Power Systems 1
Cornerstone Electronics Technology and Robotics III
(Notes primarily from "Underwater Robotics – Science Design and Fabrication", an excellent book for the design, fabrication, and operation of Remotely Operated Vehicles ROVs)

- **Administration:**
    - Prayer
- **Work, Energy, Power, and Efficiency:**
    - **Work:** The word "work" as used in mechanical systems has a narrower meaning than it does in everyday life. Work is done when a force pushes an object and the object moves some distance in the direction it's being pushed. When the force exerted on an object is in the same direction as the displacement of the object, calculating work is a simple matter of multiplication:

$$W = F\ d,$$

Where:
W = Work in ft-lbs (SI units: newton-meters or joules since 1 joule = 1 N x 1 meter)
F = Force in lbs (SI units: newton)
d = Displacement or distance moved in ft (SI units: meters)

If you push a really heavy object a certain distance, you do more work than if you push a lighter object that same distance. However, according to this definition, if you push on a heavy object and you are unable to move it, you have not performed any work since d = 0.

Work is further defined as the product of the magnitude of the displacement (d) times the component of the force parallel to the displacement ($F * \cos\theta$).

$$W = F_{parallel} * d$$

$$W = (F * \cos\theta) * d$$

Where:
θ = The angle between the force and the displacement.

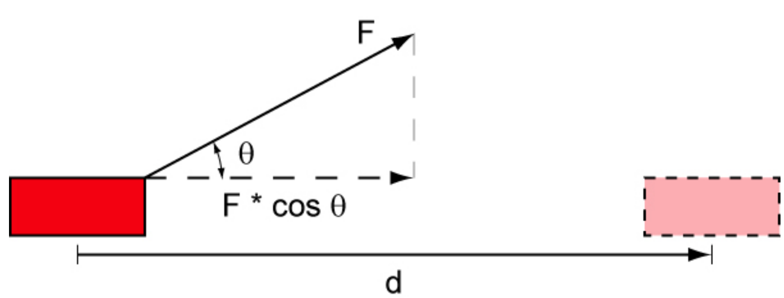


Figure 1: Work Is the Product of the Distance (d) Times the Component of Force Parallel to the Distance (F * cos θ)

See: http://canu.ucalgary.ca/map/content/position/posivect/simulate/applet.html
http://phet.colorado.edu/en/simulation/forces-and-motion
http://lectureonline.cl.msu.edu/~mmp/kap5/work/work.htm

- **Energy:** Energy is the ability to do work. The more energy you have, the more work you can do. Both energy and work are measured in the same units.
  - Energy exists in six basic forms: heat, magnetic, mechanical, chemical, light, and electrical energy. Energy is commonly converted from one of these forms to another.
  - According to the law of conservation of energy, the total energy of a system remains constant, though energy may transform into other forms.
  - Units:
    - In the International System of Units (SI), energy is measured in joules (J).

$$1\ J = 1\ N*m = 1\ (kg*m^2)/s^2 = 1\ Pa * m^3 = 1\ W * s$$

Where:

J = Joules
N = Newtons
m = Meters
kg = Kilograms
s = Seconds
Pa = Pascals
W = Watts

- In imperial units, energy is measured in foot-pounds (ft-lb) or British Thermal Units (BTUs).

$$1\ ft*lb = 0.001285\ BTUs = 1.356\ J$$

Where:

ft*lb = Foot-pounds
BTU = British Thermal Units
J = Joules

- **Power:**
  - Power is the rate at which work is done or energy is transferred. It is the work/time or energy/time ratio. Mathematically, it is computed using the following equation.

$$P = W/t = E/t$$

Where:

P = Power in watts
W = Work in joules
E = Energy in joules
t = Time in seconds

Sometimes, work is done quickly and at other times the work is done rather slowly. If more power is available, the same amount of work can be performed more quickly. Also, let's look at an example of power as the rate that energy is transferred. The rate at which a light bulb transforms electrical energy into heat and light is measured in watts—the more wattage, the more power, or equivalently the more electrical energy is used per unit time.

Figure 2: The Maximum Power Output of Hoover Dam Is 2.08 Gigawatts
From: http://wedoitallvegas.com/

  - Units:
    - In SI units, power is in watts (W).

      1 Watt = 1 joule/second

    - In imperial units, power is measured in horsepower (hp).

      1 hp = 746 W

- Power Transmission:
    - Power normally must be conveyed from one location to another. For example, the car engine drives belts, shafts, and gears to transfer its power to the air conditioner compressor, power steering, wheels, and other powered features offered in the car.
    - In mechanical systems, power is transferred with belts, shafts, gears, pulleys, levers, sliding rods, or other mechanisms. Also, pressurized liquids or gases can convey power through pipes, tubes, valves, and pistons. Liquids are favored over gases since gases compress and store part of the energy rather than transfer it.
    - Electrical power is moved through a conductor such as wires.

- **Efficiency:**
    - When energy is used to perform useful work, the original energy is transformed into two or more other forms of energy during the process. Some part of the energy is always converted into the forms of energy (such as vibration and heat) that are not useful for the task at hand.

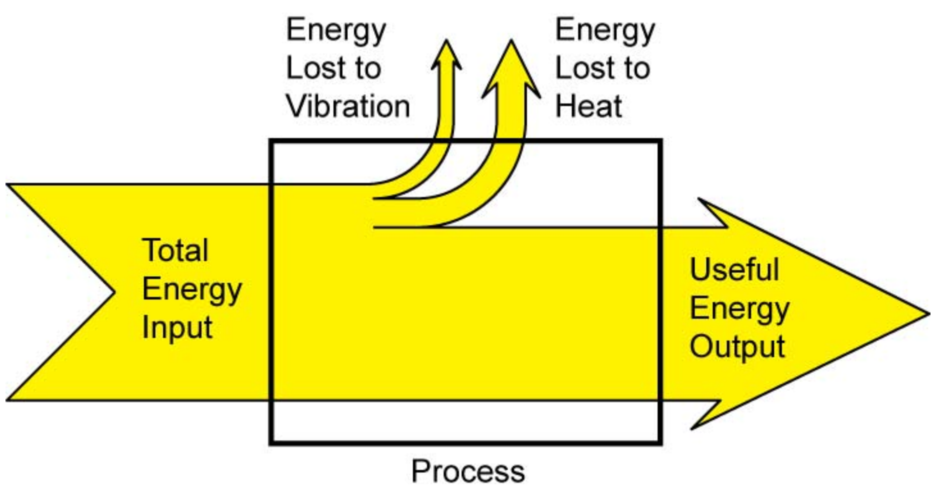


Figure 3: Some Energy is Lost during a Process

The percentage of the energy that comes out of a process as useful energy compared to the total energy input is called efficiency.

$$\text{Efficiency} = \frac{\text{Useful Energy Output}}{\text{Total Energy Input}} \times 100\%$$

Efficiency is a valuable model whether it is applied to performing useful work, converting energy from one form to another, or conveying energy from one location to another. In the later case, energy is lost in all conventional methods of power transmission. In mechanical systems, the loss can be in the form of friction and in electrical systems, the loss is from resistive heating.

- Design implications for your ROV:
  - Most energy conversions in well designed machines have efficiency between 10% and 40%. Each conversion step in your design will compound the losses. For example, if you have four conversion steps in a vehicle system and each step has an efficiency of 40%, your overall efficiency is the product of all the efficiencies.

Overall Efficiency = 40% x 40% x 40% x 40%
Overall Efficiency = 0.4 x 0.4 x 0.4 x 0.4 = 0.0256 = 2.56%

It is clear that you want to limit the number of energy conversion steps in your vehicle design.

  - You will need to put much more power into vehicle systems than you will get out of them. Your systems will encounter losses from heat, vibration, unwanted sound generation, friction, and drag.
  - One of the major contributors to energy loss is heat.
    - Allowed to go unchecked, heat can cause damage or even failure in a ROV system.
    - One advantage of working in a water environment is that cool bodies of water readily absorb heat, that is, they are superb heat sinks.
    - On the other hand, most of the heat producing components on a ROV are packaged in confined, airtight canisters. For this reason, metal canisters are preferable to plastic since they are better conductors of heat to the outside water. As a rule, if a ROV component is warm to the touch in open air, then you need to be concern about confining it in a plastic canister.

