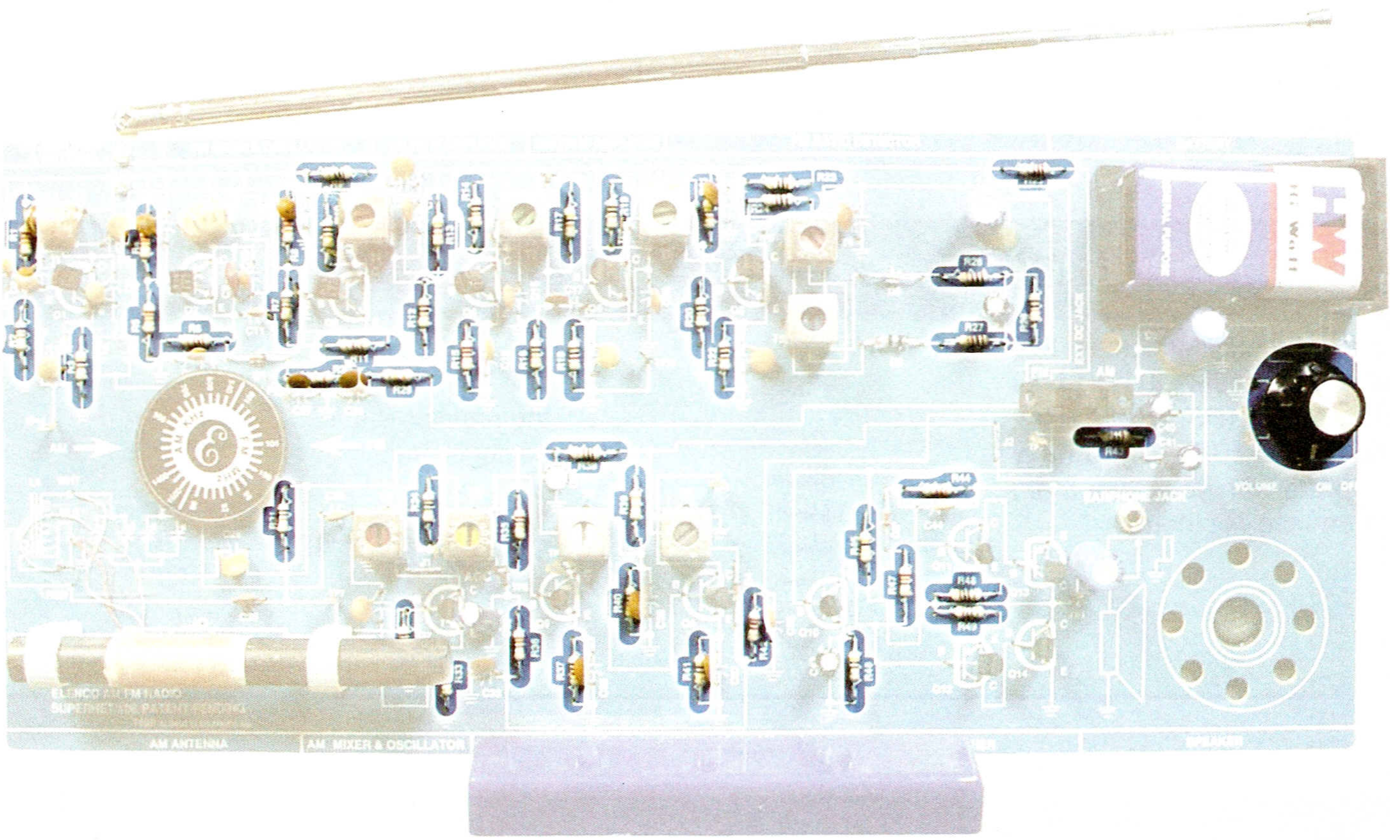
Learn By Doing®

All of the circuits and components studied in chapters 1 and 2 are commonly used by electricians, though the actual parts used will be for much higher voltages and currents than the Snap Circuits® parts representing them. Electricians are concerned with getting the electricity to where it will be used as efficiently as possible, without wasting energy.

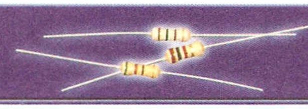
In consumer products like toys, radios, and computers, electronics engineers and technicians want to control how it is used.

In this chapter you will learn about resistors, which are used to limit and control the flow of electricity. As an example of how important resistors are in electronics, consider a typical AM/FM radio:



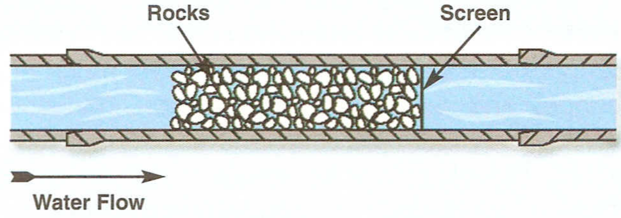
This radio contains 50 resistors, which are highlighted. The radio needs every one to operate properly. Televisions contain hundreds of resistors, and computers contain even more.

3-1 Resistors



Why is the water pipe that goes to your kitchen faucet smaller than the one that comes into your house from the water company? And why is it much smaller than the main water line that supplies water to your entire town? The reason is that you don't need so much water. The pipe size limits the water flow to what you actually need.

