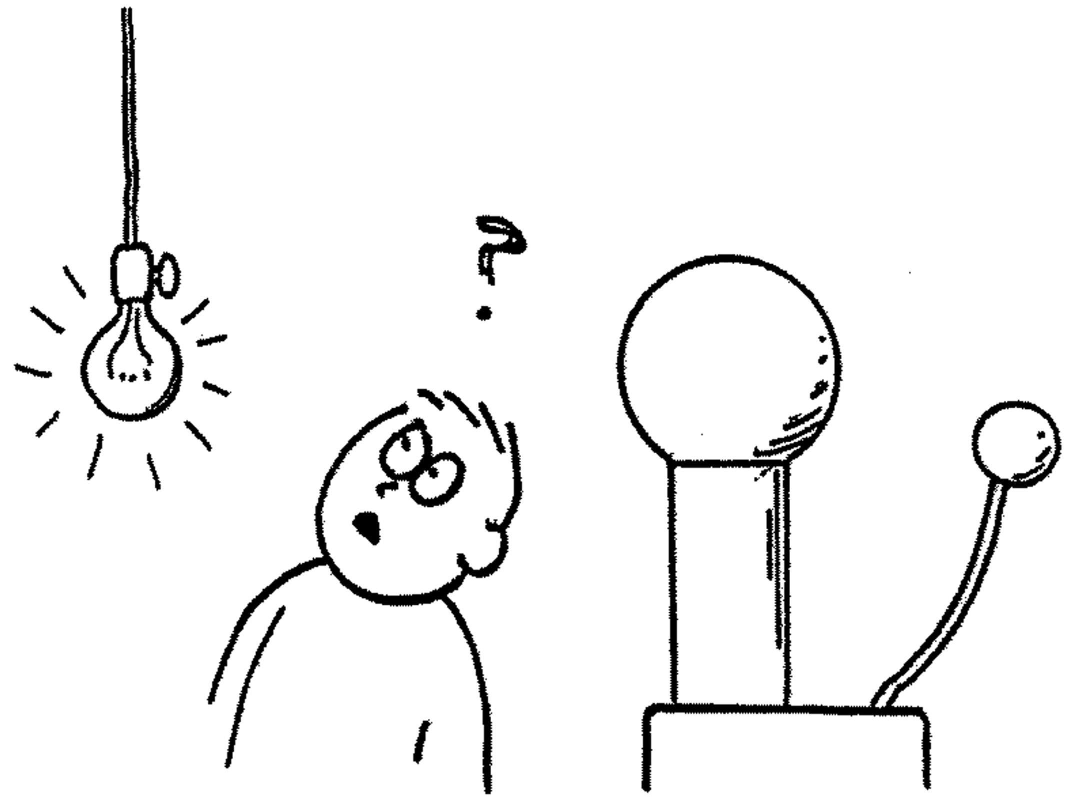
QUESTION:



Which is
more dangerous,

1. touching a faulty 110-volt light bulb?
2. touching a Van de Graaff generator
   charged to 100,000 volts?

Electric current

- Charges in motion:
  - Count positive charges going from left to right
  - Add negative charges going from right to left
  - Subtract all charges moving in the opposite direction
  - Divide by time =>
- $I = \Delta q_{net} / \Delta t$
- Typically occurs inside conducting medium (wires, sea water, etc.); also discharges (lightning)…
- Analog: water flowing through a pipe
- Doesn't require any NET charge, only different motion of different types of charges
- Unit: Ampere [A] = Coulomb/second [C/s]

Electric current II

- Electrical currents require work: *)
  - Charges keep bumping into each other and the "lattice" of positively charged atoms making up a conductor
  - This heats up the conductor (lightbulb, heater, resistor)
  - This heat energy must come from somewhere!
- Analog: water flowing through a pipe: you need a pressure difference to keep the water flowing
- => Voltage difference! (Analog to pressure difference)
- The more resistance you have in the "pipe", the more you have to push to make a current flow: $V = RI$

