# 13c: Resistance

The amount of **current** flowing in a circuit depends, in part, on the **voltage**.

- By increasing the **voltage** (maybe by using a more powerful battery) you increase the "pumping power" that is moving current through the circuit.
- **Current** flow also depends on how the material of the conductor resists the motion of electrons.
    - **Gold**: an excellent conductor, because its electrons are quite easily moved.
    - **Aluminum**: not a great conductor, since its electrons don't move well.
- We would say that **gold** has a low **resistance**, and **aluminum** has a high **resistance**.

To understand the relationship between **voltage**, **current**, and **resistance**, look at the following analogy.

- Imagine a water pump that is being used to get some water out of the basement of a house. The people first try using a thin hose, and then a wider hose.

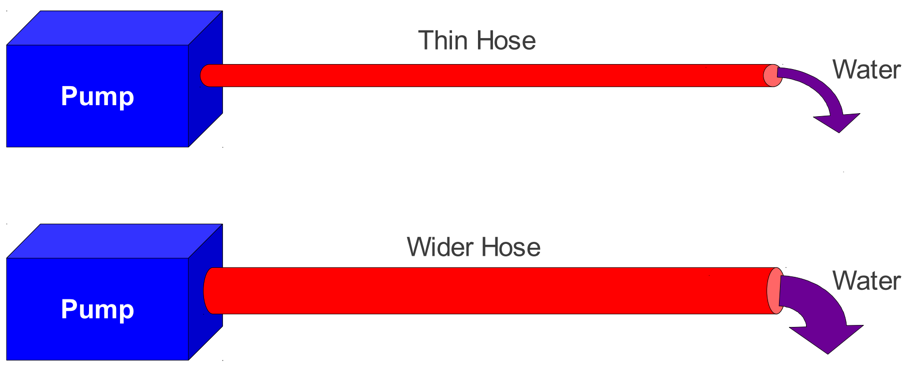



*Illustration 1: Two different setups for pumping water.*

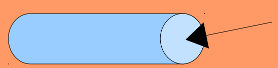
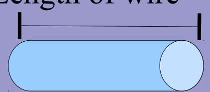
- The wider hose has a much lower **resistance** to the water flowing through it, so more water comes out the other end.

This is the same way that electricity works:

1. The **pump** is like **voltage**: think of voltage (potential difference) as the pumping power that is shoving electrons through the wire.
2. The **hose diameter** is like the wire's **resistance**: a thin hose let's only a little water through, just like a poor conductor only lets a little current through.
3. The **water** is like **current**: a little water pouring out is like a little current running through a wire.

# Calculating Resistance

We can figure out the **resistance** of a particular piece of wire if we examine a few related factors:

| ***Property*** | ***Relationship*** | ***Example*** |
|---|---|---|
| Resistivity of material | Different materials used as conductors result in different resistances. This is compared by assigning a resistivity (ρ) to materials. $R \alpha \rho$ | Gold has a low resistivity because it is such a good conductor. |
| Cross section area of wire  | Larger areas result in low resistances. $R \alpha \frac{1}{A}$ | A large diameter wire is a wider opening for electrons to move through, just like a wide doorway can allow more people to walk easily through. |
| Length of wire  | Shorter lengths of wire result in low resistances. $R \alpha l$ | Moving current through a long piece of wire is like forcing the electrons to run a marathon race. A lot of the energy is used up just trying to get to the end. |
| Temperature* | Higher temperatures result in higher resistances. $R \alpha T$ | As discussed earlier, superconductors exist at lower temperatures. When conductors are colder, their atoms are moving less. This makes it easier for the electrons to "move through". |

* We will not take into account the ***temperature coefficient*** (α) in calculations.

Three of these factors can be put together to give us the formula...

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

**R** = **resistance** (ohms = Ω)
ρ = resistivity (Ω·m)
A = area ($m^2$)

The symbol for Ohms, Ω, is the Greek letter "omega". It was chosen because if the letter "O" was used, most people would mistake it for a zero. Values for resistivity can be found on various websites such as Wikipedia.

**Did you know?**
Have you ever noticed that light bulbs usually burn out when you first turn them on? When the bulb is turned off, the filament is at room temperature, so its resistance is quite low. You turn it on and there's a sudden rush of electrons pushing through the filament at a very low resistance… this might cause the filament to snap. If it can survive those first couple of seconds, the temperature of the filament quickly increases, which increases the resistance, so the electrons don't go ripping through the filament quite as fast anymore.

**Example 1**: Wire gauge is a method used to compare different cross sectional areas of wires; the higher the gauge, the smaller the area. 14-gauge wire has a diameter of 1.628 mm. If aluminum has a resistivity of 2.82-8 Ω·m, **determine** the resistance of a 12.5 m long piece of 14-gauge aluminum wire.

First, figure out the cross section area of the wire. Remember that radius is half the diameter, and the diameter was given in millimetres. Then determine the resistance.

$$A = \pi r^2$$
$$A = (3.14)\left(\frac{1.628\text{e-}3}{2}\right)^2$$
$$A = 2.081\text{e-}6\ m^2$$

$$R = \frac{\rho l}{A}$$
$$R = \frac{2.82\text{e-}8(12.5)}{2.081\text{e-}6}$$
$$R = 0.169\ \Omega$$

Some typical resistances for everyday objects are:

- Electrical Cord ⇒ Less than 1 Ω
- Incandescent Light Bulb ⇒ 100 Ω
- Clothes Iron ⇒ 15 Ω

**Example 2**: **Explain** why you think each of the three items listed above would have such different resistances.

- A cord needs a low resistance since its entire purpose is to transfer energy from an outlet to the device that needs the electricity. We want to transfer that energy (as current) with as little loss as possible.
- An incandescent light bulb is designed so that the filament will get so hot that it actually glows. To have this happen the filament must have a very high resistance. That way, as current flows through it, there's a lot of friction which is transformed into heat energy that makes the filament glow.
- A clothes iron is somewhere in between the other two. We want it to get hot (which requires a high resistance), but not so hot that it would start to glow.

## Ohm's Law

The physicist Georg Simon Ohm made a discovery about certain conductors.

- If a conductor's **resistance** stays constant even when different voltages are applied to it, the conductor is said to obey **Ohm's Law**.
- As far as we are concerned for our calculations in this course, *all* conductors obey Ohm's Law.
- The formula Ohm came up with is…

$$V = I R$$

**I** = **current** (A)
V = voltage (V)
**R** = **resistance** (Ω)

**Example 3**: A voltage of 220V goes through the 14-gauge aluminum wire from Example 1. **Determine** the amount of current flowing through the wire.

$$V = I R$$
$$I = \frac{V}{R} = \frac{220}{0.169}$$
$$I = 1.30\text{e}3\ A$$