Electricity works in a similar manner, except that wires have so little resistance that they would have to be very, very thin to limit the flow of electricity. They would be hard to handle and break easily. But the water flow through a large pipe could also be limited by filling a section of the pipe with rocks (a thin screen would keep the rocks from falling over), which would slow the flow of water but not stop it.

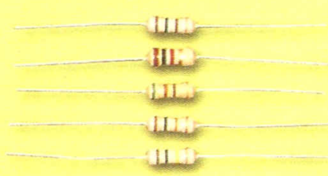


Resistors are like rocks for electricity, they control or limit how much electric current flows. The resistance, expressed in **ohms** (Ω, named after George Ohm) or kilohms (KΩ, 1000 ohms) is a measure of how much a resistor resists the flow of electricity.

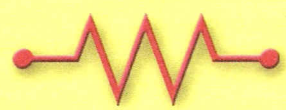
To increase the water flow through a pipe you can increase the water pressure or use less rocks. To increase the electric current in a circuit you can increase the voltage or use a lower value resistor.

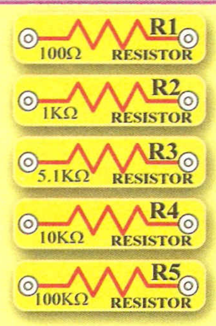
Introducing New Parts

Snap Circuits® includes five resistors: 100Ω (R1), 1KΩ (R2), 5.1KΩ (R3), 10KΩ (R4), and 100KΩ (R5). If you have the parts with you, take them out and look at them.



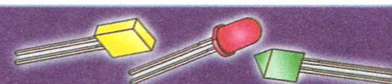
The symbol for the resistor is this squiggly line:





Resistors R1 - R5

3-2 LEDs

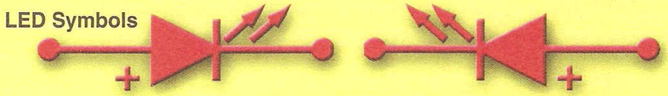


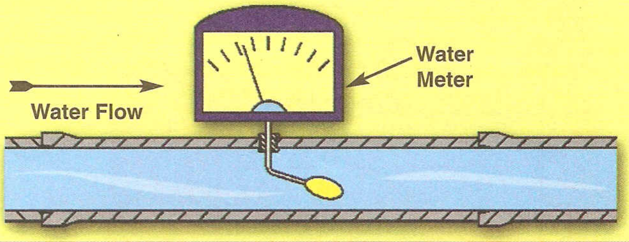
The Snap Circuits® lamps you have (parts L1 and L2) need a high current to be bright, and can be thought of as high current meters since their brightness is an indication of how much current is flowing in a circuit. Even the smallest resistor included in Snap Circuits® will limit the current such that the lamps would not light at all. So you need a low current meter.

Light Emitting Diodes (**LEDs**) may be thought of as one-way, low-current meters. Like light bulbs, their brightness increases as the current through them is increased. But they are made from different materials and so have other characteristics. They are more sensitive than light bulbs and become bright at much smaller currents, but will be damaged by high currents (which is why they should always be used with resistors or other parts to limit the current). They can be made to produce specific colors of light, usually red, green, or yellow. They also completely block current flow in one direction.

Introducing New Parts

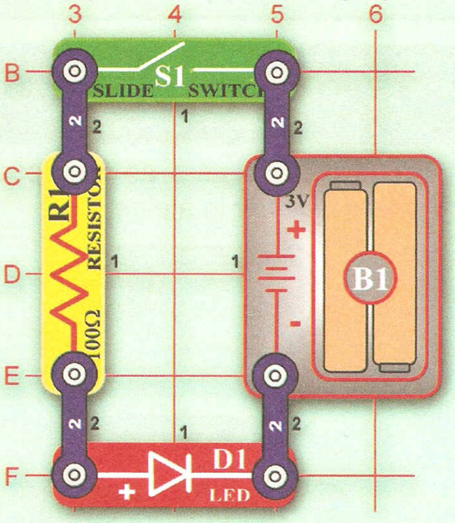
Snap Circuits® includes both a red and a green LED. The arrow in the symbol of the part includes which direction it allows current to flow in (referred to as the forward direction):





Experiments

Consider this simple circuit (which is project 7):

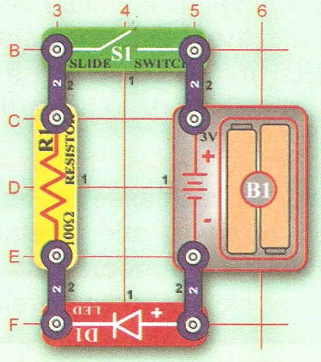


If the switch is on, the LED (D1) will light. The resistor limits the current so that the LED is not damaged (never place an LED directly across the battery). The LED is just like a lamp here, except that it would not be as bright and would use less battery power. Also, an LED appears much brighter when viewed from above than from the side. LEDs concentrate most of their light in one direction, unlike a light bulb which emits light nearly equally in all directions.

If the resistor value in the circuit were increased, the LED would become much dimmer. For example, if the 100Ω resistor (R1) was replaced with the 10KΩ resistor (R4), the LED light could only be seen if the room was very dark.

