Quick reminders

- What is current?

  Current is a flow of charge - the amount of charge per second that passes a point is defined as the current through that point. It is not a speed!. Its symbol is I; its unit is coulombs/second, or the Amps (that is, 1 A = 1 C / 1 sec)

- What makes current flow?

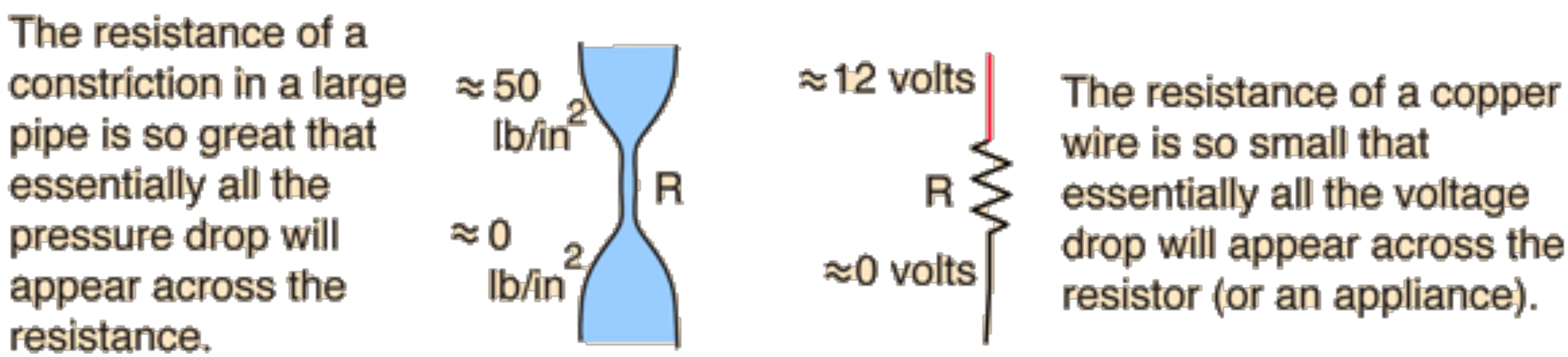
  Current flows due to a potential difference (voltage) within a circuit. The battery generates a potential difference that produces an electric field in the wires that motivates charge to flow. A battery does not "make" charge or "give" charge to the wires - the charge is already there!

- What is required for a circuit to exist and function?

  A circuit is a closed loop of conductors (wires) that includes a voltage source (e.g. battery) and a load (resistors).

What else affects current?

- Properties of the wires and circuit components also affect the current in a circuit. Back to the pipes for a moment…
  - Which is easier to drink soda from: a big thick straw (think boba straws) or a skinny little straw (think coffee straw)? Why?
- The impedance of flow is called **resistance (R)**. This depends on many factors, but one is the thickness of the path - we'll talk about the others, too.

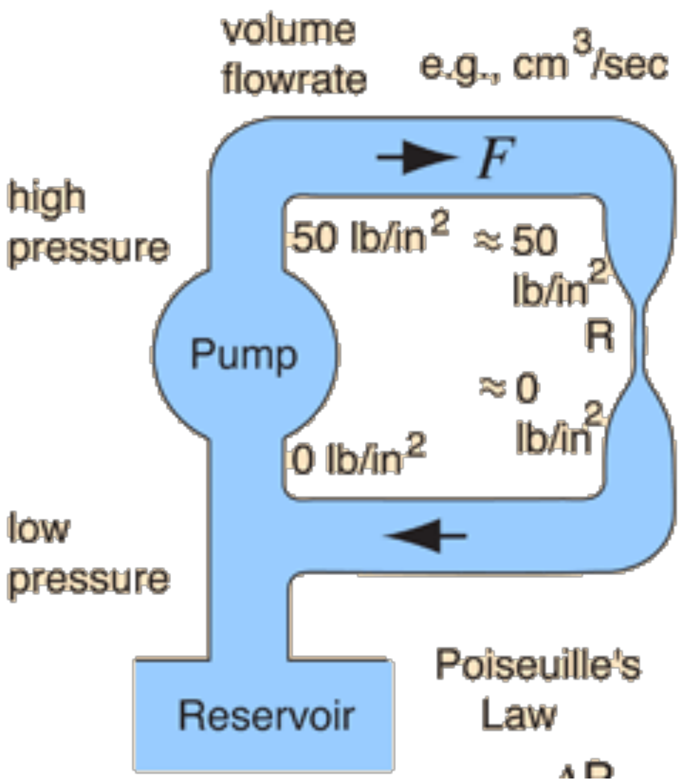


Why might it be important that wires of a circuit have low resistance?

