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

<table>
<thead>
<tr>
<th>chemical energy</th>
<th>heat</th>
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<th>solar power</th>
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<td>efficiency</td>
<td>horsepower</td>
<td>potential energy</td>
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<td>electrical energy</td>
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<td>energy</td>
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<td>energy transformations</td>
<td>law of conservation of energy</td>
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5.1 Work

When you arranged the string on the ropes and pulleys to pull with less force, you had to pull more string to raise the weight. When you built a lever with a large advantage, you had to move the input arm down a great distance while the output arm moved only a little. These details are clues to one of the most powerful laws of physics. In this chapter, you will learn about work and energy and about a fundamental rule that applies to all machines.

What is work?

The word *work* means many different things.
- You *work* on science problems.
- You go to *work*.
- Your toaster doesn’t *work*.
- Taking out the trash is too much *work*.

In science, *work* has a very specific meaning. If you push a box with a force of one newton for a distance of one meter, you have done exactly one joule of work (figure 5.1). In physics, work is force times distance. When you see the word *work* in a physics problem, it means force times distance.

\[ W = Fd \]

To be exact, work is force times the distance moved in the direction of the force. A force at an angle (figure 5.2) is not as effective at doing work. Only the part of the force in the direction of the motion does work in the physics sense.

Machines do work in the physics sense

When we apply force to machines we are doing work. For example, when a block and tackle machine lifts a heavy weight, force is applied. As a result of the force, the weight moves a distance. Work has been done by the machine because force was exerted over some distance.
Work done by a machine

In physics, work is done by forces. When thinking about work you should always be clear about which force is doing the work. Work is done on objects. If you push a block one meter with a force of one newton, you have done one joule of work on the block. We need to keep careful track of where the work goes because later we will see that it may be possible to get the work back.

Units of work

The unit of measurement for work is the joule. One joule is equal to one newton of force times one meter of distance. Joules are a combination unit made of force (newtons) and distance (meters).

Input work and output work

Just as we did for forces, we want to analyze machines in terms of work input and work output (figure 5.3). As an example, consider using the block and tackle machine to lift a load weighing 10 newtons. Suppose you lift the load a distance of 1/2 meter. Your machine has done five joules of work on the load (figure 5.4) so the work output is five joules.

What about the work input? You pulled on the string with a force of only five newtons because your machine gave you an advantage of two. But you had to pull the string twice as far as you lifted the block. The weight moved up 1/2 meter, but you pulled one whole meter of string. The work input is the force you apply times the distance you pulled the string. This is five newtons times one meter, or five joules. The work input is the same as the work output!

The work output of a simple machine can never exceed the work input.

The example illustrates a rule that is true for all machines. You can never get more work out of a machine than you put into it. Nature does not give something for nothing. When you design a machine that multiplies force, you pay by having to apply the force over a greater distance.
Efficiency

What is an efficient machine? In a very efficient machine, all (or most) of the work input becomes work output. In the block and tackle machine on the previous page, all five joules of input work were transformed to five joules of output work. An engineer would say the machine was 100 percent efficient, because all the input work became output work and none was lost.

How friction affects real machines In real machines, the work output is always less than the work input. Other forces, like friction, use up some of the input work before it reaches the output of the machine. For example, a wheel turning on an axle can get very hot. When the wheel gets hot, it means some of the input work is being converted to heat. The work output is reduced by the work that is converted to heat.

The definition of efficiency The efficiency of a machine is the ratio of work output to work input. Efficiency is usually expressed in percent. A machine that is 75 percent efficient can produce three joules of output work for every four joules of input work. One joule out of every four (25 percent) is lost to friction. You calculate efficiency by dividing the work output by the work input. You can convert the ratio into a percent by multiplying by 100.

The ideal machine The ideal machine would be 100 percent efficient. Even though friction always lowers efficiency, engineers strive to make the efficiency as close to 100 percent as possible.

