Lab 1

Basic Circuit Concepts

ENG 1450 Labs - General Info

In the ENG 1450 labs you will explore electric circuit concepts, and electric devices. You will also learn a little about the science and history of Electrical and Computer Engineering.

Students should form into groups of 4.

Students should bring the following supplies to each lab.

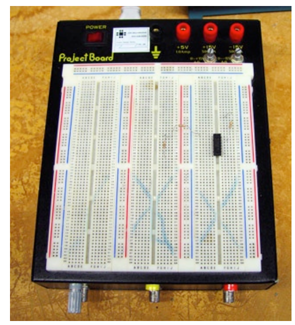
- A 30 cm ruler
- Scissors
- A roll of masking tape
- A scientific calculator

Introduction to Lab 1

In this lab you will explore electric voltage, current, and resistance, and learn about some of the people who discovered these concepts.

- You will build circuits with resistors connected in series and in parallel with each other.

- You will learn how to use a multimeter to measure electric voltage, current, and resistance.



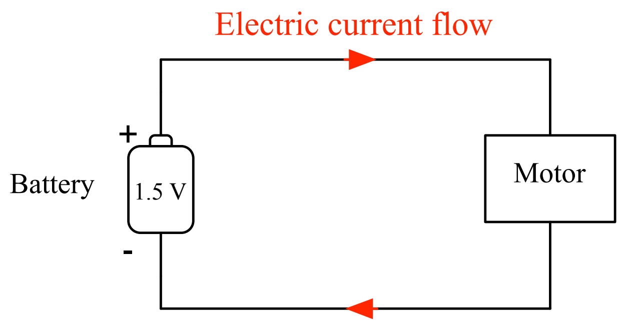
- You will learn how to use the project boards to connect your electric components and wires together.

An Electric Circuit

An Electric Circuit

An electric circuit is a network of electrical elements forming a closed loop.

- In the below circuit, ***electric current*** flows from the battery through the motor, and back to the battery.
- The ***voltage*** across the battery causes the electric current to flow.
- The amount of electric current that flows is limited by the ***resistance*** of the motor and all connecting wiring.



Electric Current

Electric current is the rate of flow of electric charge, which in a metal wire is carried by electrons.

- The SI unit of current is the ampere (or amp for short).
- Its symbol is: A

1 Ampere = 1 Coulomb / second

An electron has a charge equal to -1.602×10^{-19} Coulombs.

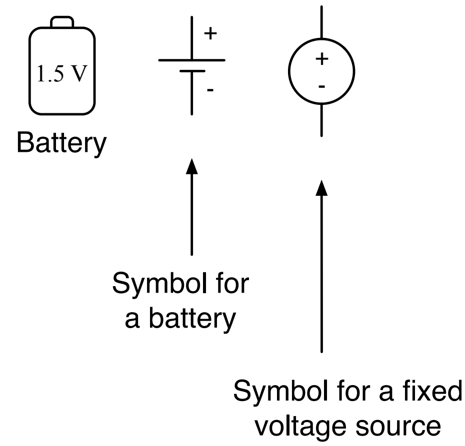
- Coulomb (C) is the SI unit of electric charge.
- This unit is named after the French physicist Charles-Augustine de Coulomb (1736-1806).

Voltage

The short name we commonly use to describe an electric potential difference is voltage.

- The SI unit for voltage is the volt.
- Its symbol is: V

1 Volt = 1 Joule / Coulomb



It is important to realize that voltage is the measure of the ***difference in electric potential between two points***.

- And so a voltage measurement at one point in an electric circuit is always made relative to another point.

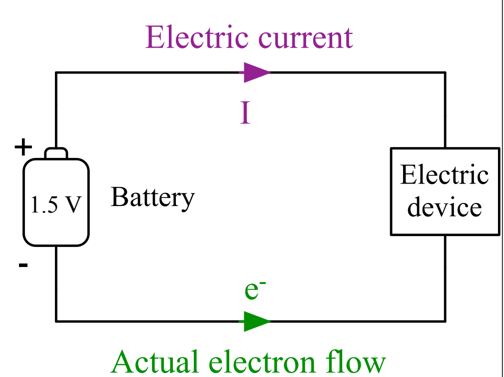
Direction of Electric Current Flow

Electric current is defined as the direction of flow of positive charge.

- Since electrons have a negative charge, electric current flows opposite to the actual electron flow.

Electrons flow towards higher electric potentials (voltages).

- Thus, electric current flows from higher voltages towards lower voltages.

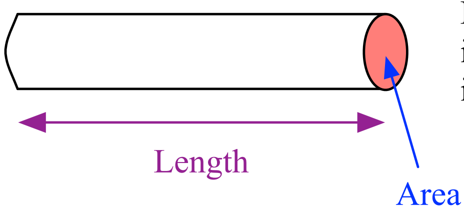


Electrical Resistance

Electrons don't flow freely in wires (unless the wire is made of superconducting material).

