5.2 Energy Conservation

In this unit you will learn about energy. *Energy* is one of the fundamental building blocks of our universe. Energy appears in different forms, such as motion and heat. Energy can travel in different ways, such as light, sound, or electricity. The workings of the universe (including all of our technology) can be viewed from the perspective of energy flowing from one place to another and changing back and forth from one form to another.

What is energy?

The definition of energy

Energy is the ability to do work. That means anything with energy can produce a force that is capable of acting over a distance. The force can be any force, and it can come from many different sources, such as your hand, the wind, or a spring.

Energy is the ability to do work. Any object that has energy has the ability to create force.

- A moving ball has energy because it can create forces on whatever tries to stop it or slow it down.
- A sled at the top of a hill has energy because it can go down the hill and produce forces as it goes.
- The moving wind has energy because it can create forces on any object in its path.
- Electricity has energy because it can turn a motor to make forces.
- Gasoline has energy because it can be burned in an engine to make force to move a car.
- You have energy because you can create forces.

Units of energy

Energy is measured in joules, the same units as work. That is because energy is really stored work. Any object with energy has the ability to use its energy to do work, which means creating a force that acts over a distance.

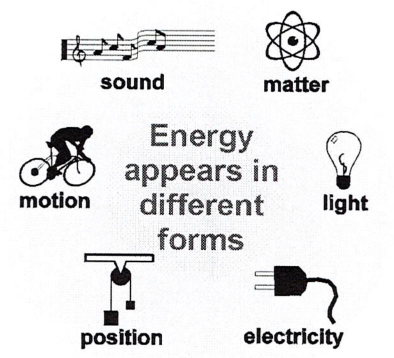


Figure 5.5: *Energy appears in many different forms.*

Potential energy

What is potential energy?

The first type of energy we will explore is called potential energy. Potential energy comes from the position of an object relative to Earth. Consider a marble that is lifted off the table (Figure 5.6). Since Earth's gravity pulls the marble down, we must apply a force to lift it up. Applying a force over a distance requires doing work, which gets stored as the potential energy of the marble. Potential energy of this kind comes from the presence of gravity.

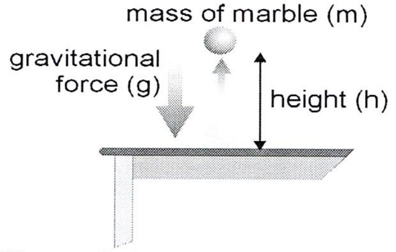


Figure 5.6: *The potential energy of a marble is equal to its mass times gravity (9.8 m/sec^2) times the height of the marble above the surface.*

Where does potential energy come from?

How much energy does the marble have? The answer comes from our analysis of machines from the last section. It takes work to lift the marble up. Energy is stored work, so the amount of energy must be the same as the amount of work done to lift the marble up.

How to calculate potential energy

We can find an exact equation for the potential energy. The force required to lift the marble is the weight of the marble. From Newton's second law we know that the weight (the force) is equal to mass of the marble (m, in kilograms) times the acceleration of gravity (g, equal to 9.8 m/sec^2). We also know that work is equal to force times distance. Since force is the weight of the marble (mg) and the distance is how far we lift the marble (h), the work done equals weight times height.

Potential Energy

Potential energy (joules) → E_p

$$E_p = mgh$$

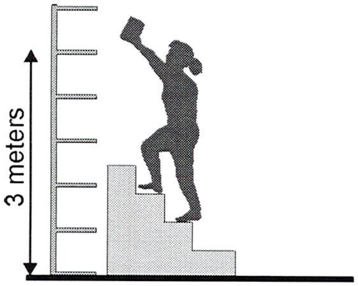
Mass (kilograms) → m

Height (meters) → h

Acceleration of gravity (9.8 m/sec^2) → g

Why is it called potential energy?

Objects that have potential energy don't use their energy until they move. That's why it is called *potential* energy. Potential means that something is capable of becoming active. Any object that can move to a lower place has the potential to do work on the way down, such as a ball rolling down a hill.



Example:

You need to put a 1-kilogram mass that is on the floor, away on a shelf that is 3 meters high. How much energy does this require?

Solution:

(1) You are asked for the potential energy.

(2) You know the mass and height.