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

BIG IMPORTANT POINT

- In the water circuit, where is the flow rate greatest: before the skinny pipe, in the skinny pipe, after the skinny pipe? Why?



The flow rate (current) is the same everywhere in the pipes. The same amount of water must be moving in all parts of the circuit.

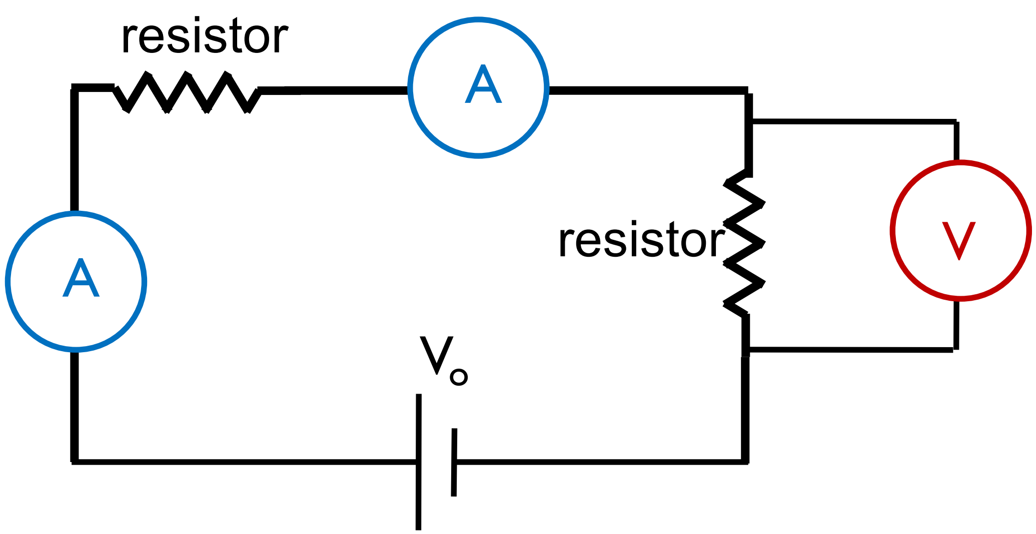
The <u>pressure</u> drops as you move through the skinny pipe, but the actual amount of water flowing does not! The same is true for charge in a circuit: the <u>voltage</u> drops across a resistor, but the current does not.

This means current is <u>the same everywhere in a circuit</u>.

Measuring current and voltage

- We need a way to measure these things to help understand what's going on in a circuit, or to predict behavior.
- Current is measured with an **ammeter**
  - Where should an ammeter be placed to measure current?
- Voltage is measured with a **voltmeter**
  - Where should a voltmeter be placed to measure voltage? (hint: what does "voltage" really mean?)

Ammeters go "in line" - current has to go through it to be measured without affecting the current. Effective ammeters should have low resistance.



Voltmeters go "across" a resistor, to measure the potential difference (drop) across that object. Voltmeters have high resistance, so they don't divert current and affect the behavior of the circuit.

Putting it all together

- If you increase the potential difference driving the circuit, what happens to the current?
  - It increases: bigger potential difference = more energy to move more charge
- If you increase the resistance that current encounters throughout the circuit, what happens to the current?
  - It decreases: more resistance = harder for charge to flow
  - Remember that this decreases the current EVERYWHERE in the circuit, not just through the resistor itself!
- These observations are summarized in **Ohm's law**:

$$\Delta V = IR$$

Potential difference in whatever part of the circuit you're looking at, units = Volts

Current in that part of the circuit, units = Amps

Resistance of that part of the circuit, units = ohms (*Ω*)

Some points about Ohm's Law

- Ohm's law can be applied for an entire circuit
  - For example, we can predict the current in a given circuit if we know the total voltage drop across the circuit (= battery voltage) and the total resistance of the circuit (we'll talk about that in a moment)
- Ohm's law can also be applied for an individual resistor or portion of a circuit
  - For example, for a given resistor, R, we can say $\Delta V_R = \mathrm{IR}$
  - Remember that the ΔV can be taken between any two points, and even when it's written V = IR (a common shorthand), that "V" is really a potential <u>difference</u>, not an absolute potential
- For Ohm's law to work, the resistors must be **ohmic**, which means their resistance is constant over a wide range of applied voltages or currents
  - This means if you graph V vs. I, there is a linear relationship. Most resistors we will use in problems will be ohmic unless stated otherwise.
  - **Nonohmic** materials have nonlinear relationships (e.g. diodes, transistors)

Resistance and resistivity

- What could affect the resistance of something in a circuit?

