RoboJackets Electrical Training – Informational Sheet

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Electricity

Electricity is, as defined by Wikipedia:

> [A] set of physical phenomena associated with the **presence** and **motion** of **electric charge**

Electric Charge

Electric **Charge** is a physical property of particles, it can be either positive or negative. Charges carried by electrons are negative and protons/nuclei are positive. Particles with the same charge repel each other and particles of opposite charges attract each other.

Voltage

Voltage is the driving force for most, if not all, electrical applications. It is an **electric field potential difference**. Charged particles naturally move from higher potential to lower potential. The value of voltage does not necessarily matter: current may flow from 5V to 3.3V and also from -5V to -12V. **Charged particles always tend to move if there is a potential difference in place.**

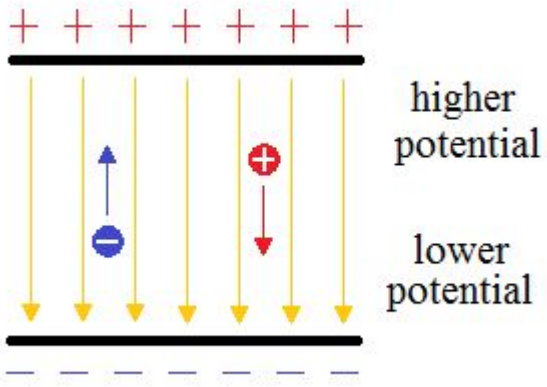


Figure 1. Demo of electric potential.

Current

Net flow of charged particles is called current (*I*), measured in Amperes (A). By convention, the current direction is opposite to the direction of the particles flow. Current is usually induced by voltages and when there is no voltage, charged particles moves randomly thus there exists no current.

Resistance

Resistance is a measure of the difficulty for current to pass through a component, it is measured in Ohms (Ω). The resistance can be calculated by dividing V by I.

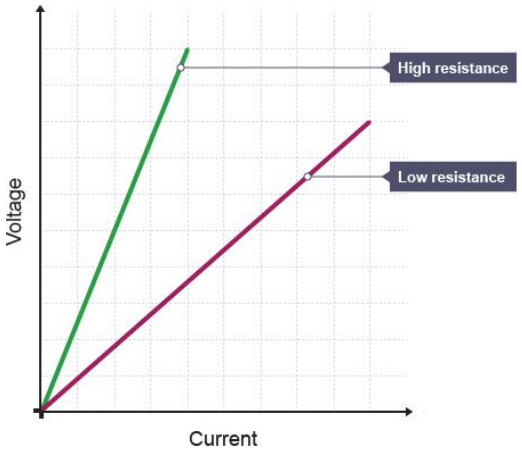


Figure 2. Example of voltage v. current plot showing resistance.

The current, voltage and resistance are linked by the formula V=RI.

A resistor is a passive (component that requires no energy to work) two-terminal electrical component that implements electrical resistance as a circuit element.

Application

Resistors are used to reduce current flow, adjust signal levels, divide voltage, etc.

The power dissipated by a resistor is calculated by P = $V \times I$, this may further expand to P = $V^2/R \; and \; P = I^2 \times R$. In fact, $P = V \times I$ applies to the power dissipation of nearly all electrical components.
The resistance of a wire is calculated with the formula $R = \rho \cdot l/A$ (p=resistivity of the material, l=length of the wire, A=cross sectional area of the wire).

if you are confused by current, voltage, and resistance; this is an analogy with water.

