Using Sensors with Embedded Controllers

From Yesterday…

- With a one-line code change, the Uno can go from 144kHz to 1.3Mhz.
- The secret is this paragraph in the datasheet: (page 85 of 651)

14.2.2 Toggling the Pin

Writing a logic one to PINxn toggles the value of PORTxn, independent on the value of DDRxn. Note that the SBI instruction can be used to toggle one single bit in a port.

The complete code for 1.3MHz blink:

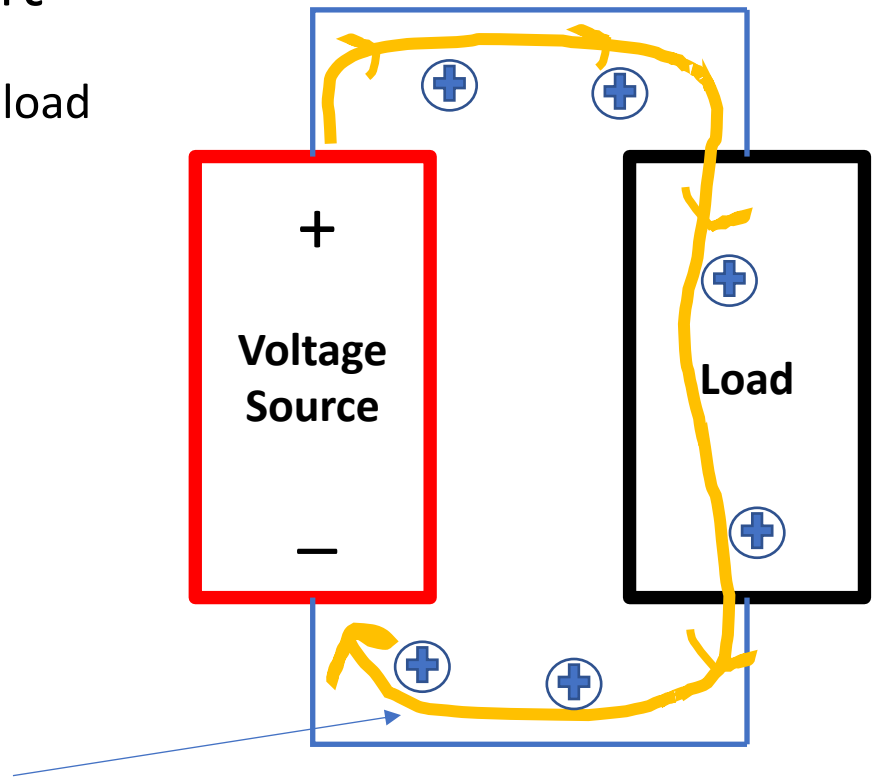
```
while(1)
    {
        /* toggle led on and off */
        PINB |= (_BV(PORTB5));
    }
```

Overview

- This lab explores how you can read physical attributes (light, heat, moisture, etc) with a microcontroller
- We'll use a breadboard to support our sensor circuits
- We'll read the position of a potentiometer
- We'll make plots of the sensor reading vs time
- If time permits, we'll read the temperature of a thermistor

Simple Electronic Circuit

- Every circuit is simply a source and a load
- Source – provides electrical power:
  - Battery
  - Power supply
  - Power pins from Arduino
  - Static electricity (very briefly)
- Load – absorbs electrical power:
  - Resistor
  - Electric Motor
  - You (very briefly)
  - LED?
- Current flows out of + side of source, returns to – side.

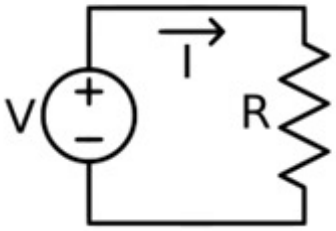


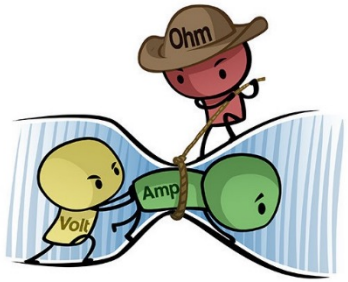
Ohm's Law [edit]

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

$$V = I \cdot R$$

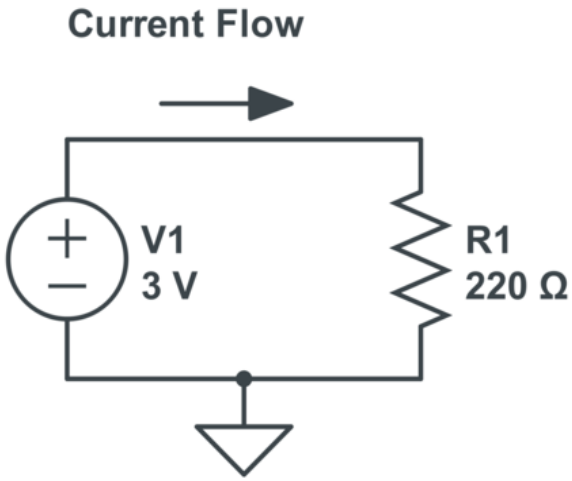
Voltage (V) is measured in volts (V); Current (I) in amperes (A); and resistance (R) in ohms (Ω).