*) Except in a superconductor

Resistors and Power

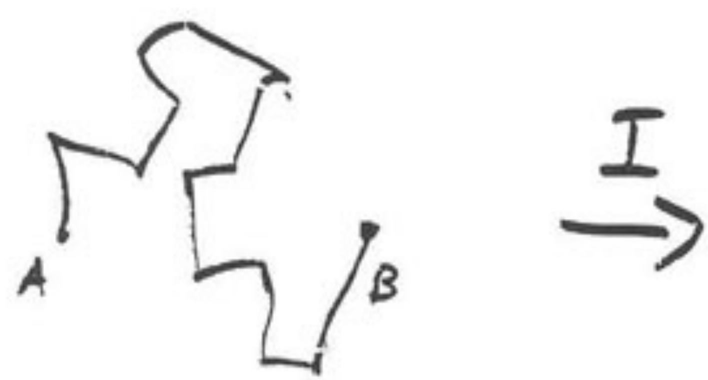
- R is the resistance of a piece of conductor
- Measured in Ω = V/A (Ohm)
- Ohm's law: $I = V/R$
- *R* **increases** with the length of the conductor and **decreases** with the cross section; for most metals it increases with temperature
- Example: Electric shock - it's the Amperes that hurt you
- Summary:
  - Because a conductor has resistance *R*, a voltage *V* is required to push a current *I* through
  - In the process, electrical energy is converted into heat
  - The higher the voltage AND the higher the current, the more energy can be converted to heat per second -> Power = $I \cdot V$ -> determines brightness of lightbulb, heat from heater, power of motor, etc.
  - Watt [W] = Volt · Ampere [VA]
- This energy has to come from SOMEWHERE

“Voltage Sources”

- Electric field alone doesn’t suffice
  - Due to imbalance in charges
  - Current flow will try to even out that imbalance
  - Eventually everything will come to a halt (no field inside conductor)
  - Analog: Water flowing between two reservoirs until both have same height
- => “Pump” = device that can move charges AGAINST an electric field and thereby maintain a voltage difference. Examples:
  - Batteries
  - Van de Graph generators
  - Fuel cells
  - Solar panels
  - Electromagnetic generators (later)

AC/DC

- In a real conductor, there are 3 types of motions in play:
  - Extremely fast thermal motion (10^6 m/s, but random)
  - Even faster "message transmission" via **E** (all electrons move in near lockstep)
  - Net displacement of electrons over time at a snail's pace (0.05 mm/s)
  - => current



- DC current: direction of motion stays the same - electrons keep pushing through like cars on I-64 at rush hour
- AC current: direction reverses frequently (e.g. back and forth in 1/60 of a second) -> no single electron ever makes the roundtrip

Circuits

- Water can flow out of a reservoir for a while, but then the reservoir has to be replenished
- Electric current cannot be maintained for any extended time without constantly replenishing the charge -> CIRCUITS! *)
- Simplest form: Closed loop
  - Battery, wire, lamp
  - Battery, wire, several lamps in series
  - Same current flows through all pieces, voltage changes in steps
- Can have several branches (like estuary) -> parallel circuit
  - Current splits up between different branches, nodes at fixed voltage

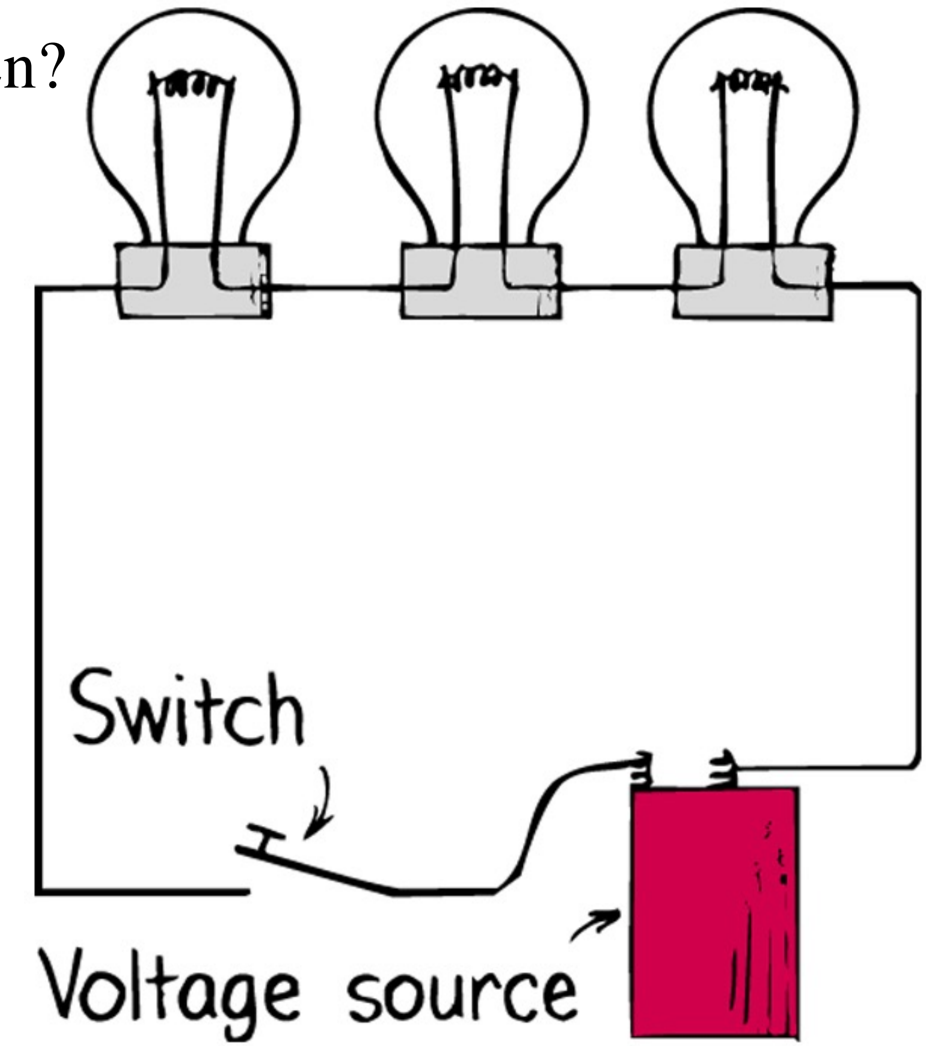
*) Example: charging capacitor - works only for a SHORT time