Experiments

What would happen if the LED position were reversed, in a circuit like this:

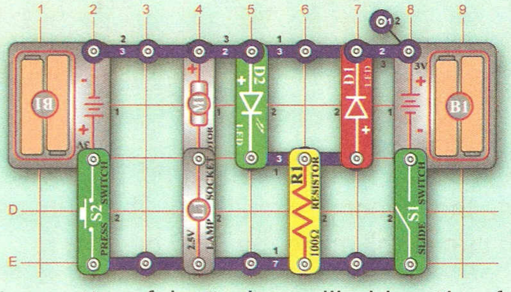


Nothing will happen. The LED prevents any current from flowing, and the LED will be off.

Other Snap Circuits® projects related to this subject: 175

Experiments

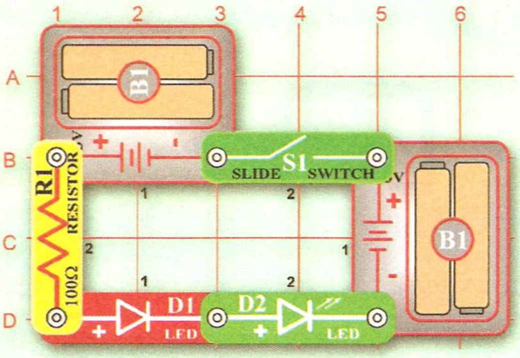
For another example, consider this circuit (which is project 276; be sure the fan is on the motor):



The two sets of batteries will drive the fan in opposite directions, depending on which switch is turned on. Only one LED will light, indicating direction. Unlike the LEDs, the lamp has no polarity and will light in either case. Note that if both switches are on, a short circuit is created and nothing will happen (but the batteries get weaker).

Experiments

Now consider this circuit (which is project 102, redrawn):



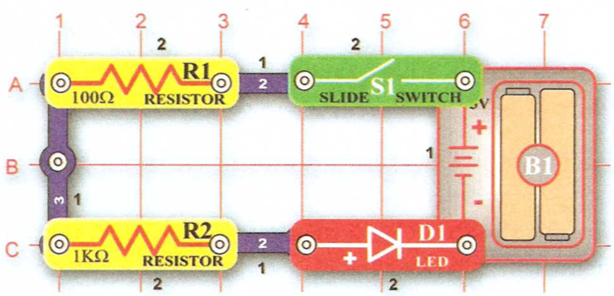
The LEDs would have the same brightness. The same current will flow through both, since they are in series.

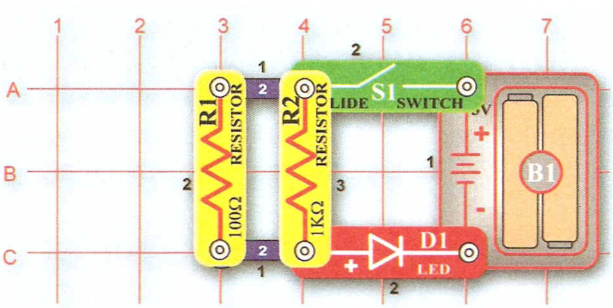
Can you guess why this circuit uses two sets of batteries instead of just one? Each LED has a "turn-on" threshold of about 1.5V that must be exceeded before current will start to flow, after that the brightness depends on the current. When two LEDs are in series the combined threshold is 3V, so one set of batteries will not exceed the threshold by any noticeable degree. This threshold is due to the semiconductor material used in its construction.

LEDs are used as indicator lights in a wide range of electronic products. They are more efficient than ordinary light bulbs and so use less electricity to be seen. But they cannot handle high currents, and so cannot be used to light up a room like light bulbs do.

3-3 Resistors in Series & Parallel

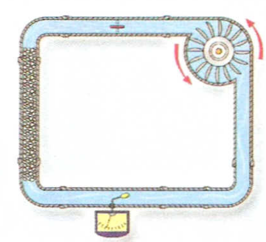
Consider these two mini-circuits:

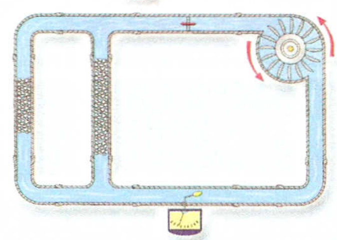




The first circuit has the 100Ω and 1KΩ resistors in series, the second circuit has them in parallel. Which circuit will make the LED brighter?

Just think of the resistors as rock piles slowing down the flow of water in a pipe:





From the water diagrams, it should be easy to see that the circuit with the resistors in parallel will have the brighter LED. You can build these mini-circuits with your snap circuits parts to prove this.

Placing resistors in series increases the total resistance, and so decreases the current to the LED. Resistors in series add together. **Placing resistors in parallel decreases the total resistance**, and so increases the current to the LED.