In circuit at right

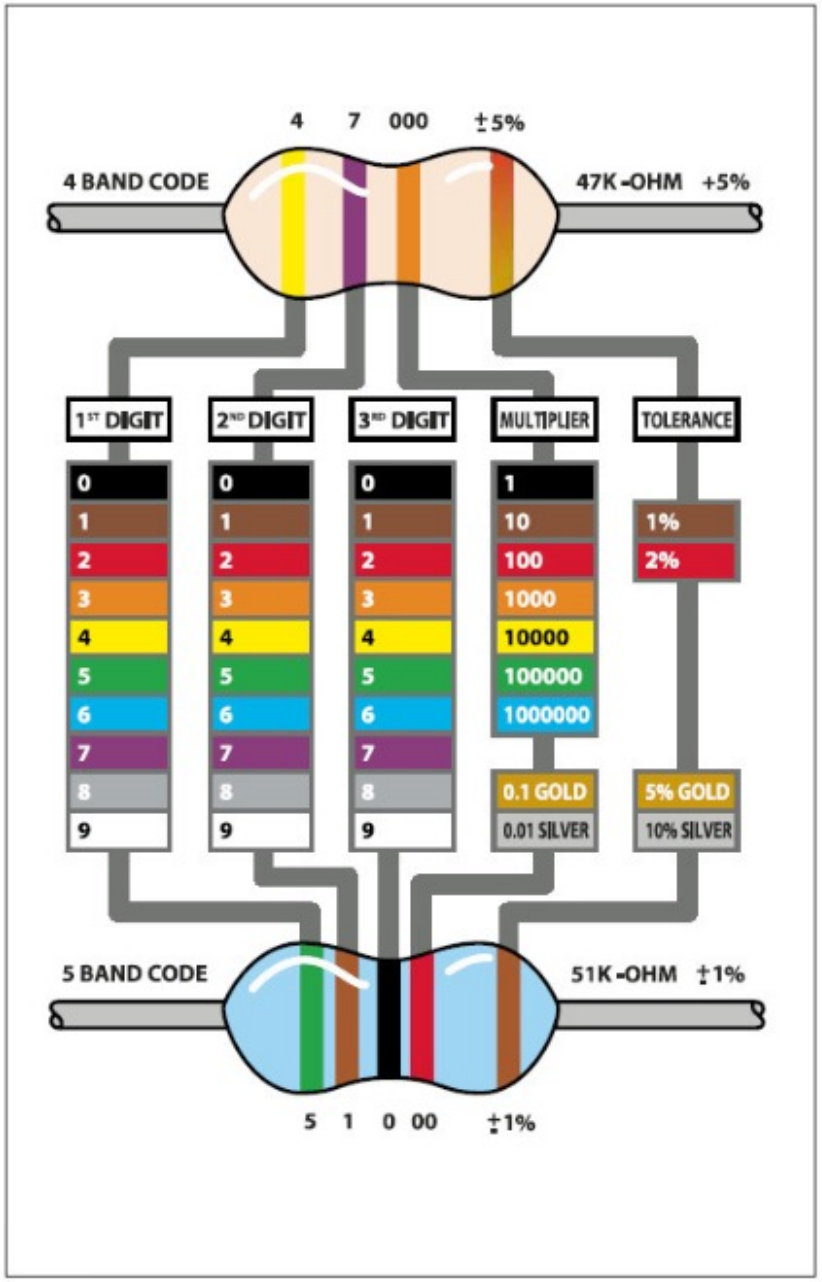
- Voltage = Current Flow x Resistance
- 3V = Current Flow x 220 Ohms
- Current Flow = 3V/ 220 Ohms
- Current Flow = .0136 Amps
  (or 13.6 milliAmps)



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.

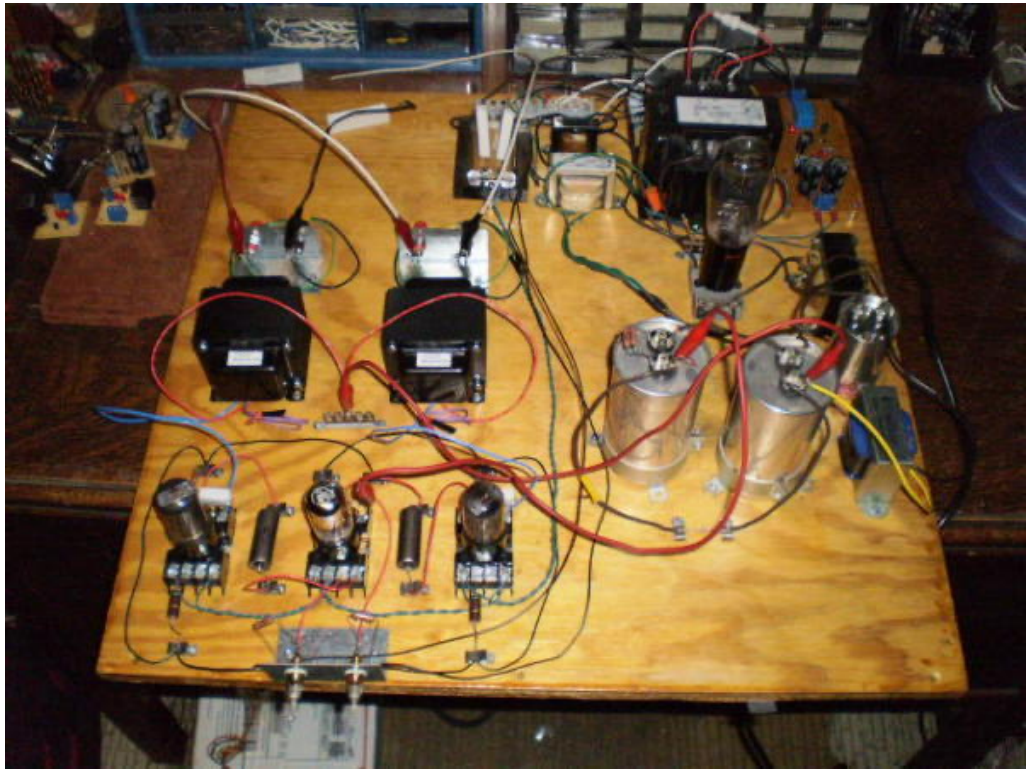


Quesitons: Color Codes

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?

