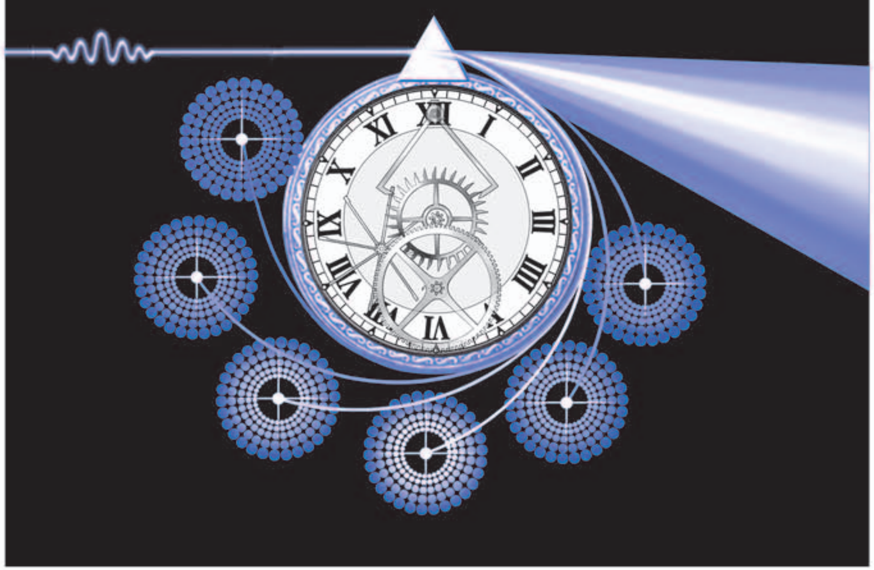
Foundations of Physical Science



with Earth and Space Science

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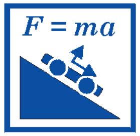
Unit 1: Forces and Motion



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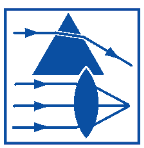

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UNIT 2

Work and Energy

Chapter 5

Work, Energy and Power

Introduction to Chapter 5

This chapter introduces the concept of work. Understanding the scientific meaning of work leads to an understanding of energy. Once we understand energy, we can look at both natural and human-made systems from the perspective of the flow and transformation of energy from one form to another.

Investigations for Chapter 5

5.1	**Work**	*What happens when you multiply forces in a machine?*

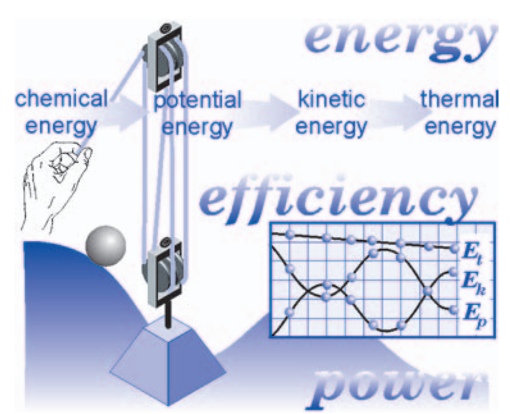
Nature gives nothing away for free. In this Investigation you will discover what you pay for making clever machines that multiply force. You will come to an interesting conclusion about work and energy that is true for all machines.

5.2	**Energy Conservation**	*What is energy and how does it behave?*

What happens to the speed of a marble as it rolls up and down hills? By making measurements of height and speed, you will investigate one of the most important laws in physics: the law of conservation of energy. By applying the concepts of potential and kinetic energy, you will develop a theory for how objects move.

5.3	**Energy Transformations**	*Where did the energy go?*

Our world runs on energy. Working with a group of students, you will analyze and identify the energy transformations that occur in real-life situations. By charting the flow of energy you will come to understand some of the interactions between humans and their environment. This Investigation requires you not only to apply what you have learned so far, but also to use your creativity and imagination.



Learning Goals

In this chapter, you will:

- ✔ Calculate the amount of work done by a simple machine.
- ✔ Use units of joules to measure the amount of work done.
- ✔ Analyze the effects of changing force or distance in a simple machine.
- ✔ Calculate the efficiency of a machine.
- ✔ Calculate power in machines.
- ✔ Discuss perpetual motion machines.