Advanced students can compute the total resistance as follows:

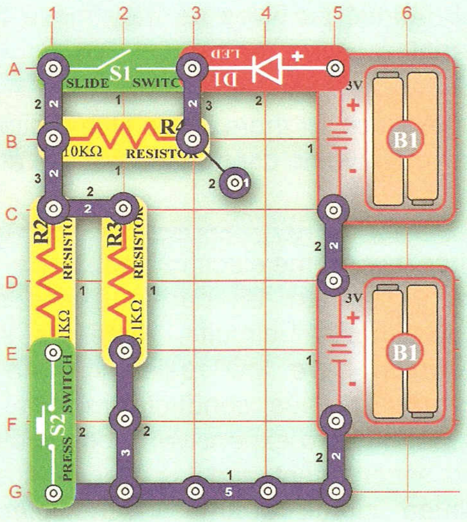
$$R_{series} = R1 + R2 + R3 + \ldots$$

$$\frac{1}{R_{parallel}} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \ldots$$

The total series resistance is greater than the biggest resistor, and the total parallel resistance is smaller than the smallest resistor.

Experiments

As a review, consider this circuit (which is project 173):



If the slide switch (S1) is on, then the LED will be on but not very bright as the 5.1K resistor limits the current. Turning off the slide switch places the 10K resistor in series and the LED becomes very dim. If both switches are on, the 1K resistor is in parallel with the 5.1K and so the LED becomes very bright.

You've learned that when you increase resistance in a circuit, less current flows (making an LED dimmer). This relationship between voltage, current, and resistance is the most important one in electronics. It is known as **Ohm's Law** (after George Ohm who discovered it in 1828):

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

The most basic rules for analyzing circuits as known as **Kirchhoff's Laws** (known after Gustav Kirchhoff, who stated them in 1847):

1. The total voltages driving a circuit must equal the voltage drops within it.
2. All current flowing into a point must flow out of it.

The "**power**" of electricity is a measure of how much energy is moving through a wire. It is expressed in **Watts** (W, after James Watt for his work with engines). It is a combination of the electrical voltage (pressure) and current:

$$\text{Power} = \text{Voltage} \times \text{Current}$$

OR

$$\text{Power} = \frac{\text{Voltage} \times \text{Voltage}}{\text{Resistance}}$$

Resistor Color Code:

You may have seen the colored bands on the resistors and may be wondering what they mean. They are the method for marking the value of resistance on the part. The first ring represents the first digit of the resistor's value. The second ring represents the second digit of the resistor's value. The third ring tells you the power of ten to multiply by, (or the number of zeros to add). The fourth and final ring represents the construction tolerance. Most resistors have a gold band for a 5% tolerance. The colors below are used to represent the numbers 0 through 9.

COLOR	VALUE
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9

Use the color code to check the values of the five snap circuits resistors. They are all 5% tolerance.

3-4 Resistance

Just what is Resistance? Take your hands and rub them together very fast. Your hands should feel warm. The friction between your hands converts your effort into heat. **Resistance** is the electrical friction between an electric current and the material it is flowing through; it is the loss of energy from sub-atomic particles as they move through the material.

You can also compare resistors to the friction with the ground when you walk. If there is too much friction (like two feet of snow) you have to go very slow or get stuck. If there is too little friction (like ice) then you have no control and will slip and fall.

Resistors are made from carbon and can be constructed with different resistive values, such as the five parts included in Snap Circuits®. If a large amount of current is passed through a resistor then it will become warm due to the electrical friction. Resistors get warm because they exert control by wasting power as heat. Light bulbs use a small piece of a highly resistive material called tungsten. Enough current is passed through this tungsten to heat it until it glows white hot, producing light.

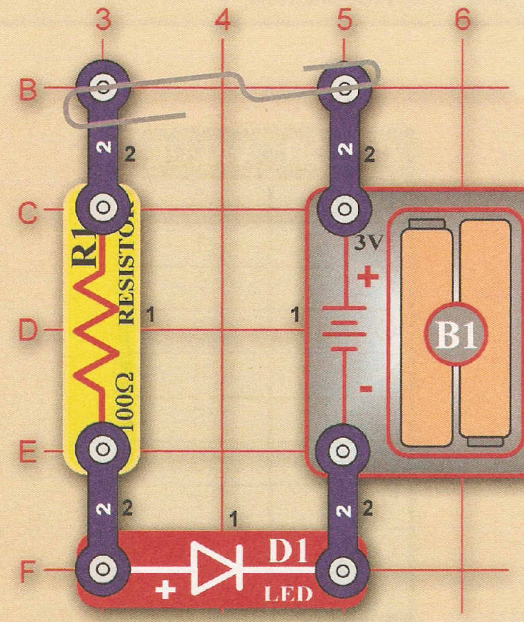
Electric stoves and heaters use resistors to change electricity into heat.

Metal wires have some electrical resistance, but it is very low (less than 1Ω per foot) and can be ignored in almost all circuits. Materials, such as metals, which have low resistance are called **conductors**. The best conductor material known is silver, but it is too expensive to be widely used. Copper is second best, and it is used in most wires and printed circuit boards in the electronics industry.

Materials such as paper, plastic, and air have extremely high values of resistance and are called **insulators**.