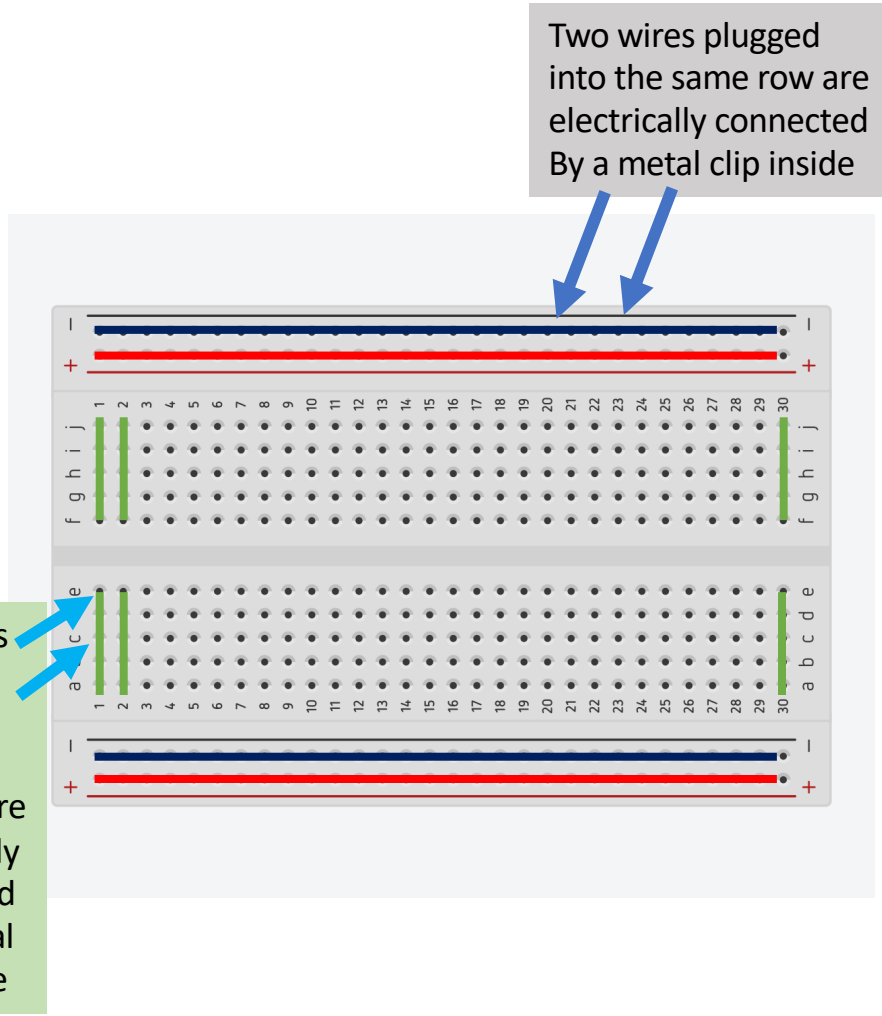
The Original Way of Connecting Circuits

- Components were screwed down to a board (often a “bread board”)
- The board allowed the addition and removal of components.



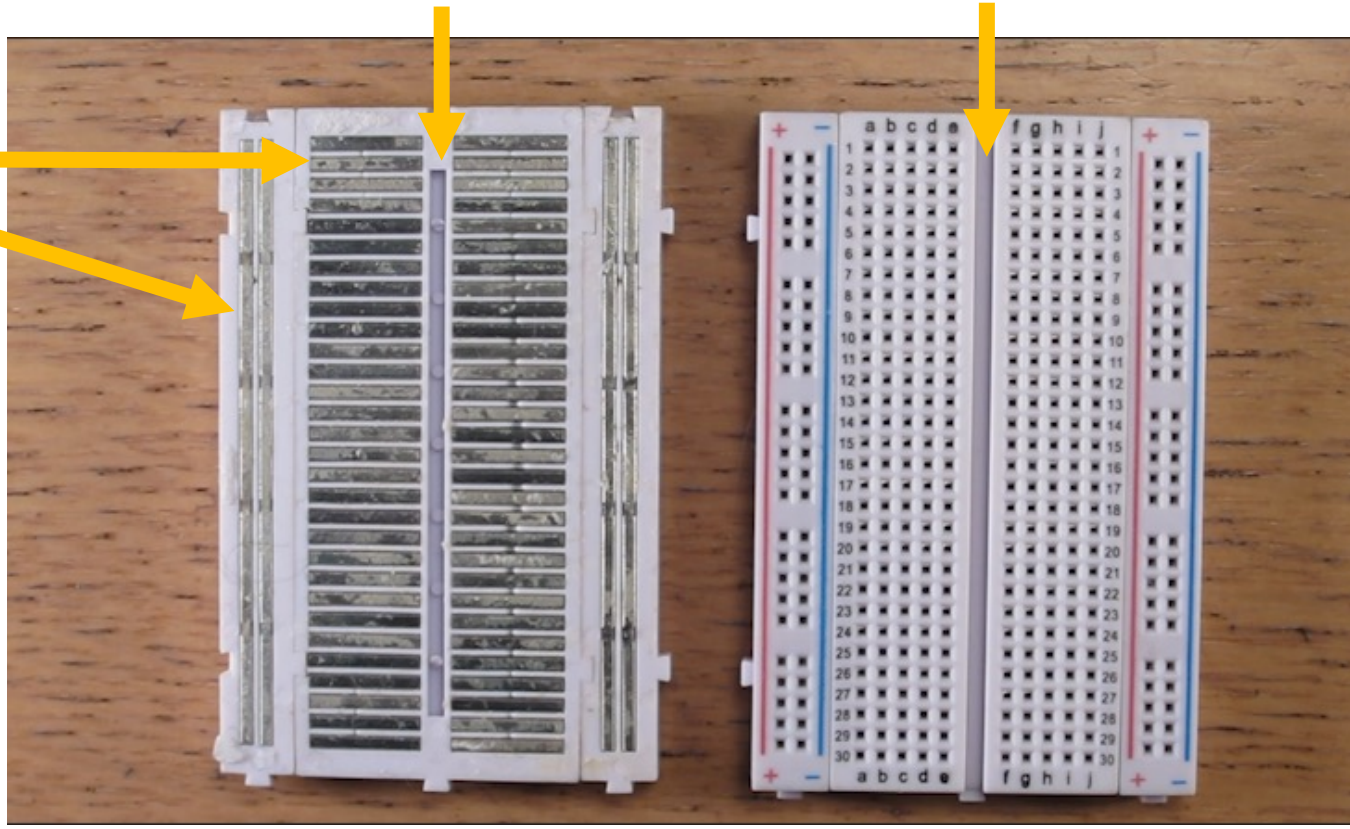
The New and Improved Bread board

- Bread boards keep circuits easy to manage and modify
- Note the lines, they represent connectivity or wires
- Black is ground (-), Red is Positive, and the green vertical lines are connected points
- So our new circuit looks like this…

