Energy Mechanics

HOW WOULD YOU CHOOSE?

Energy Conversions

Energy can be classified into many forms, which allows us to study the conversion of energy from one form into another in a device or machine. Two devices that can illustrate energy forms are the hybrid car and the hydroelectric power plant. Which of these two examples would you choose to illustrate the conversion of energy from one form to another and why would you choose it?

A. Introduction

Not many years ago an invention came on the market that claimed to put out more energy than was put into it. Some demonstrations of the device were given and a good deal of stock in the company was sold. The entrepreneur claimed this device would solve the energy crisis. It *did* solve his own financial crisis, but proved to be nothing but a clever trick. Had the investors known some simple physical laws about energy, they could have saved their money.

This chapter will serve to introduce some of the basic scientific principles needed for an understanding of energy and energy technologies. Much of this background comes from a study of basic physics. Physics is an experimental science concerned with understanding the natural world. The term "physics" is derived from the Greek word "*physike*," meaning science or knowledge of nature; one dictionary defines physics as "the science dealing with the properties, changes, interactions, etc., of matter and energy." While some significant technological advances will have occurred since the first writing of this book in the areas of energy use and power production, the basic concepts explained here and in the following chapters should provide a key to understanding many of them.

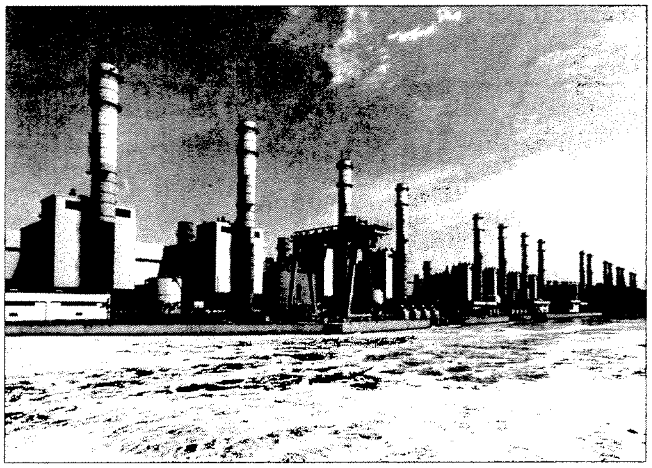
Science as a way of knowing is devoted to discovering the general principles that govern our world. A good part of this process is **observing** things around us in order to understand how they work. Our knowledge of ozone depletion and air pollution and their effects on humans have come from observations over the past several decades. After many observations, a **hypothesis** is usually proposed that tries to generalize the observations. The observation that collies and poodles have four legs might lead you to hypothesize that all dogs have four legs. But before we can be sure, we have to **test** our hypothesis by observing more dogs. A hypothesis that has been supported by a large body of observations and experiments becomes a **theory.** A good theory grows or is revised as new facts and observations arise. A scientific theory must be organic and open to change. Present day theories of global warming are not fixed in stone. There are a variety of opinions within the scientific community on such issues. At the end of each of the chapters to come there are "Further Activities" suggested that will allow you to try your hand in the scientific process.

As we study energy, we must be aware of the limitations of science. Many things of great concern to us cannot be studied by a scientific approach; it is not the only road to knowledge. Science can address the questions of *how* something happened but not *why* something happened. As issues of energy policy emerge in the chapters ahead, we shall consider many questions or problems that lie outside the domain of science. There is clearly a need for more research in many areas of energy technology, but when and how these discoveries are applied will probably depend as much on the social, political, and economic atmosphere as it will on science and engineering. For example, some politicians feel that requiring more fuel-efficient cars would be an unwarranted federal intrusion into the private sector. Likewise, the selection of a site for the disposal of high-level radioactive waste is as much a political decision as a geophysical one.

B. Forms of Energy and Energy Conversions

As mentioned in Chapter 1, too often the term "energy" brings to mind only a vague picture of an electrical generating plant or a person bounding up from the breakfast table "full of energy." We more correctly might think of energy as something that makes automobiles move or that provides us with light and heat. We would have a better definition of energy if we thought of it as related to the capacity of certain materials in certain situations to perform useful tasks. To be consistent in our use of this term for the remainder of this book, we need a more rigorous definition. We will begin by identifying various forms of energy and the transformations of energy from one form to another.

One of the basic types of energy is the energy associated with an object's *motion*. We call this **kinetic energy.** A moving car or a rotating shaft has kinetic energy. There is also energy associated with an object's *position*, which is called **potential energy.** A stretched spring or a ball positioned above a table has potential energy. Kinetic and potential energy can be classified as forms of what we call **mechanical energy.**



Korea Electric power plant. With a total output of 4000 MWe, this plant is one of the world's largest and most efficient (57%) combined cycle facilities (gas turbine and steam turbine system). (General Electric Power Systems)

Other forms of energy are **chemical energy, nuclear energy, thermal energy, electrical energy,** and **light** (or **radiant**) **energy.** The fossil fuels as well as food possess chemical energy. The energy found within the atomic nucleus is nuclear energy. A hot object possesses thermal energy (a function of its mass and its temperature). Electrical energy is produced at an electrical power plant or from the batteries in your Walkman. Radiant energy is also called electromagnetic radiation, and covers everything from radio and television waves to infrared radiation to visible light to X rays. The electromagnetic radiation received from the sun is usually referred to as solar energy.

All these kinds of energy on a microscopic level are examples of kinetic energy or potential energy. The chemical energy stored within oil may be considered as potential energy associated with molecular bonds, which are changed or broken during combustion. Radiant energy and electrical energy may be loosely thought of as related to the kinetic energy of light or electrons, respectively. The thermal energy of an object consists primarily of the sum of the kinetic energy of all the molecules of that object. We can categorize the primary energy sources introduced in Chapter 1 into chemical, nuclear, or radiant energy. The "end uses" of energy—the ways in which we see energy

Table 2.1 FORMS OF ENERGY

Chemical
Nuclear
Radiant
Thermal
Sound
Electrical
Mechanical (kinetic, potential)

Primary Sources		End Uses
Coal	Chemical	Heat
Oil		Light
Natural Gas		Motion
Uranium–nuclear		Electricity
Sun—radiant/solar		Chemical processes

being used—include the forms light, heat, motion, electricity, and some chemical reactions. Table 2.1 summarizes the forms, sources, and end uses of energy.

The transformation of energy from primary sources to end uses usually occurs through one or more *energy conversion processes.* Electrical energy is not a primary energy source but is the result of a conversion process that began with chemical, nuclear, or solar energy sources. For example, the chemical energy contained in oil is converted into other forms (thermal, electrical, and/or mechanical energy) beginning with combustion. The heat energy released by burning oil in a boiler turns water into steam, which drives a turbine that is connected to a generator to produce electrical energy.

Another example of energy conversion occurs in a solar cell. Sunlight impinging on a solar cell (Fig. 2.1) produces electricity, which in turn can be used to run an electric motor. Energy is converted from the primary source of solar energy into electrical energy and then into mechanical energy.

Table 2.2 lists a variety of devices to illustrate conversions from one energy form to another. For example, a toaster illustrates the conversion of electrical energy to thermal

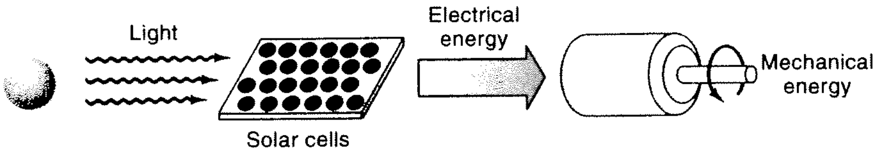


Figure 2.1
Illustration of conversions between different forms of energy. Here, solar energy is converted into electrical energy by a solar cell, which is used to run a motor.