- The SI unit describing the resistance to electron flow is the ohm.
- Its symbol is: Ω

1 Ohm = 1 Volt / Ampere



In a simple cylindrical wire, the electrical resistance is proportional to the length of the wire, and inversely proportional to its cross-sectional area.

$$\text{Resistance} \propto \frac{\text{Length}}{\text{Area}}$$

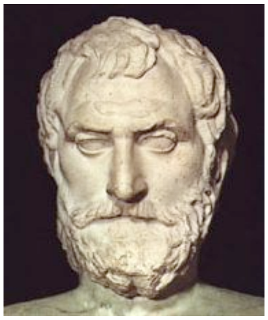
Electricity, Electron, Ohm, Volt, Ampere.

Where did these unit names come from?

Electricity In The Ancient World

People have known about "electric shocks" and static electricity for a long time.

- The ancient Greeks observed that when amber is rubbed with fur, it will attract small objects. They also noticed that if rubbed long enough, a spark could jump.



In 600 BC, Thales of Miletos (624 - 546 BC) theorized that rubbing the amber caused it to become magnetic.

- He wasn't completely correct. Today we now distinguish between attraction by electric force and magnetic force.

He was a philosopher, astronomer, and mathematician. Many consider him to be the first philosopher in the Greek tradition.

- He rejected mythological explanations, and defined general principles and set forth hypotheses. These ideas led the scientific and natural philosophy revolution in ancient Greece.

William Gilbert (1544 - 1603)

The William Gilbert was an English physician and natural philosopher. He studied static electricity and magnetism.

- He coined the word *electricus* from the Greek word for amber, *elektron*. From this came the English words electric and electricity.

He is famous for his work in magnetism.

- He concluded that the reason a compass needle points north is because the Earth was magnetic.
- His theory that the earth exerted a magnetic influence throughout the solar system was a precursor to the modern conception of gravity.

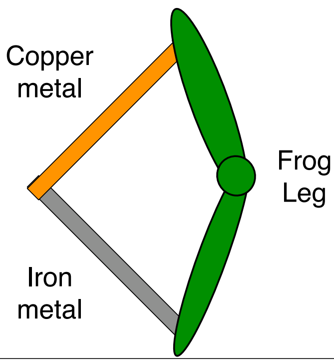
Luigi Galvani (1737 - 1798)

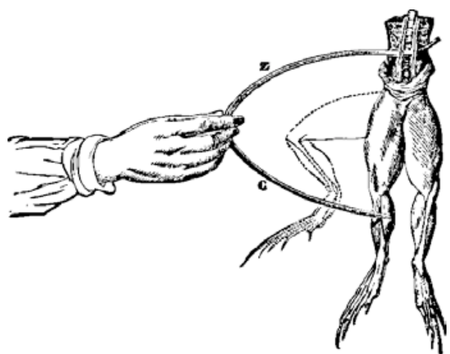
Luigi Galvani was an Italian physician and physicist.

- In 1786, he discovered that static electricity can animate the leg of a dissected frog.

He also discovered that if two different metals were connected together at one end, and then if their other ends touched the frog leg at the same time, they made the leg muscle contract.

- He thought there must be electric charge in muscle, and he called this “animal electricity”.





Picture source: http://butler.cc.tut.fi/~malmivuo/bem/bembook/01/01.htm

Alessandro Volta (1745 - 1827)

The Italian physicist Count Alessandro Giuseppe Antonio Anastasio Volta showed that Galvani’s conclusion of animal electricity was incorrect.

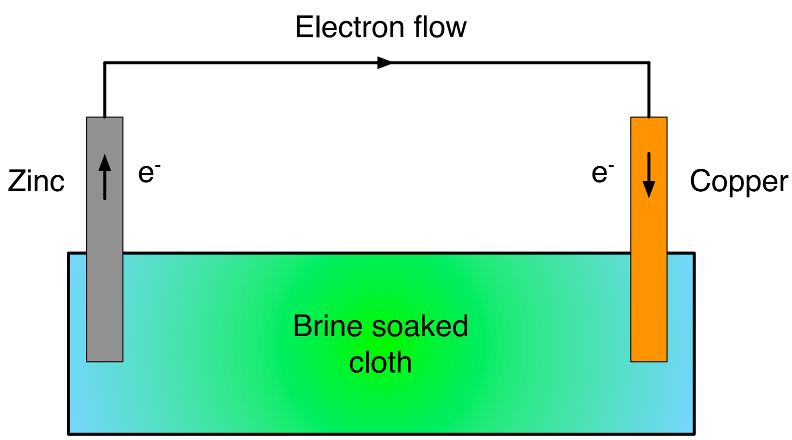
- He showed that the source of the electric charge was not the animal, but the contact between the two dissimilar metals.
- And that the frog’s moist tissues acted as a conductor of electricity, and could be replaced by cloth or paper soaked in salt water.

