ENERGY

Objectives

• Define and describe work. (9.1)

• Define and describe power.

(9.2)

• State the two forms of

mechanical energy. (9.3)

• State three forms of potential

energy. (9.4)

• Describe how work and kinetic

energy are related. (9.5)

• State the work-energy

theorem. (9.6)

• State the law of conservation

of energy. (9.7)

• Describe how a machine uses

energy. (9.8)

• Explain why no machine can be

100% efficient. (9.9)

• Describe the role of energy in

living organisms. (9.10)

9 ENERGY

THE BIG

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IDEA

Energy can change from one form

to another without a net loss or gain.

E

nergy is the most central concept underlying all

of science. Surprisingly, the idea of energy was

unknown to Isaac Newton, and its existence

was still being debated in the 1850s. Even though

the concept of energy is relatively new, today we

find it ingrained not only in all branches of science,

but in nearly every aspect of human

society. We are all quite familiar with

energy. Energy comes to us from the

sun in the form of sunlight, it is in the

food we eat, and it sustains life. Energy

may be the most familiar concept in science,

yet it is one of the most difficult to define.

Persons, places, and things have energy, but we observe

only the effects of energy when something is happen-

ing—only when energy is being transferred from one

place to another or transformed from one form to

another. We begin our study of energy by observing

a related concept, work.

discover!

Where Does a Popper Toy Get

Its Energy?

1. Turn a popper (slice of a hollow rubber ball)

inside out and place it on a table or floor.

Observe what happens to the popper toy.

2. Once again compress the popper and drop it

onto a table or floor. Observe what happens

to the popper.

Analyze and Conclude

1. Observing What propelled the popper into

the air?

2. Predicting Will dropping the popper from

greater heights make the popper jump

higher? Explain.

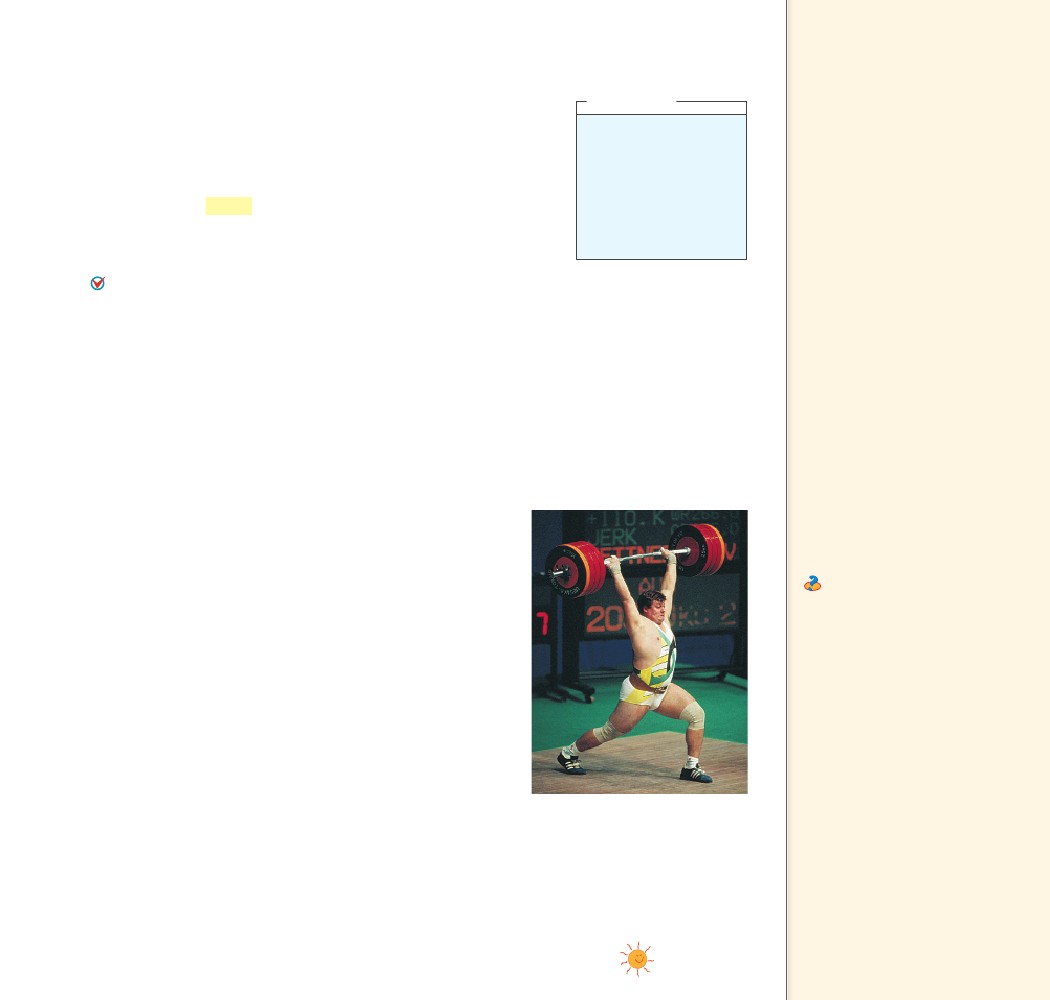
3. Making Generalizations Describe where the

popper got the energy to move upward and

downward through the air.

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9.1 Work

9.1 Work

The previous chapter showed that the change in an object’s motion is

related to both force and how long the force acts. “How long” meant

time. Remember, the quantity force time is called impulse. But “how

long” need not always mean time. It can mean distance also. When

we consider the quantity force distance, we are talking about the

concept of work. Work is the product of the net force on an object

and the distance through which the object is moved.

We do work when we lift a load against Earth’s gravity. The

heavier the load or the higher we lift it, the more work we do.

Work is done when a force acts on an object and the object

moves in the direction of the force.

Let’s look at the simplest case, in which the force is constant and

the motion takes place in a straight line in the direction of the force.

Then the work done on an object by an applied force is the product

of the force and the distance through which the object is moved.9.1

work

In equation form,

W

Fd

net force

distance

think!

Suppose that you apply a

60-N horizontal force to

a 32-kg package, which

pushes it 4 meters across

a mailroom floor. How

much work do you do on

the package?

Answer: 9.1

Key Terms

work, joule

Teaching Tip When

describing work, specify on what

object the work is done. If you

push a wall, you do no work on

the wall unless it moves. The key

point here is that if work is done

on an object, then the energy of

that object changes.

Teaching Tip Define work

and relate it to the lifting of a

barbell, as shown in Figure 9.1.

When work is done on the

barbell, two things happen: (1) a

force is exerted on the barbell,

and (2) the barbell is moved by

that force. If the barbell is simply

held still, the weightlifter will get

tired, and feel like he is doing

work. With each contraction of

the weight lifter’s heart, a force

is exerted through a distance on

his blood and so does work on

the blood. He may well be doing

work on himself through tiny

movements in his body tissues,

but he is doing no work on the

barbell unless the force he exerts

moves the barbell.

Ask Work is done lifting a

barbell. How much more work

is done lifting a twice-as-heavy

barbell the same distance? Twice

as much How much more work

is done lifting a twice-as-heavy

barbell twice as far? Four times

as much

If we lift two loads up one story, we do twice as much work

as we would in lifting one load the same distance, because the

force needed to lift twice the weight is twice as great. Similarly,

if we lift one load two stories instead of one story, we do twice

as much work because the distance is twice as great.

Notice that the definition of work involves both a force and

a distance. The weight lifter in Figure 9.1 is holding a barbell

weighing 1000 N over his head. He may get really tired hold-

ing it, but if the barbell is not moved by the force he exerts, he

does no work on the barbell. Work may be done on the muscles

by stretching and squeezing them, which is force times distance

on a biological scale, but this work is not done on the barbell.

Lifting the barbell, however, is a different story. When the weight

lifter raises the barbell from the floor, he is doing work on it.

Work generally falls into two categories. One of these is the

work done against another force. When an archer stretches her

bowstring, she is doing work against the elastic forces of the

bow. Similarly, when the ram of a pile driver is raised, work is

required to raise the ram against the force of gravity. When you

do push-ups, you do work against your own weight. You do

work on something when you force it to move against the influ-

ence of an opposing force—often friction.

FIGURE 9.1

Work is done in lifting the barbell

but not in holding it steady. If the

barbell could be lifted twice as

high, the weight lifter would have

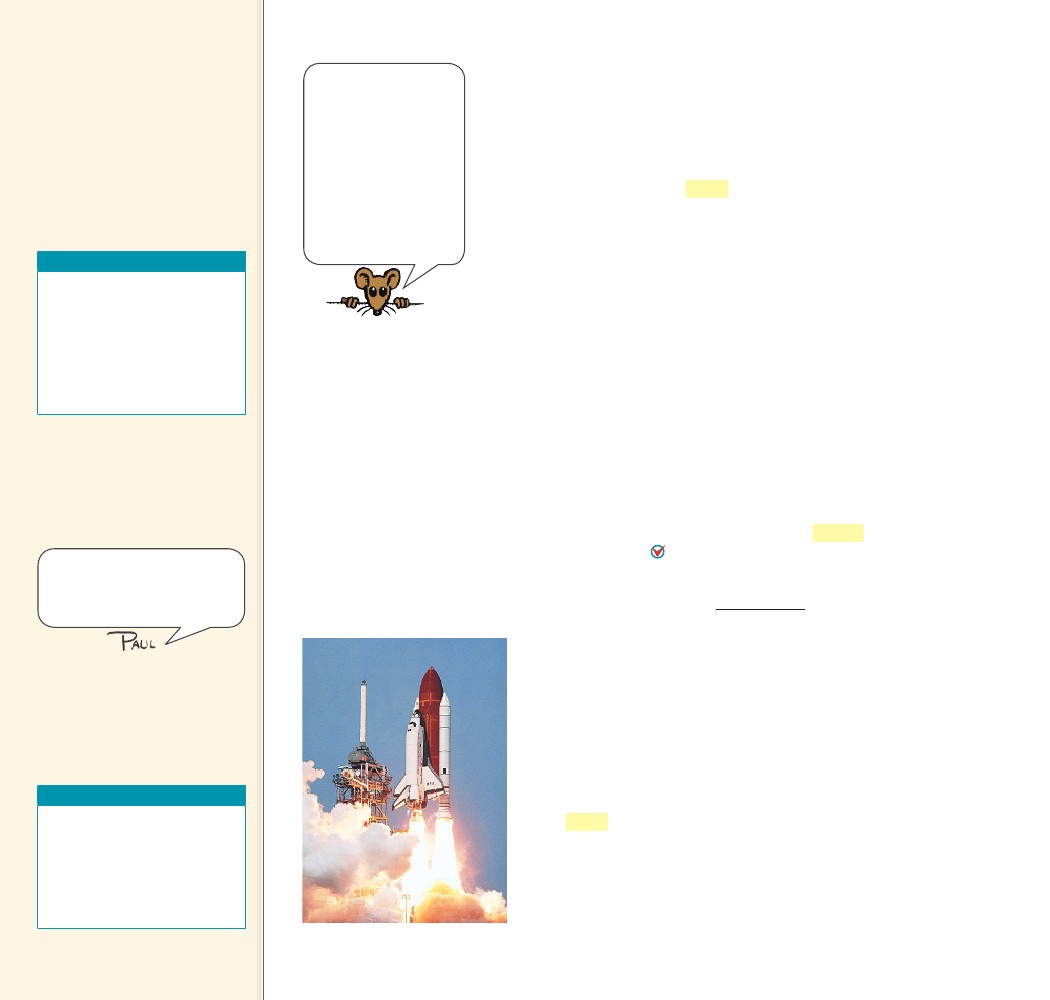
to do twice as much work.

CHAPTER 9

ENERGY

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 Teaching Tip Compare

work to impulse of the previous

chapter. In both concepts, a force

is exerted. For impulse, the force

is exerted over a certain time

interval; for work, it is exerted

over a certain distance.

Work is done when a

CHECK force acts on an

object and the object moves in

the direction of the force.

CONCEPT

The physics of a

weightlifter holding a

stationary barbell over-

head is no different

than the physics of a

table supporting a bar-

bell’s weight. No net

force acts on the bar-

bell, no work is done

on it, and no change in

its energy occurs.

Teaching Resources

• Reading and Study

Workbook

• PresentationEXPRESS

• Interactive Textbook

• Next-Time Question 9-1

• Conceptual Physics Alive!

DVDs Energy

The other category of work is work done to change the speed

of an object. This kind of work is done in bringing an automobile

up to speed or in slowing it down. In both categories, work involves

a transfer of energy between something and its surroundings.

The unit of measurement for work combines a unit of force, N,

with a unit of distance, m. The resulting unit of work is the newton-

meter (N·m), also called the joule (rhymes with cool) in honor

of James Joule. One joule (J) of work is done when a force of 1 N

is exerted over a distance of 1 m, as in lifting an apple over your

head. For larger values, we speak of kilojoules (kJ)—thousands of

joules—or megajoules (MJ)—millions of joules. The weight lifter

in Figure 9.1 does work on the order of kilojoules. To stop a loaded

truck going at 100 km/h takes megajoules of work.

CONCEPT

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CHECK

When is work done on an object?

9.2 Power

The definition of work says nothing about how long it takes to do the

work. When carrying a load up some stairs, you do the same amount

of work whether you walk or run up the stairs. So why are you more

tired after running upstairs in a few seconds than after walking

upstairs in a few minutes? To understand this difference, we need to

talk about how fast the work is done, or power. Power is the rate

at which work is done. Power equals the amount of work done

divided by the time interval during which the work is done.

power

work done

time interval

9.2 Power

Key Terms

power, watt

FIGURE 9.2

The three main engines

of the space shuttle can

develop 33,000 MW of

power when fuel is burned

at the enormous rate of

3400 kg/s. This is like emp-

tying an average-size swim-

ming pool in 20 seconds!

Tell students that to vertically

lift a quarter-pound hamburger

with cheese 1 m in 1 s requires

one watt of power.

Power equals the

CHECK amount of work

done divided by the time interval

during which the work is done.

CONCEPT

Teaching Resources

• Reading and Study

Workbook

• Problem-Solving Exercises in

Physics 6-1

• PresentationEXPRESS

• Interactive Textbook

A high-power engine does work rapidly. An automobile

engine that delivers twice the power of another automobile

engine does not necessarily produce twice as much work or go

twice as fast as the less powerful engine. Twice the power means

the engine can do twice the work in the same amount of time

or the same amount of work in half the time. A powerful

engine can get an automobile up to a given speed in less time

than a less powerful engine can.

The unit of power is the joule per second, also known as

the watt, in honor of James Watt, the eighteenth-century

developer of the steam engine. One watt (W) of power is

expended when one joule of work is done in one second.

