Electronic Components
Preparation

Preparation	Introduction	Value of a Resistor	Resistors	Diodes	Transistors	Glossary

Grade level: 7-12	**Time:** 3 sessions of 40-50 minutes
Group size: 20-30	**Presenters:** 3-4

NSTA

Standards
This lesson aligns with the following National Science Content Standards:

Physical Science, 5-8 and 9-12

History and Nature of Science, 5-8 and 9-12

Science and Technology, 5-8 and 9-12

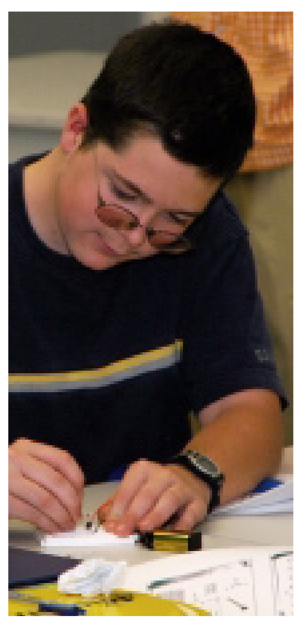
Materials
Each group of students will need a set of materials specific to the activities. Student handouts are sets for all activities.

Student handout

For resistance activities:
- Resistors of various values
- A multimeter or an ohmmeter
- Chart/table of resistor band codes
- Glossary handouts

For diode activities:
- LEDs (light emitting diodes)
- 9V battery
- Resistors of various values

For transistor activities:
- A transistor
- A diode
- Resistors of various values
- 9V battery
- A bread board
- Memory chips



Resistors, Diodes, Transistors, and the Semiconductor
Preparation

Related Micron lessons:

- Binary Coding
- History of Semiconductors

Preparation

Review the Glossary of Terms with students or provide copies of the Glossary for reference as terms are required during the lesson. Divide the class into groups of 3-4 students. Distribute memory chips. Prepare components for easy distribution to groups as needed. Give each group a set of the materials listed above. Review these links for additional information.

www.micron.com/education About Semiconductors
www.micron.com/education How RAM Works
www.intel.com/education How Transistors Work

Resistors, Diodes, Transistors, and the Semiconductor
Introduction

The computer allows us to do two things very well: communicate more quickly and completely and store vast amounts of information in very small spaces. How does the computer do this?

Whatever form the information takes – text, graphics, sound, music, or video–-it must first be converted into a digital form so the computer can process and store it within its electrical circuits. These circuits are basically a collection of on/off switches which allow the data input into the computer to be translated into binary code, in which each command becomes a series of 0s and 1s. A switch that is "on" is interpreted by the computer to be a 1. A switch that is "off" is a 0. By assigning an alpha-numeric character to a specific string of 1s and 0s, text and programming instructions can be encoded so the computer can "read" them. For example, an "a" is represented by 01100001. A "b" is 01100010. A "c" is 01100011. And so on.

Early computers used vacuum tubes as these electronic switches. However they were large and generated intense heat which made them unreliable. In the late 1940s, a typical computer filled up a whole warehouse! Then engineers at Bell Labs invented the transistor, which performed the same function as the vacuum tube but was much smaller. A transistor is essentially a vacuum tube built on a microscopic scale. It uses less power and creates less heat. Eventually transistors became so small that millions of them could be put on a small silicon chip called an integrated circuit. As a result, computers have become increasingly smaller, less expensive, and more dependable.

A semiconductor is a material such as silicon that is used to create a network of millions of transistors, diodes, capacitors, and other circuit elements. Different kinds of semiconductor circuits do different tasks. Some store information. Some process data. Others make the hero in your video game run and jump. What a given semiconductor does depends on how all those transistors and other devices are arranged on the chip.

Today semiconductor companies like Micron can make transistors so small that 512 million of them will fit on a chip the size of your fingernail. Yet they are so powerful they can perform millions of calculations in one second. They allow memory chips to temporarily store billions of bits of data and programming instructions. They run your computer's software and allow data to be created and changed before it's saved. If you use an MP3 player, you're using memory chips**.**

Since the integrated circuits in computers are microscopic, they are not suitable for us to study. However, by studying circuits that are easy to build and observe we can understand how computer circuits function. There are three parts to the circuit that we can explore: resistors, diodes, and transistors. Each individual section will take 30-45 minutes to complete.

A resistor controls the amount of electricity flowing through a circuit. To learn how the flow of electricity is controlled, we need to know the value of the resistor that we are using in an experiment. For our convenience, the values of resistance are encoded onto the resistors using stripes painted onto the resistor. The value of a resistor is measured in the unit called ohm. The plural is ohms.