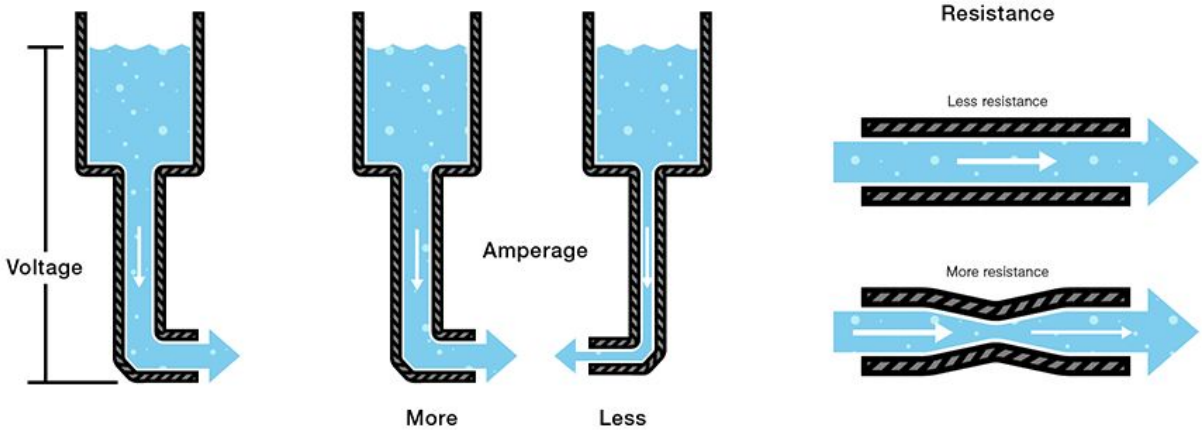


Figure 3. Water analogy for electricity

Imagine a pipe with water flowing. Electric charge is the water, voltage is the pressure of water through the pipe, and current is the flow of the water. Resistance would be the width of the tube at a specific point.

Capacitors

A capacitor is a passive two-terminal electrical component that stores potential energy in an electric field. The larger the capacitance, the more energy a capacitor can store and the longer it (dis)charges.

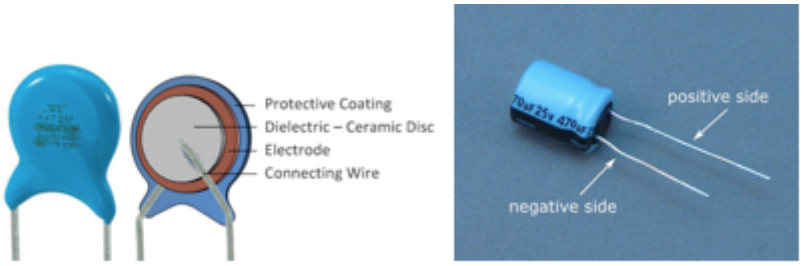


Figure 4. Ceramic (Left) and Electrolytic Capacitor (Right).

There are primarily two kinds of capacitors: Ceramic and Electrolytic. In our scope of application, we need to know that electrolytics easily obtain high capacitance values with low cost and electrolytic ones are usually much larger compared to ceramics, rendering most capacitors on PCBs (printed circuit board) to be ceramic. Electrolytic capacitors have polarity (they have an orientation on the board, see figure 4).

Capacitors act as energy sources when discharging, so they're often placed in parallel with voltage sources to maintain voltage levels during sudden load spikes or voltage source failures. This application is known as "decoupling capacitance"

Inductor

Also known as a coil, an inductor is a passive two-terminal electrical component that stores energy in a magnetic field when current flows through it. An Inductor can help smooth sudden current spikes in the circuit as it stores current temporarily. Thus, they are commonly placed in series with power supplies.

Inductors are also a primary component in electromechanical actuators such as relays (electromagnetically actuated switches), solenoids (electromagnetically actuated linear actuators) , and motors (electromagnetically actuated rotating actuators).

Diodes

A **diode** is a two-terminal electronic component that conducts current primarily in one direction. It has ideally zero resistance in one direction and infinite resistance in the other.

LED (Light emitting diode): When designing an LED circuit, one must consider the maximum current the diode can handle.To implement an LED to a circuit, an additional resistor is needed as otherwise the LED will burn down. Below is an example of LED circuit.

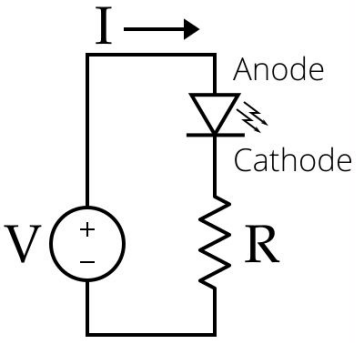


Figure 5. LED Circuit.

Value of R depends on the voltage applied and the type of LED.

Application:

Diodes have many applications for reverse polarity protection (preventing current from flowing if the circuit is plugged in backwards) and voltage source protection (preventing current from flowing from one source to another). LEDs are used for indication and signaling of status, power, or fault.
Most diodes have a maximum reverse voltage: the breakdown voltage. Any higher than this voltage, and the diode will break unless it is a zener diode, specifically designed to be reversible. This breakdown property is exploited in circuits which limit the voltage between two nodes by applying a zener diode of specified voltage between them.

