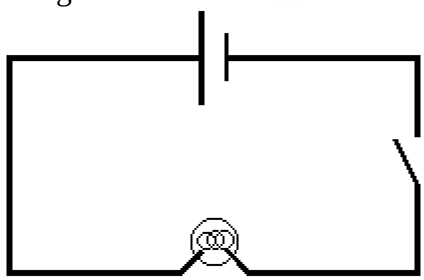
Note-A-Rific: Characteristics

Any path along which electrons can flow is a circuit.

- For a continuous flow of electrons, there must be a complete circuit with no gaps.
- A gap is usually an electric switch that can be closed to allow electron flow or open to cut it off.
- There is a standard set of symbols used to represent parts of a circuit (you've already seen a couple).
  - Check out the diagrams on page 641 of the text book… you must memorize these!
- If I wanted to draw a diagram of a light bulb powered by a battery that can be turned off and on, it might look like this…



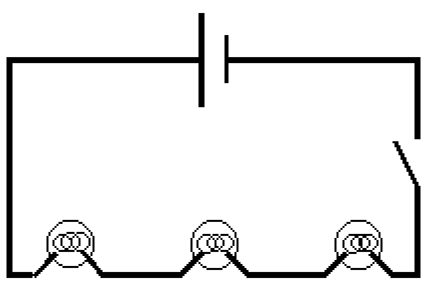
Most circuits that are found in homes have more than one device hooked up.

- Two main types of circuits are series or parallel.

  Series → a single pathway for electron flow between the terminals of the battery

  Parallel → branches, each of which is a separate path for the flow of electrons

Series Circuit



When the switch is closed, a current exists almost immediately in all three lamps.

- There is only one pathway that you can trace with your finger, so this is a series circuit.
- The current does not "pile up" in any lamp but flows *through* each lamp.
- Electrons that make up this current leave the negative terminal of the battery, pass through each of the *resistive* filaments in the lamps in turn, and then end up at the positive terminal of the battery.

- The same amount of current passes through the battery, since it is part of the circuit.
- A break anywhere in the path results in an open circuit, and the flow of electrons stops.
  - Burning out of one of the lamp filaments or simply opening the switch could cause such a break.

Important characteristics of series connections:

1. Electric current has a single pathway through the circuit.
   - This means that the **current passing through each resistor is the same**.

2. This current is resisted by the first resistor, the second resistor, and the third resistor also.
   - The total resistance to current in the circuit is the sum of the individual resistances along the circuit path.

3. The current in the circuit is equal to the voltage supplied by the source divided by the total resistance of the circuit. ($I = V / R_{total}$)

4. The voltage drop (potential difference) across each device is proportional to its resistance.
   - This is because more energy is used to move a unit of charge through a large resistance than through a small resistance.

5. The total voltage across a series circuit is divided among the individual electrical devices in the circuit
   - The sum of the voltage drops across each individual device is equal to the total voltage supplied by the source.

Example: This example is a long one, so pay attention! The diagram above shows three light bulbs, with resistances of 3.0Ω, 4.0Ω, and 5.0Ω hooked up in series to a 9.0V battery. Calculate…

a) the current in the circuit.

- First we need to find what single resistance ***R*** could replace the three true resistors without altering the rest of the circuit.
- We let ***V*** represent the voltage across all three resistors.
- ***V*** also equals the voltage of the battery.
- We let V_1, V_2, and V_3 be the potential differences across each of the resistors R_1, R_2 and R_3.

$V_1 = IR_1$ $\qquad$ $V_2 = IR_2$ $\qquad$ $V_3 = IR_3$

** Note: The current is the same throughout a series circuit, so it is a constant in all three formulas.*

- Since the resistors are connected end to end, the total voltage V is equal to the sum of the voltages across each resistor, so we have

  $V = IR$

  $V = V_1 + V_2 + V_3$

  $IR = IR_1 + IR_2 + IR_3$

  $R = R_1 + R_2 + R_3$

- So, for several resistances in series, the total resistance is the sum of the separate resistances.
  - This works for any number of resistances.
  - When you add more resistance to the circuit, the current will decrease.

- For our example, the total resistance in the circuit is

  $R = R_1 + R_2 + R_3$

  $R = 3.0\Omega + 4.0\Omega + 5.0\Omega = 12.0\Omega$

- For our example, the current in the circuit is

  $V = IR$

  $I = V / R = 9.0V / 12.0\Omega =$ **0.75A**

b) the voltage drop across each resistor.