One kilowatt (kW) equals 1000 watts. One megawatt (MW)

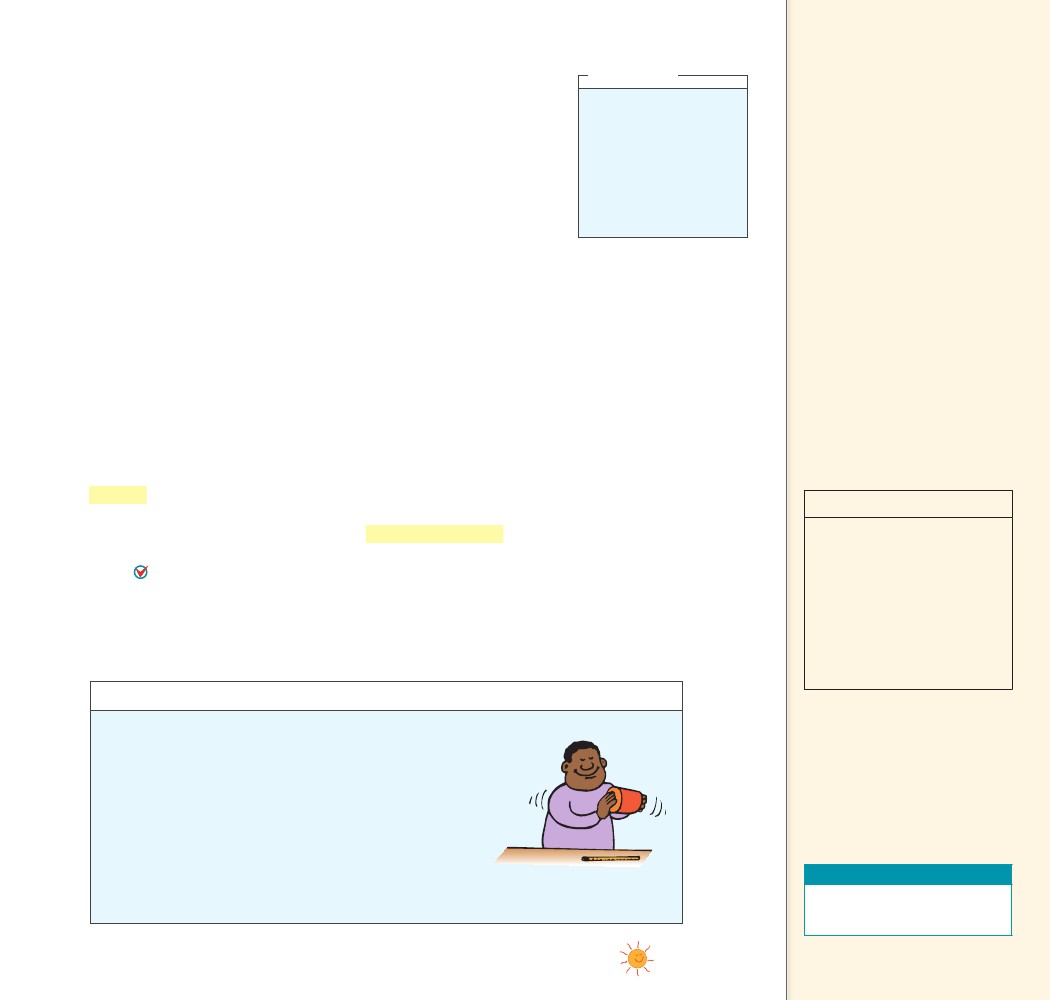
equals one million watts. The space shuttle in Figure 9.2 uses

33,000 MW of power.

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 In the United States, we customarily rate engines in units of

horsepower and electricity in kilowatts, but either may be used. In the

metric system of units, automobiles are rated in kilowatts. One horse-

power (hp) is the same as 0.75 kW, so an engine rated at 134 hp is a

100-kW engine.

CONCEPT

think!

If a forklift is replaced

with a new forklift that

has twice the power, how

much greater a load can

it lift in the same amount

of time? If it lifts the same

load, how much faster can

it operate? Answer: 9.2

9.3 Mechanical

Energy

Key Terms

energy, mechanical energy

Teaching Tip Explain that

mechanical energy becomes

evident only when it changes

from one form to another, or

when there is motion.

Teaching Tip Point out that

mechanical energy is relative.

It depends on the location we

choose for our reference frame.

A 1-N apple held 1 m above the

floor has 1 J of PE, but when

held out the window 10 m above

the ground it has 10 J. The same

apple held in your lap has 0 KE,

but if your lap is on the seat of

a high-flying jet plane, it has

many joules of KE relative to

the ground below. PE and KE

are relative to a specified or an

implied frame of reference.

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CHECK

How can you calculate power?

9.3 Mechanical Energy

When work is done by an archer in drawing back a bowstring, the

bent bow acquires the ability to do work on the arrow. When work is

done to stretch a rubber band, the rubber band acquires the ability to

do work on an object when it is released. When work is done to wind

a spring mechanism, the spring acquires the ability to do work on

various gears to run a clock, ring a bell, or sound an alarm.

In each case, something has been acquired that enables the object

to do work. It may be in the form of a compression of atoms in the

material of an object; a physical separation of attracting bodies; or

a rearrangement of electric charges in the molecules of a substance.

The property of an object or system that enables it to do work is

energy. 9.3 Like work, energy is measured in joules. It appears in

many forms that will be discussed in the following chapters. For

now we will focus on mechanical energy. Mechanical energy is the

energy due to the position of something or the movement of some-

thing. The two forms of mechanical energy are kinetic energy

and potential energy.

CONCEPT

discover!

MATERIALS

dry sand, can with

cover, thermometer

The

temperature of the sand rises

as a student shakes the can.

EXPECTED OUTCOME

THINK

......

CHECK

What are the two forms of mechanical energy?

The work that a person

does in shaking the can is

converted into the thermal

energy of the sand.

discover!

What Happens When You Do Work on Sand?

1.

2.

3.

4.

Pour a handful of dry sand into a can.

Measure the temperature of the sand with a thermometer.

Remove the thermometer and cover the can.

Shake the can vigorously for a minute or so. Now remove

the cover and measure the temperature of the sand again.

5. Describe what happened to the temperature of the sand

after you shook it.

6. Think How can you explain the change in temperature of

the sand in terms of work and energy?

The two forms of

CHECK mechanical energy

are kinetic energy and potential

energy.

CONCEPT

Teaching Resources

• Laboratory Manual 26

• Probeware Lab Manual 7

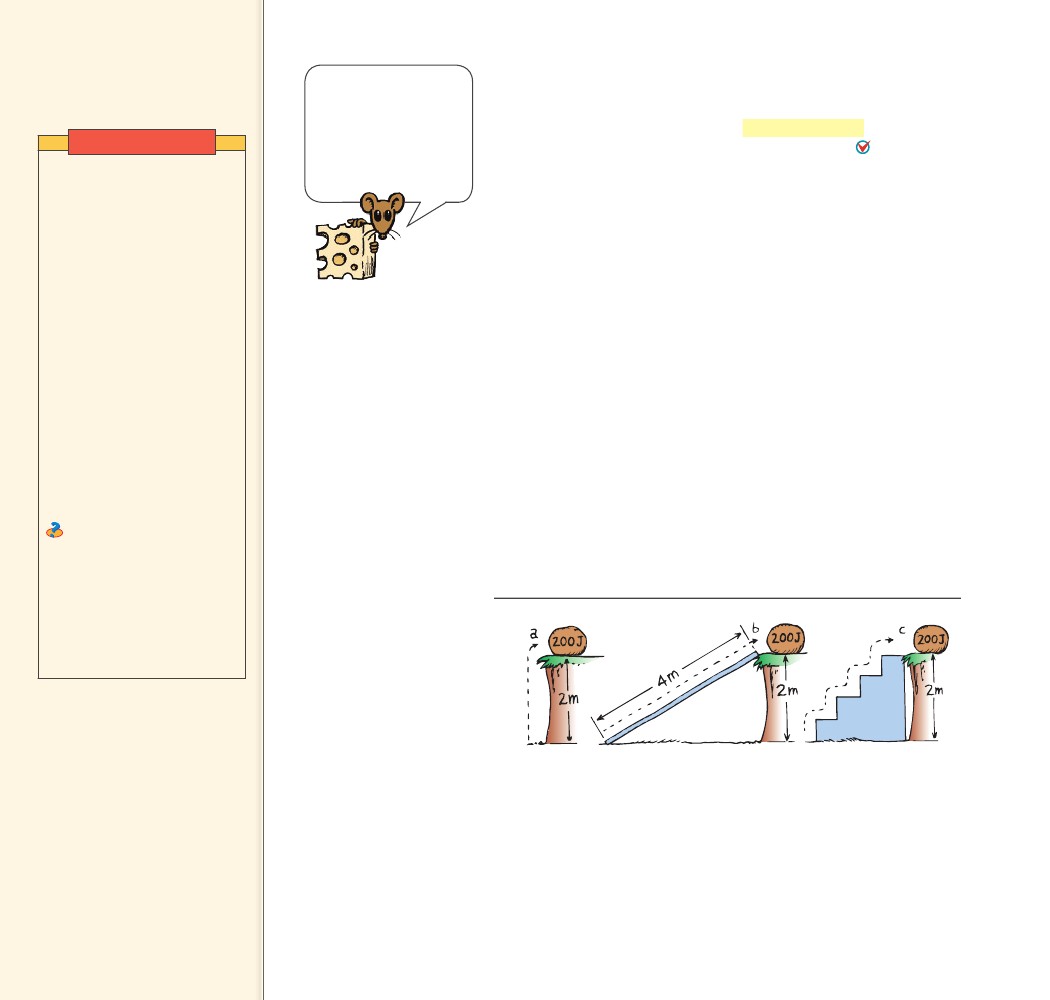
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ENERGY

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9.4 Potential Energy

Key Term

potential energy

Demonstration

Attach a spring scale to a

pendulum bob at its rest

position. Show that a small

force pulls it sideways from

its rest position. Compare this

force to the force that would

be necessary to lift it vertically

(its weight). Show that as

the bob is pulled farther up

the arc, the force required

to move it increases. This is

because it is being pulled

against gravity, which has

no vector component along

the pendulum path when

the pendulum is hanging at

its lowest point, but which

increases as the pendulum is

raised. More work is required

to move the pendulum equal

distances the farther the

pendulum is raised.

Ask Keeping the spring

scale perpendicular to the

string, predict what the force

will be if the string is pulled

through an angle of 90º and

is horizontal. The force will

be equal and opposite to the

force of gravity on the bob—

its weight.

What tells you whether

or not work is done

on something is a

change in its energy.

No change in energy

means that no net work

was done on it.

9.4 Potential Energy

An object may store energy by virtue of its position. Energy that is

stored and held in readiness is called potential energy (PE) because

in the stored state it has the potential for doing work. Three

examples of potential energy are elastic potential energy, chemical

energy, and gravitational potential energy.

Elastic Potential Energy A stretched or compressed spring, for

example, has a potential for doing work. This type of potential energy

is elastic potential energy. When a bow is drawn back, energy is stored

in the bow. The bow can do work on the arrow. A stretched rubber

band has potential energy because of its position. If the rubber band

is part of a slingshot, it is also capable of doing work.

Chemical Energy The chemical energy in fuels is also potential

energy. It is actually energy of position at the submicroscopic level.

This energy is available when the positions of electric charges within

and between molecules are altered, that is, when a chemical change

takes place. Any substance that can do work through chemical reac-

tions possesses chemical energy. Potential energy is found in fossil

fuels, electric batteries, and the food we eat.

Gravitational Potential Energy Work is required to elevate

objects against Earth’s gravity. The potential energy due to elevated

positions is gravitational potential energy. Water in an elevated

reservoir and the raised ram of a pile driver have gravitational poten-

tial energy.

Teaching Tip Discuss the

elevated boulder in Figure 9.3.

Point out that the resulting PE of

the boulder is the same in each

case.

Teaching Tip An average

apple weighs 1 N. When it is

held 1 m above the ground, then

relative to the ground it has a PE

of 1 J.

FIGURE 9.3

The potential energy of the 100-N boulder with respect

to the ground below is 200 J in each case because the

work done in elevating it 2 m is the same whether the

boulder is a. lifted with 100 N of force, b. pushed up

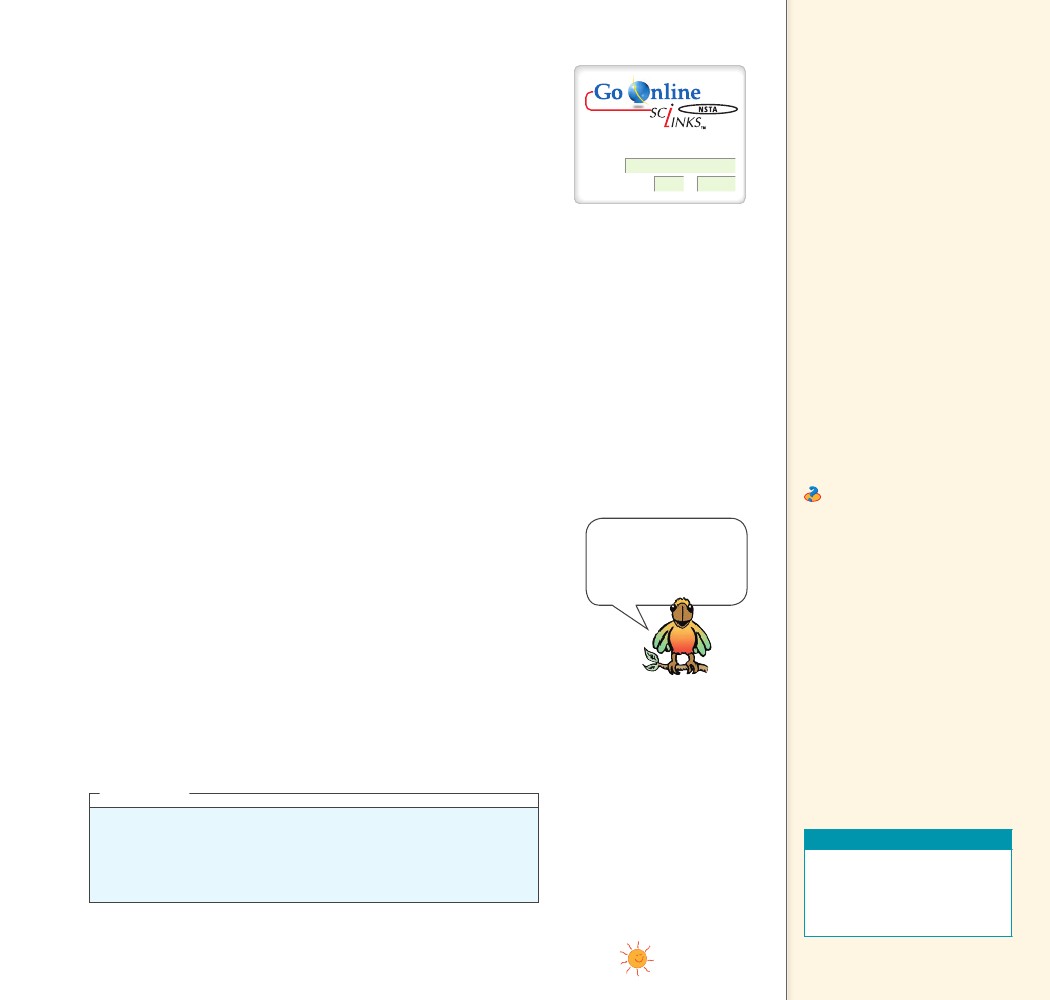
the 4-m incline with 50 N of force, or c. lifted with 100 N

of force up each 0.5-m stair. No work is done in moving

it horizontally, neglecting friction.