FETS

Transistors are simple electronic switches. There are primarily two types of transistors: BJT (Bipolar junction transistor) and MOSFET (Metal oxide field-effect transistor). They typically have 3 terminals, the base being the 'controller'. There exist two types of BJT: NPN and PNP. NPN is normally OFF and conducts current when there is positive voltage at its base.PNP works in the exact opposite way (it is normally closed and stops conducting when the base voltage is high).

nFET and pFET MOSFETS work in a similar fashion to NPN and PNP respectively.

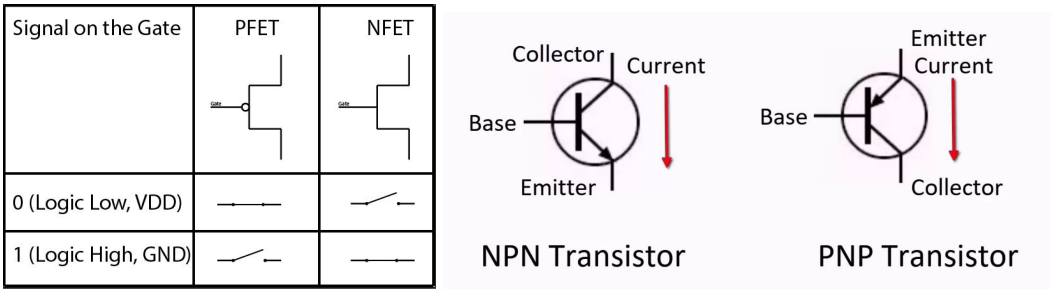


Figure 6. Sign and operation of MOSFET and BJT.

Note :

VDD (Voltage Drain Drain) is the power source of the system, the voltage.
GND (ground) is "the reference point in an electrical circuit from which voltages are measured, a common return path for electric current, or a direct physical connection to the earth" to cite wikipedia. In the case above, the first definition is used.

Application

In the scope of our application, 5V and 3.3V are usually the logical operating levels of printed circuit boards, 12V and 24V are usually the voltage level that power the robot. **Never directly** connect 5V directly to 0V. This is called a short circuit. 5V and 3.3V shorted will cause sparks and break your circuit, connecting 12V or 24V to 0V will cause major fire and explosion.

Transistors used between these two levels allows for a low voltage, low current circuit to control a high voltage, high current circuit.

Circuit analysis

A circuit with components in series has all of its components on the same “path” whereas a circuit with its components in parallel has all of its components on different “paths.”

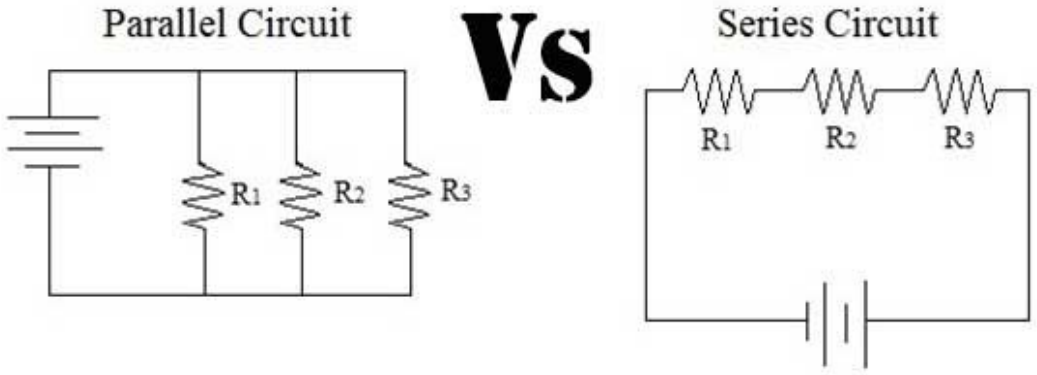


Figure 7. Example of components in parallel and in series.

Circuit components in series:

$$R_{total} = \Sigma R_i$$
$$C_{total} = 1/(\Sigma(1/C_i))$$
$$L_{total} = \Sigma L_i$$

Circuit components in parallel:

$$R_{total} = 1/(\Sigma(1/R_i))$$
$$C_{total} = \Sigma C_i$$
$$L_{total} = 1/(\Sigma(1/L_i))$$

Kirchhoff’s Law:

Kirchhoff's Current Law: Sum of current flowing into a node (or a junction) must be equal to the sum of current flowing out of it.
Kirchhoff's Voltage Law: The algebraic sum of the voltage (potential) differences in any closed circuit must equal zero.