- For a <u>wire</u>, the resistance depends on three main things:
  - The length of the wire (longer = more resistance)
  - The cross sectional area of the wire (thicker wire = less resistance)
  - The physical properties of the wire (material, temperature, etc.), measured by something called *resistivity* (ρ)

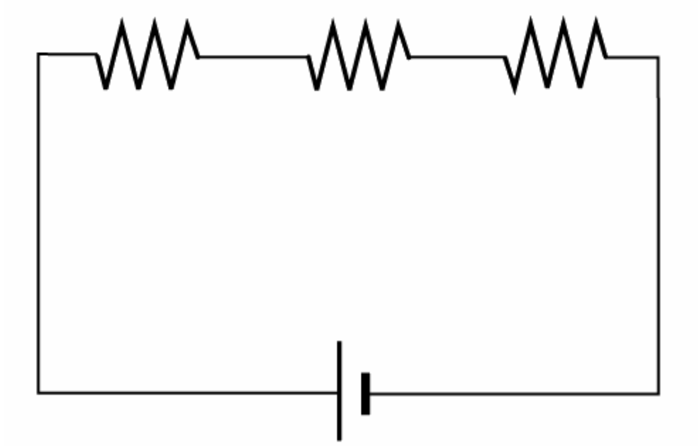
$$R = \rho \frac{L}{A}$$

  - We won't be using this for problems now, but the concept will come back later - and it helps understand what's going on, too!

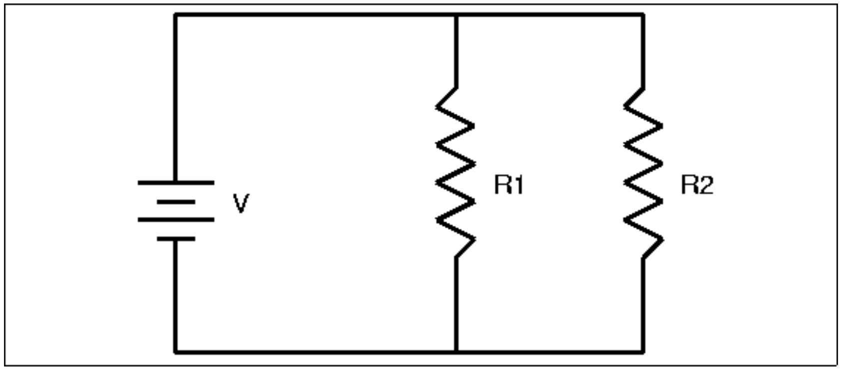
DC circuits

- There are two main ways to arrange resistors within a circuit

Series



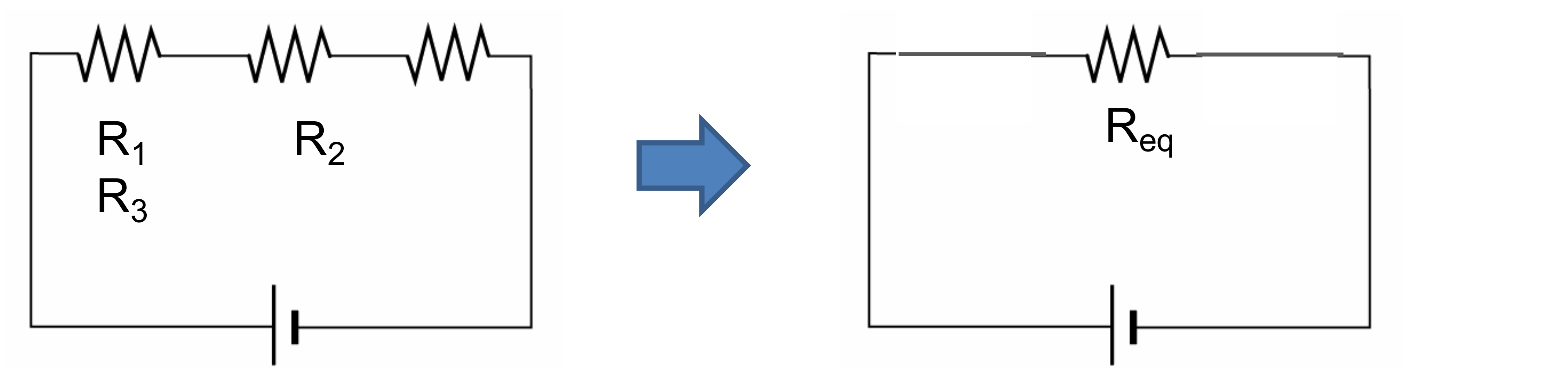
Parallel



- What can you say about the current in each circuit? Is it constant? Does it change? Why?
- What can you say about the voltage drop in each circuit? Where does it happen? Why does it happen?

