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Exploring Hydroelectricity

Student Guide

NEED

National Energy Education Development Project

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What Is Energy?

Energy makes change; it does things for us. It moves cars along the road and boats on the water. It bakes cakes in the oven and keeps ice frozen in the freezer. It plays our favorite songs on the radio and lights our homes. Energy helps our bodies grow and allows our minds to think. Energy is defined as the ability to do work or produce change.

Energy is found in different forms, such as light, heat, sound, and motion. There are many forms of energy, but they can all be put into two categories: potential and kinetic.

Potential Energy

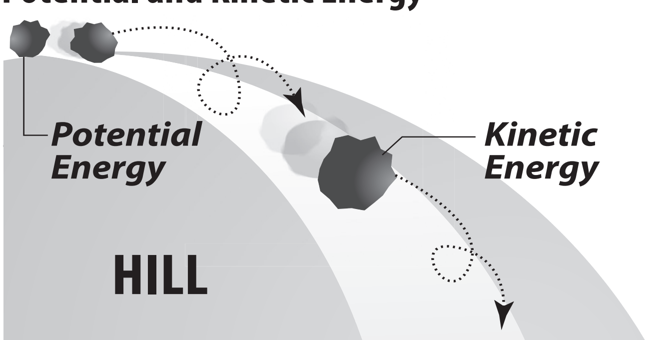
Potential energy is stored energy or the energy of position. There are several forms of potential energy, including:

- **Chemical energy** is energy that is stored in the bonds of atoms and molecules that holds these particles together. Biomass, petroleum, natural gas, and propane are examples of stored chemical energy.
- **Nuclear energy** is energy stored in the nucleus of an atom—the energy that binds the nucleus together. The energy can be released when small nuclei are combined (fusion) or large nuclei are split apart (fission). In both fission and fusion, mass is converted into energy, according to Einstein's Theory, $E = mc^2$.
- **Stored mechanical energy** is energy stored in objects by the application of a force. Compressed springs and stretched rubber bands are examples of stored mechanical energy.
- **Gravitational potential energy** is the energy of position or place. A rock resting on top of a hill contains gravitational potential energy because of its position. If a force pushes the rock, it rolls down the hill because of the force of gravity. The potential energy is converted into kinetic energy until it reaches the bottom of the hill and stops.

  The water in a **reservoir** behind a hydropower dam is another form of gravitational potential energy. The stored energy in the reservoir is converted into kinetic energy of motion as the water flows down a pipe called a **penstock** and spins a turbine.

  The **turbine** spins a shaft inside a **generator**, where magnets and coils of wire convert the motion energy into electrical energy. This electricity is transmitted over power lines to consumers who use it to accomplish many tasks.

Potential and Kinetic Energy

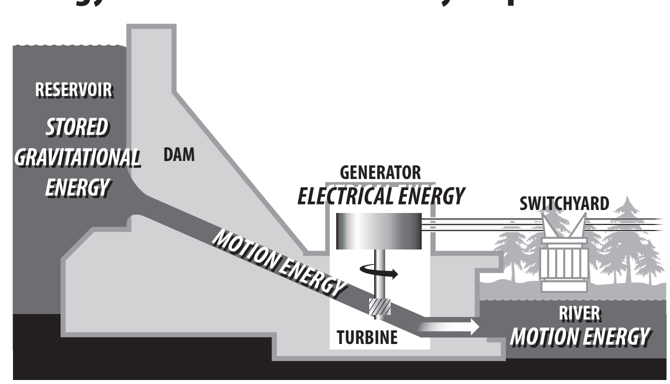


Kinetic Energy

Kinetic energy is energy in motion—the motion of electromagnetic and radio waves, electrons, atoms, molecules, substances, and objects. Forms of kinetic energy include:

- **Electrical energy** is the movement of **electrons**. Everything is made of tiny particles called atoms. **Atoms** are made of even smaller particles—electrons, protons, and neutrons. Applying a force can make some of the electrons move. The movement of electrons in a wire is called electricity. Lightning is another example of electrical energy.
- **Radiant energy** is electromagnetic energy that travels in transverse waves. Radiant energy includes visible light, x-rays, gamma rays, and radio waves. Solar energy is an example of radiant energy.
- **Thermal energy** is the internal energy in substances—the vibration and movement of the atoms and molecules within substances. The more thermal energy a substance posesses, the faster the atoms and molecules vibrate and move, and the hotter it becomes. Geothermal energy is an example of thermal energy.
- **Sound** is the movement of energy through substances in longitudinal (compression/rarefaction) waves. Sound is produced when a force causes an object or substance to vibrate. The energy is transferred through the substance in a longitudinal wave.
- **Motion** is the movement of objects and substances from one place to another. Objects and substances move when an unbalanced force acts on them according to Newton's Laws of Motion. Wind is an example of motion energy.

Energy Transformations in a Hydropower Dam



Conservation of Energy

Your parents may tell you to conserve energy. "Turn out the lights," they might say. But to scientists, conservation of energy means something quite different. The Law of Conservation of Energy states that energy is neither created nor destroyed. When we consume energy, it doesn't disappear; we change it from one form into other forms. Energy can change form, but the total quantity of energy in the universe remains the same.

