3 Energy

Oil wells in California.

The word energy has become part of everyday life. We say that an active person is energetic. We hear a candy bar described as being full of energy. We complain about the cost of the electric energy that lights our lamps and turns our motors. We worry about some day running out of the energy stored in coal and oil. We argue about whether nuclear energy is a blessing or a curse. Exactly what is meant by energy?

In general, energy refers to an ability to accomplish change. When almost anything happens in the physical world, energy is somehow involved. But "change" is not a very precise notion, and we must be sure of exactly what we are talking about in order to go further. Our procedure will be to begin with the simpler idea of work and then use it to relate change and energy in the orderly way of science.

Work

Changes that take place in the physical world are the result of forces. Forces are needed to pick things up, to move things from one place to another, to squeeze things, to stretch things, and so on. However, not all forces act to produce changes, and it is the distinction between forces that accomplish change and forces that do not that is central to the idea of work.

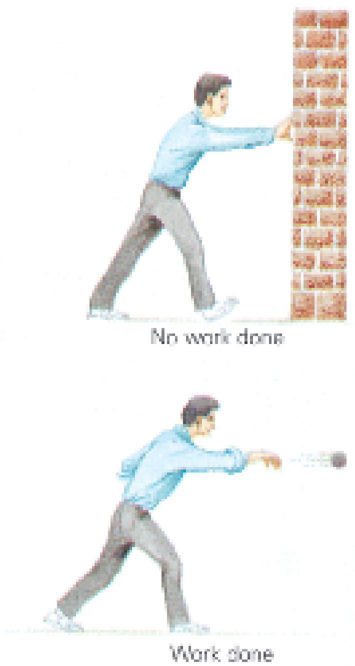


Figure 3-1 Work is done by a force when the object it acts on moves while the force is applied. No work is done by pushing against a stationary wall. Work is done when throwing a ball because the ball moves while being pushed during the throw.

3.1 The Meaning of Work

A Measure of the Change a Force Produces

Suppose we push against a wall. When we stop, nothing has happened even though we exerted a force on the wall. But if we apply the same force to a stone, the stone flies through the air when we let it go (Fig. 3-1). The difference is that the wall did not move during our push but the stone did. A physicist would say that we have done work on the stone, and as a result it was accelerated and moved away from our hand.

Or we might try to lift a heavy barbell. If we fail, the world is exactly the same afterward. If we succeed, though, the barbell is now up in the air, which represents a change (Fig. 3-2). As before, the difference is that in the second case an object moved while we exerted a force on it, which means that work was done on the object.

To make our ideas definite, **work** is defined in this way:

> **The work done by a force acting on an object is equal to the magnitude of the force multiplied by the distance through which the force acts when both are in the same direction.**

If nothing moves, no work is done, no matter how great the force. And even if something moves, work is not done on it unless a force is acting on it.

What we usually think of as work agrees with this definition. However, we must be careful not to confuse becoming tired with the

Figure 3-2 Work is done when a barbell is lifted, but no work is done while it is being held in the air even though this can be very tiring.

amount of work done. Pushing against a wall for an afternoon in the hot sun is certainly tiring, but we have done no work because the wall didn't move.

In equation form,

$$W = Fd \qquad \textit{Work} \qquad 3\text{-}1$$

Work done = (applied force)(distance through which force acts)

The direction of the force **F** is assumed to be the same as the direction of the displacement **d.** If not, for example in the case of a child pulling a wagon with a rope not parallel to the ground, we must use for F the magnitude F_d of the projection of the applied force **F** that acts in the direction of motion (Fig. 3-3).

A force that is perpendicular to the direction of motion of an object can do no work on the object. Thus gravity, which results in a downward force on everything near the earth, does no work on objects moving horizontally along the earth's surface. However, if we drop an object, work is definitely done on it as it falls to the ground.

The Joule The SI unit of work is the **joule** (J), where one joule is the amount of work done by a force of one newton when it acts through a distance of one meter. That is,

$$1 \text{ joule (J)} = 1 \text{ newton-meter (N} \cdot \text{m)}$$

The joule is named after the English scientist James Joule and is pronounced "jool." To raise an apple from your waist to your mouth takes about 1 J of work.

Work Done Against Gravity It is easy to find the work done in lifting an object against gravity. The force of gravity on the object is its weight of mg. In order to raise the object to a height h above its original position (Fig. 3-4*a*), we need to apply an upward force of $F = mg$. With $F = mg$ and $d = h$, Eq. 3-1 becomes

$$W = mgh \qquad \textit{Work done against gravity} \qquad 3\text{-}2$$

Work = (weight)(height)

Only the total height h is involved here: the particular route upward taken by the object is not significant. Excluding friction, exactly as

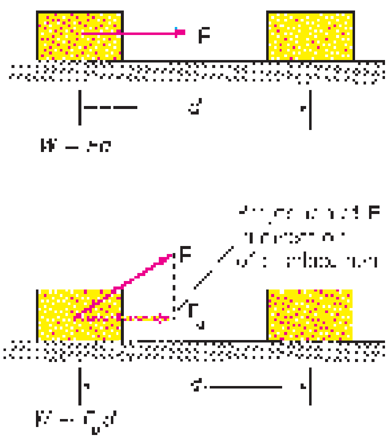


Figure 3-3 When a force and the distance through which it acts are parallel, the work done is equal to the product of F and d. When they are not in the same direction, the work done is equal to the product of d and the magnitude F_d of the projection of **F** in the direction of **d.**

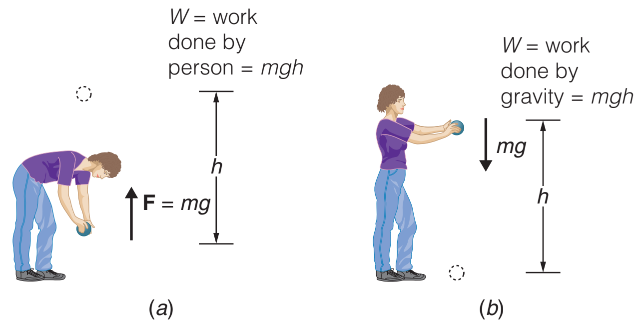


Figure 3-4 (*a*) The work a person does to lift an object to a height *h* is *mgh*. (*b*) If the object falls through the same height, the force of gravity does the work *mgh*.

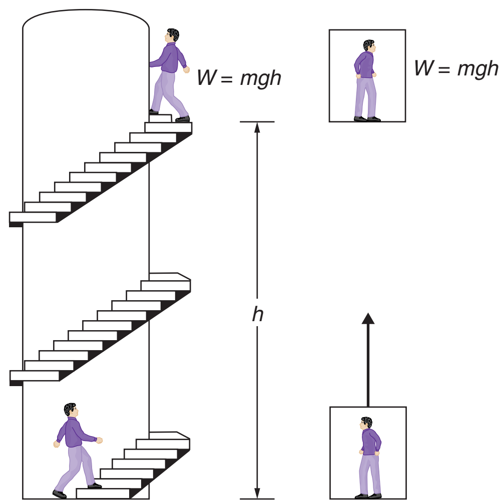


Figure 3-5 Neglecting friction, the work needed to raise a person to a height *h* is the same regardless of the path taken.

much work must be done when you climb a flight of stairs as when you go up to the same floor in an elevator (Fig. 3-5)—though the source of the work is not the same, to be sure.

If an object of mass m at the height h falls, the amount of work done *by* gravity on it is given by the same formula, $W = mgh$ (Fig. 3-4*b*).

Example 3.1

(a) A horizontal force of 100 N is used to push a 20-kg box across a level floor for 10 m. How much work is done? (b) How much work is needed to raise the same box by 10 m?

(a) The work done in pushing the box is

$$W = Fd = (100\ \text{N})(10\ \text{m}) = 1000\ \text{J}$$

The mass of the box does not matter here. What counts is the applied force, the distance through which it acts, and the relative directions of the force and the displacement of the box.

(b) Now the work done is

$$W = mgh = (20\ \text{kg})(9.8\ \text{m/s}^2)(10\ \text{m}) = 1960\ \text{J}$$

The work done in this case does depend on the mass of the box.

3.2 Power

The Rate of Doing Work

The time needed to carry out a job is often as important as the amount of work needed. If we have enough time, even the tiny motor of a toy train can lift an elevator as high as we like. However, if we want the elevator to take us up fairly quickly, we must use a motor whose output of work is rapid in terms of the total work needed. Thus the rate at which work is being done is significant. This rate is called **power:** The more powerful something is, the faster it can do work.

If the amount of work W is done in a period of time t, the power involved is

$$P = \frac{W}{t} \qquad \textit{Power} \qquad \textit{3-3}$$

$$\text{Power} = \frac{\text{work done}}{\text{time interval}}$$

The SI unit of power is the **watt** (W), where

$$1 \text{ watt (W)} = 1 \text{ joule/second (J/s)}$$

Thus a motor with a power output of 500 W is capable of doing 500 J of work per second. The same motor can do 250 J of work in 0.5 s, 1000 J of work in 2 s, 5000 J of work in 10 s, and so on. The watt is quite a small unit, and often the **kilowatt** (kW) is used instead, where 1 kW = 1000 W.

A person in good physical condition is usually capable of a continuous power output of about 75 W, which is 0.1 horsepower. A runner or swimmer during a distance event may have a power output 2 or 3 times greater. What limits the power output of a trained athlete is not muscular development but the supply of oxygen from the lungs through the bloodstream to the muscles, where oxygen is used in the metabolic processes that enable the muscles to do work. However, for a period of less than a second, an athlete's power output may exceed 5 kW, which accounts for the feats of weightlifters and jumpers.

The Horsepower

The **horsepower** (hp) is the traditional unit of power in engineering. The origin of this unit is interesting. In order to sell the steam engines he had perfected two centuries ago, James Watt had to compare their power outputs with that of a horse, a source of work his customers were familiar with. After various tests he found that a typical horse could perform work at a rate of 497 W for as much as 10 hours per day. To avoid any disputes, Watt increased this figure by one half to establish the unit he called the horsepower. Watt's horsepower therefore represents a rate of doing work of 746 W:

$$1 \text{ horsepower (hp)} = 746 \text{ W} = 0.746 \text{ kW}$$

$$1 \text{ kilowatt (kW)} = 1.34 \text{ hp}$$

Few horses can develop this much power for very long. The early steam engines ranged from 4 to 100 hp, with the 20-hp model being the most popular.

Example 3.2

A 15-kW electric motor provides power for the elevator of a building. What is the minimum time needed for the elevator to rise 30 m to the sixth floor when its total mass when loaded is 900 kg?

The work that must be done to raise the elevator is $W = mgh$. Since $P = W/t$, the time needed is

$$t = \frac{W}{P} = \frac{mgh}{P} = \frac{(900\ \text{kg})(9.8\ \text{m/s}^2)(30\ \text{m})}{15 \times 10^3\ \text{W}} = 17.6\ \text{s}$$

Energy

We now go from the straightforward idea of work to the complex and many-sided idea of **energy:**

Energy is that property something has that enables it to do work.

When we say that something has energy, we mean it is able, directly or indirectly, to exert a force on something else and perform work. When work is done on something, energy is added to it. Energy is measured in the same unit as work, the joule.

3.3 Kinetic Energy

The Energy of Motion

Energy occurs in several forms. One of them is the energy a moving object has because of its motion. Every moving object has the capacity to do work. By striking something else, the moving object can exert a force and cause the second object to shift its position, to break apart, or to otherwise show the effects of having work done on it. It is this property that defines energy, so we conclude that all moving things have energy by virtue of their motion. The energy of a moving object is called **kinetic energy** (KE). ("Kinetic" is a word of Greek origin that suggests motion is involved.)

The kinetic energy of a moving thing depends upon its mass and its speed. The greater the mass and the greater the speed, the more the KE. A train going at 30 km/h has more energy than a horse galloping at the same speed and more energy than a similar train going at 10 km/h. The exact way KE varies with mass m and speed v is given by the formula

$$\text{KE} = \tfrac{1}{2} mv^2 \qquad \textit{Kinetic energy} \qquad 3\text{-}4$$

The v^2 factor means the kinetic energy increases very rapidly with increasing speed. At 30 m/s a car has 9 times as much KE as at 10 m/s—and requires 9 times as much force to bring to a stop in the

Deriving the Kinetic Energy Formula

Here is a simple derivation of the formula $KE = \frac{1}{2}mv^2$ for the kinetic energy of a moving object.

When we throw a ball, the work we do on it becomes its kinetic energy KE when it leaves our hand. Suppose we apply a constant force F for a distance d while the ball is in our hand, as in Fig. 3-6*a*. The work we do is $W = Fd$, so the ball's kinetic energy is

$$KE = Fd \qquad \textit{Work done on ball} \qquad 3\text{-}5$$

According to the second law of motion,

$$F = ma \qquad \textit{Force applied to ball} \qquad 3\text{-}6$$

where a is the ball's acceleration while the force acts on it. If the time during which the force was applied is t, as in Fig. 3-6*b*, Eq. 2-12 gives us the distance d as

$$d = \tfrac{1}{2}at^2 \qquad \textit{Distance moved during the acceleration} \qquad 3\text{-}7$$

Next we substitute the formulas for F and d into Eq. 3-5 to give

$$KE = Fd = (ma)(\tfrac{1}{2}at^2) = \tfrac{1}{2}m(at)^2$$

But at is the ball's speed v when it leaves our hand at the end of the acceleration, as in Fig. 3-6*c*, so that

$$KE = \tfrac{1}{2}mv^2 \qquad \textit{Kinetic energy of moving ball}$$

which is Eq. 3-4.