Series circuits overview

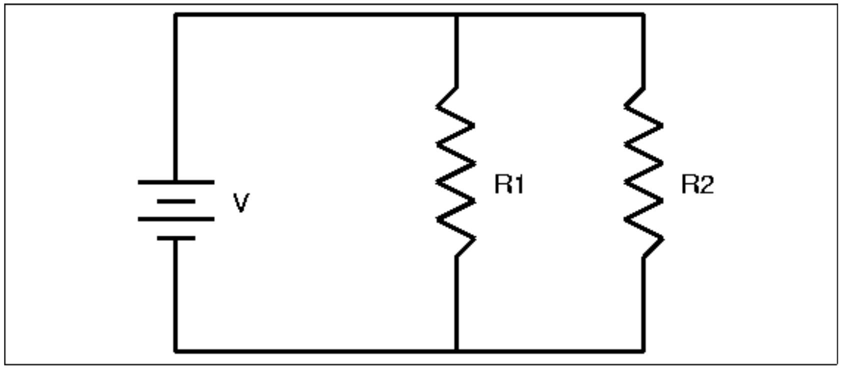
- In **series**, the current must go through each resistor - there is only one path. Therefore, the current in all part of the circuit must be the same ($I_1=I_2=I_n=I_{tot}$)
- The voltage drop across each resistor may vary, depending on the resistor, but the total voltage drop across all the resistors must equal the voltage of the battery ($\Delta V_{tot} = \Delta V_1 + \Delta V_2 + \cdots \Delta V_n$)
- This means we can treat the circuit as if it had one big resistor with the same resistance as all the series ones added together. We call this the **equivalent resistance**: $R_{eq,series} = R_1 + R_2 + \cdots R_n$



Parallel circuits overview

- In **parallel**, there are multiple paths for charge to take, so the current in the parallel strands is not necessarily the same. The total current going in and out of the parallel branches must remain equal, and it divides among the parallel branches.
  - For the circuit below, $I_{tot} = I_1 + I_2$
- The potential difference across the parallel branches is the same, however, because each is connected directly to the battery terminals (and we saw before that the potential doesn't change along a wire, only across a resistor).
  - This means we can find I_1 and I_2 by applying Ohm's Law to each branch: $I_1 = \frac{\Delta V}{R_1}$ and $I_2 = \frac{\Delta V}{R_2}$
  - Thus, $I_{tot} = \frac{\Delta V}{R_{eq,parallel}}$

$$\frac{1}{R_{eq}} = \sum_{i=1}^{n} \frac{1}{R_i} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots \frac{1}{R_n}$$

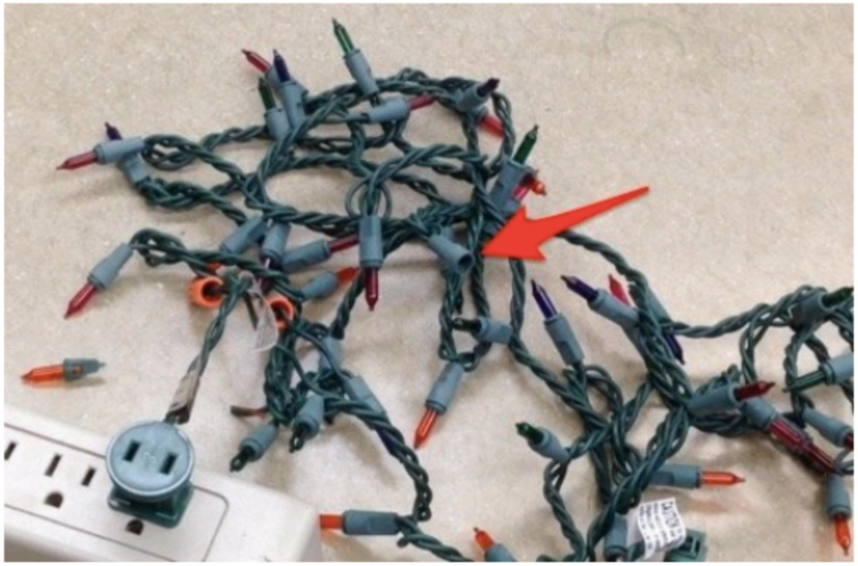


Series vs. parallel example (18.2)

- Three 9 Ω resistors are connected to a 12 V battery.
  - If connected in series, find the equivalent resistance of the circuit, the current through each resistor, and the voltage drop across each resistor.
  - If connected in parallel, find the equivalent resistance of the circuit, the current through each resistor, and the voltage drop across each resistor.

