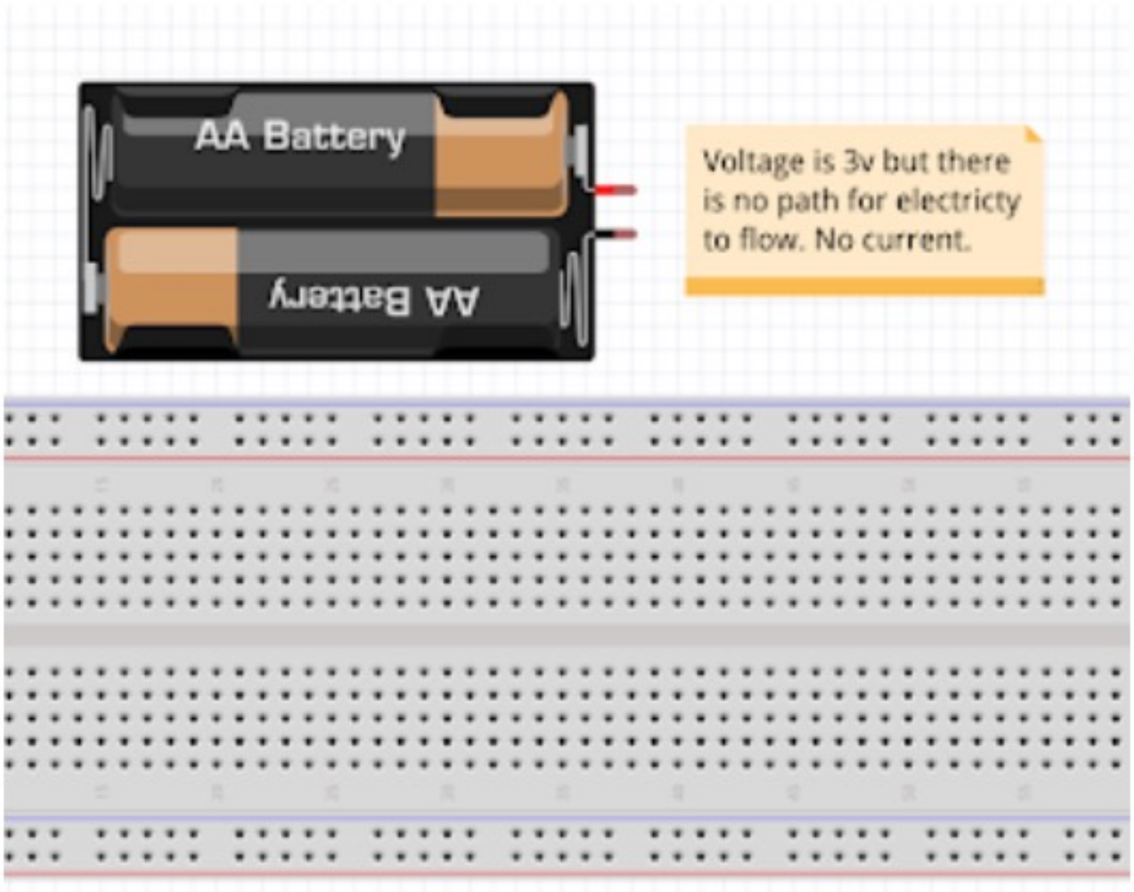
CSIS10C
Lecture 3 – Basic Electronics

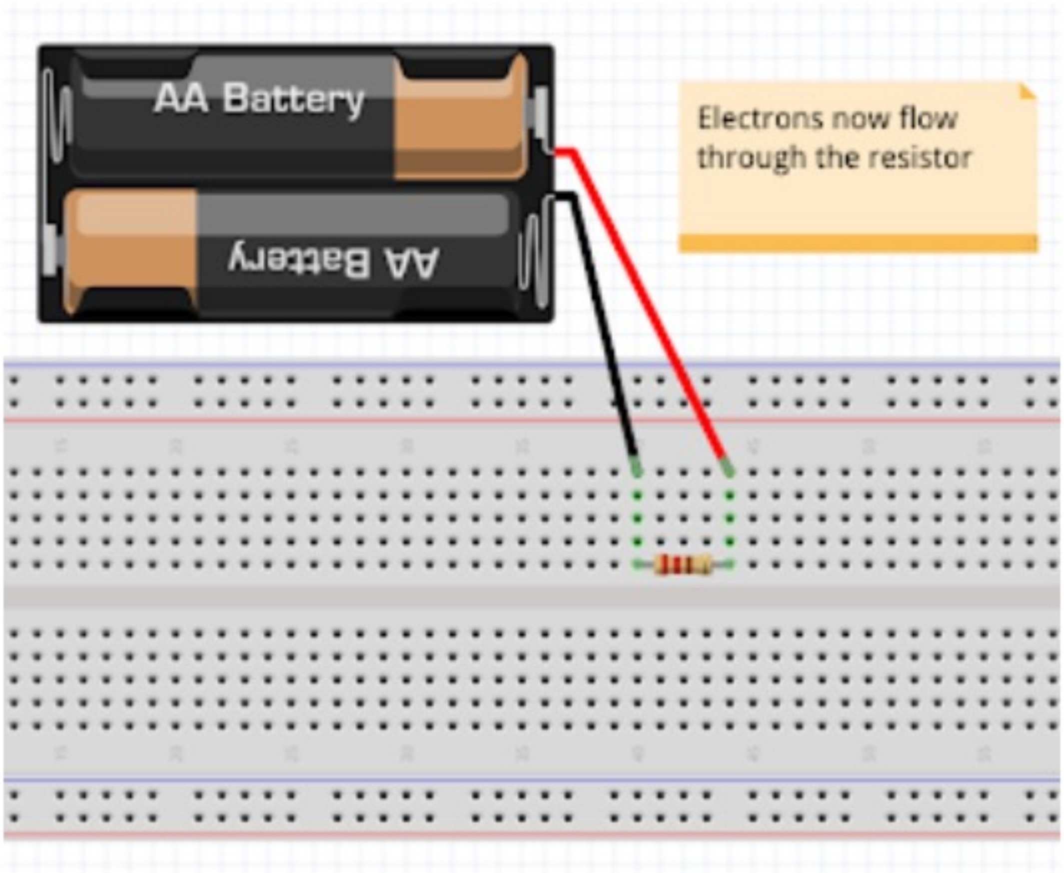
Electricity Basics

There are two fundamental quantities in electrical systems:

- **Voltage**, or electrical potential, which is the force that causes electrons to move and
- **Current** which is the rate of flow of electrons



Electrons can flow through air but it takes [tremendous voltage] (or [high voltage]) to do that. Electrons flow easily through wire. Giving electrons a path allows them to flow.



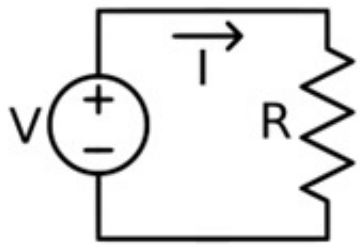
The resistor keeps the electrons from flowing too fast. If you connect the positive and negative pins of a battery directly together that's a short circuit. The rapid flow of electrons will cause the battery to heat up possibly causing it to burst and expose you to toxic chemicals.

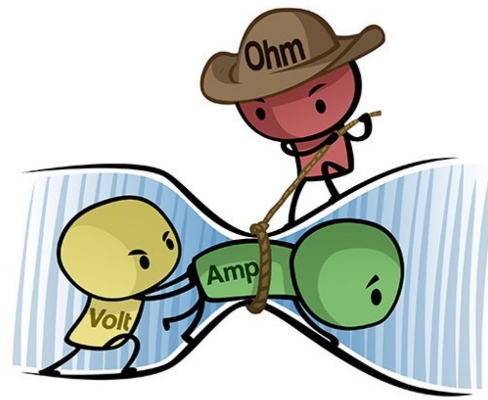
Ohm's Law [edit]

Ohm's law describes the relationship between voltage, current, and resistance.Voltage and current are proportional to the potential difference and inversely proportional to the resistance of the circuit

$$V = I \cdot R$$

Voltage (V) is measured in volts (V); Current (I) in amperes (A); and resistance (R) in ohms (Ω).

