ELECTRICAL ENGINEERING

A multimeter or a multitester, also known as a VOM, is an electronic measuring instrument that combines several measurement functions in one unit. A typical multimeter can measure voltage, current, and resistance. Analog multimeters use a microammeter with a moving pointer to display readings.

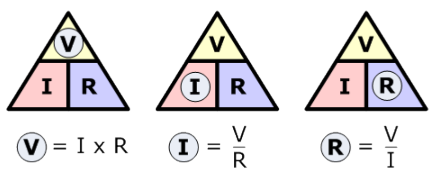
Electrical Charge

Electricity is the movement of electrons. Electrons create charge, which we can harness to do work. Your lightbulb, your stereo, your phone, etc., are all harnessing the movement of the electrons in order to do work. They all operate using the same basic power source: the movement of electrons.

The three basic principles for this tutorial can be explained using electrons, or more specifically, the charge they create:

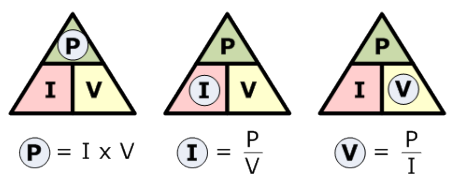
- **V = Voltage (volts)** is the difference in charge between two points.
- **I = Current (amps)** is the rate at which charge is flowing.
- **R = Resistance (ohms)** is a material's tendency to resist the flow of charge (current).

OHM's Law V=IR



To find the Power (P)

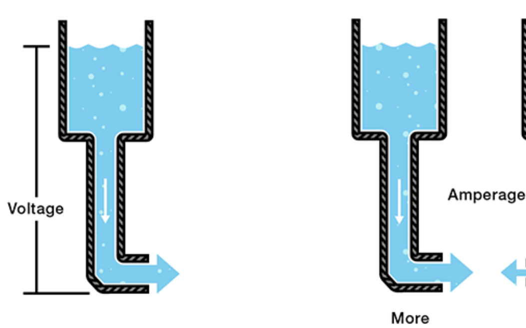
P =VxI P (watts) = V (volts) x I (amps)

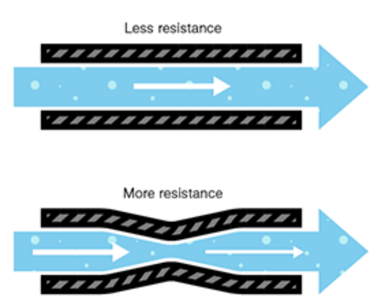


When describing voltage, current, and resistance, a common analogy is a water tank. In this analogy, charge is represented by the water *amount*, voltage is represented by the water *pressure*, and current is represented by the water *flow*. So for this analogy, remember:

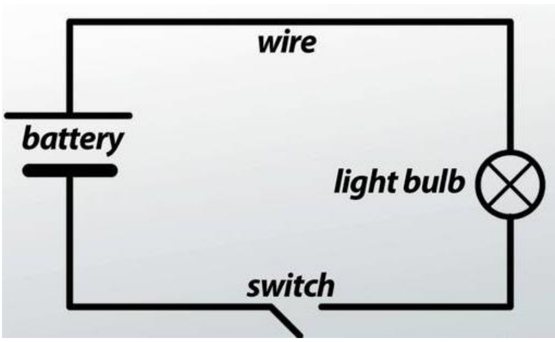
- Water = Charge
- Pressure = Voltage
- Flow = Current

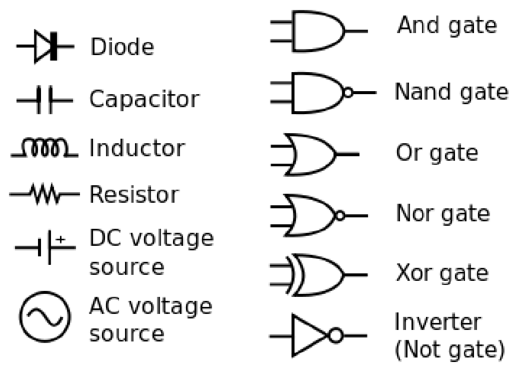
Consider a water tank at a certain height above the ground. At the bottom of this tank there is a hose.