Objective

To learn how to break the code painted on the resistor to find the value of the resistor.

Materials

This lesson requires the following classroom materials:

- Resistors of various values
- Chart/table of resistor band codes
- An ohmmeter or a multimeter

Procedure

(Distribute student handout)

Most resistors look like the following:

A Four-Band Resistor

As you can see, there are four color-coded bands on the resistor. The value of the resistor is encoded into them. We will follow the procedure below to decode this value.

- When determining the value of a resistor, orient it so the gold or silver band is on the right, as shown above.
- You can now decode what resistance value the above resistor has by using the table on the following page.
- We start on the left with the first band, which is BLUE in this case. So the first digit of the resistor value is 6 as indicated in the table.
- Then we move to the next band to the right, which is GREEN in this case. So the second digit of the resistor value is 5 as indicated in the table.
- The next band to the right, the third one, is RED. This is the multiplier of the resistor value, which is 100 as indicated in the table.
- Finally, the last band on the right is the GOLD band. This is the tolerance of the resistor value, which is 5%. The fourth band always indicates the tolerance of the resistor.
- We now put the first digit and the second digit next to each other to create a value. In this case, it's 65. 6 next to 5 is 65.
- Then we multiply that by the multiplier, which is 100. 65 x 100 = 6,500.
- And the last band tells us that there is a 5% tolerance on the total of 6500. Therefore, we have a resistor value of 6,500 ohms plus or minus 5% (i.e., plus or minus 325 ohms).

Resistors, Diodes, Transistors, and the Semiconductor
Value of a Resistor

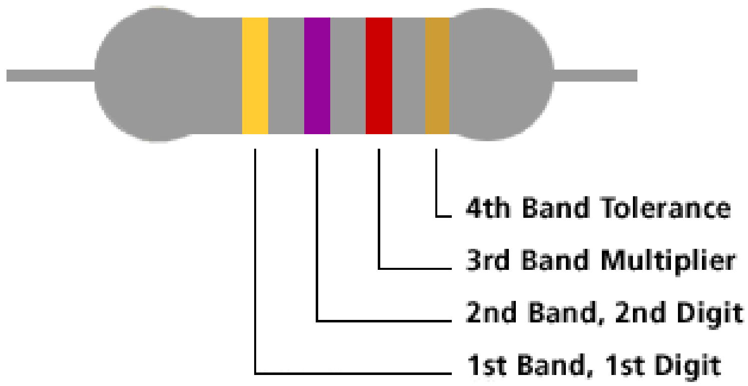
- Measure the value of the resistor using an ohmmeter or a multimeter. To measure the value on an ohmmeter, turn on the ohmmeter, touch the two sides of the resistor with the two probes attached to the ohmmeter, and read the value on the scale. To measure the value on a of the multimeter, turn on the multimeter, set the multimeter to measure ohms, touch the two sides resistor with the two probes attached to the multimeter and read the value on the scale. The value you calculated by decoding the bands on the resistor should be close to the value displayed on the ohmmeter or the multimeter.

Band Code Reference Table

Band Color	First Band	Second Band	Third Band (Multiplier)	Fourth Band (Tolerance)
Black	0	0	1	N/A
Brown	1	1	10	1%
Red	2	2	100	2%
Orange	3	3	1000	N/A
Yellow	4	4	10000	N/A
Green	5	5	100000	N/A
Blue	6	6	1000000	N/A
Violet	7	7	10000000	N/A
Gray	8	8	100000000	N/A
White	9	9	1000000000	N/A
Gold	N/A	N/A	0.1	5%
Silver	N/A	N/A	0.01	10%

Resistors, Diodes, Transistors, and the Semiconductor
Value of a Resistor

Example (Refer to student handout)
Here is another example of color bands on a resistor. The color bands are hiding the value of the resistor. Can you figure out the value of the resistor?



Solution
Step One:
Turn the resistor so that the gold or silver stripe is at the right end of the resistor, as shown above.

Step Two:
Look at the color of the first two stripes on the left end. These correspond to the first two digits of the resistor value. Use the table to determine the first two digits. In this case they are 4 and 7, making 47.

Step Three:
Look at the third stripe from the left. This corresponds to a multiplication value. Find the value using the table. In this case, it is red which translates to a multiplier of 100 or two zeroes.

