pressure side, around the pipe circuit.
  - What controls how much flows?

    The available space in the pipes - the narrow part on the right side limits how much water can flow in a given time.
  - How do we measure how much flows?

    A flow rate - for water, a "volume" flow rate. How much water per second -- NOT a velocity!



Now a circuit

- Same questions for this picture:
  - What is flowing through the circuit?

    Something in the wires - charge!
    (is it positive charge? Negative charge? Why?)

  - What causes it to flow?

    The battery, which acts like a pump.

  - Which way does it flow?

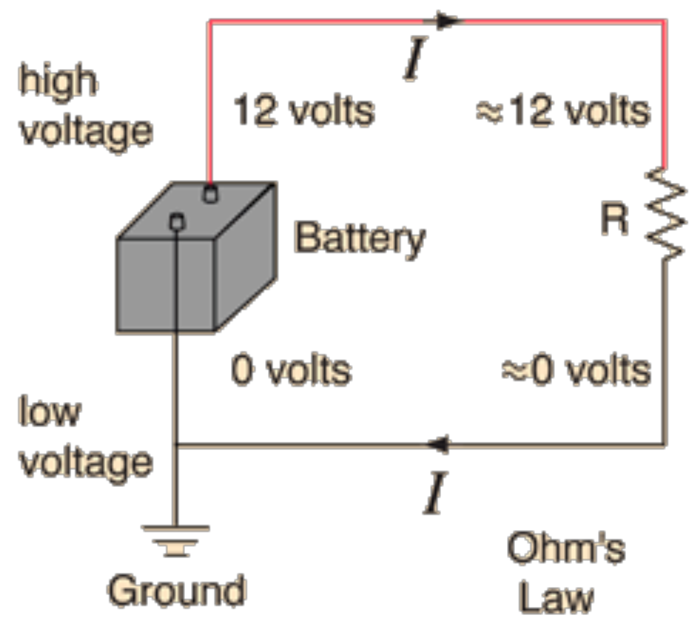
    From the high potential energy side to the low potential energy side. (Does that change your answer to #1? How does it relate to #1?)

  - What controls how much flows?

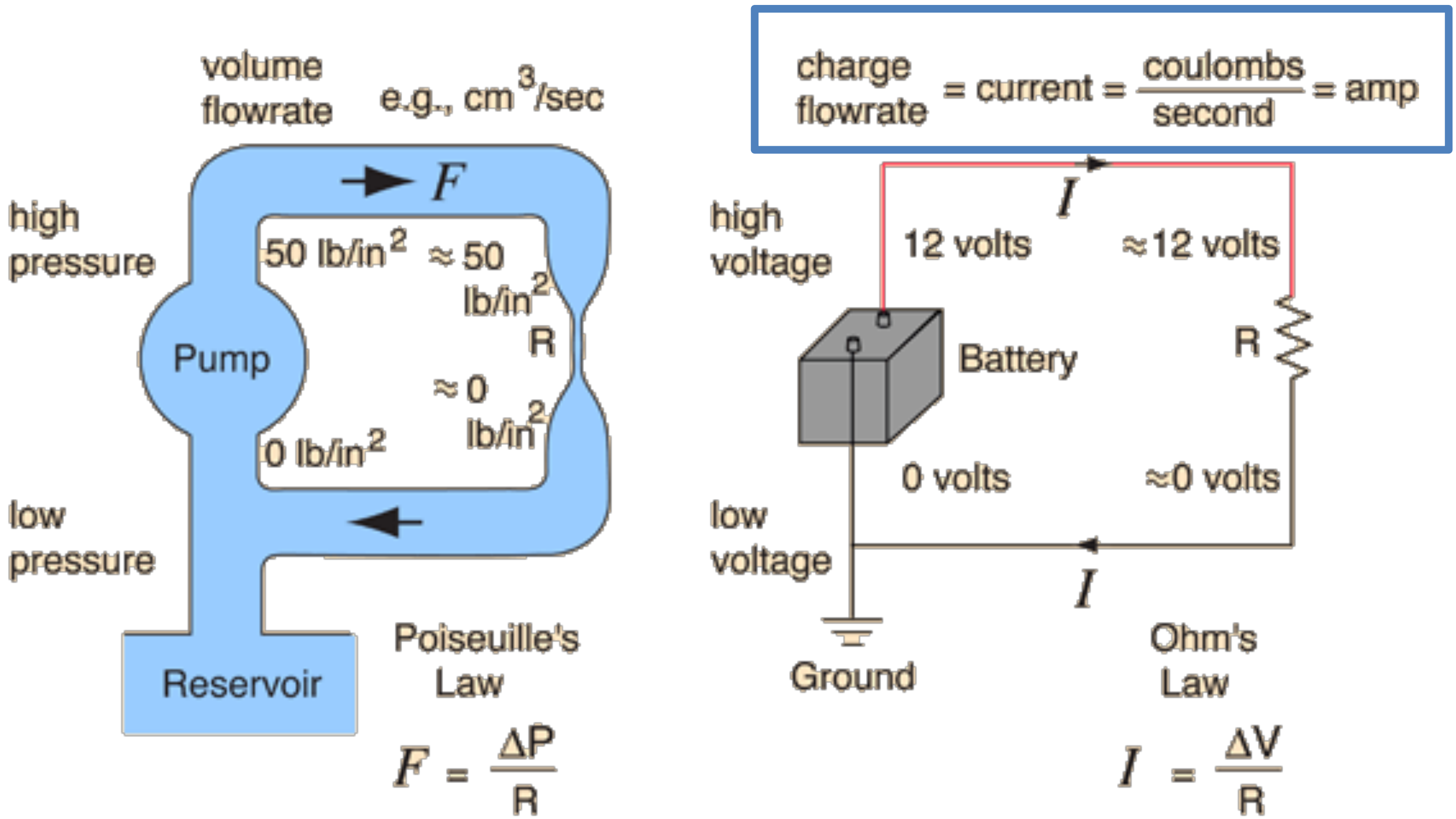
    How difficult the path to flow through is - what do you think "R" means in the diagram?