A car engine, for example, burns gasoline, converting the chemical energy in the gasoline into useful motion or mechanical energy. Some of the energy is also converted into light, sound, and heat. Solar cells convert radiant energy into electrical energy. Old-fashioned windmills changed kinetic energy in the wind into motion energy to grind grain.

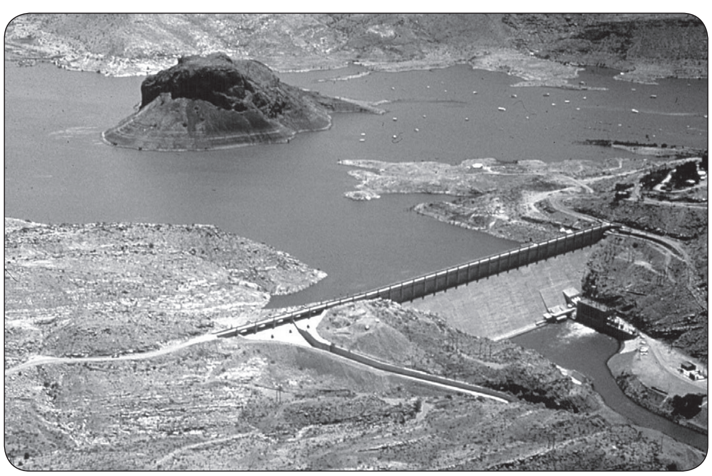
Energy Efficiency

Energy **efficiency** is the amount of useful energy produced by a system compared to the energy input. In theory, a 100 perecnt energy-efficient machine would convert all of the energy input into useful work. Converting one form of energy into another form always involves a loss of usable energy—usually in the form of heat—from friction and other processes. This 'waste heat' dissipates and is very difficult to recapture and use as a practical source of energy.

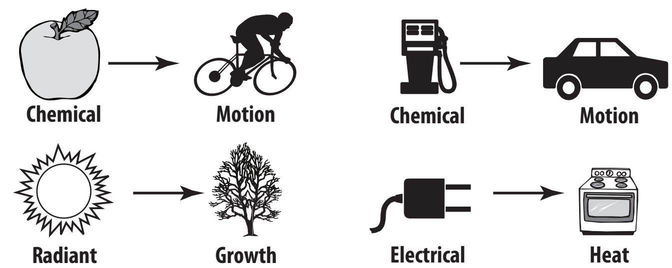
A typical coal-fired power plant converts about 35 percent of the chemical energy in the coal into electricity. A hydropower plant, on the other hand, converts about 90 percent of the kinetic energy of the water flowing through the system into electricity.

Most energy transformations are not very efficient. The human body is a good example. Your body is like a machine, and the fuel for your machine is food. Food gives you the energy to move, breathe, and think. Your body is about fifteen percent efficient at converting food into useful work. The rest of the energy is converted to thermal energy.

GRAVITY DAM

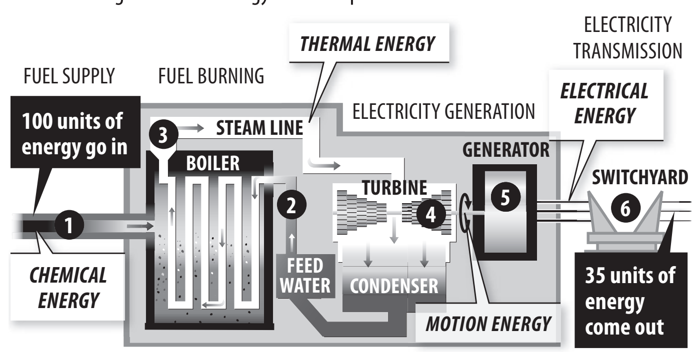


Energy Transformations



Efficiency of a Thermal Power Plant

Most thermal power plants are about 35 percent efficient. Of the 100 units of energy that go into a plant, 65 units are lost as one form of energy is converted to other forms. The remaining 35 units of energy leave the plant to do usable work.



Fuel Sources

How a Thermal Power Plant Works

1. Fuel is fed into a boiler, where it is burned (except for uranium which is fissioned) to release thermal energy.
2. Water is piped into the boiler and heated, turning it into steam.
3. The steam travels at high pressure through a steam line.
4. The high pressure steam turns a turbine, which spins a shaft.
5. Inside the generator, the shaft spins a ring of magnets inside coils of copper wire. This creates an electric field, producing electricity.
6. Electricity is sent to a switchyard, where a transformer increases the voltage, allowing it to travel through the electric grid.