- **Vehicle Power Choices:**
  - A variety of power systems are available to the underwater vehicle designer. They include solar power, onboard rechargeable electrical batteries, tethered battery power, ultra-capacitors, fuel cells, nuclear reactors, and ocean thermal power.
  - Criteria for evaluating underwater power systems:
    - Can the power system store sufficient energy to accomplish the entire mission?
    - Can the power system meet the peak power demands of your vehicle?
    - How much space will the power system require?
    - Can the system operate under water?
    - How easy is it to obtain, install, use, maintain, and retire the power system?
    - How easily can energy be distributed from the source to the various systems that need it?
    - What forms of power are required by the various vehicle systems?
    - How safe is it?
    - How much does it cost?

- Electrical power – a logical choice for small ROV and AUV projects:
  - The advantages of electrical power are:
    - Convenience
    - Simplicity
    - Air-independent
    - Low cost
    - Flexibility and scalability
    - Ease of maintenance
    - Ease of power distribution
    - Compatibility with a variety of sensors, motors, lights, and other electrical components
    - Safety with low-voltage batteries

- **Introduction to Electricity and Electrical Circuits:**
    - Unlike mechanical systems where you are familiar with the quantities like friction, springs, mass, speed, etc., electricity and electronics are based upon unfamiliar quantities like current, voltage, resistance, capacitance, etc. This makes it more difficult to relate to and understand. You will have to work with these electrical quantities before you will gain some comfort with them.
    - An introductory electrical circuit course is available at: http://cornerstonerobotics.org/curriculumyear1.php
    - **Atomic Structure and Charge:**
        - **Introduction:** We will use the Bohr model of atomic structure. The model which was developed by Danish scientist Niels Bohr states that an atom consists of a nucleus at the center and electrons orbiting around the nucleus much like the planets orbit around the sun. Another model of atomic structure is the quantum mechanical model which will not be covered here. See Bohr model applet: http://www.germane-software.com/~dcaley/atom/Atom.html
        - **Nucleus:** The nucleus is the center of the atom which contains the protons and neutrons. See: http://education.jlab.org/atomtour/listofparticles.html
        - **Protons:** Protons are positively charged particles contained in the nucleus. The mass of a proton is about 1800 times that of an electron.
            - **Atomic Number**: The atomic number equals the number of protons in the nucleus.
        - **Neutrons:** Neutrons are uncharged particles contained in the nucleus. The mass of a neutron is about the same as a proton.
        - **Electrons:** Electrons are the basic particles of negative charge that whirl in orbits around the nucleus. Sometimes the orbits are called rings or shells. See applet: http://www.lon-capa.org/~mmp/applist/coulomb/orbit.htm
            - In an atom, the number of electrons in orbit equals the number of protons in the nucleus; therefore the number of negative charges equals the number of positive charges. In this state, the atom is electrically balanced or neutral.
            - See: http://www.colorado.edu/physics/2000/applets/a2.html
            - **Ionization**: The *removal* or addition of an electron *from* or to a neutral atom so that the resulting atom (called an ion) has a *positive* (+) or negative charge (-). An ion is an atom that is not electrically neutral. A positive ion has had an electron removed, while a negative ion has gained an electron.
            - In electricity and electronics, the most important part of an atom is the electrons because they can be stripped off an atom to produce electricity.
            - Electronics is about controlling electrons with components such as resistors, diodes, capacitors, transistors and integrated circuits to produce the desired results.

- **Voltage (Units in Volts, V):** In general terms, voltage is the force or pressure that is exerted on electrons which causes them to move or flow. The voltage between two points is a short name for the electrical force that would drive an electric current between those points. If we compare electric current to water flowing through a pipe, then voltage would be the water pressure. Voltage is represented by the letter V or E.

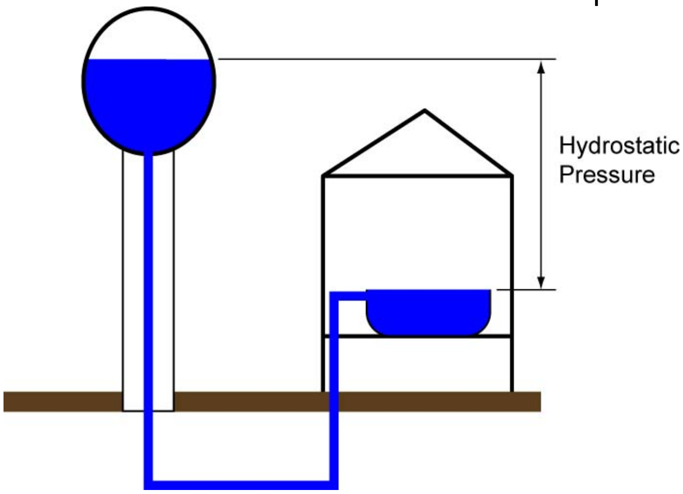


Figure 4: Water Pressure from a Water Tower

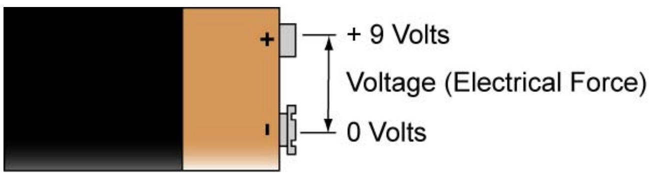


Figure 5: Voltage (Electrical Force or Pressure) From a Battery

Voltage is *always relative between two points*. The voltage reading on a voltmeter is the voltage at one point in the circuit compared to another point in the circuit. Also, voltage is measured <u>across</u> a component, *not through* a component.

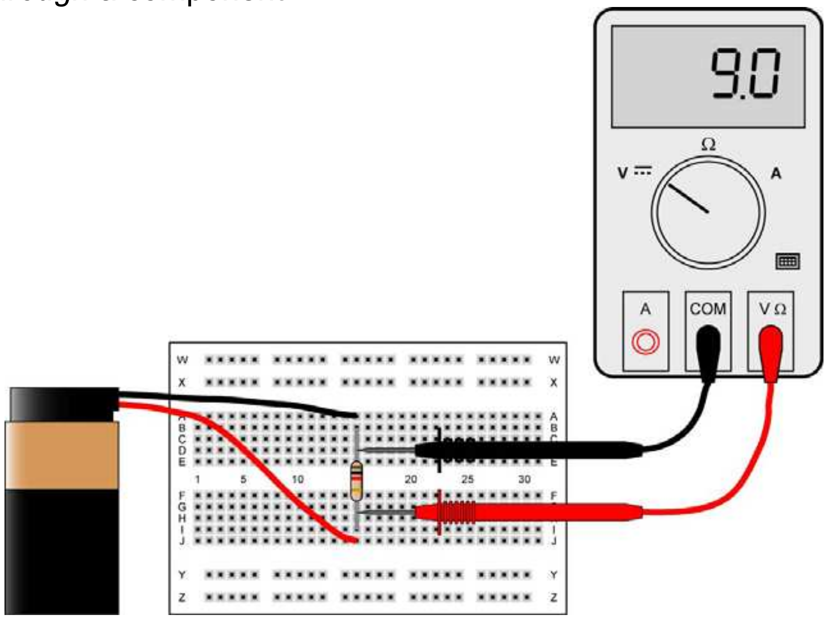


Figure 6: Measuring Voltage *across* a Component (Resistor)

See:
http://www.upscale.utoronto.ca/IYearLab/Intros/DCI/Flash/WaterAnalogy.html
http://www.mste.uiuc.edu/murphy/WaterTower/default.html

- **Current (Units in Amperes, A):** In our water analogy, current is the flow of water. In most electrical circuits, current is the flow of electrons passing a given point. However, in water, especially saltwater, electrical current is carried by ions such as Na^+ and Cl^-. Current is represented by the letter I.
    - Conventional Current Flow: An old theory attributed to Ben Franklin that assumes all current consists of moving positive charges. The fact is that the electrical charges moving are really the negatively charged electrons. Generally it doesn't matter that the assumed electric charge moves in the opposite direction that it actually does because in most cases positive charges flowing one direction is equivalent to negative charges flowing in the opposite direction. Conventional flow concludes that current flows from the positive terminal (a surplus of "positive" charge) and into the negative terminal (a deficiency of "positive" charge). Since conventional flow is followed by most electrical engineers, we will use conventional flow to define the direction of current.