Table 2.2 ENERGY CONVERSIONS

Conversion From:	To Chemical	To Electric	To Heat	To Light	To Mechanical
Chemical	Food Plants	Battery Fuel cell	Fire Food	Candle Phosphorescence	Rocket Animal muscle
Electrical	Electrolysis Electroplating	Transistor Transformer	Toaster Heat lamp Spark plug	Fluorescent lamp Light emitting diode	Electric motor Relay
Heat	Gasification Vaporization	Thermocouple	Heat pump Heat exchanger	Fire	Turbine Gas engine Steam engine
Light	Plant photosynthesis Camera film	Solar cell	Heat lamp Radiant solar	Laser	Photoelectric door opener
Mechanical	Heat cell (crystallization)	Generator Alternator	Friction brake	Flint Spark	Flywheel Pendulum Water wheel

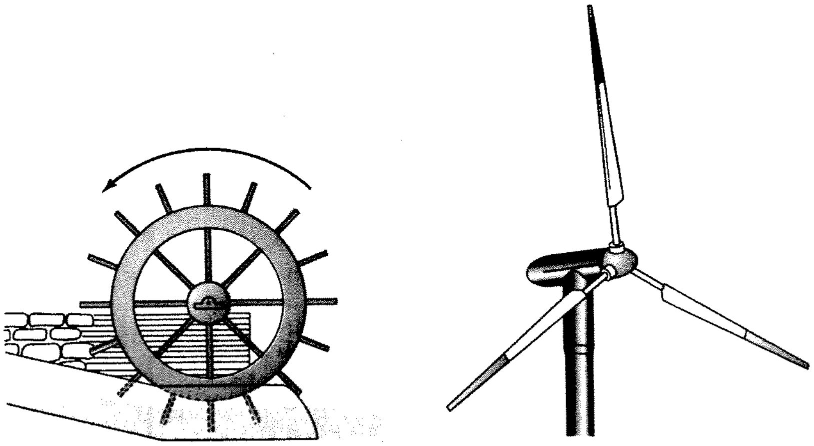
ACTIVITY 2.1

Provide additional examples of devices to illustrate the energy conversion processes found in Table 2.2. This activity works best in small groups.

energy; a battery converts chemical energy into electrical energy. Mechanical energy (the kinetic energy part) of a car is converted into heat when the brakes are applied.

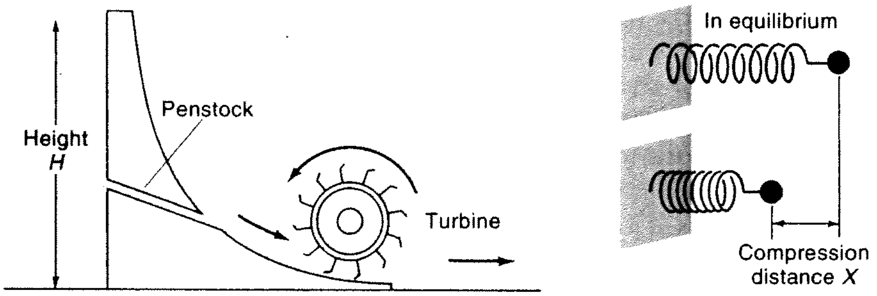
Let's further discuss the two different types of **mechanical energy (ME). Kinetic energy (KE)** is the energy associated with the motion of an object. Examples of objects having kinetic energy include a moving stream of water, a bug flying through the air, a spinning flywheel, and the wind. Moving water has kinetic energy by virtue of its motion; this can be converted into useful work as it hits the blades of a waterwheel (Fig. 2.2). As moving air interacts with the blades of a wind-turbine, the shaft rotates. The kinetic energy of the wind is converted into the kinetic energy of the shaft and then into electrical energy through a generator.

The other form of mechanical energy is associated with the relative position of an object. It is stored energy. The water at the top of a dam has gravitational **potential energy (PE)** by virtue of its position relative to the bottom of the dam. The amount



(a) (b)

Figure 2.2
Two examples illustrating the conversion of kinetic energy (KE) of water or air into the motion of a waterwheel or a blade, which can be used to grind grain or generate electricity, respectively. (a) An undershot water wheel. (b) A horizontal-axis, three-bladed, wind-powered generator.



(a)

(b)

Figure 2.3

Examples of potential energy. (a) The gravitational potential energy of the water in the reservoir behind the dam is equal to the weight of the water times its height above the turbine. (b) The potential energy of the compressed spring is proportional to the square of the displacement of the spring from equilibrium X.

of gravitational potential energy depends on the amount of water and the height of the water behind the dam wall. There is also potential energy associated with a compressed spring. The potential energy of an object attached to the spring is proportional to the displacement of the spring from its equilibrium (uncompressed) position (Fig. 2.3). You can probably remember the wind-up toys you had as a child; potential energy stored in the spring could be released to turn the toy's wheels, giving the toy kinetic energy.

C. Motion

Before attempting a more rigorous definition of "energy," and in order to appreciate the subject of energy from a physics perspective, you should be familiar with motion and its causes. We will briefly discuss this in this section. These topics are reviewed in more detail at the end of this chapter under the Special Topic "Newton's Laws of Motion."

One of the most basic terms in the description of motion is **speed.** The speed of an object is equal to the distance it has traveled divided by the time taken to travel that distance. Commonly used units for speed are meters per second (m/s), kilometers per hour (km/h), feet per second (ft/s), and miles per hour (mph). **Velocity** provides additional information about motion, namely its direction; our velocity while walking briskly across campus might be one meter per second to the northeast.

In our everyday experience, it is more common to observe objects speeding up or slowing down than to see them moving at a constant velocity. These objects are accelerating; **acceleration** is the change in velocity divided by the time elapsed during that change. If an object's velocity changes at a constant rate, such as would occur to a coin dropped from your desk, its acceleration is a constant. The International System of Units (SI) for acceleration are m/s^2, pronounced meters per second per second.

What causes the velocity of an object to change (that is, to accelerate) is a **force,** specifically a **net** (or unbalanced) **force.** A force can be defined as the interaction of an object with other objects in its environment, and usually takes the form of a push or a pull. These forces can be long range (as the force of gravity between the earth and the moon) or contact forces (as the force pushing a box). The net force is the (vector) sum of all the forces acting on the object. **Newton's second law of motion** states the mathematical relationship between net force and acceleration. It says that the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to the object's mass *m:*

$$a = F_{\text{net}}/m \quad \text{or} \quad F_{\text{net}} = ma$$

The SI unit of force is the **newton** (N). An object with a mass of 1 kilogram (kg) will be accelerated 1 m/s^2 by the application of a net force of 1 N. In the English system of measurement, the unit of force is the pound (lb). One pound is equal to about 4 N.

EXAMPLE

A 6-kg meteor is moving in space. If a 3-newton force is applied to it, what will be its acceleration?

SOLUTION

Newton's second law gives us

$$a = F/m = 3\text{ N}/6\text{ kg} = 0.5\text{ m/s}^2$$

Acceleration only occurs if the object is acted on by a net force, that is, if the sum of all the forces acting on an object is not zero. One of the most common forces in nature is the force of friction, which always acts to *oppose* the motion taking place (Fig. 2.4). If a cart is pushed across the ground at a constant velocity, the net force on the cart must be 0 (Fig. 2.5). If your force pushing the cart is, say 100 N, this force is balanced or opposed by a force of friction of 100 N, so that the net force is 0. (Note that a constant velocity implies that the acceleration is 0.)

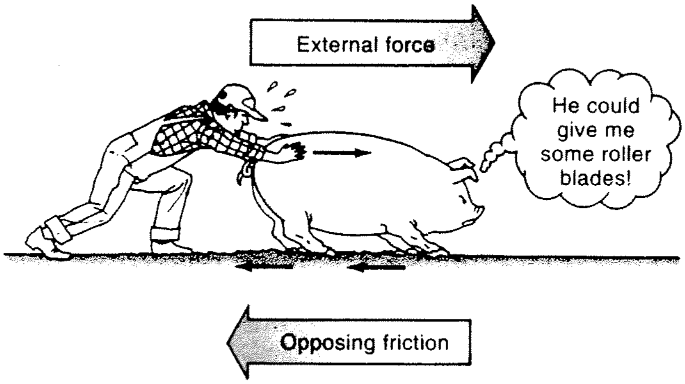


Figure 2.4
Friction enters into almost every situation in the real world. In order to accelerate the object, the force of the person's push must exceed the force of friction.