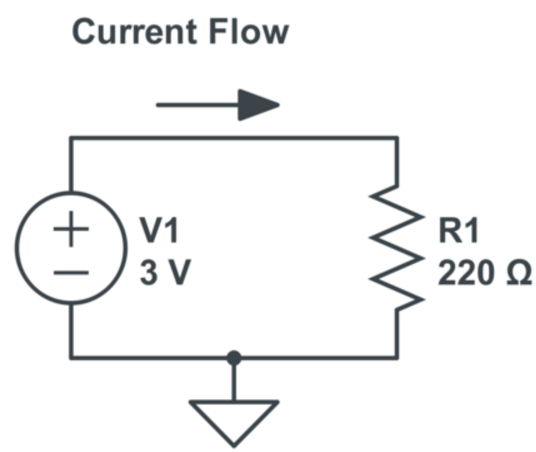




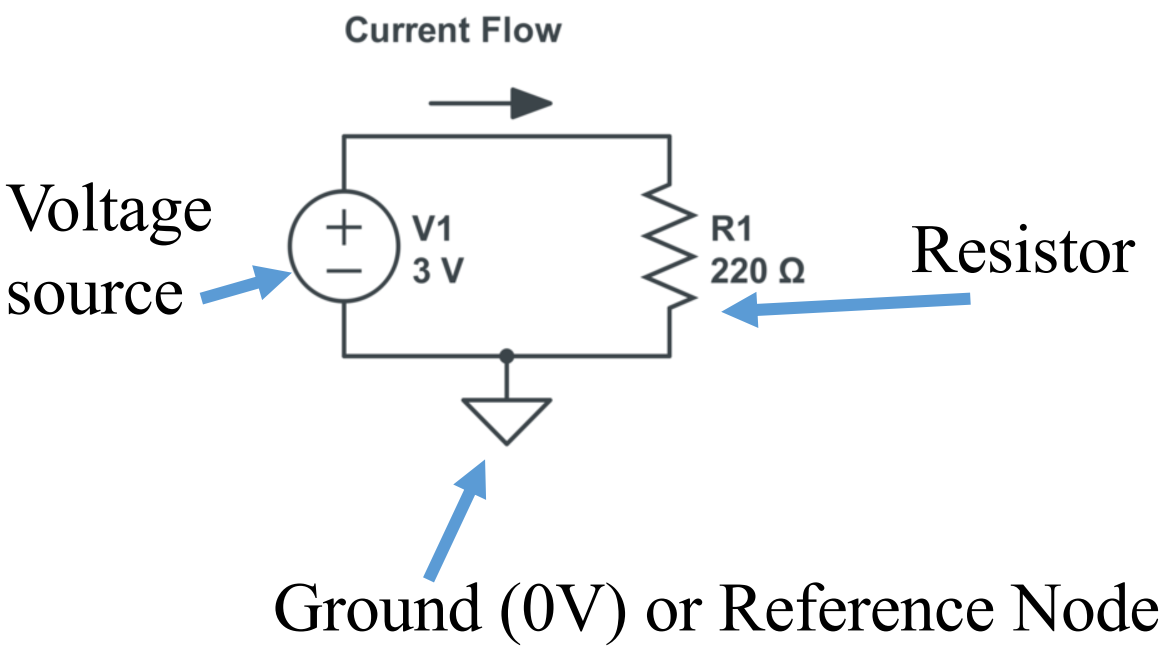
In circuit at right

- Voltage = Current Flow x Resistance
- 3V = Current Flow x 220 Ohms
- Current Flow = 3V/ 220 Ohms
- Current Flow = .0136 Amps

  (or 13.6 milliAmps)



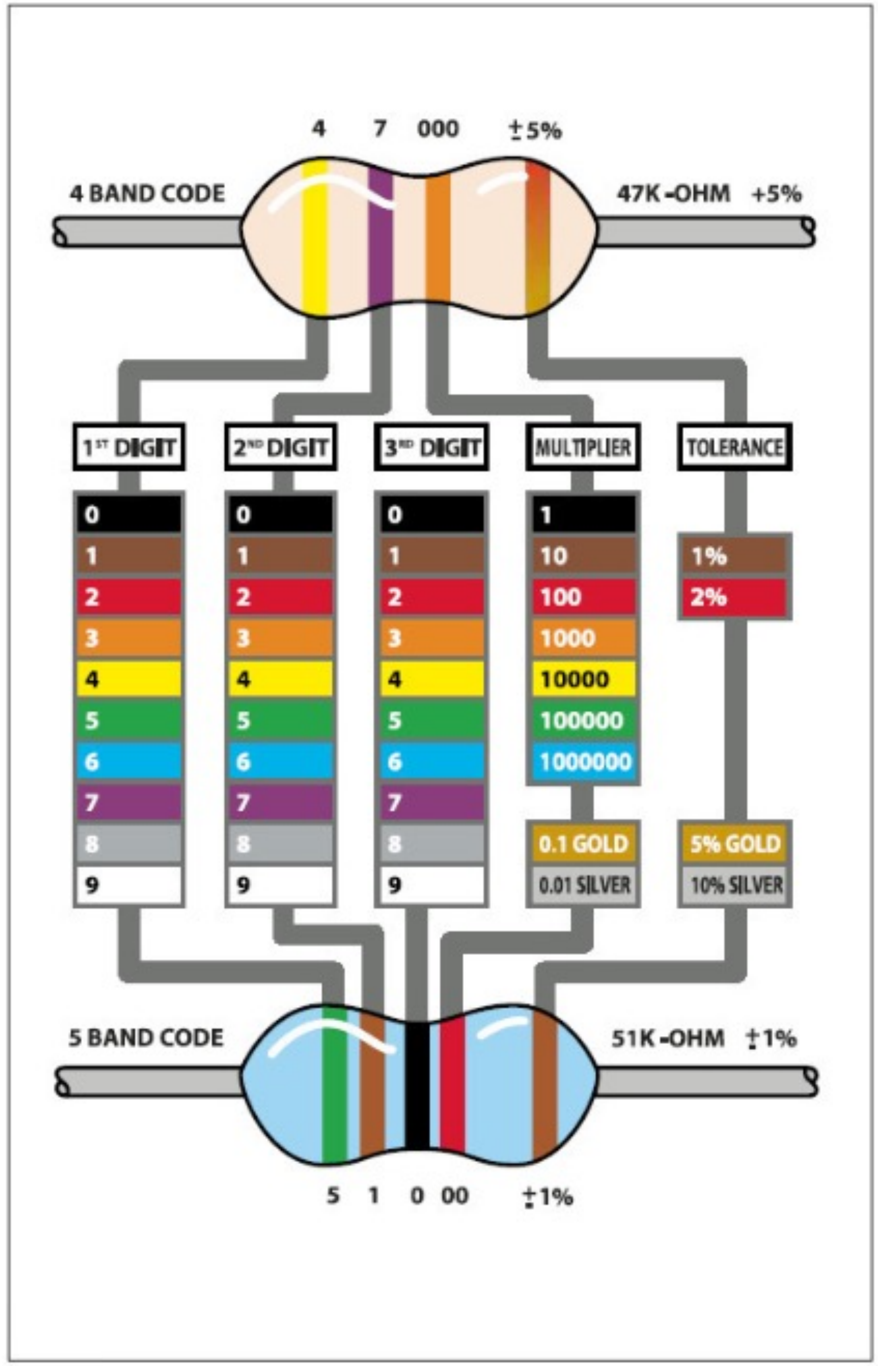
- **Schematic Symbols**
- Schematics are drawings that make it easy to show someone else a circuit without having to take a picture of a breadboard. In a schematic each circuit element has a symbol that's usually easy to draw by hand.