Electrical schematics represent components with standard symbols, is helpful in troubleshooting a circuit, shows how components are interconnected

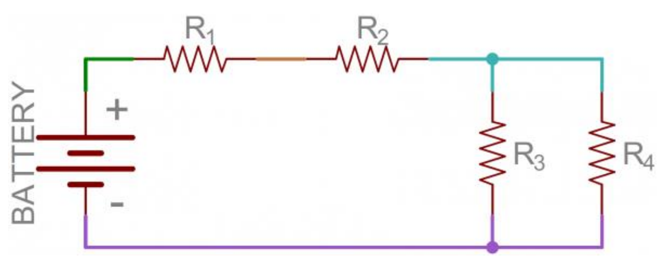




Series Circuits

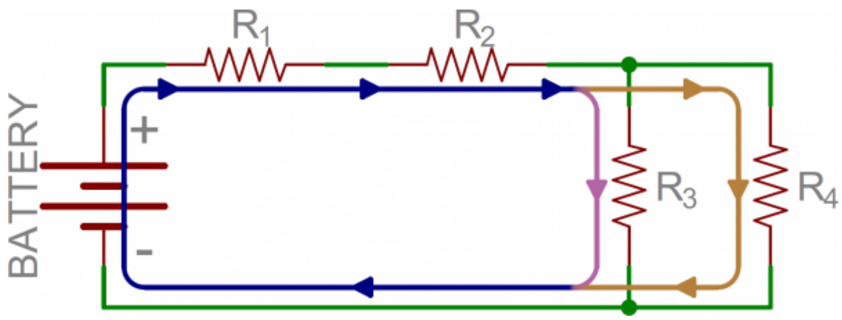
Nodes and Current Flow

Before we get too deep into this, we need to mention what a **node** is. It's nothing fancy, just the electrical junction between two or more components. When a circuit is modeled on a schematic, the nodes are the wires between components.



Example schematic with four uniquely colored nodes.

That's half the battle towards understanding the difference between series and parallel. We also need to understand **how current flows** through a circuit. Current flows from a high voltage to a lower voltage in a circuit. Some amount of current will flow through every path it can take to get to the point of lowest voltage (usually called ground). Using the above circuit as an example, here's how current would flow as it runs from the battery's positive terminal to the negative:



Current (indicated by the blue, orange, and pink lines) flowing through the same example circuit as above. Different currents are indicated by different colors.

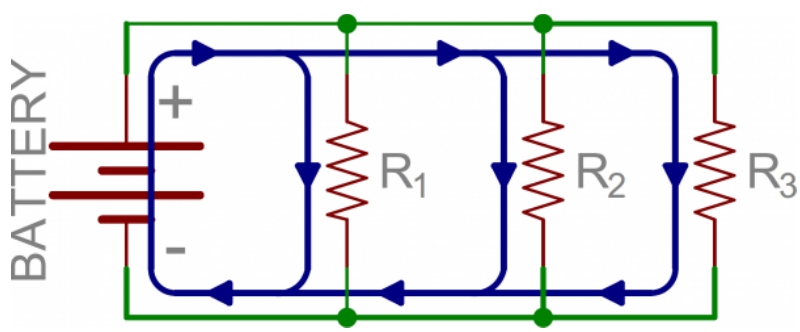
Notice that in some nodes (like between R_1 and R_2) the current is the same going in as at is coming out. At other nodes (specifically the three-way junction between R_2, R_3, and R_4) the main (blue) current splits into two different ones. *That's* the key difference between series and parallel!

Series Circuits Defined

Two components are in series if they share a common node and if the **same current** flows through them. Here's an example circuit with three series resistors:

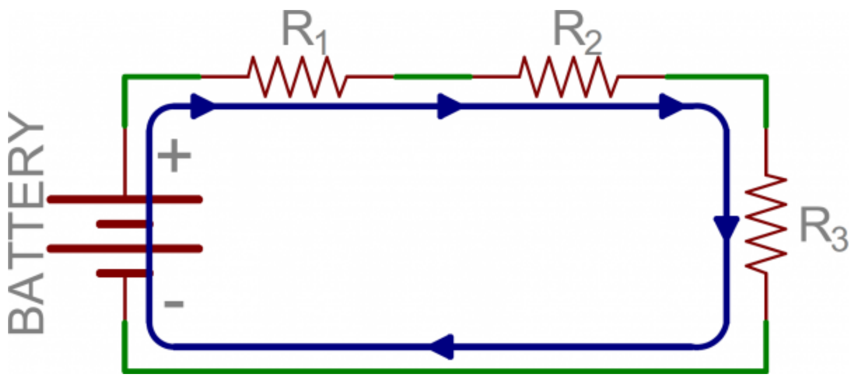
Parallel Circuits Defined

If components share *two* common nodes, they are in parallel. Here's an example schematic of three resistors in parallel with a battery:



From the positive battery terminal, current flows to R_1... and R_2, and R_3. The node that connects the battery to R_1 is also connected to the other resistors. The other ends of these resistors are similarly tied together, and then tied back to the negative terminal of the battery. There are three distinct paths that current can take before returning to the battery, and the associated resistors are said to be in parallel.