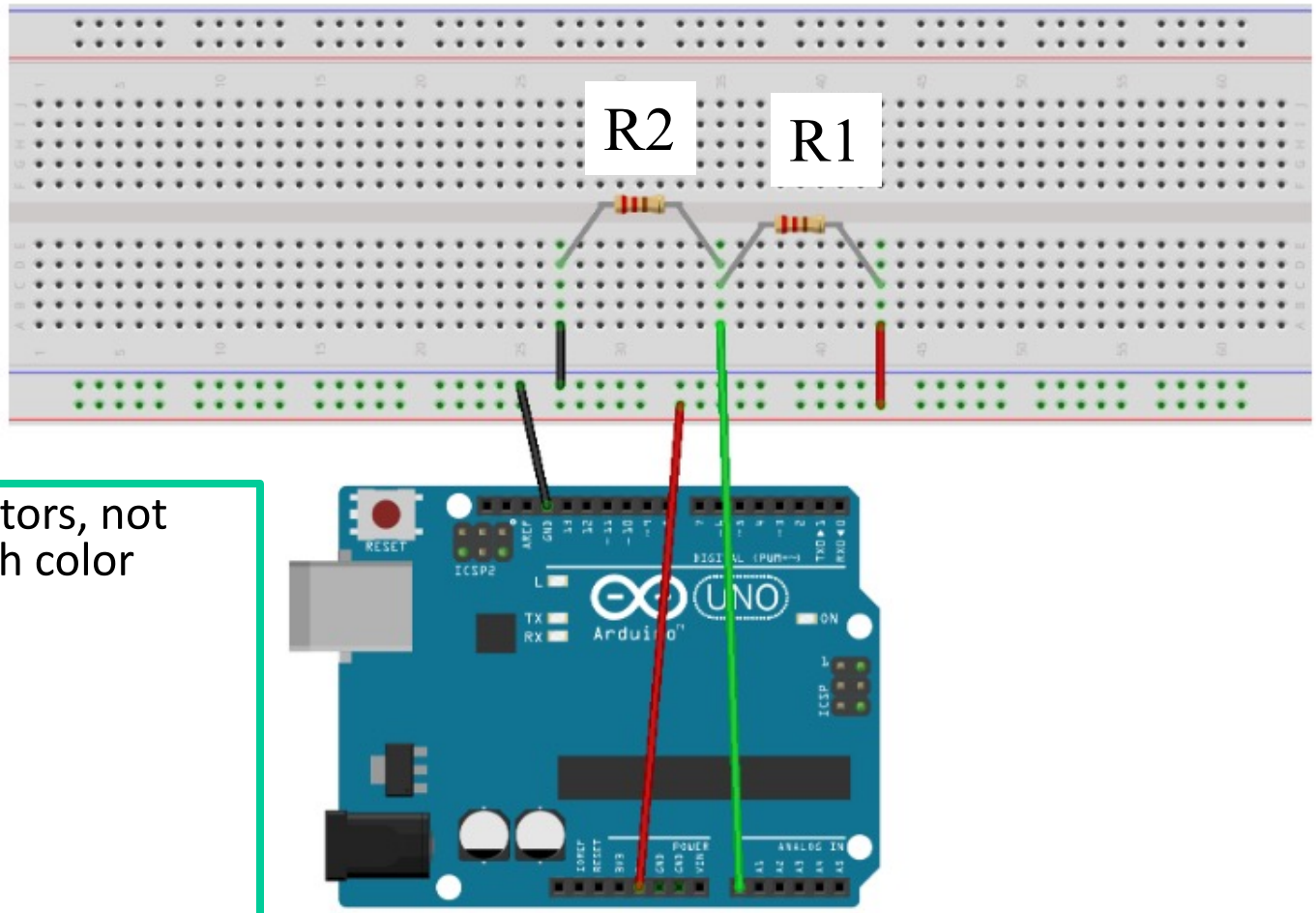


If you flip over a breadboard and tear off the backing…

- This is just an air gap – no connection across sides
- Notice the metal clips



Add two resistors to the breadboard and connect to the Arduino



Choose any two resistors, not necessarily those with color bands shown.

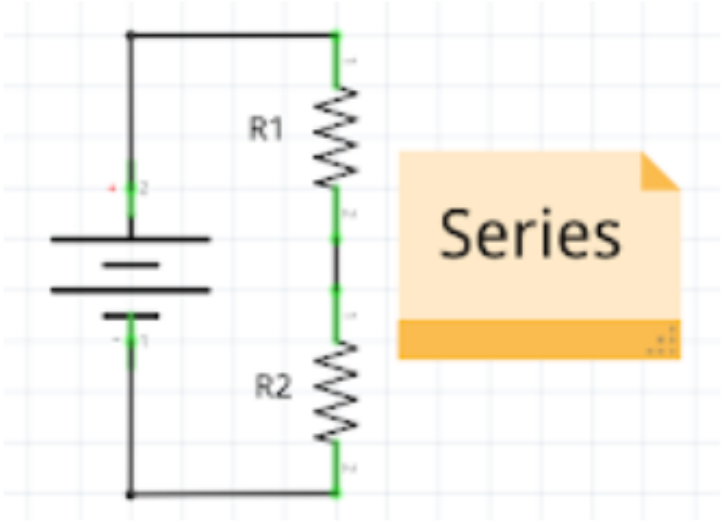
What value are your

R1 and R2 resistors?