Step Four:
Multiply the two-digit number from step two by the number from step three. In this case, 47 x 100 = 4700 ohms. Other ways to say it are 4.7 thousand ohms or 4.7k ohms. This is the value of the resistor in ohms. The fourth stripe indicates the accuracy of the resistor. A gold stripe means the value of the resistor may vary by 5% from the value indicated by the stripes.

Step Five:
Measure the value of the resistor using an ohmmeter or a multimeter. To measure the value on an ohmmeter, turn on the ohmmeter, touch the two sides of the resistor with the two probes attached to the ohmmeter, and read the value on the scale. To measure the value on a multimeter, turn on the multimeter, set the multimeter to measure ohms, touch the two sides of the resistor with the two probes attached to the multimeter, and read the value on the scale. The value you calculated by decoding the bands on the resistor should be close to the value displayed on the ohmmeter or the multimeter.

Resistors, Diodes, Transistors, and the Semiconductor
Resistors

A resistor controls the amount of electricity flowing through a circuit by increasing or decreasing the resistance to that flow. The less the resistance, the greater the electron flow. The more the resistance, the less the electron flow.

Objective
To learn how resistors affect the flow of electricity through a circuit.

Materials
This lesson requires the following classroom materials:
- Resistors of various values
- A multimeter or an ohmmeter
- Glossary handouts

Related Lessons
Refer to any of the lesson plans below for related ideas:
- Binary Coding
- Transistors
- Diodes
- History of Semiconductors

Preparation
Review the Glossary of Terms with students or provide copies of the Glossary for reference as terms are required during the lesson. Divide the class into groups of 3-4 students. Distribute memory chips. Prepare components for easy distribution to groups as needed. Each group will need a set of the materials listed above. Review the following links for additional information:

www.micron.com/education About Semiconductors
www.micron.com/education How RAM Works
www.intel.com/education How Transistors Work

What Is Resistance?
With regard to electricity, resistance is the term used to describe the force that limits the flow of electrons in a conductor or circuit. All materials have a characteristic resistance associated with them. For example, gold, silver, copper, and aluminum all have very low resistance and are good conductors. Glass, plastic, wood, and rubber all have high resistance, which makes them poor conductors or even non-conductors.

An analogy would be to think of water flowing through a pipe between two points. Certain characteristics about the pipe resist the flow of water through it.
- Length of the pipe: The longer the pipe, the more force it takes to push the water through it.
- Diameter of the pipe: The smaller the opening, the more force it takes to push the water through it.
- Texture of the inside surface of the pipe: The rougher the surface, the more force it takes to push the water through it.

Resistors, Diodes, Transistors, and the Semiconductor
Resistors

A resistor controls the amount of electricity flowing through a circuit by increasing or decreasing Those same concepts can be applied to a wire that conducts electricity between two points. The flow of electricity is affected by:

- Length of the wire.
- Diameter of the wire.
- Material the wire is made of. (Gold, silver, copper, etc.)

Units
Resistance is measured in ohms which are named after the German physicist Georg Simon Ohm. One ohm is the resistance of a circuit or circuit element that permits a steady current of 1 ampere (1 coulomb per second) to flow when a steady potential of 1 volt is applied to the circuit.

Ohm's Law
The formula for calculating resistance is shown below and is called Ohm's Law.
(Draw formula for all students to see)

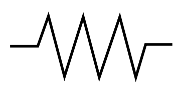
$R = V / I$

Where

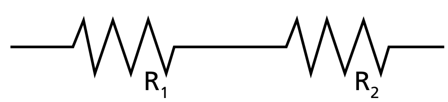
- R = Resistance.
- V = Voltage.
- I = Current.

Therefore, resistance is the voltage divided by the current.

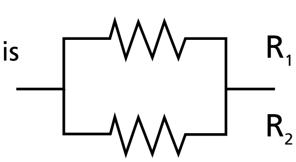
Resistors
If we have a circuit and the characteristic resistance of the wire being used is not enough to slow the flow of electrons, what do we do? There are electronic components called resistors that we can insert in the wire between the two points where the added resistance is needed. This would be analogous to inserting a valve in a length of pipe and partially closing it to limit the amount of water that flows between the two points. Resistors are usually made of carbon and can be round, square, cylindrical, or flat. (Draw schematics for all students to see.)

The schematic symbol for a resistor is 

Resistors can be placed in a circuit in two different configurations, either in series or in parallel. How they are configured determines how to calculate the overall resistance.

For resistors in series, the schematic symbol is 

The formula is $R_{total} = R_1 + R_2$.