Rules for Circuits

- Inside a single closed loop, the **current** must be the same everywhere (series circuit). An interruption anywhere causes no current everywhere. The total voltage drop around the entire circuit determines the power required. The voltage drop across each single element determines the power delivered to that element: $P = V\, I$ (I const.)
- For several parallel branches (parallel circuit), the **voltage** must be the same across each branch. An interruption of any one branch doesn't affect the others. The total amount of current drawn is the sum of the currents through each branch. The current through each branch determines the power delivered to that branch: $P = V\, I$ (V const.)
- You can have a parallel branch made out of a series circuit etc. => Apply the rules to the entire (top level) circuit and then to each individual branch.

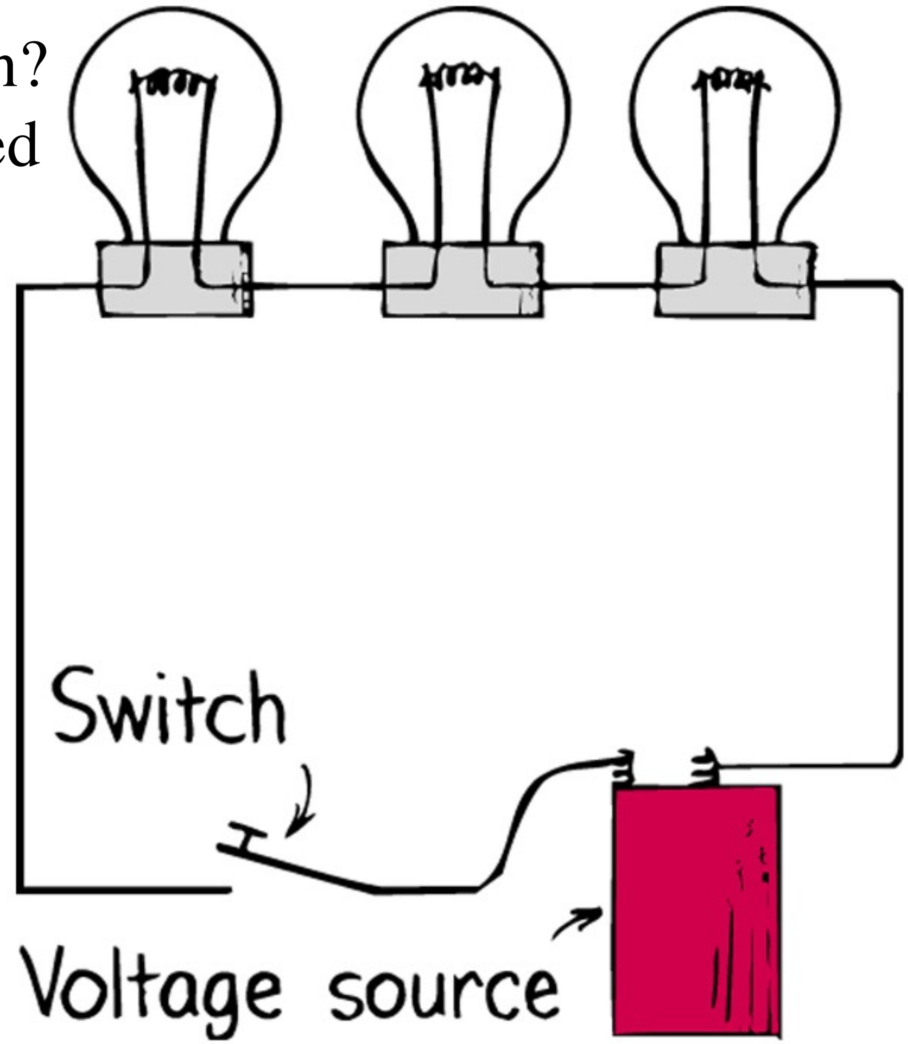
Series Circuit

- Q: What happens if switch is open?