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 The amount of gravitational potential energy possessed by an

elevated object is equal to the work done against gravity in lifting it.

The work done equals the force required to move it upward times the

vertical distance it is moved (remember W = Fd). The upward force

required while moving at constant velocity is equal to the weight, mg,

of the object, so the work done in lifting it through a height h is the

product mgh.

gravitational potential energy

PE

mgh

weight

height

For: Links on potential energy

Visit: www.SciLinks.org

Web Code: csn – 0904

Note that the height is the distance above some arbitrarily

chosen reference level, such as the ground or the floor of a building.

The gravitational potential energy, mgh, is relative to that level and

depends only on mg and h. For example, if you’re in a third-story

classroom and a ball rests on the floor, you can say the ball is at

height 0. Lift it and it has positive PE relative to the floor. Toss it out

the window and it has negative PE relative to the floor. We can see in

Figure 9.3 that the potential energy of the boulder at the top of the

ledge does not depend on the path taken to get it there.

Hydroelectric power stations make use of gravitational potential

energy. When a need for power exists, water from an upper reservoir

flows through a long tunnel to an electric generator. Gravitational

potential energy of the water is converted to electrical energy. Most

of this energy is delivered to consumers during daylight hours. A

few power stations buy electricity at night, when there is much less

demand. They use this electricity to pump water from a lower res-

ervoir back up to the upper reservoir. This process, called pumped

storage, is practical when the cost of electricity is less at night. Then

electrical energy is transformed to gravitational potential energy.

Although the pumped storage system doesn’t generate any overall net

energy, it helps to smooth out differences between energy demand

and supply.

CONCEPT

Teaching Tip Point out that

the arc path to any elevation is

longer than the vertical path. The

computation of the work done

along the arc path is complicated

because the force continually

varies with distance. However,

the answer is also obtained by

multiplying the weight of the

bob by the vertical distance

it is raised! The work done in

elevating the bob is the same

along either path, straight up

or along the arc. Gravitational

PE depends only on weight and

height—not the path taken to

get it there.

Teaching Tip Use the

example of dropping a bowling

ball on your toe—first from a

distance of 1 mm above your toe

and then from distances up to

1 m above your toe. Each time,

the bowling ball would do more

work on your toe, because it

would possess more gravitational

PE when released.

Ask Does a car hoisted for

lubrication in a service station

have PE? Yes, any elevated

body has PE with respect to any

chosen reference level—usually

the “ground level.” How much

work will raise the car twice as

high? Twice as much How much

work is required to raise it three

times as high, and how much PE

will it have? Three times as much

of each

When h is below a

reference point, PE is

negative relative to

that reference point.

......

CHECK

Name three examples of potential energy.

think!

You lift a 100-N boulder 1 m.

a. How much work is done on the boulder?

b. What power is expended if you lift the boulder in a time of 2 s?

c. What is the gravitational potential energy of the boulder in the lifted

position? Answer: 9.4

Three examples of

CHECK potential energy are

elastic potential energy, chemical

energy, and gravitational

potential energy.

CONCEPT

Teaching Resources

• Reading and Study

Workbook

• PresentationEXPRESS

• Interactive Textbook

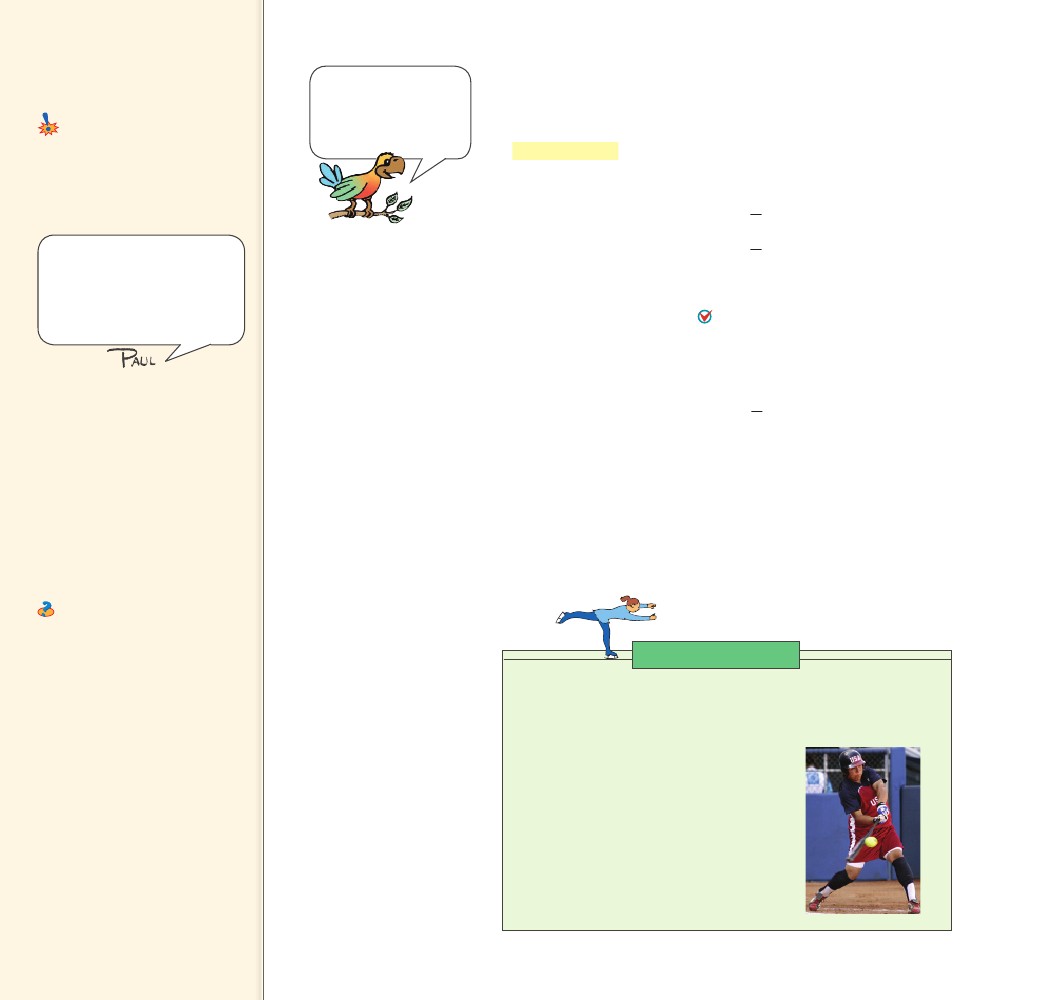
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9.5 Kinetic Energy

Key Term

kinetic energy

Common Misconception

Momentum and KE are the same

concept.

FACT

Refer to Note 9.5 in

Appendix G for the

derivation of the

equation WKE .

9.5 Kinetic Energy

Push on an object and you can set it in motion. If an object is

moving, then it is capable of doing work. It has energy of motion,

or kinetic energy (KE). The kinetic energy of an object depends on

the mass of the object as well as its speed. It is equal to half the mass

multiplied by the square of the speed.

kinetic energy

1

2 mass

122 mv

Momentum is mv; KE is

1/2mv2.

speed2

Failure to distinguish between

momentum and KE gave rise to

much controversy in Europe

after the time of Newton. (The

concept of KE was developed

after Newton’s time.)

KE

When you throw a ball, you do work on it to give it speed as it

leaves your hand. The moving ball can then hit something and push

it, doing work on what it hits. The kinetic energy of a moving

object is equal to the work required to bring it to its speed from

rest, or the work the object can do while being brought to rest. 9.5

net force distancekinetic energy

Fd

122 mv

Teaching Tip Explain that a

moving body has motion energy,

or kinetic energy, and can do

work because of its motion.

Relate KE to force 3 distance.

Teaching Tip Mention that

KE comprises thermal energy

(haphazard motion of molecules),

sound (vibratory motion of

molecules), and light (emitted by

the vibratory motion of electrons

in an atom).

Ask Does a car moving along

a road have KE? Any moving

object has KE, which is a relative

quantity, as is speed. The cup

of tea you hold in a high-flying

jet has KE with respect to the

ground, but no KE with respect

to the saucer on which it sits. If

the speed of the car doubles, by

how much does the KE increase?

It’s multiplied by 4. If the speed

triples? It’s multiplied by 9.

The kinetic energy of

CHECK a moving object is

equal to the work required to

bring it to its speed from rest, or

the work the object can do while

being brought to rest.

CONCEPT

Note that the speed is squared, so if the speed of an object is

doubled, its kinetic energy is quadrupled (22 4). Consequently, it

takes four times the work to double the speed. Also, an object moving

twice as fast takes four times as much work to stop. Whenever work is

done, energy changes.

CHECK

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CONCEPT How are work and the kinetic energy of a moving

object related?

Physics of Sports

The Sweet Spot

The sweet spot of a softball bat or a tennis racquet is the place where

the ball’s impact produces minimum vibrations in the racquet or bat.

Strike a ball at the sweet spot and it goes

faster and farther. Strike a ball in another

part of the bat or racquet, and vibrations

can occur that sting your hand! From an

energy point of view, there is energy in the

vibrations of the bat or racquet. There is

energy in the ball after being struck. Energy

that is not in vibrations is energy available to

the ball. Do you see why a ball will go faster

and farther when struck at the sweet spot?

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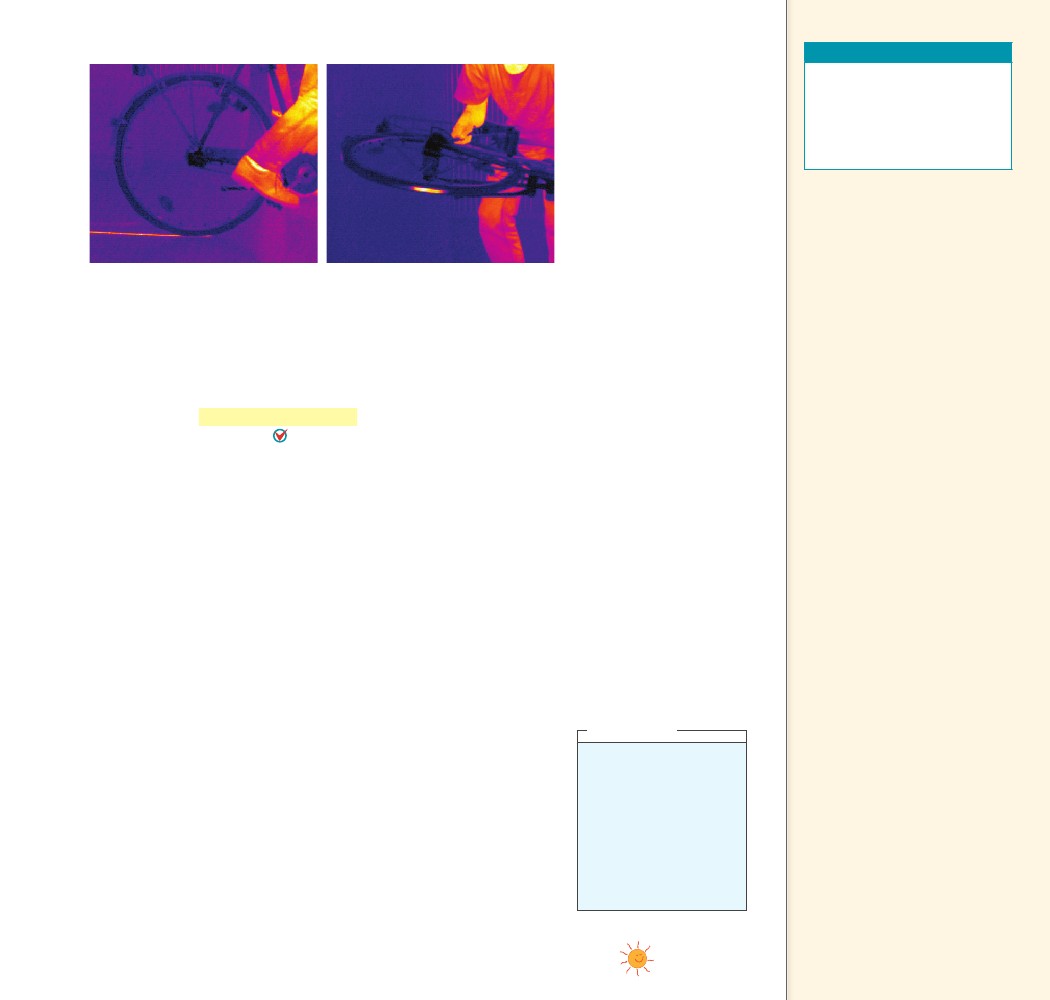
Teaching Resources

FIGURE 9.4

Due to friction, energy

is transferred both into

the floor and into the tire

when the bicycle skids to

a stop. a. An infrared cam-

era reveals the heated tire

track on the floor. b. The

warmth of the tire is also

revealed.

• Reading and Study

Workbook

• Laboratory Manual 30

• PresentationEXPRESS

• Interactive Textbook

9.6 Work-Energy

Theorem

Key Term

work-energy theorem

Teaching Tip Note the pair

of photos in Figure 9.4 that

nicely show the heat generated

by friction on a skidding bicycle

tire. How interesting it would

be to see infrared photos of the

heat generated when a couple

of cars collide. Recall that half

the KE for a collision of identical

cars goes into heat. Seeing that

via an infrared photo would be

interesting.

Teaching Tip To a close

approximation, skidding force

is independent of speed. Hence,

change in KE is approximately

equal to change in skidding

distance.

Teaching Tip Point out

that when a car’s brakes are

applied, the car’s KE is changed

into internal energy in the brake

pads, tires, and road as they all

become warmer.

a

b

9.6 Work-Energy Theorem

So we see that to increase the kinetic energy of an object, work must

be done on it. Or if an object is moving, work is required to bring it

to rest. In either case, the change in kinetic energy is equal to the net

work done. The work-energy theorem describes the relationship

The work-energy theorem states thatbetween work and energy.

whenever work is done, energy changes. We abbreviate “change in”

with the delta symbol, , and say

Work

KE

Work equals change in kinetic energy. The work in this equation is the

net work—that is, the work based on the net force.