Where series components all have equal currents running through them, parallel components all have the same voltage drop across them -- series:current::parallel:voltage.



There's only one way for the current to flow in the above circuit. Starting from the positive terminal of the battery, current flow will first encounter R_1. From there the current will flow straight to R_2, then to R_3, and finally back to the negative terminal of the battery. Note that there is only one path for current to follow. These components are in series.

SERIES CIRCUITS:

Resistances in series add up.

$R_T = R_1 + R_2 + R_3$

Current in series is Constant

$I_T = I_1 = I_2 = I_3$

Voltage in series adds up

$V_T = V_1 + V_2 + V_3$

PARALLEL CIRCUITS:

Resistances in parallel .

$1/R_T = 1/R_1 + 1/R_2 + 1/R_3$

Current in parallel adds up

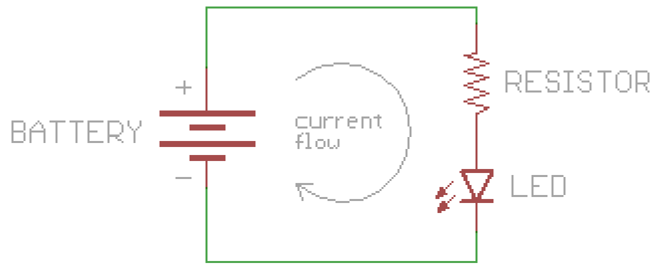
$I_T = I_1 += I_2 + I_3$

Voltage in parallel remains constant

$V_T = V_1 = V_2 = V_3$

The Simplest Circuit

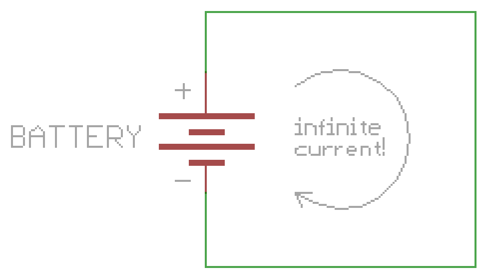
We're finally ready to make electricity work for us! If we connect the positive side of a voltage source, through something that does some work such as a Light Emitting Diode (LED), and back to the negative side of the voltage source; electricity, or **current**, will flow. And we can put things in the path that do useful things when current flows through them, like LEDs that light up.



This circular path, which is always required to get electricity to flow and do something useful, is called a circuit.A circuit is a path that starts and stops at the same place, which is exactly what we're doing.

Short Circuit

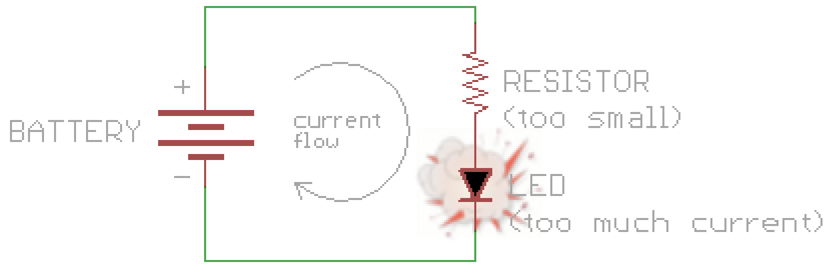
DON'T DO THIS, but if you connect a wire directly from the positive to the negative side of a power supply, you'll create what is called a **short circuit**. This is a very bad idea.



This seems like the best possible circuit, so why is it a bad idea? Remember that electrical current wants to flow from a higher voltage to a lower voltage, and if you put a load into the current, you can do something useful like light up an LED.

If you DO have a load in the current, the current flow through your circuit will be limited to that which your device consumes, which is usually a very small amount. However, if you DON'T put anything in to restrict the current flow, there won't be anything to slow down the current, and it will try to be infinite!

Your power supply can't provide infinite current, but it will provide as much as it can, which may be a lot. This could cause your wire to burn up, damage the power supply, drain your battery, or other exciting things. Most of the time your power supply will have some sort of safety mechanism built into it to limit the maximum current in the event of a short circuit, but not always. This is the reason all homes and buildings have circuit breakers, to prevent fires from starting in the event of a short circuit somewhere in the wiring.



A closely related problem is accidentally letting too much current flow through part of your circuit, causing a part to burn up. This isn't quite a short circuit, but it's close. This most often happens when you use the incorrect **resistor** value, which lets too much current flow through another component such as an LED.