Volta was an extremely driven person. When engrossed in experiments, the only way his manservant could convince him to change his clothes was by distracting him with scientific questions while helping him dress.

Volta's Simple Battery

In 1791, Volta demonstrated that when two dissimilar metals and a brine soaked cloth are connected in series, they produce an electric current.

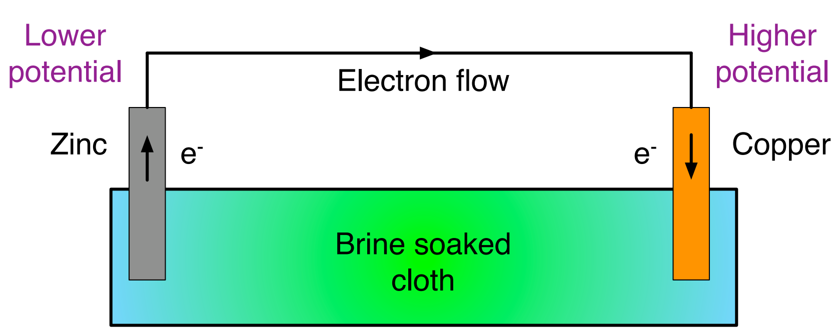
- Why does this happen?



A Simple Battery

Electrons flow from the zinc to the copper because the "reduction potential" of these metals in the brine solution is not equal.

- The reduction potential is the tendency of a metal to acquire or lose electrons.
- The metal with the lower reduction potential loses electrons to the other metal.

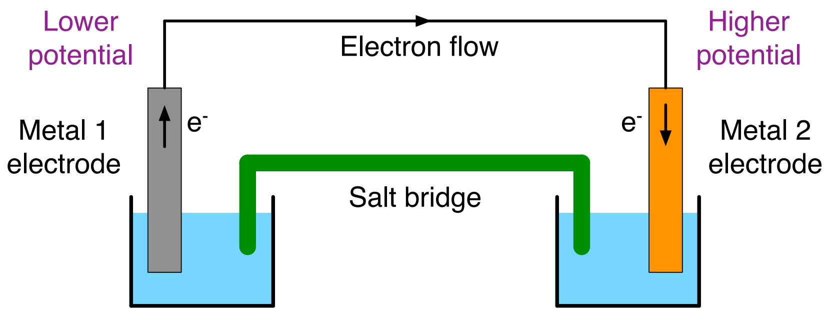


In the above picture the zinc loses electrons to the copper electrode, because zinc has a 1.1 volt lower reduction potential than copper.

- We then say that the copper electrode is 1.1 volts higher than the zinc electrode.

A Modern Version - The Galvanic Cell

A Galvanic cell (sometimes called a Voltaic cell) uses separate solutions around each electrode, and a salt bridge connecting the solutions.



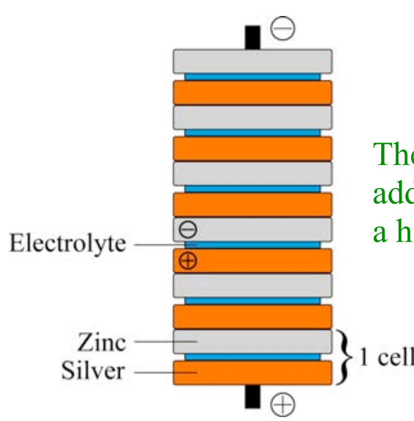
The salt bridge allows exchange of ions, without the solutions mixing.

- As electrons flow in the wire joining Metal 1 and Metal 2, ion exchange also occurs between the solutions and the salt bridge, balancing the electric charge transfer. Without this balancing, the electron flow would stop.
- The salt bridge can be a tube filled with, or paper soaked with, an electrolyte. An electrolyte is a substance or solution containing free ions (such as NaCl or KCl).

Voltaic Pile (the Battery)

Pictures from Wikipedia

In 1799, Volta constructed the Voltaic pile by connecting several voltaic cells in series.



The voltage of the cells add together, achieving a higher total voltage.

The name battery comes from a "battery" of voltaic cells connected together.

- In many parts of Europe batteries are called piles.

Hans Christian Ørsted (1777 - 1851)

Hans Christian Ørsted was a Danish physicist and chemist. He observed that electric currents induce magnetic fields.

- In 1820, he noticed that an electric current in a wire can deflect a compass needle.
- He later showed that electric current produces a magnetic field as it flows through a wire, forming a direct relationship between electricity and magnetism.