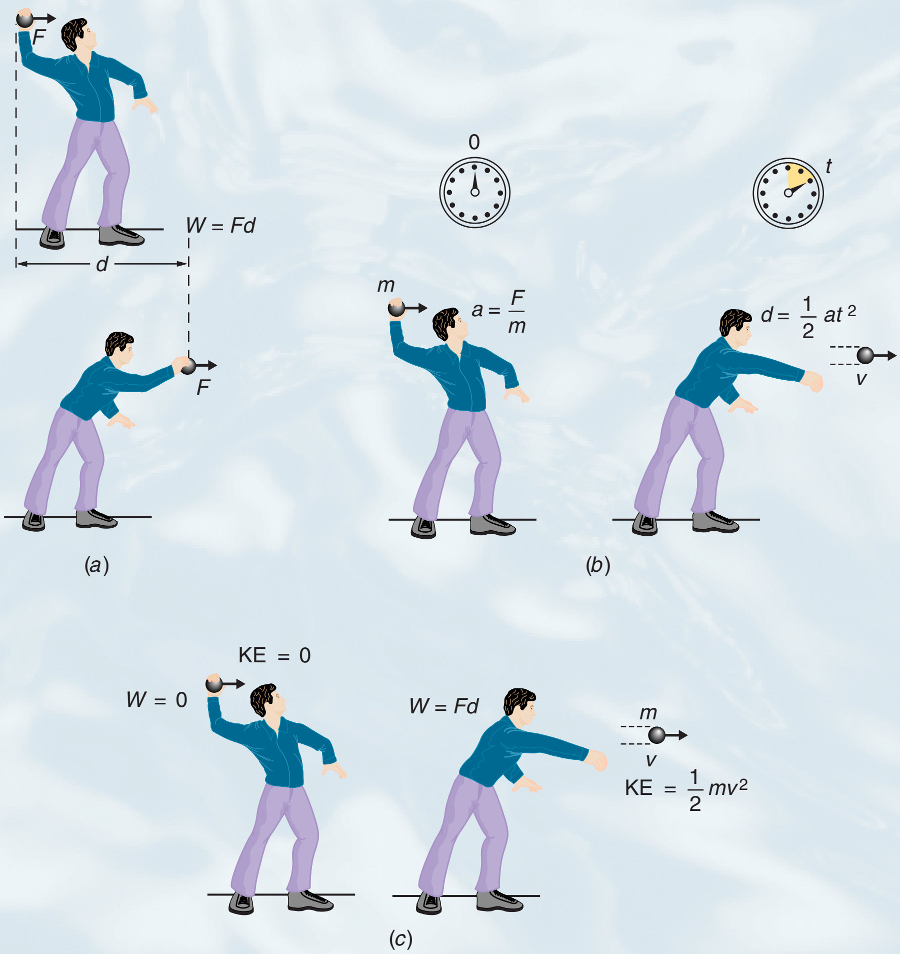


Figure 3-6 How the formula $KE = \frac{1}{2}mv^2$ for the kinetic energy of a moving object can be derived.

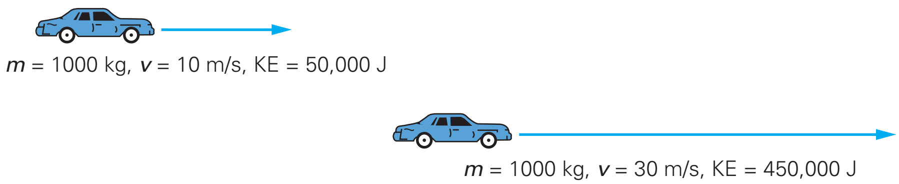


Figure 3-7 Kinetic energy is proportional to the square of the speed. A car traveling at 30 m/s has 9 times the KE of the same car traveling at 10 m/s.

same distance (Fig. 3-7). The fact that KE, and hence the ability to do work (in this case, damage), depends upon the square of the speed is what is responsible for the severity of automobile accidents at high speeds. The variation of KE with mass is less marked: a 2000-kg car going at 10 m/s has just twice the KE of a 1000-kg car with the same speed.

Example 3.3

Find the kinetic energy of a 1000-kg car when its speed is 10 m/s.

From Eq. 3-4 we have

$$\text{KE} = \tfrac{1}{2}mv^2 = (\tfrac{1}{2})(1000\text{ kg})(10\text{ m/s})^2$$
$$= (\tfrac{1}{2})(1000\text{ kg})(10\text{ m/s})(10\text{ m/s}) = 50{,}000\text{ J} = 50\text{ kJ}$$

In order to bring the car to this speed from rest, 50 kJ of work had to be done by its engine. To stop the car from this speed, the same amount of work must be done by its brakes.

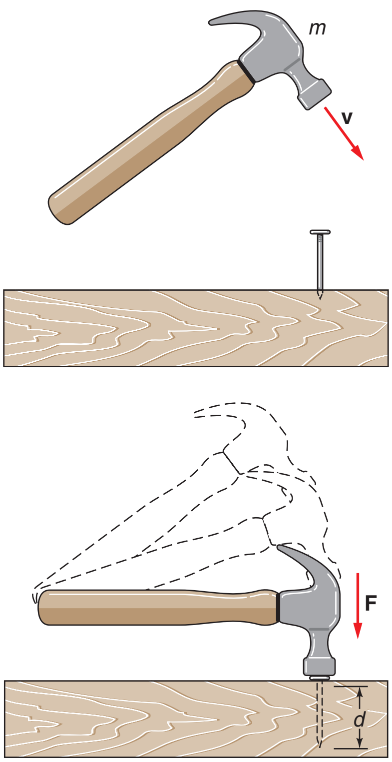


Figure 3-8 When a hammer strikes this nail, the hammer's kinetic energy is converted into the work done to push the nail into the wooden board.

Example 3.4

Have you ever wondered how much force a hammer exerts on a nail? Suppose you hit a nail with a hammer and drive the nail 5 mm into a wooden board (Fig. 3-8). If the hammer's head has a mass of 0.6 kg and it is moving at 4 m/s when it strikes the nail, what is the average force on the nail?

The KE of the hammer head is $\frac{1}{2}mv^2$, and this amount of energy becomes the work Fd done in driving the nail the distance d = 5 mm = 0.005 m into the board. Hence

$$\text{KE of hammer head} = \text{work done on nail}$$
$$\tfrac{1}{2}mv^2 = Fd$$

and

$$F = \frac{mv^2}{2d} = \frac{(0.6\text{ kg})(4\text{ m/s})^2}{2(0.005\text{ m})} = 960\text{ N}$$

This is 216 lb—watch your fingers!

Running Speeds

The relationship $Fd = \frac{1}{2}mv^2$ between work done and the resulting kinetic energy can be solved for speed v to give $v = \sqrt{2Fd/m}$. Let us interpret v as an animal's running speed, F as the force its muscles exert over the distance d, and m as its mass. As mentioned in Sec. 2-9, if L is the animal's length, its mass is roughly proportional to L^3 and its muscular forces are roughly proportional to L^2. The distance through which corresponding muscles act is roughly proportional to L. This means that the quantity Fd/m in the formula for v varies with L as $(L^2)(L)/L^3 = 1$, so that in general v should not vary with L at all! And, in fact, although different animals have different running speeds, there is little correlation with size over a wide span. A fox can run about as fast as a horse.

3.4 Potential Energy

The Energy of Position

When we drop a stone, it falls faster and faster and finally strikes the ground. If we lift the stone afterward, we see that it has done work by making a shallow hole in the ground (Fig. 3-9). In its original raised position, the stone must have had the capacity to do work even though it was not moving at the time and therefore had no KE.

The amount of work the stone could do by falling to the ground is called its **potential energy** (PE). Just as kinetic energy may be thought of as energy of motion, potential energy may be thought of as energy of position.

Examples of potential energy are everywhere. A book on a table has PE since it can fall to the floor. A skier at the top of a slope, water at the top of a waterfall, a car at the top of the hill, anything able to move toward the earth under the influence of gravity has PE because of its position. Nor is the earth's gravity necessary: a stretched spring has PE since it can do work when it is let go, and a nail near a magnet has PE since it can do work in moving to the magnet (Fig. 3-10).

Gravitational Potential Energy When an object of mass m is raised to a height h above its original position, its gravitational potential energy is equal to the work that was done against gravity to bring it to that height (Fig. 3-11). According to Eq. 3-2 this work is $W = mgh$, and so

$$\text{PE} = mgh \qquad \textit{Gravitational potential energy} \qquad 3\text{-}8$$

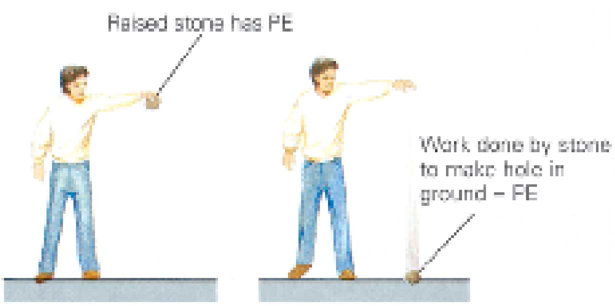


Figure 3-9 A raised stone has potential energy because it can do work on the ground when dropped.

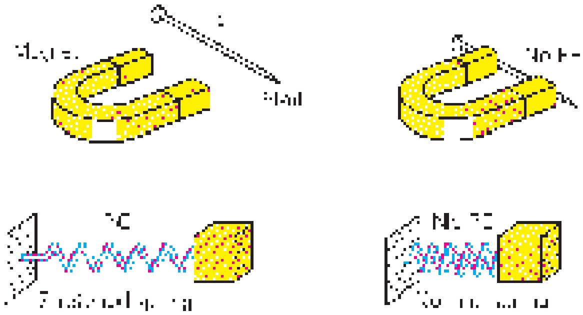


Figure 3-10 Two examples of potential energy.

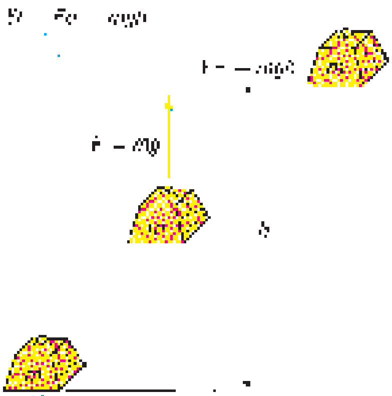


Figure 3-11 The increase in the potential energy of a raised object is equal to the work *mgh* used to lift it.

This result for PE agrees with our experience. Consider a pile driver (Fig. 3-12), a simple machine that lifts a heavy weight (the "hammer") and allows it to fall on the head of a pile, which is a wooden or steel post, to drive the pile into the ground. From the formula PE = mgh we would expect the effectiveness of a pile driver to depend on the mass m of its hammer and the height h from which it is dropped, which is exactly what experience shows.

Example 3.5

Find the potential energy of a 1000-kg car when it is on top of a 45-m cliff.

From Eq. 3-8 the car's potential energy is

$$\text{PE} = mgh = (1000\ \text{kg})(9.8\ \text{m/s}^2)(45\ \text{m}) = 441{,}000\ \text{J} = 441\ \text{kJ}$$

This is less than the KE of the same car when it moves at 30 m/s (Fig. 3-7). Thus a crash at 30 m/s into a wall or tree will yield more work—that is, do more damage—than dropping the car from a cliff 45 m high.

Figure 3-12 In the operation of a pile driver, the gravitational potential energy of the raised hammer becomes kinetic energy as it falls. The kinetic energy in turn becomes work as the pile is pushed into the ground.

PE Is Relative It is worth noting that the gravitational PE of an object depends on the level from which it is reckoned. Often the earth's surface is convenient, but sometimes other references are more appropriate.

Suppose you lift this book as high as you can above the table while remaining seated. It will then have a PE *relative to the table* of about 12 J. But the book will have a PE *relative to the floor* of about twice that, or 24 J. And if the floor of your room is, say, 50 m above the ground, the book's PE *relative to the ground* will be about 760 J.

What is the book's true PE? The answer is that there is no such thing as "true" PE. Gravitational PE is a relative quantity. However, the *difference* between the PEs of an object at two points *is* significant, since it is this difference that can be changed into work or KE.

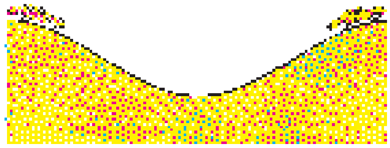


Figure 3-13 In the absence of friction, a car can coast from the top of one hill into a valley and then up to the top of another hill of the same height as the first. During the trip the initial potential energy of the car is converted into kinetic energy as the car goes downhill, and this kinetic energy then turns into potential energy as the car climbs the next hill. The total amount of energy (KE + PE) remains unchanged.