Vocabulary

chemical energy	heat	nuclear energy	solar power
efficiency	horsepower	potential energy	watt
electrical energy	joule	power	work
energy	kinetic energy	radiant energy	
energy transformations	law of conservation of energy	radiation	

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.

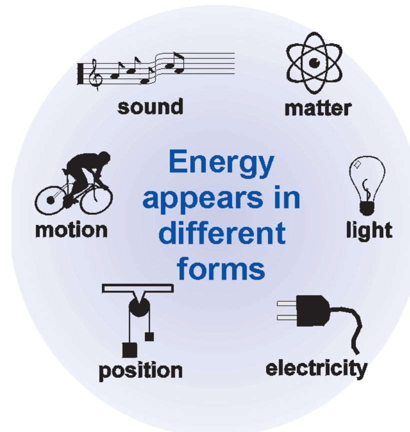


Figure 5.5: *Energy appears in many different forms.*

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 the Earth. Consider a marble that is lifted off the table (figure 5.5). Since the 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.

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

$$E_p = mgh$$

- Potential energy (joules) → E_p
- Mass (kilograms) → m
- Acceleration of gravity (9.8 m/sec^2) → g
- Height (meters) → h

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.

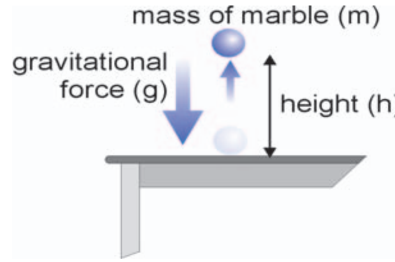
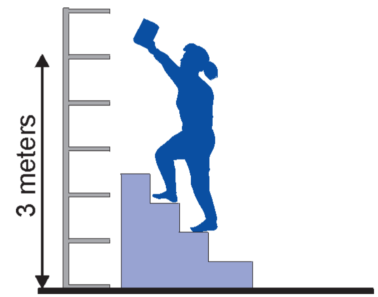


Figure 5.6: *The potential energy of a marble is equal to its mass times gravity (9.8 m/sec^2) times the height of the marble above the surface.*



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 use?

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 kg) x (9.8 m/sec^2) x (3 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

$$E_k = \frac{1}{2}mv^2$$

Kinetic energy (joules) → E_k

Mass (kilograms) → m

Speed (m/sec) → v

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!

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.

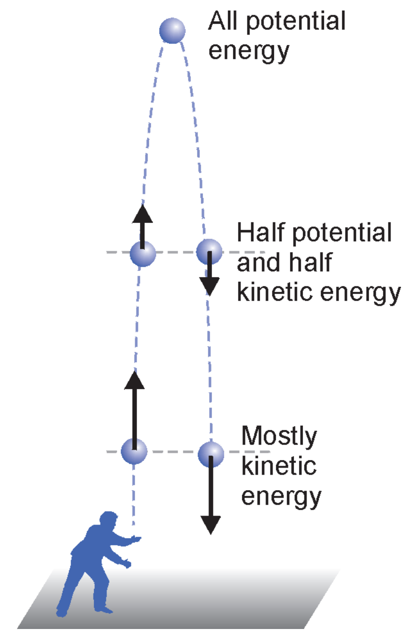


Figure 5.8: *When you throw a ball in the air, its energy transforms from kinetic to potential and back to kinetic.*

The cover colorfully combines illustrations of the forces of nature studied in the various fields of the physical sciences. Here, the "evolving tapestry of conceptual thinking" begins with water. Water droplets dance with the planets including our own watery planet and Saturn with its icy rings. Water reappears in the combustion reaction of methane, as the substance on which plants depend, as pounding waves, and, on the back cover, as the darkening clouds of a coming storm. From this cycle of water, a modern bicycle rolls into a graphical interpretation of white light split into its rainbow of wavelengths and a fiber optic. You may lose yourself in many of these images which represent hundreds of years of scientific and technological innovation. Nevertheless, that our innovations are inextricably woven into and from the natural world is illustrated by the images of Earth and the spiral connection between the DNA helix and a bicyclist ever-moving forward. On the back cover, images from physics, chemistry, and earth and space science move around a chambered nautilus seen through the windows of the Golden Rectangle. We at CPO Science with Bruce Holloway, the spirited illustrator of the cover, hope these images will inspire your interest and excitement about the discovery of science.

The CPO Science Development Team

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