Sources of Energy

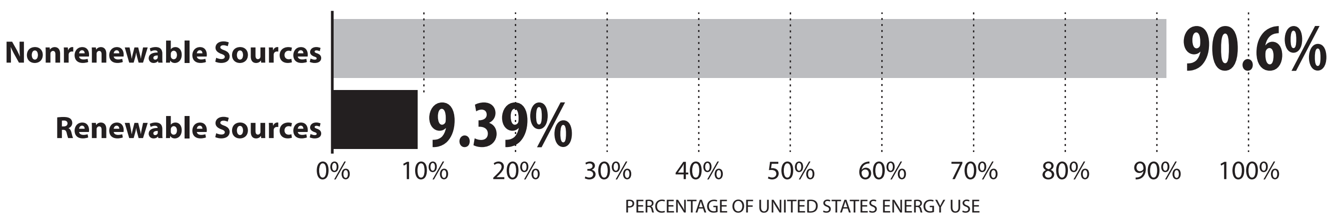
We use many energy sources to meet our needs. All of them have advantages and disadvantages—limitation or reliability of supply, and economic, environmental, or societal impacts. Energy sources are usually classified into two groups—renewable and nonrenewable.

In the United States, most of our energy comes from **nonrenewable energy sources**. Coal, petroleum, natural gas, propane, and uranium are nonrenewable energy sources. They are used to generate electricity, heat homes, move cars, and manufacture all kinds of products from candy bars to MP3 players. They are called nonrenewable because their supplies are limited, and they can not be replenished in a short period of time. Petroleum, for example, was formed hundreds of millions of years ago, before dinosaurs lived, from the remains of ancient sea plants and animals. We could run out of economically recoverable nonrenewable resources some day.

Renewable energy sources include biomass, geothermal, hydropower, solar, and wind. They are called renewable because they are replenished in a short time. Day after day the sun shines, the wind blows, and the rivers flow. We use renewable energy sources mainly to make electricity.

HYDROPOWER

U.S. Consumption of Energy by Source, 2011



Nonrenewable Energy Sources and Percentage of Total Energy Consumption

PETROLEUM 34.67%
Uses: transportation, manufacturing

NATURAL GAS 25.57%
Uses: heating, manufacturing, electricity

COAL 20.22%
Uses: electricity, manufacturing

URANIUM 8.5%
Uses: electricity

PROPANE 1.64%
Uses: heating, manufacturing

Renewable Energy Sources and Percentage of Total Energy Consumption

BIOMASS 4.54%
Uses: heating, electricity, transportation

HYDROPOWER 3.26%
Uses: electricity

WIND 1.2%
Uses: electricity

GEOTHERMAL 0.23%
Uses: heating, electricity

SOLAR 0.16%
Uses: heating, electricity

Data: Energy Information Administration

NOTE: Sum of renewable and nonrenewable energy consumption does not equal 100% due to independent rounding.

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Electricity

Electricity is different from primary energy sources like petroleum or wind—it is a **secondary source of energy**. That means we must use another energy source to produce electricity. Electricity is sometimes called an energy carrier because it is an efficient and safe way to move energy from one place to another, and it can be used for so many tasks. Since electricity is used for many tasks in our daily lives, it is needed and produced in large quantities each day.

A Mysterious Force

What exactly is the mysterious force we call electricity? It is moving electrons. And what are electrons? They are tiny particles found in atoms. Everything in the universe is made of atoms—every star, every tree, every animal. The human body is made of atoms. Air and water are, too. Atoms are the building blocks of the universe. Atoms are so small that millions of them would fit on the head of a pin.

Atomic Structure

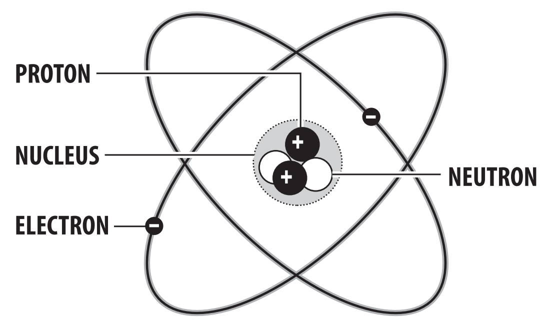
Atoms are made of smaller particles. The center of an atom is called the **nucleus**. It is made of particles called **protons**, which carry a positive (+) charge, and **neutrons**, which carry no charge. Protons and neutrons are approximately the same size. The mass of a single proton is 1.67×10^{-24} gram. Nuclear energy is contained within the nucleus, because a strong nuclear force holds the protons and nuetrons together.

Protons and neutrons are very small, but electrons are much smaller—1836 times smaller, to be precise. Electrons carry a negative charge (-) and move around the nucleus in orbits a relatively great distance from the nucleus. If the nucleus were the size of a tennis ball, the diameter of the atom with its electrons would be several kilometers.

If you could see an atom, it might look a little like a tiny center of spheres surrounded by giant invisible clouds (or energy levels). Electrons are found in these energy levels and are held there by an electrical force. The protons and electrons of an atom are attracted to each other. They both carry an electrical charge. The positive charge of the protons is equal to the negative charge of the electrons. Opposite charges attract each other.