For resistors in parallel, the schematic symbol is 

The formula is $R_{total} = (R_1 \times R_2) / (R_1 + R_2)$

Using these formulas, engineers can arrange resistors of standard values to obtain desired resistance for a circuit.

Resistors

Resistors in Our Everyday Life

One of the common uses of resistors is before us everyday. When electricity runs through a resistor, the resistor can heat up according to the value of its resistance and the amount of electricity flowing through it. Light bulbs use this property to create light to brighten our nights. The filaments in the light bulbs are resistors made from special materials to give off light and to last for relatively long periods of time.

The filaments in electric ovens and electric ranges also are specialized resistors. When electricity passes through these filaments, they heat up to cook, bake, and broil.

Electric room heaters have resistors that heat up as electricity flows through them after they have been turned on.

Procedure: Resistors in Series (Distribute materials)

- Select two resistors of the same value (same stripe pattern) so that $R_1 = R_2$. Read their values, R_1 and R_2.
- Add their values, $R_1 + R_2$. This is their resistance when attached in series, $R = R_1 + R_2$ (see the formula above).
- Connect the two resistors, R_1 and R_2, in series as shown.
- Using the multimeter, measure the resistance of the two resistors when attached in series.
- Is the measured value of the resistance the same as the value you just calculated? A small difference should be accounted for by the tolerance of the resistors.

Procedure: Resistors in Parallel

- Select two resistors of the same value (same stripe pattern) so that $R_1 = R_2$. Read their values.
- Find the expected value of their resistance when arranged in parallel, $R_{total} = (R_1 \times R_2) / (R_1 + R_2)$.
- Connect the two resistors, in parallel as shown.
- Using the multimeter, measure the resistance of the two resistors attached in parallel.
- Is the measured value of the resistance the same as the value you just calculated? A small difference should be accounted for by the tolerance of the resistors.

Resistors, Diodes, Transistors, and the Semiconductor
Diodes

A diode is an electrical component that controls the direction of the flow of electricity.

Objective
Learn how a diode works.

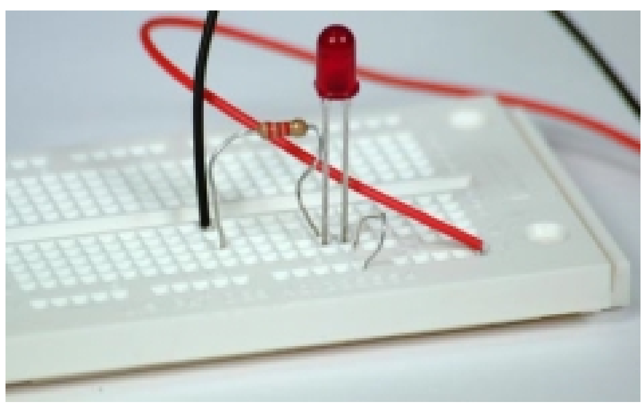
Materials
This lesson requires the following classroom materials:

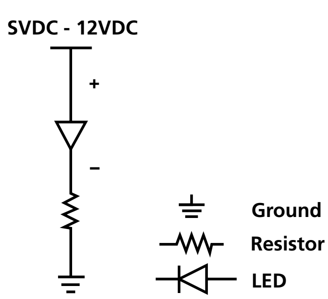
- An LED (light emitting diode)
- 9V battery
- Resistors of various values

Procedures (Refer to student handout)
The following two experiments demonstrate that the diode conducts only in one direction. Engineers use this property to design complex circuits in which diodes control the flow of electrons.

Forward-biased diode

- Connect one terminal of the resistor to the negative terminal of the battery.
- Connect the other terminal of the resistor to the negative terminal of the diode (the shorter leg of the diode).
- Connect the positive terminal of the diode (the longer leg of the diode) to the positive terminal of the battery.
- The LED should light up if the connections were made correctly. This circuit is shown in the schematic diagram and in the picture of the breadboard below.





Procedures *(cont.)*

Backward-biased diode

- Connect one terminal of the resistor to the negative terminal of the battery.
- Connect the other terminal of the resistor to the positive terminal of the diode (the longer leg of the diode).
- Connect the negative terminal of the diode (the shorter leg of the diode) to the positive terminal of the battery.
- The LED should NOT light up if the connections were made correctly, because we changed the direction of the diode.

This experiment demonstrates that the diode conducts only in one direction. Engineers use this property of the diode to design complex circuits where diodes control the flow of electrons.