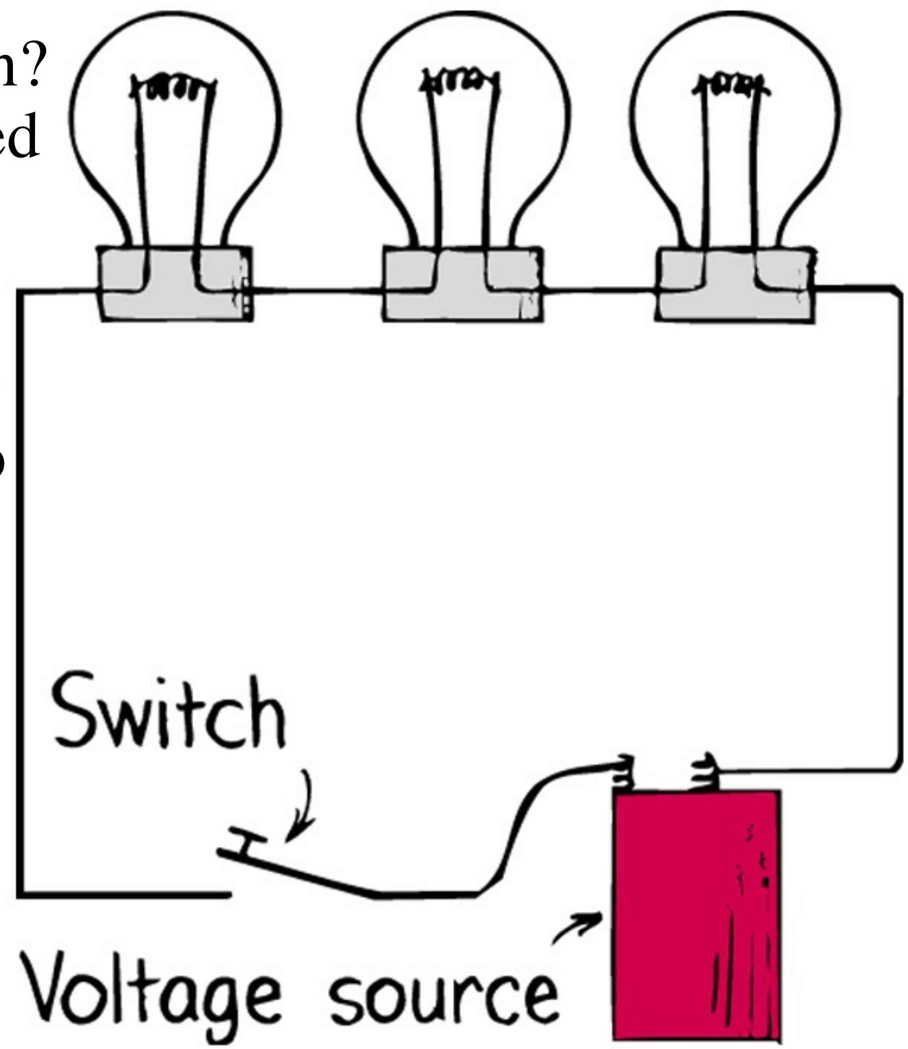
Series Circuit

- Q: What happens if switch is open?
  A: Nothing - circuit must be closed
- Q: Which light bulb burns brightest?



