

CHAPTER 27: Current and Resistance

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The Analogy

Consider a pipe system through which water flows. What characteristics might that system have?

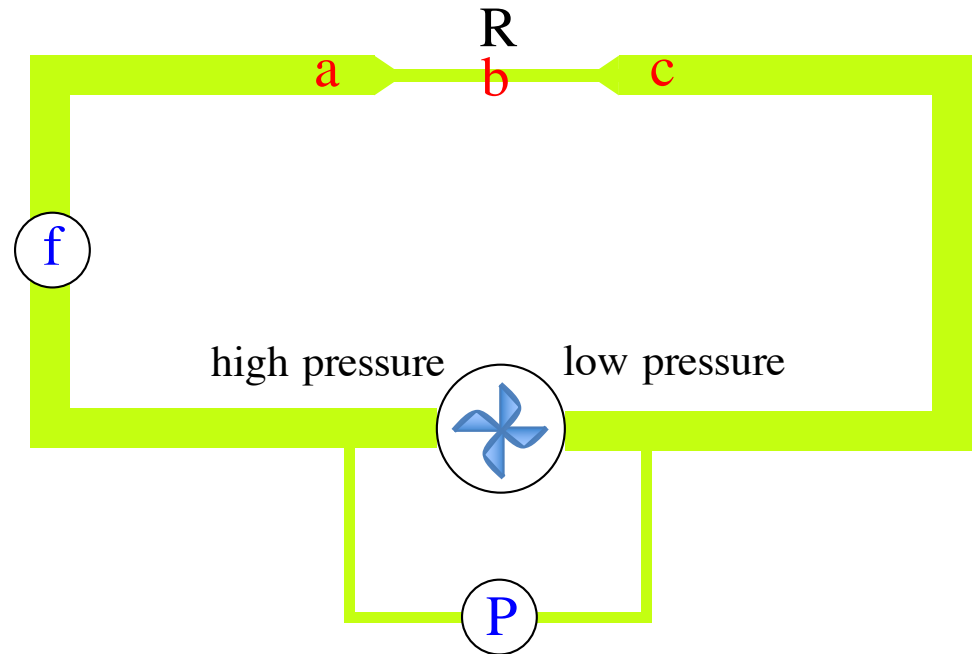
--It needs a pumping system that produces a pressure difference that will motivate water to flow. To measure the pressure difference, you need a meter across the pump.

--There is water flow. To measure the amount of flow that passes by per unit time, you need a meter located in the flow.

--There is resistance to flow created by the geometry of the pipe.

--So consider the points *a*, *b* and *c* shown in the upper section. Where is the flow rate the greatest?

Flow rate measures how much water passes by per unit time. It HAS to be the same at every point (otherwise, what happened to the water that didn't make it?)



Simple Electrical Circuit

Analogously, the lowly electrical circuit:

--A *battery* provides power by producing a *voltage difference* across its terminals. The *voltage difference* creates an *electric field* through the wires which *motivates charge to move*.

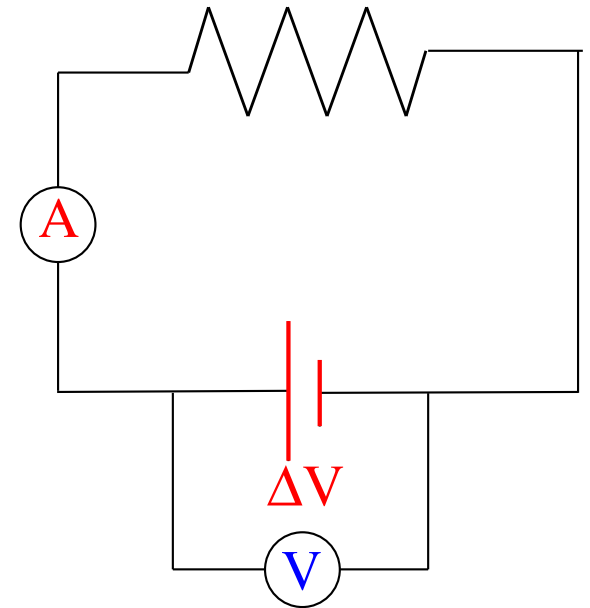
--To *measure* the *voltage difference* across the battery, you need a *voltmeter* across the power supply.