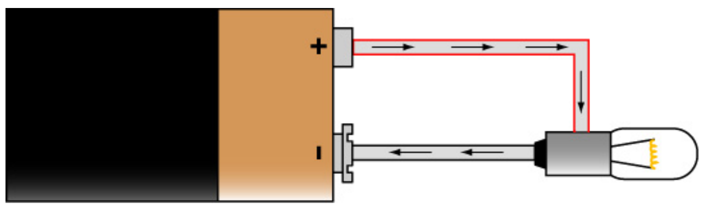


Figure 7: Conventional Flow – Current Flow from Positive to Negative

- **Resistance (Units in Ohms, Ω, the Greek letter "Omega"):** Resistance is the opposition to the flow of electrons. It is used to control the amount of voltage and/or amperage in a circuit. Resistance is represented by the letter R. See: http://www.mste.uiuc.edu/murphy/Resistance/default.html
- For a lesson on voltmeters, ammeters, and ohmmeters, see: http://cornerstonerobotics.org/curriculum/lessons_year1/ER%20Week3,%20Meters.pdf
- **Ohm's Law:** The mathematical relationship between voltage, current, and resistance.

  $V = I \times R$ where:

  V = voltage in volts,
  I = current in amperes, and
  R = resistance in ohms

  From $V = I \times R$, we can derive the two equations,

  $I = V / R$ and,

  $R = V / I$.

  So voltage is directly related to current and resistance, while current is inversely related to resistance. Also, resistance is inversely related to current. Is current directly or inversely related to voltage?

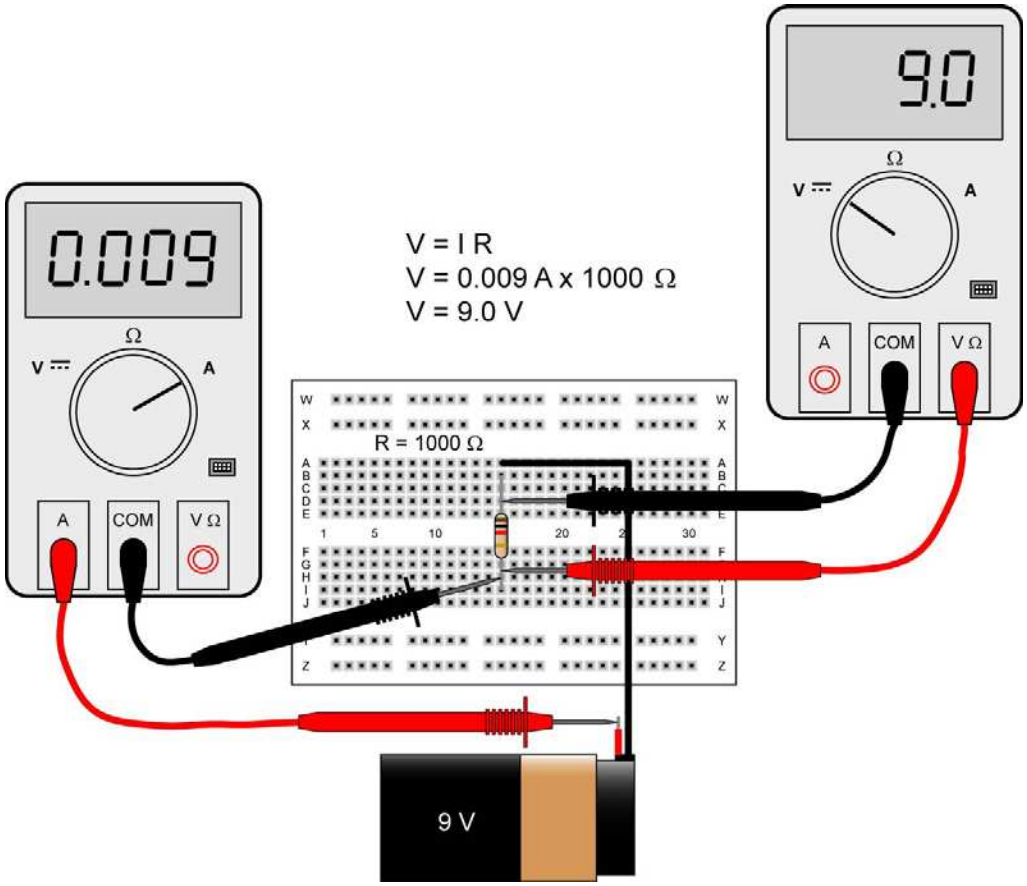


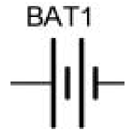
Figure 8: Using a Digital Multimeters to Demonstrate Ohm's Law – Ammeter on Left Is Inserted into the Circuit, the Voltmeter on Right is Parallel to the 1K Resistor

See Ohm's Law applets at:
http://micro.magnet.fsu.edu/electromag/java/ohmslaw/index.html
http://www.youtube.com/watch?v=-mHLvtGjum4&feature=related
http://www.electricalfacts.com/Neca/Exp/Exp2/ohm1.shtml
http://www.falstad.com/circuit/e-ohms.html
http://www.angelfire.com/pa/baconbacon/page2.html

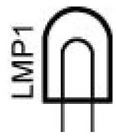
- Perform Power Systems 1 Lab 1 – Ohm's Law Measurements and Calculations

- **Conductors:** A low resistance material through which electrical electrons can easily flow. The conduction of electricity is done by transferring electrons from one atom to the next atom in the conductor. The speed of this transfer approaches the speed of light, 186,000 miles/second. The electrons themselves are not traveling at the speed of light, but the effect of all of the electrons from one end of a conductor to the other end appears to approach the speed of light.
  - Electricity is always looking for a conductor!
  - The body as a conductor: Do not allow electrical current to pass through from one hand to another or from one hand to your feet. This current will pass through your heart which may prove fatal.
- **Insulators:** A material with few or no free electrons which will not let electrons flow freely. Insulators provide a protective coating around a conductor.

- A basic electrical circuit consists of three main parts:
  - Circuit, Latin for “go around”
  - **Source:** A source of potential energy called voltage (a battery, electrical outlet, solar panel, etc.).
    - Battery Symbol:



  - **Load:** Converts the electrical energy to some other form of energy such as heat, light, motion, or magnetism (a light, a bell, a motor, etc.). This is the part of a circuit that performs work.
    - Lamp Symbol:



    - Resistor Symbol:

  - **Conductor:** The wires between the source and the load are made up of a low resistance material through which electrons can easily flow.
    - Wire symbol is a line.
  - A fourth part is a control device like a switch or a fuse which is not required in a circuit but they provide a safety and practical function of turning a circuit on and off.
    - Switch Symbol:

  - Illustration of basic electrical circuit components:

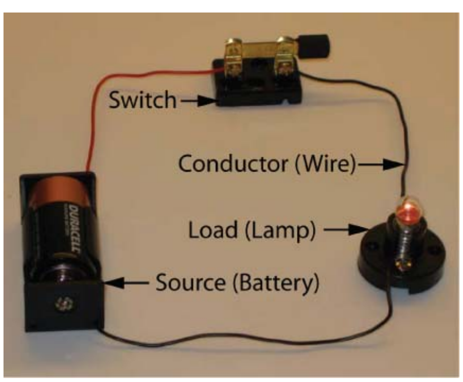


Figure 9: Simple Circuit

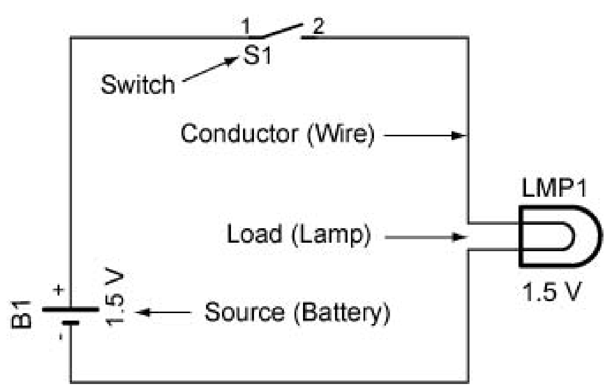


Figure 10: Schematic Diagram of Simple Circuit

- Three basic circuit conditions:
  - **Open Circuit**, a broken path therefore, no current flow.

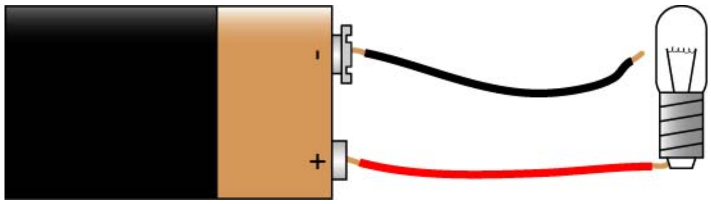


Figure 11: Open Circuit

  - **Closed Circuit**, an unbroken path for current from a source to a load and back to the source. In general, if the circuit works, then it is a closed circuit.