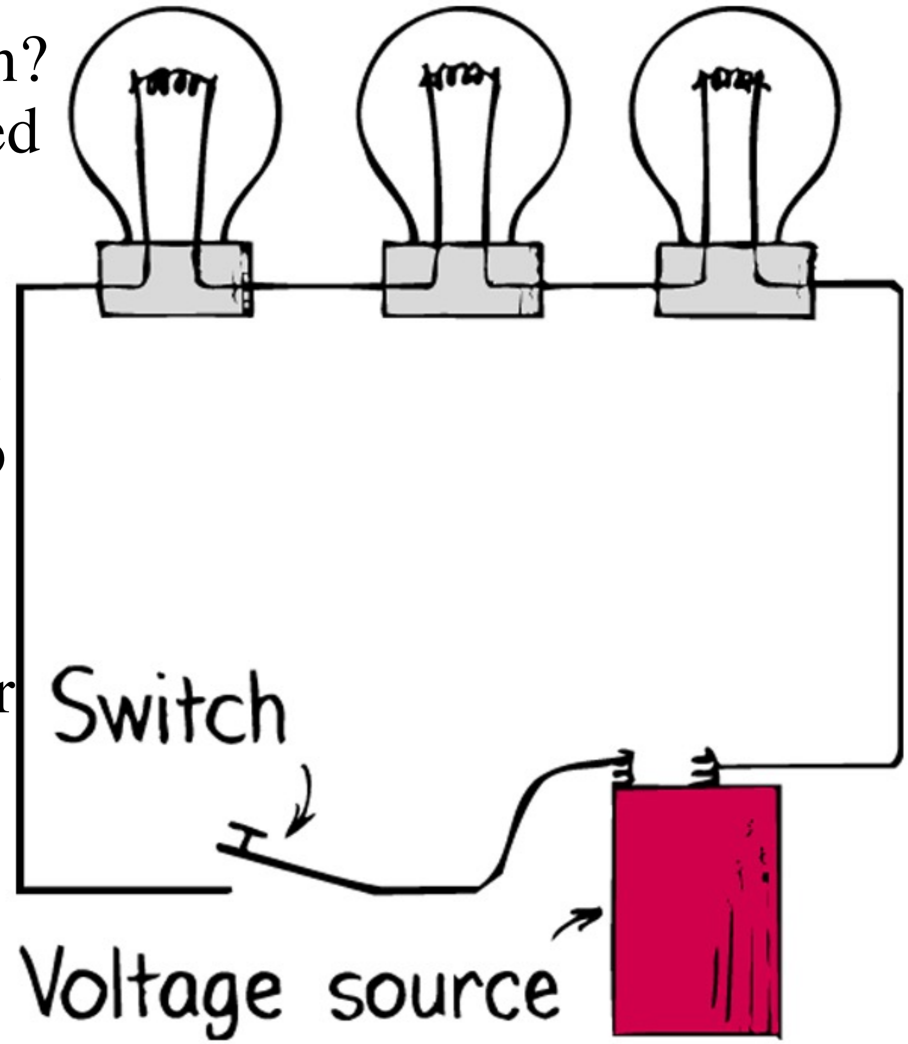
Series Circuit

- Q: What happens if switch is open?
  A: Nothing - circuit must be closed
- Q: Which light bulb burns brightest?
  A: All 3 have the same brightness
- Q: What happens if one light bulb burns out?



Series Circuit

- Q: What happens if switch is open?
  A: Nothing - circuit must be closed
- Q: Which light bulb burns brightest?
  A: All 3 have the same brightness
- Q: What happens if one light bulb burns out?
  A: All 3 go dim
- Q: Would 2 bulbs burn brighter or dimmer than 3?