3.5 Energy Transformations

Easy Come, Easy Go

Nearly all familiar mechanical processes involve interchanges among KE, PE, and work. Thus when the car of Fig. 3-13 is driven to the top of a hill, its engine must do work in order to raise the car. At the top, the car has an amount of PE equal to the work done in getting it up there (neglecting friction). If the engine is turned off, the car can still coast down the hill, and its KE at the bottom of the hill will be the same as its PE at the top.

Changes of a similar nature, from kinetic energy to potential and back, occur in the motion of a planet in its orbit around the sun (Fig. 3-14) and in the motion of a pendulum (Fig. 3-15). The orbits of the planets are ellipses with the sun at one focus (Fig. 1-10), and each planet is therefore at a constantly varying distance from the sun. At all times the total of its potential and kinetic energies remains the same. When close to the sun, the PE of a planet is low and its KE is high. The additional speed due to increased KE keeps the planet from being pulled into the sun by the greater gravitational force on it at this point in its path. When the planet is far from the sun, its PE is higher and its KE lower, with the reduced speed exactly keeping pace with the reduced gravitational force.

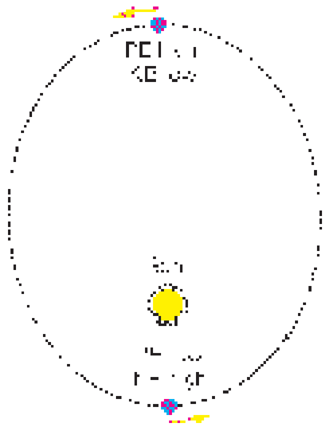


Figure 3-14 Energy transformations in planetary motion. The total energy (KE + PE) of the planet is the same at all points in its orbit. (Planetary orbits are much more nearly circular than shown here.)

A pendulum (Fig. 3-15) consists of a ball suspended by a string. When the ball is pulled to one side with its string taut and then released, it swings back and forth. When it is released, the ball has a PE relative to the bottom of its path of mgh. At its lowest point all this PE has become kinetic energy $\frac{1}{2}mv^2$. After reaching the bottom, the ball continues in its motion until it rises to the same height h on the opposite side from its initial position. Then, momentarily at rest since all its KE is now PE, the ball begins to retrace its path back through the bottom to its initial position.

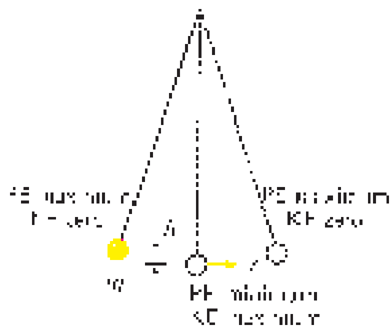


Figure 3-15 Energy transformations in pendulum motion. The total energy of the ball stays the same but is continuously exchanged between kinetic and potential forms.

Example 3.6

A girl on a swing is 2.2 m above the ground at the ends of her motion and 1.0 m above the ground at the lowest point. What is the girl's maximum speed?

(*continued*)

Example 3.6 (continued)

The maximum speed v will occur at the lowest point where her potential energy above this point has been entirely converted to kinetic energy. If the difference in height is $h = (2.2\text{ m}) - (1.0\text{ m}) = 1.2\text{ m}$ and the girl's mass is m, then

$$\text{Kinetic energy} = \text{change in potential energy}$$
$$\tfrac{1}{2}mv^2 = mgh$$
$$v = \sqrt{2gh} = \sqrt{2(9.8\text{ m/s}^2)(1.2\text{ m})} = 4.8\text{ m/s}$$

The girl's mass does not matter here.

Transformations to and from kinetic energy may involve potential energies other than gravitational. An example is the elastic potential energy of a bent bow, as in Fig. 3-16.

Other Forms of Energy Energy can exist in a variety of forms besides kinetic and potential. The *chemical energy* of gasoline is used to propel our cars and the chemical energy of food enables our bodies to perform work. *Heat energy* from burning coal or oil is used to form the steam that drives the turbines of power stations. *Electric energy* turns motors in home and factory. *Radiant energy* from the sun performs work in causing water from the earth's surface to rise and form clouds, in producing differences in air temperature that cause winds, and in promoting chemical reactions in plants that produce foods.

Just as kinetic energy can be converted to potential energy and potential to kinetic, so other forms of energy can readily be transformed. In the cylinders of a car engine, for example, chemical energy stored in gasoline and air is changed first to heat energy when the mixture is ignited by the spark plugs, then to kinetic energy as the expanding gases push down on the pistons. This kinetic energy is in large part transmitted to the wheels, but some is used to turn the generator and thus produce electric energy for charging the battery, and some is changed to heat by friction in bearings. Energy transformations go on constantly, all about us.

Figure 3-16 The elastic potential energy of the bent bow becomes kinetic energy of the arrow when the bowstring is released.

3.6 Conservation of Energy

A Fundamental Law of Nature

A skier slides down a hill and comes to rest at the bottom. What became of the potential energy he or she had at the top? The engine of a car is shut off while the car is allowed to coast along a level road. Eventually the car slows down and comes to a stop. What became of its original kinetic energy?

All of us can give similar examples of the apparent disappearance of kinetic or potential energy. What these examples have in common is that heat is always produced in an amount just equivalent to the "lost" energy (Fig. 3-17). One kind of energy is simply being converted to another; no energy is lost, nor is any new energy created. Exactly the same is true when electric, magnetic, radiant, and chemical energies are changed into one another or into heat. Thus we have a law from which no deviations have ever been found:

> **Energy cannot be created or destroyed, although it can be changed from one form to another.**

Figure 3-17 The potential energy of these skiers at the top of the slope turns into kinetic energy and eventually into heat as they slide downhill.

This generalization is the **law of conservation of energy.** It is the principle with the widest application in science, applying equally to distant stars and to biological processes in living cells.

We shall learn later in this chapter that matter can be transformed into energy and energy into matter. The law of conservation of energy still applies, however, with matter considered as a form of energy.

3.7 The Nature of Heat

The Downfall of Caloric

Although it comes as little surprise to us today to learn that heat is a form of energy, in earlier times this was not so clear. Less than two centuries ago most scientists regarded heat as an actual substance called **caloric.** Absorbing caloric caused an object to become warmer; the escape of caloric caused it to become cooler. Because the weight of an object does not change when the object is heated or cooled, caloric was considered to be weightless. It was also supposed to be invisible, odorless, and tasteless, properties that, of course, were why it could not be observed directly.

Actually, the idea of heat as a substance was fairly satisfactory for materials heated over a flame, but it could not account for the unlimited heat that could be generated by friction. One of the first to appreciate this difficulty was the American Benjamin Thompson (Fig. 3-18), who had supported the British during the Revolutionary War and thought it wise to move to Europe afterward, where he became Count Rumford.

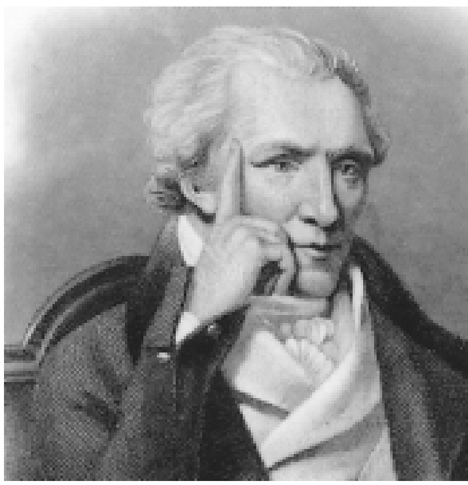


Figure 3-18 Count Rumford (1753–1814).

One of Rumford's many occupations was supervising the making of cannon for a German prince, and he was impressed by the large amounts of heat given off by friction in the boring process. He showed that the heat could be used to boil water and that heat could be produced again and again from the same piece of metal. If heat was a fluid,

Figure 3-19 James Prescott Joule (1818–1889).

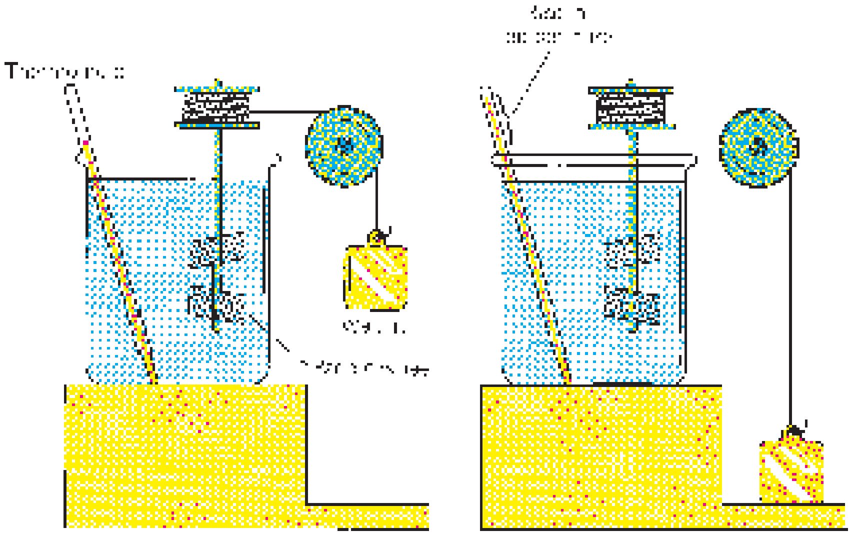


Figure 3-20 Joule's experimental demonstration that heat is a form of energy. As the weight falls, it turns the paddle wheel, which heats the water by friction. The potential energy of the weight is converted first into the kinetic energy of the paddle wheel and then into heat.

What is Heat?

As we shall learn in Chap. 4, the heat content of a body of matter consists of the KE of random motion of the atoms and molecules of which the body consists.

it was not unreasonable that boring a hole in a piece of metal should allow it to escape. However, even a dull drill that cut no metal produced a great deal of heat. Also, it was hard to imagine a piece of metal as containing an infinite amount of caloric, and Rumford accordingly regarded heat as a form of energy.

James Prescott Joule (Fig. 3-19) was an English brewer who performed a classic experiment that settled the nature of heat once and for all. Joule's experiment used a small paddle wheel inside a container of water (Fig. 3-20). Work was done to turn the paddle wheel against the resistance of the water, and Joule measured exactly how much heat was supplied to the water by friction in this process. He found that a given amount of work always produced exactly the same amount of heat. This was a clear demonstration that heat is energy and not something else.

Joule also carried out chemical and electrical experiments that agreed with his mechanical ones, and the result was his announcement of the law of conservation of energy in 1847, when he was 29. Although Joule was a modest man ("I have done two or three little things, but nothing to make a fuss about," he later wrote), many honors came his way, including naming the SI unit of energy after him.

Momentum

Because the universe is so complex, a variety of different quantities besides the basic ones of length, time, and mass are useful to help us understand its many aspects. We have already found velocity, acceleration, force, work, and energy to be valuable, and more are to come. The idea behind defining each of these quantities is to single out something that is involved in a wide range of observations. Then we can boil down a great many separate findings about nature into a brief, clear statement, for example, the law of conservation of energy. Now we shall learn how the concepts of linear and angular momenta can give us further insights into the behavior of moving things.

3.8 Linear Momentum

Another Conservation Law

As we know, a moving object tends to continue moving at constant speed along a straight path. The **linear momentum** of such an object is a measure of this tendency. The more linear momentum something has, the more effort is needed to slow it down or to change its direction. Another kind of momentum is **angular momentum,** which reflects the tendency of a spinning body to continue to spin. When there is no question as to which is meant, linear momentum is usually referred to simply as momentum.

The linear momentum **p** of an object of mass *m* and velocity **v** (we recall that velocity includes both speed and direction) is defined as

$$\mathbf{p} = m\mathbf{v} \qquad \textit{Linear momentum} \qquad 3\text{-}9$$

Linear momentum = (mass)(velocity)

The greater *m* and **v** are, the harder it is to change the object's speed or direction.

This definition of momentum is in accord with our experience. A baseball hit squarely by a bat (large **v**) is more difficult to stop than a baseball thrown gently (small **v**). The heavy iron ball used for the shot-put (large *m*) is more difficult to stop than a baseball (small *m*) when their speeds are the same (Fig. 3-21).

Conservation of Momentum Momentum considerations are most useful in situations that involve explosions and collisions. When outside forces do not act on the objects involved, their combined momentum (taking directions into account) is conserved, that is, does not change:

> **In the absence of outside forces, the total momentum of a set of objects remains the same no matter how the objects interact with one another.**

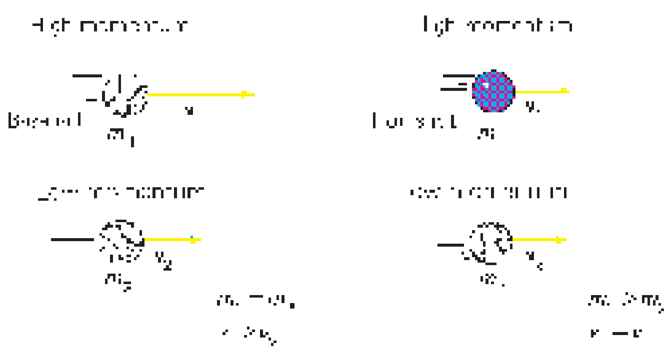


Figure 3-21 The linear momentum $m\mathbf{v}$ of a moving object is a measure of its tendency to continue in motion at constant velocity. The symbol > means "greater than."

