

## Additional Information

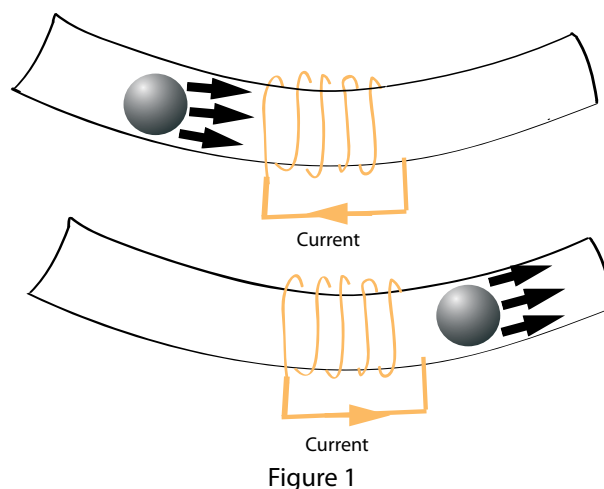
### How The Marble Generator Works

When the magnetic marble is in motion, it has kinetic energy. The marble's kinetic energy increases as its speed increases. The marble generator is able to convert this kinetic energy into electric energy by taking advantage of a physical phenomenon known as electromagnetic induction, which is described by Faraday's Law.

### Faraday's Law of Electromagnetic Induction

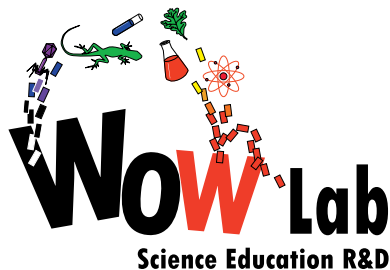
Faraday's Law is one of four fundamental principles of electromagnetism collectively known as the Maxwell's Equations. This law states: "the induced electromotive force is proportional to the rate of change of magnetic flux in a closed circuit".

A magnet moving through a closed coil of conducting wire will induce a current in that wire whose magnitude is proportional to the magnet's speed. When the marble moves towards the coil, a current is induced in one direction. When the marble moves away from the coil, the direction is reversed. **Figure 1** demonstrates the relationship between current direction and the marble's motion relative to the coil. Although this is a very simplified explanation of Faraday's Law, it helps explain the physics behind this activity.



### Closed and Open Circuits

Notice that Faraday's Law refers to a "closed circuit". Current can only flow around a closed path. Notice also that the original construction of the marble generator forms an "open circuit" with the coiled wire; the two ends of the wire are not attached to each other to form a complete loop. The question to ask is what happens in the coil as the marble moves through it. If the two ends were attached to each other, then Faraday's Law guarantees current flow around the closed circuit formed by the coil. When the two ends hang freely, forming an open circuit, obviously no current is induced in the coil regardless of marble movement. However, the generator still acts as a source of electricity, because the instant the two ends are attached to each other, or to some device that will provide a closed path, current will flow (provided the marble is moving). Since the two ends of the coil have the potential to drive an electronic device, they act as a voltage source, such as a battery. The two ends can be connected to a voltmeter to measure the voltage. They can be connected to an LED, which will cause the LED to light up.



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## Marble Generator - Additional Information

### Diodes

LED stands for Light Emitting Diode. There are many varieties of diodes, but in general, a diode is a two-ended device that only allows current to flow in one direction. Without the LED, the moving marble simply induces a voltage across the two ends of coil. The open circuit is closed by connecting the LED. The voltage will drive current out of one end of the coil, through the LED, then into the other end.

Since diodes only conduct current in one direction, it is important to distinguish the two ends. All LEDs will have one pin that is longer than the other. The longer pin is called the anode and the shorter pin is called the cathode. Current flows into the anode and out of the cathode. In a circuit diagram, the tail of the arrow representing a diode is the anode. The polarity of the voltage across a diode is conventionally defined to be positive at the anode and negative at the cathode. In other words, a positive voltage across a diode means the anode has higher potential than the cathode, and a negative voltage means the anode has lower potential. Also by convention, positive current is defined to flow into the positive terminal of a device and out of the negative. Therefore, only positive current can flow through a diode.

It is often inconvenient to study the current flowing through a diode or any electronic device. It is much easier to measure voltage across the terminals of a device and make deductions about the current. In an ideal situation, when a positive voltage is applied across a diode, it is turned on and current flows into the anode and out of the cathode. This condition is known as forward biased. When the voltage is negative, the device turns off and no current flows through the device. This is because current can only flow in one direction and reversing voltage polarity also reverses current direction. This condition is known as reverse biased.

In practice, a positive voltage is not sufficient to turn on a diode. In order for current to flow, the applied voltage must surpass a certain threshold. In standard LEDs, this threshold ranges between 1.2 V to 2.5 V and is known as the forward voltage. The forward voltage of an ideal diode is 0 V. Due to this forward voltage, the marble cannot move through the coil too slowly because it will not generate enough voltage to turn on the LED.

Finally, recall that the direction of the current induced in the wire of the coil changes depending on whether the marble is moving towards or away from the coil. It doesn't matter which end of the coil is connected to the anode and the cathode. In one situation, the LED will only turn on when the marble moves towards the coil. In the other situation, it will turn on when the marble moves away. Therefore, the LED will turn on regardless of whether the marble is moving from left to right, or right to left. Unfortunately, these events happen too fast to be observed.