Series Circuit

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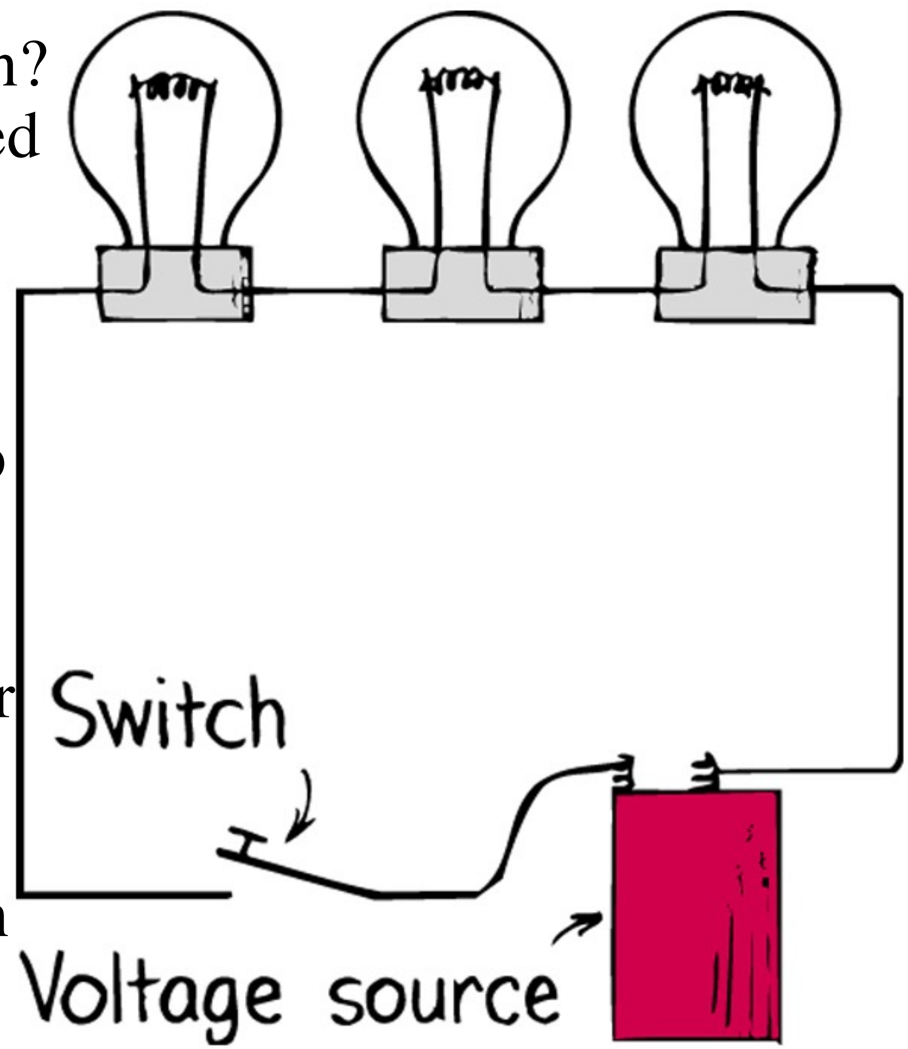
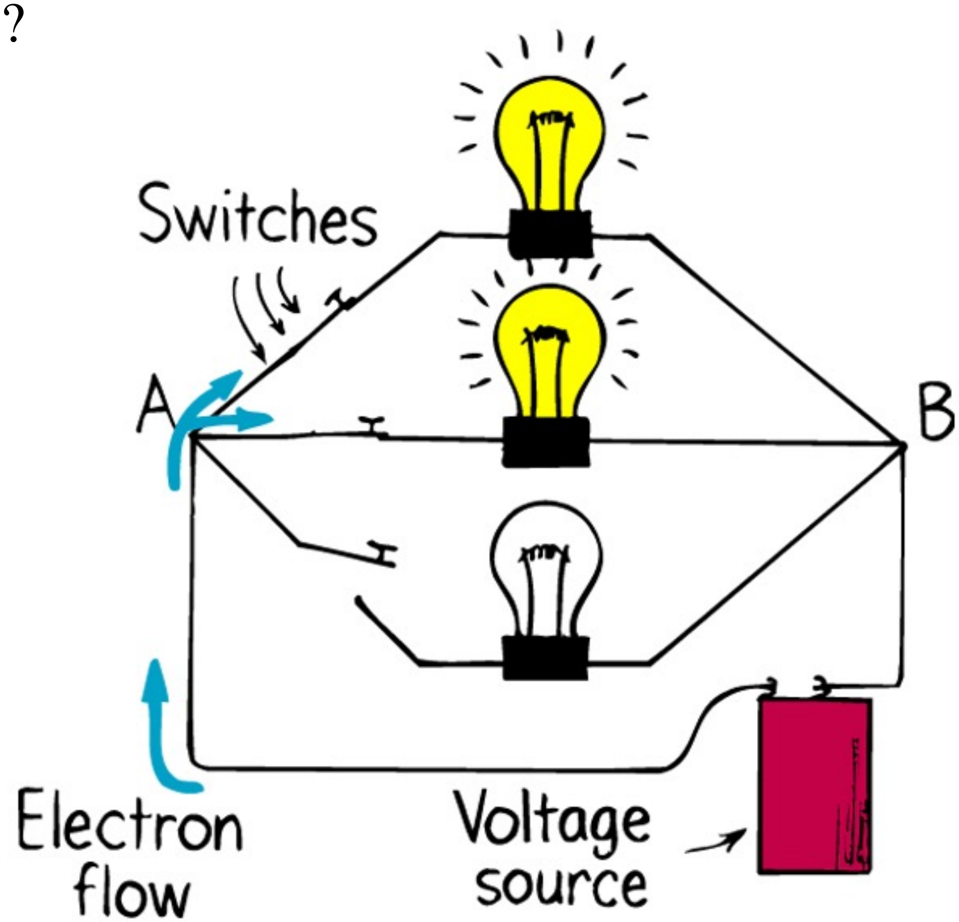
- Q: Which light bulb burns brightest?
  A: All 3 have the same brightness
- Q: What happens if one light bulb burns out?
  A: All 3 go dim
- Q: Would 2 bulbs burn brighter or dimmer than 3?
  A: Brighter! Because the total R would be smaller, $I = V/R$ through each bulb would be larger.