  - How do we measure how much flows?

    A flow rate - **current!**



Water vs. electricity



Note: as we continue through this unit, we will point out ways in which this analogy is both good and bad. Remember that charge is <u>not</u> water, and there are some big differences we will explore!

Charge flow rate

- We talk about the “charge flow rate” in a circuit in terms of amount of charge per second -- this is called **current**
  - This is not a speed! It’s how much, not how fast, per second.
  - Current (symbol: I) is measured in Amperes (A), where 1 A = 1 C/second

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

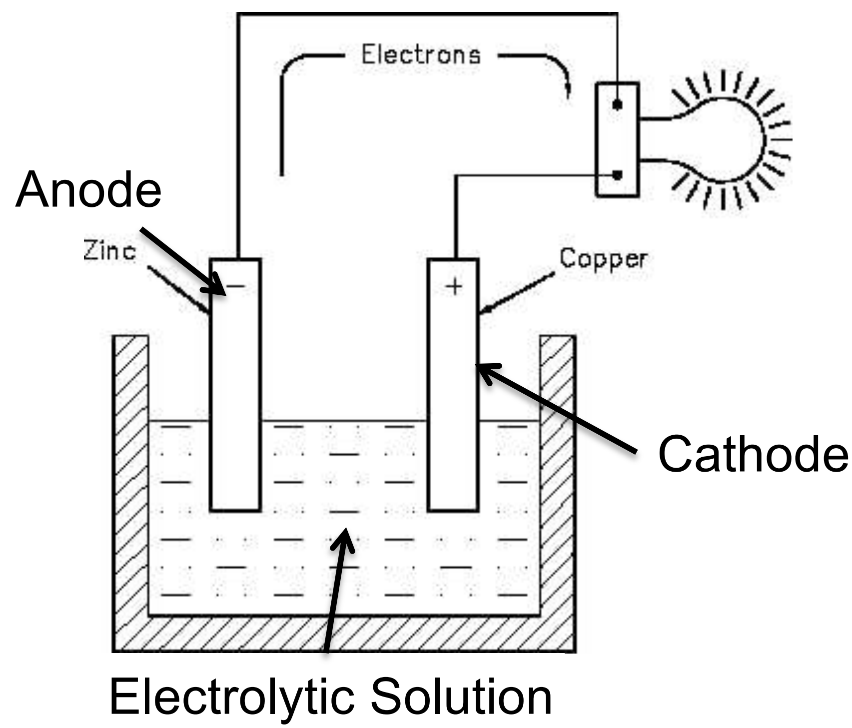
- What could affect the amount of current in a circuit?

