Electrical Fundamentals

Lecture 02.01

In the LaACES program, you will almost certainly be building using electronics to store data, take measurements, and cause or observe changes in the environment.

This will be accomplished by measuring and manipulating a fundamental physical quantity called charge. In this lecture, we will talk about charge and a few other fundamental measurements used to describe the movement of charge in a circuit

Electric Charge

- In the SI system, the unit of charge is the Coulomb (C)

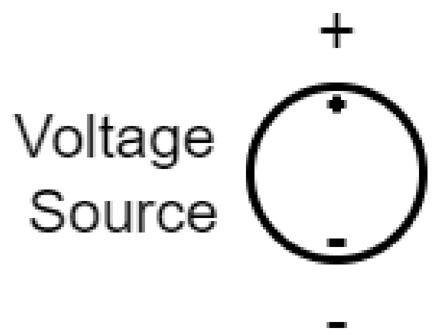
- Charge can either be positive (+) or negative (-)
  - This is a fundamental physical quality; electrons and protons have opposite but equal charges
  - Historically, the electron was assigned a negative charge
  - A Coulomb is “large” charge compared 1 electron charge (e)

$$1\ e = 1.602X10^{-19}\ C$$

- While electrons are usually the actual charged particles moving in a circuit, common practice is to describe things in terms of positive charges (the math is identical)
  - You will likely encounter something called **a hole**, which is just the absence of an electron

Voltage

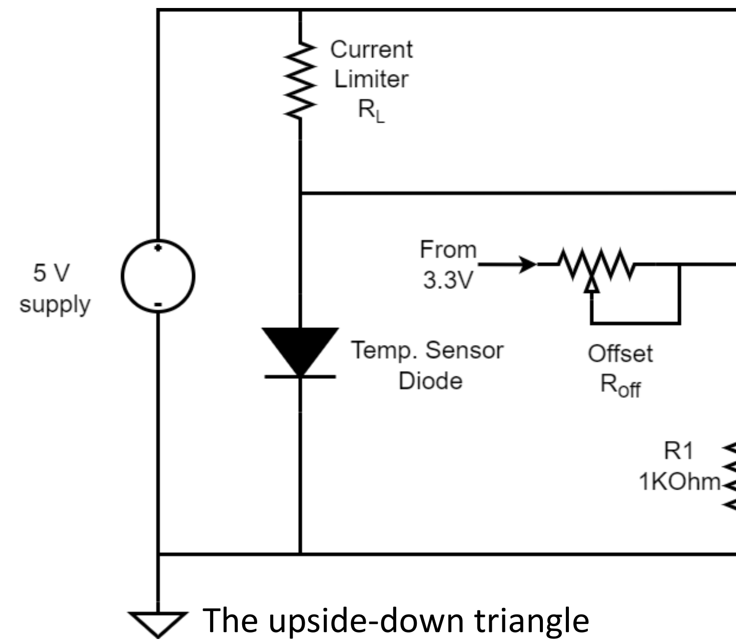
- Voltage is the measure of potential energy a charge has per unit of charge
  - It will sometimes be called Electrical Potential
- The Unit is a Volt (V), which is 1 Joule (SI Energy) per Coulomb (SI Charge)
- Voltage is defined so that a positive voltage means a positive charge has increased in energy
- For example: a 1.5 V battery will cause an electron to increase its energy by $1.5 \times 1.602 \times 10^{-19}$ J (or 1.5 electron-volts)



Voltage sources usually increase the voltage, so choosing the negative terminal as 0 you would measure an increase in voltage at the positive terminal

Measuring Voltage

- There is no absolute 0 point in energy; we always measure Voltage as a difference relative to another point
  - For single components, we often say voltage “across” the component, the difference in energy from one side to the other, ie, from the negative terminal of a battery to its positive lead
  - For more complex circuits, we pick a point to be 0V (similar to picking the surface of the Earth to be 0 in gravitational potential)
  - Often, you choose the negative lead of the power supply
  - This may be referred to as “Ground” or indicated with special symbol



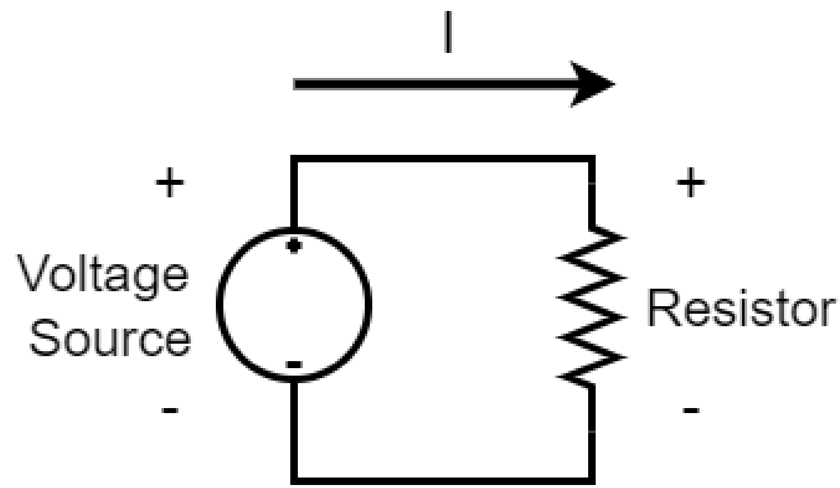
The upside-down triangle indicates ground, so discussing the circuit, we would assume voltage measurements were relative to that being 0V