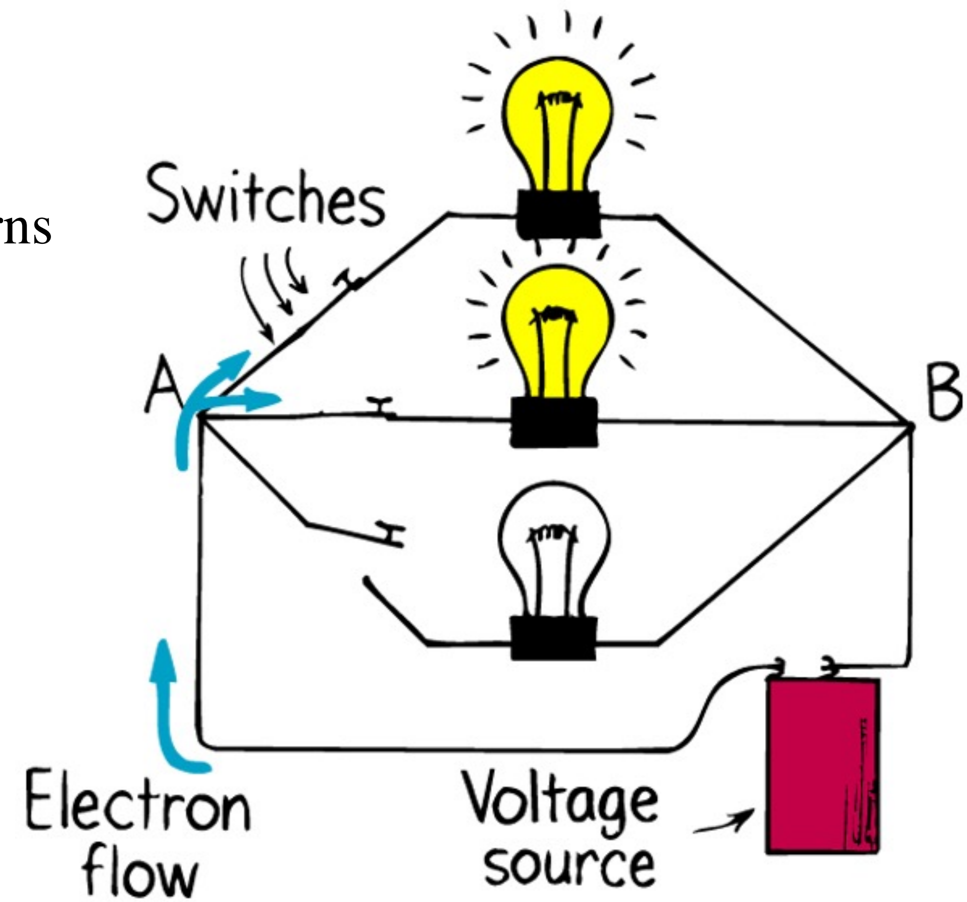
Parallel Circuit

- Q: What happens if switch is closed?