(3) The equation for potential energy is $E_p = mgh$.

(4) The equation is already in the right form.

(5) Plug in numbers. Remember: 1 N = 1 kg·m/sec^2, and 1 joule = 1 N·m.

$E_p = (1\ \text{kg}) \times (9.8\ \text{m/sec}^2) \times (3\ \text{m})$

$= 29.4$ joules

Kinetic energy

Kinetic energy is energy of motion

Objects also store energy in motion. A moving mass can certainly exert forces, as you would quickly observe if someone ran into you in the hall. Energy of motion is called **kinetic energy**.

Kinetic energy increases with speed

We need to know how much kinetic energy a moving object has. Consider a shopping cart moving with a speed *v*. To make the cart move faster you need to apply a force to it (Figure 5.7). Applying a force means you do some work, which is stored as energy. The higher the speed of the cart, the more energy it has because you have to do work to increase the speed.

Kinetic energy increases with mass

If you give the cart more mass, you have to push it with more force to reach the same speed. Again, more force means more work. Increasing the mass increases the amount of work you have to do to get the cart moving, so it also increases the energy. Kinetic energy depends on two things: mass and speed.

The formula for kinetic energy

To get an equation for kinetic energy, we would look at work, just like we did for potential energy. The energy is equal to the amount of work you have to do to get a mass (m) from rest up to speed (*v*). The amount of work you need can be calculated from the formula for kinetic energy.

Kinetic Energy

Mass (kilograms)

Kinetic energy (joules) →

$$E_k = \frac{1}{2} m v^2$$

Speed (m/sec)

Kinetic energy increases as the square of the speed

The kinetic energy increases as the square of the speed. This means if you go twice as fast, your energy increases by four times ($2^2 = 4$). If your speed is three times higher, your energy is nine times bigger ($3^2 = 9$). More energy means more force is needed to stop, which is why driving fast is so dangerous. Going 60 mph, a car has four times as much kinetic energy as it does at 30 mph. At a speed of 90 mph you have *nine times* as much energy as you did at 30 mph.

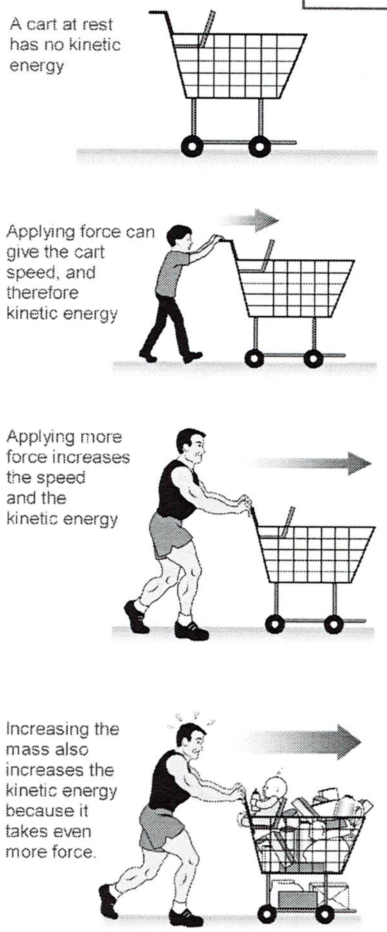


Figure 5.7: *Kinetic energy depends on two things: mass and speed. The amount of kinetic energy the cart has is equal to the amount of work you do to get the cart moving.*

Conservation of energy

The law of conservation of energy

Nature never creates or destroys energy; energy only gets converted from one form to another. This concept is called the **law of conservation of energy**. The rule we found for the input and output work of a machine was an example of the law of conservation of energy.

> ***Energy can never be created or destroyed, just transformed from one form into another***

An example of energy transformation

What happens if you throw a ball straight up in the air? The ball leaves your hand with kinetic energy from the speed you give it when you let go. As the ball goes higher, it gains potential energy. The potential energy gained can only come from the kinetic energy the ball had at the start, so the ball slows down as it gets higher.

Eventually, all the kinetic energy has been converted to potential energy. At this point the ball has reached as high as it will go and its upward speed has been reduced to zero.