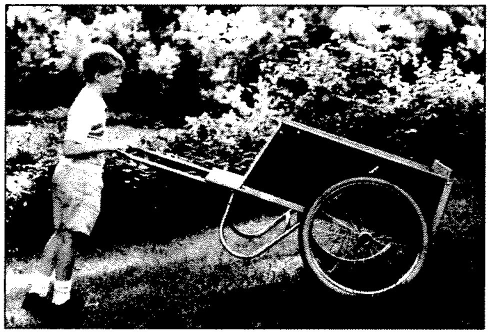
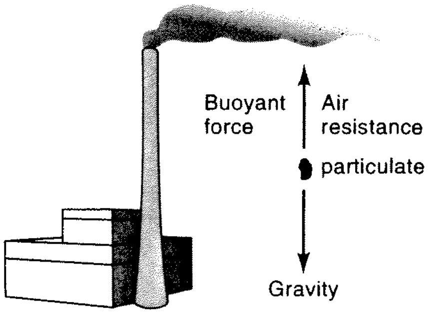


Figure 2.5
Pushing a cart at a constant velocity means that the net force on the cart (the person's force minus the force of friction on the tires minus the force of gravity down the hill) must be zero. The acceleration is zero. (R. Hinrichs)

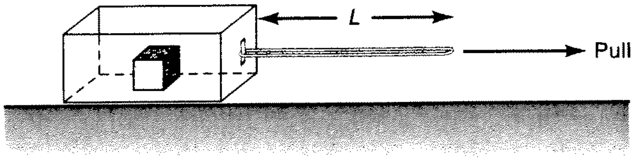


As an example of Newton's laws of motion, consider the following: One of the environmental problems associated with the burning of fossil fuels is the emission of particulates (very small fly-ash particles) from the stack. These particles (from about one millionth to a hundred millionth of a meter in size) have been known to travel many hundreds of kilometers before landing, depending on wind velocity. This mobility is a problem because of the health effect these particles will have on those who inhale them. Their travel a large distance becomes possible if the net vertical force on the particle is zero, or close to it, and so there is very little acceleration toward the ground. The force of gravity downward on the particle is balanced out by the upward buoyant force of the air and by air resistance, and so the particles can drift with the wind great distances.

ACTIVITY 2.2

You can study forces and Newton's second law with the following activity:

1. Attach a rubber band to a shoe box or a Styrofoam bowl or an aluminum tart pan so that it can be pulled along a table top. Measure how far the rubber band will stretch (final length minus initial length) to move the box at a constant velocity with a weight in it. Make this measurement when the box is moving, not just when it starts. (Why should the velocity be kept constant?) Add weights to the box and repeat the experiment. Propose a relationship between the stretch distance and the weight of the box.



2. Put some round pencils or dowels under the box and repeat the experiment. Compare these results with your results in part 1.

EXAMPLE

An average sized fly-ash particle has a (constant) settling velocity of 0.3 m/s. If these particulates are emitted from a 200-meter-high stack and there is a 15 km/h wind, how far away from the stack will the particle land?

SOLUTION

The time it will take for the particle to reach the ground is

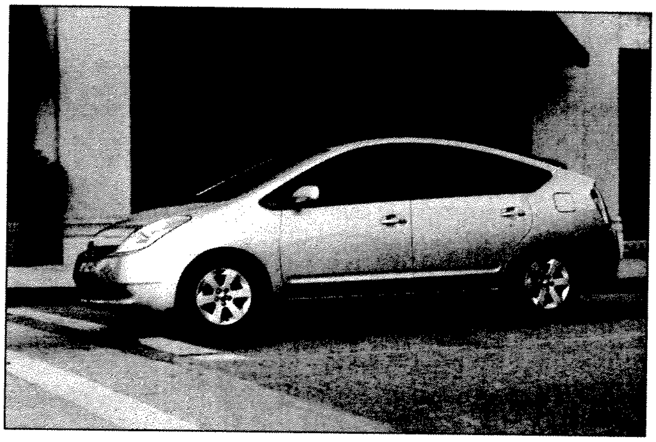
$$\text{Time} = \frac{\text{distance}}{\text{vertical velocity}} = \frac{200\text{ m}}{0.3\text{ m/s}} = 667\text{ s} = 0.19\text{ hr}$$

In this time it will have covered a horizontal distance of $d = vt = 15$ km/h × 0.19 hr = 2.8 km.

Newton's second law says that the acceleration of an object depends on both the net force acting on it and its own mass. For example, if identical engines were placed into a Cadillac and a Dodge Neon, the acceleration of the Neon would be greater than that of the Cadillac because the mass of the Neon is much less, even though the force accelerating the car is the same in both cases. (See the example in the Special Topics section at end of this chapter.)

Driving in a city with stop-and-go traffic, we burn more fuel than we do driving comparable distances in the country. This is because in the city we quite frequently have to accelerate from rest, which requires a net force acting on the car. While the gas mileage of new cars has remained relatively constant over the last several decades, it is a large improvement over the 1970s and before as a result of many factors. The most important change was the reduction in the mass of a car, not more efficient engines or better aerodynamics. Focus On 2.1 "Energy Losses in a Car" explains some of the factors that determine fuel efficiency.

An exception to city/highway fuel efficiency is the hybrid car, introduced into the market in 1999 by Honda and Toyota, but now produced by nearly all automobile companies. This vehicle uses both a small gasoline internal combustion engine and a DC motor which is run from a battery pack. When the batteries are sufficiently charged, they provide power to the motor, especially at lower speeds. The gasoline engine charges up the batteries and provides power at highway speeds. The hybrid gets great mileage (60 mpg city and 51 mpg highway—Toyota Prius), more in stop-and-go driving than on the highway. The electric motor acts as a generator during braking and deceleration to return energy to the battery pack.



The Toyota Prius hybrid gets 60 mpg city and 51 mpg highway. (Toyota Motor Sales, USA, Inc.)

D. Energy and Work

From this introduction to the forms of energy and to motion, let us now proceed to a definition of energy. **Energy is defined as the "capacity to do work."** While the word "work" might bring to mind various pictures in such fields as literature and biology, in physics **work** is defined as *the product of a force times the distance through which that force acts.* If you push this book across the desk, a force is being applied.

FOCUS ON 2.1

ENERGY LOSSES IN A CAR

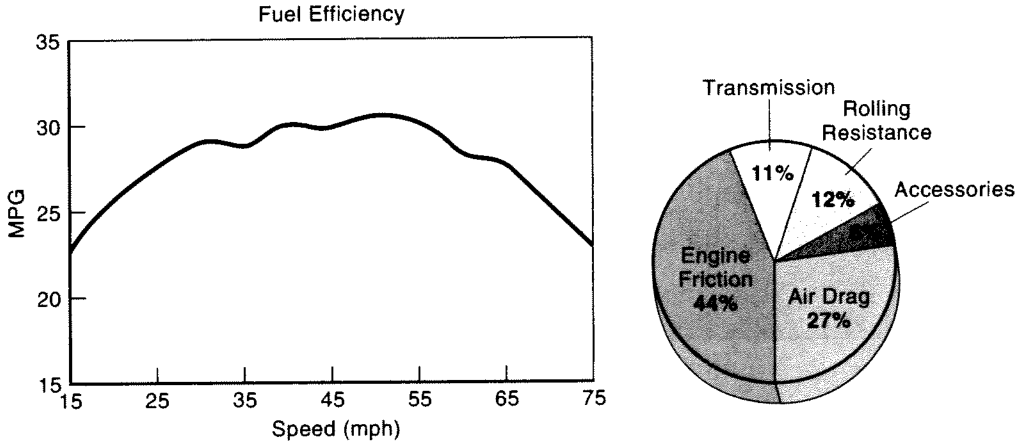
Overall automobile fuel efficiency is a function of two factors: engine efficiency (called thermal efficiency—how much of the chemical energy of the fuel is converted into work moving the pistons) and mechanical efficiency—the fraction of that work delivered by the engine that actually goes to move the vehicle. This includes aerodynamic losses and frictional losses within the engine. Thermal efficiency (see Chapter 4) for standard gasoline engines today is about 38%. Mechanical efficiency at cruising speeds is about 50%.

The net force on a moving automobile is equal to the difference between the force delivered by the engine and the friction forces due to air drag, rolling resistance of the tires, and friction within the engine. This can be written as

$$F_{\text{net}} = F_{\text{engine}} - F_{\text{friction}} = ma$$

When a car is cruising on level ground at a constant speed, F_{net} is equal to 0, since the acceleration is 0.

Frictional losses within the engine are much larger at lower speeds, while air drag increases as the square of the velocity; that is, air drag will be



(a) (b)

(a) Gas mileage as a function of car's speed. (Oak Ridge National Laboratory, *Transportation Energy Data Book*, 2003)
(b) Energy losses in an average sales-weighted car at cruising speeds. (Engine efficiency is not included.) (*Annual Review of Energy*, vol. 19)

Table 2.3 NEW PASSENGER CAR FLEET AVERAGE CHARACTERISTICS

Characteristics	1975	1987	2004
Weight (lb)	4060	3220	4066
Horsepower	137	118	208
0 to 60 Time (seconds)	14.1	13.1	10.0
Miles per gallon (combined city/highway)	13.1	22.1	20.8
Percent Truck, SUV Sales	19%	28%	48%

Source: U.S. Department of Transportation

four times as much at 60 mph than at 30 mph. The graph shows fuel economy in mpg as a function of the car's speed. The most efficient cruise speed is about 40 to 50 mph. Fuel economy drops off at higher speeds due to the air drag.