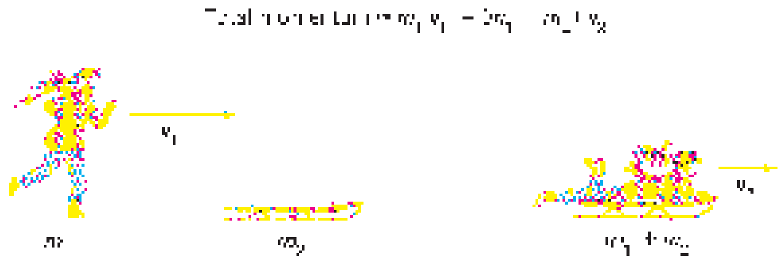


Figure 3-22 When a running girl jumps on a stationary sled, the combination moves off more slowly than the girl's original speed. The total momentum of girl + sled is the same before and after she jumps on it.

This statement is called the **law of conservation of momentum.** What it means is that, if the objects interact only with one another, each object can have its momentum changed in the interaction, provided that the total momentum after it occurs is the same as it was before.

Momentum is conserved when a running girl jumps on a stationary sled, as in Fig. 3-22. Even if there is no friction between the sled and the snow, the combination of girl and sled moves off more slowly than the girl's running speed. The original momentum, which is that of the girl alone, had to be shared between her and the sled when she jumped on it. Now that the sled is also moving, the new speed must be less than before in order that the total momentum stay the same.

Example 3.7

Let us see what happens when an object breaks up into two parts. Suppose that an astronaut outside a space station throws away a 0.5-kg camera in disgust when it jams (Fig. 3-23). The mass of the spacesuited astronaut is 100 kg, and the camera moves off at 6 m/s. What happens to the astronaut?

The total momentum of the astronaut and camera was zero originally. According to the law of conservation of momentum, their total momentum must therefore be zero afterward as well. If we call the astronaut A and the camera C, then

$$\text{Momentum before} = \text{momentum afterward}$$
$$0 = m_A v_A + m_C v_C$$

Hence

$$m_A v_A = -m_C v_C$$

where the minus sign signifies that $\mathbf{v}_A$ is opposite in direction to $\mathbf{v}_C$. Throwing the camera away therefore sets the astronaut in motion as well, with camera and astronaut moving in opposite directions. Newton's third law of motion (action-reaction) tells us the same thing, but conservation of momentum enables us to find the astronaut's speed at once:

$$v_A = -\frac{m_C v_C}{m_A} = -\frac{(0.5\ \text{kg})(6\ \text{m/s})}{100\ \text{kg}} = -0.03\ \text{m/s}$$

After an hour, which is 3600 s, the camera will have traveled $v_C t$ = 21,600 m = 21.6 km, and the astronaut will have traveled $v_A t$ = 108 m in the opposite direction if not tethered to the space station.

Figure 3-23 The momentum $m_C v_C$ to the right of the thrown camera is equal in magnitude to the momentum $m_A v_A$ to the left of the astronaut who threw it away.

Collisions

Applying the law of conservation of momentum to collisions gives some interesting results. These are shown in Fig. 3-24 for an object of mass m and speed v that strikes a stationary object of mass M and does not stick to it. Three situations are possible:

1. The target object has more mass, so that $M > m$. What happens here is that the incoming object bounces off the heavier target one and they move apart in opposite directions.
2. The two objects have the same mass, so that $M = m$. Now the incoming object stops and the target object moves off with the same speed v the incoming one had.
3. The target object has less mass, so that $m > M$. In this case the incoming object continues in its original direction after the impact but with reduced speed while the target object moves ahead of it at a faster pace. The greater m is compared with M, the closer the target object's final speed is to $2v$.

The third case corresponds to a golf club striking a golf ball (Fig. 3-25). This suggests that the more mass the clubhead has for a given speed, the faster the ball will fly off when struck. However, a heavy golf club is harder to swing fast than a light one, so a compromise is necessary. Experience has led golfers to use clubheads with masses about 4 times the 46-g mass of a golf ball when they want maximum distance. A good golfer can swing a clubhead at over 50 m/s.

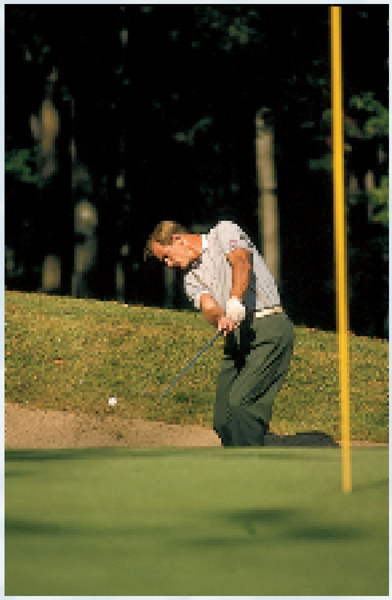


Figure 3-25 The speed of a golf ball is greater than the speed of the clubhead that struck it because the mass of the ball is smaller than that of the clubhead.

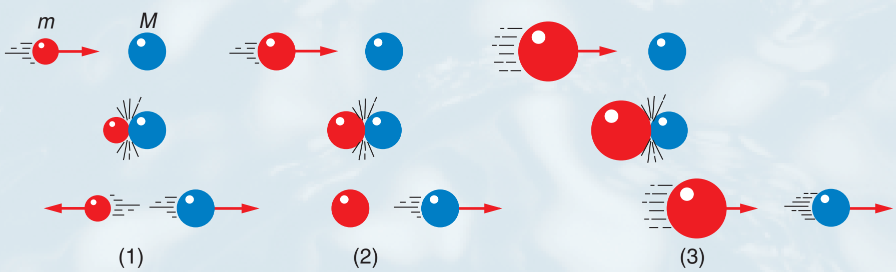


Figure 3-24 How the effects of a head-on collision with a stationary target object depend on the relative masses of the two objects.

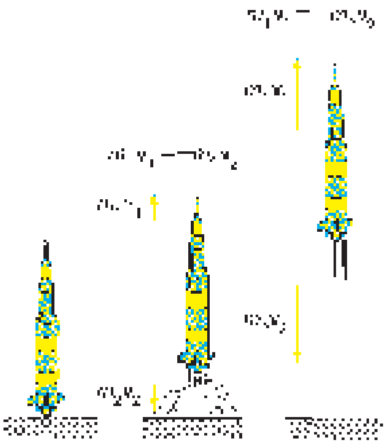


Figure 3-26 Rocket propulsion is based upon conservation of momentum. If gravity is absent, the downward momentum of the exhaust gases is equal in magnitude and opposite in direction to the upward momentum of the rocket at all times.

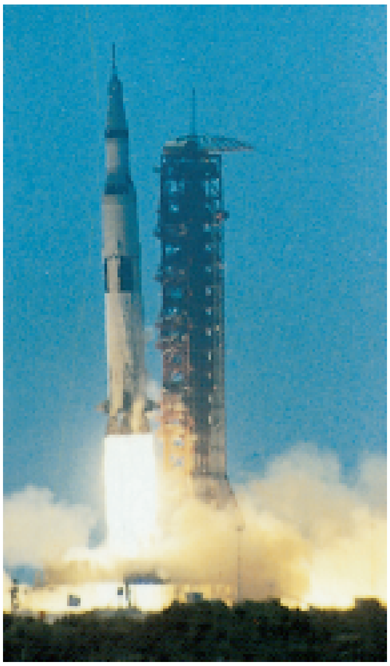


Figure 3-27 Apollo 11 lifts off its pad to begin the first human visit to the moon. The spacecraft's final speed was 10.8 km/s, which is equivalent to 6.7 mi/s. Conservation of linear momentum underlies rocket propulsion.

3.9 Rockets

Momentum Conservation Is the Basis of Space Travel

The operation of a rocket is based on conservation of linear momentum. When the rocket stands on its launching pad, its momentum is zero. When it is fired, the momentum of the exhaust gases that rush downward is balanced by the momentum in the other direction of the rocket moving upward. The total momentum of the entire system, gases and rocket, remains zero, because momentum is a vector quantity and the upward and downward momenta cancel (Fig. 3-26).

Thus a rocket does not work by "pushing" against its launching pad, the air, or anything else. In fact, rockets function best in space where no atmosphere is present to interfere with their motion.

The ultimate speed a rocket can reach is governed by the amount of fuel it can carry and by the speed of its exhaust gases. Because both these quantities are limited, **multistage rockets** are used in the exploration of space. The first stage is a large rocket that has a smaller one mounted in front of it. When the fuel of the first stage has burnt up, its motor and empty fuel tanks are cast off. Then the second stage is fired. Since the second stage is already moving rapidly and does not have to carry the motor and empty fuel tanks of the first stage, it can reach a much higher final speed than would otherwise be possible.

Depending upon the final speed needed for a given mission, three or even four stages may be required. The Saturn V launch vehicle that carried the Apollo 11 spacecraft to the moon in July 1969 had three stages. Just before takeoff the entire assembly was 111 m long and had a mass of nearly 3 million kg (Fig. 3-27).

3.10 Angular Momentum

A Measure of the Tendency of a Spinning Object to Continue to Spin

We have all noticed the tendency of rotating objects to continue to spin unless they are slowed down by an outside agency. A top would spin indefinitely but for friction between its tip and the ground. Another example is the earth, which has been turning for billions of years and is likely to continue doing so for many more to come.

The rotational quantity that corresponds to linear momentum is called **angular momentum,** and **conservation of angular momentum** is the formal way to describe the tendency of spinning objects to keep spinning.

The precise definition of angular momentum is complicated because it depends not only upon the mass of the object and upon how fast it is turning, but also upon how the mass is arranged in the body. As we might expect, the greater the mass of a body and the more rapidly it rotates, the more angular momentum it has and the more pronounced is its tendency to continue to spin. Less obvious is the fact that, the farther away from the axis of rotation the mass is distributed, the more the angular momentum.

Conservation Principles

The conservation principles of energy, linear momentum, and angular momentum are useful because they are obeyed in all known processes. They are significant for another reason as well. In 1917 the German mathematician Emmy Noether (Fig. 3-28) proved that:

1. If the laws of nature are the same at all times, past, present, and future, then energy must be conserved.
2. If the laws of nature are the same everywhere in the universe, then linear momentum must be conserved.
3. If the laws of nature do not depend on direction, then angular momentum must be conserved.

Thus the existence of these principles testifies to a profound order in the universe, despite the irregularities and randomness of many aspects of it. In 1933 Noether moved to the United States where, after a period at the Institute for Advanced Study in Princeton, she became a professor at Bryn Mawr.

Figure 3-28 Emmy Noether (1882–1935).

An illustration of both the latter fact and the conservation of angular momentum is a skater doing a spin (Fig. 3-29). When the skater starts the spin, she pushes against the ice with one skate to start turning. Initially both arms and one leg are extended, so that her mass is spread as far as possible from the axis of rotation. Then she brings her arms and the outstretched leg in tightly against her body, so that now all her mass is as close as possible to the axis of rotation. As a result, she spins faster. To make up for the change in the mass distribution, the speed must change as well to conserve angular momentum.

Planetary Motion

Kepler's second law of planetary motion (Fig. 1-11) has an origin similar to that of the changing spin rate of a skater. A planet moving around the sun has angular momentum, which must be the same everywhere in its orbit. As a result the planet's speed is greatest when it is close to the sun, least when it is far away.

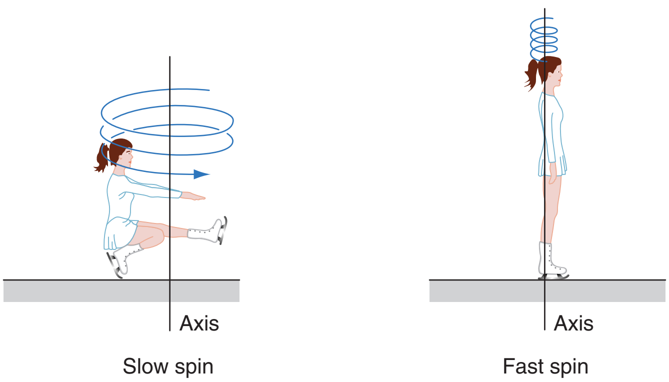


Figure 3-29 Conservation of angular momentum. Angular momentum depends upon both the speed of turning and the distribution of mass. When the skater pulls in her arms and extended leg, she spins faster to compensate for the change in the way her mass is distributed.