Experiments

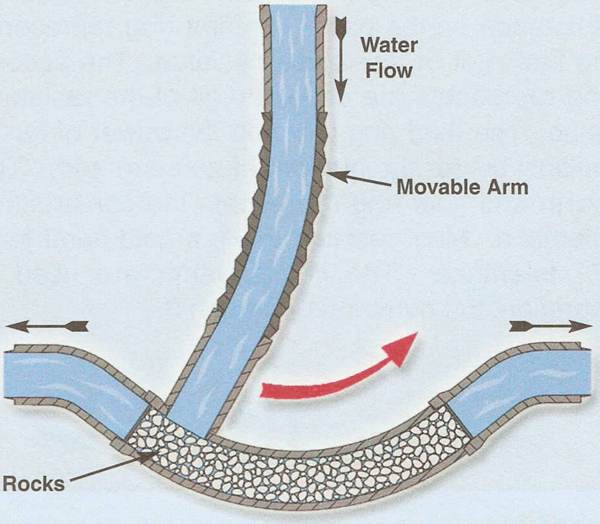
You can use Snap Circuits® to test whether materials are conductors or insulators. Consider this simple circuit (which is project 9):



Place any material across the 2-snap wires (the circuit shows a paperclip). If the LED is bright then it is a conductor, if the LED is off then it is an insulator.

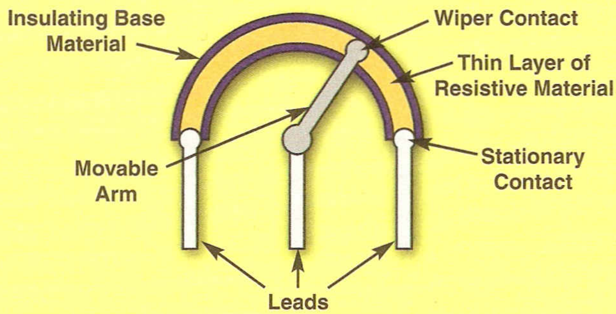
3-5 The Adjustable Resistor

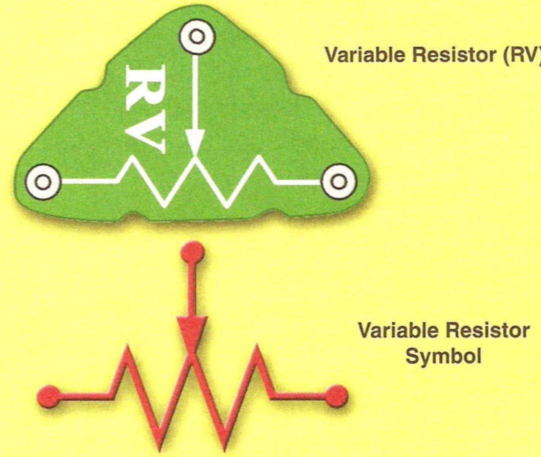
A switch is used to turn the electricity on and off just like a valve is used to turn the water on and off. But there are many times when you want some water but don't need all that the pipe can deliver, so you control the water by adjusting an opening in the pipe with a faucet. Unfortunately, you can't adjust the thickness of an already thin wire. But you could also control the water flow by forcing the water through an adjustable length of rocks, as in the rock arm shown below.



Introducing New Parts

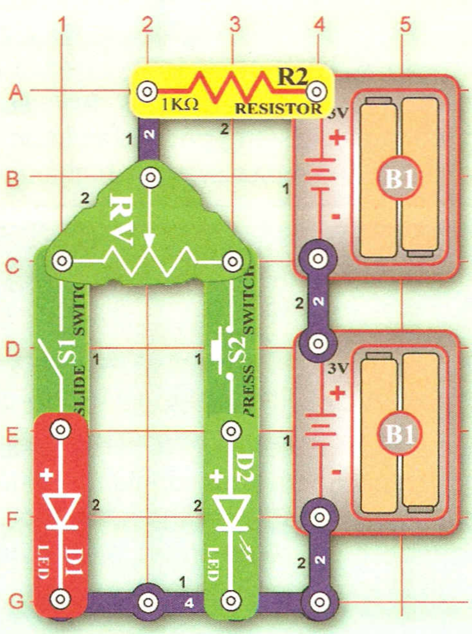
In electronics we use an adjustable resistor. This is a normal resistor (50KΩ in Snap Circuits®) with an additional arm contact that can move along the resistive material and tap off a portion of it.





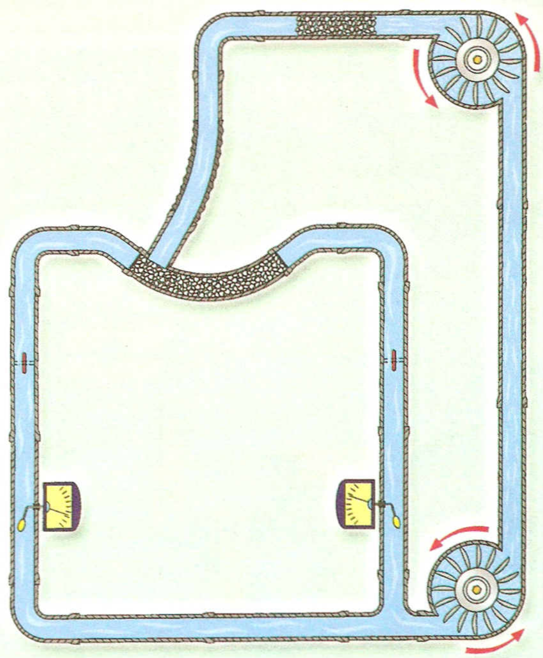
Experiments

Consider this circuit (which is project 172):



If the slide switch and the press switch are both on, moving the adjustable resistor's control lever around will adjust the brightness of the LEDs. When the adjustable resistor is set to one side, that side will have low resistance and its LED will be bright while the other side will have high resistance and its LED will be dim or off. The 1K resistor (R2) limits the current so the LEDs cannot be damaged.