He is also known for his contribution to chemistry.

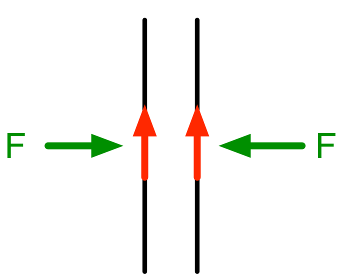
- In 1825, he isolated aluminum for the first time.

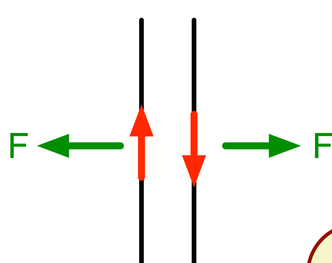
He was a close friend of Hans Christian Anderson, the Danish author and poet who wrote The Steadfast Tin Solder, Thumbelina, The Little Mermaid, The Ugly Duckling, and other stories.

André-Marie Ampère (1775 - 1836)

André-Marie Ampère was a French mathematician and physicist. One week after hearing of Ørsted's discovery, Ampère demonstrated:

- That parallel wires carrying currents moving in the same direction attract each other.
- And if the currents move in opposite directions the wires repel each other.





Ampère was often absent minded. In one instance he forgot to honour an invitation to dine with the Emperor Napoleon.

Georg Ohm (1789 - 1854)

Georg Simon Ohm was a German physicist. He discovered that the electric current flowing in a conductor is proportional to the voltage across it.

- In 1827, he published what we now call Ohm's law.

$I = V / R$ or $V = I \times R$

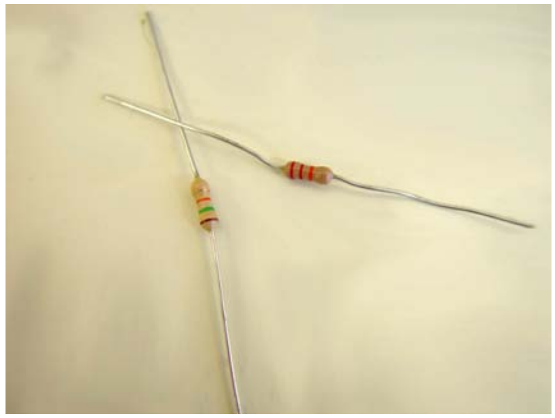
Before Ohm's discovery, the British scientist Henry Cavendish (1731 - 1810) had already discovered this relationship. This, and many other electrical experiments done by Cavendish, were not known until James Clerk Maxwell published them in 1879.

Additional Electric Circuit Concepts That You Need For Today's Lab

Resistance & Resistors

A resistor is a device that has a specified resistance to electron flow.

- The circuit symbol for a resistor is: 



Resistors Colour Code

The colour bands on resistors indicate their resistance value. There are 4 colour bands.

- The first two bands are numbers.
- The third band is the number of following zeros (decimal multiplier).
- The fourth colour at the end indicates the tolerance (accuracy) value.

Examples:

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red - blue - orange - gold
 2      6       000        5% = 26,000 ±5%

brown - black - red - gold
  1        0       00      5% = 1,000 ±5%
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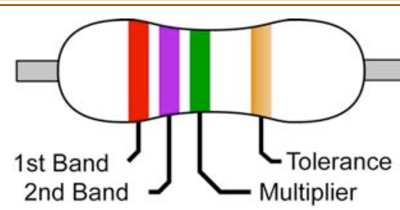
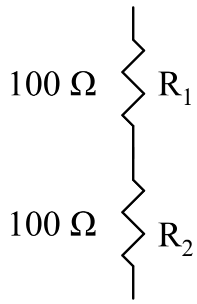


Color	Significant figures	Multiplier	Tolerance
Black	0	$\times 10^0$	–
Brown	1	$\times 10^1$	±1%
Red	2	$\times 10^2$	±2%
Orange	3	$\times 10^3$	–
Yellow	4	$\times 10^4$	–
Green	5	$\times 10^5$	±0.5%
Blue	6	$\times 10^6$	±0.25%
Violet	7	$\times 10^7$	±0.1%
Gray	8	$\times 10^8$	±0.05%
White	9	$\times 10^9$	–
Gold	–	$\times 10^{-1}$	±5%
Silver	–	$\times 10^{-2}$	±10%
None	–	–	±20%

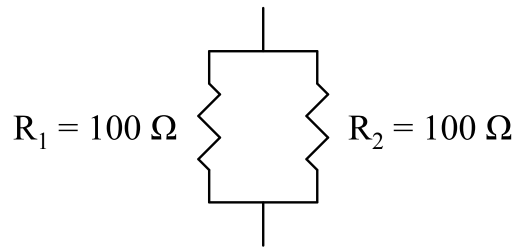
Series and Parallel Resistors

Resistors in series add.