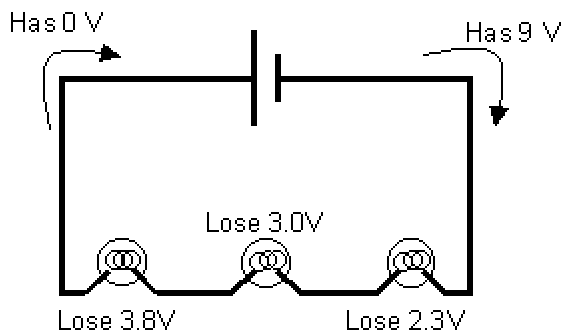
- Voltage drop is how much of the voltage is used by each resistor.
  - Remember to think of voltage as "pumping power"
  - As the current goes around the circuit, it loses some of its "pumping power" at each resistor.
  - By the time the current has gone all the way around the circuit, it shouldn't have any "pumping power" left.
- Remember that the current you calculated in (a) is the current anywhere in the circuit.
  - We will use this current and the resistance of each resistor to figure out the voltage drop across each resistor…

    The 3.0Ω resistor → $V = IR = 0.75A\ (3.0\Omega) = 2.3\ V$

    The 4.0Ω resistor → $V = IR = 0.75A\ (4.0\Omega) = 3.0\ V$

    The 5.0Ω resistor → $V = IR = 0.75A\ (5.0\Omega) = 3.8\ V$

- Notice that if you take rounding off into account, these three voltages add up to 9 volts, which is what the battery supplies!

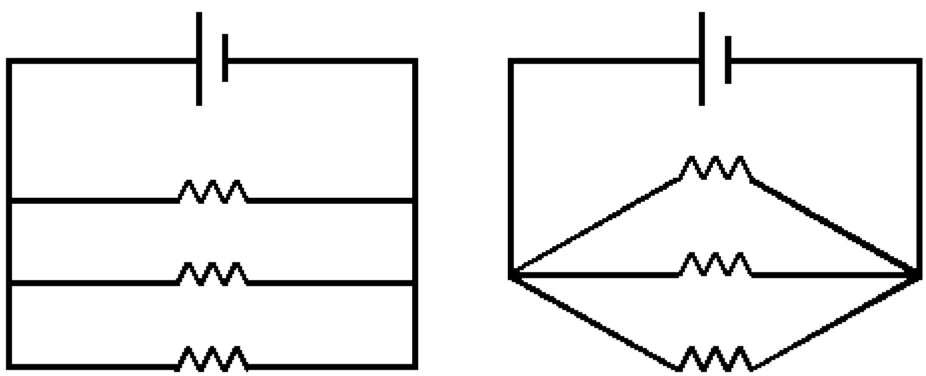


c) **the total voltage drop across all three resistors.**

- We know that by the time the current has gone all the way around the circuit, the voltage must drop by 9 volts. This is the answer! If you don't believe me, you can calculate it this way…

$$V = IR$$
$$= (0.75A)(12.0\Omega)$$
$$V = 9.0V$$

Parallel Circuits



Resistors connected in parallel are connected to the same two points of an electric circuit.

- Notice that in the diagrams above, you could trace three different paths from one terminal to the other with your finger.
- Electrons leaving the negative terminal of the battery will travel through only one resistor before returning to the positive terminal of the battery.
- In the example, current branches into three separate pathways.
- A break in any one path does not interrupt the flow of charge in the other paths.

<u>Important characteristics of parallel connections</u>:

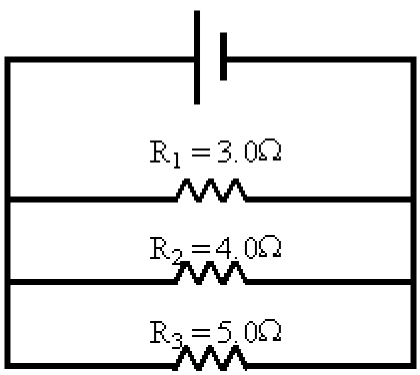
1. Each device connects at the same two points of the circuit. Therefore the <u>voltage</u> is the same across each device.
   - If you look at it, <u>each</u> of those resistors is connected to both ends of the battery, without any other resistors in series in the way.