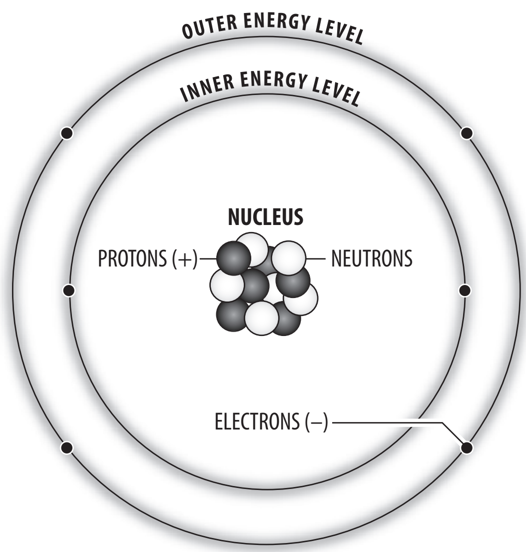
When an atom is in balance, it has an equal number of protons and electrons. The number of neutrons can vary.

Atom



Carbon Atom

A carbon atom has six protons and six neutrons in the nucleus, two electrons in the inner energy level, and four electrons in the outer energy level.



Elements

An element is a substance in which all of the atoms have the same number of protons. The number of protons is given by an element's **atomic number**, which identifies elements. A stable atom of hydrogen, for example, has one proton and one electron, with almost always no neutrons. A stable atom of carbon has six protons, six electrons, and typically six neutrons. The **atomic mass** of an element is the combined mass of all the particles in one atom of the element.

Electrons

The electrons usually remain a constant distance from the nucleus in **energy levels**. The level closest to the nucleus can hold two electrons. The next level can hold up to eight. Additional levels can hold more than eight electrons.

The electrons in the levels closest to the nucleus have a strong force of attraction to the protons. Sometimes, the electrons in the outermost level—the **valence energy level**—do not. In this case, these electrons—**valence electrons**—easily leave their energy levels. Other times, there is a strong attraction between valence electrons and the protons. Often, extra electrons from outside the atom are attracted and enter the valence energy level. When the arrangement of electrons changes in these ways, energy is gained or transformed. We call this energy from electrons electrical energy.

Applying a force can make the electrons move from one atom to another.

Electrical Energy

The positive and negative charges within atoms and matter usually arrange themselves so that there is a neutral balance. However, sometimes there can be a buildup of charges creating more negative than positive charges, or more positive charges than negative charges. This imbalance produces an electric charge. Unlike electric current where electrons are moving, these electrons don't move until there is another object for them to move to. This is called static electricity. When the charges become too unbalanced there is a discharge of electrical energy between positively and negatively charged areas. This is what causes lightning to jump from cloud to cloud, or between a cloud and the ground.

Magnets

In most objects the molecules that make up the substance have atoms with electrons that spin in random directions. They are scattered evenly throughout the object. Magnets are different—they are made of molecules that have north- and south-seeking poles.

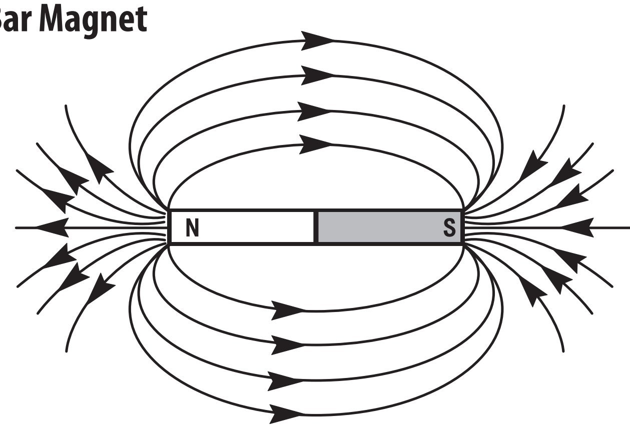
The molecules in a magnet are arranged so that most of the north-seeking poles point in one direction and most of the south-seeking poles point in the other.

Spinning electrons create small **magnetic fields** and act like microscopic magnets or micro-magnets. In most objects, the electrons located around the nucleus of the atoms spin in random directions throughout the object. This means the micro-magnets all point in random directions cancelling out their magnetic fields. Magnets are different—most of the atoms' electrons spin in the same direction which means the north- and south-seeking poles of the micro-magnets they create are aligned. Each micro-magnet works together to give the magnet itself a north- and south-seeking pole.

Several Common Elements

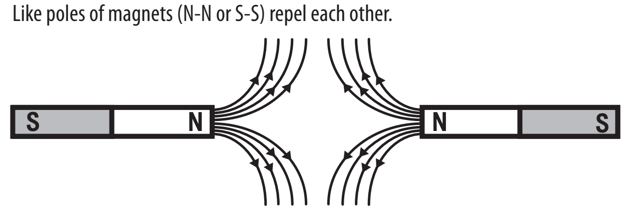
ELEMENT	SYMBOL	PROTONS	ELECTRONS	NEUTRONS
Hydrogen	H	1	1	0
Lithium	Li	3	3	4
Carbon	C	6	6	6
Nitrogen	N	7	7	7
Oxygen	O	8	8	8
Magnesium	Mg	12	12	12
Iron	Fe	26	26	30
Copper	Cu	29	29	34
Gold	Au	79	79	118
Uranium	U	92	92	146