Resistors in parallel reduce.



$$R_{Total} = R_1 + R_2 = 200\ \Omega$$

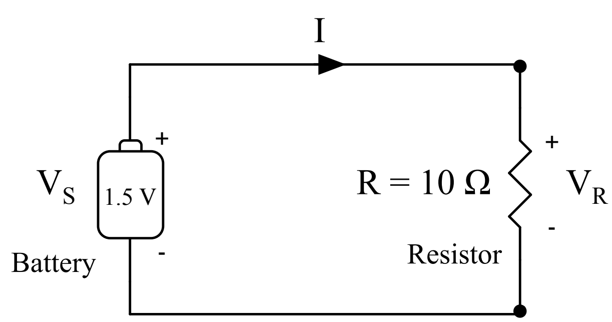


$$R_{Total} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{1}{\frac{1}{100\ \Omega} + \frac{1}{100\ \Omega}} = 50\ \Omega$$

Ohm's Law

Ohm's law describes a linear relationship between voltage, current, and resistance.

$$V = I \times R$$



In this circuit, a 1.5 V battery is suppling power to a 10 Ω resistor.

- The voltage supplied is: $V_S = 1.5$ V
- The voltage lost by electrons flowing through the resistor is: V_R
- The current in the circuit is:

$$I = \frac{V_S}{R} = \frac{1.5\ V}{10\ \Omega} = 0.15\ A$$

Some Electrical Safety Concepts

The voltages on the project boards in this lab are low, no more than ± 15V.

- It is safe to touch these voltages with your **dry** skin, since your skin has enough resistance to result in low current flow through your body.

Recall Ohm's Law: $V = I \times R$ or $I = V / R$

The resistance of your skin is highly variable.

- It depends on the voltage, current, and frequency of the electricity.
- It depends on the contact area, wetness, and saltiness of the skin.
- Dry skin can have resistance over 10,000 Ω/cm^2.
- Wet or broken skin may be as low as 150 Ω.

Electric Current & The Human Body

It is the current that passes through your body, ***and the path it takes***, that harms you.

- ~ 0.001 A is the human sensation threshold.
- ~ 0.01 A causes a painful shock, and it is difficult to let go.
- ~ 0.1 A Let-go threshold. If it passes through your heart it can cause ventricular fibrillation (death).
- Currents > 1 A can cause severe burns. It may be possible that normal heart rhythm can return if the current stops quickly, because the muscle contractions are so severe that the heart is forcibly clamped, which can prevent fibrillation.

Is it safe to touch a 15 V wire on the project board? Using Ohm's law:

$$I = \frac{V}{R_{\text{Dry Skin}}} = \frac{15\text{ V}}{10{,}000\ \Omega} = 1.5\text{ mA}$$

Is it safe to touch the 120 V wall socket?

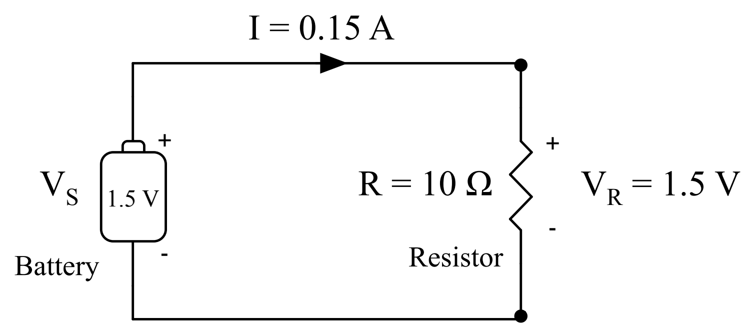
$$I = \frac{V}{R_{\text{not-so-dry Skin}}} = \frac{170\text{ V}_{peak}}{1{,}000\ \Omega} = 0.17\text{ A}$$

Power

Power (SI unit is watts) is defined as: $P = V \times I$

Using Ohm's law we also have: $P = I^2 \times R$ or $P = V^2 / R$

In this circuit, the power absorbed by the resistor is:



$$P = V_R \times I = \frac{V_R^2}{R} = I^2 \times R = 0.225\ \mathrm{W}$$

Important Things To Remember

Important Points

In the zinc-copper galvanic cell, the zinc electrode has a more negative electric potential than the copper electrode since it has a lower reduction potential.

An electric current in a wire generates a magnetic field, and so it can deflect a compass needle.

Ampère showed that parallel wires carrying currents moving in the same direction attract each other, and opposing currents create a repelling force.

Electric currents > ~10 mA passing through your body can be dangerous.

Georg Ohm showed that the electric current flowing in a conductor is proportional to the voltage across it.