Write these values down

Series and Parallel Circuits

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



What would your Series Rtotal be with your

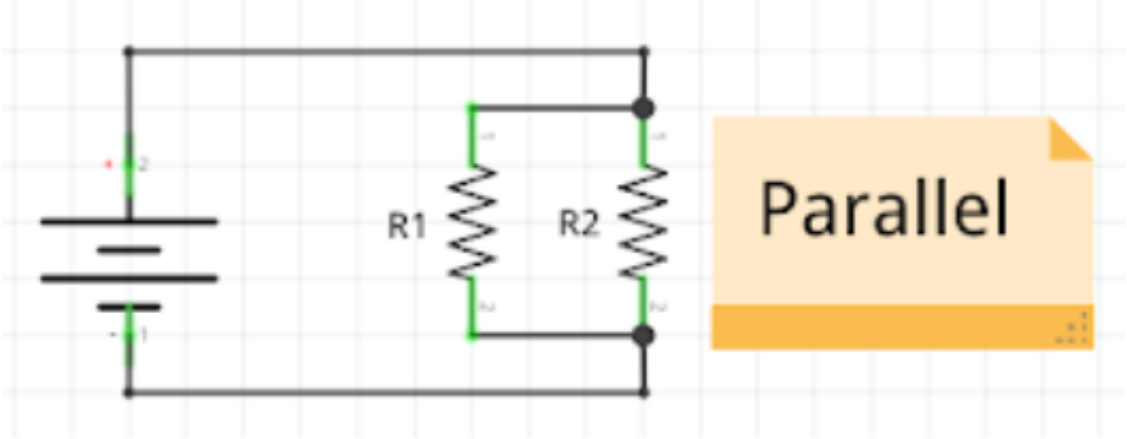
R1 and R2 resistors?

Write this value down.

When resistors are in series the resistance values add together.

R (total) = R1 + R2

Parallel configuration is shown in the picture below:



What would your Parallel Rtotal be with your

R1 and R2 resistors?

Write this value down.

When resistors are in parallel the equivalent resistance is:

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

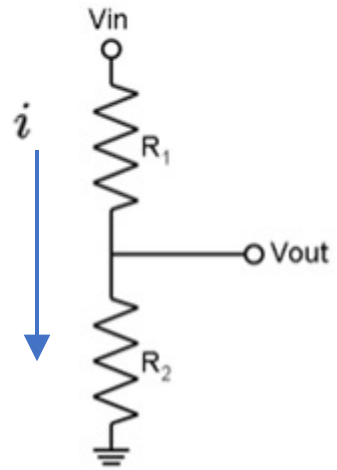
Activity: What is the equivalent value if you put two identical resistors in parallel? (2 minutes)

- 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?

see appendix for more slides on this

Voltage Dividers

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.



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

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

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

Calculate Vout given:

1) your values of R1 and R2
2) a Vin of 5V

Write your Vout value down

What Arduino pin does Vout connect to in your circuit?

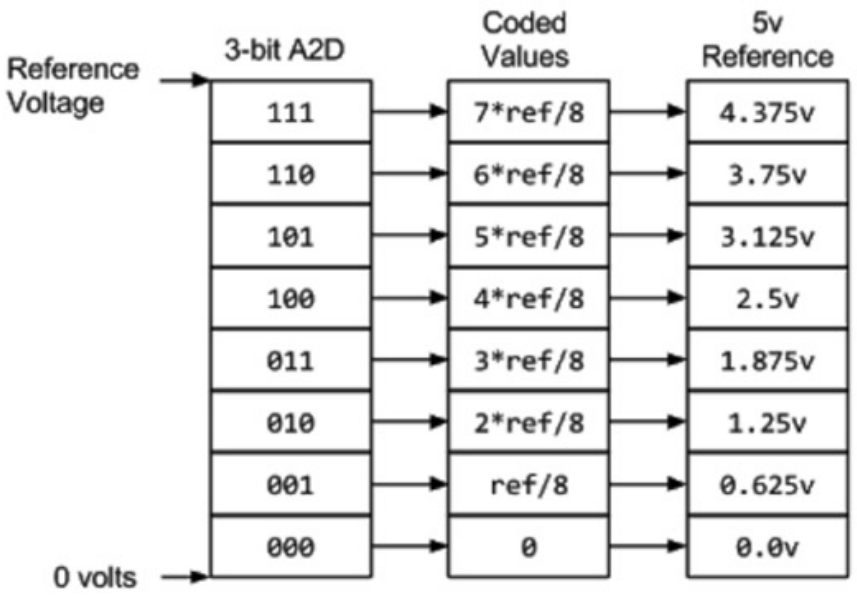
What about Vin?

Run the following program to measure the value at the midpoint of the two resistors

```
int sensorValue = 0;        // value read from the pot


void setup() {
  // initialize serial communications at 9600 bps:
  Serial.begin(9600);
}

void loop() {
  // read the analog in value:
  sensorValue = analogRead(A0); // read pin A0

  // print the results to the Serial Monitor:
  Serial.print("sensor = ");
  Serial.print(sensorValue);

  // wait 2 milliseconds for the analog-to-digital
  // converter to settle after the last reading:
  delay(2);
}
```

Analog Input 3 Bit ADC

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:



If we read a decimal 3, what voltage does that correspond to?

If we know the voltage at pin A0 on the Arduino is 3.9 V, what decimal value should we read?

In our program what variable corresponds to "coded value"?