Bar Magnet



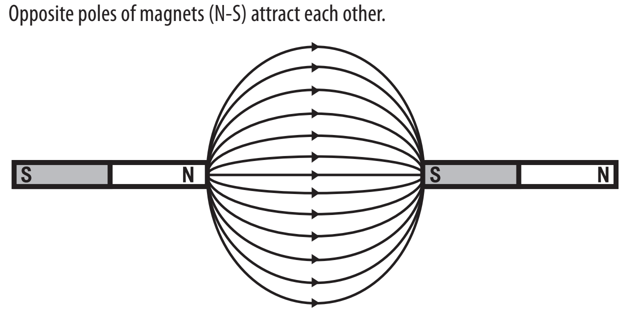
Like Poles

Like poles of magnets (N-N or S-S) repel each other.



Opposite Poles

Opposite poles of magnets (N-S) attract each other.



Electromagnetism

A magnetic field can produce electricity. In fact, magnetism and electricity are really two inseparable aspects of one phenomenon called **electromagnetism**. A changing magnetic field can produce electricity. Every time there is a change in an electric field, a magnetic field is produced. This relationship is used to produce electricity. Some metals, such as copper, have electrons that are loosely held. They can be pushed from their valence energy levels by the application of a magnetic field. If a coil of copper wire is moved around a changing magnetic field, or if magnets are moved around a coil of copper wire, an electric current is generated in the wire.

Electric current can also be used to produce magnets. Around every current-carrying wire is a magnetic field, created by the uniform motion of electrons in the wire. Magnets used to produce electric current are called **electromagnets**.

Generating Electricity

When it comes to the production of electricity, it's all turbines and generators. A turbine is a device that converts the flow of a medium such as air, steam, or water into motion energy to power a generator. A generator is an engine that converts motion energy into electrical energy using electromagnetism.

An electric generator is actually an electric motor that runs backward. Work is done to cause magnets to spin within coils of wire to produce electricity. Depending on the generator's design, work can also cause the wires to move. When the wire moves through the external magnetic field, electrons in the wire are pulled and move through the wire. These electrons can be directed out of the generator as electricity.

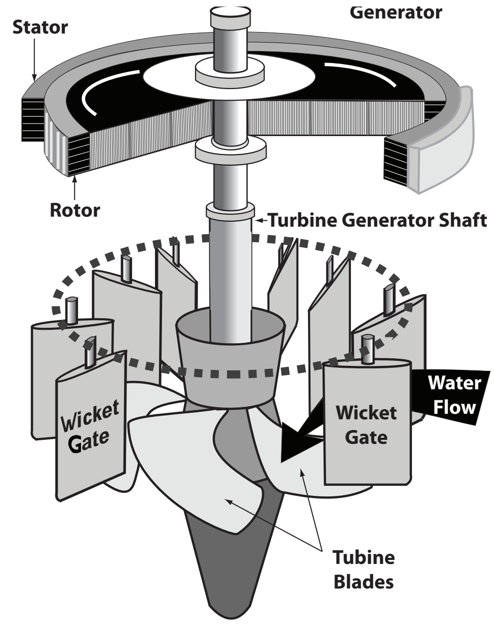
Although electric motors and generators may seem complicated, the principle of electromagnetism is simple. When electricity moves through a wire, a magnetic field is created around the wire. In an electric motor, the motor's wire is placed between external magnets. When electricity is sent through the wire, the magnetic field created around the wire interacts with the magnetic field of the external magnets. This interaction causes the wire to move. If the wire is designed so it is free to turn, the wire will spin and you have an electric motor.

Power plants use huge turbine generators to generate the electricity we use in our homes and businesses. The power plants use many fuels to spin turbines. They can burn coal, oil, biomass, or natural gas to heat water into high-pressure steam, which is used to spin the turbines. They can split atoms of uranium in a nuclear power plant to heat water into steam.

Geothermal power plants harness hot water and steam from underground reservoirs to spin turbines. We can also harness the energy in flowing water and the energy in the wind to spin turbines. Photovoltaic (solar) cells are made with chemically infused silicon that allows them to convert radiant energy from the sun directly into electricity.

Once the electricity is produced, it is moved to our homes and businesses. It moves through large electrical lines. Electricity moves most efficiently under high voltage. When the electricity leaves the power plant, its voltage must be drastically increased. When it reaches our homes and businesses, the voltage must be reduced so it will not burn up or damage things that use electricity. The voltage of electricity is easily increased or decreased by a **transformer.** Transformers are commonly seen in our neighborhoods. Electrical substations are a series of transformers used to increase or decrease voltage. If you have an overhead electrical line that goes into your house, you will see a transformer on the pole where the overhead line leaves the larger power line. Usually, these overhead transformers are grey cylinders. They reduce the voltage so that the electricity can safely enter your house.