Changing the Brightness of the Diode

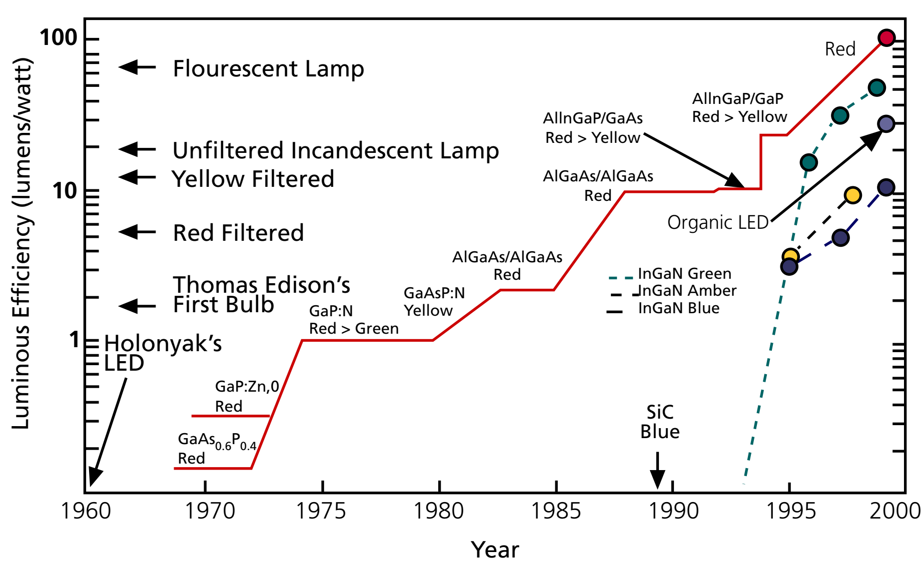
In this experiment, we will see how a change in the flow of electrons affects the brightness of the LED. A change in the value of the resistor in our circuit will change the amount of current or electrons flowing through the LED.

- Change the resistor in the forward-biased diode circuit with a resistor of higher value.
- Does this increase the amount of current or decrease the amount of current?
  Hint: R=V/I, so I=V/R. Remember, we are not changing the battery, which means V stays the same. So when we increase R, I should decrease. A decrease in I should make the LED dimmer.
- Now replace the resistor with one with a value smaller than the original. The current should increase due to the lower resistance making the LED brighter.

Using the information from this experiment, describe how a light dimmer is designed.

LED Development Timeline (Refer to student handout)

Many kinds of light emitting diodes (LEDs) have been developed over the years. LEDs are junctions of appropriate materials that produce a color of light specific to those materials when contacted by the flow of electrons. The following timeline shows when the materials were discovered and the color of light they emit. Use a periodic table to find the names of the materials listed on the chart.



Diodes

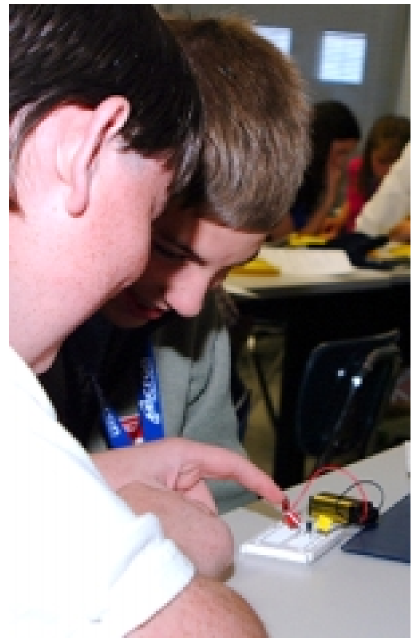
Uses of LEDs

You'll find light emitting diodes at work throughout your day.

- They can be arranged to make electronic displays like the bright red numbers on digital clocks.
- They can be used in fiber optic cables to send data and signals to far off places at very high speeds.
- The electricity we use in our homes comes in the form of alternating current, or AC, which fluctuates between positive and negative limits 50-60 times per second. However, some of the appliances in our homes may require direct current, or DC, which stays at a constant level and does not fluctuate. Because it has a low resistance to electric current in one direction and a high resistance in the reverse direction, a diode can convert the AC into DC.
- Some diodes are light sensitive. As the amount of light striking them increases or decreases, the voltage moving across them rises or drops accordingly. They can be used to measure illumination or brightness.