Reading Resistors

The colored bands on resistors tell you the resistors value in Ohms. The color code system was invented when it was not practical to write tiny numbers on the resistor and still exists today because it's very easy to use. The chart on the right shows what each color band means.

Some resistors have four bands and some resistors have five. You can tell which band is the "left" side because there's always a space before the last band, which tells you the precision or tolerance of the resistor.

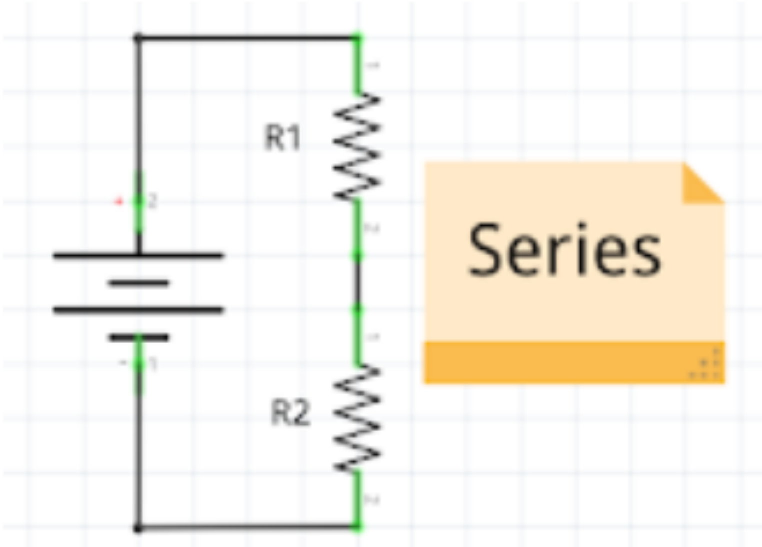


Quesitons: Color Codes

1. Decode: Red - Red - Black
2. Decode: Brown - Black - Red
3. Decode: Blue - Green - Black - Brown
4. What's the color code of a 550 Ohm resistor?
5. What's the color code of a 10,000 Ohm resistor?

Series and Parallel Circuits

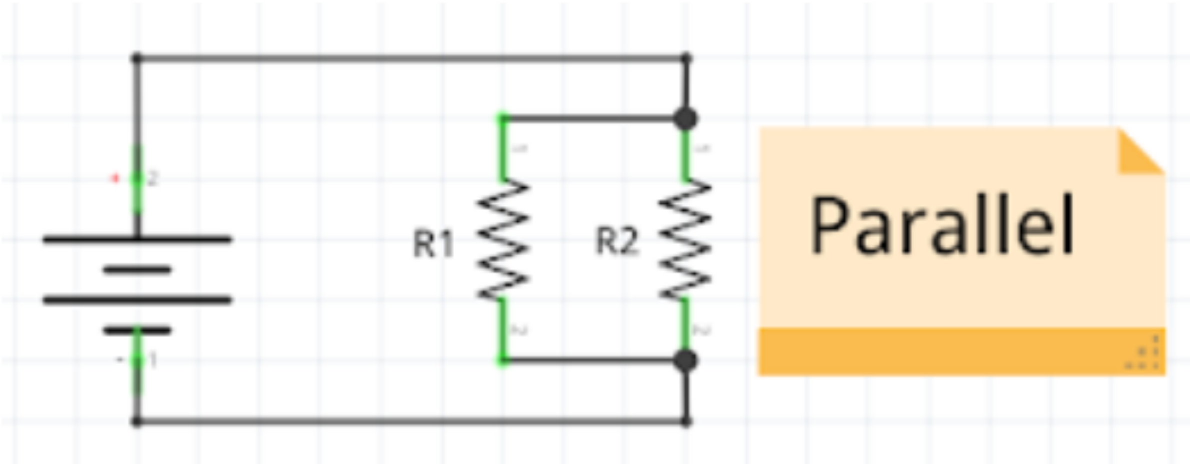
Resistors (and other components) can be arranged in two fundamental configurations called series and parallel. Series configuration is pictured below:



When resistors are in series the resistance values add together.