A most efficient machine

The bicycle is the most efficient machine ever invented for turning the work of human muscles into motion. Its efficiency is more than 95 percent.

The need for simple, efficient machines for traveling inspired many inventions that led to today’s bicycle. In the mid-1800s, a very shaky ride could be achieved with the “bone shaker,” which had a huge front wheel. The big wheel allowed the rider to travel farther with one push of the pedals, but it was not always safe!

James Starley (1830-1881) of the Coventry Sewing Machine Company in Britain is credited with building the first modern two-wheel bicycle in 1885. The derailleur, which is the heart of a modern multispeed bike, was invented by the Italian bicycle racer Tullio Campagnolo in 1933.

The bicycle also figured into another important invention: the airplane. Wilbur and Orville Wright were bicycle mechanics and inventors. They used their expertise in racing and building lightweight bicycles to create the first successful powered airplane in 1903.
Chapter 5

Power

How fast the work is done

It makes a difference how fast you do work. Suppose you drag a box with a force of 100 newtons for 10 meters, and it takes you 10 seconds. You have done 1,000 joules of work. Suppose your friend drags a similar box but takes 60 seconds. You both do the same amount of work because the force and distance are the same. But something is different. You did the work in 10 seconds and your friend took six times longer.

What is power?

The rate at which work is done is called power. You and your friend did the same amount of work, but you used six times more power because you did the work six times faster. You can determine the power of a machine by dividing the amount of work done by the time it takes in seconds. A more powerful machine does the same amount of work in less time than a less powerful machine.

\[ P = \frac{W}{t} \]

Example:

You can lift your own weight (500 newtons) up a staircase that is 5 meters high in 30 seconds.

a) How much power do you use?

b) How does your power compare with a 100-watt light bulb?

Solution:

(1) You are asked for power.

(2) You know force, distance, and time.

(3) Relationships that apply:

\[ W = Fd \quad P = \frac{W}{t} \]

(4) Solve for power.

\[ P = \frac{FD}{t} \]

(5) Plug in numbers. Remember:

1 joule = 1 N-m
1 watt = 1 N-m/sec

\[ P = \frac{(500 \text{ N}) \times (5 \text{ m})}{30 \text{ sec}} \]

Answers:

(a) \[ 2500 \text{ N-m/30 sec} = 83 \text{ watts} \]

(b) This is less power than a 100-watt light bulb. Most human activities use less power than a light bulb.

The units of power

The unit of power is called the watt, named after James Watt (1736-1819), the Scottish engineer and inventor of the steam engine. One watt is equal to one joule of work done in one second. Another unit of power commonly used is the horsepower. One horsepower is equal to 746 watts. As you might have guessed, one horsepower was originally the average power output of a horse.
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?**

*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.
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.

\[ E_p = mgh \]

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 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.
\[ E_p = (1 \text{ kg}) \times (9.8 \text{ m/sec}^2) \times (3 \text{ m}) = 29.4 \text{ joules} \]
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.

\[ E_k = \frac{1}{2} mv^2 \]

Kinetic energy increases as the square of the speed. The kinetic 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.
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.

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.
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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.
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5.3 Energy Transformations

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:

\[
P = \frac{19,600 \text{ J}}{1 \text{ sec}}
\]

\[
= 19,600 \text{ watts}
\]

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

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.
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.

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 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.

<table>
<thead>
<tr>
<th>Set One</th>
<th>Set Two</th>
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<tr>
<td><strong>1. energy</strong></td>
<td><strong>1. efficiency</strong></td>
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<tr>
<td>a. The ability to do work</td>
<td>a. Force times distance</td>
</tr>
<tr>
<td><strong>2. joule</strong></td>
<td><strong>2. perpetual motion machine</strong></td>
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<tr>
<td>b. The combined units of force and distance used to quantify work</td>
<td>b. The amount of work performed over time</td>
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<tr>
<td><strong>3. law of conservation of energy</strong></td>
<td><strong>3. power</strong></td>
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<tr>
<td>c. One newton-meter is equal to one of these</td>
<td>c. One joule of work performed in 1 second</td>
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<tr>
<td><strong>4. newton-meter</strong></td>
<td><strong>4. watt</strong></td>
</tr>
<tr>
<td>d. Energy is never created or destroyed</td>
<td>d. An imaginary machine that can be 100 percent efficient</td>
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<tr>
<td><strong>5. work</strong></td>
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<tr>
<td>e. The amount of work that can be done by an object is equal to the energy available in the object</td>
<td>e. The ratio of work output to work input</td>
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<td>f. Force times distance</td>
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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?