Resistors, Diodes, Transistors, and the Semiconductor
Transistors and the Semiconductor

Objectives
This lesson will enable students to
- Explain how a transistor works
- Explain what a transistor does



Materials
Each group of students will need a set of materials
- A transistor
- A diode
- Some resistors
- A 9V battery
- A bread board
- Memory chips
- Glossary handouts

Related lessons
- Binary Coding
- Resistors
- Diodes
- History of Semiconductors

Preparation
Review the Glossary of Terms with students or provide copies of the Glossary for reference as terms are required during the lesson. Divide the class into groups of 3-4 students. Distribute memory chips. Prepare components for easy distribution to groups as needed. Each group will need a set of the materials listed above. Review the following links for additional information:
www.micron.com/education About Semiconductors
www.micron.com/education How RAM Works
www.intel.com/education How Transistors Work

What is a Transistor?
Electricity can be best described as the flow of current (electrons and holes) through a conductor. When an electron is freed from an atom, it leaves a "hole" where it used to be. Thus, as electrons flow in one direction, holes move in the opposite direction.

In order for electrons to flow, there must be a conduction path as well as some force that causes them to move. The force that causes electrons to move is known as "voltage." Voltage is the potential difference between two points. A positive voltage will attract the negatively charged electrons, and a negative voltage will repel negatively charged electrons. A battery is a good example of a voltage source.

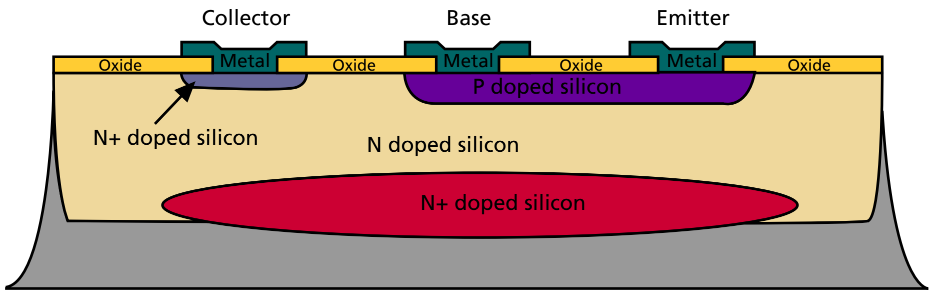
Resistors, Diodes, Transistors, and the Semiconductor
Transistors and the Semiconductor

(Refer to student handout)

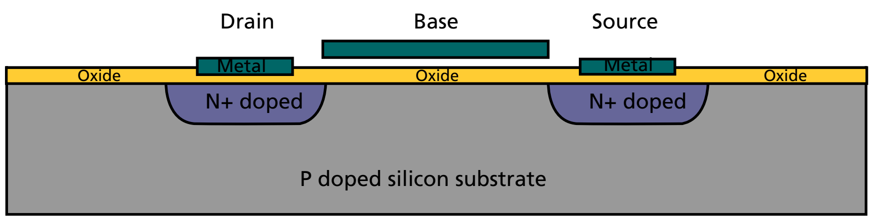
There are two main semiconductor processes used to make transistors. The first and oldest process is called the "Bipolar" process. It's used to make Bipolar Junction Transistors (BJT) commonly known as NPNs and PNPs. NPN and PNP refer to the layering of "N" (negative) doped silicon or "P" (positive) doped silicon. "N" doped silicon is silicon that is doped with a substance containing a donor electron such as arsenic or phosphorus. "P" doped silicon is silicon that is doped with a substance containing an acceptor hole such as boron.

The second semiconductor process used to make transistors is known as Complimentary Metal Oxide Semiconductor or CMOS. The CMOS process is much simpler and thus is more commonly used. There are two types of CMOS transistors, the N-Channel and the P-Channel. The N-Channel transistor is similar to the NPN BJT in its layering of "N" doped silicon and "P" doped silicon. The P-Channel transistor is similar to the PNP BJT in its layering of "P" doped silicon and "N" doped silicon.