The ball falls back down again and gets faster and faster as it gets closer to the ground. The gain in speed comes from the potential energy being converted back to kinetic energy. If there were no friction the ball would return to your hand with exactly the same speed it started with—except in the opposite direction (Figure 5.8)!

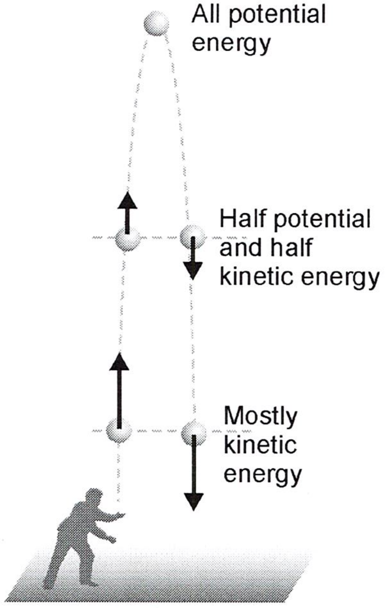


Figure 5.8: *When you throw a ball in the air, its energy transforms from kinetic to potential and back to kinetic.*

The total energy never exceeds the starting energy

At any moment in its flight, the ball has exactly the same energy it had at the start. The energy is divided between potential and kinetic, but the total is unchanged. In fact, we can calculate exactly how high the ball will go if we know the mass and speed we have at the beginning.

Friction can divert some energy

The law of conservation of energy still holds true, even when there is friction. Some of the energy is converted to heat or wearing away of material. The energy converted to heat or wear is no longer available to be potential energy or kinetic energy, but it was not destroyed.

5.3 Energy Transformations

In the last section, you investigated how energy is changed from one form to another. You discovered that kinetic and potential energy change back and forth with the total amount of energy staying constant. In this section, you will apply what you learned to a wide variety of real-life situations involving other kinds of energy transformations.

Following an energy transformation

The different kinds of energy

Kinetic energy and potential energy are only two of the forms energy can take. Sometimes these two forms are called mechanical energy because they involve moving things. There are many other kinds of energy, including *radiant energy, electrical energy, chemical energy* and *nuclear energy*. Just as you saw with kinetic and potential, any of these forms of energy can be transformed into each other and back again. Every day of your life, you experience multiple energy transformations (Figure 5.9) whether you know it or not!

An example of energy transformation

For example, suppose you are skating and come up to a steep hill. You know skating up the hill requires energy. From your mass and the height of the hill you can calculate how much more potential energy you will have on the top (Figure 5.10). You need at least this much energy, plus some additional energy to overcome friction and inefficiency.

Chemical energy to potential energy

The energy you use to climb the hill comes from food. The chemical potential energy stored in the food you ate is converted into simple sugars. These sugars are burned as your muscles work against external forces to climb the hill—in this case, the external force is gravity. In climbing the hill you convert some chemical energy to potential energy.

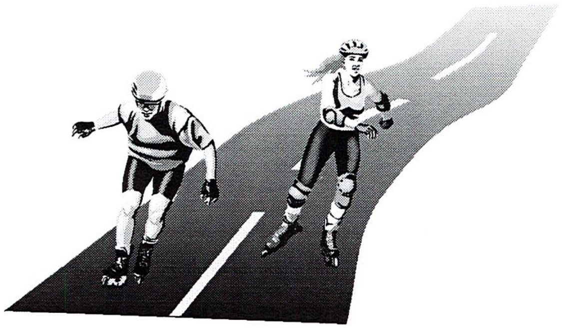
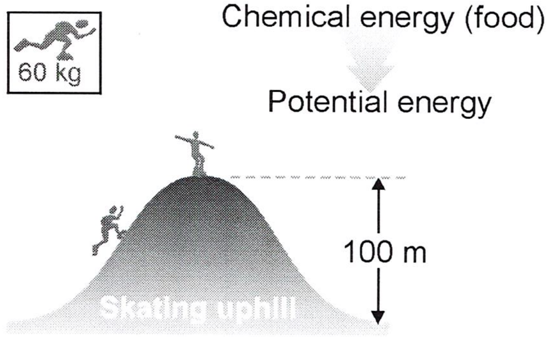


Figure 5.9: *Anything you do involves transforming energy from one kind to another. Exercise transforms chemical energy from food into kinetic and potential energy.*



Potential energy gained = mgh

$= (60 \text{ kg}) \times (9.8 \text{ m/sec}^2) \times (100 \text{ m})$

$= 58{,}800$ joules

Figure 5.10: *At the top of the hill you have gained 58,800 joules of potential energy. This energy originally started as chemical energy in food.*

Where does "spent" energy go?