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.
4. Which requires more work, lifting a 15-newton load a distance of 3 meters with a block and tackle, or lifting a 7-newton load a distance of 10 meters with the same block and tackle machine? Be sure to show your work and explain your answer clearly.

5. A block and tackle machine performed 30 joules of work on a 15-newton block. How high did the machine lift the block?

6. At the end of the ride up a steep hill, Ken was at an elevation of 1,600 meters above where he started. He figured out that he and his bicycle had accomplished 1,000,000 joules of work. If Ken has a mass of 54 kg, what is the mass of his bicycle? (Note: \( g = 9.8 \, \text{m/sec}^2 \).)

7. If a block and tackle machine has a mechanical advantage of 2, you can use 20 newtons of force to lift a 40-newton load. If you lift the block 1 meter, what length of rope do you have to pull?

8. A machine has a work output of 45 joules. In order to accomplish the work, 48 joules of work was put into the machine. What is the efficiency of this machine? Be sure to give your answer as a percentage.

9. One machine can perform 280 joules of work in 40 seconds. Another machine can produce 420 joules of work in 2 minutes. Which machine is more powerful? Justify your answer by calculating the amount of power in watts each machine produces.

10. You attach a motor to a block and tackle machine. After using it, you find that you want a more powerful motor. You purchase one that has twice the power of the old motor.

   a. How much bigger a load can the new motor lift in the same amount of time?
   b. If the new motor lifts the same load as the old motor, how much faster can it go?

11. A motor pushes a car with a force of 35 newtons for a distance of 350 meters in 6 seconds.
   a. How much work has the motor accomplished?
   b. How powerful is the motor in watts?

12. How much power is required to do 55 joules of work in 55 seconds?

13. The manufacturer of a machine said that it is 86 percent efficient. If you use 70 joules to run the machine (input work), how much output work will it produce?

14. A machine is 72 percent efficient. If it produces 150 joules of work output, how much work was put into the machine?
Applying your knowledge

1. A car is about 15 percent efficient at converting energy from gas to energy of motion. The average car today gets 25 miles for each gallon of gas.
   a. What would the gas mileage be if the car could be made 100 percent efficient?
   b. Name three things that contribute to lost energy and prevent a car from ever being 100 percent efficient.

2. Why, according to the laws of physics, is it impossible to build a perpetual motion machine?

3. Research question: Investigate light bulb wattage and describe what watts mean in terms of power and work.

4. Imagine we had to go back to using horses for power. One horse makes 746 watts (1 hp). How many horses would it take to light up all the light bulbs in your school?
   a. First, estimate how many light bulbs are in your school.
   b. Estimate the power of each light bulb, or get it from the bulb itself where it is written on the top.
   c. Calculate the total power used by all the bulbs.
   d. Calculate how many horses it would take to make this much power.

5. Make a chart that shows the flow of energy in the situation described below. In your chart, use some of the key concepts you learned, including potential energy and kinetic energy.

Martha wakes up at 5:30 am and eats a bowl of corn flakes. It’s a nice day, so she decides to ride her bicycle to work, which is uphill from her house. It is still dark outside. Martha’s bike has a small electric generator that runs from the front wheel. She flips on the generator so that her headlight comes on when she starts to pedal. She then rides her bike to work. Draw a diagram that shows the energy transformations that occur in this situation.