NPN BJT Transistor



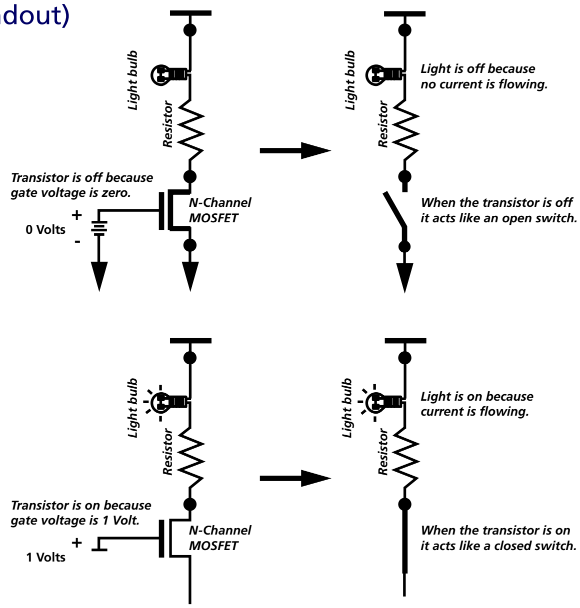
N-Channel MOSFET



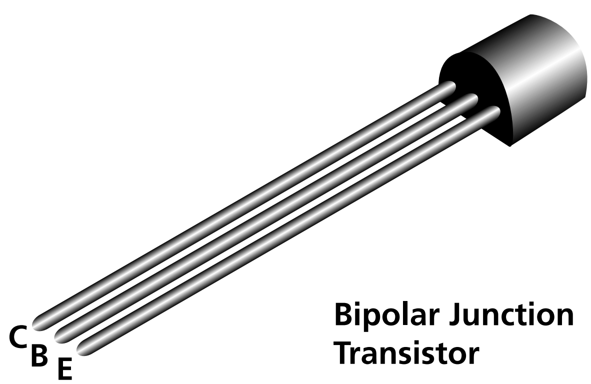
A transistor is an electronic component that is used as a switch and as an amplifier in electronic circuits. In this lesson, we will see a transistor working in real life.

A transistor can be thought of as a switch. When the transistor is off, it acts as an open circuit, preventing the flow of current. When the transistor is on, it allows current to flow with a very small voltage drop.

Transistor as a Switch
(Refer to student handout)



Identify the Terminals of a Transistor
(Distribute diagrams)



A typical Bipolar Junction Transistor (BJT) has three terminals attached to a plastic body. The body has a flat side. The terminals can be recognized by their position on the body. With the terminals pointing towards you and the flat side pointing away from you, the right terminal is the emitter (labeled E in the diagram), the middle terminal is always the base (labeled B in the diagram), and the left terminal is the collector (labeled C in the diagram).

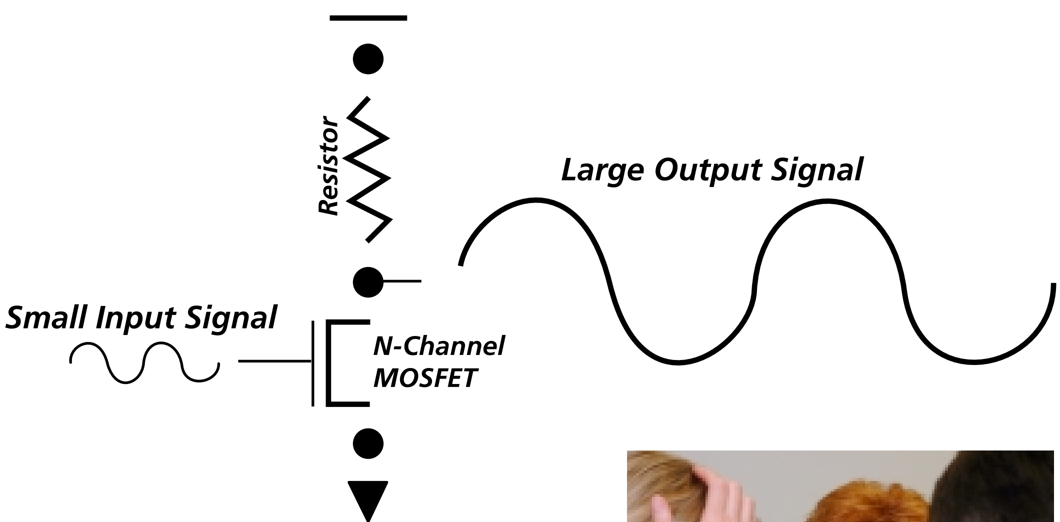
Transistors and the Semiconductor

The diode should light up if you made the connections correctly. If the diode does not light up, check the connections and make needed corrections.

Change the values of the resistors and write down what changes make the LED brighter and what changes make it dimmer.

A transistor is also considered an amplifier because it only takes a small signal (voltage/current) applied to its gate to turn it on. Once the transistor is on, it can pass a very large signal. Therefore, a very small signal may control a very large signal.