--*Current* is defined as *the amount of charge that passes by a point per unit time*. Mathematically, this is:

$$i = \frac{\Delta q}{\Delta t} \left(\frac{\text{coulombs}}{\text{second}} \right)$$

where *coulombs/second* is given a special name, the *ampere* (or *amp*).

--*Current is measured* with an *ammeter* placed directly into the circuit.



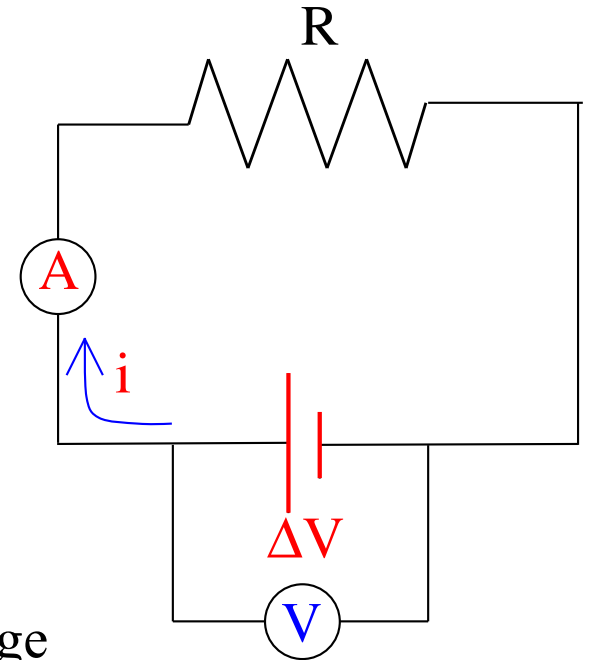
--*Oddly*, when analyzing circuits, current is defined as the motion of **POSITIVE CHARGE CARRIERS**. That means that “current” (called *conventional current* to separate it from what is called *electron current*, which highlights what’s *actually* happening with electron flow in a circuit), flows **from higher to lower voltage**. Weird, but that’s the convention.

--*A resistor* is a circuit element that does two things:

a.) *Resistors limit* the current in the sense that a large resistance means relatively small current, and a small resistance means relatively big current.

b.) *Resistors dissipate* energy in the sense that they convert electrical energy into other forms of energy (heat, light, etc.).

Note: Because current is a measure stuff (charge) passing by per unit time, the current entering a resistor must equal the current exiting a resistor. Just sayin ...



Ohm's Law

--It has been observed that the voltage across a resistor is proportional to the current through the resistor, or:

$$\Delta V_{\text{across } R} \propto i_{\text{thru } R}$$

--The proportionality constant that makes that relationship into an equality is called the resistance R of the resistor, and the relationship becomes:

$$V_R = iR.$$

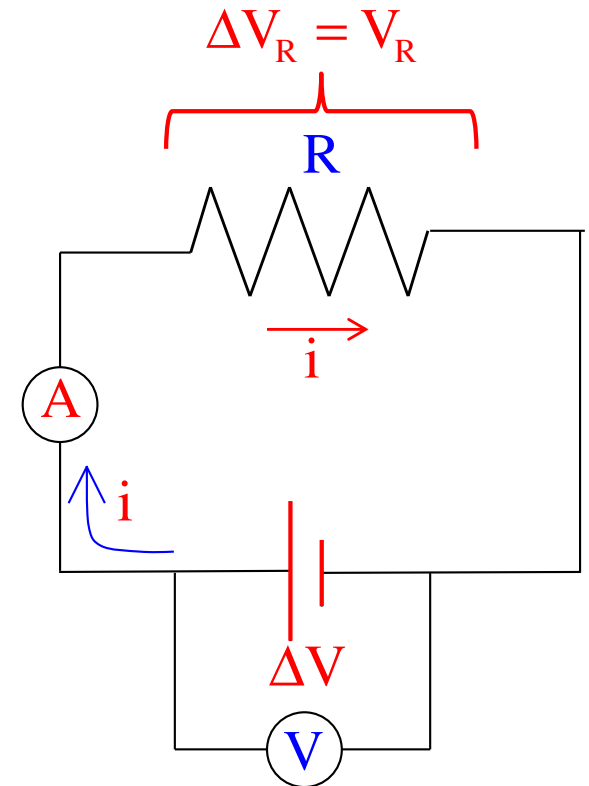
--This is called Ohm's Law.