  -Battery (big vs. small voltage)
  -Wire properties (e.g. thicker wire, more conductive wire)
  -Circuit properties (e.g. resistors!)

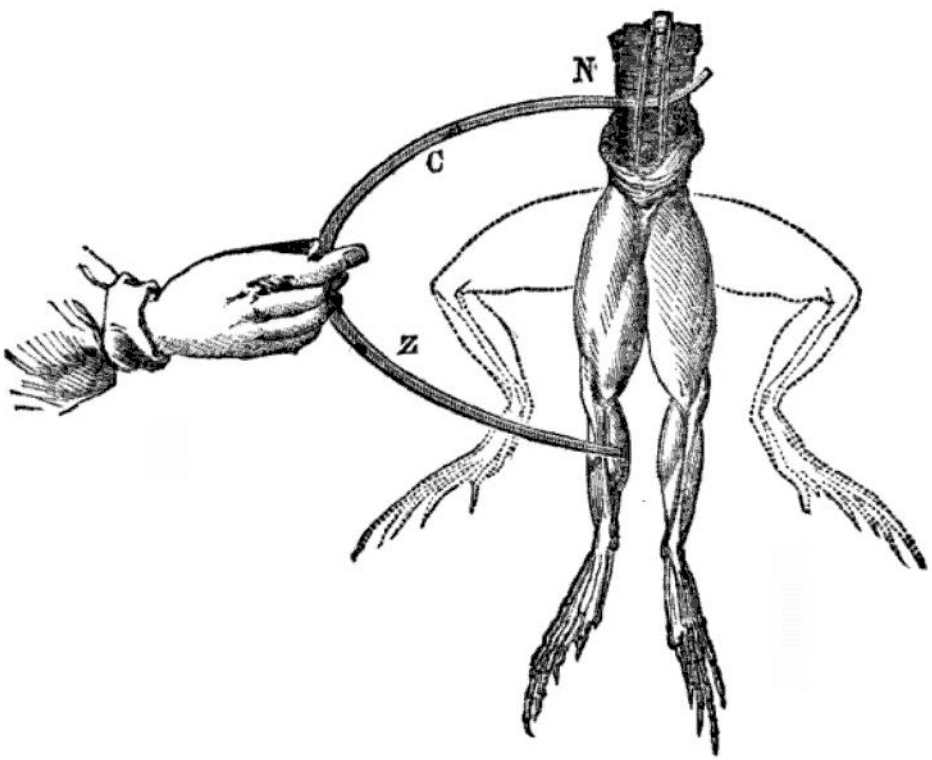
- For a current to flow, we need:
  - A closed loop of conductors (this is what we mean by ”circuit”)
  - A potential difference (aka voltage, produced by the battery)

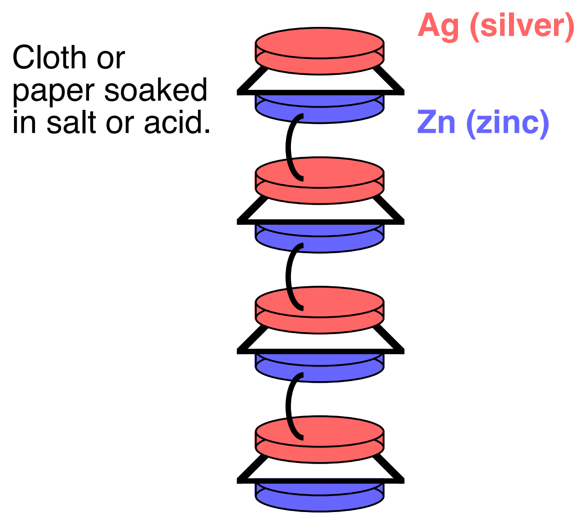
Basic battery

- An electric battery consists of an anode (negative node) and a cathode (positive node) which are both immersed in an electrolytic solution like an acid or a base. The nodes are usually called terminals.
- The solution oxidizes the cathode and reduces the anode, resulting in opposite charges, and thus a potential difference, between the nodes.
- **Here's the key!**
  - If the nodes aren't connected, the voltage doesn't change - it stores this potential energy
  - If the nodes are connected, charge flows due to the potential difference
  - As long as the oxidation/reduction reactions continue, the battery will maintain its voltage