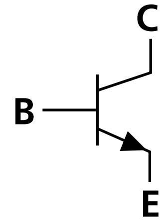
Transistor as an amplifier



Resistors, Diodes, Transistors, and the Semiconductor

Transistors and the Semiconductor

The Bipolar Junction Transistor (BJT) and its three terminals are shown as electrical circuits in the diagram below: (Draw for all students to see)

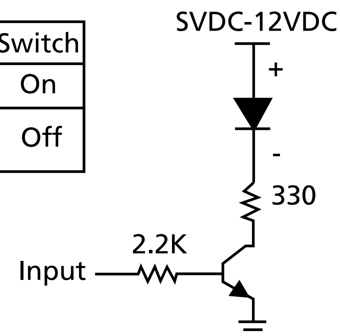


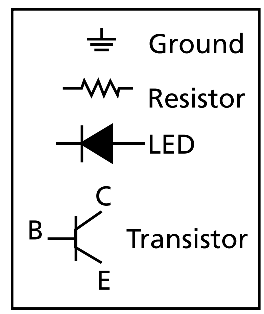
Procedure

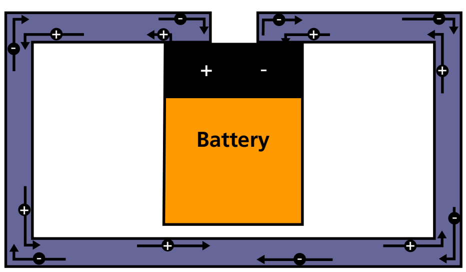
(Refer to student handout)

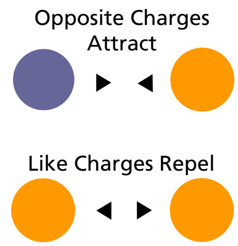
Connect two resistors, one transistor, one battery, and a diode as shown in the schematic below.

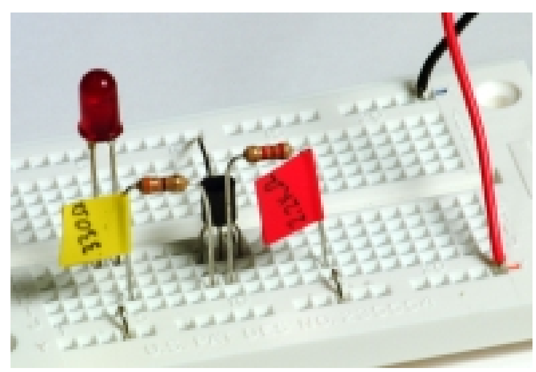
Input	Switch
5V	On
0V	Off











Your connections should look like the photo on the left.

Resistors, Diodes, Transistors, and the Semiconductor
Glossary

Alternating current - Electricity fluctuating between specific high and low voltage limits at a specific rate.

Ampere - Rate of flow of electrons through a circuit.

Battery - Source of electrons/electricity.

Conductor - Any material that allows the flow of electrons. Some examples of conductors are metals and water.

Coulomb - A measure of electrical charge. The number of electrons flowing past a particular point in one second.

Current - The flow of electrons between two points in response to a voltage difference between those two points. It is measured in amps.

Diode - A specialized electronic component that has a conductor in one direction and an insulator in the other. The longer leg should be the positive terminal.

Direct current - Current that stays at a specified positive or negative voltage level.

Electricity - The physical phenomenon rising from the behavior of electrons and protons that is caused by the attraction of particles with opposite charges and the repulsion of particles with the same charge.

Insulator - Any material that does not allow the flow of electrons. Some examples are rubber, wood, and air. However, some insulators WILL conduct electricity if there is a high enough voltage. Air, for example, will begin to conduct at approximately 1 million volts per inch (static shock!).

LED (Light Emitting Diode) - Emits light in the conducting direction. More current equals more light used.

Multimeter - Device used to measure electrical parameters, such as resistance, voltage, etc.

Ohmmeter - Device used to measure resistance.

Open circuit - Any circuit that has an insulator preventing the flow of electrons.

Potential - Electrical pressure (difference) between two points.

Rectifier - Converts electricity from alternating current to direct current.

Resistance - Any material that restricts the flow of electrons. Electrons can still flow, but they do not flow freely. Measured in ohms.

Resistors, Diodes, Transistors, and the Semiconductor
Glossary

Resistor - Component in an electric circuit regulating the flow of electrons.

Semiconductor - A material that is neither a good conductor nor a good insulator.

Short circuit - A connection between two points without any resistance.

Tolerance - Expected variation from the target value.

Transistor - A small electronic device containing a semiconductor and having at least three electrical contacts. A transistor is used in a circuit as an amplifier, a detector, or a switch.

Volt - Unit of measure of the pressure of electrons (electrical potential difference) between two points.

Voltage - Electrical pressure (difference) between two points.