About two thirds of all the oil the United States uses is for transportation (Fig. 7.7). The fuel efficiency of new cars rose steadily until the late 1980s and leveled off over the last twenty years (see Table 2.3). However, the total amount of oil used for transportation has been increasing because there are more cars on the road and more miles traveled per car than in the past.

In 1975, the U.S. Congress passed Corporate Average Fuel Economy (CAFE) standards that set minimum average fuel economy for a manufacturer's fleet of cars. This minimum went from 13.8 mpg in 1975 to 27.5 mpg in the 1980s, but has remained at that value. However, this standard only applied to cars and not to light trucks, vans, and sport utility vehicles. Their standards have been at 20.7 mpg for 20 years, and only recently have been increased to 22.2 mpg. Because sales of these vehicles have risen steadily over the last 20 years, to about half of the U.S. light vehicle market, the overall fuel efficiency has actually declined from its peak in 1988. Increases in the average weight of light vehicles and greater horsepower have contributed to this trend.

One of the reasons for the greater use of gasoline per person in the United States than in other countries is that fuel prices are comparatively low. Some prices per gallon for selected countries are listed below. American auto manufacturers have argued that higher gasoline taxes, and not higher fuel efficiency standards, would be a better approach to reduce gasoline consumption.

continued

MOTOR FUEL TAX RATES FOR SELECTED COUNTRIES

Country	Gasoline Tax (cents per gallon)
United Kingdom	342
Netherlands	307
Germany	297
France	292
Italy	277
Japan	190
United States	38

Source: Federal Highway Administration, 2004.

The work done on an object (such as the book) equals the applied force times the distance through which that object moves in the direction of the force. This may be expressed by the formula

$$\text{Work} = \text{force} \times \text{distance}$$
$$W = F \times d$$

According to this definition, no work is done if the object on which you are applying a force does not move, no matter how hard you push or pull it.

To look at energy and work in another way, we can say that the **consequence of doing work on an object is to give the object energy.** If you apply a force to a cart and move it a certain distance on a flat surface, work has been done and the cart has gained kinetic energy. When an object is raised to a certain height, work has been done to increase the object's gravitational potential energy. The force in this case is the one required to lift the object against the gravitational force on it. The distance through which the force acts is the height through which the object was raised.

The units of both energy and work are those of force times distance. In the SI system, this is expressed as newtons times meters, or joules (J). (One newton times one meter equals one joule. One joule is approximately equivalent to the potential energy of one apple one meter above the floor.) In the English system, the units are pounds times feet, or foot-pounds (ft-lb); one ft-lb ≈ 1.4 joules. See Table 2.4 for a summary

Table 2.4 UNITS IN MECHANICS

Quantity	SI	English	Conversions
Velocity	m/s	ft/s	1 ft/s = 0.305 m/s 1 mph = 0.447 m/s
Acceleration	m/s^2	ft/s^2	1 ft/s^2 = 0.305 m/s^2
Force	newton (N)	lb	1 lb = 4.45 N
Energy	joule (J)	ft-lb	1 ft-lb = 1.356 J
Power	watt (W)	ft-lb/sec, hp	550 ft-lb/s = 1 hp = 746 W

of units in mechanics. (Other energy units are discussed in section F of Chapter 3 and given in Table 3.4.)

EXAMPLE

A man pushes a box across the floor by exerting a force of 150 N on it in the direction of motion. If the box is moved 3 m, how much work (W) did he do?

SOLUTION

$$W = F \times d = 150\ \mathrm{N} \times 3\ \mathrm{m} = 450\ \mathrm{J}$$

Work is one way of transferring energy to an object. If we push an object up a hill from rest, we are doing work to give it both kinetic energy and gravitational potential energy. The work has been used to increase the object's mechanical energy. We can write this as an equation

$$W = \Delta(\mathrm{KE} + \mathrm{PE})$$

The Δ (delta) in this expression means a "change in." The mechanical energy—kinetic energy plus potential energy—of the object (our system) has become larger by the amount of work done.

Let us return to other forms of energy. Recall from the section "Forms of Energy and Energy Conversions" that the thermal energy (TE) of an object is a function of its temperature. TE is the internal energy of an object and is equal to the total of all the microscopic energies of the molecules that make up that object. We can change the thermal energy of a body by rubbing it on a rough surface. If you move a block of wood back and forth on a flat surface, the kinetic energy and potential energy of the block do not change (the speed remains about the same) but work has been done. What is occurring is that the block's temperature is increasing and so its TE is changing. As a result, we need to add a thermal energy term to our expression for work:

$$W = \Delta(\mathrm{KE} + \mathrm{PE} + \mathrm{TE})$$

In the previous paragraph, if there was friction on the hill, some of the work done on the object would go to an increase in its thermal energy.

Another way of transferring energy to a system is by the addition of heat. (This will be covered in more detail in Chapter 4.) The block of wood in the preceding paragraph could have its thermal energy increased by placing it against a very hot object: heat will flow from the hot object to the cooler block. **Heat is the energy transferred as a result of a temperature difference between two objects.** Note the distinction between heat and thermal energy: Heat is never contained within an object; an object contains thermal energy.

Putting these two ideas together, we say that the thermal energy of an object can be changed by doing work W as well as by adding heat Q. Our basic energy equation now becomes:

$$W + Q = \Delta(\mathrm{KE} + \mathrm{PE} + \mathrm{TE})$$

(Work or heat can also change the electrical energy or chemical energy of a system, so these terms could also be added to this energy equation, but we will ignore them now for simplicity.)

Summarizing this equation, the total energy of a system can be increased by doing work on it or by adding heat. This relationship is known as the **first law of thermodynamics.**

E. Examples of Work and Energy

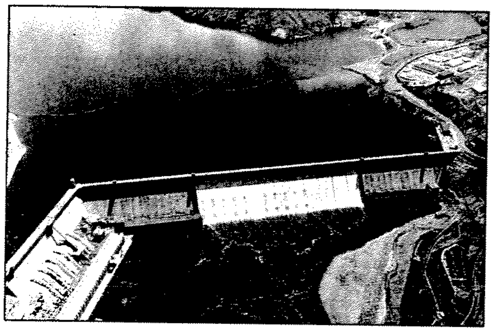
Let us bring together the concepts of energy and work that we have discussed so far. Work is done by the application of a force over a distance. Doing work on an object gives it more energy. Conversely, energy is the capacity for doing work. Consider two examples of work and mechanical energy:

1. A moving object has KE. A moving body can exert a force on another object and cause it to move, thereby doing work. For example, a moving bullet can imbed itself in a block of wood and move the wood. Energy is the capacity for doing work.
2. If we are pushing a block on a horizontal surface and it is moving at a constant velocity, the kinetic energy remains the same. Since there is no acceleration, the net force on the block must be zero. This must mean that the force we are applying is balanced by the force of friction. However, *we* are doing work as *we* are applying a force over a distance. Our work generates heat as a result of the friction between the block and the table.

As introduced earlier, gravitational potential energy (PE_G) is energy as a result of the relative height of an object. It is stored energy. When an object is raised to a certain height, work has been done to give it gravitational potential energy. Force is required to lift the object against the gravitational force on it. The force of gravity on an object is equal to the weight of the object, *mg*, where *g* is the acceleration due to gravity, 9.8 m/s^2. The object has gained an amount of gravitational potential energy equal to its weight times the vertical height *h* through which the object was raised.

$$PE_G = \text{weight} \times \text{height} = mgh$$

Note that the "height" *h* in this expression is not an absolute number (such as the elevation above sea level) but a vertical distance measured from a selected reference point. For example, the water at the top of a dam possesses a certain amount of potential energy (stored energy) relative to the water level at the bottom of the dam. The height *h* is the vertical distance of the water behind the dam measured from the bottom of the dam.



Greer's Ferry Dam on the Little Red River in North Central Arkansas.

(U.S. Department of Energy)

EXAMPLE

How much potential energy is possessed by 10,000 kg of water (about 10 m^3 or 2600 gallons) behind a dam if the distance the water will fall before it hits the blades of a turbine is 20 m?

SOLUTION

PE_G = weight × height = $10^4 \text{ kg} \times 9.8 \text{ m/s}^2 \times 20 \text{ m} = 196 \times 10^4$ J. (This is equivalent to the energy contained in about $\frac{1}{50}$th of a gallon of gasoline.)

Energy associated with motion is kinetic energy. An object at rest has no kinetic energy. The expression for kinetic energy (KE) of an object in motion is

$$\text{KE} = \tfrac{1}{2}mv^2$$

where m is the mass of the object and v is its velocity.