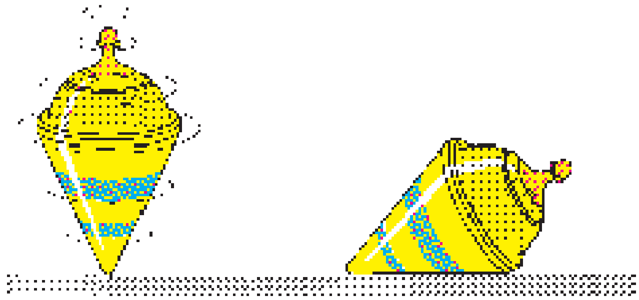


Figure 3-30 The faster a top spins, the more stable it is. When all its angular momentum has been lost through friction, the top falls over.

Figure 3-31 Conservation of angular momentum keeps a spinning football from tumbling end-over-end, which would slow it down and reduce its range.

Spin Stabilization Like linear momentum, angular momentum is a vector quantity with direction as well as magnitude. Conservation of angular momentum therefore means that a spinning body tends to maintain the *direction* of its spin axis in addition to the amount of angular momentum it has. A stationary top falls over at once, but a rapidly spinning top stays upright because its tendency to keep its axis in the same orientation by virtue of its angular momentum is greater than its tendency to fall over (Fig. 3-30). Footballs and rifle bullets are sent off spinning to prevent them from tumbling during flight, which would increase air resistance and hence shorten their range (Fig. 3-31).

Relativity

In 1905 a young physicist of 26 named Albert Einstein published an analysis of how measurements of time and space are affected by motion between an observer and what he or she is studying. To say that Einstein's **theory of relativity** revolutionized science is no exaggeration.

Relativity links not only time and space but also energy and matter. From it have come a host of remarkable predictions, all of which have been confirmed by experiment. Eleven years later Einstein took relativity a step further by interpreting gravity as a distortion in the structure of space and time, again predicting extraordinary effects that were verified in detail.

3.11 Special Relativity

Things Are Seldom What They Seem

Thus far in this book no special point has been made about how such quantities as length, time, and mass are measured. In particular, who makes a certain measurement would not seem to matter—everybody ought to get the same result. Suppose we want to find the length of an airplane when we are on board. All we have to do is put one end of a tape measure at the airplane's nose and look at the number on the tape at the airplane's tail.

But what if we are standing on the ground and the airplane is in flight? Now things become more complicated because the light that carries information to our instruments travels at a definite speed. According to Einstein, our measurements from the ground of length, time, and mass in the airplane would differ from those made by somebody moving with the airplane.

Einstein began with two postulates. The first concerns **frames of reference.** When we say something is moving, we mean that its position relative to something else—the frame of reference—is changing. A passenger walking down the aisle moves relative to an airplane, the airplane moves relative to the earth, the earth moves relative to the sun, and so on (Fig. 3-32).

If we are in the windowless cabin of a cargo airplane, we cannot tell whether the airplane is in flight at constant velocity or is at rest on the ground, since without an external frame of reference the question has no meaning. To say that something is moving always requires a frame of reference. From this follows Einstein's first postulate:

> **The laws of physics are the same in all frames of reference moving at constant velocity with respect to one another.**

Figure 3-32 All motion is relative to a chosen frame of reference. Here the photographer has turned the camera to keep pace with one of the cyclists. Relative to him, both the road and the other cyclists are moving. There is no fixed frame of reference in nature, and therefore no such thing as "absolute motion"; all motion is relative.

If the laws of physics were different for different observers in relative motion, the observers could find from these differences which of them were "stationary" in space and which were "moving." But such a distinction does not exist, hence the above postulate.

The second postulate, which follows from the results of a great many experiments, states that

The speed of light in free space has the same value for all observers.

The speed of light in free space is $c = 3 \times 10^8$ m/s, about 186,000 mi/s.

Length, Time, and Mass Let us suppose I am in an airplane moving at the constant velocity **v** relative to you on the ground. I find that the airplane is L_0 long, that it has a mass of m, and that a certain time interval (say an hour on my watch) is t_0. Einstein showed from the above postulates that you, on the ground, would find that

1. The length L you measure is shorter than L_0.
2. The time interval t you measure is longer than t_0.
3. The kinetic energy KE you determine is greater than $\frac{1}{2}mv^2$.

That is, to you on the ground, the airplane appears shorter than to me and to have more KE, and to you, my watch appears to tick more slowly.

The differences between L and L_0, t and t_0, and KE and $\frac{1}{2}mv^2$ depend on the ratio v/c between the relative speed v of the frames of reference (here the speed of the airplane relative to the ground) and the speed of light c. Because c is so great, these differences are too small to detect at speeds like those of airplanes. However, they must be taken into account in spacecraft flight. And, at speeds near c, which often occur in the subatomic world of such tiny particles as electrons and protons, relativistic effects are conspicuous. Although at speeds much less than c the formula $\frac{1}{2}mv^2$ for kinetic energy is still valid, at high speeds the theory of relativity shows that the KE of a moving object is higher than $\frac{1}{2}mv^2$ (Fig. 3-33).

As we can see from the graph, the closer v gets to c, the closer KE gets to infinity. Since an infinite kinetic energy is impossible, this conclusion means that nothing can travel as fast as light or faster: c is the absolute speed limit in the universe. The implications of this limit for space travel are discussed in Chap. 18.

Einstein's 1905 theory, which led to the above results among others, is called **special relativity** because it is restricted to constant velocities. His later theory of **general relativity,** which deals with gravity, includes accelerations.

3.12 Rest Energy

Matter Is a Form of Energy

The most far-reaching conclusion of special relativity is that mass and energy are related to each other so closely that matter can be

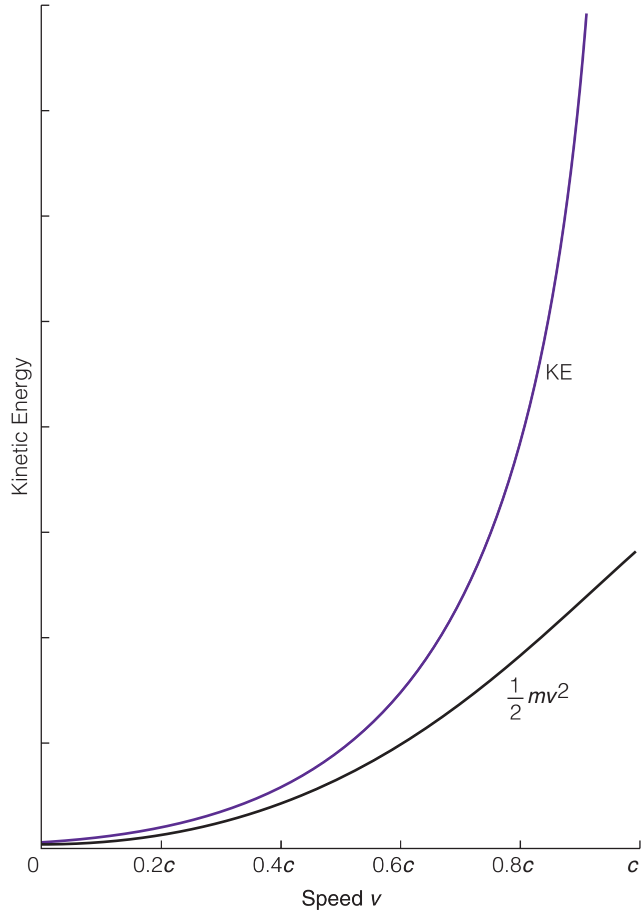


Figure 3-33 The faster an object moves relative to an observer, the more the object's kinetic energy KE exceeds $\frac{1}{2}mv^2$. This effect is only conspicuous at speeds near the speed of light $c = 3 \times 10^8$ m/s, which is about 186,000 mi/s. Because an object would have an infinite KE if $v = c$, nothing with mass can ever move that fast or faster.

converted into energy and energy into matter. The **rest energy** of a body is the energy equivalent of its mass. If a body has the mass m, its rest energy is

$$E_0 = mc^2 \qquad \textit{Rest energy} \tag{3-10}$$

$$\text{Rest energy} = (\text{mass})(\text{speed of light})^2$$

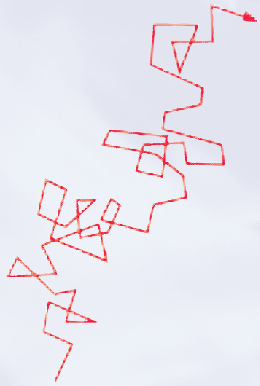
The rest energy of a 1.5-kg object, such as this book, is

$$E_0 = mc^2 = (1.5\text{ kg})(3 \times 10^8\text{ m/s})^2 = 1.35 \times 10^{17}\text{ J}$$

quite apart from any kinetic or potential energy it might have. If liberated, this energy would be more than enough to send a million tons to the moon. By contrast, the PE of this book on top of Mt. Everest, which is 8850 m high, relative to its sea-level PE is less than 10^4 J.

How is it possible that so much energy can be bottled up in even a little bit of matter without anybody having known about it until Einstein's work? In fact, we do see matter being converted into energy around us all the time. We just do not normally think about what we

BIOGRAPHY Albert Einstein (1879–1955)



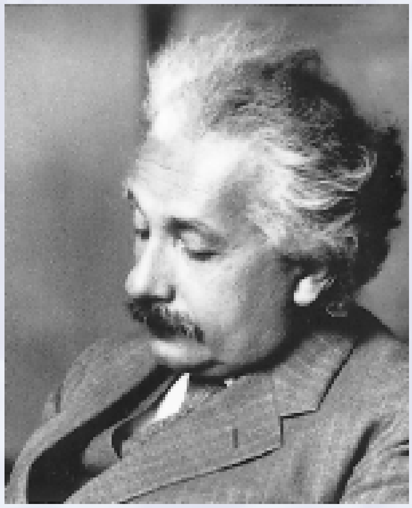


Figure 3-34 The irregular path of a microscopic particle bombarded by molecules. The line joins the positions of a single particle observed at constant intervals. This phenomenon is called brownian movement and is direct evidence of the reality of molecules and their random motions. It was discovered in 1827 by the British botanist Robert Brown.

Bitterly unhappy with the rigid discipline of the schools of his native Germany, Einstein went to Switzerland at 16 to complete his education and later got a job examining patent applications at the Swiss Patent Office in Berne. Then, in 1905, ideas that had been in his mind for years when he should have been paying attention to other matters (one of his math teachers called Einstein a "lazy dog") blossomed into three short papers that were to change decisively the course of not only physics but modern civilization as well.

The first paper proposed that light has a dual character with particle as well as wave properties. This work is described in Chap. 8 together with the quantum theory of the atom that flowed from it. The subject of the second paper was brownian motion, the irregular zigzag motion of tiny bits of suspended matter such as pollen grains in water (Fig. 3-34). Einstein arrived at a formula that related brownian motion to the bombardment of the particles by randomly moving molecules of the fluid in which they were suspended. Although the molecular theory of matter had been proposed many years before, this formula was the long-awaited definite link with experiment that convinced the remaining doubters. The third paper introduced the theory of relativity.

Although much of the world of physics was originally either indifferent or skeptical, even the most unexpected of Einstein's conclusions were soon confirmed and the development of what is now called modern physics began in earnest. After university posts in Switzerland and Czechoslovakia, in 1913 Einstein took up an appointment at the Kaiser Wilhelm Institute in Berlin that left him able to do research free of financial worries and routine duties. His interest was now mainly in gravity, and he began where Newton had left off more than 200 years earlier.

The general theory of relativity that resulted from Einstein's work provided a deep understanding of gravity, but his name remained unknown to the general public. This changed in 1919 with the dramatic discovery that gravity affects light exactly as Einstein had predicted. He immediately became a world celebrity, but his well-earned fame did not provide security when Hitler and the Nazis came to power in Germany in the early 1930s. Einstein left in 1933 and spent the rest of his life at the Institute for Advanced Study in Princeton, New Jersey, thereby escaping the fate of millions of other European Jews at the hands of the Germans. Einstein's last years were spent in a fruitless search for a "unified field theory" that would bring together gravitation and electromagnetism in a single picture. The problem was worthy of his gifts, but it remains unsolved to this day although progress is being made.

find in these terms. All the energy-producing reactions of chemistry and physics, from the lighting of a match to the nuclear fusion that powers the sun and stars, involve the disappearance of a small amount of matter and its reappearance as energy. The simple formula $E_0 = mc^2$ has led not only to a better understanding of how nature works but also to the nuclear power plants—and nuclear weapons—that are so important in today's world.

Table 3-1 Energy, Power, and Momentum

Quantity	Type	Symbol	Unit	Meaning	Formula
Work	Scalar	W	Joule (J)	A measure of the change produced by a force that acts on something	$W = Fd$
Power	Scalar	P	Watt (W)	The rate at which work is being done	$P = W/t$
Kinetic energy	Scalar	KE	Joule (J)	Energy of motion	$\mathrm{KE} = \frac{1}{2}mv^2$
Potential energy	Scalar	PE	Joule (J)	Energy of position	$\mathrm{PE}_{\text{gravitational}} = mgh$
Rest energy	Scalar	E_0	Joule (J)	Energy equivalent of the mass of an object	$E_0 = mc^2$
Linear momentum	Vector	$\mathbf{p}$	Kg · m/s	A measure of the tendency of a moving object to continue moving in the same straight line at the same speed	$\mathbf{p} = m\mathbf{v}$
Angular momentum	Vector	—	—	A measure of the tendency of a rotating object to continue rotating about the same axis at the same speed	—

Example 3.8

How much mass is converted into energy per day in a 100-MW nuclear power plant?