Analog Input 10 Bit ADC

- Actually, the Arduino has a 10 Bit ADC
- With 10 bits we have 1024 "steps" in the ADC
  - 0 to 1023 decimal values correspond to
  - 0 to 5V at the Arduino Pin A0
- Now the formula is:
  - coded value = Vout * 1024 / 5V
  - Vout = coded value/1024 * 5V

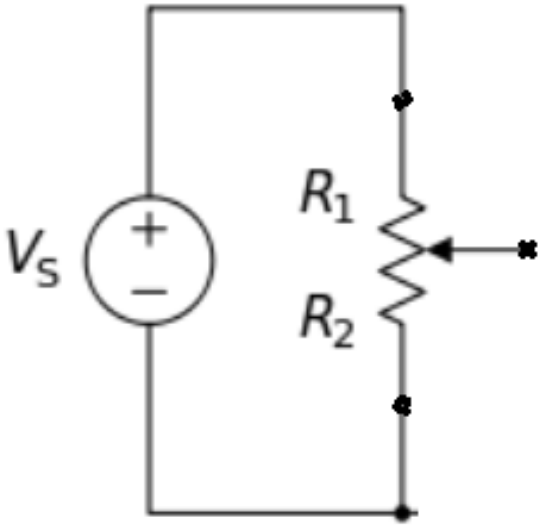
If we read a decimal 512, what voltage does that correspond to?

If we know the voltage at pin A0 on the Arduino is 4 V, what coded value should we read?

What should the coded value be for the Vout you calculated and wrote down for your voltage divider R1,R2 values?

A potentiometer is like a variable voltage divider

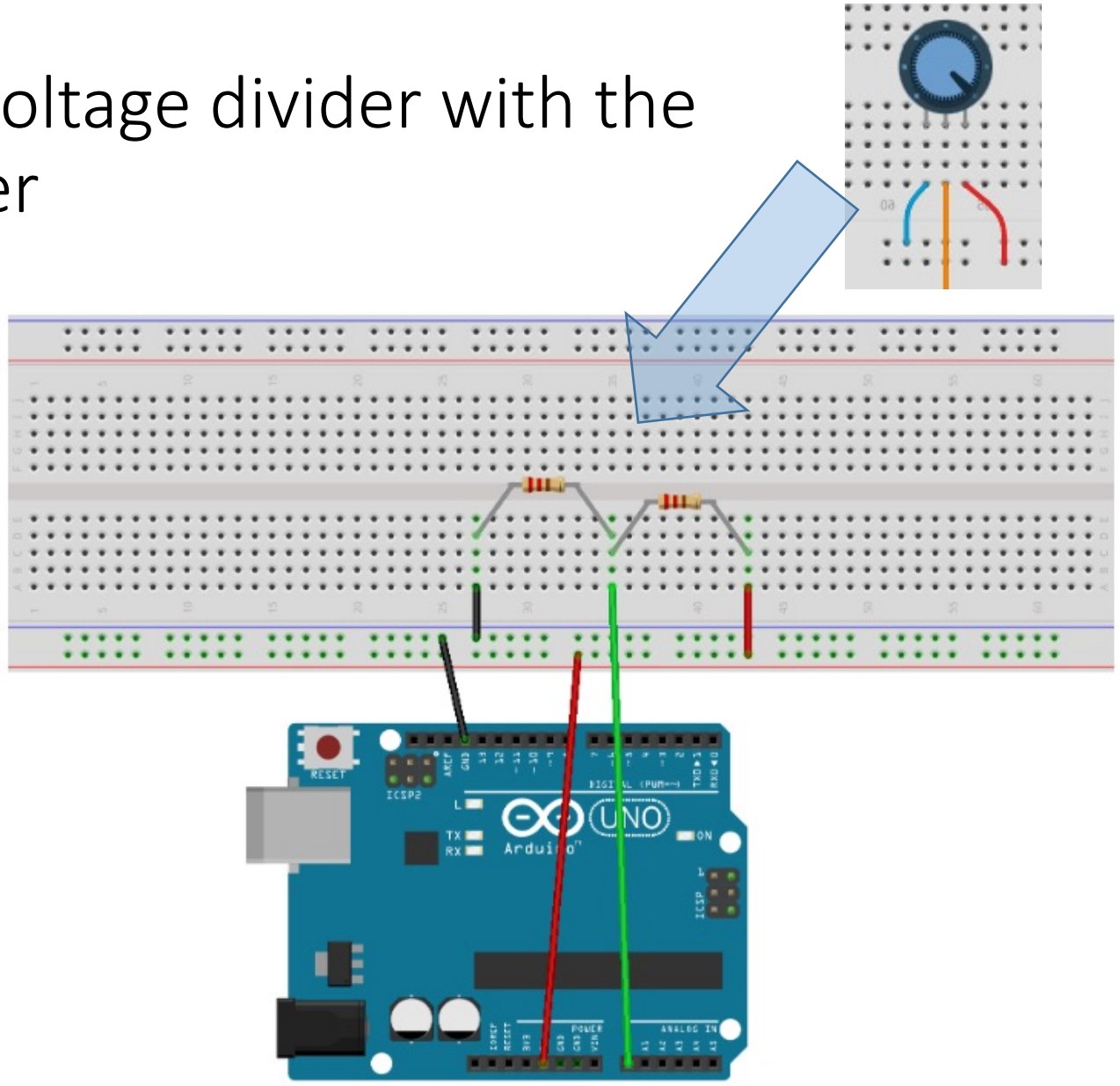
- The center wire "sweeps" up and down the resistor when dial is rotated
- The values of R1 and R2 change accordingly