Early batteries - Galvani vs. Volta (1780s)

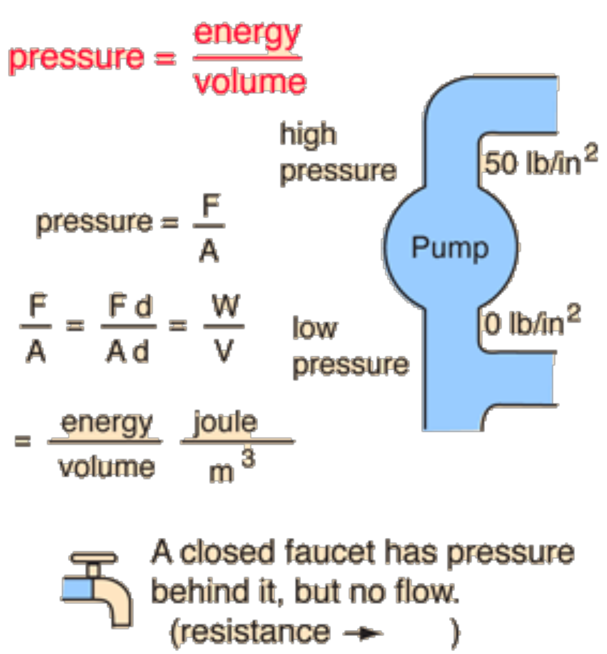


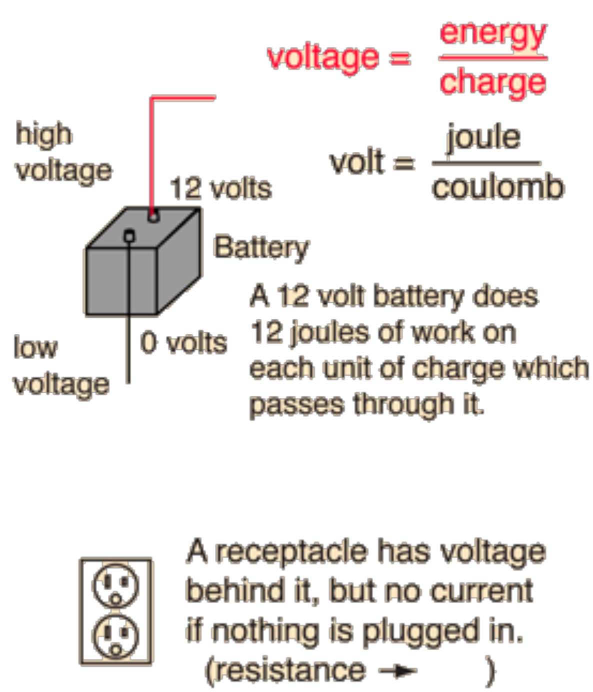


This slide courtesy of Mr. White!

Battery as a "pump"

- In the water circuit, the pump took in water at low pressure, did work on it (compressed it), then released it at high pressure to cause the flow through the pipes
- In an electrical circuit, what does the battery do?