Electric Current

- Electrical current is the flow of charge through "something"
  - That can be an electrical component, a wire, an individual pin of a chip, an arbitrary point in space
- The unit of Current is 1 Ampere = movement of 1 Coulomb of charge per Time interval of 1 second
- Current is defined as the direction positive charges are flowing

Electric Current (Direction)

- Current is usually drawn with an arrow indicating the direction of flow
- Often, you describe the current in relation the (+) voltage lead of a component
  - We would say the current if coming “out” of the voltage source and “into” the resistor
- When doing circuit analysis, you may not actually know the direction
  - In that case, you pick a direction and if you get a negative value, that means the current is flowing in the opposite direction from arrow



Electric Resistance

- Many materials and components have a simple proportional relationship between the current that passes through the component and the voltage across the component

Ohms's Law $V = R*I$

V = Potential in Volts

I = Current in Amperes

R = Resistance in Ohms

The voltage will be 1V lower at the outlet of a 1 ohm (Ω) of resistance with 1 A current flowing through it compared to the inlet

Kirchoff's Laws

Voltage Law (KVL)

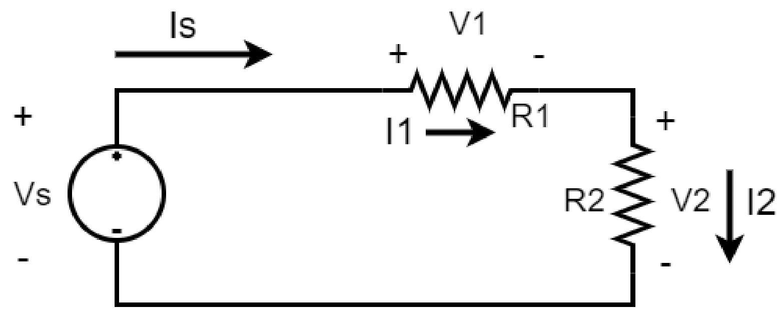
- Energy is conserved
- If we go in a complete loop around a circuit, we are back to where we started
- So all of the Voltage changes must add to 0
- $\Sigma V_i = 0$
- Sign is given by (+) or (-) hit first

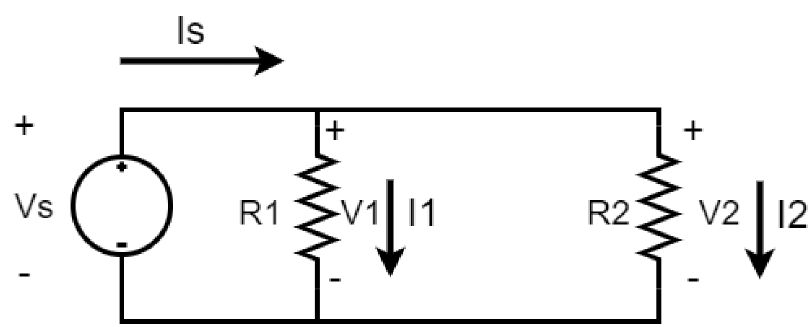
Current Law (KCL)

- Charge is conserved and does not build up in the circuit
- At any forks or splits the current flowing in must equal the current flowing out
- $\Sigma I_i = 0$
- Sign is given by the direction of the arrow

Kirchoff's Voltage Law

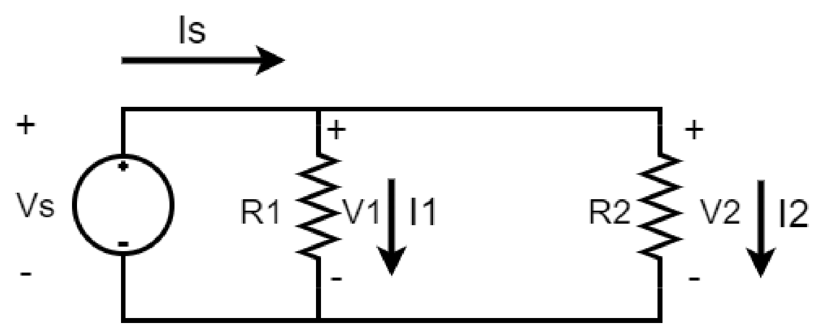
- Top Circuit
  - Starting at Negative Lead of the power supply and going clockwise, we only have one loop
  - $-V_s + V_1 + V_2 = 0$
  - $V_s = V_1 + V_2$
- Bottom Circuit
  - We can make 3 loops, and get 3 equations
  - $V_s = V_1, V_s = V_2, V_2 = V_1$
  - $V_s = V_1 = V_2$
  - We refer to R_1 and R_2 as being "in parallel" or a parallel circuit

