# Terminology and Definitions

## English Units

English units are difficult to use since there is no standard unit. For example, to measure length, you could use[1]:

| | | |
|---|---|---|
| Inch | 1" | The length of one digit. |
| Hand | 4" | Width of your palm. Used to measure the height of horses. |
| Foot | 12" | Length of a foot. |
| Cubit | 18" | From fingertips to elbow |
| Yard | 36" | Distance from your nose to finger tip |
| Ell | 45" | From fingertip of outstretched arm to opposite shoulder. Used for cloth. |
| Fathom | 6' | Distance fingertip to fingertip arms outstretched. Depth of water. |
| Rod | 16.5' | Used for surveying |
| Chain | 66' | Also used in surveying |
| Furlong | 660' | The distance a plough team can go without rest |
| Mile | 5280' | 8 furlongs |
| League | 3 miles | The distance you walk in an hour |

These definitions are not precise - so it causes problems when trading between cities. It's also difficult to compare items in English units. For example, which is more:

- A person who is 5'10",
- A horse which is 20 1/2 hands, or
- A pond which is 1 fathom deep?

## SI Units

Metric (or SI: System International) uses standard unit for everything (unless you are a chemistry major). [2]

| Name | Symbol | Parameter | Definition |
|---|---|---|---|
| Meter | m | length | Distance light travels in a vacuum |
| kilogram | kg | mass | mass of a the standard kilogram in Paris |
| second | s | time | Oscillations of a $Cs_{133}$ atom |
| Coulomb | Q | charge | 6.02E23 electrons |
| Kelvin | K | temperature | 0K = -273 Celsius |
| radian | | angle | 180/pi degrees |

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[1] from www.Wikipedia.com

[2] http://en.wikipedia.org/wiki/SI_units

## Derived Units:

| Name | Symbol | Parameter | Units |
|---|---|---|---|
| Newton | N | Force | kg m / $s^2$ |
| Joule | J | Energy | Force * distance = kg $m^2$ / $s^2$ |
| Watt | W | Power | Joule / second = kg $m^2$ / $s^3$ |
| Amp | A | current | Q / s |
| Volt | V | Electric potential | Watts / Amp |
| Ohm | Ω | Electrical resistance | Volts / Amp |
| Farad | F | Capacitance | $Q^2$ $s^2$ / kg $m^2$ = Coulomb / Volt |
| Henry | H | Inductance | kg $m^2$ / $Q^2$ = Joules / $Amp^2$ |

| Prefix | Symbol | Multiplier | Comments |
|---|---|---|---|
| Giga | G | $10^9$ | |
| Mega | M | $10^6$ | |
| kilo | k | $10^3$ | |
| milli | m | $10^{-3}$ | |
| micro | u | 10-6 | |
| nano | n | 10-9 | |
| pico | p | 10-12 | |
| | | | |

One nice feature of using metric units is even if you don't know the equation, you can usually get the right answer by getting the units to match up. For example, solve the following problem:

Determine the resistance of 100 meters of copper wire which has a cross sectional area of 1mm2. The conductivity of copper is

$$\rho = 1.68 \cdot 10^{-8} \Omega m$$

Solution: Even if you don't know what conductivity is, you can get the right equation.

You have

- $\rho = 1.68 \cdot 10^{-8} \Omega m$ conductivity
- $L = 100m$ length
- $A = 10^{-6} m^2$ cross sectional area

To get Ohms, multiply

$$R = \frac{\rho L}{A} = \frac{(\Omega m)(m)}{\left(m^2\right)} = \Omega$$

$$R = \frac{\left(1.68 \cdot 10^{-8} \Omega m\right)(100m)}{10^{-6} m^2} = 1.68\Omega$$

# Voltage / Current / Power:

**Protons:** Part of the nucleus of an atom. Protons do not move and are bound in place by chemical bonds.

**Electrons:** Part particle, part wave. Electrons are negatively charged particles which are locked in place in insulators and free to move in conductors. Note that current was discovered before electrons. The definition of positive current flow was somewhat arbitrary at that point. They got it wrong. (The direction of current flow is opposite of the direction of electron flow.)