The work-energy theorem emphasizes the role of change. If there

is no change in an object’s kinetic energy, then we know no net work

was done on it. Push against a box on a floor. If it doesn’t slide, then

you are not doing work on the box. Put the box on a very slippery

floor and push again. If there is no friction at all, the work of your

push times the distance of your push appears as kinetic energy of the

box. If there is some friction, it is the net force of your push minus

the frictional force that is multiplied by distance to give the gain in

kinetic energy. If the box moves at a constant speed, you are pushing

just hard enough to overcome friction. Then the net force and net

work are zero, and, according to the work-energy theorem, KE = 0.

The kinetic energy doesn’t change.

The work-energy theorem applies to decreasing speed as well.

The more kinetic energy something has, the more work is required

to stop it. Twice as much kinetic energy means twice as much work.

When we apply the brakes to slow a car, or the bike in Figure 9.4, we

do work on it. This work is the friction force supplied by the brakes

multiplied by the distance over which the friction force acts.

think!

A friend says that if you

do 100 J of work on a

moving cart, the cart

will gain 100 J of KE.

Another friend says this

depends on whether or

not there is friction. What

is your opinion of these

statements? Answer: 9.6.1

Teaching Tidbit The work-

energy theorem can be further

stated as DE 5 W 1 Q, where Q

is the energy transfer due to a

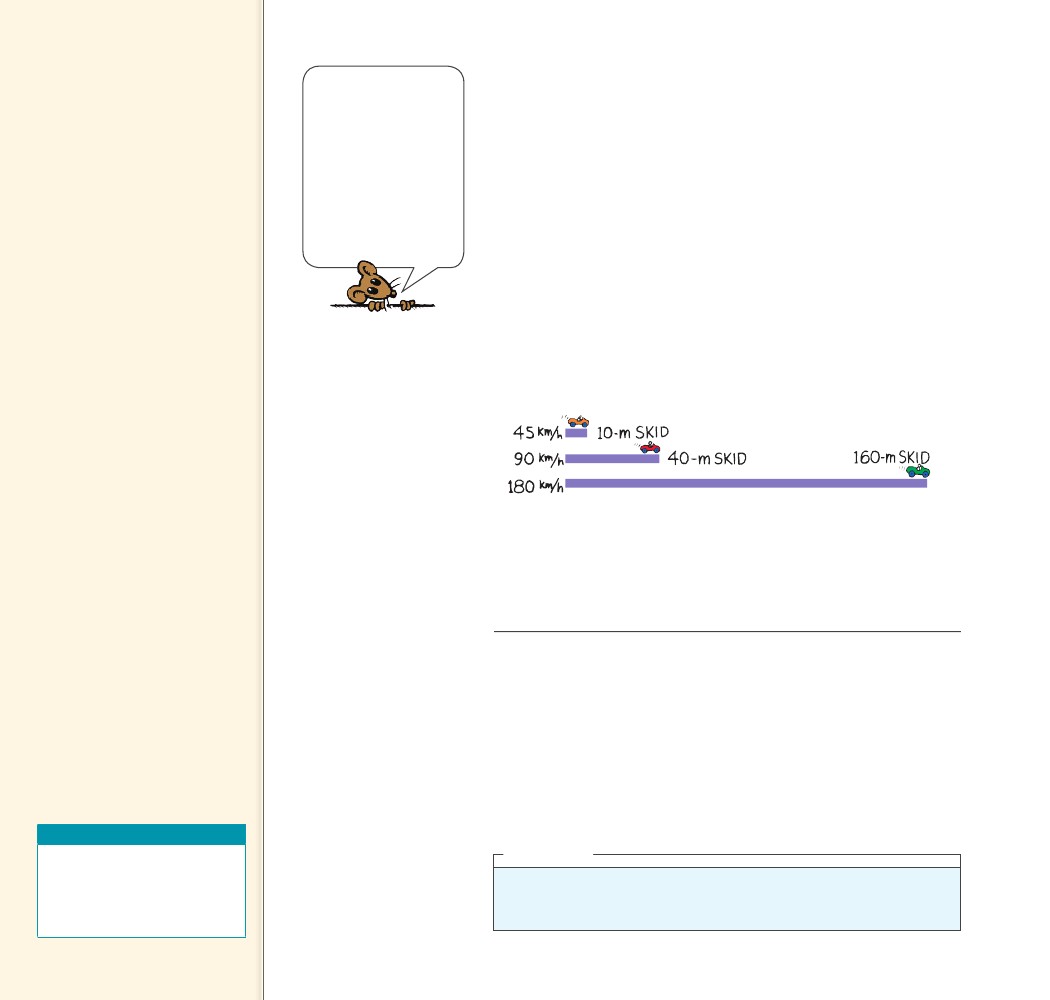
temperature difference.

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ENERGY

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 Teaching Tip Revisit the

demonstration on page 131 and

ask why lifting and dropping two

balls doesn’t result in one ball

popping out at twice the speed.

If that were to occur, momentum

would be conserved (2mv 5

m2v). But this doesn’t occur

because the KE of the twice-

as-fast ball would exceed (be

twice) the KE of the two incident

balls! [1/2 (2mv2) ? 1/2m(2v)2,

a conservation of energy no

no!] This is a stumper for most

students.

Automobile brakes

convert KE to heat.

Professional drivers are

familiar with another

way to brake—shift to

low gear and let the

engine slow the vehicle.

Hybrid cars similarly

divert braking energy

to stored energy in

batteries.

Interestingly, the maximum friction that the brakes can supply is

nearly the same whether the car moves slowly or quickly. In a panic

stop with antilock brakes, the only way for the brakes to do more

work is to act over a longer distance. A car moving at twice the speed

of another has four times (22 4) as much kinetic energy, and will

require four times as much work to stop. Since the frictional force is

nearly the same for both cars, the faster one takes four times as much

distance to stop. The same rule applies to older-model brakes that can

lock the wheels. The force of friction on a skidding tire is also nearly

independent of speed. So, as accident investigators are well aware, an

automobile going 100 kilometers per hour, with four times the kinetic

energy it would have at 50 kilometers per hour, skids four times as far

with its wheels locked as it would with a speed of 50 kilometers per

hour. Figure 9.5 shows the skid distances for a car moving at 45 km/h,

90 km/h, and 180 km/h. The distances would be even greater if the

driver’s reaction time were taken into account. Kinetic energy depends

on speed squared.

FIGURE 9.5

Typical stopping distances for cars

equipped with antilock brakes traveling

at various speeds. The work done to

stop the car is friction force distance

of slide.

CONCEPT

......

The work-energy

CHECK theorem states that

whenever work is done, energy

changes.

CONCEPT

Kinetic energy often appears hidden in different forms of energy,

such as heat, sound, light, and electricity. Random molecular motion

is sensed as heat. Sound consists of molecules vibrating in rhythmic

patterns. Even light energy originates in the motion of electrons

within atoms. Electrons in motion make electric currents. We see that

kinetic energy plays a role in other energy forms.

......

CHECK

Teaching Resources

• Reading and Study

Workbook

• PresentationEXPRESS

• Interactive Textbook

What is the work-energy theorem?

think!

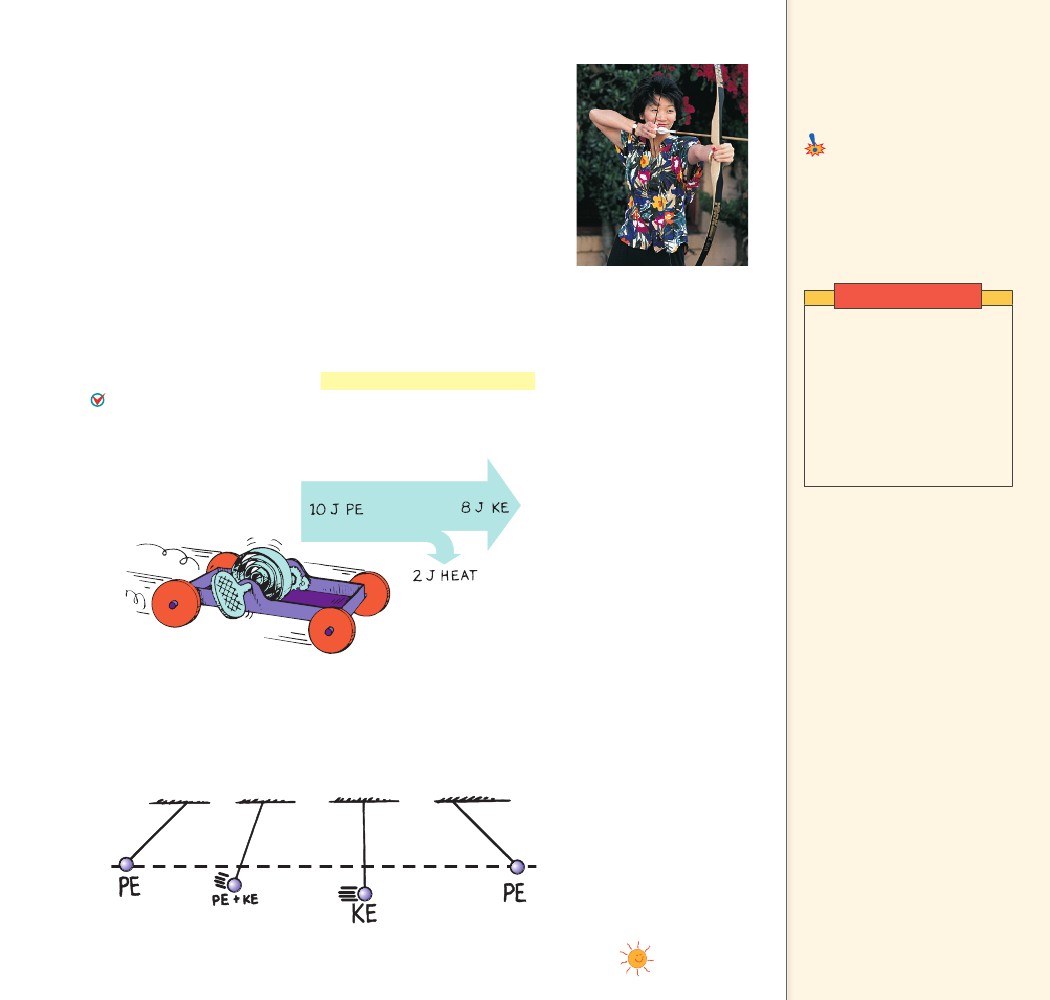
When the brakes of a car are locked, the car skids to a stop. How much farther

will the car skid if it’s moving 3 times as fast?

Answer: 9.6.2

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9.7 Conservation

9.7 Conservation of Energy

More important than knowing what energy is, is understanding how

it behaves—how it transforms. We can understand nearly every pro-

cess that occurs in nature if we analyze it in terms of a transforma-

tion of energy from one form to another.

As you draw back the arrow in a bow, as shown in Figure 9.6,

you do work stretching the bow. The bow then has potential energy.

When released, the arrow has kinetic energy equal to this potential

energy. It delivers this energy to its target. The small distance the

arrow moves multiplied by the average force of impact doesn’t quite

match the kinetic energy of the target. But if you investigate further,

you’ll find that both the arrow and target are a bit warmer. By how

much? By the energy difference. Energy changes from one form to

another without a net loss or a net gain.

The study of the various forms of energy and the transformations

from one form into another is the law of conservation of energy.

The law of conservation of energy states that energy cannot be

created or destroyed. It can be transformed from one form into

another, but the total amount of energy never changes.

of Energy

Key Term

law of conservation of energy

Common Misconception

Energy is conserved only under

certain conditions.

When energy changes from

one form to another, it always

transforms without net loss or

gain.

FACT

FIGURE 9.6

When released, potential

energy will become the

kinetic energy of the arrow.

Demonstration

Attach a small weight to

the end of a 1-m length of

string. Swing the pendulum

to and fro, and describe the

transformations from PE to

KE to PE. Discuss the role

of friction in damping the

pendulum motion (and the

subsequent warming of the

room!).

FIGURE 9.7

Part of the PE of the wound

spring changes into KE.

The remaining PE goes into

heating the machinery and

the surroundings due to fric-

tion. No energy is lost.

Teaching Tip Tell students

that when gasoline combines

with oxygen in a car’s engine, the

chemical potential energy stored

in the fuel is converted mainly

into molecular KE, or thermal

energy. Some of this energy is

transferred to the piston and

some of this energy in turn causes

motion of the car.

Teaching Tip Tell students

that when you rub two sticks

together to start a fire, you

transform mechanical energy into

heat. When you do work to wind

up a spring in a toy cart, you

give it PE which then transforms

to KE when the cart speeds up

on the floor. When the speed

becomes constant, continued

transformation of PE does work

against friction and produces

heat. (Without friction, KE

would keep increasing with

decreasing PE.)

Figures 9.7 and 9.8 demonstrate conservation of energy in two dif-

ferent systems. When you consider any system in its entirety, whether

it is as simple as the swinging pendulum or as complex as an explod-

ing galaxy, there is one quantity that does not change: energy. Energy

may change form, but the total energy score stays the same.

FIGURE 9.8

Everywhere along the path

of the pendulum bob, the

sum of PE and KE is the

same. Because of the work

done against friction, this

energy will eventually be

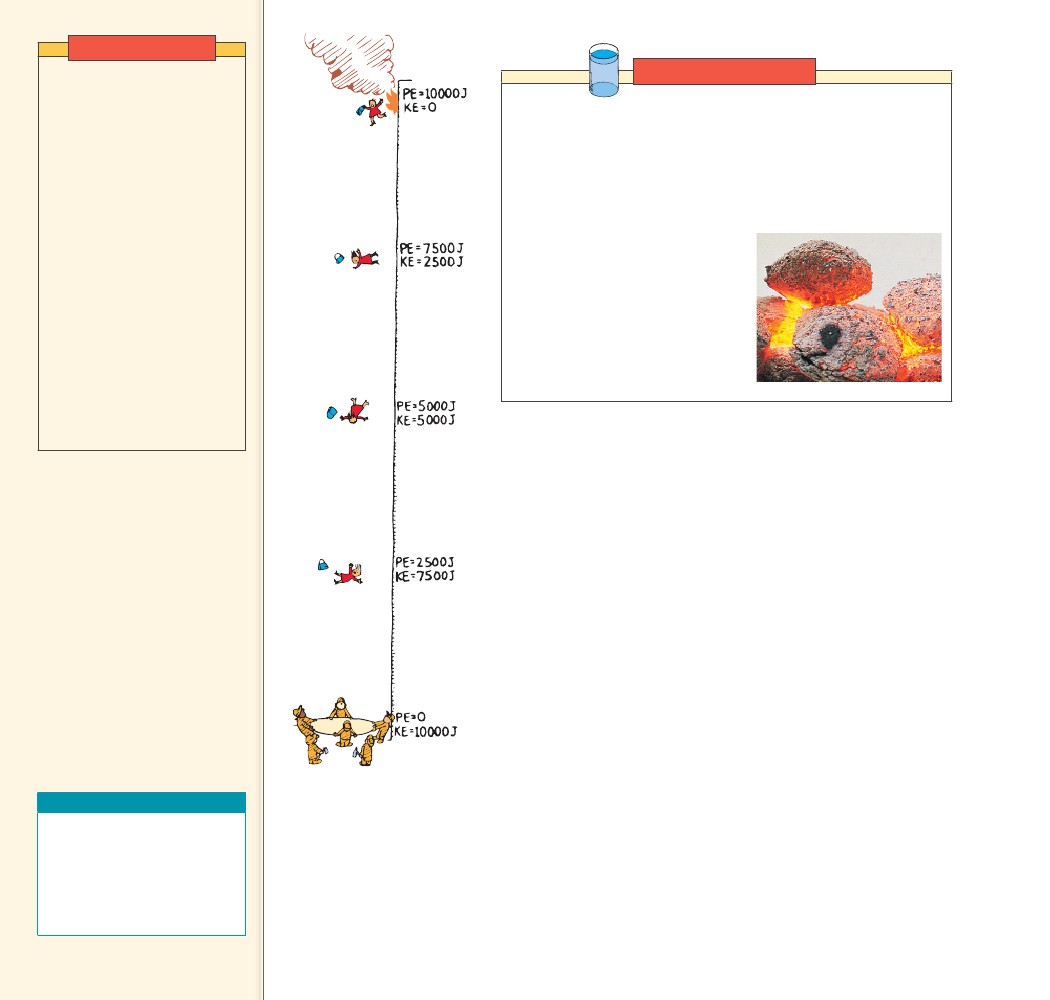
transformed into heat.