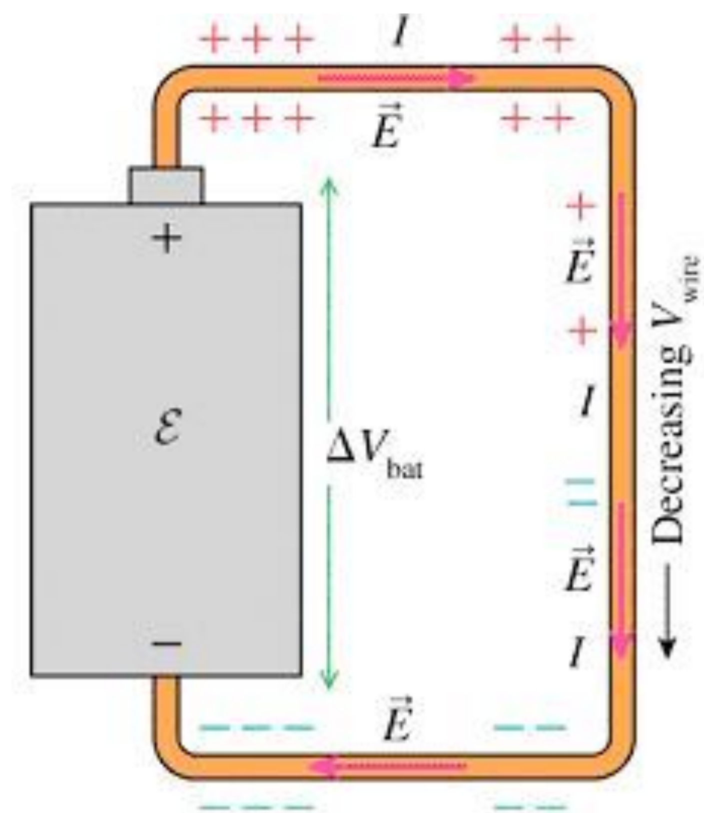
A battery takes charge, does work on it, then releases it at high potential energy. **It does not create or provide charge, it merely pumps the charge already in the wires.**

Remember that the voltage of a battery is the potential difference between the terminals!

http://hyperphysics.phy-astr.gsu.edu/hbase/electric/watcir.html

Conventional current

- Electrons will flow from the negative node, anode, to the positive node, cathode, as long as a potential difference exists.
  – More generally, **charge carriers** will flow in a direction determined by the electric field
- Conventional current is visualized as flowing from the cathode to the anode. Conventional current aligns with the electric field within the conductor.
- The electric field within the conducting path drives the current.
  – Remember, an electric field does not exist within a conductor when the charges are not moving, but it does exist within the conductor when charges do move!



More about current and energy

- In electrostatics, why was the electric potential the same everywhere in a conductor?

- In circuits, this is no longer true. Charge moving along the wire moves from high to low potential, meaning they lose energy (and it doesn't go to KE, like a test charge did before).
  - The relationship $\Delta U = q\Delta V$ still holds! The electrons lose energy $q\Delta V$, and energy $-q\Delta V$ is deposited in the wire.
  - That energy goes into whatever the circuit is trying to do: make light, heat, run an appliance, etc.
  - If you can calculate the ΔU, dividing it by the time elapsed gives the power in Watts: $P = W/t = \Delta U/t$

Example problem

- 4 C of charge flows through a lightbulb filament in 2 seconds.
  - What's the (average) current in the lightbulb?

$$\mathrm{I} = \frac{\Delta \mathrm{Q}}{\Delta \mathrm{t}} = \frac{4\ \mathrm{C}}{2\ \mathrm{s}} = 2\ \mathrm{A}$$

  - How many electrons pass through the filament in 5 seconds?

$\Delta Q = I\Delta t$, and ΔQ can also be thought of as Nq (where N is the number of electrons (q)), so…

$$\mathrm{N} = \frac{\mathrm{I}\Delta \mathrm{t}}{\mathrm{q}} = \frac{(2\ \mathrm{A})(5\ \mathrm{s})}{1.6\mathrm{x}10^{-19}\mathrm{C}} = 6.7\mathrm{x}10^{19}\ electrons$$

  - If connected to a 12-V battery for 2 seconds, what's the total energy and the power delivered?

$$\Delta \mathrm{U} = \mathrm{q}\Delta \mathrm{V} = (4\ \mathrm{C})(12\ \mathrm{V}) = 48\ \mathrm{J}$$

$$\mathrm{P} = \frac{\Delta \mathrm{U}}{\mathrm{t}} = \frac{48\ \mathrm{J}}{2\ \mathrm{s}} = 24\ \mathrm{W}$$