Replace the voltage divider with the potentiometer

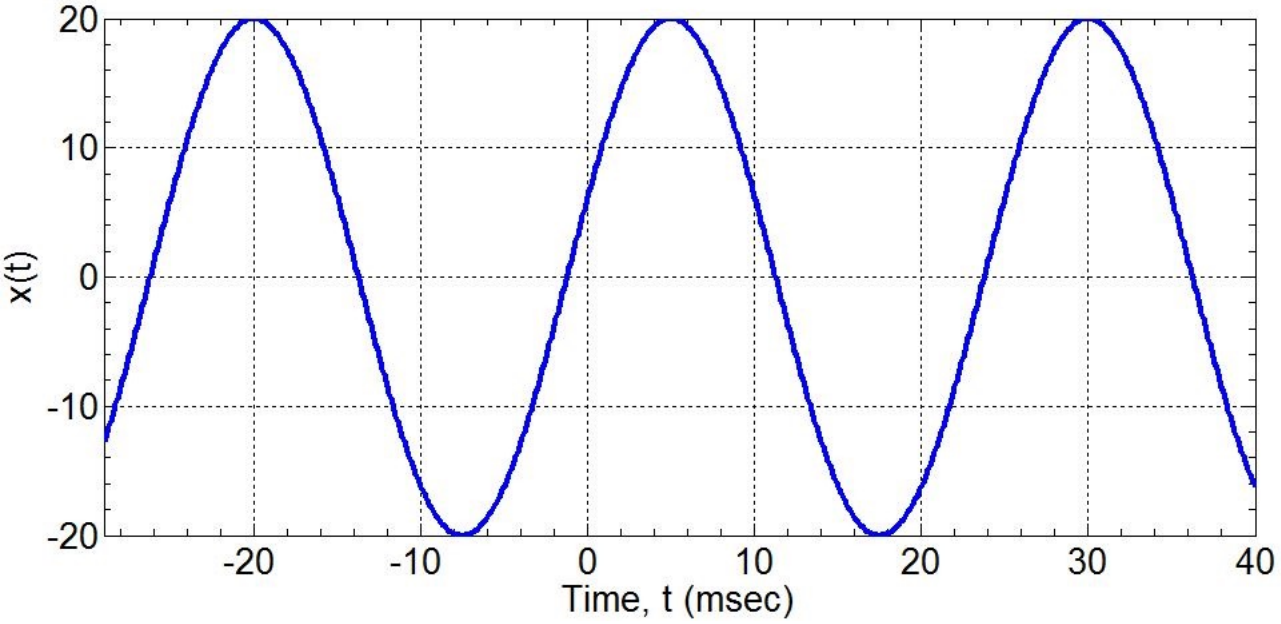
Run the program again.

Notice how the sensor value changes with rotation of the dial.



Electrical Waveforms

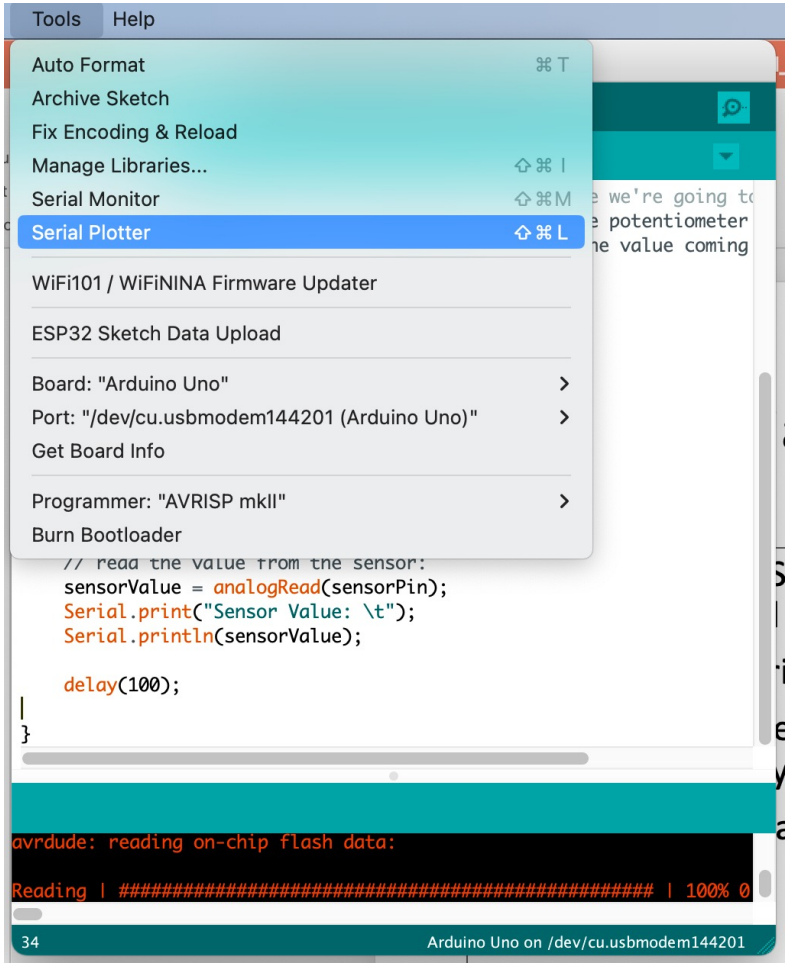
- While DC Voltage is one value, (a flat line), AC voltage is a sinusoidal wave as in:



Arduino Serial Plotter

- Use the Arduino Serial Plotter to plot the values being read from the Uno
- Go to Tools -> Serial Plotter
- Begin to move the pot forwards and backwards, slowly