**Current:** The flow of electrons. $1A = 6.02 * 10^{23}$ electrons per second.

**Voltage:** The force that causes current to flow, or, the energy released when current flows.

1 Amp of current flowing across 1 Volt produces 1 Joule.

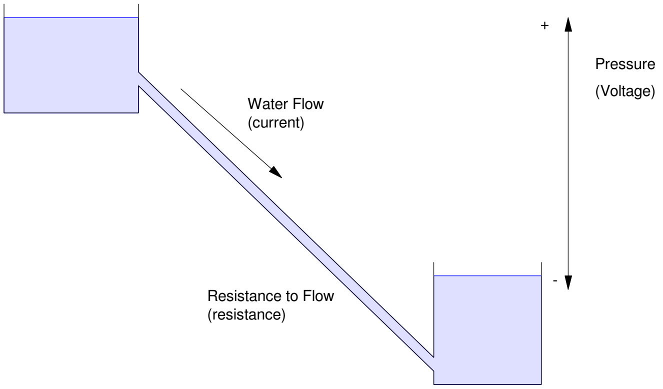
**Resistance:** The resistance to current flow.

$V = I R$

1 Volt = 1 Amp flowing across 1 Ohm

An analogy which is often used is water flowing downhill.

- The pressure (or distance) the water flows downhill corresponds to voltage
- The actual flow of water corresponds to current
- The pipe which limits the flow of the water is resistance.



Note that for current to flow, there must be an inlet and an outlet (water in equals water out). The same holds for current.

**Electrons (current) can neither be created nor destroyed. They can only be pushed around.**

If you have a wire with only one end connected to a circuit, you know right away that the current is zero. The voltage can be anything - just the current is zero.

## Power (Watts) and Energy (Joules):

Energy is a fundamental property in a system. Unless you are creating matter, energy is always conserved. Many techniques in engineering use this property: if you understand how the energy in the system is moving around, you've gone a long way in understanding the system.

There are several types of energy:

Thermal energy: The energy required to raise one CC of water one degree Celsius is 4.18 Joules

$E = C \cdot m \cdot T$ C = specific heat

Potential Energy: The energy required to lift 1 kg 1 meter is 9.8 Joules

$$PE = mgh$$

Kinetic Energy: The energy required to accelerate 1 kg of mass up to 1 m/s is 1/2 kg

$$KE = \frac{1}{2}mv^2$$

Electric Energy: The energy released when moving 1 Coulomb of electrons across 1 Volt - or - the energy released when 1 Amp of current flows across 1 Volt for one second

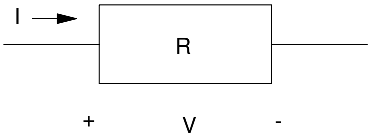
$$w = \int v \cdot i \cdot dt$$

Power is the instantaneous rate of energy release

$$p = \frac{dw}{dt} = v \cdot i$$

$$w = \int p \cdot dt$$

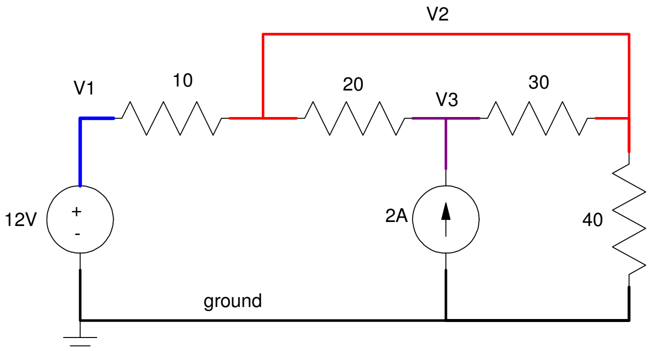
The notation used in electrical engineering is for current to flow into the + terminal for voltage. With this convention, positive energy is energy absorbed (you're producing heat or charging a battery for example.) Negative energy is energy produced (typically by a battery driving a circuit).



# Circuit Notation:

## Nodes:

A node is indicated by a solid line. It represents a wire (with a resistance of zero ideally). The voltage at any point on the wire is the same. The following circuit, for example, has four voltage nodes including ground.



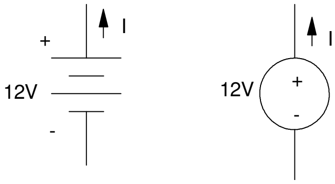
## Ground:

Ground is a voltage node which all other voltages are referenced to. Usually, ground is the same as earth ground - it doesn't have to be, however. Birds sitting on a high-voltage line, for example, treat the 13kV line as their ground reference.