R (total) = R1 + R2

Parallel configuration is shown in the picture below:



When resistors are in parallel the equivalent resistance is:

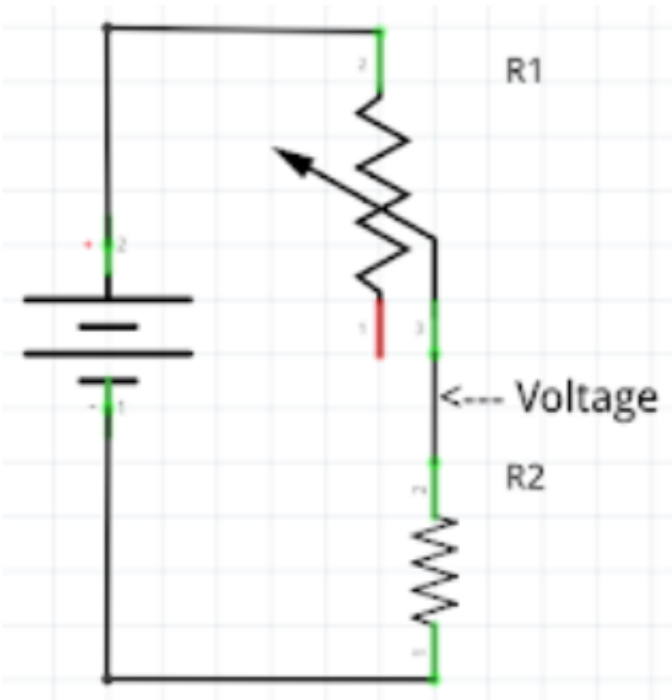
R (total) = (R1 * R2) / (R1 + R2)

Activity: What is the equivalent value if you put two identical resistors in parallel? (2 minutes)

- Solve the parallel equation for any resistor value.
- R1 and R2 should be the same value
- Answer the following questions
    - What resistor value did you choose?
    - What is the resistance of two of those resistors in parallel?

Voltage Dividers

A voltage divider is a special use of series resistors that is very handy when one of your resistors is a sensor or a knob. The picture below shows a potentiometer (which is a variable resistor) in series with another resistor.



Notice the "Voltage" label. Controlling the knob or sensor will change the voltage on that wire. The formula for the voltage on the wire is:

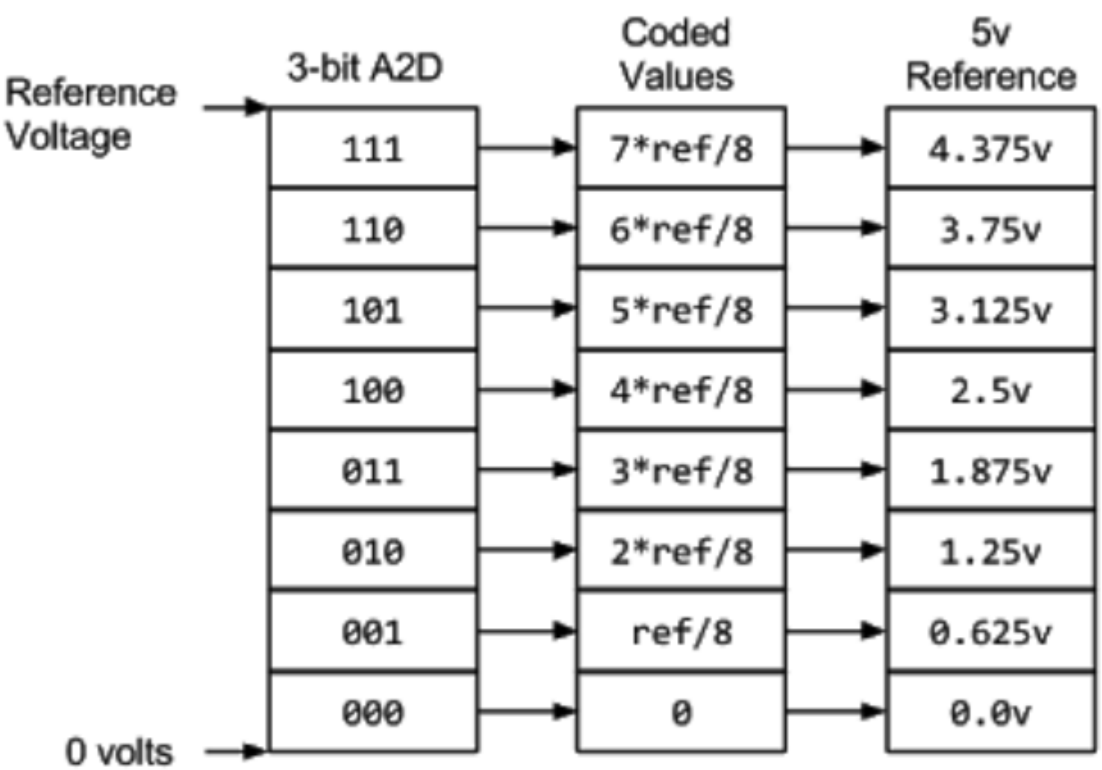
eVoltage = Voltage (Battery) x R2 / (R1 + R2)

Analog Input and Output

The Arduino, like all processors, is Digital, it only understands ones and zeros. In order to make sense out of our analog world it takes special circuitry on the Arduino. In this section you'll learn how to control that circuitry using C++ commands.