EXAMPLE

What is the kinetic energy of 1 kg of air (about 1 m^3) moving at 15 m/s (about 32 mph)?

SOLUTION

The expression for kinetic energy is $\frac{1}{2}mv^2$, so

$$\text{KE} = \tfrac{1}{2} \times 1 \text{ kg} \times (15 \text{ m/s})^2 = 112 \text{ J}$$

(One of the problems with generating electricity with the wind is the low density (mass per volume) of air. An equivalent volume of water with the same velocity will have about 1000 times as much energy.)

F. Power

Another basic concept of energy mechanics is "power." **Power** is the rate of doing work or the rate at which energy is used, produced, or transferred.

$$\text{Power} = \frac{\text{work done}}{\text{time taken}} = \frac{\text{energy used}}{\text{time taken}}$$

As you lift a block up to a table from the ground, work is being done by you on the block as you apply a force over a distance. The same amount of work is done on the block whether it took one second or one hour to do the task; however, the power supplied by you is different if the work was done in different time intervals. More power is required for the short time interval job.

The unit of power is the unit of energy divided by the unit for time. In SI units this is joule/second, which is given the name watt (abbreviated W).

$$1 \text{ watt} = \frac{1 \text{ joule}}{1 \text{ second}}$$

EXAMPLE

If it takes 2 seconds to raise an 8 kg block a vertical height of 1 m, what is the power output?

SOLUTION

$$\text{Power} = \frac{\text{work}}{\text{time}} = \frac{\text{weight} \times \text{height}}{\text{time}} = \frac{8 \text{ kg} \times 9.8 \text{ m/s}^2 \times 1 \text{ m}}{2 \text{ s}} = 39.2 \text{ W}$$

Since the watt is a relatively small unit of power, we commonly use the kilowatt, where 1 kilowatt (kW) = 1000 watts (W). In English units, the unit for power is ft-lb/s. Similarly, a larger unit called the horsepower (hp) is often used in the English system, where 1 hp = 550 ft-lb/s. Note that 1 hp = 746 W (Table 2.4). Many times in dealing with power and energy, conversions between different sets of units have to be made, as illustrated by the next example.

EXAMPLE

Ascending to the top of Muir Pass in the Sierra Nevada Mountains in California, Robert climbed 2000 ft (vertically) in a time of 2.5 hours. What was his average power expended (in watts)? Robert plus backpack weigh 180 lbs.

SOLUTION

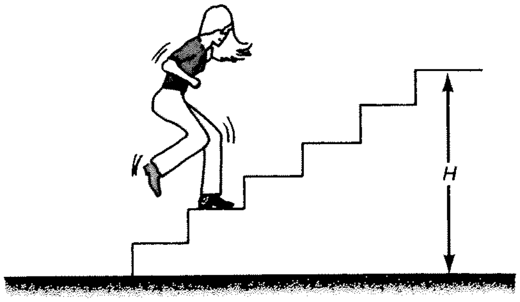
$$\text{Power} = \text{work/time} = \text{weight} \times \text{vertical height/time}$$

We wish to convert this to SI units.

$$\text{Power} = (180\ \text{lbs} \times 4.45\ \text{N/lb}) \times (2000\ \text{ft} \times 0.305\ \text{m/ft})/(2.5\ \text{hr} \times 3600\ \text{s/hr}) = 54\ \text{W}$$

ACTIVITY 2.3

You can determine your own power rating by measuring the time it takes you to climb a flight of stairs. The work done is equal to your weight times the vertical height through which you moved, and power is the work done divided by the time taken. Don't expect that your output will be more than about 0.5 hp.



We can rearrange the equation for power, to yield

$$\text{Energy used} = \text{power} \times \text{time in use}$$

This is especially useful when one wants to find the energy used in a particular conversion when the power expended is known. Your electrical bill is a charge for the amount of energy you have used, not power. To figure the cost of using an electrical appliance, you must know the time the appliance is operating and the power rating of the appliance. Electrical energy is usually expressed in units of kilowatts × hours, or kWh. The cost of running an appliance is equal to the energy used times the cost per kWh.

ACTIVITY 2.4

Locate an electric bill for your house or apartment. Notice the total bill and the price per kWh. Are there different rates for special times of use? Does the bill divide the cost into distribution and generation? How much electricity did you use last month per person? What item do you think is the biggest contributor to your total electric bill?

EXAMPLE

An electric heater has a power rating of 1500 watts (1.5 kW). If the heater is run for 6 hours and electricity costs $.12 per kWh, how much will it cost to run the heater for this time interval?

SOLUTION

Since energy used = power × time of use, the energy used = 1.5 kW × 6 hrs = 9 kWh. The cost is equal to 9 kWh × $.12/kWh = $1.08.

The average power expended per person in the United States is about 12 kW. This is calculated as follows: The annual consumption of energy in the United States is about 98×10^{15} Btu/year = 103×10^{18} joules/year. The average per capita energy consumption is thus

$$\frac{103 \times 10^{18}\ \text{J/yr}}{281{,}000{,}000\ \text{people}} = 3.67 \times 10^{11}\ \text{J/person/yr}$$

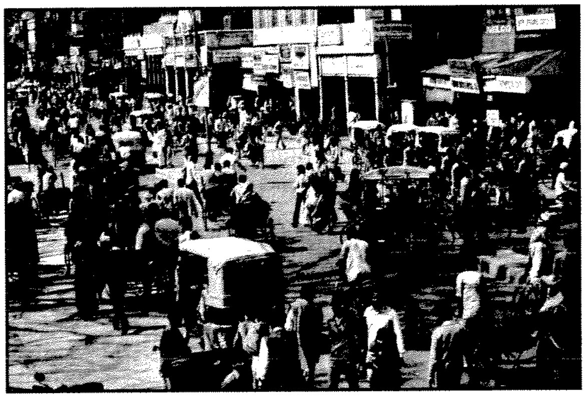
FOCUS ON 2.2

ENERGY USE IN INDIA

In recent years, economic reforms in India, such as privatization of many industries and relaxation of restrictions on foreign ownership, have helped to double the GDP growth rate to approximately 6% per year. The commercial/industrial use of energy has been rising at a rate of about 5% per year, the highest of any major country, yet the *per capita* use of energy is only about one-eighth the world's average. The main energy resources used today are biomass (wood, dung) and coal; oil provides about one-fourth of the energy mix, over half of which is imported. Increasing use of energy and a population growth rate of 1.8% per year continue to bring changes in the environment. Access to clean water and sanitation in both rural and urban areas and increasing levels of air pollution are serious concerns. Air pollution in some of India's largest cities is among the worst in the world, mainly due to commercial vehicles. About 70% of India's electricity is generated by highly polluting coal. The key energy challenge facing India today is preventing bottlenecks in energy supply from constraining economic growth.

A few interesting points:

- Biomass fuels provide about one-third of India's total energy needs
- Electricity use has been rising about 7% per year since 1970. Due to delays in regulatory approval and adequate financing, annual additions are not able to keep up with demand, leading to power shortages.
- Two-thirds of Indians live in rural areas
- India has the largest solar cooking program in the world
- More than 8000 villages use solar cells for electricity
- India is the fifth largest producer of electricity from wind energy
- India has more than tripled food production since 1950 (mainly through the use of high yield grains), outpacing population growth.



Street scene, New Delhi, India.
(Porterfield/Chickering/Photo Researchers, Inc.)

Since 1 year = 3.16×10^7 seconds, the average per capita power expenditure in the United States is

$$\frac{3.67 \times 10^{11}\ \text{J/person/year}}{3.16 \times 10^{7}\ \text{sec/year}} = 11.6 \times 10^3\ \text{watts/person} = 12\ \text{kW/person}$$

This number comes not only from an individual's personal use of energy but also from a share of cooling shopping malls, making steel and aluminum, lighting offices, and so forth. The United States has one of the highest energy uses per capita in the world as well as one of the highest standards of living. In most countries, higher standards of living, as measured by GDP per capita, are matched by higher levels of energy consumption per capita. This is seen in Figure 2.6. (An enlargement of this figure for developing countries is shown in the questions at the end of the chapter.) However, some countries can have a high GDP per capita but a significantly lower energy consumption per capita. (See Question 7.) The average power consumption per person is 6 kW for Switzerland and for Japan, countries that have approximately the same standard of living as the United States. The power consumption per capita in India is about 0.5 kW.