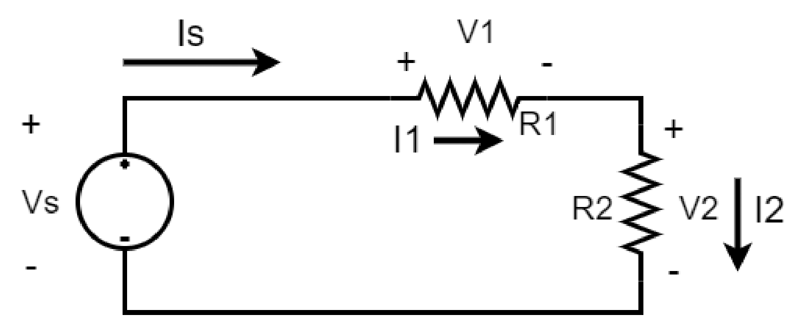




Kirchoff's Current Law

- Top Circuit
  - The current from the Source I_s splits into I_1 and I_2
  - $I_s = I_1 + I_2$
- Bottom Circuit
  - The current from the Source I_s has nowhere else to go so I_s, I_1 and I_2 must all be equal
  - $I_s = I_1 = I_2$
  - We refer to R_1 and R_2 as being "in series" or a series circuit





Electric Power

- If we multiply the units for Current and Voltage

$$\frac{J}{C} * \frac{C}{s} = \frac{J}{s} = W$$

- We get Watts, the SI unit of power
- 1 Watt of power is produced or consumed when a potential of 1 volt causes a current of 1 ampere to flow in a circuit

$$P = IV$$

V = Potential in volts

I = Current in amperes

P = power in watts

- Using Ohm's Law $V = IR$ and $P = I\,V$, then $P = I^2R$ and $\mathrm{P} = \frac{V^2}{R}$
- Current flowing out of (+)V is component generating power
- Current flowing into a (+)V is component generating power

Taking Measurements

- We use a tool called Digital MultiMeter (DMM)
- Measures voltage, current, resistance, and other parameters depending on the model

Plugging in the Leads

- Positive RED test lead is plugged into the plug labeled for the quantity being measured
    - Usually, there are multiple plugs labelled with measurements. The example to the right uses one plug for 10A current and a second plug for everything else
- The negative BLACK test lead is plugged into the **COM** (common) terminal
    - Usually only a single negative
- If you mix up the negative and positive, you will just get a negative number indicated by a minus sign
    - Red and black leads are identical, the colors are just for easy ID

Select the measurement

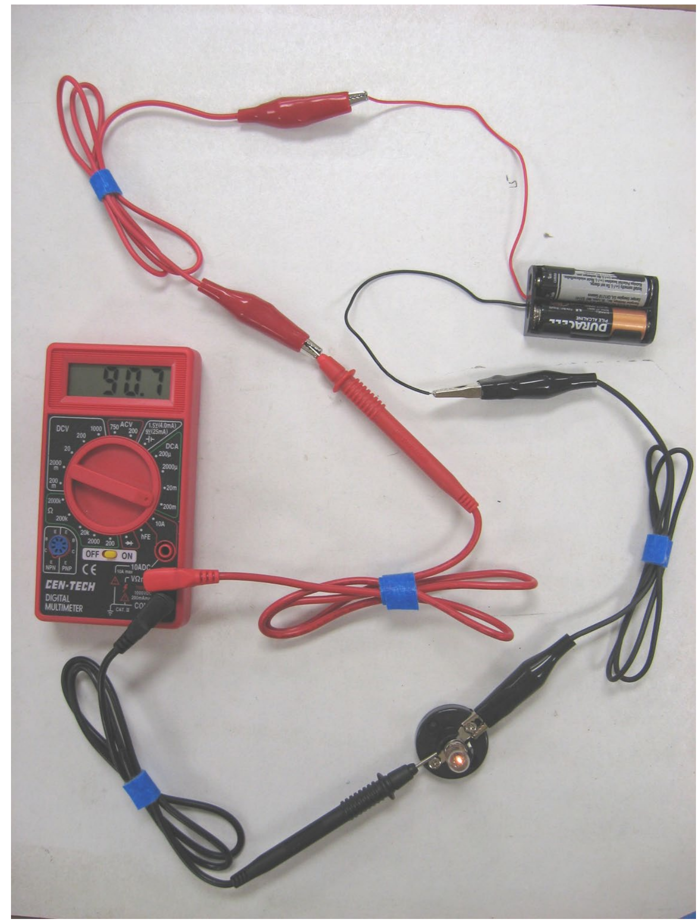
- Meters will usually have some kind of knob for selecting the value you want to measure
- The example on the right has multiple settings for differing ranges, ie 2000 mV, 20 V, 200V, 1000V for voltage
- Other meters will be autoranging
- Also notice this meter has settings for DC and AC
  - AC is Alternating Current where the value oscillates from positive to negative around 0 and it is more useful to know the amplitude
  - For circuits we will almost always wait DC settings