Analog Input

Your Arduino has pins labeled with "A" and a number (e.g. A0, A1, etc). These pins are special pins because they are connected to an internal *Analog to Digital Converter* (A2D). That circuit turns a voltage into a binary number based on a reference. The reference sets the maximum allowable input voltage. An A2D gives you a coded number that represents a voltage between zero and the reference. The drawing below shows an example of how that number is generated:



The chart shows you how to interpret the output of a 3-bit A2D with a 5v reference voltage. The Arduino has a 10-bit A2D which means that the values it gives you are between zero and 1024 (way too many to draw!). The reference voltage can be set in your program but it's best to keep it at the default setting (5v). The Arduino code below reads the voltage on pin A0:

```
void setup() {
  // The default on Arduino UNO is 5v
  Serial.begin(9600);
  analogReference(DEFAULT);
}

void loop() {
  // Read the voltage on pin A0
  int reading = analogRead(0);
}
```

- If we print out reading we should see a number about 675.

Exercise: Read the 3.3 volt power rail. (15 minutes)

Add a System.println() statement to the code above to print out the reading. Connect pin A0 to the pin labeled 3.3v and read the value.

1. What value do you get?
2. Convert that to a voltage it might not be exactly 3.3 volts, what is it?

Save your program as `voltmeter.ino` and submit it to Canvas with next week's lab.

```
if digital code 1023 corresponds to 5V
what voltage does digital code 675 convert to?

  V = code * 5    =   675 * 5
      ----            -------   = 3.299 V
      1023            1023
```

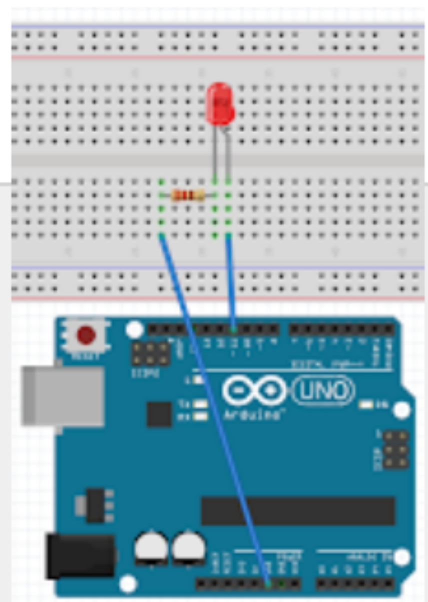
Analog Output

Arduino is not capable of making a true analog output. However, for many things that need an "analog" signal you can use a trick called Pulse Width Modulation. Arduino.cc has an excellent tutorial on PWM. Please read it.

You can use PWM to make an LED glow with different intensities. The LED blinks so fast your eye cannot see the difference.

Exercise: Using Analog with LEDs (15 minutes)

Build the circuit pictured at the right. Don't forget the resistor! When you're done program Arduino with the following code. What happens?



```
void setup() {
    pinMode(11, OUTPUT);
}

void loop() {
    int i;
    for (i=0; i<255; i++) {
        analogWrite(11, i);
        delay(10);
    }
}
```

1. Change the code so that the LED fades from light to dark.
2. Compile and upload your code to verify it works correctly.
3. Save your `fader.ino` file to submit to Canvas with the next lab.