There are (60)(60)(24) = 86,400 s/day, so the energy liberated per day is

$$E_0 = Pt = (10^2)(10^6\ \text{W})(8.64 \times 10^4\ \text{s}) = 8.64 \times 10^{12}\ \text{J}$$

From Eq. 3-10 the corresponding mass is

$$m = \frac{E_0}{c^2} = \frac{8.64 \times 10^{12}\ \text{J}}{(3 \times 10^8\ \text{m/s})} = 9.6 \times 10^{-5}\ \text{kg}$$

This is less than a tenth of a gram—not much. To liberate the same amount of energy from coal, about 270 tons would have to be burned.

The discovery that matter and energy can be converted into each other does not affect the law of conservation of energy provided we include mass as a form of energy. Table 3-1 lists the basic features of the various quantities introduced in this chapter.

3.13 General Relativity

Gravity Is a Warping of Spacetime

Einstein's general theory of relativity, published in 1916, related gravitation to the structure of space and time. What is meant by "the structure of space and time" can be given a quite precise meaning mathematically, but unfortunately no such precision is possible using ordinary language. All the same, we can legitimately think of the force of gravity as arising from a warping of spacetime around a body of matter so that a nearby mass tends to move toward the body, much as a marble rolls toward the bottom of a saucer-shaped hole (Fig. 3-35). It may seem as though one

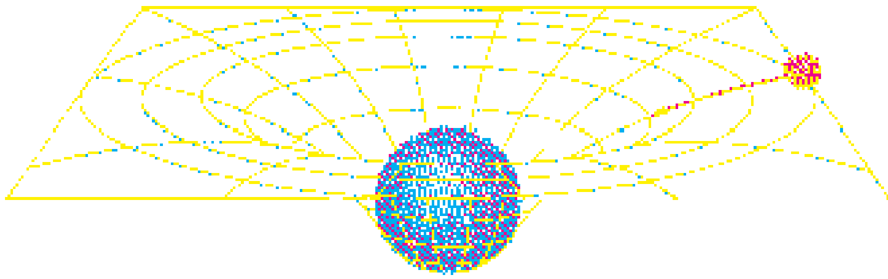


Figure 3-35 General relativity pictures gravity as a warping of the structure of space and time due to the presence of a body of matter. An object nearby experiences an attractive force as a result of this distortion in spacetime, much as a marble rolls toward the bottom of a saucer-shaped hole in the ground.

abstract concept is merely replacing another, but in fact the new point of view led Einstein and other scientists to a variety of remarkable discoveries that could not have come from the older way of thinking.

Perhaps the most spectacular of Einstein's results was that light ought to be subject to gravity. The effect is very small, so a large mass, such as that of the sun, is needed to detect the influence of its gravity on light. If Einstein was right, light rays that pass near the sun should be bent toward it by 0.0005°—the diameter of a dime seen from a mile away. To check this prediction, photographs were taken of stars that appeared in the sky near the sun during an eclipse in 1919, when they could be seen because the moon obscured the sun's disk (see Chap. 16). These photographs were then compared with photographs of the same region of the sky taken when the sun was far away (Fig. 3-36), and the observed changes in the apparent positions of the stars matched Einstein's calculations. Other predictions based on general relativity have also been verified, and the theory remains today without serious rival.

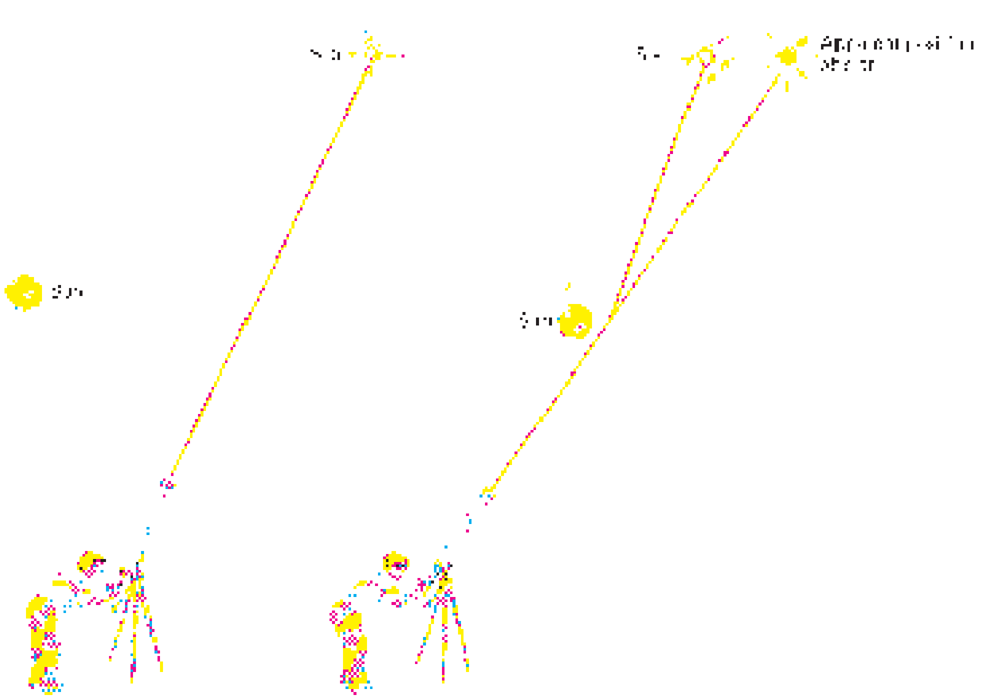


Figure 3-36 Starlight that passes near the sun is deflected by its strong gravitational pull. The deflection, which is very small, can be measured during a solar eclipse when the sun's disk is obscured by the moon.

Gravitational Waves

The existence of **gravitational waves** that travel with the speed of light was the prediction of general relativity that had to wait longest for experimental evidence. To visualize such waves, we can think in terms of the two-dimensional model of Fig. 3-35 by imagining space-time as a rubber sheet distorted by masses lying on it. If one of the masses vibrates, waves will be sent out in the sheet (like waves on a water surface) that set other masses in vibration. Gravitational waves—"ripples in space-time"—are expected to be extremely weak, and none has yet been directly detected. However, in 1974 indirect but strong evidence for their existence was discovered in the behavior of a pair of close-together stars that revolve around each other. A system of this kind gives off gravitational waves and slows down as it loses energy to them. This slowing down was indeed observed and agrees well with the theoretical expectation. Ultrasensitive instruments are now operating that may be able to pick up gravitational waves directly.

Energy and Civilization

The rise of modern civilization would have been impossible without the discovery of vast resources of energy and the development of ways to transform it into useful forms. All that we do requires energy. The more energy we have at our command, the better we can satisfy our desires for food, clothing, shelter, warmth, light, transport, communication, and manufactured goods.

Unfortunately oil and gas, the most convenient fuels, although currently abundant and not too expensive, have limited reserves. Other energy sources all have serious handicaps of one kind or another and nuclear fusion, the ultimate energy source, remains a technology of the future. At the same time, world population is increasing and with this increase comes a need for more and more energy. The choice of an appropriate energy strategy for the future is therefore one of the most critical of today's problems.

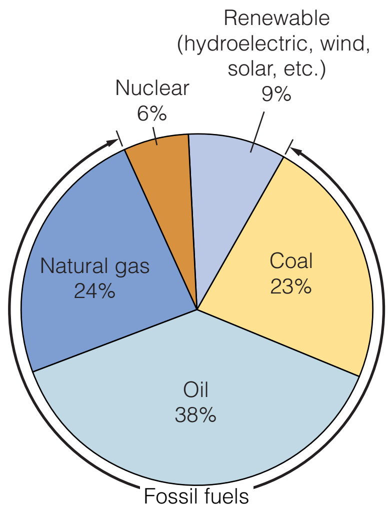


Figure 3-37 Sources of commercial energy production worldwide in 2005. Fossil fuels are responsible for 85 percent of the world's energy consumption (apart from firewood, still widely used, which is not included here). The percentages for energy sources in the United States are not very different from those of the world as a whole.

3.14 The Energy Problem

Limited Supply, Unlimited Demand

Almost all the energy available to us today has a single source—the sun. Light and heat reach us directly from the sun; food and wood owe their energy content to sunlight falling on plants; water power exists because the sun's heat evaporates water from the oceans to fall later as rain and snow on high ground; wind power comes from motions in the atmosphere due to unequal heating of the earth's surface by the sun. The fossil fuels coal, oil, and natural gas were formed from plants and animals that lived and stored energy derived from sunlight millions of years ago. Only nuclear energy and heat from sources inside the earth cannot be traced to the sun's rays (Figs. 3-37 and 3-38).

In the advanced countries, the standard of living is already high and populations are stable, so their need for energy is not likely to grow very much. Indeed, this need may even decline as energy use becomes more efficient. Elsewhere rates of energy consumption are still low, less than 1 kW per person for more than half the people of the world

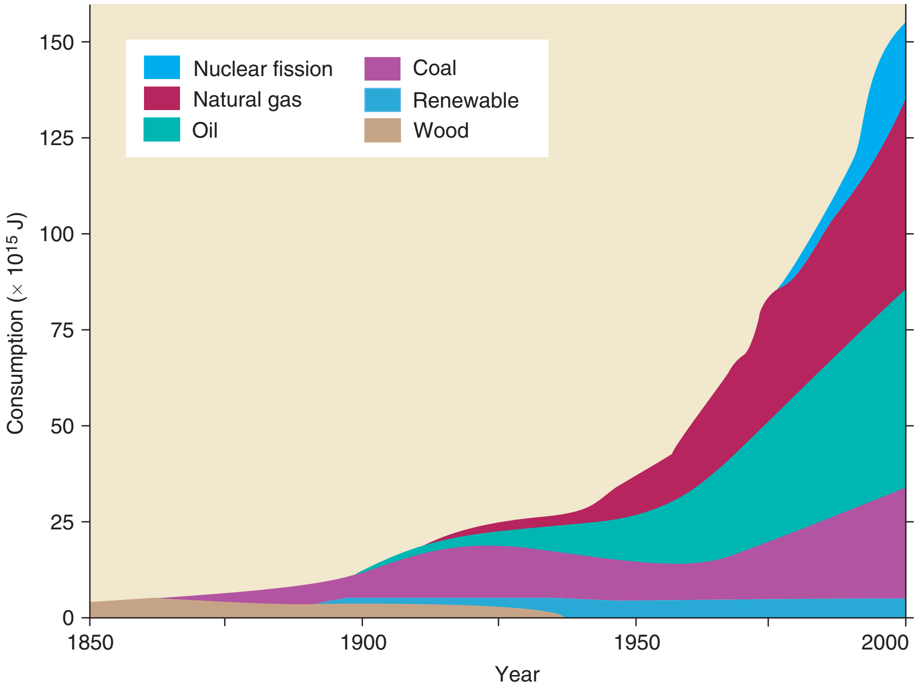


Figure 3-38 Annual energy consumption from various sources in the United States from 1850 to 2000. The total is forecast to be around 16 percent greater in 2010 with the largest increases being in the use of energy from natural gas and renewable sources. The curves will look very different a century from now as economic supplies of the nonrenewable fossil fuels coal, oil, and natural gas run out.

Solar Cells

Bright sunlight can deliver over 1 kW of power to each square meter on which it falls. At this rate, an area the size of a tennis court receives solar energy equivalent to a gallon of gasoline every 10 min or so. Photovoltaic cells are available that convert solar energy directly to electricity. Although the supply of sunlight varies with location, time of day, season, and weather, solar cells have the advantages of no moving parts and almost no maintenance. For a given power output solar cells are much more expensive than fossil-fuel plants, but improving technology is steadily increasing their efficiency (now as much as 20 percent) and dropping their price. Worldwide production of solar cells is over 1000 MW of peak power per year and rising.

A big advantage of solar cells is that they can be installed close to where their electricity is to be used, for instance on rooftops (Fig. 3-39). This can mean a major saving because it eliminates distribution costs in rural areas where power lines would otherwise have to be built. In Kenya, more households get their electricity from solar cells than from power plants.

Figure 3-39 Array of solar cells being installed over the back porch of a house in California.

compared with 11 kW per person in the United States. These people seek better lives, which means more energy, and their numbers are increasing rapidly, which means still more energy. Where is the energy to come from?

Fossil fuels, which today furnish by far the greatest part of the world's energy, cannot last forever. Oil and natural gas will be the first to be exhausted. At the current rate of consumption, known oil reserves will last only about another century. More oil will certainly be found, and better technology will increase the yield from existing wells, but even so oil will inevitably become scarce sooner or later. The same is true for natural gas. This situation will be a real pity because oil and gas burn efficiently and are easy to extract, process, and transport. Half the oil used today goes into fuels that power ships, trains, aircraft, cars, and trucks, and oil and gas are superb feedstocks for synthetic materials of all kinds. Although liquid fuels can be made from coal and coal itself can serve as the raw material for synthetics, these technologies involve greater expense and greater risk to health and to the environment.