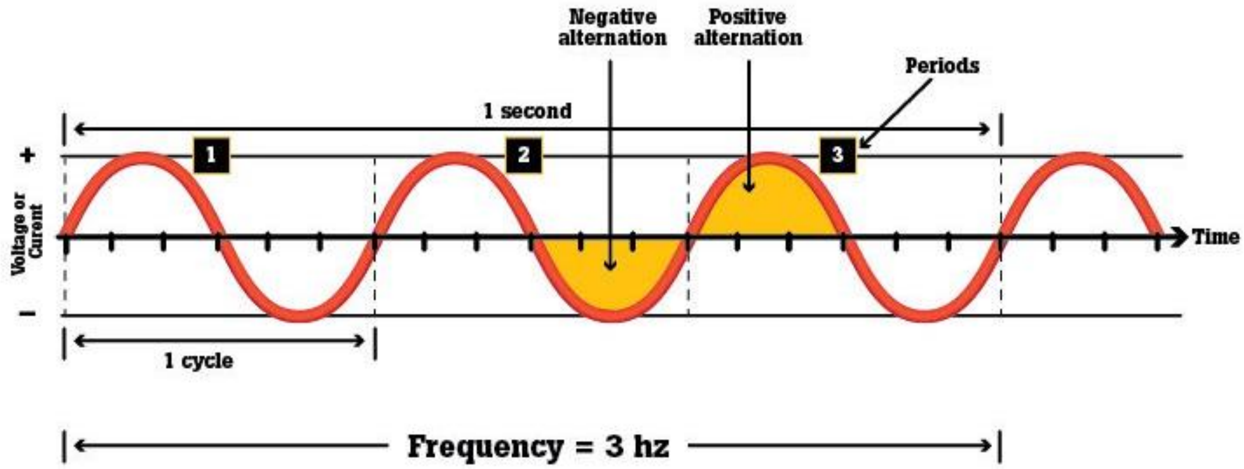
The bottom line: **if you notice that things are suddenly becoming hot or a part suddenly burns out, immediately turn off the power and look for possible short circuits.**

AC **frequency** is the number of cycles per second in an alternating current (ac) sine wave.

Said another way, frequency is **the rate at which current changes direction per second**. It is measured in hertz (Hz), an international unit of measure where 1 hertz is equal to 1 cycle per second.

At its most basic, frequency is how often something repeats. In the case of electrical current, frequency is **the number of times a sine wave repeats, or completes, a positive-to-negative cycle**.

Example: If an alternating current is said to have a frequency of 5 Hz (see diagram below), that indicates its waveform repeats 5 times in 1 second.



The more cycles that occur per second, the higher the frequency.

The following is some of the terminology of frequency:

Hertz (Hz): One hertz is equal to one cycle per second.
Cycle: One complete wave of alternating current or voltage.
Alternation: One half of a cycle.
Period: The time required to produce one complete cycle of a waveform.

Frequency is typically used to describe electrical equipment operation. Below are some common frequency ranges:

- Power line frequency (normally 50 Hz or 60 Hz).
- Variable-frequency drives, which normally use a 1-20 kilohertz (kHz) carrier frequency.
- Audio frequency: 15 Hz to 20 kHz (the range of human hearing).
- Radio frequency: 30-300 kHz.
- Low frequency: 300 kHz to 3 megahertz (MHz).
- Medium frequency: 3-30 MHz.
- High frequency: 30-300 MHz.

Circuits and equipment are often designed to operate at a fixed or variable frequency.

Equipment designed to operate at a fixed frequency performs abnormally if operated at a different frequency than specified.

Example: An ac motor designed to operate at 60 Hz runs slower if the frequency drops below 60 Hz, faster if it exceeds 60 Hz.

For ac motors, any change in frequency causes a proportional change in motor speed.

Example: A 5% reduction in frequency produces a 5% reduction in motor speed.

A digital multimeter (DMM) that includes a Frequency Counter mode can measure the frequency of alternating current signals. A DMM may also offer these modes:

- **MIN/MAX Recording:** Permits frequency measurements to be recorded:
    1. over a specific time period;
    2. the same way voltage, current or resistance measurements are recorded.
- **Autorange:** Automatically selects the frequency range (unless the measured voltage is outside the frequency measurement range).

Power grids vary by nation. In the United States, the grid is based on a highly stable 60-hertz signal, meaning it cycles 60 times per second.

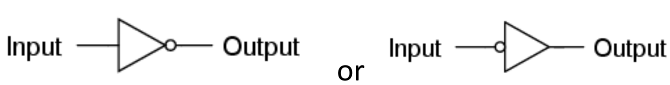
In the U.S., household electrical power is based on a single-phase, 120-volt AC power supply. Power measured at a wall outlet in a U.S. home will yield sine waves that oscillate between 170 and minus-170 volts, with the true-rms voltage measuring at 120 volts. The rate of oscillation will be 60 cycles per second.