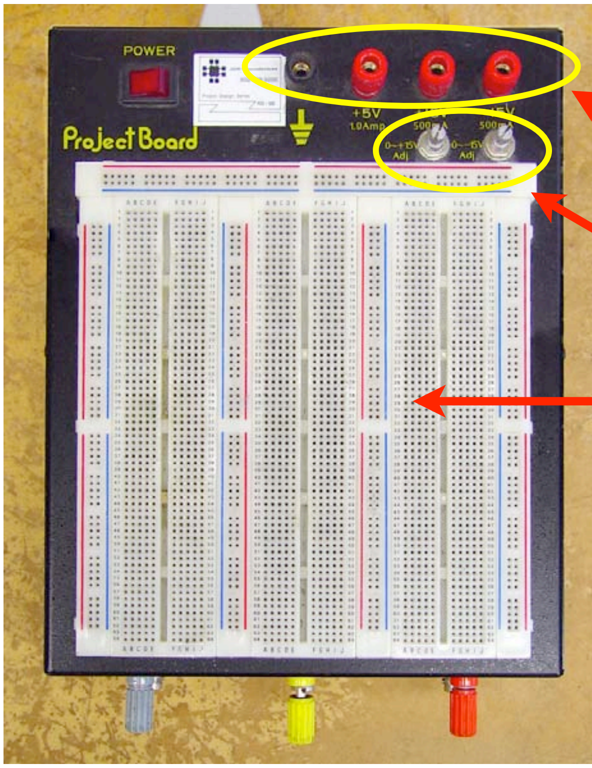
$$I = V / R \quad \text{or} \quad V = I \times R$$

Power (SI unit is watts) is defined as: $P = V \times I$

Using Ohm's law we also have: $P = I^2 \times R$ or $P = V^2 / R$

Equipment Used in Today's Lab

The Project Board



Voltage and ground plugs

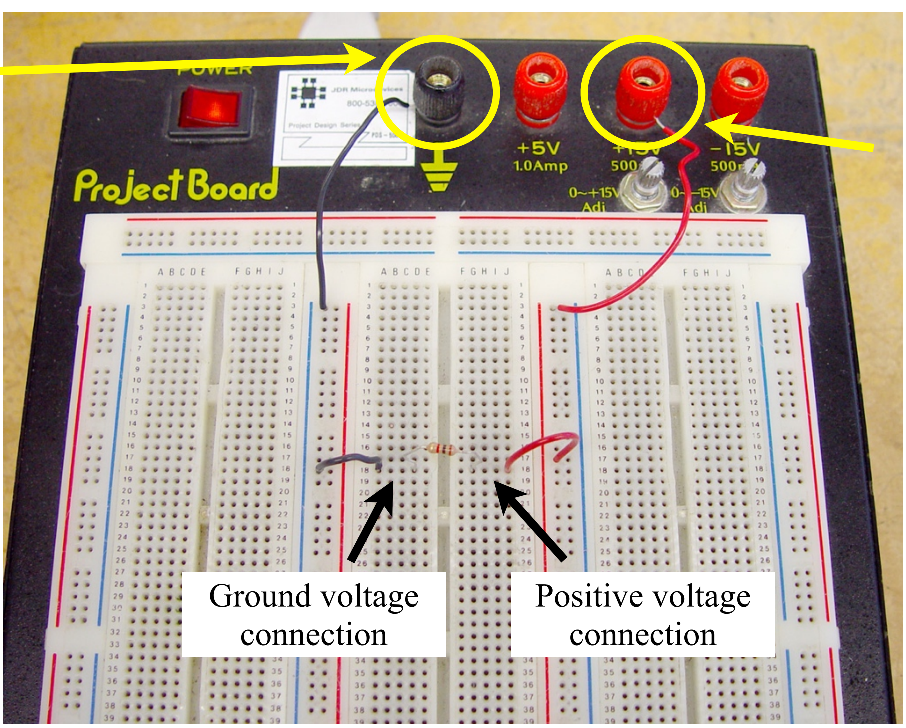
Voltage adjustment dials

Connection pins

The project board is used to connect your electrical components together.