This circuit can also be thought of as if it were water flowing through pipes:



3-6 The Photo Resistor

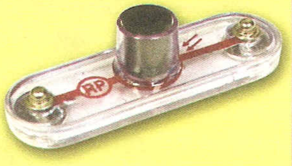
Some materials, such as Cadmium Sulfide, change their resistance when light shines on them. Electronic parts made with these light-sensitive materials are called photoresistors. Their resistance decreases as the light becomes brighter.

Introducing New Parts

Snap Circuits® includes one photoresistor. Its resistance value changes from nearly infinite in total darkness to about 1KΩ when bright light shines directly on it. Note that a black plastic case partially shields the Cadmium Sulfide part.

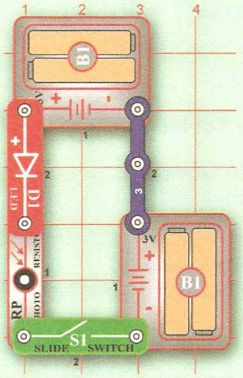
Photo Resistor (RP)

Photo Resistor Symbol



Experiments

Consider this circuit (which is project 272):



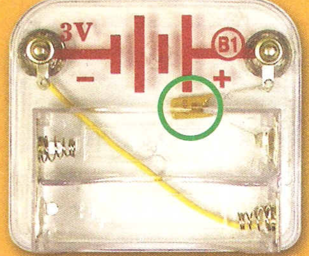
The brightness of the LED depends on how much light shines directly on the photoresistor. If the photoresistor were held next to a flashlight or other bright light, then the LED would be very bright.

Photoresistors are used in applications such as streetlamps, which come on as it gets dark due to night or a severe storm.

Thermistors: Resistors can also be made to change resistance as the temperature changes. These are called thermo-resistors. They are used in applications like electronic thermometers, or to compensate for other circuit characteristics that are changing with temperature.

Thermistors can also be made to act as fuses. At low currents they have only slight resistance and don't affect a circuit. High currents (due to a short circuit) cause them to heat up and greatly increase resistance, limiting the current to prevent damage.

A thermistor like this is inside each of the battery holders in Snap Circuits®:

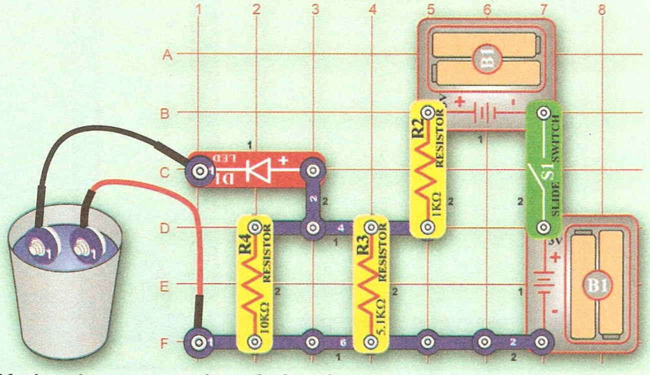


This thermistor will activate to limit current if a short circuit occurs for more than a few seconds. Running the motor for long periods will sometimes activate it, since the motor draws a high current.

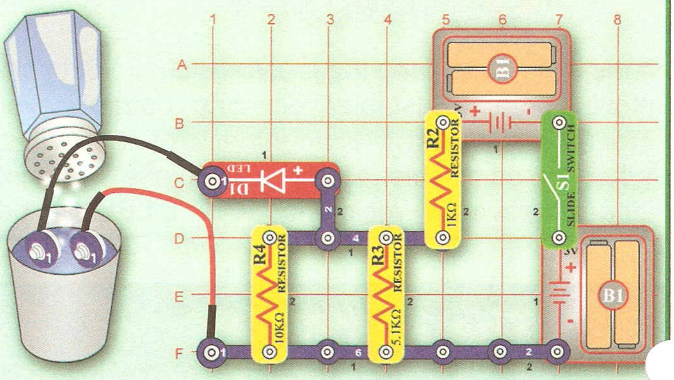
3-7 Resistance of Water

Experiments

Consider this circuit (which is project 166):



If the loose ends of the jumper wires are placed into a cup of water, the LED will be dimly lit. The circuit was designed so that the LED acts as a water detector. The brightness depends on your local water supply. If more water were added to the cup, the LED brightness would increase slightly. Adding more water is like placing more "water resistors" in parallel; and so decreases the total resistance. Pure water (like distilled water) has very high resistance, but drinking water has impurities mixed in that lower the resistance. What would happen if salt was added to the cup and dissolved in the water?