The rate of producing electricity by an electrical generating plant is electrical power, expressed in units of watts. A modern-size plant produces electrical energy at a

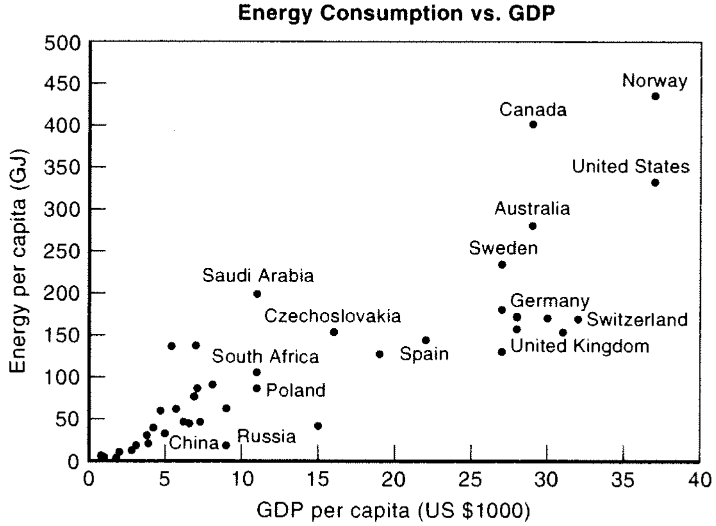


Figure 2.6

Comparison of 2003 energy use per capita versus GDP per capita for various countries. 1 GJ = 10^9 J. 320 GJ/yr = 10 kW. (USEIA World Almanac & Book of Facts) rate of about 1 billion watts, or 1000 Megawatts (1000 MWe, where the "e" signifies electrical power output, not thermal power output). Note that this is *not* expressed as MW/sec, since watts already has time included as J/s.

An example of electrical power obtained from a renewable source is hydropower. It now provides about 9% of the U.S. total electrical energy needs. Hydropower in the United States generates as much electricity as about 80 large-sized (1000 MWe) coal power plants. Because of its zero fuel cost, it is used by utilities whenever available. The largest hydroelectric dam in the United States is the Grand Coulee Dam in the state of Washington, with a capacity of 6500 MWe and a height of 168 m. The largest operating hydroelectric plant in the world is in Brazil, with a capacity of 12,000 MWe. The Three Gorges Dam in China will have a capacity of 18,000 MWe when completed in 2009. Hydroelectric power will be discussed in more detail in Chapter 12.

G. Summary

In this chapter we have defined and illustrated the fundamental concepts of work and energy. Work is defined as the product of an applied force times the distance through which that force acts. Doing work gives an object (and/or the environment) energy. Energy can be found in many forms (mechanical, thermal, electrical, radiant, chemical, nuclear) and is the capacity to do work. Mechanical energy is the sum of an object's kinetic energy and its potential energy. The study of energy includes a study of its transformations from one form to another, for example, from mechanical to electrical to thermal energy. This will be examined in more detail in the next chapter.

HOW WOULD YOU CHOOSE—REVISITED

Energy Conversions

An understanding of energy requires you to be able to follow the different energy conversions from one form to another that take place in a device. This will be important when discussing the efficiency of energy conversions in the next chapter. Having read this chapter, would you retain your choice of the hybrid car or the hydroelectric power plant to illustrate energy conversions? Why?

Internet Sites

For an up-to-date list of Internet sites related to the material in this chapter go to the book's companion website at **http://physics.brookscole.com/hinrichs4e.**

InfoTrac® College Edition

For additional readings on the material in this chapter, explore InfoTrac® College Edition, your online library. Go to www.infotrac-college.com and use the pass code that came with your book. Try these search terms: **Newton's second law, forms of energy, energy consumption per capita, power, hybrid cars, air drag, automobile fuel efficiency,** and **first law of thermodynamics.**

References

DeCicco, John, and Marc Ross. 1994. "Improving Automobile Efficiency." *Scientific American,* 271 (December).

Gartrell, Jack. 1989. *Methods of Motion: An Introduction to Mechanics.* Washington, D.C.: National Science Teachers Association.

Greene, D.L., and J. DeCicco. 2000. "Engineering-Economic Analyses of Automotive Fuel Economy Potential in the United States." *Annual Review of Energy,* 25.

Kirkpatrick, Larry, and Gregory Francis. 2007. *Physics: A World View.* 7th ed. Belmont, CA: Brooks/Cole.

Ross, M., 1994. "Automobile Fuel Consumption and Emissions: Effect of Vehicle and Driving Characteristics." *Annual Review of Energy,* 19.

Schafer, A., and D. Victor. 1997. "The Past and Future of Global Mobility," *Scientific American,* 277 (October).

Schipper, Lee. 1995. "Determinants of Automobile Use and Energy Consumption in OECD Countries." *Annual Review of Energy,* 20.

Serway, Raymond, et al. 2006. *College Physics.* 7th ed. Belmont, CA: Brooks/Cole.

Taylor, B. 1998. *Exploring Energy with Toys*. Middletown OH: Terrific Science Press.

VanCleave, Janice. 1991. *Physics for Every Kid.* New York: John Wiley.

Zubrowski, Bernie. 1986. *Wheels at Work: Building and Experimenting with Models of Machines.* New York: Beech Tree.

QUESTIONS

1. List five different forms or types of energy. Give one example of a conversion from each of these forms to another form.
2. Discuss the types of energy transformations that are involved in the following devices or events:
   - **a.** striking a match
   - **b.** windmill
   - **c.** ball rolling off table top and bouncing on floor until it stops
   - **d.** microphone
   - **e.** flashlight

3. List the energy conversions that occur when (a) riding a bicycle and (b) using a windmill to pump water.
4. Discuss the transformation of the potential energy of water behind a dam as it flows through a pipe at the bottom to turn a turbine-generator.
5. What happens to the kinetic energy of a car as it rolls up an incline and stops?
6. Refer to the discussion of energy losses in a car. What are some ways to increase the fuel economy of a car?
7. Why is there a large difference in the per capita use of energy between the United States (or Canada) and European countries (see Fig. 2.6)? Answer the same question for countries of Eastern Europe and other developing countries. (See Fig. 2.7.)

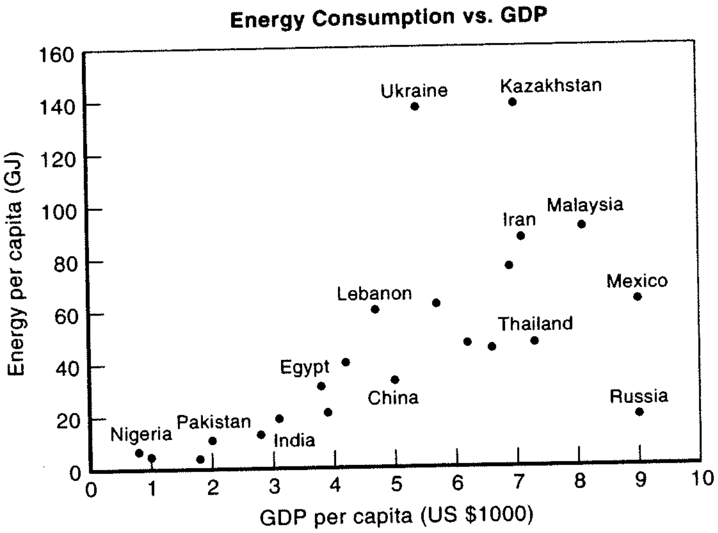


Figure 2.7
Comparison of 2003 energy use per capita versus GDP per capita for various developing countries. Included in the energy consumption numbers are both commercial fuels and traditional ones (dung, biomass). (USEIA. *World Almanac & Book of Facts*)

8. If a constant non-zero net force is applied to an object, what can you say about the velocity and the acceleration of the object?
9. If the acceleration of an object is not zero, can the velocity of the object be zero?
10. A car accelerates from 30 mph to 40 mph. Give an expression for the net force causing this acceleration in terms of the forces acting on the car. How does this expression change when the car is moving at a constant velocity of 40 mph?
11. Work is expressed as force times distance. There is a gain in energy when work is done. In terms of energy, what happens to the work done in pushing an object across a level floor with a constant force?

12. Distinguish between work done in completing a task and the power expended.
13. Categorize the following units as those of work or power: joules, watts, kilowatt-hours, ft-lb, calories, kW, ft-lb/min.
14. What factors determine the amount of electrical power that can be produced by a stream or river?