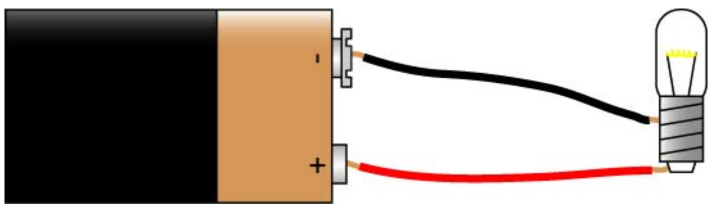


Figure 12: Closed Circuit

  - **Short Circuit**, an unwanted circuit condition where the current bypasses the load causing damage to the circuit. Note: Don't put a 9 volt battery in pocket that has coins in it; the coins can easily short the battery causing your pocket to get quite warm.

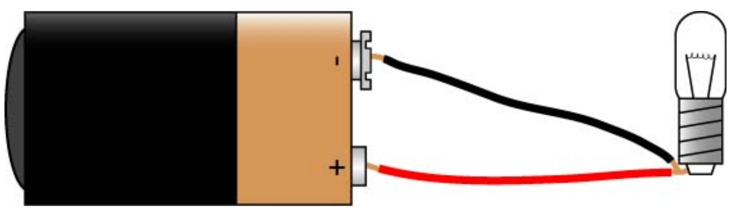


Figure 13: Short Circuit

- **Schematic Diagrams:** A schematic diagram is a shorthand way to draw an electric circuit. It is a diagram that illustrates components (electrical parts) and how they are connected to each other. Symbols are used to represent circuit components and lines are used to represent wires or connections.
  - Other electrical diagrams include block diagrams and wiring diagrams
    - Block diagrams show major electrical systems are related.

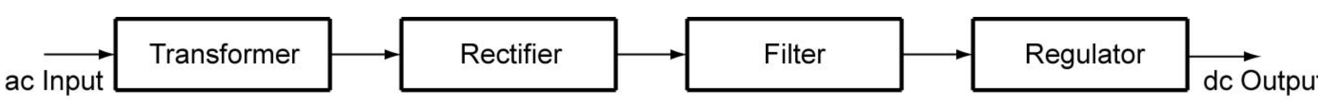


Figure 14: Block Diagram of a DC Power Supply

- Wiring diagrams are used to help with the actual circuit wiring.

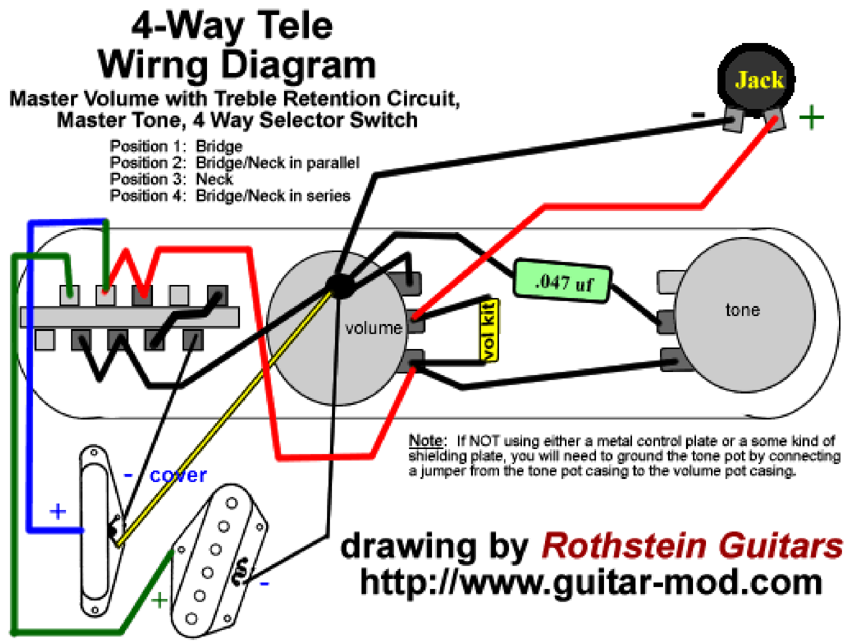
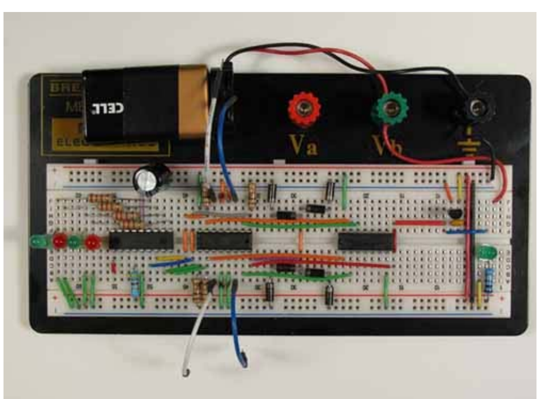


Figure 15: Wiring diagrams Show the Component Parts in Pictorial Form

- Example of an electrical circuit and the corresponding schematic diagram:



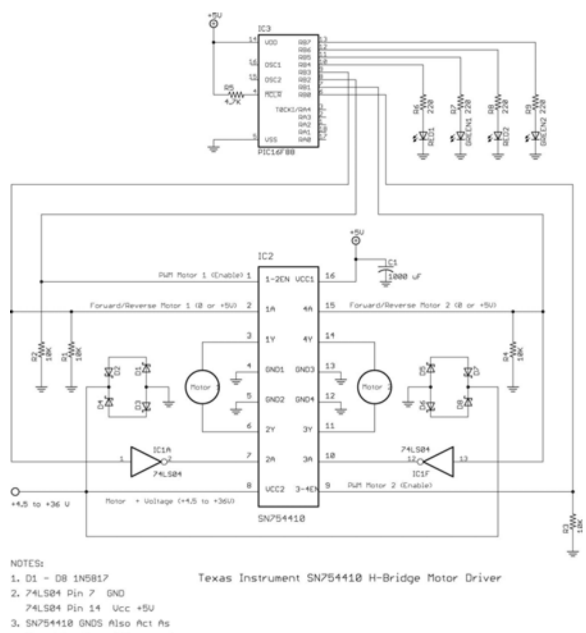


Figure 16: Photo of an H-bridge Circuit **Figure 17: Schematic Diagram of the Circuit**

- General Rules and Hints for Schematics:

(From: http://opencircuitdesign.com/xcircuit/goodschem/goodschem.html)

- Wires connecting are indicated by a heavy black dot; wires crossing, but not connecting, have no dot.
- Wires and components are aligned horizontally or vertically, unless there's a good reason to do otherwise.
- In a schematic drawing, the distance between components does not represent the actual distance when wiring the components.
- Label pin numbers on the outside of a symbol, signal names on the inside.
- All parts should have values or types indicated; it's best to give all parts a label, too, e.g., *R*7 or *IC*3.
- Give the value of the component where applicable.
- Show polarity (+ and -) for components that have polarity.
- In general, signals go from left to right
- Put positive supply voltages at the top of the page, negative at the bottom.
- Don't attempt to bring all wires around to the supply rails, or to a common ground wire. Instead, use the ground symbol(s) and labels like +Vcc to indicate those voltages where needed.
- It is helpful to label signals and functional blocks and show waveforms; in logic diagrams it is especially important to label signal lines, e.g., RESET or CLK.
- It is helpful to bring leads away from components a short distance before making connections or jogs.
- Leave some space around circuit symbols