--As $R = V/i$, the unit for resistance is the volts/amps, or *ohms*. The symbol for *ohms* is Ω (i.e., a capital omega).

--Resistors are temperature dependent. We don't do anything with this.

--Note that the resistance of a wire of length L , cross sectional area A and resistivity ρ is:

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

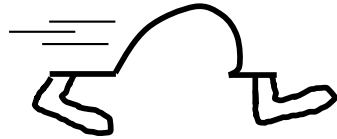


Lab Cover Artwork

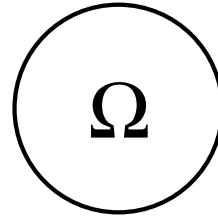
--*You are now* in a position to come up with some *great* lab cover artwork. To wit:



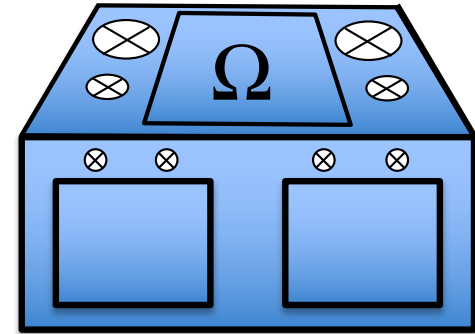
mobile ohm



ohm run



ohm plate

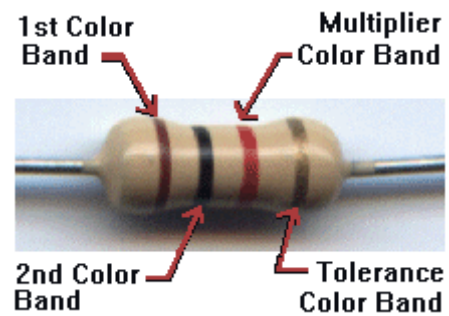


ohm on the range

Or go to:

<http://home.earthlink.net/~cfletcher>

Secret Resistor Code (courtesy of Mr. White)