Upon reaching the top of the hill, you will probably feel like you "spent" a lot of energy. Where did the energy you spent climbing the steep hill go? Some of the energy you spent is now stored as potential energy because your position is higher than when you began. Some of the energy was also converted by your body into heat, chemical changes in muscles, and the evaporation of sweat from your skin. Can you think of any other places the energy might have gone?

How does potential energy get used?

Once you get over the top of the hill and start to coast down the other side, your speed increases, even if you just coast. An increase in speed implies an increase in kinetic energy. Where does all this kinetic energy come from? The answer is that it comes from the potential energy that was increased while you were climbing up the hill. Nature did not steal your energy. Instead, it was saved up and used to "purchase" greater speed as you descend down the other side of the hill.

Kinetic energy is used up in the brakes

If you are not careful, the stored up potential energy can generate too much speed! Assuming you want to make it down the hill with no injuries, some of the kinetic energy must change into some other form. That is what brakes do. Brakes convert kinetic energy into heat and the wearing away of the brake pads.

As you slow to a stop at the bottom of the hill, you should notice that your brakes are very hot, and some of the rubber is worn away. This means that some of the energy from the food you ate for lunch ended up heating your brake pads and wearing them away!

The flow of energy

During the trip up and down the hill, energy flowed through many forms. Starting with chemical energy, some energy appeared in the form of potential energy, kinetic energy, heat, air friction, sound, evaporation, and more. During all these transformations no energy was lost because energy can never be created or destroyed. All the energy you started with went somewhere.

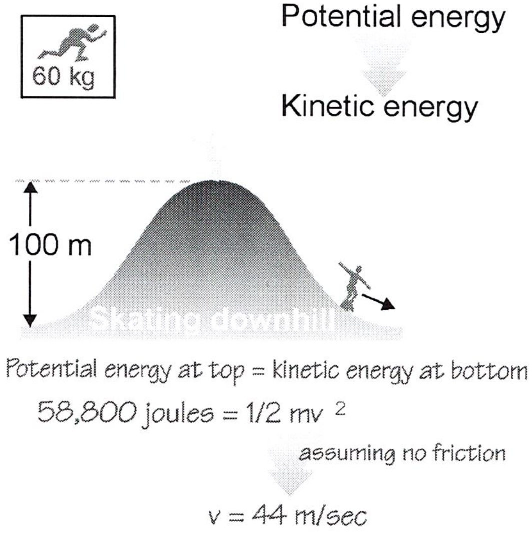


Figure 5.11: *On the way down, your potential energy is converted to kinetic energy and you pick up speed. In real life not all the potential energy would become kinetic energy. Air friction would use some and you would use your brakes*

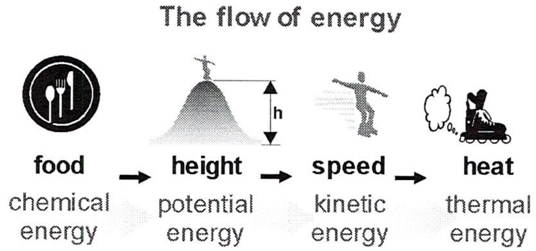


Figure 5.12: *A few of the forms the energy goes through during the skating trip.*

Other forms of energy

Energy: nature's money One way to understand energy is to think of it as nature's money. It is spent and saved in a number of different ways any time you want to do something. You can use energy to buy speed, height, temperature, mass, and other things. But you have to have some energy to start with, and what you spend diminishes what you have left.

Mechanical energy Mechanical energy is the energy possessed by an object due to its *motion* or its stored energy of *position*. Mechanical energy can be either kinetic (energy of motion) or potential (energy of position). An object that possesses mechanical energy is able to do work. Mechanical energy is the form involved in the operation of the simple machines you have studied in this unit.