PROBLEMS

1. A 50-kg meteor is moving in outer space. If a 12 N force is applied opposite the direction of motion, what will be its deceleration?
2. Suppose you apply a force of 40 N to a box of mass 2 kg. The force of friction opposing the motion of the box is 15 N. What is the acceleration of the box?
3. What is the potential energy of a 70-kg person sitting on a ladder 2 m off the ground?
4. Calculate the work done in lifting a 4 lb book to a height of 8 ft.
5. How much work do you expend to move a 450 lb refrigerator 6 ft across the floor if you are exerting a force of 90 lb?
6. What is the kinetic energy of a 3000 lb car traveling at 60 mph? (Remember that pounds are not units of mass.)
7. To what height would a 2 kg object have to be raised such that its gravitational potential energy would equal the kinetic energy it would possess if it were moving at 3 m/s? (This is why a person's kinetic energy was ignored when calculating power in Activity 2.3.)
8. A cart of mass 20 kg, initially at rest, is pushed with a net force of 40 N on a flat surface. If the cart is pushed 5 m, what is the final KE? What is the final velocity? (Assume no heat losses.)
9. What is the potential energy of the water in a lake of surface area 10 square miles, average depth 40 ft, and elevation above the electrical generator of 600 ft? (Note that 1 square mile is about 28 million square feet and 1 ft^3 of water weighs 62 lb.)
10. The per capita rural consumption of household energy in some Bangladesh villages is 7×10^9 J/year. This is what fraction of the U.S. average per capita energy use?
11. An engine performs 4000 joules of work in 10 seconds. What is its power output in kilowatts and in horsepower?
12. How much work (in J) is required to lift a 5-lb bag of sugar to the countertop from the floor, a height of 3 ft?
13. A Boeing 757 makes the 1395-mile trip from Seattle to Minneapolis in a time of 3 hr 15 min. What was the plane's average velocity, in mph and m/s?
14. A 100-W light bulb is accidentally left on for two days in a basement. If electricity costs 12¢/kWh, how much did this oversight cost?

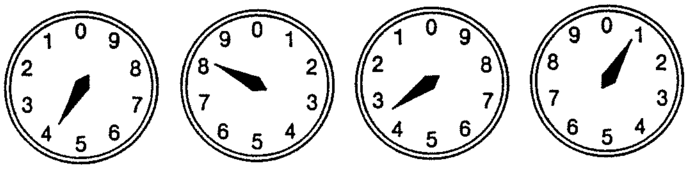
15. A small stream flowing at a rate of 8 liters per second has a vertical drop of 1.5 m. What is the maximum power one can obtain from this stream? (1 liter of water has a mass of 1 kg.)

16. If the average electrical power usage of an American home is 2 kW, then for how many homes could electricity needs be met by one 2 MW wind turbine?

17. Suppose you had to carry ten 30-lb concrete blocks up a 24-ft ladder (to build a chimney). If you were paid for the work that you did on the blocks at the same price as electrical energy costs (say, 14¢/kWh), how much money would you make from this job?

FURTHER ACTIVITIES

1. Be a meter reader. Record the numbers on your electric meter at the beginning of one day and the beginning of the next. How many kWh of electric energy were used in one day? (The meter below is reading 4831.)



Kilowatt-hours

2. Measure the speed (in m/s) of one or more of the following:
- **a.** the water in a stream or river
- **b.** an ant or other insect moving across the floor
- **c.** yourself, as you go to your first morning class

3. Why do heavy cars use more gasoline than light cars? Check this out (in your library) by comparing EPA mileage ratings with car weight.

4. Find (or remember) a self-propelled toy you used to play with. Describe the energy transformations that take place. A toy that can sometimes be found at an outdoor market is a "rubber band racer," in which a stretched rubber band powers the rear wheels of the car. If you have access to one of these, an interesting study can be made of the number of turns of the rear wheels (thereby stretching the rubber band) versus the distance the car travels.

5. You can study acceleration and the forces of friction and air resistance on an automobile with the following investigations. While moving on an open, level highway (with little traffic), shift your car into neutral and measure the time it takes for the velocity to decrease from:
- **a.** 55 to 45 mph
- **b.** 45 to 35 mph
- **c.** 35 to 25 mph

6.

7.

SPECIAL TOPIC

Newton's Laws of Motion

This section can serve as a review of the terms and concepts of energy mechanics as presented earlier in the chapter. It amplifies some of the material presented in the section on motion.

Speed, Velocity, Acceleration

One of the most basic terms in the description of motion is speed. *Speed* is equal to the ratio of distance traveled to the time taken to travel that distance. Mathematically,

$$\text{Speed} = \frac{\text{distance traveled}}{\text{elapsed time}}$$

If you travel a distance of 20 kilometers (km) in 30 minutes, your average speed over that interval is 20 kilometers per 30 minutes, or 40 km/h. Each car's starting position for the Indianapolis 500 race is determined by measuring the time that car takes to drive one lap around the track. The average speed is the total distance traveled divided by the total time taken. Average speeds in excess of 250 km/h (150 mph) are recorded for this race. However, the speed at any time on the track varies, depending on whether the race car is on a curve or a straightaway. The speed at a particular time is called the instantaneous speed.

Many times we speak of "velocity" when we mean speed. *Velocity* provides additional information about the motion of an object, namely its direction. Velocity indicates not only that your speed is 40 km/h, but also that you are going in a particular direction, for example, west. Two cars that leave a parking lot and proceed with the same average speed can end up at entirely different places because their directions of travel were different; they had different velocities.

The equation for speed can be arranged another way to yield:

$$\text{Distance traveled} = \text{average speed} \times \text{time}$$

We'll use this expression in the following example.

EXAMPLE

A train travels in a straight line between two cities in 40 min at an average speed of 30 m/s. How far apart are the cities?

SOLUTION

We use the formula in the form distance = speed × time, and remember to convert minutes to seconds:

$$d = vt = 30 \text{ m/s} \times 40 \text{ min} \times 60 \text{ s/min} = 72{,}000 \text{ m} = 72 \text{ km}$$

EXAMPLE

The speed of light is approximately 300,000 km/s, and the distance from the earth to the sun is 155,000,000 km. How much time does it take light to travel to earth?

SOLUTION

Since

$$\text{Speed} = \frac{\text{distance traveled}}{\text{time}}$$

then

$$\text{Time} = \frac{\text{distance}}{\text{speed}} = \frac{155{,}000{,}000 \text{ km}}{300{,}000 \text{ km/s}} = 517 \text{ s} = 8.6 \text{ minutes}$$

Many times in physics problems units have to be converted from one system to another. For example, when discussing speed, mph are more commonly used in the United States than are m/s.

EXAMPLE

How many mph is 1 m/s?

SOLUTION

$$1 \text{ m/s} = 1 \text{ m/s} \times \frac{1 \text{ ft}}{0.305 \text{ m}} \times \frac{1 \text{ mile}}{5280 \text{ ft}} \times \frac{3600 \text{ s}}{1 \text{ h}} = 2.24 \text{ mph}$$

The change in velocity in a certain amount of time is called the acceleration, written as

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time elapsed}}$$

Acceleration is the rate of change in either an object's speed or its direction or both. If a car goes around a corner at a constant speed, its direction of motion is changing, and so we can say that the car is accelerating. When a car slows down, it is decelerating or experiencing a negative acceleration.

If an object's velocity changes at a constant rate, its acceleration is constant. When any object is dropped to the ground near sea level, its velocity changes 9.8 meters per second for each second of travel. At the end of the first second its velocity will be 9.8 m/s, after 2 seconds it will be 19.6 m/s, after 3 seconds it will be 29.4 m/s, and so on. This is the "acceleration due to gravity" of $9.8\ \text{m/s}^2$. In English units, it is $32\ \text{ft/s}^2$.

EXAMPLE

A car accelerates from rest to a speed of 20 m/s (45 mph) in 2 s. What is its acceleration?

SOLUTION

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time elapsed}} = \frac{(20\ \text{m/s} - 0\ \text{m/s})}{2\ \text{s}} = 10\ \text{m/s}^2$$

(This is close to the acceleration due to gravity.)

Figure 2.9 shows the vertical positions of an object at 1-second intervals after it has been dropped and is experiencing an acceleration due to gravity. The distance traveled for any 1-second interval is greater than during any previous 1-second interval, since the velocity is constantly changing. The same figure shows a graph of velocity versus time; note that the velocity is changing but the acceleration (the rate of change of velocity) remains constant (at $9.8\ \text{m/s}^2$).