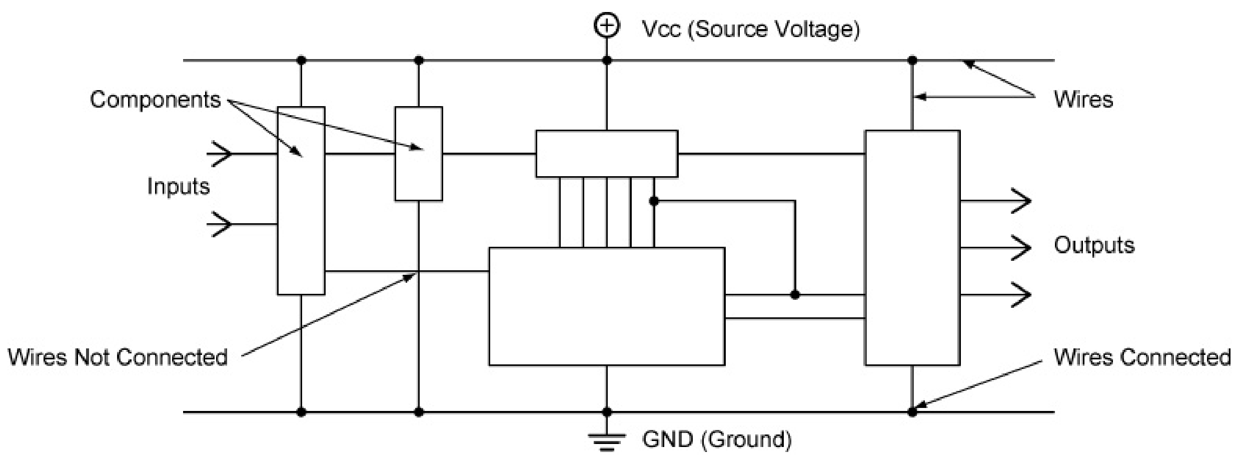
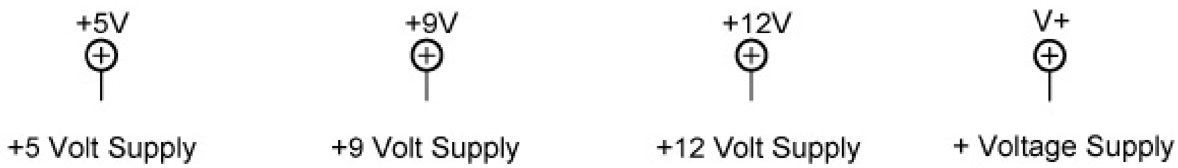


Figure 18: General Layout of a Schematic Drawing

- Ground: The point in a circuit that remains at 0 volts.
  - Electrical grounding is important because it provides a reference voltage level (0 volts) against which all other voltages in a system can be established and measured. You can speak of a voltage "at Point A in the circuit as 12 volts" when it is referenced to ground.
  - An electrical system may have more than one ground. In underwater vehicles, the motor ground may be separate from the sensor ground. Motors produce electrical spikes on the power and ground lines causing interference with sensitive sensor voltage signals.
- Another way to show voltage source and ground:
  - In order to make schematics cleaner and easier to read, the battery symbol is left out all together from the schematic; voltage source and ground symbols are substituted. This really cleans up a large schematic where lots of parts are connected to the voltage source and ground.
    - A voltage source may be drawn as shown in the following examples:



    - A earth ground may be represented by the following symbol:

      This symbol may also be used to indicate a point in a circuit that is the common reference voltage (0 Volts) from which all other voltages are measured.
  - Example of a schematic using a voltage source and ground:

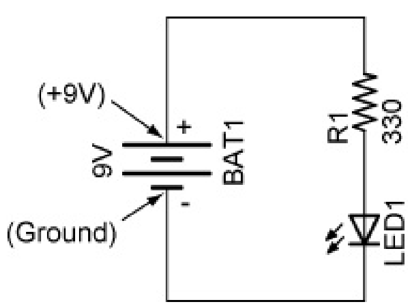


Figure 19: Schematic with Battery Symbol

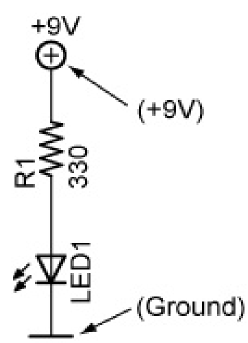


Figure 20: Equivalent Schematic Using +9V Supply and Ground Symbols

The equivalent schematic serves the same function as the schematic with a battery. In both schematics, the 330 ohm resistor is connected to the positive terminal of the battery and the cathode of the LED is connected to the negative terminal. The LED will light in both circuits.

- Perform Power Systems 1 Lab 2 – Drawing Schematics

- Power in Electrical Circuits:
  - Watt's Law:
    - The formula to calculate electrical power.

      P = E x I, where:

      P = Power (work/time), in watts (W)
      E = Voltage (work/charge), in volts (V)
      I = Current (charge/time), in amperes (A)
  - Two main reasons that a designer of an underwater vehicle must be consider power for their vehicle.
    - As stated earlier, can the power system meet the peak power demands of your vehicle?
    - Care must be taken not exceed the power rating of the electrical components that are used on the vehicle.
- **Direct Current (DC):**
  - Direct current moves in only one direction in a circuit.
  - Though DC must travel in only one direction, its value does not necessarily have to remain constant. See Figure 21.
  - Constant DC typical of a battery or regulated DC power supply output.
  - Digital DC common when working with digital circuitry such as computers.
  - Analog DC encountered when dealing with electrical sensor outputs.
  - Pulsating DC associated with DC power supply circuits.

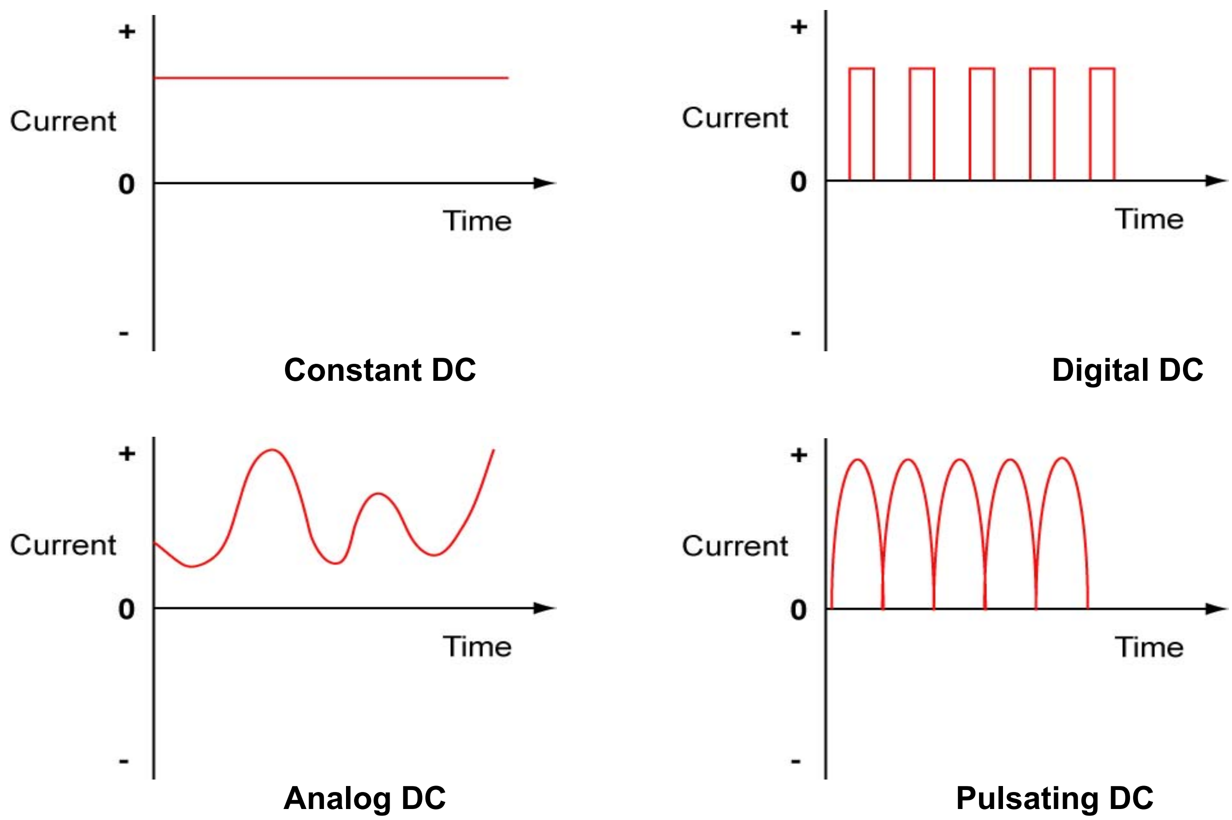


Figure 21: Direct Current Waveforms

- **Alternating Current (AC):**
  - Alternating current changes direction (polarity) and amplitude cyclically, i.e., at regular intervals.
  - An example of sine-wave AC is common household utility current.
  - Common AC waveforms:

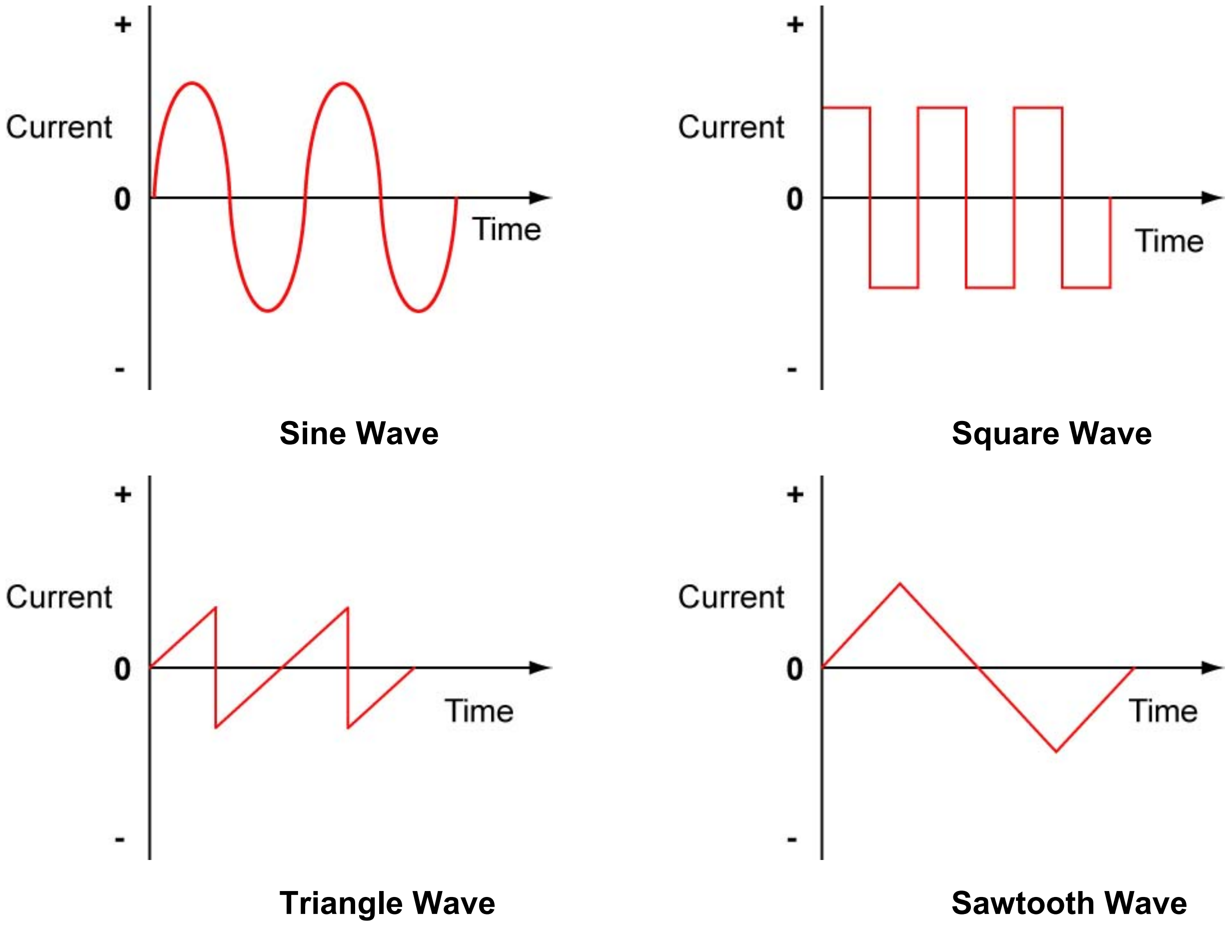


Figure 22: Common Alternating Current Waveforms

- A series circuit is one with all the loads in a row, like links in a chain. There is only one path for the electrons to flow. In Figure 23, if one of the resistors (loads) is removed, the current stops flowing.

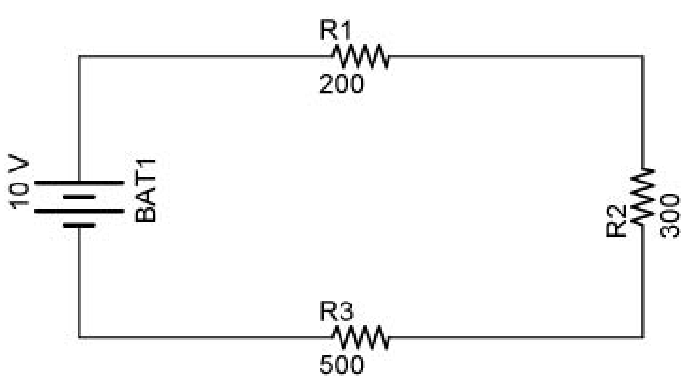


Figure 23: Resistors in Series

DC voltage sources can also be placed in series to increase the voltage available.

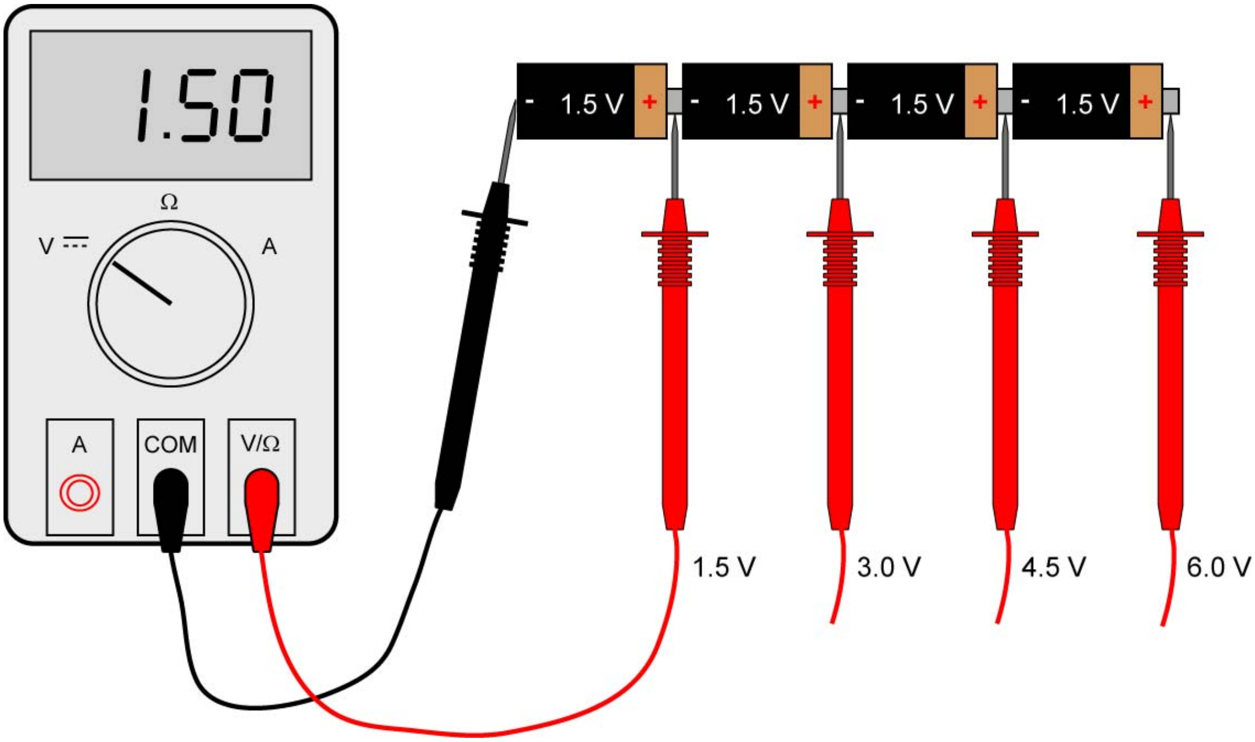


Figure 23: Voltages Add when Batteries Are in Series

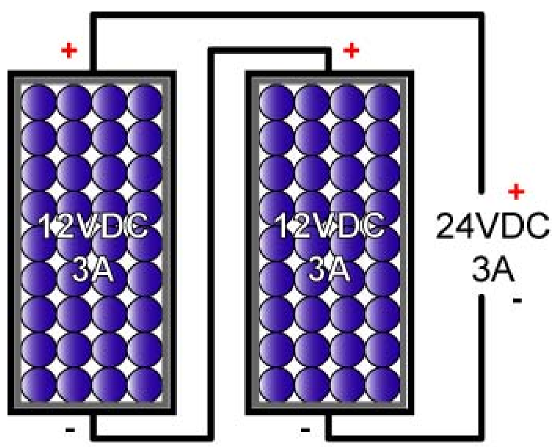


Figure 24: Solar Panels in Series – Voltages Add, Amperage Remains the Same

- A parallel circuit is one that has more than one pathway for the electrons to flow. Unlike a series circuit, when you remove one resistor in a parallel circuit, electrons (current) continue to flow through the other resistors.