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ENERGY

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Demonstrations

Make a long pendulum that

extends from the ceiling 2 or

3 m away from a wall. Stand

on a chair against the wall

with the extended heavy

pendulum bob held at the tip

of your nose, or against your

teeth. Release the bob and let

it swing out, and then back

to your face. Don’t flinch.

Comment on your confidence

in one of the most central

of the physical laws—the

conservation of energy.

Preview electricity and

magnetism and bring out

the hand-cranked horseshoe-

magnet generator that lights

up a lamp. Have student

volunteers note that more

work is needed to turn the

crank when the lamp is

connected than when it is not.

Link to CHEMISTRY

Reactions What process provides energy for rockets that lift the

space shuttle into orbit? What process releases energy from the food

we eat? The answer is chemical reactions. During a chemical reaction

the bonds between atoms break and then reform. Breaking bonds

requires energy, and forming bonds releases it. Pulling atoms apart

is like pulling apart two magnets stuck together; it takes energy to

do it. And when atoms join, it is like two separated magnets that slam

together; energy is released. Rapid

energy release can produce flames.

Slow energy release occurs during

the digestion of food. The conser-

vation of energy rules chemical

reactions. The amount of energy

required to break a chemical bond

is the same amount released when

that bond is formed.

The law of

CHECK conservation of

energy states that energy cannot

be created or destroyed. It can be

transformed from one form into

another, but the total amount of

energy never changes.

CONCEPT

Teaching Resources

• Concept-Development

Practice Book 9-1

• Problem-Solving Exercises in

Physics 6-2

• Laboratory Manual 28, 29, 32

• Next-Time Questions 9-2, 9-3

FIGURE 9.9

When the woman in dis-

tress leaps from the burning

building, note that the sum

of her PE and KE remains

constant at each successive

position all the way down to

the ground.

This energy score takes into account the fact that each atom that

makes up matter is a concentrated bundle of energy. When the nuclei

(cores) of atoms rearrange themselves, enormous amounts of energy

can be released. The sun shines because some of its nuclear energy is

transformed into radiant energy. In nuclear reactors, nuclear energy

is transformed into heat.

Enormous compression due to gravity in the deep hot interior

of the sun causes hydrogen nuclei to fuse and become helium nuclei.

This high-temperature welding of atomic nuclei is called thermo-

nuclear fusion and will be covered later, in Chapter 40. This process

releases radiant energy, some of which reaches Earth. Part of this

energy falls on plants, and some of the plants later become coal.

Another part supports life in the food chain that begins with micro-

scopic marine animals and plants, and later gets stored in oil. Part

of the sun’s energy is used to evaporate water from the ocean. Some

water returns to Earth as rain that is trapped behind a dam. By virtue

of its elevated position, the water behind the dam has potential energy

that is used to power a generating plant below the dam. The generat-

ing plant transforms the energy of falling water into electrical energy.

Electrical energy travels through wires to homes where it is used for

lighting, heating, cooking, and operating electric toothbrushes. How

nice that energy is transformed from one form to another!

CONCEPT

......

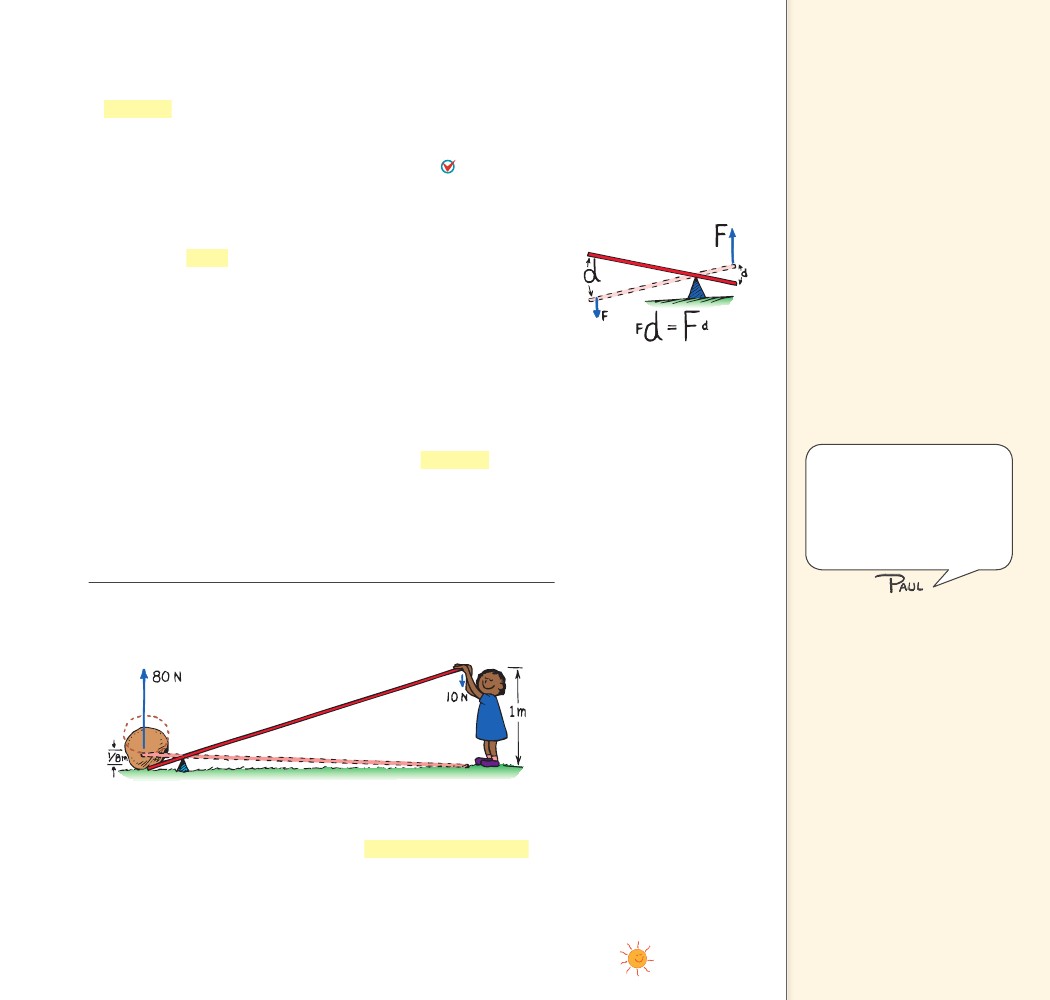
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CHECK

What does the law of conservation of energy state?

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9.8 Machines

9.8 Machines

A machine is a device used to multiply forces or simply to change

the direction of forces. The concept that underlies every machine is

the conservation of energy. A machine cannot put out more energy

A machinethan is put into it. A machine cannot create energy.

transfers energy from one place to another or transforms it from

one form to another.

Levers Consider one of the simplest machines, the lever, shown in

Figure 9.10. A lever is a simple machine made of a bar that turns

about a fixed point. At the same time we do work on one end of the

lever, the other end does work on the load. We see that the direction

of force is changed. If we push down, the load is lifted up. If the heat

from friction is small enough to neglect, the work input will be equal

to the work output.

FIGURE 9.10

In the lever, the work

(force distance)

done at one end is

equal to the work

done on the load at

the other end.

Key Terms

machine, lever, fulcrum,

mechanical advantage, pulley

Teaching Tip Apply energy

conservation to the lever

(Figure 9.10). [Be careful not

to confuse the distances moved

with the lever-arm distances of

torque (Chapter 11)—Fd here

refers to the force multiplied by

the distance the “force moves”

(parallel to the force), whereas

in the case of torque, d refers

to the leverage distance that

is perpendicular to the applied

force.] Show how varying the

position of the fulcrum changes

the relative values of output

force and distance moved. Stress

that this is in accord with the rule

“work input 5 work output.”

Good resource material is found

at the beginning of Chapter 4

in the first volume of The

Feynman Lectures on Physics.

Feynman compares the idea of

energy conservation with a

child’s misplaced blocks.

work input

(force

distance)input

work output

(force

distance)output

Since work equals force times distance, we can say

A little thought will show that the pivot point, or fulcrum, of the

lever can be relatively close to the load. Then a small input force

exerted through a large distance will produce a large output force

over a correspondingly short distance. In this way, a lever can multi-

ply forces. However, no machine can multiply work or energy. That’s

a conservation of energy no-no!

FIGURE 9.11

The output force (80 N) is eight times

the input force (10 N), while the output

distance (1/8 m) is one-eighth of the

input distance (1 m).

Consider the ideal weightless lever in Figure 9.11. The child

pushes down 10 N and lifts an 80-N load. The ratio of output force

to input force for a machine is called the mechanical advantage.

Here the mechanical advantage is (80 N)/(10 N), or 8. Notice that the

load moves only one-eighth of the distance the input force moves.

Neglecting friction, the mechanical advantage can also be determined

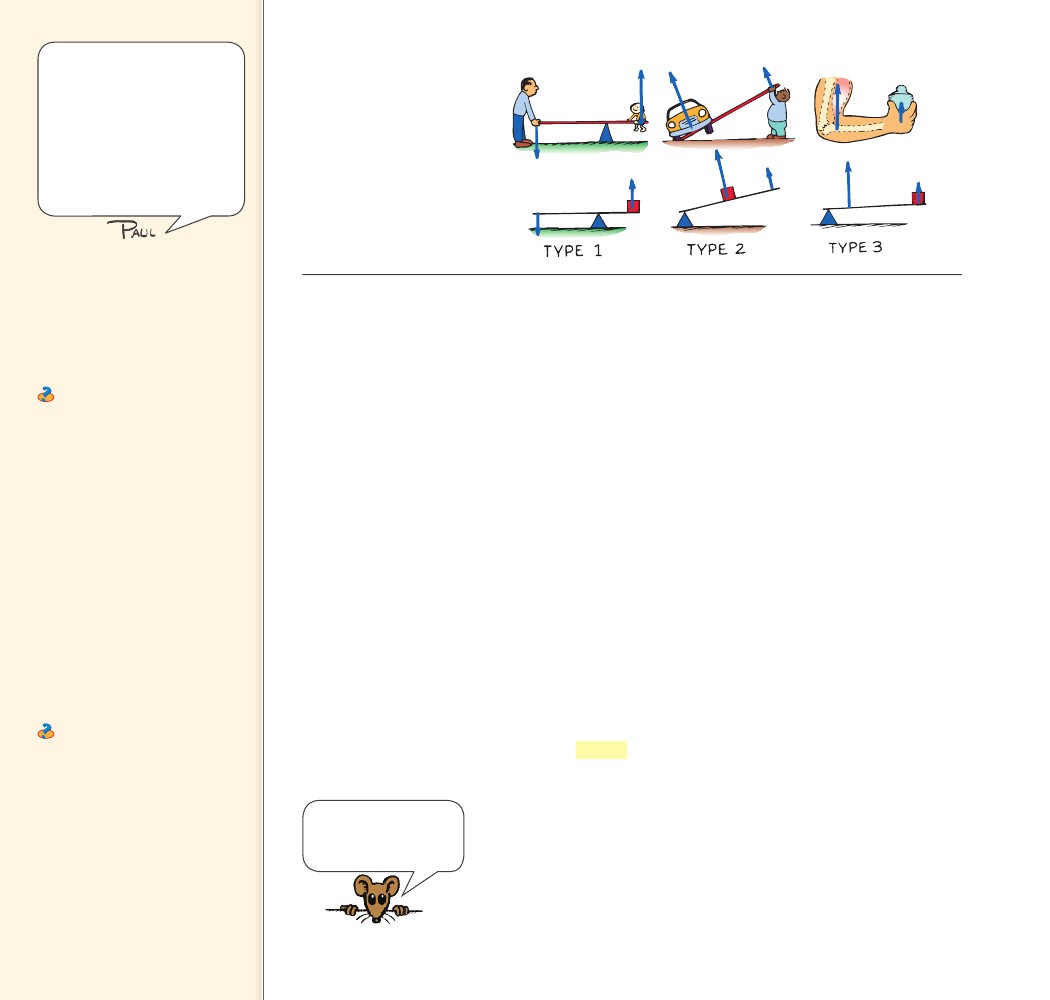
by the ratio of input distance to output distance.

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A perpetual-motion machine (a

device that can do work without

energy input) is a no no. But

perpetual motion itself, is a yes

yes. Atoms and their electrons,

and stars and their planets,

for example, are in a state of

perpetual motion. Perpetual

motion is the natural order of

things.

FIGURE 9.12

The three basic types of levers

are shown here. Notice that

the direction of the force is

changed in type 1.

Teaching Tip Acknowledge

the three different types of levers

shown in Figure 9.12, without

overstating the distinction

between the three types. Stress

the relationship fD 5 Fd, energy

conservation.

Ask Archimedes, the most

famous scientist in ancient

Greece, stated that given a long-

enough lever and a place to

stand, he could move the world.

What does this mean? In accord

with the lever equation fD 5 Fd,

a force as great as the weight of

the world could be lifted with

the force he could muster—as

long as there was a place for

him to stand and a place for the

fulcrum!

Teaching Tip Give some

other examples of levers:

Type 1: crowbar opening a

window

Type 2: a hand bottle cap

opener

Type 3: a construction crane

Ask In which type of lever is

work output greater than work

input? NONE! In no system can

work output exceed work input!