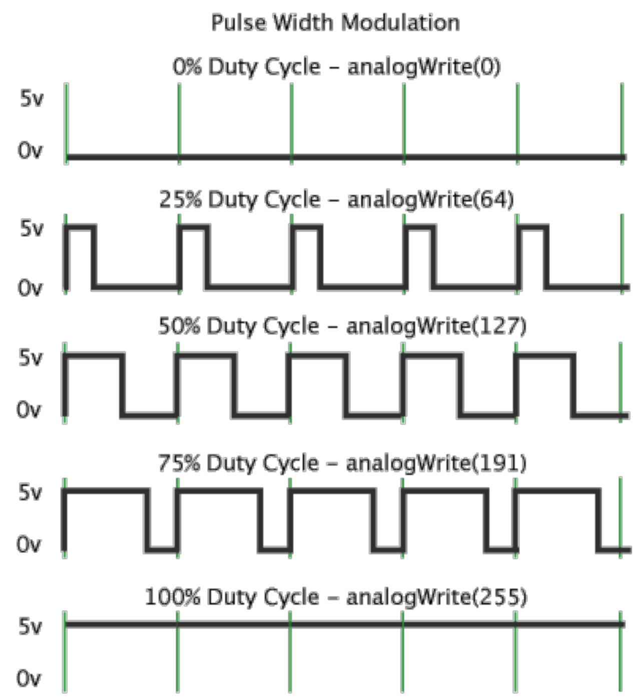
How Pulse Width Modulation works

PWM

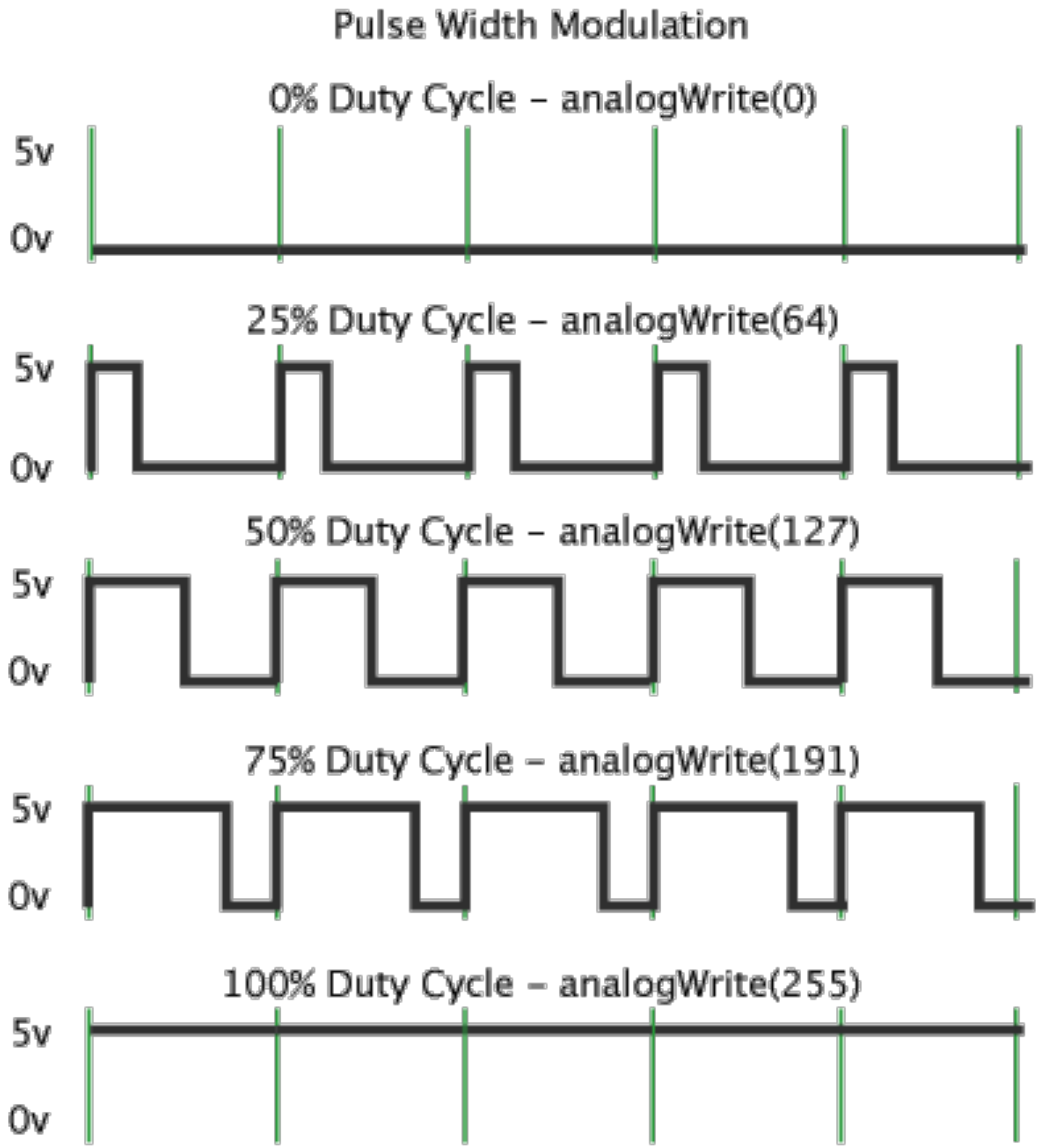
The Fading example demonstrates the use of analog output (PWM) to fade an LED. It is available in the File->Sketchbook->Examples->Analog menu of the Arduino software.

Pulse Width Modulation, or PWM, is a technique for getting analog results with digital means. Digital control is used to create a square wave, a signal switched between on and off. This on-off pattern can simulate voltages in between full on (5 Volts) and off (0 Volts) by changing the portion of the time the signal spends on versus the time that the signal spends off. The duration of "on time" is called the pulse width. To get varying analog values, you change, or modulate, that pulse width. If you repeat this on-off pattern fast enough with an LED for example, the result is as if the signal is a steady voltage between 0 and 5v controlling the brightness of the LED.

In the graphic below, the green lines represent a regular time period. This duration or period is the inverse of the PWM frequency. In other words, with Arduino's PWM frequency at about 500Hz, the green lines would measure 2 milliseconds each. A call to analogWrite() is on a scale of 0 - 255, such that analogWrite(255) requests a 100% duty cycle (always on), and analogWrite(127) is a 50% duty cycle (on half the time) for example.



Once you get this example running, grab your arduino and shake it back and forth. What you are doing here is essentially mapping time across the space. To our eyes, the movement blurs each LED blink into a line. As the LED fades in and out, those little lines will grow and shrink in length. Now you are seeing the pulse width.