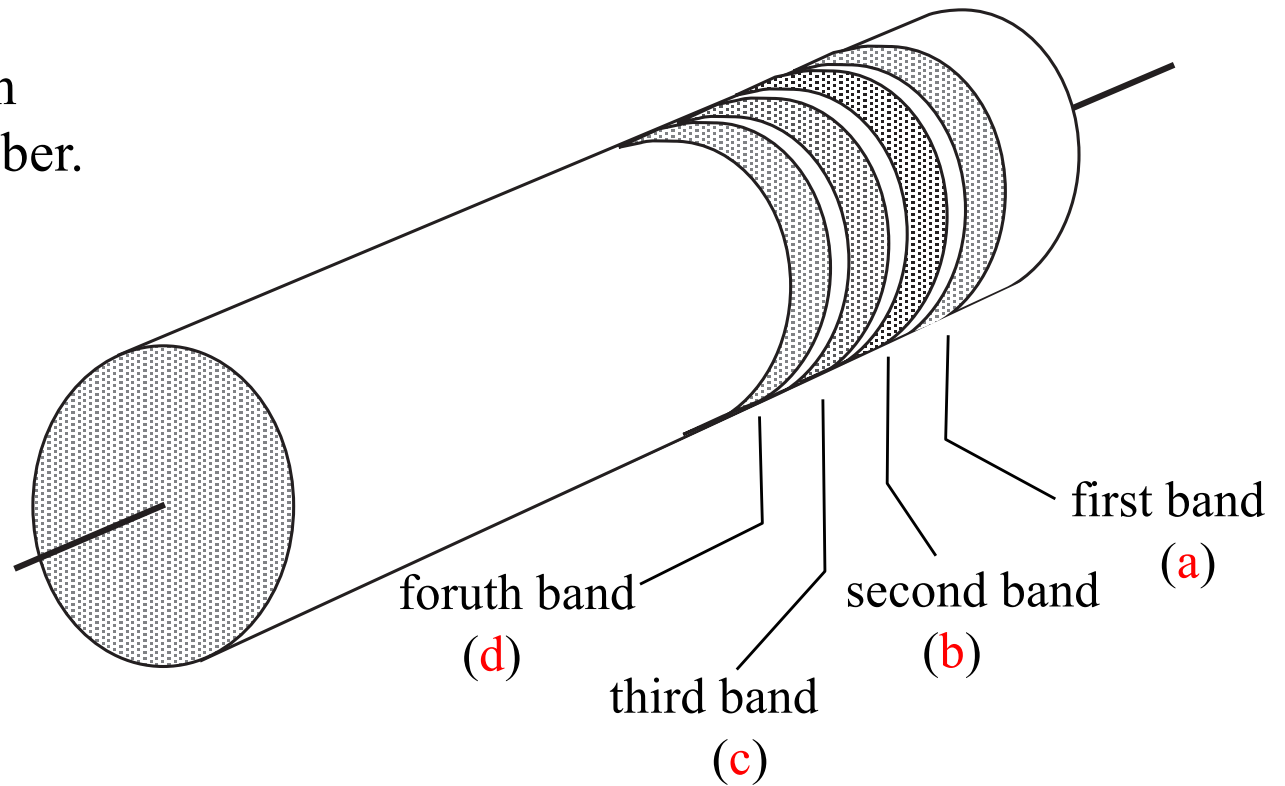


Resistor Color Code

The bands are colored with each color denoting a number.

| | | | |
|--------|---|--------|---|
| black | 0 | green | 5 |
| brown | 1 | blue | 6 |
| red | 2 | violet | 7 |
| orange | 3 | gray | 8 |
| yellow | 4 | white | 9 |

| | |
|------------------|------|
| last band gold | ± 5% |
| last band silver | ±10% |
| last band blank | ±20% |



The bands decode as: $ab \times 10^c \pm d\%$

Example: If the resistor's value is $52 \times 10^6 \pm 10\%$, the bands would be colored:

first band: green (for 5);
second band: red (for 2);
third band: blue (for 6);
fourth band: silver (to show a tolerance of 10%) 8.)

Example 1: (courtesy of Mr. White)

The video projector here uses a $120V_{\text{rms}}$ potential, and “draws” 2.7 Amps of current

a.) *What is* its resistance?

Note 1: When it comes to power supplies, the *electrical potential difference* across the power supply’s terminals is often referred to as the power supply’s *potential*.

Note 2. DC voltage (short for *direct current* voltage) sets up an electric field that is always in the same direction. AC voltage (*alternating current* voltage) sets up an electric field that alternates in direction. An AC voltage source will produce some amount of power. The DC source that provides the same amount of power is called AC source’s *RMS* voltage. It is used in exactly the same way as a DC voltage.

So using Ohm’s Law:

$$V_R = iR \Rightarrow R = \frac{V}{i} \\ = \frac{120V}{2.7A} = \Omega$$

The video projector here uses a $120V_{\text{rms}}$ potential, and “draws” 2.7 Amps of current

b.) What would be the current if the voltage used to run the machine was only 12 volts?

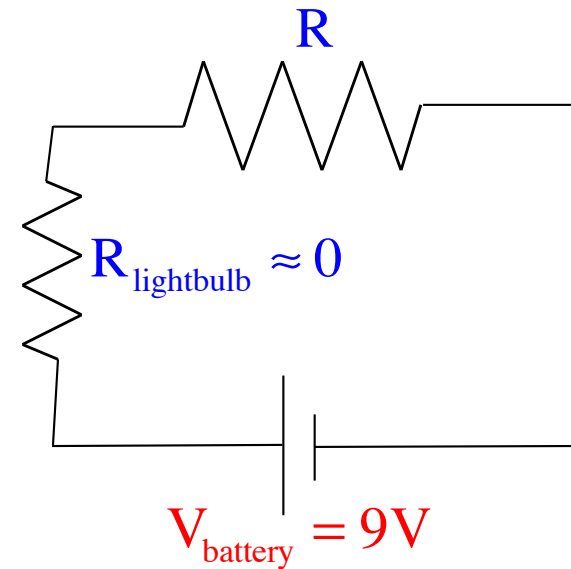
$$V_R = iR \Rightarrow i = \frac{V}{R} \\ = \frac{12V}{\Omega} = A$$