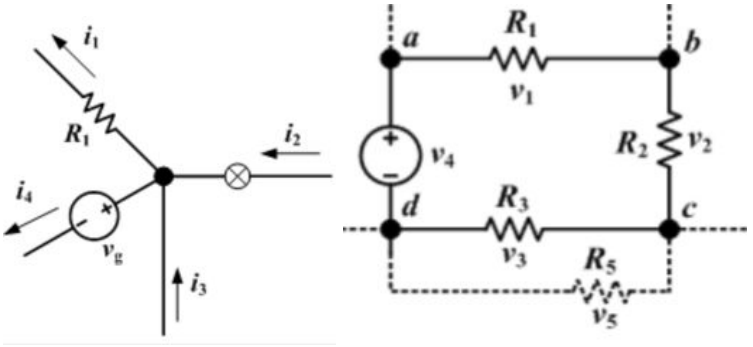


Figure 8. Kirchhoff's Law Demonstration.

As defined by Kirchhoff's law, in the left diagram $i_2 + i_3 = i_1 + i_4$; in the right figure, $v_1 + v_2 + v_3 + v_4 = 0$

Fuses

A fuse is a component that is designed to fail when there is too much current passing through it. When placed in series with your circuit, it is a safety device as it prevents over current.
Blown fuses alert you that there's excessive current, implying either:

1. A component is broken or operating in an unsafe region
2. The circuit must be redesigned taking into account maximum ratings

Breadboard

A breadboard (figure below) is a device allowing you to prototype circuits.

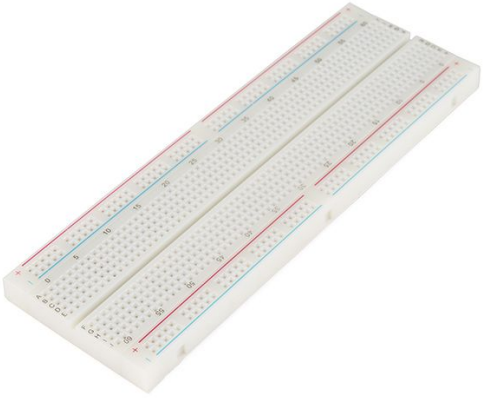


Figure 9. A breadboard

Basic Concepts

Must-know electrical concepts:

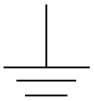
Table: Elementary Physical Quantities for Electricity

Physical Quantity and Symbol	Units	Equations
Charge (Q)	Coulomb (C)	$Q = It$
Current (I)	Ampere (A)	
Voltage (V)	Volt (V)	$V = E/Q$
Power (P)	Watt (W)	$P = E/t = V \cdot I$

Cathode: Terminal where current flows out.

Anode : Terminal where current flows in.

Basic Circuit Drawing

Component Name	Schematic	Definition
GND (ground)		the reference point in an electrical circuit from which voltages are measured, a common return path for electric current.
Resistor		implements electrical resistance as a circuit element.
Diode	 	A **diode** is a two-terminal electronic component that conducts current primarily in one direction. It has an anode and a cathode.
Capacitor		stores potential energy in an electric field.

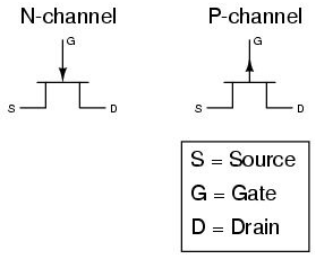
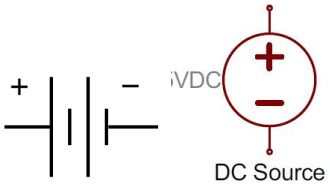
FET		electronic switches.
Inductor		stores energy in a magnetic field when current flows through it.
Power source		left drawing is a battery, right drawing is a direct current power source.

Figure 3: https://cdn.sparkfun.com/assets/learn_tutorials/1/9/3/water-analogy.png
Figure 7: https://www.ledsupply.com/blog/wiring-leds-correctly-series-parallel-circuits-explained/
Figure 8: https://www.sparkfun.com/products/12615