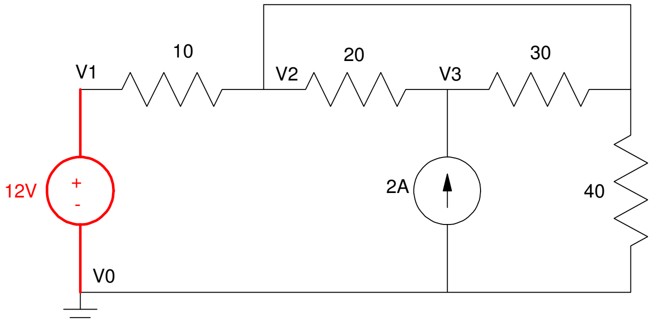
The symbol for ground is one of the following. If both are used in a circuit, it means that there are two reference voltages - which may be different. This can be important: if a person on the ground uses earth as his/her ground reference while a bird on the high-voltage line uses 13kV as her ground reference, everyone is OK as long as you keep the two grounds separate. If you connect the two, however, the bird goes poof.

## Independent Sources

**Voltage:** Voltage sources are like batteries. The voltage is fixed. The current is whatever it takes to hold the voltage (and depends upon what you're connecting the battery to.) If there is no load, the current is zero.



For example, in the following circuit, the voltage source forces $V_1 - V_0 = 12V$.



Voltages can be positive or negative. Since ground is somewhat arbitrary (think of birds sitting on a high-votlage line), assume for the moment that you're dealing with pressure (the mechanical dual of voltage.) Let 1atm represent a reference pressure (ground).

- If you have a box with 3atm pressure connected to the outside air with a straw, it tries to push air out through the straw (positive voltage)
- If the box has a pure vacuum, however, it tries to suck air into the box (negative voltage).

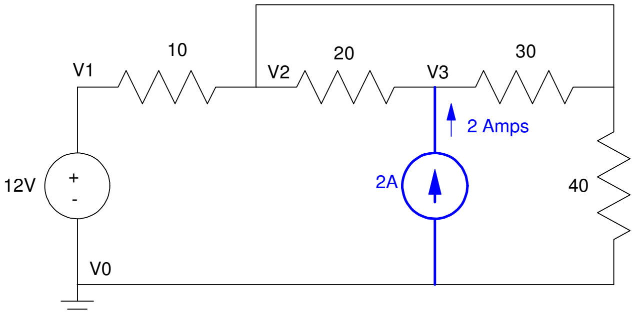
For the above circuit +12V or -12V depends upon how you connect the 12V battery.

Note that with voltage sources you cannot short the + and - terminals. This creates a conflict:

- The voltage source tries to hold the voltage at +12V
- The wire shorting out the source tries to hold the voltage at zero.

Whichever one has the higher current capacity wins.

**Current:** Current sources have the symbol shown in bold blue below. This source forces the current in the wire to be 2 Amps. The voltage at V3 is whatever it takes to maintain the 2 Amps of current. It will take some computations to find it.



Current Source: The current in the bold wire is forced to be 2A

## Dependent Sources:

A diamond indicates a controlled voltage source or a controlled current source.

Controlled sources arise from various components covered in ECE 321 Electronics

- Operational Amplifiers (voltage controlled voltage source)
- Transistors (current controlled current source)
- MOSFET (voltage controlled current source)

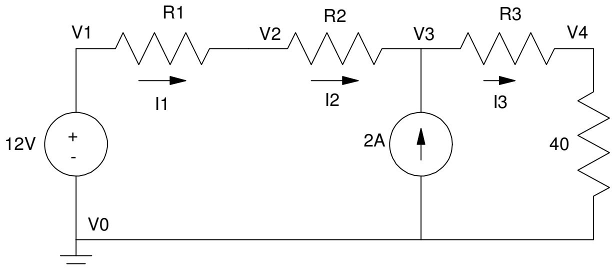
For this class, just treat them as a device.

## Passive Devices

Resistance: A resistor limits current flow. It's symbol is a zig-zag line and has the relationship of

$$V = IR$$

where current flows from + to -. For example, in the following circuit:



$$I_1 R_1 = V_1 - V_2$$

$$I_2 R_2 = V_2 - V_3$$

$$I_3 R_3 = V_3 - V_4$$

## Power:

Power (Watts) is volts times amps:

$$P = VI$$

Since V = IR, power can also be

$$P = \frac{V^2}{R}$$

$$P = I^2 R$$

In theory, all three equations are identical. Current is the physical motion of electrons, however, so the latter best reflects what creates heat (power loss) in a device.