Select the measurement

- Meters will usually have some kind of knob for selecting the value you want to measure
- The example on the right has multiple settings for differing ranges, ie 2000 mV, 20 V, 200V, 1000V for voltage
- Other meters will be autoranging
- Also notice this meter has settings for DC and AC
  - AC is Alternating Current where the value oscillates from positive to negative around 0 and it is more useful to know the amplitude
  - For circuits we will almost always wait DC settings

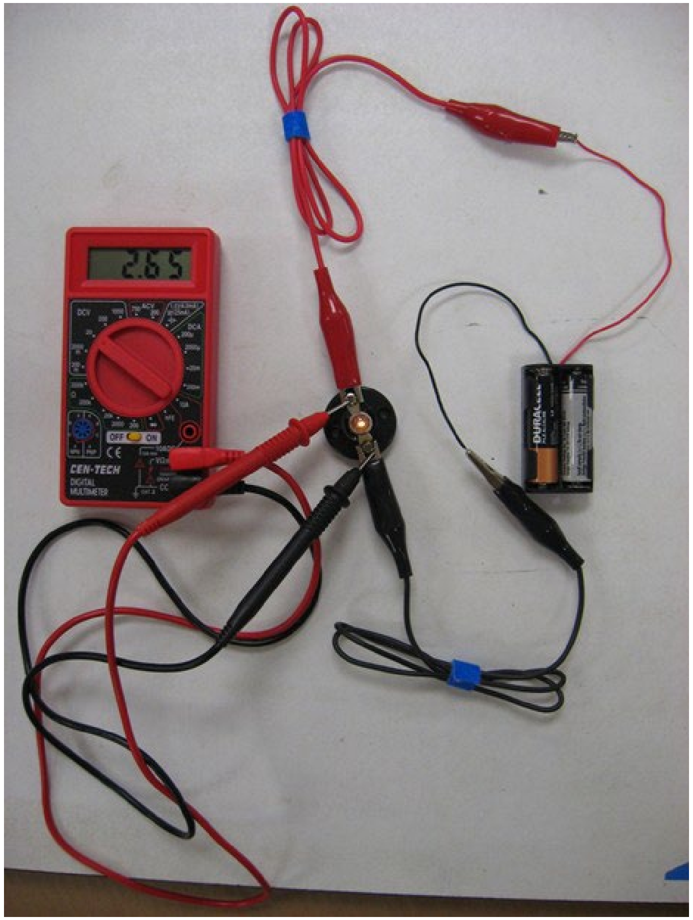
Taking Measurements (Current)

- The meter can only measure current if it flows through the meter
- If we want the meter to match the circuit, it must be **in series** with the circuit where we are trying to measure current
- We also do not want the meter to change the current when we measure, so therefore the meter should have resistance ~0 Ohms in this mode



Taking Measurements (Voltage)

- We touch the leads at the two points where we are trying voltage difference
- If we want the meter to match the circuit, it must be **in parallel** with the circuit where we are trying to measure voltage
- We also do not want the meter to change the voltage by allowing alternate paths so the meter resistance should be large >10MOhm



Taking Measurements (Resistance)

- For resistance, the meter acts as a small voltage source and measures the current
- It then calculates resistance using Ohm’s law
- But it assumes that it is only a voltage source and the measured component is the only current path
  - To get an accurate measurement component must not be powered and will often need to be isolated from the rest of the circuit

Multimeter Fuses

- What happens if you set the meter to current (**Low Resistance**) and hook it into the circuit for Voltage (**Parallel Circuit**)
- The current through the meter will become very large and potentially damage the meter or circuit
  - For this reason, meters usually have fuses designed to break and stop current flow at a mix value
  - These fuses will then need to be replaced
- What happens if you set the meter to voltage (**High Resistance**) and hook it into the circuit for current(**Series Circuit**)
  - In this case you will just make the current flow