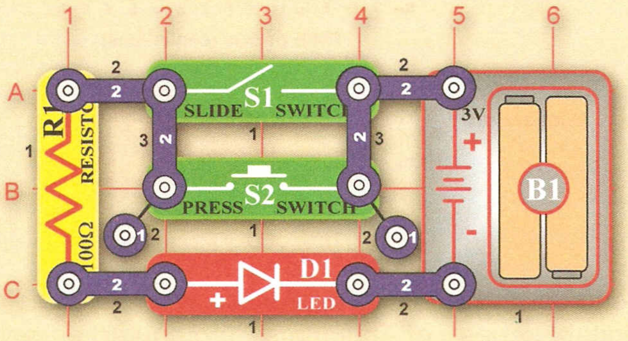
Dissolving salt in water decreases the resistance of the water, so the LED would get brighter. It could be used as a salt-water detector. Adding more water to dilute the salt could reduce the brightness.

Nearly all electricity produced eventually becomes heat. All currents flowing through resistors produce heat in them. Light from a lamp or TV produces heat in whatever it shines on. All the circuits in a computer produce heat, and most computers have vents to get this heat out.

3-8 Introduction to Logic

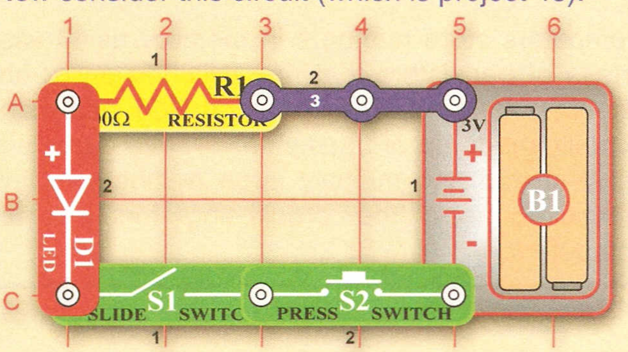
Experiments

Consider this circuit (which is project 47):



If the slide switch OR the press switch is on, the LED lights up. This is called an OR circuit. While this may seem very simple and boring, it represents an important concept in electronics. Two switches like this may be used to turn on a light in your house. You could also have more than two switches and the circuit would function the same way.

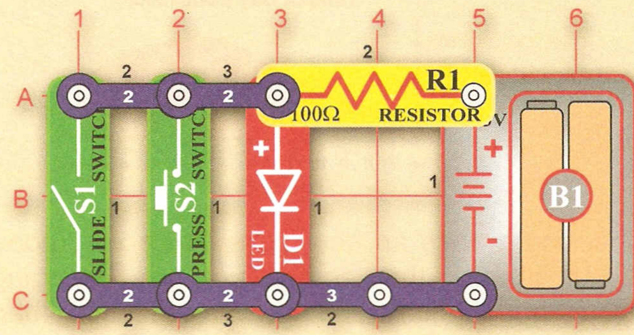
Now consider this circuit (which is project 48):



If the slide switch AND the press switch are on, the LED lights up. This is called an AND circuit. Two switches like this may be used to turn on the same light in your house, the room switch and the master switch in the electrical box.

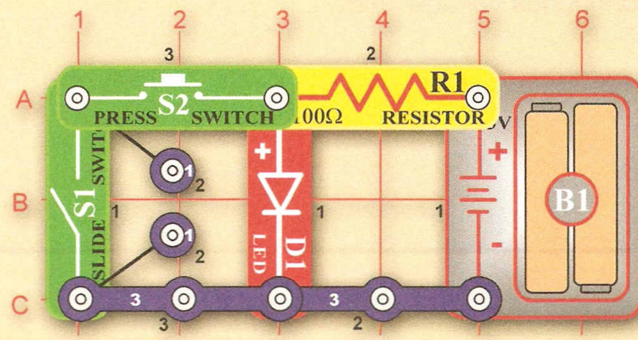
AND and OR circuits are the basic building blocks of today's computers, though transistors are used instead of switches and LEDs. Combinations of AND and OR circuits are used to add and multiply numbers together.

Now consider this circuit (which is project 49):



This circuit is the counter-part to the OR circuit, the LED lights in the opposite combinations of that circuit. Engineers called it a NOR circuit (short for "NOT this OR that").

Now consider this circuit (which is project 50):

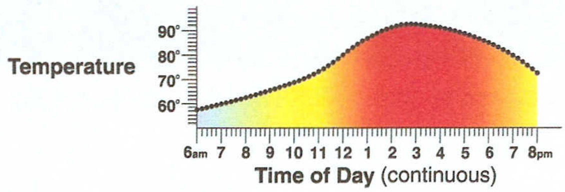


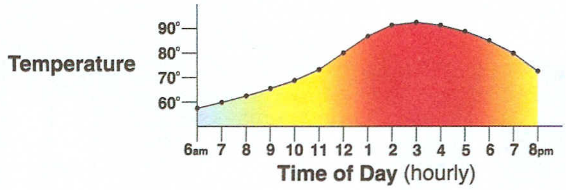
This circuit is the counter-part to the AND circuit, the LED lights in the opposite combinations of that circuit. It is called a NAND circuit (short for "NOT this AND that"). This circuit can also have more or less than two inputs, though when it only has one input it is referred to as a NOT circuit.

OR, AND, NOR, NAND and NOT circuits are all important building blocks in modern computers.