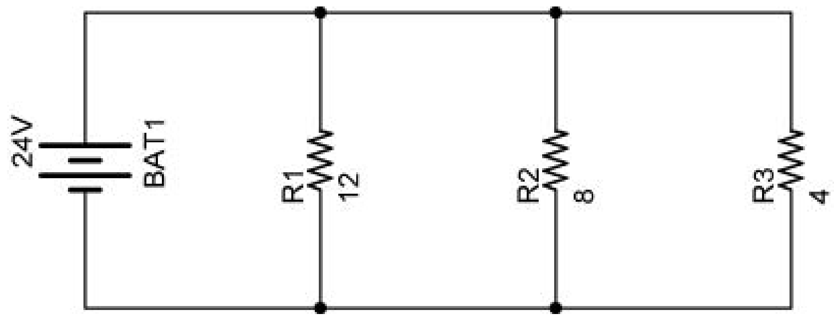


Figure 25: Resistors in Parallel

DC voltage sources can also be placed in parallel to increase the current available. The voltages do not add.

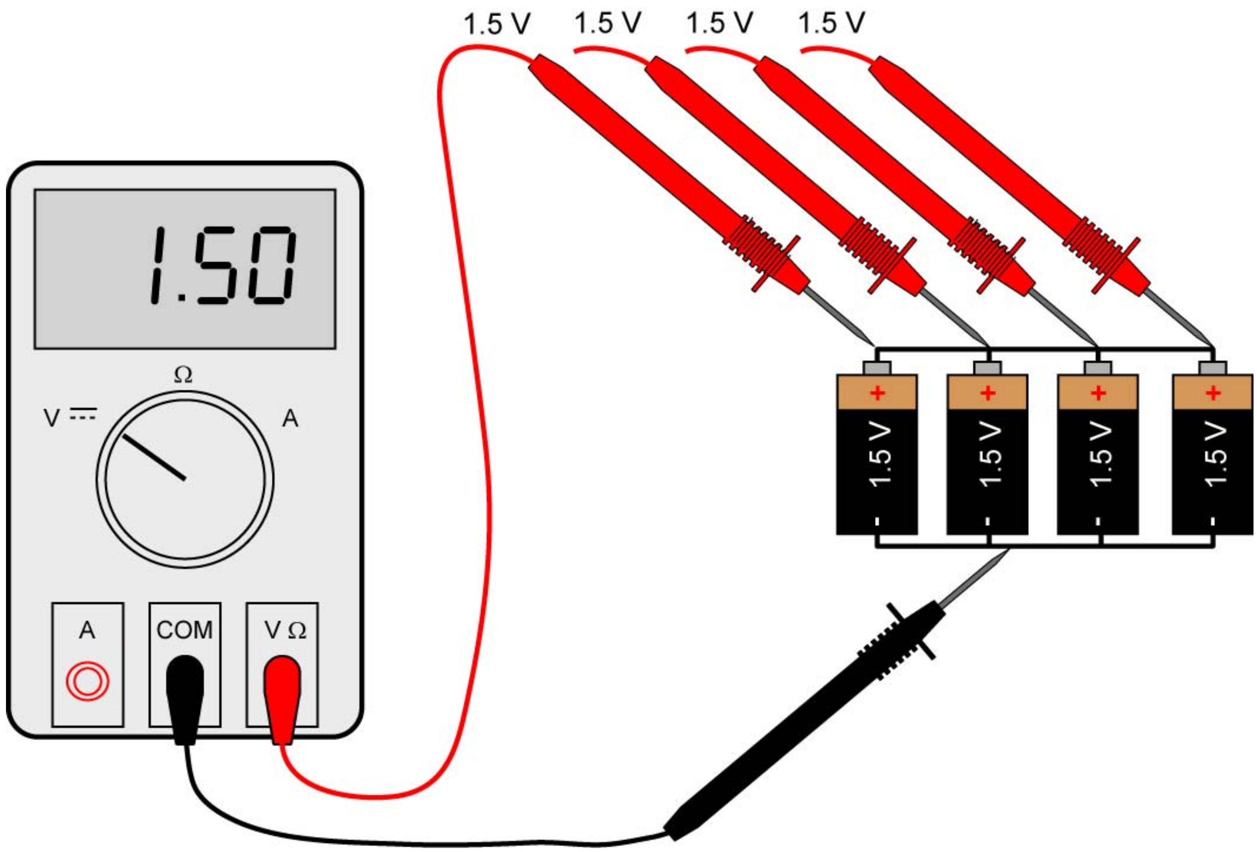


Figure 26: Voltages Do Not Add when Batteries Are in Series

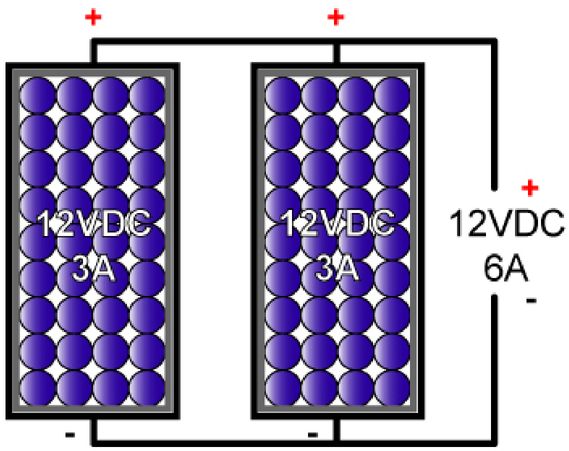


Figure 26: Solar Panels in Parallel – Amperage Available Is Added, Voltage Remains the Same

- Everyday examples of parallel circuits:
  - Electrical outlets in a home See: http://sol.sci.uop.edu/~jfalward/seriesparallelcircuits/seriesparallelcircuits.html (House wiring diagram)
  - Lights in a home
  - Electrical car functions, such as the radio, horn, starter, and lights

Cornerstone Electronics Technology and Robotics III
Power Systems 1 Lab 1 – Ohm's Law Measurements and Calculations

- **Purpose:** The purpose of this lab is to have the student apply Ohm's Law to several circuits and then verify the calculated results.

- **Apparatus and Materials:**

  - 1 – Digital Multimeter (DMM)
  - Circuits by the Instructor

- **Procedure:**
  - Use Ohm's law to analyze Circuits 1 - 6. Measure and record the quantities in the white cells of Table 1 then using Ohm's Law, calculate the unknown quantities of the shaded cells. You're your calculations in the text box.
  - Copy the calculated quantities from Table 1 into the shaded cells in Table 2.
  - Measure those unknown quantities using a DMM and compare with the calculated values.
  - Determine the differences in Table 2.

- **Results:**

Ohm's Law Calculated			
Circuit	Voltage in Volts	Resistance in Ohms	Current in A
1			
2			
3			
4			
5			
6			

Table 1

Ohm's Law Measured				
Circuit	Unknown Quantity	Calculated	Measured	Difference
1	Voltage			
2	Resistance			
3	Current			
4	Voltage			
5	Resistance			
6	Current			

Table 2

Show calculations:

1.

2.

3.

4.

5.

6.

- **Conclusions:**

- **Challenges:**
    - Design a voltage source where the single load resistance is 100 ohms and the current through the resistor is 50 mA.

Power Systems 1 Lab 1 Circuit Values

Circuit	Voltage In volts	Current In amps	Resistor In ohms	Power In watts
1	1.5	32 mA	47	.25
2	3.0	300 mA	10	10
3	3.0	14 mA	220	.25
4	6.0	40 mA	150	.25
5	9.0	7 mA	1200	.25
6	12.0	21 mA	560	.25
7	12.0	54 mA	220	10

Cornerstone Electronics Technology and Robotics III
Power Systems 1 Lab 2 – Drawing Schematics

- **Purpose:** The purpose of this lab is to have the student practice drawing schematics.