## Volt Meters - Ammeters - Ohm Meters

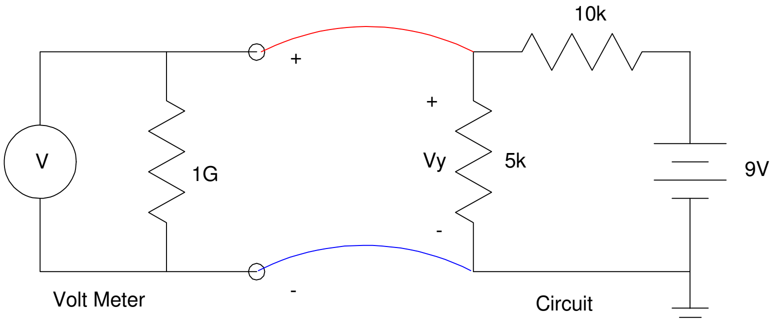
To measure voltage, current, and resistance, a multimeter is used with three settings.

**Volt Meter:** Volt meters are usually digital - meaning there is a microcontroller built in. The microcontroller has a high input impedance (typically 100MΩ or more). To measure a voltage, place the two probes across what you're trying to measure.

Voltage measurements are polarized. If you switch the leads, you get the opposite voltage (i.e. a 9V battery will read -9V).

To use a volt meter, connect the meter in parallel with what you are trying to measure, with the red (+) terminal goes to the + side.

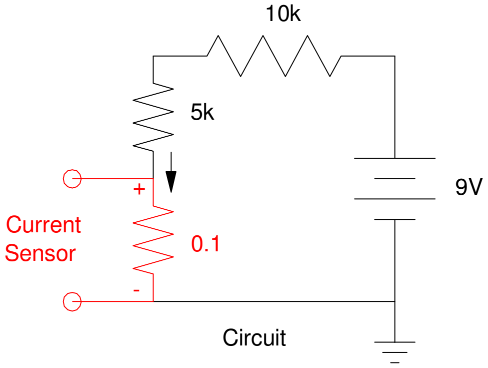
Note that if you connect a volt meter incorrectly (i.e. in series), you stop all current flow due to the high impedance. Nothing breaks, you just end up measuring the voltage of the source (rather than the voltage across the 5k resistor).



**Ammeters:** Ammeters measure current. The way they do this is they place a small resistance (0.1 Ohm typical) in series with a circuit and then measure the voltage across that resistor.

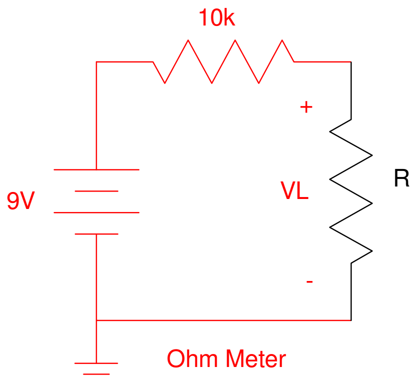
Current sensors are placed in series with the element you're trying to measure. This means:

- Current sensors are difficult to use. You have to be able to break open a circuit, inserting the sensor in series. This isn't always easy.
- Current sensors typically have blown fuses. If you (or someone before you) connect a current sensor in parallel by accident, you've shorted out what you're trying to measure with 0.1 Ohm. The low resistance creates large current, typically blowing the fuse.



Current Sensors are placed in series and add a small resistance to the circuit.

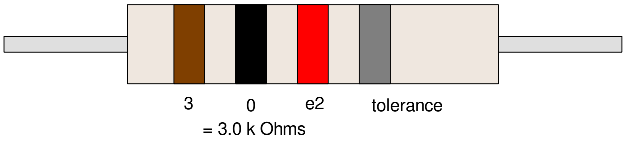
**Ohm Meters:** Unlike voltage sensors and current sensors, ohm meters are active devices. To measure resistance, a small current is sent to the load. The resulting voltage drop is then used to compute the resistance. To get the most accurate reading, the resistance in the ohm-meter (the 10k shown below) should be close to the load resistance. Likewise, ohm-meters often times have different settings: these settings change the resistance placed in series with the load.



This means

- Ohm-meters cannot be used when the circuit is powered up. The power source will conflict with the test current the meter is using, creating erroneous readings.
- Ohm-meters are a little dangerous. If you try to measure the voltage or current produced by a firing cap, nothing happens. If you try to measure the resistance. the firing cap explodes.

## Resistor Color Code



Value

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

Tolerance

| Silver | Gold | Red | Brown | Green |
|---|---|---|---|---|
| +/- 10% | +/- 5% | +/- 2% | +/- 1% | +/- 0.5% |