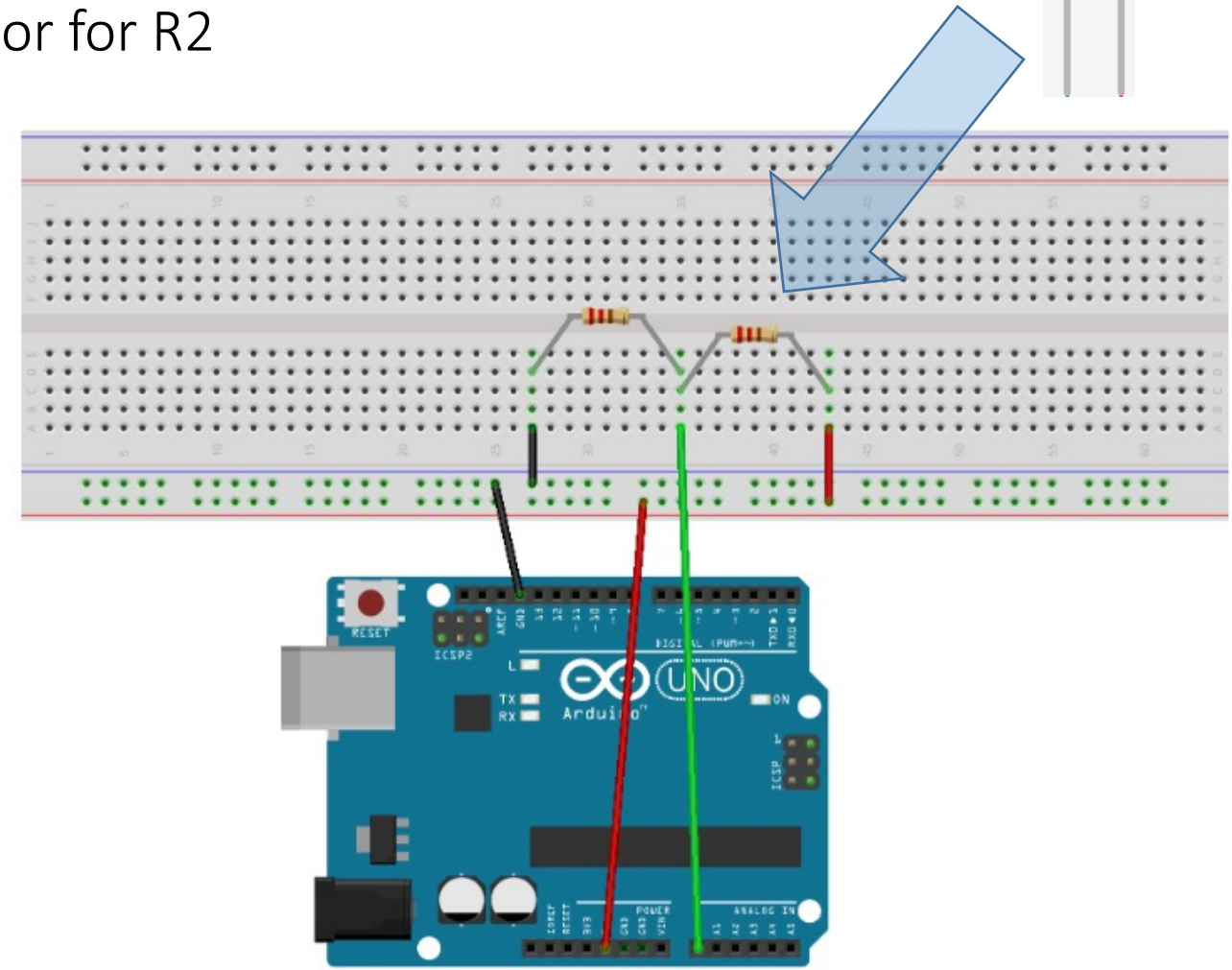
1. Can you make a nice sine wave?
2. What happens when you hit the top or the bottom?
3. What happens if you stop moving?



If time permits, rebuild the voltage divider

Use a thermistor for R1

Use a 10K resistor for R2



Notice how the sensor value changes with the warmth of your finger tips pressing on the bulb

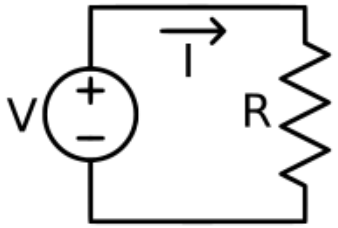
Reference Material on Ohms Law, KVL, KCL and Voltage Dividers

Ohm's Law [edit]

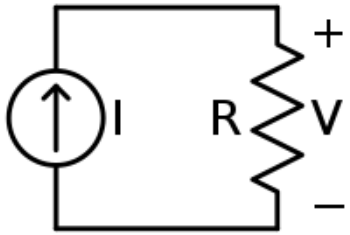
Ohm's law describes the relationship between voltage, current, and resistance.Voltage and current are proportional to the potential difference and inversely proportional to the resistance of the circuit

$$V = I \cdot R$$

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]

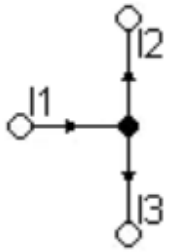
1. Voltage is the potential difference between two charged objects.
2. Potentials can be added or subtracted in series to make larger or smaller potentials as is commonly done in batteries.
3. Positive charge flow from areas of high potential to lower potential.
4. All the components of a circuit have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

Kirchoff's Current Law [edit]

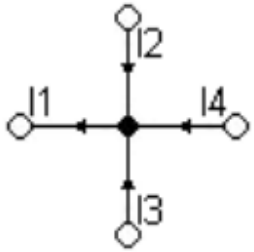
Kirchoff's Current Law (KCL):

> 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]

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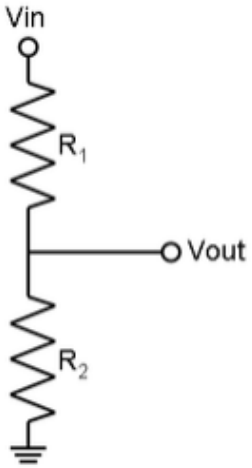

Figure A: Voltage Divider circuit.

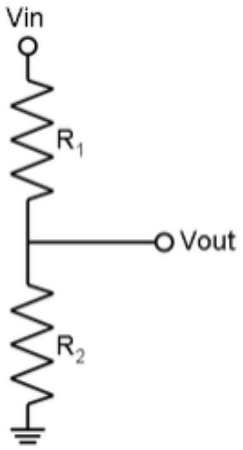

Figure A: Voltage Divider circuit.

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

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