Logic Gates and Truth Tables

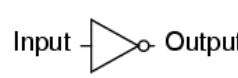
We often apply the concept of binary bits to circuits. A binary bit can only have one of two different values, either 0 or 1. Electronic circuits are physical systems that lend themselves well to the representation of binary numbers. A voltage signal measured at the output of such a circuit may also serve as a representation of a single bit, a low voltage representing a binary "0" and a (relatively) high voltage representing a binary "1."

An *inverter*, or NOT gate, because it outputs the exact opposite digital signal as what is input.

Inverter, or NOT gate



NOT gate truth table

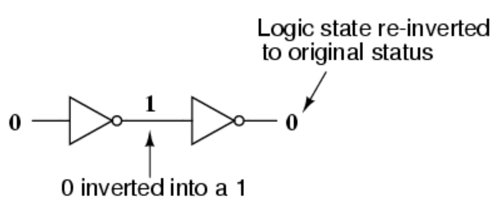


Input	Output
0	1
1	0

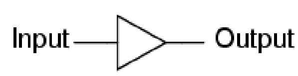
The "buffer" gate

If we were to connect two inverter gates together so that the output of one fed into the input of another, the two inversion functions would "cancel" each other out so that there would be no inversion from input to final output:

Double inversion



"Buffer" gate

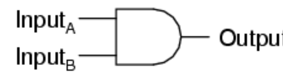


Input	Output
0	0
1	1

The AND gate

One of the easiest multiple-input gates to understand is the AND gate, so-called because the output of this gate will be "high" (1) if and only if *all* inputs (first input *and* the second input *and* . . .) are "high" (1). If any input(s) are "low" (0), the output is guaranteed to be in a "low" state as well.

2-input AND gate

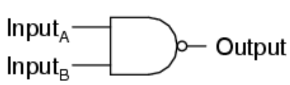


A	B	Output
0	0	0
0	1	0
1	0	0
1	1	1

The NAND gate

A variation on the idea of the AND gate is called the NAND gate. The word "NAND" is a verbal contraction of the words NOT and AND. Essentially, a NAND gate behaves the same as an AND gate with a NOT (inverter) gate connected to the output terminal. To symbolize this output signal inversion, the NAND gate symbol has a bubble on the output line. The truth table for a NAND gate is as one might expect, exactly opposite as that of an AND

2-input NAND gate



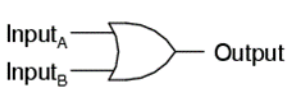
Equivalent gate circuit

A	B	Output
0	0	1
0	1	1
1	0	1
1	1	0

The OR gate

Our next gate to investigate is the OR gate, so-called because the output of this gate will be "high" (1) if *any* of the inputs (first input *or* the second input *or* . . .) are "high" (1). The output of an OR gate goes "low" (0) if and only if all inputs are "low" (0).

2-input OR gate

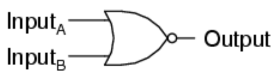


A	B	Output
0	0	0
0	1	1
1	0	1
1	1	1

The NOR gate

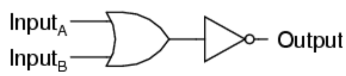
As you might have suspected, the NOR gate is an OR gate with its output inverted, just like a NAND gate is an AND gate with an inverted output

2-input NOR gate

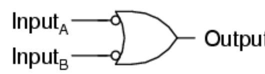


A	B	Output
0	0	1
0	1	0
1	0	0
1	1	0

Equivalent gate circuit

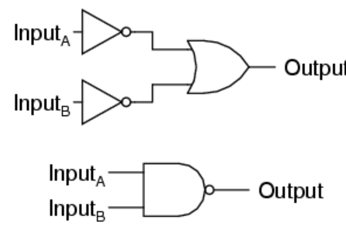


2-input Negative-OR gate



A	B	Output
0	0	1
0	1	1
1	0	1
1	1	0

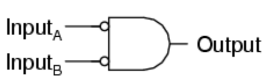
Equivalent gate circuits



The Negative-AND gate

A Negative-AND gate functions the same as an AND gate with all its inputs inverted (connected through NOT gates). In keeping with standard gate symbol convention, these inverted inputs are signified by bubbles. Contrary to most peoples' first instinct, the logical behavior of a Negative-AND gate is *not* the same as a NAND gate. Its truth table, actually, is identical to a NOR gate:

2-input Negative-AND gate



A	B	Output
0	0	1
0	1	0
1	0	0
1	1	0

Equivalent gate circuits