Radiant energy Radiant (meaning light) **energy** is also known as electromagnetic energy. Light is made up of waves called electromagnetic waves (Unit 5). There are many different types of electromagnetic waves, including the light we see, ultraviolet light, X rays, infrared radiation (also known as heat – that's how you feel the heat from a fire), radio waves, microwaves, and radar.

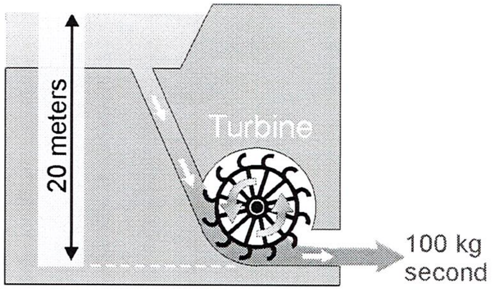
Energy from the sun Radiant heat from the sun is what keeps the Earth warm. The sun's energy falls on the Earth at a rate of about 1,400 watts for each square meter of surface area. Not all of this energy reaches the Earth's surface though; even on a clear day, about one-fourth of the energy is absorbed by the Earth's atmosphere. When we harness the radiant energy from the sun, it is called solar power.

Example

A water-powered turbine makes electricity from the energy of falling water. The diagram shows a turbine where 100 kg of water falls every second from a height of 20 meters.

(a) 100 kg of water 20 meters high has how much potential energy?

(b) How much power in watts could you get out of the turbine if it was perfectly efficient?



Solution: Part a

(1) You are asked for potential energy.
(2) You are given mass (100 kg) and height (20 m).
(3) The relationship you need is $E_p = mgh$.
(4) Plug in numbers:

$$E_p = (100 \text{ kg}) \times (9.8 \text{ m/sec}^2) \times (20 \text{ m})$$
$$= 19{,}600 \text{ joules}$$

Solution: Part b

(1) You are asked for power.
(2) You know energy (19,600 J) and time (1 sec).
(3) The relationship you need is $P = W/t$.
(4) Plug in numbers:

$$P = 19{,}600 \text{ J} / 1 \text{ sec}$$
$$= 19{,}600 \text{ watts}$$

This is enough energy for nearly 200 light bulbs if each bulb uses 100 watts.

Electrical energy

Electrical energy is something we take for granted whenever we plug an appliance into an outlet. The electrical energy we use in our daily lives is actually derived from other sources of energy. For example, in a natural gas power plant the energy starts as chemical energy in the gas. The gas is burned, releasing heat energy. The heat energy is used to make high-pressure steam. The steam turns a turbine which transforms the heat energy to mechanical energy. Finally, the turbine turns an electric generator, producing electrical energy.

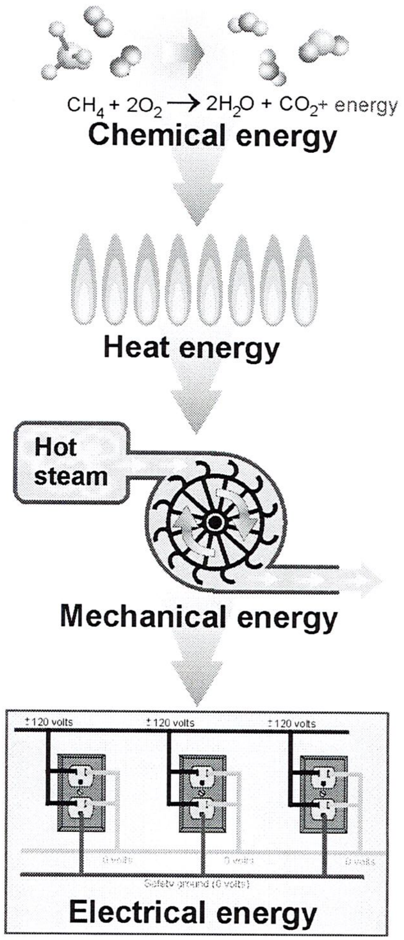


Figure 5.13: *Power plants convert chemical energy, mechanical energy and heat into electrical energy.*