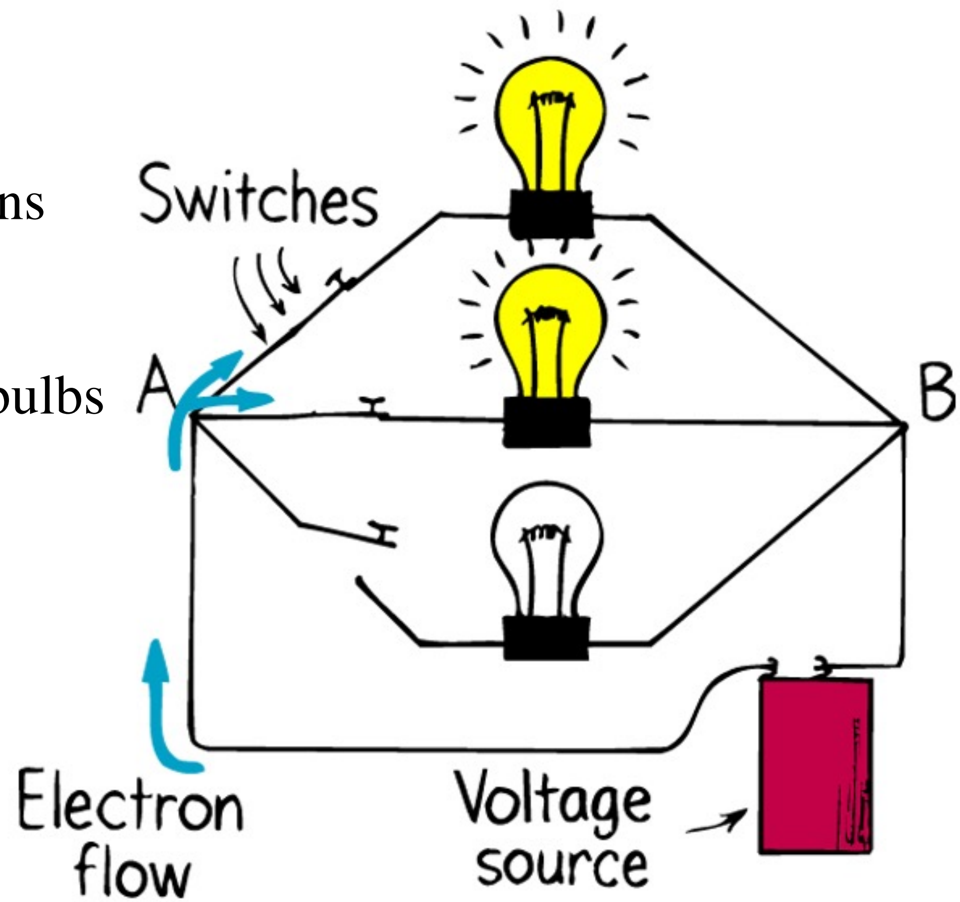
Parallel Circuit

- Q: What happens if switch is closed?
  A: Third bulb goes on, the other two remain unchanged
- Q: What happens if one light bulb burns out?



Parallel Circuit

- Q: What happens if switch is closed?
  A: Third bulb goes on, the other two remain unchanged
- Q: What happens if one light bulb burns out?
  A: Nothing happens to the other two
- Q: Are 3 bulbs in series brighter or 3 bulbs in parallel?



Parallel Circuit

- Q: What happens if switch is closed?
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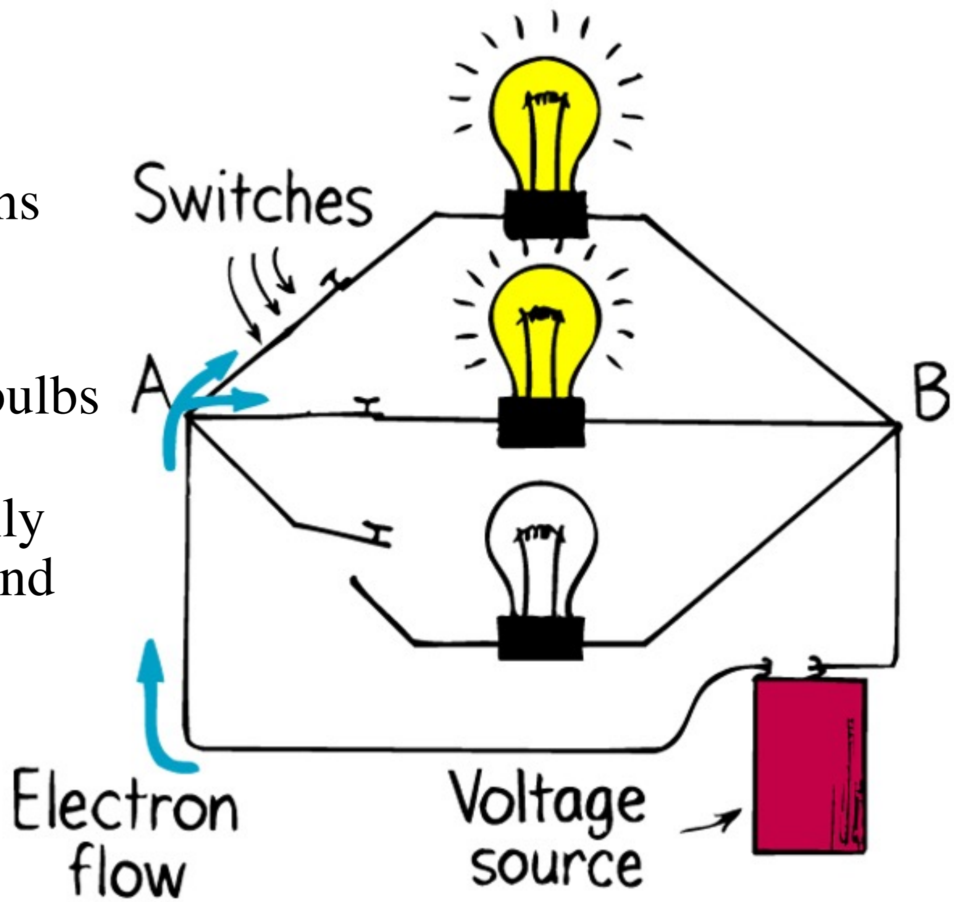
- Q: What happens if one light bulb burns out?
  A: Nothing happens to the other two
- Q: Are 3 bulbs in series brighter or 3 bulbs in parallel?
  A: 3 bulbs in parallel - each individually sees the full voltage from the battery and can draw a larger current.
- Q: How much more current does the battery have to supply for 3 parallel bulbs vs. 3 bulbs in series?



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  A: 3 bulbs in parallel - each individually sees the full voltage from the battery and can draw a larger current.
- Q: How much more current does the battery have to supply for 3 parallel bulbs vs. 3 bulbs in series?
  A: 9 times!