Even though the coal we consume every year took about 2 million years to accumulate, enough remains to last several hundred more years at the present rate of consumption. Coal reserves are equivalent in energy content to 5 times oil reserves. Before 1941, coal was the world's chief fuel, and it is likely to return to first place when oil and gas run out.

But coal is far from being a desirable fuel. Not only is mining it dangerous and usually leaves large areas of land unfit for further use,

Hydroelectric Energy

The kinetic energy of falling water is converted into electric energy as the water turns turbine blades connected to generators (Fig. 3-40). Hydroelectric plants in many places have flooded large areas and turned once fertile river valleys into wastelands unfit for agriculture. Few dam sites remain that would not lead to such ecological damage, so hydroelectricity is not likely to exceed its current 3 percent of worldwide energy production in the future.

Figure 3-40 Hydroelectric power is produced at this dam on the Niagara River in New York State.

Geothermal Energy

Geothermal power stations use the heat of the earth's interior as their energy source (Fig. 3-41). Most such plants are located in Indonesia, the Philippines, New Zealand (where they provide 11 percent of the total energy supply), Italy, and on Caribbean islands. Geothermal energy is practical today in only a few places, but it has considerable potential for the future.

Figure 3-41 This power station in Sonoma County, California runs on geothermal energy.

but also the air pollution due to burning coal adversely affects the health of millions of people. Most estimates put the number of deaths in the United States from cancer and respiratory diseases caused by burning coal at over 10,000 per year. The situation is worse in China, where coal supplies 73 percent of the country's energy; 7 of the world's 10 cities with the most air pollution are in China with correspondingly high rates of illness and death. Interestingly, coal-burning power plants expose the people living around them to more radioactivity—from traces of uranium, thorium, and radon in their smoke—than do normally operating nuclear plants.

Another result of burning fossil fuels is the formation of carbon dioxide when the carbon they contain combines with oxygen from the air. Carbon dioxide is one of the gases in the atmosphere that acts to trap heat by the greenhouse effect, as described in Chap. 13. There is general agreement among climate specialists that the billions of tons of carbon dioxide produced each year by the burning of fossil fuels is mainly responsible for the warming of the atmosphere that is going on today, a warming that is likely to have serious consequences for our planet.

Nuclear fuel reserves much exceed those of fossil fuels. Besides their having an abundant fuel supply, properly built and properly operating nuclear plants are in many respects excellent energy sources. Nuclear energy is already responsible for about a fifth of the electricity generated in the United States, and in a number of other countries the proportion is even higher; in France it is nearly three-quarters (see Sec. 7-12).

To be sure, nuclear energy has serious drawbacks. Nuclear plants are expensive, and two major reactor accidents, at Three Mile Island in Pennsylvania and at Chernobyl in Ukraine, have left many people skeptical about the safety of nuclear plants even though the possibility of large-scale disaster with the latest designs seems remote. On a smaller scale, radioactive materials have leaked into the environment from badly run nuclear installations here and abroad. Although the overall public-health record of nuclear plants is still far better than that of coal-burning ones, there remains something to worry about. Furthermore, a reactor produces many tons of radioactive wastes each year whose safe disposal, still an unsettled issue, is bound to be costly.

3.15 The Future

No Magic Solution Yet

In the long run, practical ways to utilize the energy of nuclear fusion may well be developed. As described in Sec. 7-13, a fusion reactor will get its fuel from the sea, will be safe and nonpolluting, and cannot be adapted for military purposes. But nobody can predict when, or even if, this ultimate source of energy will become an everyday reality.

Assuming that fusion energy is really on the way, the big question today is how to manage until it arrives. Fossil fuels can be used more widely for a while, but only at the cost of more human suffering and

Wind Energy

Wind turbines that generate electricity can be noisy, need a lot of space, and are practical only where winds are powerful and reliable. On the other hand, they are nonpolluting, deplete no resources, and do not contribute to global warming by emitting carbon dioxide (Fig. 3-42).

A typical large modern turbine has three fiberglass-reinforced plastic blades 30 m long and generates 1 MW at a cost that is sometimes competitive with that of the electricity generated by fossil-fuel or nuclear plants. Turbines rated at 5 or 6 MW with blades 60 m (nearly 200 ft!) long that weigh 20 tons are being developed that should reduce or even eliminate the cost gap. Wind is the world's fastest-growing source of energy with its potential barely tapped. In 2003, the global total of wind energy capacity was about 40,000 MW, of which 75 percent was in Europe (notably in Germany, Spain, and Denmark) and 15 percent in the United States. It seems quite possible that by, say, 2030 wind turbines will produce 5 percent of the world's electricity, a significant proportion. The United States government has proposed as a goal 80,000 MW of wind turbine capacity in the country by 2020.

More and more turbine farms are being sited in shallow offshore waters where they have minimal environmental impact and can take advantage of the stronger and steadier winds there. Denmark expects to eventually generate half its electricity from offshore wind turbines. In the United States, a 468-MW wind farm has been proposed for an offshore site south of Cape Cod in Massachusetts.

Figure 3-42 Wind turbine "farm" near Palm Springs, California. Such farms consist of as many as several hundred turbines and can supply energy to tens of thousands of homes and businesses. About 1 percent of the electricity used in the United States in 2003 had wind as its source.

more damage to the environment. And their continued burning will enhance global warming with the possibility of eventual disaster. Nuclear energy can certainly bridge the gap, and it seems likely that a new generation of more efficient and safer nuclear plants will be built in the United States and elsewhere before long.

What about the energy of sunlight, of winds and tides, of falling water, of trees and plants, of the earth's own internal heat? After all, the technologies needed to make use of these renewable resources already exist. But a close look shows that it will not be easy for such alternative energy to supply all future needs. In every case the required installation either is expensive for the energy obtained, or is practical only in favorable locations in the world, or both. Some cannot provide energy reliably all the time, and all of them need a lot of space.

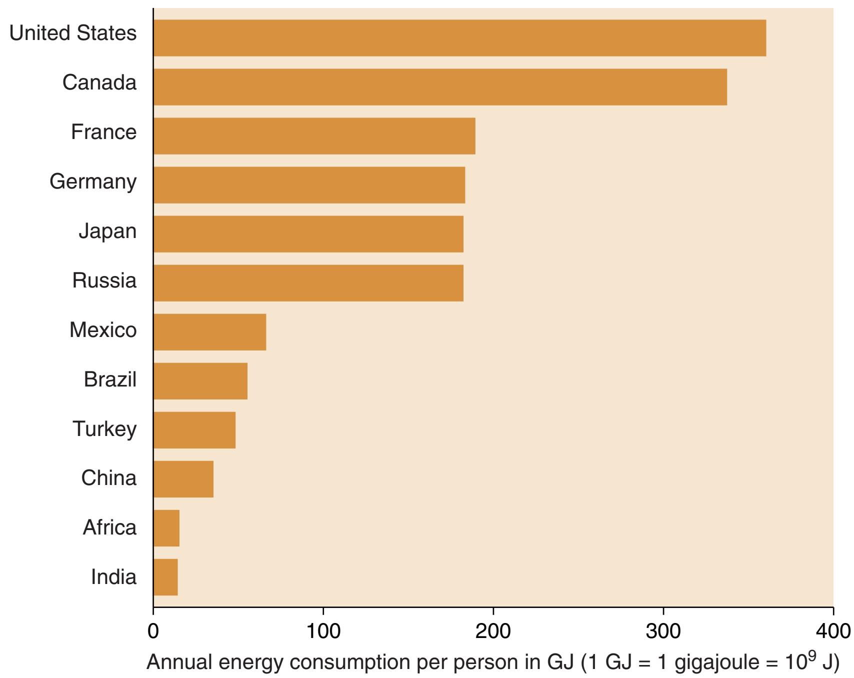


Figure 3-43 Energy used per person in 2003 in various parts of the world. The energy needs of the huge populations at the lower end of the list are sure to increase. Where will the additional energy come from?

A city of medium size might use 1000 MW of power. Less than 150 acres is enough for a 1000-MW nuclear plant, whereas solar collectors of the same capacity might need 5000 acres (including rooftops), wind turbines over 10,000 acres, and to grow crops for conversion to fuel might require 200 square miles of farmland to give 1000 MW averaged over a year. All this is not to say that such energy sources are without value, particularly where local conditions are suitable, only that they are unlikely in the foreseeable future to satisfy by themselves the world's energy appetite (Fig. 3-43).

Clearly there is no simple solution possible in the near future to the problem of safe, cheap, and abundant energy. The sensible course is to practice conservation and try to get the most from the various available renewable sources while pursuing fusion energy as rapidly as possible. Although each of these sources has limitations, it may be a reasonable choice in a given situation. If their full potential is realized and the world's population stabilizes or, better, decreases, social disaster (starvation, war) and environmental catastrophe (a planet unfit for life) may well be avoided even if fusion never becomes practical.

Important Terms and Ideas

Work is a measure of the change, in a general sense, that a force causes when it acts upon something. The work done by a force acting on an object is the product of the magnitude of the force and the distance through which the object moves while the force acts on it. If the direction of the force is not the same as the direction of motion, the projection of the force in the direction of motion must be used. The unit of work is the **joule** (J).

Power is the rate at which work is being done. Its unit is the **watt** (W).

Energy is the property that something has that enables it to do work. The unit of energy is the joule. The three broad categories of energy are **kinetic energy,** which is the energy something has by virtue of its motion, **potential energy,** which is the energy something has by virtue of its position, and **rest energy,** which is the energy something has by virtue of its mass. According to the **law of conservation of energy,** energy cannot be created or destroyed, although it can be changed from one form to another (including mass).

Linear momentum is a measure of the tendency of a moving object to continue in motion along a straight line. **Angular momentum** is a measure of the tendency of a rotating object to continue spinning about the same axis. Both are vector quantities. If no outside forces act on a set of objects, then their linear and angular momenta are **conserved,** that is, remain the same regardless of how the objects interact with one another.

According to the **special theory of relativity,** when there is relative motion between an observer and what is being observed, lengths are shorter than when at rest, time intervals are longer, and kinetic energies are greater. Nothing can travel faster than the speed of light.

The **general theory of relativity,** which relates gravitation to the structure of space and time, correctly predicts that light should be subject to gravity.

Important Formulas

Work: $W = Fd$

Power: $P = \dfrac{W}{t}$

Kinetic energy: $\text{KE} = \frac{1}{2} mv^2$

Gravitational potential energy: $\text{PE} = mgh$

Linear momentum: $\mathbf{p} = m\mathbf{v}$

Rest energy: $E_0 = mc^2$

Exercises: Multiple Choice

1. Which of the following is not a unit of power?
- **a.** joule-second
- **b.** watt
- **c.** newton-meter/second
- **d.** horsepower

2. An object at rest may have
- **a.** velocity
- **b.** momentum
- **c.** kinetic energy
- **d.** potential energy

3. A moving object does not necessarily have
- **a.** velocity
- **b.** momentum
- **c.** kinetic energy
- **d.** potential energy

4. An object that has linear momentum must also have
- **a.** acceleration
- **b.** angular momentum
- **c.** kinetic energy
- **d.** potential energy

5. The total amount of energy (including the rest energy of matter) in the universe
- **a.** cannot change
- **b.** can decrease but not increase
- **c.** can increase but not decrease
- **d.** can either increase or decrease

6. When the speed of a body is doubled,
- **a.** its kinetic energy is doubled
- **b.** its potential energy is doubled
- **c.** its rest energy is doubled
- **d.** its momentum is doubled

7. Two balls, one of mass 5 kg and the other of mass 10 kg, are dropped simultaneously from a window. When they are 1 m above the ground, the balls have the same
- **a.** kinetic energy
- **b.** potential energy
- **c.** momentum
- **d.** acceleration

8. A bomb dropped from an airplane explodes in midair.
- **a.** Its total kinetic energy increases
- **b.** Its total kinetic energy decreases
- **c.** Its total momentum increases
- **d.** Its total momentum decreases

9. The operation of a rocket is based upon
- **a.** pushing against its launching pad
- **b.** pushing against the air
- **c.** conservation of linear momentum
- **d.** conservation of angular momentum

10. When a spinning skater pulls in her arms to turn faster,
- **a.** her angular momentum increases
- **b.** her angular momentum decreases
- **c.** her angular momentum remains the same
- **d.** any of these, depending on the circumstances

11. According to the principle of relativity, the laws of physics are the same in all frames of reference
- **a.** at rest with respect to one another
- **b.** moving toward or away from one another at constant velocity
- **c.** moving parallel to one another at constant velocity
- **d.** all of these

12. When the speed v of an object of mass m approaches the speed of light c, its kinetic energy
- **a.** is less than $\frac{1}{2}mv^2$
- **b.** equals $\frac{1}{2}mv^2$
- **c.** is more than $\frac{1}{2}mv^2$ but less than $\frac{1}{2}mc^2$
- **d.** is more than $\frac{1}{2}mv^2$ and can exceed $\frac{1}{2}mc^2$

13. A spacecraft has left the earth and is moving toward Mars. An observer on the earth finds that, relative to measurements made when the spacecraft was at rest, its
- **a.** length is shorter
- **b.** KE is less than $\frac{1}{2}mv^2$
- **c.** clocks tick faster
- **d.** rest energy is greater