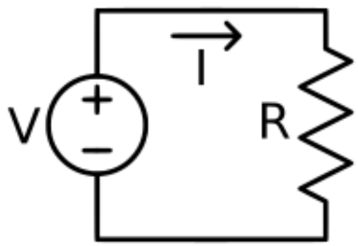

Pulse Width Modulation
0% Duty Cycle – analogWrite(0)
5v
0v
25% Duty Cycle – analogWrite(64)
5v
0v
50% Duty Cycle – analogWrite(127)
5v
0v
75% Duty Cycle – analogWrite(191)
5v
0v
100% Duty Cycle – analogWrite(255)
5v
0v

Ohm's Law [edit]

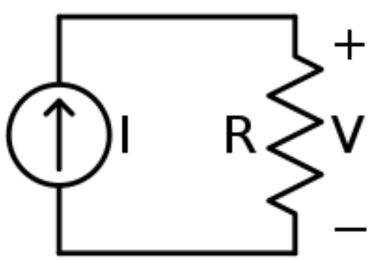
Ohm's law describes the relationship between voltage, current, and resistance.Voltage and current are proportional to the potential difference and inversely proportional to the resistance of the circuit

$$V = I \cdot R$$

Voltage (*V*) is measured in volts (V); Current (*I*) in amperes (A); and resistance (*R*) in ohms (Ω).



In this example, the current going through any point in the circuit, *I*, will be equal to the voltage *V* divided by the resistance *R*.



In this example, the voltage across the resistor, *V*, will be equal to the supplied current, *I*, times the resistance *R*.

If two of the values (*V*, *I*, or *R*) are known, the other can be calculated using this formula.

Any more complicated circuit has an equivalent resistance that will allow us to calculate the current draw from the voltage source. Equivalent resistance is worked out using the fact that all resistors are either in parallel or series. Similarly, if the circuit only has a current source, the equivalent resistance can be used to calculate the voltage dropped across the current source.

Kirchoff's Voltage Law [edit]

Kirchoff's Voltage Law (KVL):

> The sum of voltage drops around any loop in the circuit that starts and ends at the same place must be zero.

Voltage as a Physical Quantity [edit]

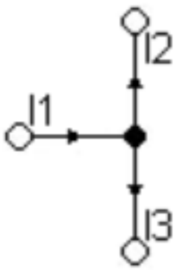
1. Voltage is the potential difference between two charged objects.
2. Potentials can be added or subtracted in series to make larger or smaller potentials as is commonly done in batteries.
3. Positive charge flow from areas of high potential to lower potential.
4. All the components of a circuit have resistance that acts as a potential drop.

Kirchoff's Current Law [edit]

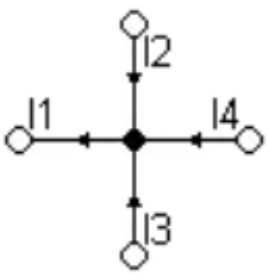
Kirchoff's Current Law (KCL):

> The sum of all current entering a node must equal the sum of all currents leaving the node.

KCL Example [edit]



$-I_1 + I_2 + I_3 = 0 \leftrightarrow I_1 = I_2 + I_3$



$I_1 - I_2 - I_3 - I_4 = 0 \leftrightarrow I_2 + I_3 + I_4 = I_1$

$$I_1 = I_2 + I_3 + \cdots + I_n$$

Here is more about Kirchhoff's laws, which can be integrated here

Consequences of KVL and KCL [edit]

Voltage Dividers [edit]

If two circuit elements are in series, there is a voltage drop across each element, but the current through both must be the same. The voltage at any point in the chain divides according to the resistances. A simple circuit with two (or more) resistors in series with a source is called a voltage divider.

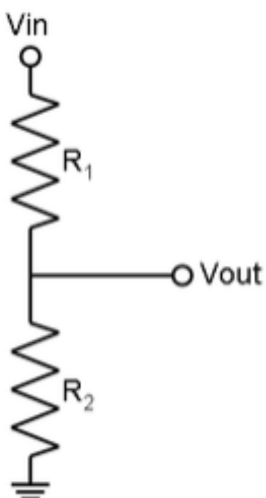


Figure A: Voltage Divider circuit.

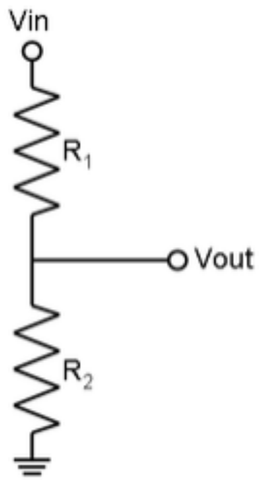


Figure A: Voltage Divider circuit.

Consider the circuit in Figure A. According to KVL the voltage V_{in} is dropped across resistors R_1 and R_2. If a current i flows through the two series resistors then by Ohm's Law.

$$i = \frac{V_{in}}{R_1 + R_2}.$$

So

$$V_{out} = iR_2$$

Therefore

$$V_{out} = \frac{V_{in} R_2}{R_1 + R_2}$$

Similary if V_{R1} is the voltage across R_1 then

$$V_{R1} = \frac{V_{in} R_1}{R_1 + R_2}$$