Connecting to Voltage and Ground

Ground voltage

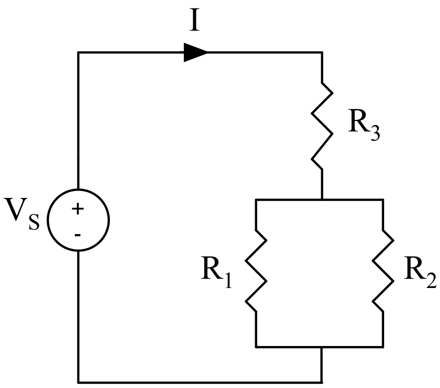


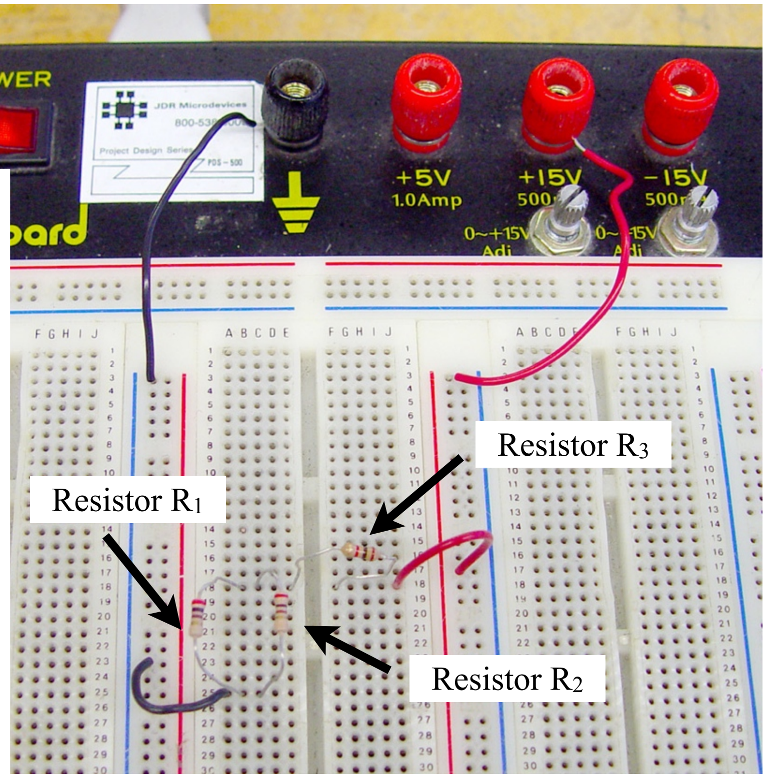
Positive voltage

Series and Parallel Connections

R_1 is in parallel with R_2.

R_3 is in series with the $R_1//R_2$ parallel combination.





The Digital Multimeter (DMM)

The digital multimeter can be used to measure voltage, current, and resistance.

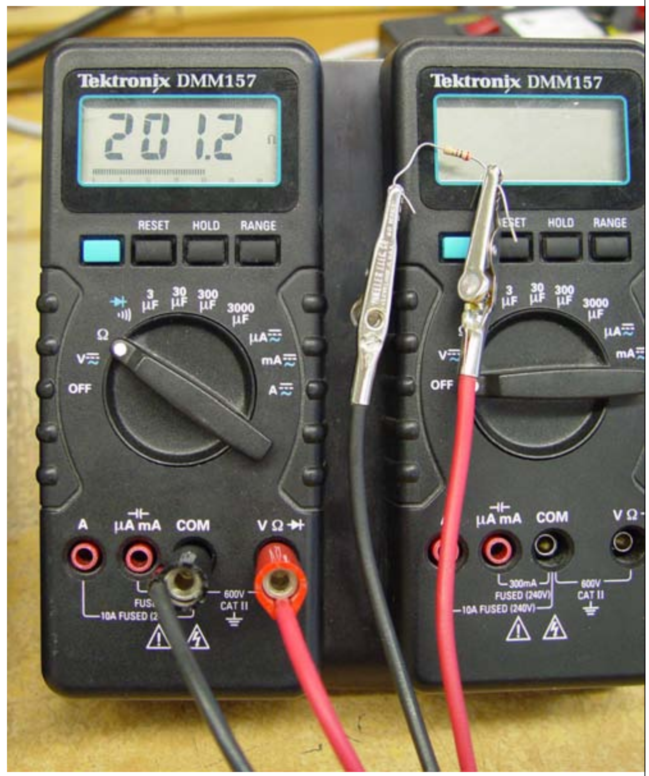
Dial to select measurement type

Cable connection plugs

Resistance Measurement

When measuring resistance:

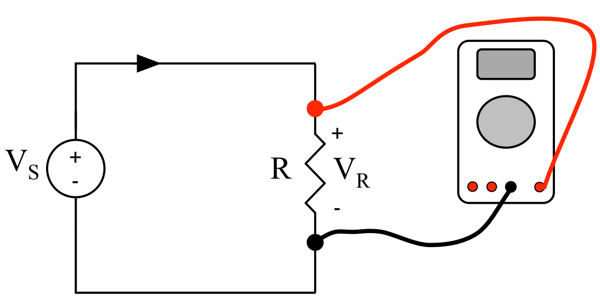
- Put the black wire in the COM plug.
- Put the red wire in the Ω plug.
- Turn the measurement selection dial to the Ω setting.
- Connect the black and red wires across the resistor.