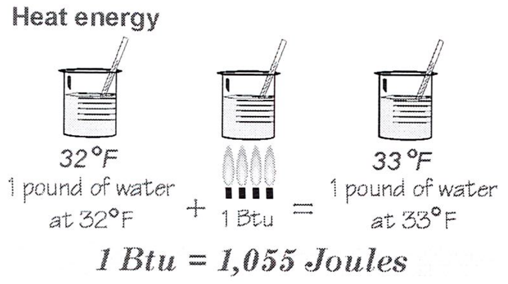
Chemical energy

Chemical energy is the type of energy stored in molecules. Chemical reactions can either use or release chemical energy. One example of chemical energy is a battery. The chemical energy stored in batteries changes to electrical energy when you connect wires and a light bulb. Your body also uses chemical energy when it converts food into energy so that you can walk or run or think. All the fossil fuels we depend on (coal, oil, gas) are useful because they contain chemical energy we can easily release.

Nuclear energy

Nuclear energy comes from splitting an atom, or fusing two atoms together. When an atom is split or fused, a huge amount of energy is released. Nuclear energy is used to generate or make electricity in power plants. A new kind of environmentally safe nuclear power (fusion) is the focus of a worldwide research program. If we could extract the fusion energy from a single teaspoon of water, it would be the equivalent of 55 barrels of oil. Nuclear energy is really the basic source for all other energy forms because it is how the sun and stars make energy. The chemical energy in fossil fuels comes from sunlight that was absorbed by plants millions of years ago. Nuclear energy is also used in medicine to treat cancer and other diseases.

Thermal energy



Heat is a form of thermal energy. When you design a heating system for a house, you need to specify how much heat energy you need. Heating contractors measure heat using the British thermal unit (Btu). One Btu is the same amount of energy as 1,055 joules.

Chapter 5 Review

Vocabulary review

Match the following terms with the correct definition. There is one extra definition in the list that will not match any of the terms.

Set One

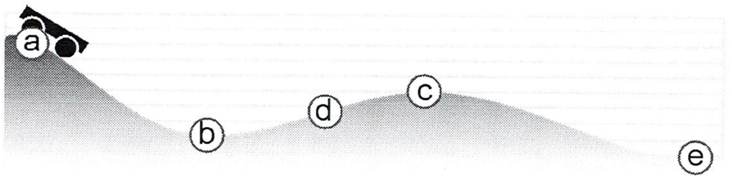
1. energy	a. The ability to do work
2. joule	b. The combined units of force and distance used to quantify work
3. law of conservation of energy	c. One newton-meter is equal to one of these
4. newton-meter	d. Energy is never created or destroyed
5. work	e. The amount of work that can be done by an object is equal to the energy available in the object
	f. Force times distance

Set Two

1. efficiency	a. Force times distance
2. perpetual motion machine	b. The amount of work performed over time
3. power	c. One joule of work performed in 1 second
4. watt	d. An imaginary machine that can be 100 percent efficient
	e. The ratio of work output to work input

Concept review

1. Why is it correct to say that energy is *conserved* in a machine?
2. In your own words, explain the relationship between work and energy.
3. You want to prove the law of conservation of energy to a friend. For your demonstration you show that you can use a block and pulley machine to lift 100 newtons with only 20 newtons of input force. What would you say to your friend to explain how this is possible?
4. You have a machine that tells you exactly how much work in joules is put into a machine and how much work was produced. The readings that you just received from the machine state that the input work was 345 joules and the output work was 330 joules. The law of conservation of energy states that input should equal output. How can you explain the "lost" 15 joules?
5. The following diagram shows a cart rolling along a hilly road. Ignore the effect of friction. Arrange the five locations in order of increasing potential and kinetic energy.



Kinetic Energy					
Potential Energy					

Smallest Energy Largest

Problems

1. Calculate work using the following values for force and distance. Give your answers in joules.
   a. 12 newtons lifted 5 meters
   b. 3 newtons pushed 3 meters
   c. 400 newtons dragged 10 meters
   d. 7.5 newtons lifted 18.4 meters
2. How many joules of work are done if you carry a box that weighs 28 newtons up a ladder for a distance of 2 meters?
3. For each statement, write W if work is being done and NW if no work is being accomplished.
   a. I carried my books upstairs to my bedroom.
   b. The wind blew the lawn chair across the yard.
   c. The wall in my classroom won't budge no matter how much I push on it.
   d. I blew some dust off my paper.
   e. I stood very still and balanced a book on my head.