Be clear about the difference

between work and force.

Three common ways to set up a lever are shown in Figure 9.12.

A type 1 lever has the fulcrum between the force and the load, or

between input and output. This kind of lever is commonly seen in a

playground seesaw with children sitting on each end of it. Push down

on one end and you lift a load at the other. You can increase force at

the expense of distance. Note that the directions of input and output

are opposite.

For a type 2 lever, the load is between the fulcrum and the input

force. To lift a load, you lift the end of the lever. One example is plac-

ing one end of a long steel bar under an automobile frame and lift-

ing on the free end to raise the automobile. Again, force on the load

is increased at the expense of distance. Since the input and output

forces are on the same side of the fulcrum, the forces have the same

direction.

In the type 3 lever, the fulcrum is at one end and the load is at the

other. The input force is applied between them. Your biceps muscles

are connected to the bones in your forearm in this way. The fulcrum

is your elbow and the load is in your hand. The type 3 lever increases

distance at the expense of force. When you move your biceps muscles

a short distance, your hand moves a much greater distance. The input

and output forces are on the same side of the fulcrum and therefore

they have the same direction.

Pulleys A pulley is basically a kind of lever that can be used to

change the direction of a force. Properly used, a pulley or system of

pulleys can multiply forces.

The single pulley in Figure 9.13a behaves like a type 1 lever. The

axis of the pulley acts as the fulcrum, and both lever distances (the

radius of the pulley) are equal so the pulley does not multiply force.

It simply changes the direction of the applied force. In this case, the

mechanical advantage equals 1. Notice that the input distance equals

the output distance the load moves.

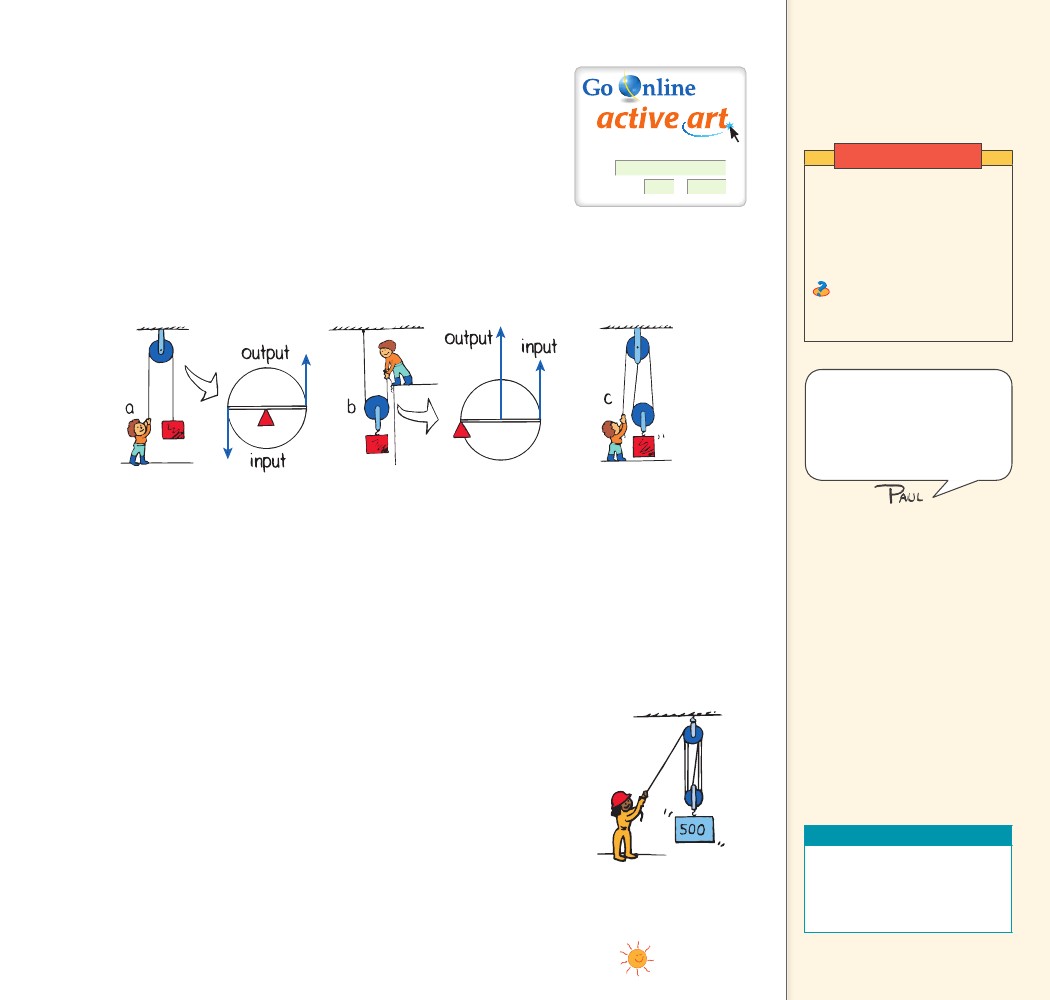
A machine can multiply

force, but never energy.

No way!

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 In Figure 9.13b, the single pulley acts as a type 2 lever. Careful

thought will show that the fulcrum is at the left end of the “lever”

where the supporting rope makes contact with the pulley. The load

is suspended halfway between the fulcrum and the input end of the

lever, which is on the right end of the “lever.” Each newton of input

will support two newtons of load, so the mechanical advantage is 2.

This number checks with the distances moved. To raise the load

1 m, the woman will have to pull the rope up 2 m. We can say the

mechanical advantage is 2 for another reason: the load is now sup-

ported by two strands of rope. This means each strand supports half

the load. The force the woman applies to support the load is there-

fore only half of the weight of the load.

Teaching Tip Explain that

a pulley is simply a lever in

disguise, as shown in Figure 9.13.

Show also that for a pulley,

fD 5 Fd.

For: Pulley activity

Visit: PHSchool.com

Web Code: csp – 1097

Demonstration

Use a spring scale and model

pulleys to show the pulley

arrangements in Figure 9.13.

The spring scale will show

the relative forces needed to

support the same load.

Ask In which pulley

arrangement can work output

exceed work input? NONE!

Cite the cases of charlatans

who devise complicated

arrangements of levers, pulleys,

and other gadgets to design a

machine that will have a greater

work output than work input.

The mechanical advantage for simple pulley systems is the same

as the number of strands of rope that actually support the load. In

Figure 9.13a, the load is supported by one strand and the mechanical

advantage is 1. In Figure 9.13b, the load is supported by two strands

and the mechanical advantage is 2. Can you use this rule to state the

mechanical advantage of the pulley system in Figure 9.13c?9.8

The mechanical advantage of the simple system in Figure 9.13c

is 2. Notice that although three strands of rope are shown, only two

strands actually support the load. The upper pulley serves only to

change the direction of the force. Actually experimenting with a

variety of pulley systems is much more beneficial than reading about

them in a textbook, so try to get your hands on some pulleys, in or

out of class. They’re fun.

The pulley system shown in Figure 9.14 is a bit more complex, but

the principles of energy conservation are the same. When the rope

is pulled 5 m with a force of 100 N, a 500-N load is lifted 1 m. The

mechanical advantage is (500 N)/(100 N), or 5. Force is multiplied at

the expense of distance. The mechanical advantage can also be found

from the ratio of distances: (input distance)/(output distance) 5.

CONCEPT

FIGURE 9.13

A pulley is useful.

a. A pulley can change

the direction of a force.

b. A pulley multiplies

force. c. Two pulleys can

change the direction and

multiply force.

Teaching Tip Some of your

students may have seen a chain

hoist being used to remove an

automobile engine from a car.

If so, they’ll have noticed that

the mechanic must pull meters

of chain to lift the engine only a

few centimeters.

A machine transfers

CHECK energy from one

place to another or transforms it

from one form to another.

CONCEPT

Teaching Resources

......

FIGURE 9.14

• Concept-Development

Practice Book 9-2, 9-3

• Transparencies 13, 14

• Laboratory Manual 27

CHECK

How does a machine use energy?

A complex pulley system is

shown here.

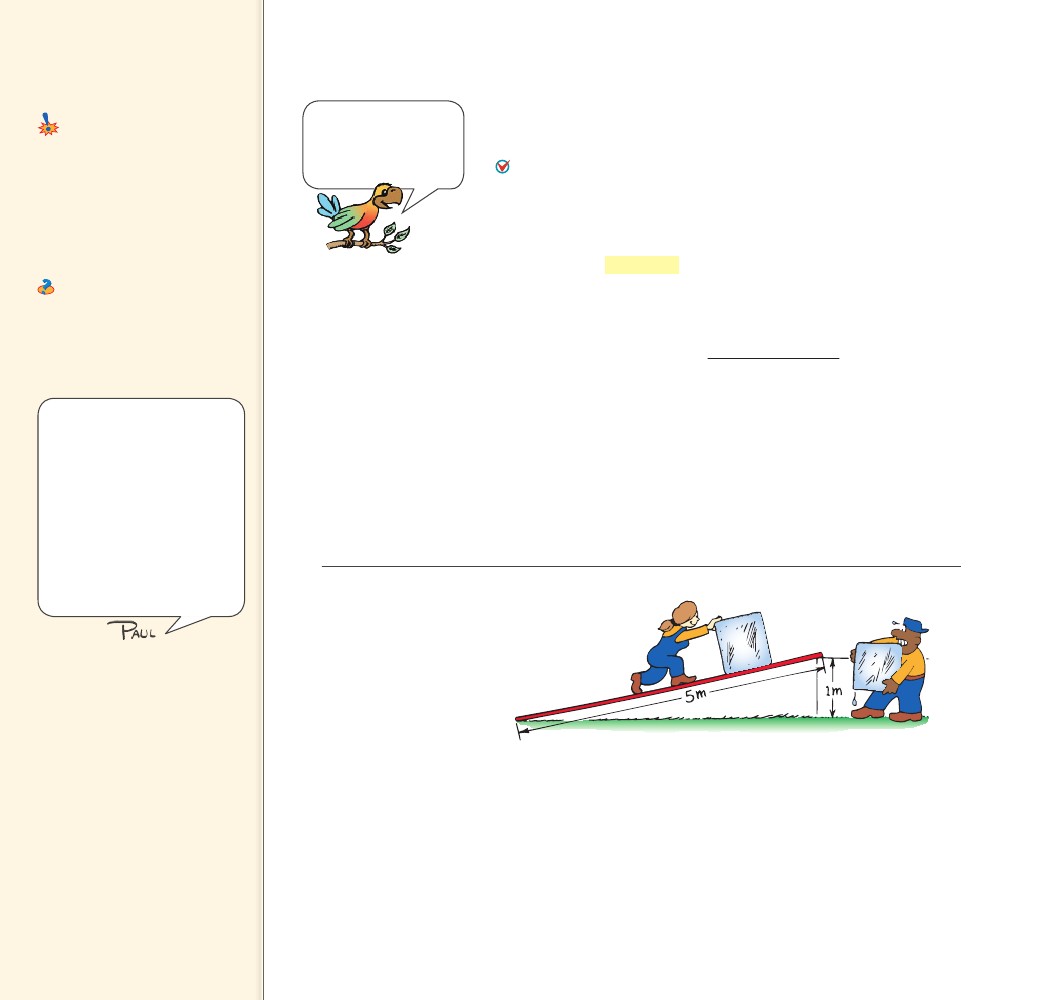
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CHAPTER 9

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9.9 Efficiency

Key Term

efficiency

Common Misconceptions

It is possible to get more energy out

of a machine than is put in.

In practice, some energy is

always dissipated as heat and so

no machine can ever be 100%

efficient, and certainly cannot

generate more energy than is put

into it.

FACT

9.9 Efficiency

When it comes to

energy, you can never

get something for

nothing.

Ask What does it mean to

say a certain machine is 30%

efficient? It means the machine

will convert 30% of the energy

input to useful work—70% of the

energy input will be wasted.

The previous examples of machines were considered to be ideal. All

the work input was transferred to work output. An ideal machine

would have 100% efficiency. No real machine can be 100% efficient.

In any machine, some energy is transformed into atomic or

molecular kinetic energy—making the machine warmer. We say

this wasted energy is dissipated as heat.9.9.1

When a simple lever rocks about its fulcrum, or a pulley turns

about its axis, a small fraction of input energy is converted into ther-

mal energy. The efficiency of a machine is the ratio of useful energy

output to total energy input, or the percentage of the work input that

is converted to work output. Efficiency can be expressed as the ratio

of useful work output to total work input.

efficiency

useful work output

total work input

It should be enough that

your students are acquainted

with the ideas of efficiency

and actual and theoretical

mechanical advantage. It is

easy to let the plow blade sink

deeper in this section, and

turn this chapter toward the

burdensome side of study. I

therefore recommend this

section be treated lightly, and

not used as primary examination

fodder.

We may put in 100 J of work on a lever and get out 98 J of work.

The lever is then 98% efficient and we lose only 2 J of work input as

heat. In a pulley system, a larger fraction of input energy is lost as

heat. For example, if we do 100 J of work, the friction on the pulleys

as they turn and rub on their axle can dissipate 40 J of heat energy.

So the work output is only 60 J and the pulley system has an effi-

ciency of 60%. The lower the efficiency of a machine, the greater is

the amount of energy wasted as heat.

FIGURE 9.15

Pushing the block of ice

5 times farther up the

incline than the vertical

distance it’s lifted requires

a force of only one-fifth its

weight. Whether pushed up

the plane or simply lifted,

the ice gains the same

amount of PE.

Teaching Tip Discuss

Figure 9.15. As the load is

pushed, the load pushes on

molecules of the ramp (due to

friction), causing them to move

too. So some of the work done is

lost to the ramp through friction.