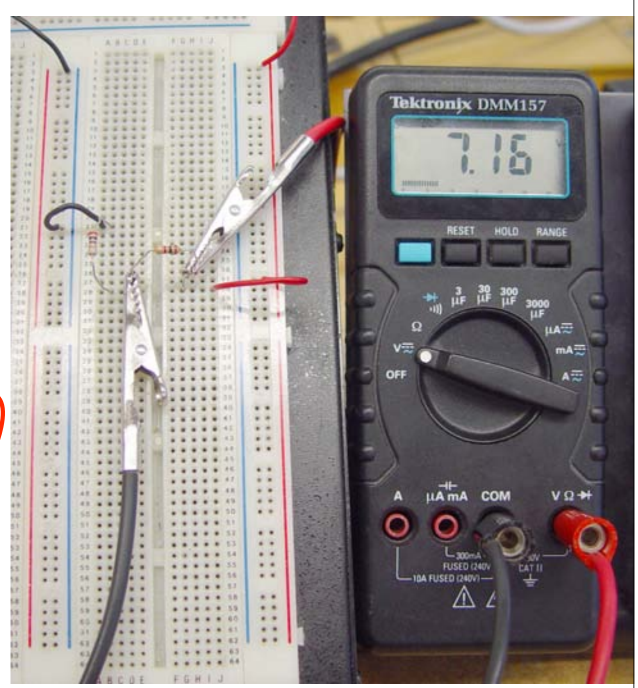


Voltage Measurement

The voltmeter must be in ***parallel*** with the resistor.

- Thus, you are measuring voltage across the resistor.
- This works because the voltmeter has a very high resistance, so that it does not affect the circuit.

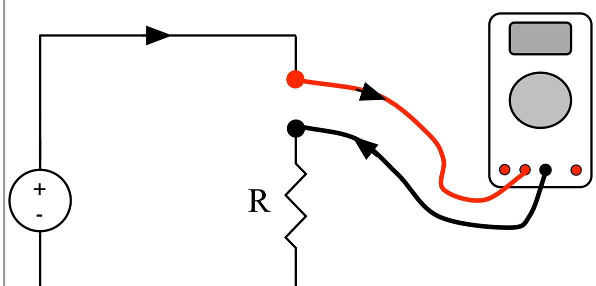


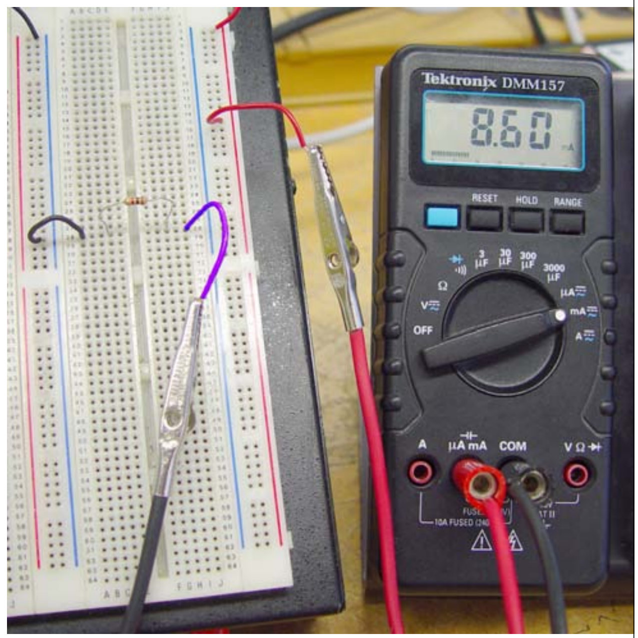


Current Measurement

The ammeter must be in ***series*** with the resistor.

- The current must pass through the ammeter in order to be measured.
- This works because the ammeter has a near zero resistance, so that it does not impede electron flow.



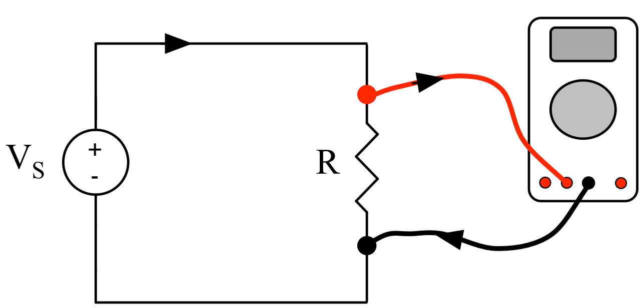


Incorrect Ammeter Connection

Very Important:

If the ammeter is connected in parallel with the resistor, the current passing through the ammeter will be very high, since its resistance is near zero.

- This will blow the fuze in the ammeter.



$$I = \frac{V_S}{R_{ammeter}} = \text{a very large number if } R_{ammeter} \approx 0\ \Omega$$