Hydro Turbine Generator

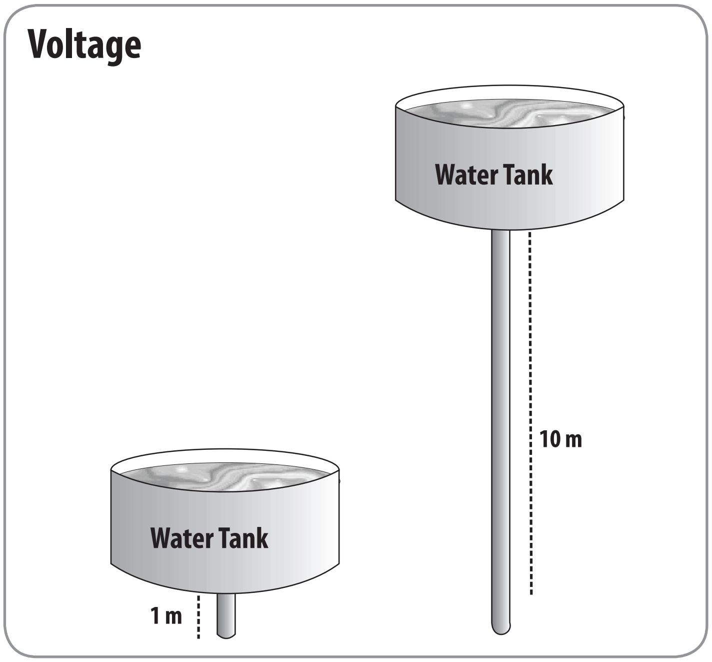


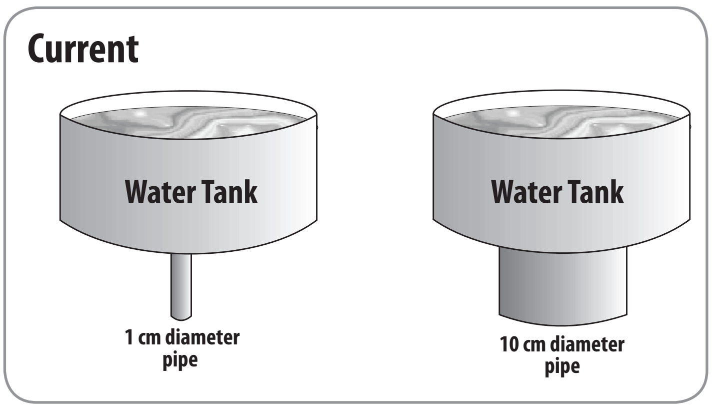
Measuring Electricity

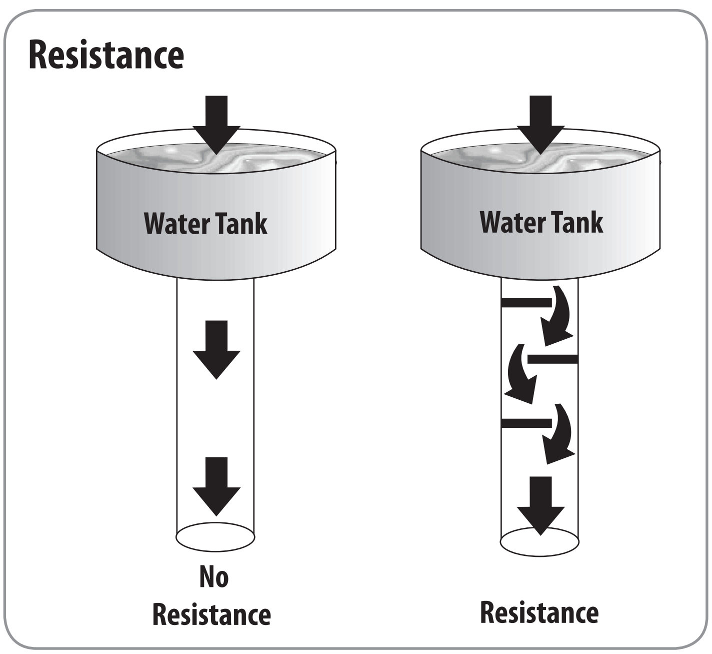
We are familiar with terms such as watt, volt, and amp, but we do not always have a clear understanding of these terms. We buy a 60-watt light bulb, a tool that requires 120 volts, or an appliance that uses 8.8 amps, but we don't think about what those units mean.

Using the flow of water as an analogy can make electricity easier to understand. The flow of electrons in a circuit is similar to water flowing through a hose. If you could look into a hose at a given point, you would see a certain amount of water passing that point each second.

The amount of water depends on how much pressure is being applied—how hard the water is being pushed. It also depends on the diameter of the hose. The harder the pressure and the larger the diameter of the hose, the more water passes each second. The flow of electrons through a wire depends on the pressure pushing the electrons and on the cross-sectional area of the wire.







Voltage

The force or pressure that pushes electrons in a circuit is called **voltage**. Using the water analogy, if a tank of water were suspended one meter above the ground with a one-centimeter pipe coming out of the bottom, the water pressure would be similar to the force of a shower. If the same water tank were suspended 10 meters above the ground, the force of the water would be much greater, possibly enough to hurt you.