3-9 DIGITAL ELECTRONICS

Suppose you wanted to keep a record of how the temperature outside was changing throughout the day. You could use a thermometer to measure it, and watch it continuously or just check it every hour and write it down. Your results might look something like this:

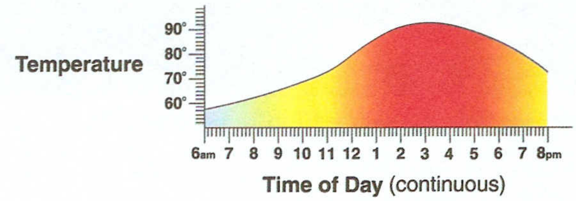


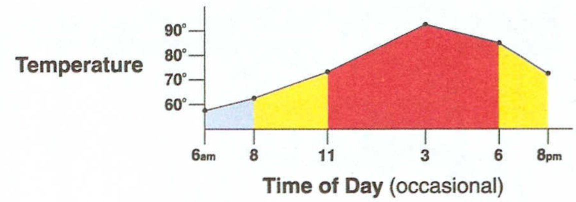


Checking it once an hour gave you a very good record of how the temperature was changing throughout the day, with much less effort than watching it all day long.

Digital electronics uses a series of numbers to represent an electrical signal. If your thermometer was electronic it might increase an output voltage as the temperature increased. It would be hard to store what that voltage was throughout the day, but easy to measure it and store it as a series of numbers. The series of numbers could be converted back into a continuous voltage later.

The accuracy of your digital representation depends on how accurately and how often you measured the original voltage. For example, you could get a better or worse representation of your temperature:





Sometimes it is easier to process information as a digital series of numbers (computers), and sometimes it is easier to use a continuously changing voltage (AM radios). Many products use both methods on the same information but at different times. The disadvantage of digital systems is that they are more complex since they have to store and process all the numbers. The advantages are that IC technology makes it inexpensive to store and process information, and digital systems are more protected from interference.

Computers store numbers in memory using vast arrays of transistors that are switched on or off. The OR, AND, NOR, NAND, and NOT gates are actually made up of transistors. These gates are used to add and multiply large numbers in tiny pieces to form the processing functions in computers.

Quick Quiz

1. Draw a schematic for a circuit using a battery set, an LED, a 50KΩ adjustable resistor, and a 1KΩ resistor. The LED must have adjustable brightness, and must never have less than 1KΩ in series with it.

Summary

Summary of Chapter 3:

1. Resistors are used to limit and control the current in a circuit.

2. Resistance is a measure of how much something opposes the flow of electricity in a circuit, and is expressed in ohms.

3. Light emitting diodes (LEDs) are one-way, low-current light bulbs. They have a turn-on threshold of about 1.5V.

4. Placing resistors in series increases the total resistance. Placing resistors in parallel decreases the total resistance.

5. In a circuit, the current equals the voltage divided by the resistance. This is known as Ohm's Law.

6. Power measures how much energy is moving through a circuit, it equals the voltage multiplied by the current and is expressed in Watts.

7. Materials which have very low resistance are called conductors. Materials which have very high values of resistance and are called insulators.

8. Photoresistors change their resistance when light shines on them.

9. All currents flowing through resistors produce heat in them.

10. OR, AND, NOR, NAND and NOT circuits are basic building blocks of computers.

11. Digital electronics uses numbers to represent an electronic signal. The accuracy of the digital representation depends on how accurately and how often the original signal was measured.

12. Computers store numbers using arrays of transistors that are switched on or off.

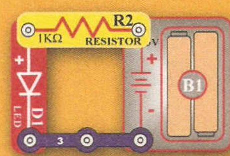
Quiz

Chapter 3 Practice Problems

1. The following are characteristics of an LED except:
   A. They block current flow in one direction.
   B. They get brighter as current increases.
   C. They can handle very high currents.
   D. They can emit different colors of light.

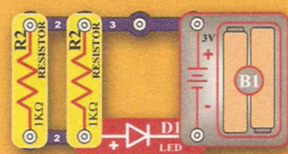
2. To increase the current through a circuit, you . . .
   A. Increase the resistance.
   B. Decrease the watts.
   C. Increase the ohms.
   D. Increase the voltage.

3. Which circuit will be the brightest? Which will be the dimmest?

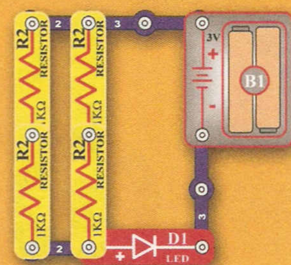


A

B

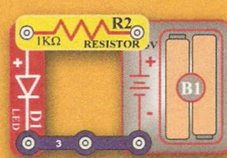


C

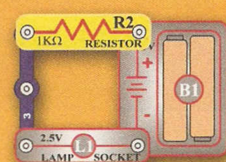


D

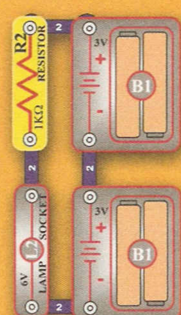
4. Which circuit will be the brightest?



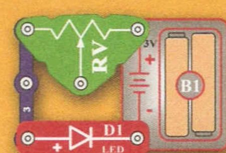
A



B



C



D

Answers: 1. C, 2. D, 3. C/B, 4. A