Xmas in February…

- Why aren't these lights working? What does that tell you about what's probably going on in this circuit?



RHETT ALLAIN

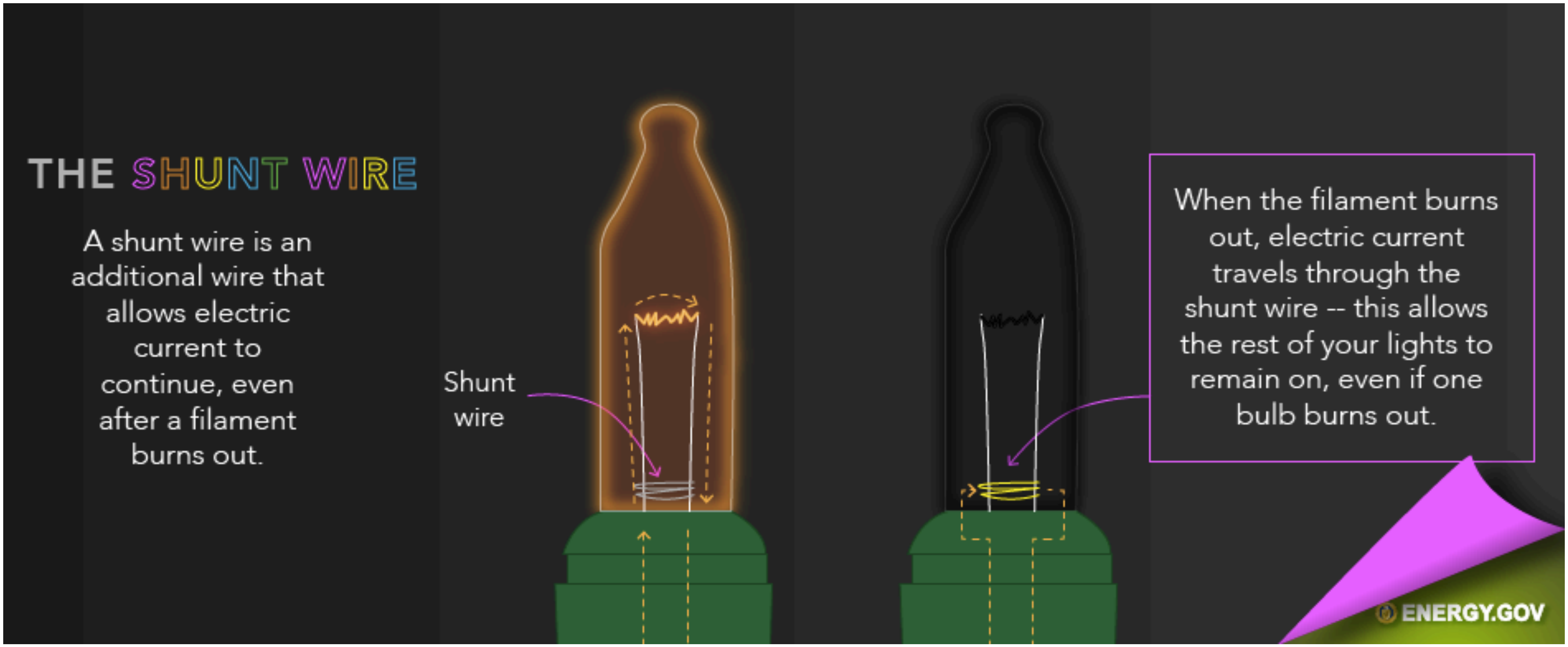
RHETT ALLAIN

❑ Based on what you saw + said above, explain <u>this</u>! (yes, it's the same string of lights)

https://www.wired.com/2014/12/christmas-lights-series-parallel/

Xmas in February...

What's inside a Christmas lightbulb:



What seems to be the obvious problem here?

Xmas in February…

- The shunt wire is normally coated in an insulating material - as long as the filament is working, the current will go through the conductive filament and not the insulated shunt wire
- When the filament burns out (breaks), the bulb's resistance goes <u>way</u> up. What does that do to the applied voltage across the shunt wire?

- That big voltage across a very small distance produces a very strong electric field in that region…and we know that strong electric fields can break down insulators (when have we seen this?)
- Thus, the insulating material burns off, allowing the shunt to conduct electricity and keep the circuit intact!