Inclined Planes An inclined plane is a machine. Sliding a load up

an incline requires less force than lifting it vertically. Figure 9.15 shows

a 5-m inclined plane with its high end elevated by 1 m. Using the

plane to elevate a heavy load, we push the load five times farther than

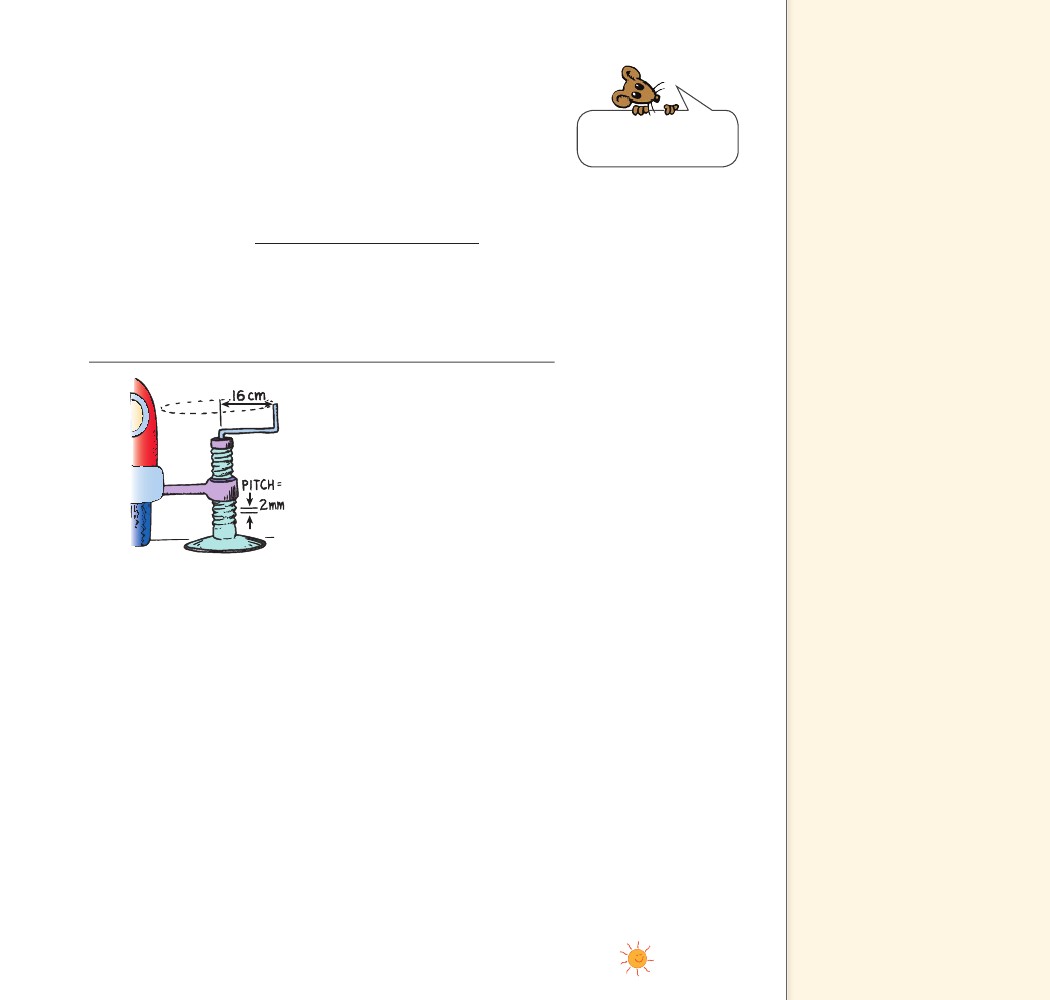
we lift it vertically. If friction is negligible, we need apply only one-

fifth of the force required to lift the load vertically. The inclined plane

shown has a theoretical mechanical advantage of 5.

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 An icy plank used to slide a block of ice up to some height might

have an efficiency of almost 100%. However, when the load is a

wooden crate sliding on a wooden plank, both the actual mechanical

advantage and the efficiency will be considerably less. Friction will

require you to exert more force (a greater work input) without any

increase in work output.

Efficiency can also be expressed as the ratio of actual mechanical

advantage to theoretical mechanical advantage.

efficiency

actual mechanical advantage

theoretical mechanical advantage

Energy is nature’s way

of keeping score.

Efficiency will always be a fraction less than 1. To convert effi-

ciency to percent, we simply express it as a decimal and multiply

by 100%. For example, an efficiency of 0.25 expressed in percent is

0.25 100%, or 25%.

Teaching Tip The efficiency

of a light bulb underscores the

idea of useful energy. To say

an incandescent lamp is 10%

efficient is to say that only 10%

of the energy input is converted

to the useful form of energy,

light. All the rest goes to heat.

However, even the energy of

light converts to heat upon

absorption, so all the energy

input to an incandescent lamp

is converted to heat. This means

it is a 100%-efficient device as a

heater (but not as a device for

emitting light)!

FIGURE 9.16

The auto jack is like an

inclined plane wrapped

around a cylinder. Every

time the handle is turned

one revolution, the load

is raised a distance of

one pitch.

Complex Machines The auto jack shown in Figure 9.16 is actu-

ally an inclined plane wrapped around a cylinder. You can see that

a single turn of the handle raises the load a relatively small distance.

If the circular distance the handle is moved is 500 times greater than

the pitch, which is the distance between ridges, then the theoretical

mechanical advantage of the jack is 500.9.9.2 No wonder a child can

raise a loaded moving van with one of these devices! In practice there

is a great deal of friction in this type of jack, so the efficiency might

be about 20%. Thus the jack actually multiplies force by about 100

times, so the actual mechanical advantage approximates an impres-

sive 100. Imagine the value of one of these devices if it had been

available when the great pyramids were being built!

An automobile engine is a machine that transforms chemical

energy stored in fuel into mechanical energy. The molecules of the

gasoline break up as the fuel burns. Burning is a chemical reaction in

which atoms combine with the oxygen in the air. Carbon atoms from

the gasoline combine with oxygen atoms to form carbon dioxide,

hydrogen atoms combine with oxygen, and energy is released. The

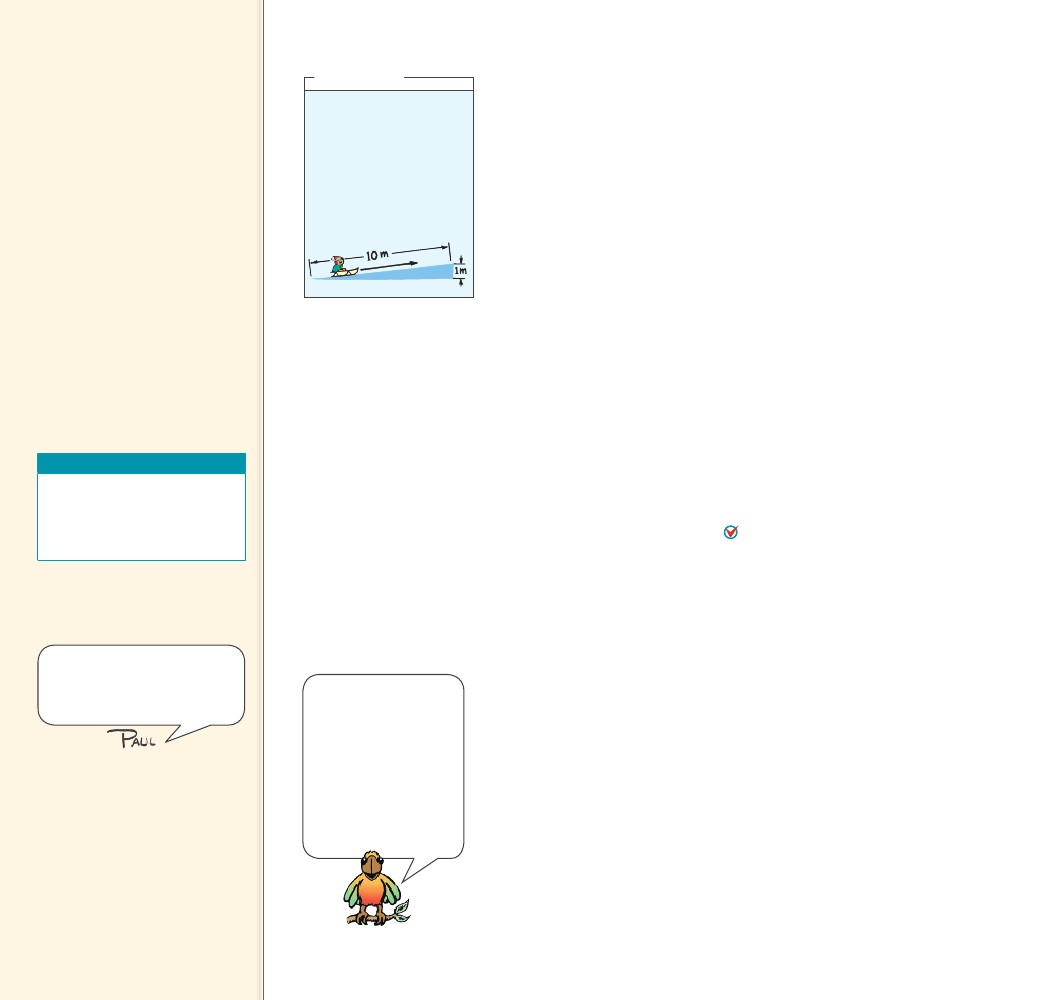
converted energy is used to run the engine.

CHAPTER 9

ENERGY

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 Teaching Tip Fuels such as

oil, gas, and wood are forms of

concentrated energy. When they

are used to do work, their energy

is degraded. If all concentrations

of energy are degraded, no more

work can be done. Heat is the

destiny of useful energy.

Teaching Tip Explain that the

degradation of energy is much

like one of your students sharing

his or her lunch (energy) with 100

other students. Rather than one

student with a lot of energy, now

there are many students, each

with a little energy. The energy

has been spread out.

In any machine, some

CHECK energy is transformed

into atomic or molecular kinetic

energy—making the machine

warmer.

CONCEPT

think!

A child on a sled (total

weight 500 N) is pulled up

a 10-m slope that elevates

her a vertical distance of

1 m. What is the theoreti-

cal mechanical advantage

of the slope?

Answer: 9.9

As physicists learned in the nineteenth century, transforming

100% of thermal energy into mechanical energy is not possible. Some

heat must flow from the engine. Friction adds more to the energy

loss. Even the best-designed gasoline-powered automobile engines are

unlikely to be more than 35% efficient. Some of the heat energy goes

into the cooling system and is released through the radiator to the air.

Some of it goes out the tailpipe with the exhaust gases, and almost

half goes into heating engine parts as a result of friction.

On top of these contributors to inefficiency, the fuel does not

burn completely. A certain amount of it goes unused. We can look at

inefficiency in this way: In any transformation there is a dilution of

the amount of useful energy. Useful energy ultimately becomes ther-

mal energy. Energy is not destroyed, it is simply degraded. Through

heat transfer, thermal energy is the graveyard of useful energy.

CONCEPT

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CHECK

Why can’t a machine be 100% efficient?

9.10 Energy for Life

Every living cell in every organism is a machine. Like any machine, liv-

ing cells need an energy supply. Most living organisms on this planet

feed on various hydrocarbon compounds that release energy when

they react with oxygen. There is more energy stored in gasoline than

in the products of its combustion. There is more energy stored in

the molecules in food than there is in the reaction products after the

food is metabolized. This energy difference sustains life.9.10

The same principle of combustion occurs in the metabolism

of food in the body and the burning of fossil fuels in mechanical

engines. The main difference is the rate at which the reactions take

place. During metabolism, the reaction rate is much slower and

energy is released as it is needed by the body. Like the burning of fos-

sil fuels, the reaction is self-sustaining once it starts. In metabolism,

carbon combines with oxygen to form carbon dioxide.

The reverse process is more difficult. Only green plants and cer-

tain one-celled organisms can make carbon dioxide combine with

water to produce hydrocarbon compounds such as sugar. This pro-

cess is photosynthesis and requires an energy input, which normally

comes from sunlight. Sugar is the simplest food. All other foods, such

as carbohydrates, proteins, and fats, are also synthesized compounds

containing carbon, hydrogen, oxygen, and other elements. Because

green plants are able to use the energy of sunlight to make food that

gives us and all other organisms energy, there is life.

CONCEPT

Teaching Resources

• Problem-Solving Exercises in

Physics 6-3

• Laboratory Manual 31

• Probeware Lab Manual 8

9.10 Energy for Life

This section can be skimmed or

can be the topic of a class on

how the conservation of energy

underlies all biology.

There is more energy

CHECK stored in the

molecules in food than there is in

the reaction products after food

is metabolized. This energy

difference sustains life.

CONCEPT

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In biology, you’ll learn

how the body takes

energy from the food

you eat to build mol-

ecules of adenosine

triphosphate, or ATP,

and how this supply of

ATP is used to run all

the chemical reactions

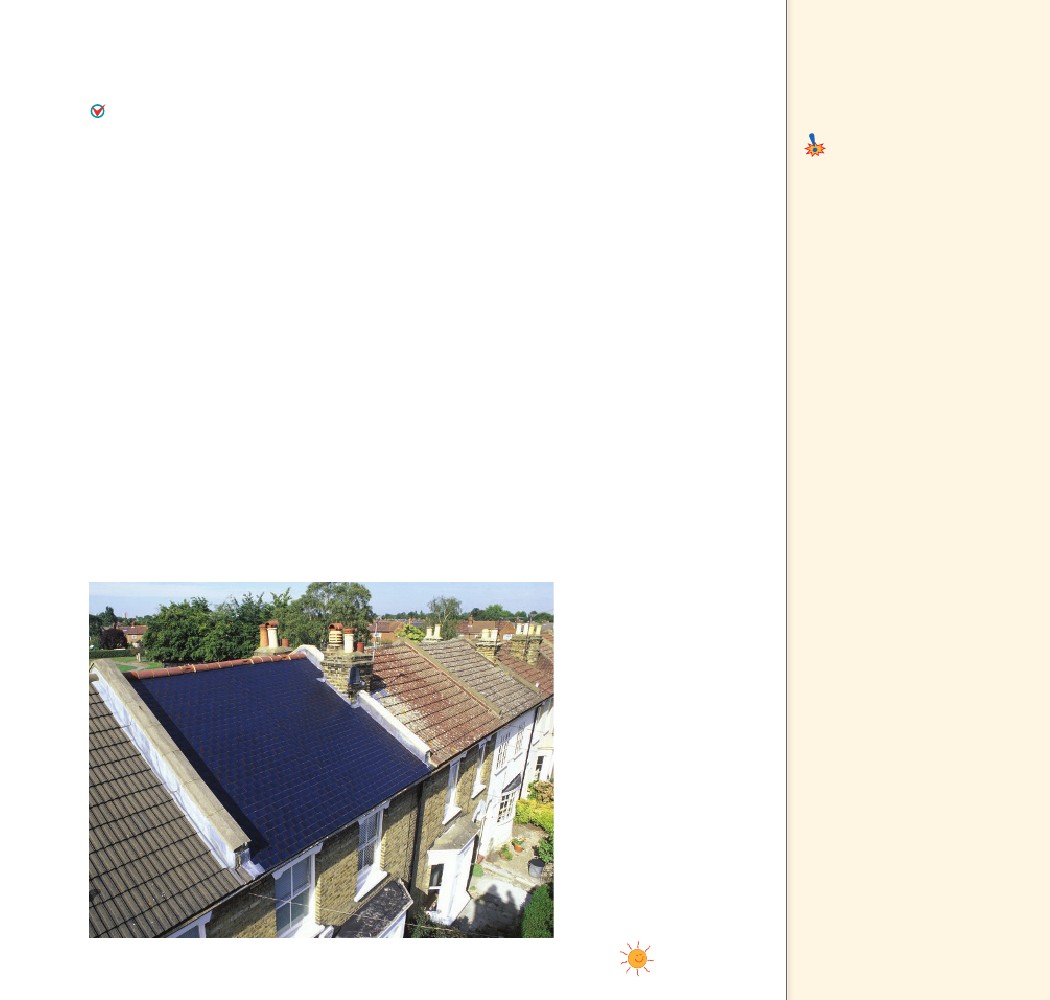
that sustain life.