14. In the formula $E_0 = mc^2$, the symbol c represents
- **a.** the speed of the body
- **b.** the speed of the observer
- **c.** the speed of sound
- **d.** the speed of light

15. It is not true that
- **a.** light is affected by gravity
- **b.** the mass of a moving object depends upon its speed
- **c.** the maximum speed anything can have is the speed of light
- **d.** momentum is a form of energy

16. Albert Einstein did not discover that
- **a.** the length of a moving object is less than its length at rest
- **b.** the acceleration of gravity g is a universal constant
- **c.** light is affected by gravity
- **d.** gravity is a warping of space-time

17. The rate at which sunlight delivers energy to an area of 1 m^2 is roughly
- **a.** 1 W
- **b.** 10 W
- **c.** 1000 W
- **d.** 1,000,000 W

18. The chief source of energy in the world today is
- **a.** coal
- **b.** oil
- **c.** natural gas
- **d.** uranium

19. The source of energy whose reserves are greatest is
- **a.** coal
- **b.** oil
- **c.** natural gas
- **d.** uranium

20. The work done in holding a 50-kg object at a height of 2 m above the floor for 10 s is
- **a.** 0
- **b.** 250 J
- **c.** 1000 J
- **d.** 98,000 J

21. The work done in lifting 30 kg of bricks to a height of 20 m is
- **a.** 61 J
- **b.** 600 J
- **c.** 2940 J
- **d.** 5880 J

22. A total of 4900 J is used to lift a 50-kg mass. The mass is raised to a height of
- **a.** 10 m
- **b.** 98 m
- **c.** 960 m
- **d.** 245 km

23. A 40-kg boy runs up a flight of stairs 4 m high in 4 s. His power output is
- **a.** 160 W
- **b.** 392 W
- **c.** 40 W
- **d.** 1568 W

24. Car A has a mass of 1000 kg and is moving at 60 km/h. Car B has a mass of 2000 kg and is moving at 30 km/h. The kinetic energy of car A is
- **a.** half that of car B
- **b.** equal to that of car B
- **c.** twice that of car B
- **d.** 4 times that of car B

25. A 1-kg object has a potential energy of 1 J relative to the ground when it is at a height of
- **a.** 0.102 m
- **b.** 1 m
- **c.** 9.8 m
- **d.** 98 m

26. A 1-kg object has kinetic energy of 1 J when its speed is
- **a.** 0.45 m/s
- **b.** 1 m/s
- **c.** 1.4 m/s
- **d.** 4.4 m/s

27. A 1-kg ball is thrown in the air. When it is 10 m above the ground, its speed is 3 m/s. At this time most of the ball's total energy is in the form of
 a. kinetic energy
 b. potential energy relative to the ground
 c. rest energy
 d. momentum

28. A 10,000-kg freight car moving at 2 m/s collides with a stationary 15,000-kg freight car. The two cars couple together and move off at
 a. 0.8 m/s **c.** 1.3 m/s
 b. 1 m/s **d.** 2 m/s

29. A 30-kg girl and a 25-kg boy are standing on frictionless roller skates. The girl pushes the boy, who moves off at 1.0 m/s. The girl's speed is
 a. 0.45 m/s **c.** 0.83 m/s
 b. 0.55 m/s **d.** 1.2 m/s

30. An object has a rest energy of 1 J when its mass is
 a. 1.1×10^{-17} kg **c.** 1 kg
 b. 3.3×10^{-9} kg **d.** 9×10^{16} kg

31. The smallest part of the total energy of the ball of multiple choice 27 is
 a. kinetic energy
 b. potential energy relative to the ground
 c. rest energy
 d. momentum

32. The 2-kg blade of an ax is moving at 60 m/s when it strikes a log. If the blade penetrates 2 cm into the log as its KE is turned into work, the average force it exerts is
 a. 3 kN **c.** 72 kN
 b. 90 kN **d.** 180 kN

33. The lightest particle in an atom is an electron, whose rest mass is 9.1×10^{-31} kg. The energy equivalent of this mass is approximately
 a. 10^{-13} J **c.** 3×10^{-23} J
 b. 10^{-15} J **d.** 10^{-47} J

Questions

1. Is it correct to say that all changes in the physical world involve energy transformations of some sort? Why?

2. Under what circumstances (if any) is no work done on a moving object even though a net force acts upon it?

3. In what part of its orbit is the earth's potential energy greatest with respect to the sun? In what part of its orbit is the earth's kinetic energy greatest? Explain your answers.

4. Does every moving body possess kinetic energy? Does every stationary body possess potential energy?

5. A golf ball and a Ping-Pong ball are dropped in a vacuum chamber. When they have fallen halfway to the bottom, how do their speeds compare? Their kinetic energies? Their potential energies? Their momenta?

6. The potential energy of a golf ball in a hole is negative with respect to the ground. Under what circumstances (if any) is the ball's kinetic energy negative? Its rest energy?

7. Two identical balls move down a tilted board. Ball A slides down without friction and ball B rolls down. Which ball reaches the bottom first? Why?

8. The kilowatt-hour is a unit of what physical quantity or quantities?

9. Why does a nail become hot when it is hammered into a piece of wood?

10. As we will learn in Chap. 5, electric charges of the same kind (both positive or both negative) repel each other, whereas charges of opposite sign (one positive and the other negative) attract each other. (a) What happens to the PE of a positive charge when it is brought near another positive charge? (b) When it is brought near a negative charge?

11. Is it possible for an object to have more kinetic energy but less momentum than another object? Less kinetic energy but more momentum?

12. What happens to the momentum of a car when it comes to a stop?

13. When the kinetic energy of an object is doubled, what happens to its momentum?

14. What, if anything, happens to the speed of a fighter plane when it fires a cannon at an enemy plane in front of it?

15. An empty dump truck coasts freely with its engine off along a level road. (a) What happens to the truck's speed if it starts to rain and water collects

in it? (b) The rain stops and the accumulated water leaks out. What happens to the truck's speed now?

16. A railway car is at rest on a frictionless track. A man at one end of the car walks to the other end. (a) Does the car move while he is walking? (b) If so, in which direction? (c) What happens when the man comes to a stop?

17. If the polar ice caps melt, the length of the day will increase. Why?

18. All helicopters have two rotors. Some have both rotors on vertical axes but rotating in opposite directions, and the rest have one rotor on a horizontal axis perpendicular to the helicopter body at the tail. Why is a single rotor never used?

19. What are the two postulates from which Einstein developed the special theory of relativity?

20. What physical quantity will all observers always find the same value for?

21. The length of a rod is measured by several observers, one of whom is stationary with respect to the rod. What must be true of the value obtained by the stationary observer?

22. If the speed of light were smaller than it is, would relativistic phenomena be more or less conspicuous than they are now?

23. The theory of relativity predicts a variety of effects that disagree with our everyday experience. Why do you think this theory is universally accepted by scientists?

24. Why is it impossible for an object to move faster than the speed of light?

25. What is the effect on the law of conservation of energy of the discovery that matter and energy can be converted into each other?

26. Which three fuels provide most of the world's energy today?

27. What energy sources, if any, cannot be traced to sunlight falling on the earth?

28. What are some of the disadvantages shared by all renewable-energy sources such as solar cells and wind turbines?

Problems

1. A horizontal force of 80 N is used to move a 20-kg crate across a level floor. How much work is done when the crate is moved 5 m? How much work would have been done if the crate's mass were 30 kg?

2. How much work is needed to raise a 110-kg load of bricks 12 m above the ground to a building under construction?

3. The sun exerts a gravitational force of 4.0×10^{28} N on the earth, and the earth travels 9.4×10^{11} m in its yearly orbit around the sun. How much work is done by the sun on the earth each year?

4. The acceleration of gravity on the surface of Mars is 37 m/s^2. If an astronaut in a space suit can jump upward 20 cm on the earth's surface, how high could he jump on the surface of Mars?

5. A total of 490 J of work is needed to lift a body of unknown mass through a height of 10 m. What is its mass?

6. A weightlifter raises a 90-kg barbell from the floor to a height of 2.2 m in 0.6 s. What was his average power output during the lift?

7. An 80-kg mountaineer climbs a 3000-m mountain in 10 h. What is the average power output during the climb?

8. A crane whose motor has a power input of 5.0 kW lifts a 1200-kg load of bricks through a height of 30 m in 90 s. Find the efficiency of the crane, which is the ratio between its output power and its input power.

9. A moving object whose initial KE is 10 J is subject to a frictional force of 2 N that acts in the opposite direction. How far will the object move before coming to a stop?

10. What is the speed of an 800-kg car whose KE is 250 kJ?

11. Is the work needed to bring a car's speed from 0 to 10 km/h less than, equal to, or more than the

work needed to bring its speed from 10 to 20 km/h?

12. Which of these energies might correspond to the KE of a person riding a bicycle on a road? 10 J; 1 kJ; 100 kJ.

13. A 1-kg salmon is hooked by a fisherman and it swims off at 2 m/s. The fisherman stops the salmon in 50 cm by braking his reel. How much force does the fishing line exert on the fish?

14. How long will it take a 1000-kg car with a power output of 20 kW to go from 10 m/s to 20 m/s?

15. A 70-kg athlete runs up the stairs from the ground floor of the Empire State Building to its one hundred second floor, a height of 370 m, in 25 min. How much power did the athlete develop?

16. During a circus performance, John Tailor was fired from a compressed-air cannon whose barrel was 20 m long. Mr. Tailor emerged from the cannon (twice on weekdays, three times on Saturdays and Sundays) at 40 m/s. If Mr. Tailor's mass was 70 kg, what was the average force on him when he was inside the cannon's barrel?

17. A 3-kg stone is dropped from a height of 100 m. Find its kinetic and potential energies when it is 50 m from the ground.

18. An 800-kg car coasts down a hill 40 m high with its engine off and the driver's foot pressing on the brake pedal. At the top of the hill the car's speed is 6 m/s and at the bottom it is 20 m/s. How much energy was converted into heat on the way down?

19. A skier is sliding downhill at 8 m/s when she reaches an icy patch on which her skis move freely with negligible friction. The difference in altitude between the top of the icy patch and its bottom is 10 m. What is the speed of the skier at the bottom of the icy patch? Do you have to know her mass?

20. A force of 20 N is used to lift a 600-g ball from the ground to a height of 1.8 m, when it is let go. What is the speed of the ball when it is let go?

21. An 80-kg crate is raised 2 m from the ground by a man who uses a rope and a system of pulleys. He exerts a force of 220 N on the rope and pulls a total of 8 m of rope through the pulleys while lifting the crate, which is at rest afterward. (a) How much work does the man do? (b) What is the change in the potential energy of the crate? (c) If the answers to these questions are different, explain why.

22. A man drinks a bottle of beer and proposes to work off its 460 kJ by exercising with a 20-kg barbell. If each lift of the barbell from chest height to over his head is through 60 cm and the efficiency of his body is 10 percent under these circumstances, how many times must he lift the barbell?

23. In an effort to lose weight, a person runs 5 km per day at a speed of 4 m/s. While running, the person's body processes consume energy at a rate of 1.4 kW. Fat has an energy content of about 40 kJ/g. How many grams of fat are metabolized during each run?

24. A boy throws a 4-kg pumpkin at 8 m/s to a 40-kg girl on roller skates, who catches it. At what speed does the girl then move backward?

25. A 70-kg person dives horizontally from a 200-kg boat with a speed of 2 m/s. What is the recoil speed of the boat?

26. A 30-kg girl who is running at 3 m/s jumps on a stationary 10-kg sled on a frozen lake. How fast does the sled with the girl on it then move?

27. The 176-g head of a golf club is moving at 45 m/s when it strikes a 46-g golf ball and sends it off at 65 m/s. Find the final speed of the clubhead after the impact, assuming that the mass of the club's shaft can be neglected.

28. A 1000-kg car moving north at 20 m/s collides head-on with an 800-kg car moving south at 30 m/s. If the cars stick together, in what direction and at what speed does the wreckage begin to move?

29. One kilogram of water at 0°C contains 335 kJ of energy more than 1 kg of ice at 0°C. What is the mass equivalent of this amount of energy?

30. When 1 g of natural gas is burned in a stove or furnace, about 56 kJ of heat is produced. How much mass is lost in the process? Do you think this mass change could be directly measured?

31. Approximately 5.4×10^6 J of chemical energy is released when 1 kg of dynamite explodes. What fraction of the total energy of the dynamite is this?

32. Approximately 4×10^9 kg of matter is converted into energy in the sun per second. Express the power output of the sun in watts.

Answers to Multiple Choice

1. a	**6.** d	**11.** d	**16.** b	**21.** d	**26.** c	**31.** a
2. d	**7.** d	**12.** d	**17.** c	**22.** a	**27.** c	**32.** d
3. d	**8.** a	**13.** a	**18.** b	**23.** b	**28.** a	**33.** a
4. c	**9.** c	**14.** d	**19.** d	**24.** c	**29.** c	
5. a	**10.** c	**15.** d	**20.** a	**25.** a	**30.** a	