- **Apparatus and Materials:**

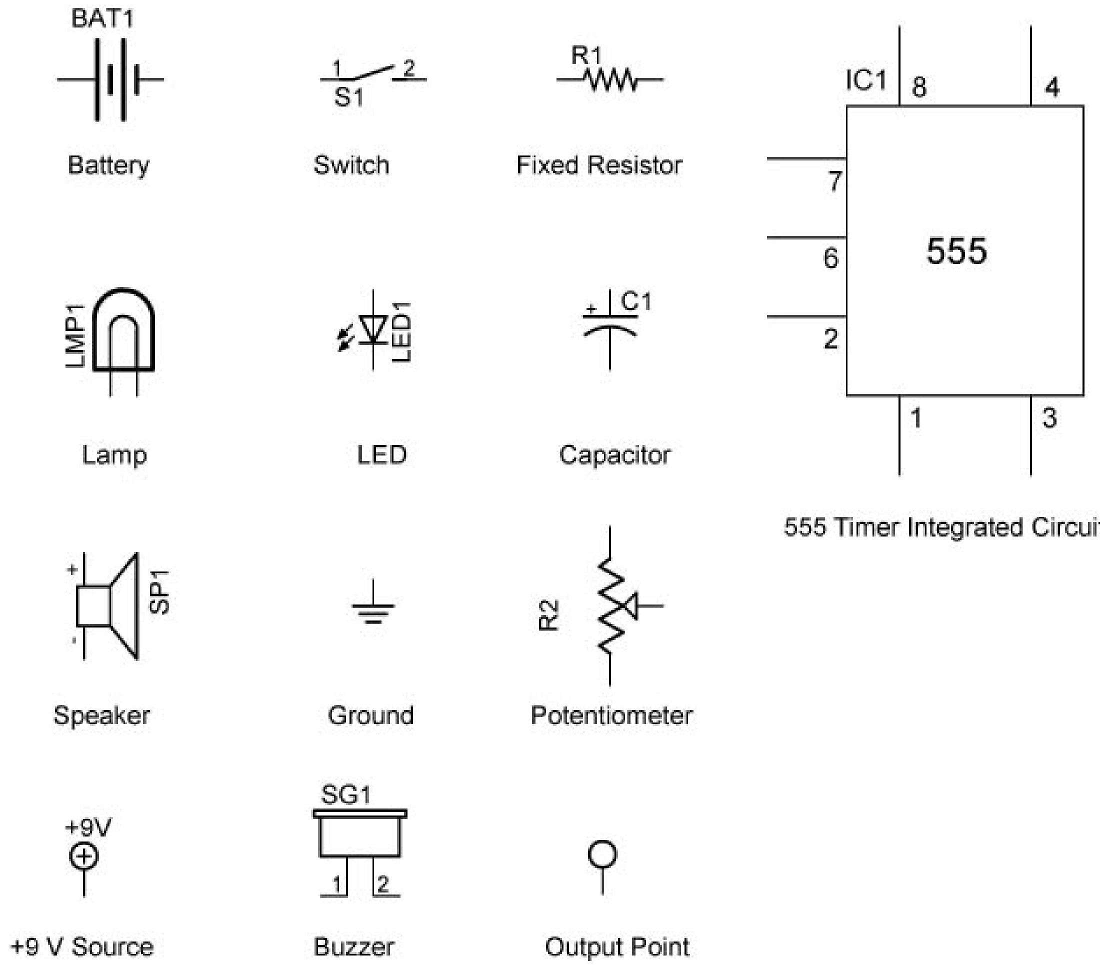
    - 1 – Digital Multimeter
    - 7 Circuits Provided by the Instructor

- **Procedure:**
    - Draw schematics for the 7 circuits displayed.
        - In Circuit 6, measure the voltage between Point A and ground. Compare it to the source voltage.

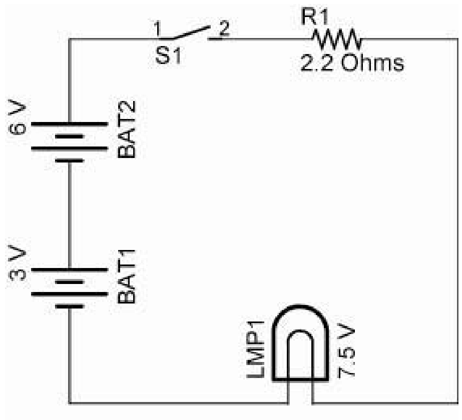
          Source Voltage = ____________________________

          Point A to GND = ____________________________

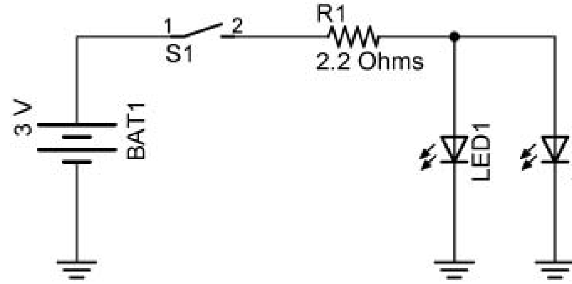
        - Use the integrated circuit (IC1) below when drawing Circuit 4, the electronic cricket.
    - Component Symbols Needed:


BAT1
Battery
1
2
S1
Switch
R1
Fixed Resistor
IC1
8
4
7
6
2
1
3
555
555 Timer Integrated Circuit
LMP1
Lamp
LED1
LED
+
C1
Capacitor
+
-
SP1
Speaker
Ground
R2
Potentiometer
+9V
+9 V Source
SG1
1
2
Buzzer
Output Point

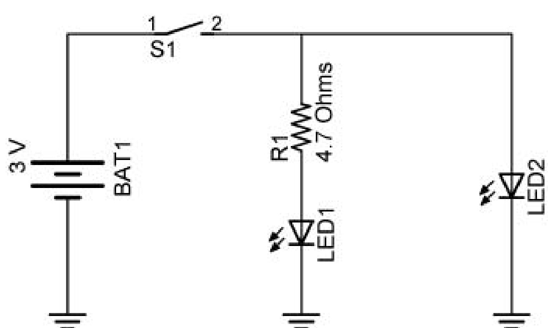
Seven Lab Circuits Used for Schematic Deawings



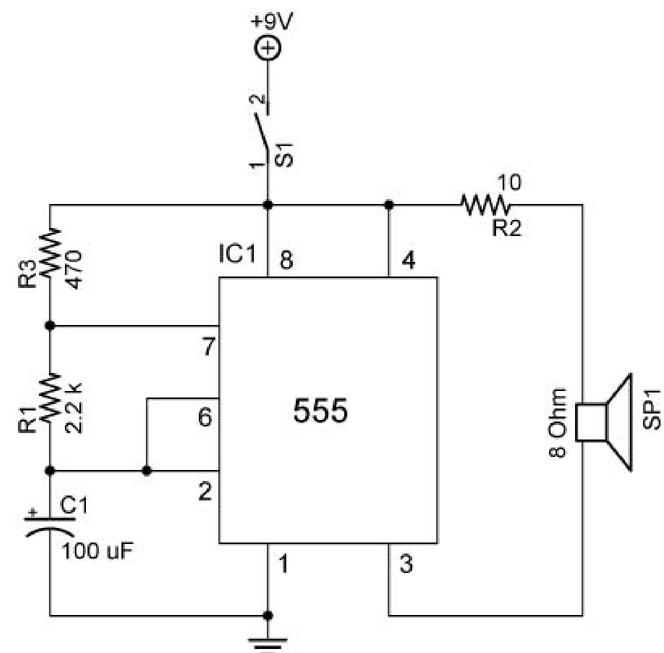
Circuit 1



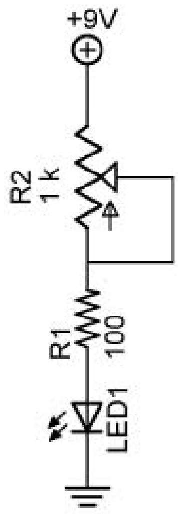
Circuit 2



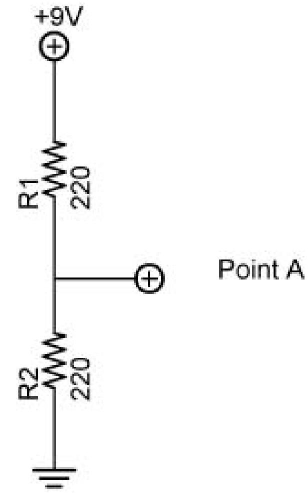
Circuit 3



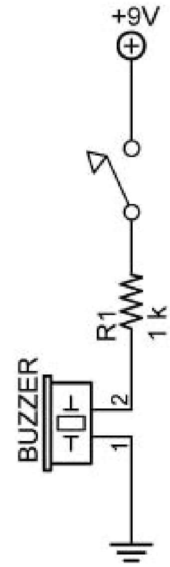
Circuit 4



Circuit 5



Circuit 6



Circuit 7