CHECK

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What role does energy play in sustaining life?

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9.11 Sources of

9.11 Sources of Energy

The sun is the source of practically all our energy on Earth.

(Exceptions are nuclear and geothermal energy.) The energy from

burning wood comes from the sun. Even the energy we obtain from

Earth’s compost of the past—fossil fuels such as petroleum, coal, and

natural gas—comes from the sun. These fuels are created by photosyn-

thesis, the process by which plants trap solar energy and store it

as plant tissue.

Solar Power Sunlight is directly transformed into electricity by

photovoltaic cells, like those found in solar-powered calculators, or

more recently, in the flexible solar shingles on the roof of the build-

ing in Figure 9.17. We use the energy in sunlight to generate electric-

ity indirectly as well. Sunlight evaporates water, which later falls as

rain; rainwater flows into rivers and turns water wheels, or it flows

into modern generator turbines as it returns to the sea.

Wind, caused by unequal warming of Earth’s surface, is another

form of solar power. The energy of wind can be used to turn gen-

erator turbines within specially equipped windmills. Because wind

is not steady, wind power cannot by itself provide all of our energy

needs. But because the wind is always blowing somewhere, windmills

spread out over a large geographical area and integrated into a power

grid can make a substantial contribution to the overall energy mix.

Harnessing the wind is very practical when the energy it produces is

stored for future use, such as in the form of hydrogen.

FIGURE 9.17

Solar shingles look like

traditional asphalt shingles

but they are hooked into

a home’s electrical system.

Energy

Key Term

fuel cell

Common Misconception

Electricity, steam, and other

transporters of energy are energy

sources.

Sources of energy include

solar, geothermal, and nuclear

energy.

FACT

Teaching Tip When

hydrogen is burned in vehicles,

as is presently being done with

commercial vehicles in Iceland,

only water vapor is ejected by the

exhaust. This makes it seem like

a dream fuel. The big problem is

that there is no free hydrogen to

burn. It must be removed from

molecules where it is abundant,

which takes energy that must

come from some energy source.

If gasoline is the source, then

it might as well be used in the

vehicles to begin with, for even

more pollutants would result at

the conversion site. Proponents

of a hydrogen economy usually

sidestep this basic physics. Saying

cars should be powered with

hydrogen is akin to saying

they should be powered with

electricity. Both are not sources

of energy—but carriers of

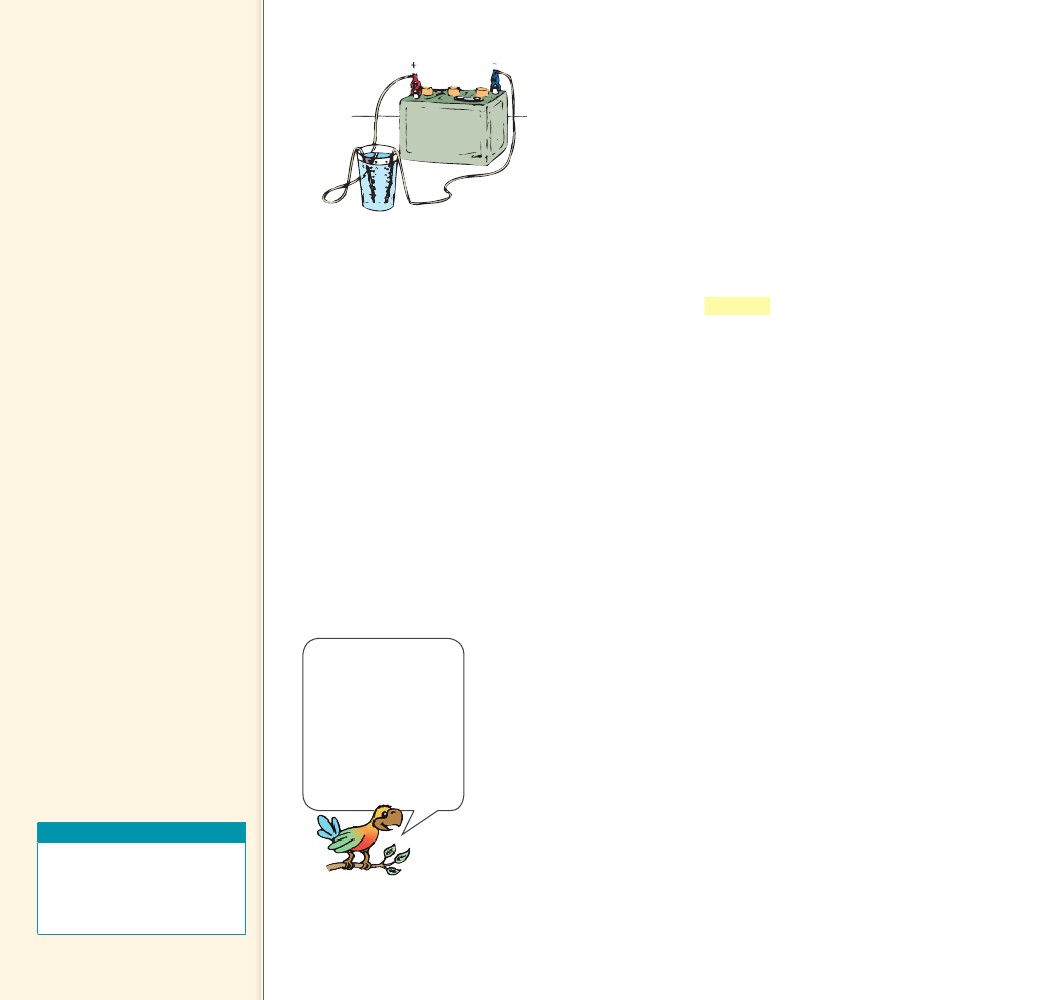
energy.

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ENERGY

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 Teaching Tip Sooner or

later, all the sunlight that falls

on an ecosystem will be radiated

back into space. Energy in an

ecosystem is always in transit—

you can rent it, but you can’t

own it.

Teaching Tip When biologists

talk of energy in living systems,

they’re talking about the same

energy discussed in this chapter.

Our bodies obey the same

principles that levers and other

machines obey.

Teaching Tip When chemical

energy in gunpowder is suddenly

turned into thermal energy,

exiting gases expand rapidly and

push the bullet out of the gun.

In doing so, the gases lose some

of their energy and cool off.

This energy goes into the kinetic

energy of the bullet. Remarkably,

if you add up all this energy,

the total energy is the same.

Chemical energy is converted

into thermal energy and kinetic

energy, and the number of

Calories (or Joules) after firing is

exactly the same as was stored

in the gunpowder. Energy is

conserved.

FIGURE 9.18

When electric current passes

through water, bubbles of

hydrogen form at one wire and

bubbles of oxygen form at the

other. In a fuel cell, the reverse

process occurs: hydrogen and

oxygen combine to produce

water and electricity.

Fuel Cells Hydrogen, the least polluting of all fuels,

holds much promise for the future. Because it takes energy

to make hydrogen (to extract it from water and carbon

compounds), it is not a source of energy. A simple method

to extract hydrogen from water is shown in Figure 9.18.

Place two platinum wires that are connected to the ter-

minals of an ordinary battery into a glass of water (with

an electrolyte dissolved in the water for conductivity). Be

sure the wires don’t touch each other. Bubbles of hydro-

gen form on one wire, and bubbles of oxygen form on the

other. Electricity splits water into its constituent parts.

If you make the electrolysis process run backward, you

have a fuel cell. In a fuel cell, hydrogen and oxygen gas

are compressed at electrodes to produce water and electric

current. The space shuttle uses fuel cells to meet its elec-

trical needs while producing drinking water for the astro-

nauts. Here on Earth, fuel-cell researchers are developing

fuel cells for buses, automobiles, and trains.

The sun is the source

CHECK of practically all our

energy on Earth.

CONCEPT

Watch for the growth

of fuel-cell technology.

The major hurdle for

this technology is not

the device itself, but

with acquiring hydro-

gen fuel economically.

One way is via solar

cells.

Nuclear and Geothermal Energy The most concentrated

form of usable energy is stored in uranium and plutonium, which are

nuclear fuels. Interestingly, Earth’s interior is kept hot by producing

a form of nuclear power, radioactivity, which has been with us since

the Earth was formed.

A byproduct of radioactivity in Earth’s interior is geothermal

energy. Geothermal energy is held in underground reservoirs of hot

water. Geothermal energy is a practical energy source in areas of vol-

canic activity, such as Iceland, New Zealand, Japan, and Hawaii. In

these places, heated water near Earth’s surface is tapped to provide

steam for running turbogenerators.

Energy sources such as nuclear, geothermal, wind, solar, and

water power are environmentally friendly. The combustion of fossil

fuels, on the other hand, leads to increased atmospheric concentra-

tions of carbon dioxide, sulfur dioxide, and other pollutants.

As the world population increases, so does our need for energy.

With the rules of physics to guide them, technologists are now

researching newer and cleaner energy sources. But they race to keep

up with world population and greater demand in the developing

world.

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Teaching Resources

• Reading and Study

Workbook

• PresentationEXPRESS

• Interactive Textbook

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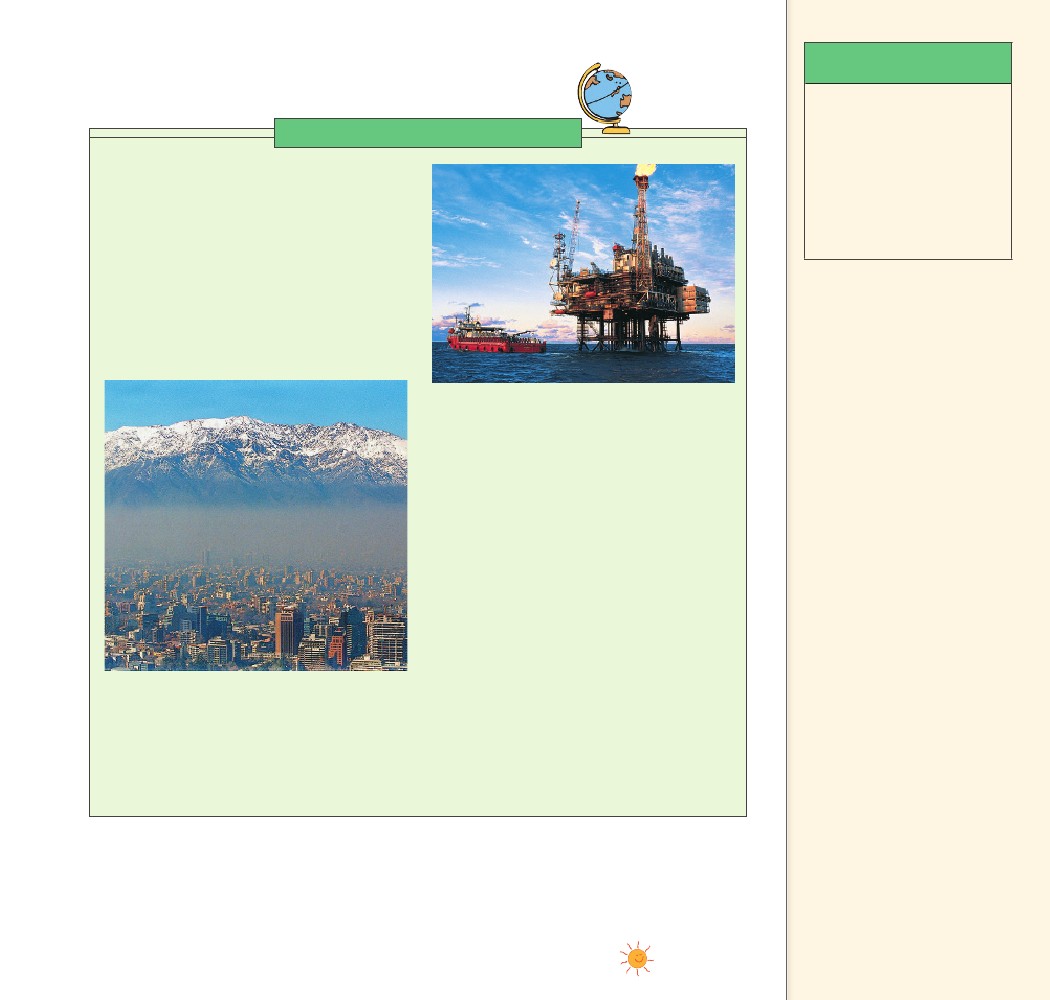
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CONCEPT What is the source of practically all of our

energy on Earth?

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Science, Technology,

and Society

Discuss with students your local

and regional energy sources.

Note the environmental impact

in your area and ways it is being

reduced.

CRITICAL THINKING

Science, Technology, and Society

Energy Conservation Most energy consumed

in America comes from fossil fuels. Oil, natural

gas, and coal supply the energy for almost all

our industry and technology. About 70% of

electrical power in the United States comes from

fossil fuels, with about 21% from nuclear power.

Worldwide, fossil fuels also account for most

energy consumption. We have grown to depend

on fossil fuels because they have been plentiful

and inexpensive. Until recently, our consumption

was small enough that we could ignore their

environmental impact.

to be as inexhaustible as the sun’s glow and as

acceptable as Mom’s apple pie, because these

fuels lasted and nurtured us through the 1900s.

Financially, fossil fuels are still a bargain, but this

is destined to change. Environmentally, the costs

are already dramatic. Some other fuel must take

the place of fossil fuels if we are to maintain

the industry and technology to which we are

accustomed. The French have chosen nuclear, with

about 74% of their electricity coming from nuclear

power plants. What energy source would you

choose as an alternative?

In the meantime, we shouldn’t waste energy.

As individuals, we should limit the consumption

of useful energy by such measures as turning off

unused electrical appliances, using less hot water,

going easy on heating and air conditioning, and

driving energy-efficient automobiles. By doing

these things, we are conserving useful energy.

Critical Thinking In how many reasonable ways

can we reduce energy consumption?

Accept any

reasonable answer as long

as students support their

suggestions with pros and cons.

Teaching Tidbits In Iceland

93% of homes are heated by

geothermal power. In China

30 million households use solar

water heating. In the Philippines

27% of electricity is generated

from geothermal power. In

Denmark 20% of its electricity

is provided by wind turbines. As

of 2007, the state of Texas is the

leading wind-energy producer in

the US.

But things have changed. Fossil fuels are being

consumed at a rate that threatens to deplete the

entire world supply. Locally and globally, our fossil

fuel consumption is measurably polluting the air

we breathe and the water we drink. Yet, despite

these problems, many people consider fossil fuels

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