2. The total current in the circuit divides among the parallel branches. Current passes more readily into devices of low resistance, so the amount of current in each branch is inversely proportional to the resistance of the branch.
   - This means if one of the branches has a very low resistance the majority of the current will flow through that resistor.
   - Less current will flow through branches that have high resistance.

3. The total current in the circuit equals the sum of the currents in its parallel branches.

4. As the number of parallel branches is increased, the overall resistance of the circuit is decreased.

Example: This is another long one! Look at the following diagram with three resistors, 3.0Ω, 4.0Ω, and 5.0Ω, hooked up in parallel to a 9.0V battery. Calculate…



a) the current in the wire before it branches off into all the different resistors.

- The current starts at the negative terminal and runs clockwise.
- The total current that leaves the battery breaks into three branches I_1, I_2, and I_3 in the resistors R_1, R_2, and R_3.
- To figure out the current before it splits, we need to figure out what the current would be if there was only one resistor in the way… and equivalent resistor.
- This follows a different set of rules than series circuits.
- Because charge is conserved, the current flowing into a junction must equal the current flowing out, so

$$I = I_1 + I_2 + I_3$$

- The total voltage of the battery is applied to each resistor, so…

$$I_1 = V/R_1 \qquad I_2 = V/R_2 \qquad I_3 = V/R_3$$

- Combine and cancel out V to get…

$$V/R = V/R_1 + V/R_2 + V/R_3$$

$$1/R = 1/R_1 + 1/R_2 + 1/R_3$$

- You can NOT just say "Oh, now I'll take the inverse of this formula and just get R = R1 + R2 + R_3"… they are NOT mathematically equivalent.
- For this circuit the equivalent resistance is…

$$1/R = 1/R_1 + 1/R_2 + 1/R_3$$

$$1/R = 1/(3.0\Omega) + 1/(4.0\Omega) + 1/\ (5.0\Omega)$$

$$1/R = 0.78\Omega^{-1}$$
$$R = 1.3\ \Omega$$

Remember to take the inverse to get the final answer. Overlooking this is a very common mistake!

- Now, to figure out the current before the electricity reaches the branch where 3.0Ω resistor is sitting…

$$V = IR$$
$$I = V / R$$
$$= (9.0V) / (1.3\Omega)$$
$$I = 7.1\ A$$

b) the current in each branch of the circuit.

- When the current starts branching off into those resistors, the 7.1 A you calculated above will start to branch off as well.
    - Whichever pathway offers the least resistance will have the most current flowing through it.
- We do know that since this is a parallel circuit, each part of the circuit is connected to the same voltage, 9.0V.
- For the R_1 resistor…

$$V = IR$$
$$I = V / R$$
$$= (9.0V) / (3.0\Omega)$$
$$I = 3.0\ A$$

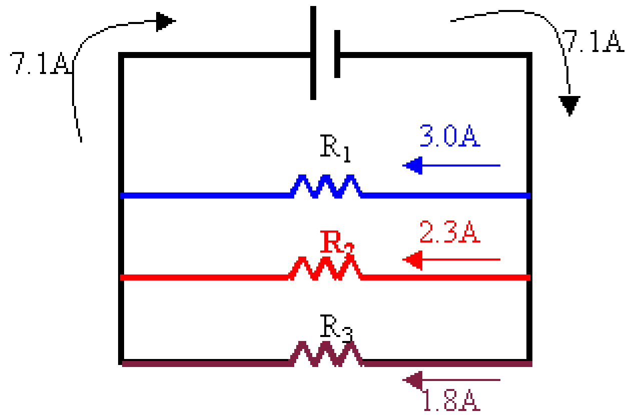
- For the R_2 resistor…

$$V = IR$$
$$I = V / R$$
$$= (9.0V) / (4.0\Omega)$$
$$I = 2.3\ A$$

- For the R_3 resistor…

$$V = IR$$
$$I = V / R$$
$$= (9.0V) / (5.0\Omega)$$
$$I = 1.8\ A$$

- Add all three currents together (as they join back up from the branches and flow towards the positive terminal in a single wire) and you'll see that you have 7.1A!



c) the voltage drop over each resistor.

- Like we've already said… they all have the same voltage across them, 9.0V

d) the total voltage drop across all the resistors.

- Still 9.0V. Can you say why?