Voltage (V) is a measure of the pressure applied to electrons to make them move. It is a measure of the strength of the current in a circuit and is measured in **volts** (V). Just as the 10-meter tank applies greater pressure than the one-meter tank, a 10-volt power supply (such as a battery) would apply greater pressure than a one-volt power supply.

AA batteries are 1.5 volt; they apply a small amount of voltage for lighting small flashlight bulbs.

A car usually has a 12-volt battery—it applies more voltage to push current through circuits to operate the radio or defroster. The standard voltage of wall outlets is 120 volts—a dangerous voltage. An electric clothes dryer is usually wired at 240 volts—a very dangerous voltage.

Current

The flow of electrons can be compared to the flow of water. The water current is the number of molecules of water flowing past a fixed point; **electric current** (I) is the number of electrons flowing past a fixed point.

With electricity, conducting wires take the place of the pipe. As the cross-sectional area of the wire increases, so does the amount of electric current (number of electrons) that can flow through it. Current is measured in **amperes** (A).

Resistance

Resistance (R) is a force that opposes the movement of electrons, slowing their flow. Using the water analogy, resistance is anything that slows water flow, such as a smaller pipe or fins on the inside of a pipe. In electrical terms, the resistance of a conducting wire depends on the properties of the metal used to make the wire and the wire's diameter. Copper, aluminum, and silver—metals used in conducting wires—have different resistance.

Resistance is measured in units called **ohms** (Ω). There are devices called **resistors**, with set resistances, that can be placed in circuits to reduce or control the current flow. Any device placed in a circuit to do work is called a **load**. The light bulb in a flashlight is a load. A television plugged into a wall outlet is also a load. Every load has resistance.

Ohm's Law

The relationship between voltage, current, and resistance is defined in **Ohm's Law**. George Ohm, a German physicist, discovered that in many materials, especially metals, the current is proportional to the voltage. He found that if he doubled the voltage, the current also doubled. If he reduced the voltage by half, the current dropped by half. The resistance of the material remained the same. This relationship is called Ohm's Law and can be described using the formula to the right.

Electric Power

Power (P) is a measure of the rate of doing work or the rate at which energy is converted. Electric power is the rate at which electricity is produced or consumed. Using the water analogy, electric power is the combination of the water pressure (voltage) and the rate of flow (current) that results in the ability to do work.

A large pipe carries more water (current) than a small pipe. Water at a height of 10 meters has much greater force (voltage) than at a height of one meter. The power of water flowing through a one-centimeter pipe from a height of one meter is much less than water through a 10-centimeter pipe from 10 meters.

Electric power is defined as the amount of electric current flowing due to an applied voltage. It is the amount of electrictiy required to start or operate a load for one second. Electric power is measured in **watts** (W).

Electric Energy

Electrical energy introduces the concept of time to electric power. In the water analogy, it would be the amount of water falling through the pipe over a period of time. When we talk about using power over time, we are talking about using energy. Using our water example, we could look at how much work could be done by the water in the time that it takes for the tank to empty.

The electrical energy that a device consumes can be determined if you know how long (time) it consumes electric power at a specific rate (power). To find the amount of energy consumed, you multiply the rate of energy consumption (watts) by the amount of time (hours) that it is being consumed. Electrical energy is measured in watt-hours (Wh).

energy (E) = power (P) x time (t)
E = P x t or E = W x h = Wh

Another way to think about power and energy is with an analogy to traveling. If a person travels in a car at a rate of 40 miles per hour (mph), to find the total distance traveled, one would multiply the rate of travel by the amount of time traveled at that rate. If a car travels for one hour at 40 miles per hour, it would travel 40 miles.

distance = 40 mph x 1 hour = 40 miles

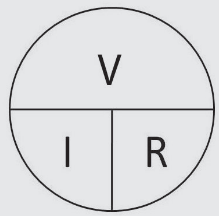
If a car travels for three hours at 40 miles per hour, it would travel 120 miles.

distance = 40 mph x 3 hours = 120 miles

Ohm's Law

- **Voltage = current x resistance**
  V = I x R or V = A x Ω
- **Current = voltage / resistance**
  I = V / R or A = V / Ω
- **Resistance = voltage / current**
  R = V / I or Ω = V / A

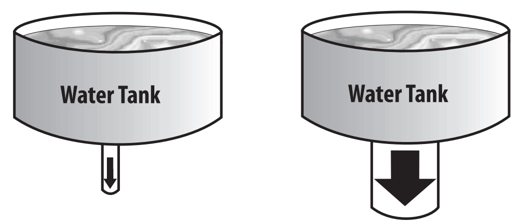
Formulas for Measuring Electricity



V = I x R
I = V/R
R = V/I

The formula pie works for any three variable equation. Put your finger on the variable you want to solve for and the operation you need is revealed.