Example 2: (courtesy of Mr. White)

You have an LED with essentially no resistance, that takes 300 mA of current to light. You have a 9 Volt battery that you'd like to use to light the LED.

a.) *What will* your circuit look like?

b.) *How large* a resistor should you use to make sure that the LED doesn't blow out?



$$V_R = iR \Rightarrow R = \frac{V}{i} \\ = \frac{9.0V}{300 \times 10^{-3} A} = 30 \Omega$$

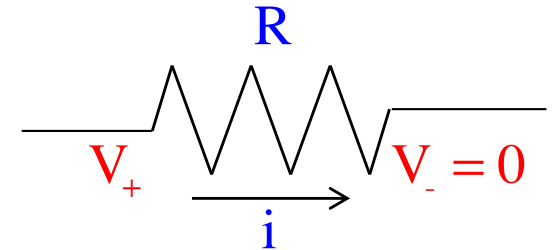
c.) *What* color code should you look for on your resistor?

$30 \times 10^0 \pm 20\%$ orange, black, black, blank

Example 3: *Current passes* through a resistor? During some period of time, assume q 's worth of charge passes through the resistor. How much work is done on that charge?

Assume the voltage on either side of the resistor is V_+ and $V_- = 0$ respectively. With that, we can write:

$$\begin{aligned} W &= -\Delta U = -q\Delta V \\ &= -q(V_- - V_+) \\ &= qV_+ \\ &= qV_R \end{aligned}$$



Example 4: *How much power* is being dissipated by the resistor in the previous problem?

Power is work per unit time, so:

In short: $P = iV_R$

This is generally true, but according to **Ohm's Law**, we can write:

$$\begin{aligned} P &= iV_R = i(iR) \\ &= i^2R \end{aligned}$$

$$\begin{aligned} P &= \frac{W}{\Delta t} = \frac{-\Delta U}{\Delta t} \\ &= \frac{qV_R}{\Delta t} = \left(\frac{q}{\Delta t} \right) V_R \\ &= i V_R \end{aligned}$$

Power

The most general expression for the **power rating** of an element is:

$$P = iV$$

where i is the **current through the element** and V is the **voltage across the element**. Its unit is **WATTS**.

This is the relationship you would use if you wanted to **determine** how much **power a power supply was providing** to a circuit.

When dealing specifically with a *resistor*, where **Ohm's Law** holds sway, the relationship can be written as:

$$P = i^2R$$

or on very rare occasions, $P = \frac{V^2}{R}$.

Example 5: A *light bulb* is rated at 120 volts (RMS), 75 W. Assuming the bulb is powered by a 120 V RMS power supply, determine:

a.) *the current* in the bulb?

$$\begin{aligned} P &= iV \\ \Rightarrow i &= \frac{P}{V} \\ &= \frac{75 \text{ W}}{120 \text{ V}} \\ &= .625 \text{ A} \end{aligned}$$

b.) *the resistance* of the bulb?

$$\begin{aligned} P &= i^2R \\ \Rightarrow R &= \frac{P}{i^2} \\ &= \frac{75 \text{ W}}{(.625 \text{ A})^2} \\ &= 192 \text{ } \Omega \end{aligned}$$

Example 6: An electric heater draws 15 amps on 120 volts (RMS). It operates 3 hours/day for 30 days/month. PG&E charges \$.08 per kilowatt-hour.

a.) *how much* power does the heater draw?

$$\begin{aligned} P &= iV \\ &= (15 \text{ A})(120 \text{ V}) \\ &= 1800 \text{ W} \quad (=1.8 \text{ kW}) \end{aligned}$$

b.) *how much* does it cost to run the heater for a month?

A *kilowatt* is a thousand watts, which is a thousand *joules per second*. A kilowatt-hour is a thousand joules per second times an hour (3600 seconds), which is a unit of *energy* (that's what the power company is charging you for when it registers your kW-hr usage for the month, the *energy* you use). We can leave things in kW-hrs, though, and just use dimensional analysis on this:

$$\begin{aligned} &(3 \text{ hr/day})(30 \text{ days/month})(1.8 \text{ kW})(\$0.08 / \text{kW} - \text{hr}) \\ &\Rightarrow \text{cost} = \$12.96 \text{ per month} \end{aligned}$$