Electric Power

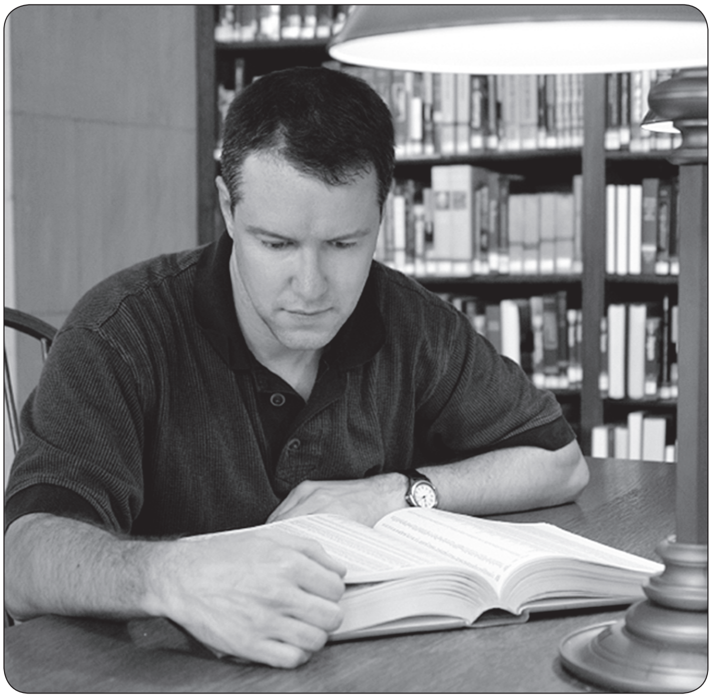


Electric Power Formula

- **Power = voltage x current**
  P = V x I or W = V x A

The distance traveled represents the work done by the car. When we look at power, we are talking about the rate that electrical energy is being produced or consumed. Energy is analogous to the distance traveled or the work done by the car.

A person wouldn't say he took a 40-mile per hour trip because that is the rate. The person would say he took a 40-mile trip. We would describe the trip in terms of distance traveled, not rate traveled. The distance represents the amount of work done. The same applies with electrical energy. You would not say you used 100 watts of light energy to read a book, because a watt represents the rate you use energy, not the total energy used. The amount of energy used would be calculated by multiplying the rate by the amount of time you read.



If you read for five hours with a 100-watt light bulb, for example, you would use the formula as follows:

$$\textbf{energy} = \textbf{power x time } (E = P \times t)$$
$$\textbf{energy} = 100\text{ W} \times 5\text{ hours} = 500\text{ Wh}$$

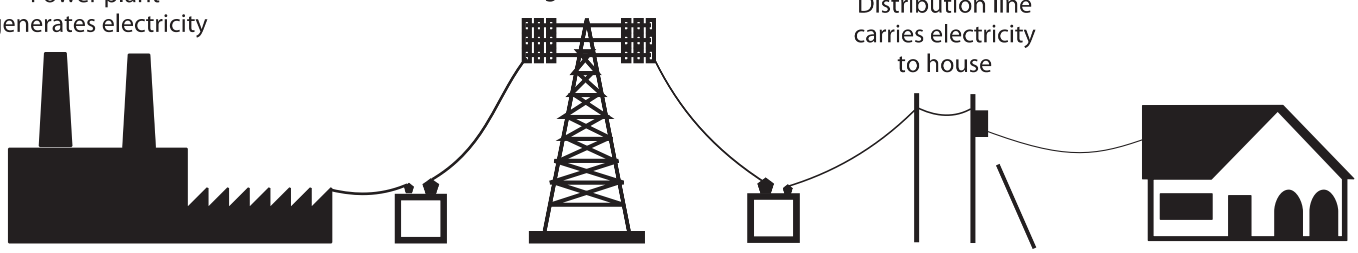
One watt-hour is a very small amount of electrical energy. Usually, we measure electric power in larger units called **kilowatt-hours (kWh)** or 1,000 watt-hours (kilo = thousand). A **kilowatt**-hour is the unit that utilities use when billing most customers. The average cost of a kilowatt-hour of electricity for residential customers is about $0.12.

To calculate the cost of reading with a 100-watt light bulb for five hours, you would change the watt-hours into kilowatt-hours, then multiply the kilowatt-hours used by the cost per kilowatt-hour, as shown below:

$$500\text{ Wh} \times (1\text{ kW}/1{,}000\text{ W}) = 0.5\text{ kWh}$$
$$0.5\text{ kWh} \times \$0.12/\text{kWh} = \$0.06$$

Therefore, it would cost about six cents to read for five hours with a 100-watt light bulb.

Transporting Electricity



Demand for Electricity

Electricity cannot be easily stored in large quantities. It must be generated quickly to meet the fluctuating demand of consumers. Flexible generators, such as hydropower plants, are very important.

As we use more technology, the demand for electricity continues to grow. In the U.S. today, about 40 percent of the energy we consume is in the form of electricity. This percentage is expected to increase and poses many challenges for the nation, with no easy answers.

Global climate change is one important issue, since most U.S. electricity is produced by fossil fuels today. Should fossil fuel plants be required to minimize carbon dioxide emissions? Should we build more nuclear power plants? Can we reduce demand with conservation and efficiency measures? Can renewable energy sources meet the increasing demand? How much are consumers willing to pay for a reliable supply of electricity, for a cleaner environment, for efficient technologies? These questions will only become more important.