Force and Newton's Laws of Motion

FIRST LAW The part of mechanics that deals with the causes of motion is called **dynamics,** and it is based on three laws that are called Newton's laws of motion, after

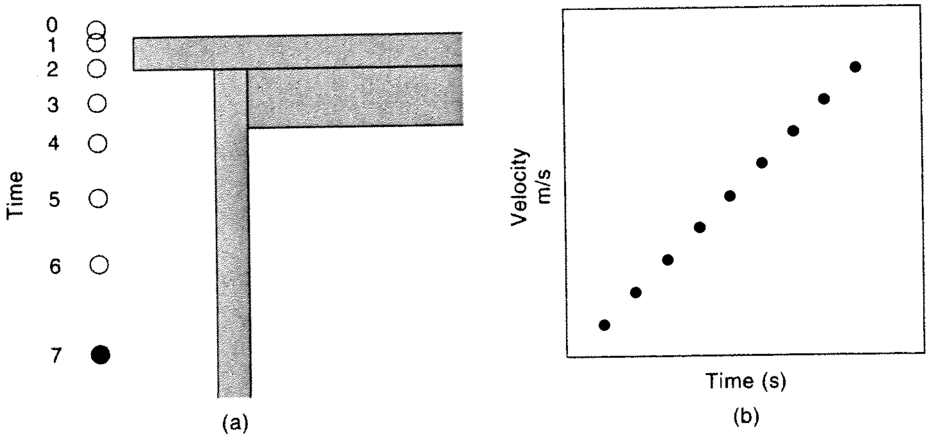


Figure 2.9
A freely falling object. (a) Positions of a ball at equally spaced time intervals after it was dropped from a tabletop. (b) Graph of velocity of the ball versus time. Even though the velocity is changing, the rate of change of velocity (the acceleration) remains constant. (Air resistance is assumed to be zero.)

Isaac Newton (1642–1727). The first of these laws refers to the "natural motion" of an object:

> **I. A body continues in a state of rest, or motion with a constant velocity (i.e., with a constant speed in a straight line), unless compelled to change by an unbalanced (net) outside force.**

This statement was formulated not by Newton but by the Italian scientist Galileo Galilei (1564–1642) on the basis of experiment, and many consider it to be the first successful application of the scientific method; it is also called the law of inertia. **Inertia** is the tendency of all objects to resist changes in their motion. A body continues to move because of its inertia. The measure of an object's inertia is its mass. It is more difficult to stop a heavy car than a light car, both moving at the same speed, because of the greater inertia of the heavy car. The dining room trick of pulling a tablecloth out from under a setting of dishes without disturbing them is possible because of the inertia of the dishes and silverware (Fig. 2.10).

Newton's first law is certainly not self-evident and appears to be contradicted by our everyday experience. If you take your foot off the gas pedal of your car, you will slow down. Give this book a push across the table and it will come to rest in a short distance. In fact, most scientists before Galileo, dating back at least to Aristotle (~300 BC), felt that the natural state of all objects was to be at rest. They thought that a push or a pull was required to keep an object moving.

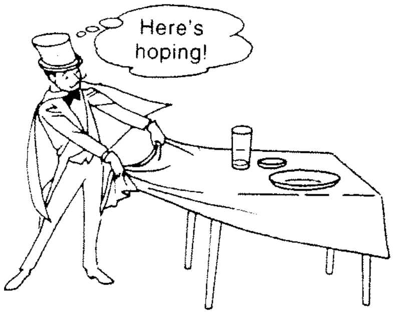


Figure 2.10
Because of their inertia, the dishes should stay on the table after the tablecloth is quickly pulled out.

However, objects such as the car and book stop moving because of an external resistive force acting on them, known as the force of friction. Friction is a result of the interaction of two surfaces in contact and always acts to oppose the motion that is taking place. The amount of friction depends on the types of surfaces in contact and the mass of the moving object. According to the law of inertia, the friction force causes the motion of the object to change. We don't find many situations in nature in which the force of friction is absent (or very small). One example is motion on an icy surface. If we set a hockey puck in motion across a frictionless pond of ice, it will continue to move at a constant velocity until it reaches the far side; the resistive force on the puck is near zero. Another situation occurs in outer space, in which a spacecraft can continue moving indefinitely after the engines are turned off.

As our experience also indicates, the application of a force to an object will not necessarily cause the velocity of the object to change. A person pushing on a car will not usually cause it to move. Several forces can act on an object in such a way as to produce no change in its motion. What changes the motion is the application of a *net* or *unbalanced* force, as the first law states. In the example of the car, the force exerted by one person is balanced by the force of friction. If the net force on an object is zero, then we say that the object is in equilibrium; its velocity is not changing; the acceleration is zero. Note that the velocity can be non-zero and the object can still be in equilibrium (i.e., there is zero acceleration).

SECOND LAW As the first law states, the application of a net force to an object results in a change in its velocity, that is, an acceleration. The second law of motion quantifies this relationship between net force and acceleration:

> II. The acceleration of an object is directly proportional to the net force acting upon it and inversely proportional to its mass. The direction of the acceleration will be the same direction as the net force.

Mathematically,

$$a = \frac{F_{\text{net}}}{m} \quad \text{or} \quad F_{\text{net}} = ma$$

A force can cause deceleration as well as acceleration. If a car smashes into a brick wall, its rate of change of velocity is very large, that is, its deceleration is large and the force on the car is large. If the deceleration were smaller, as would occur if the car smashed into the barrels of water that guard some exits from freeways, then the force on the car and its occupants would be smaller. A pole-vaulter would rather land on foam rubber than dirt because his or her deceleration will not be as large on the foam rubber, and therefore the force on the athlete will be smaller (Fig. 2.11).

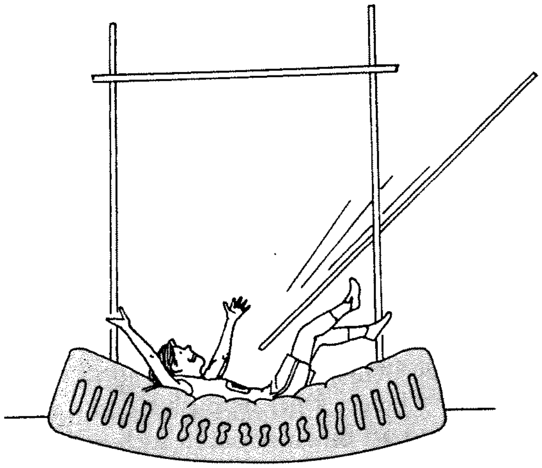


Figure 2.11
Foam rubber slows your landing. The small deceleration of the pole-vaulter while landing on the foam rubber makes the force he experiences also small, since $F = ma$.

EXAMPLE

A cart of mass 15 kg has a *net* force applied on it of 120 N. What will be its velocity after 5 s if it starts from rest?

SOLUTION

We need to first find the acceleration of the cart.
Newton's second law says that $a = F/m = 120\text{ N}/15\text{ kg} = 8\text{ m/s}^2$.
Now acceleration $a =$ change in velocity/time $= (v - 0)/5\text{s}$.
Therefore,

$$v = at = (8\text{ m/s}^2)(5\text{s}) = 40\text{ m/s}$$

As gas mileage and car weight are inversely related, we have seen the average mpg of American passenger vehicles decrease over the last decade as heavier SUVs and light trucks make up a larger percentage of sales.

EXAMPLE

A 2600-lb Dodge Neon car can accelerate from 0 to 60 mph in 9 sec. If a 3550-lb Cadillac had an engine that provided the same net force as for the Neon, then how long would it take the Cadillac to accelerate from 0 to 60 mph?

SOLUTION

Since $a = F/m$, the acceleration of the Cadillac will be 2600/3550 = 0.732 times less. Now $v = at$ and $t = v/a$. So the time will be 9/0.732 = 12.3 sec.

Newton's second law also says that the acceleration of an object will be in the direction of the net force. If two people pull on a box in opposite directions, one with a force of 10 lb and the other with a force of 20 lb, the box will accelerate in the direction of the 20 lb force. Note that the result of a net force is the acceleration of the object, that is, a change of its velocity.

THIRD LAW Have you ever stopped to think what is responsible for the acceleration of a rocket in outer space? There certainly is no air on which the rocket can push, yet it *can* accelerate. The explanation for this phenomenon is the same as that for many common, everyday experiences: "forces always act in pairs." Nothing can exert a force without a force being exerted on it. If you push on a wall with a force (called the "action force"), then the wall pushes back on you with a force (called the "reaction force"), equal in magnitude but opposite in direction to the action force. It is as if a person were standing on the other side of the wall pushing on you. (However, you don't move because friction keeps your feet from sliding.) Newton saw the importance of this relationship and stated it as the third law of motion:

III. For every action force there is an equal and opposite reaction force.

A good illustration of this law occurs in the interaction between two skaters on a frozen pond. If one pushes on the other, both skaters will move, the one who initially pushed being subject to the reaction force of the other skater. If both skaters have the same mass, then they will both experience the same acceleration, but in opposite directions (Fig. 2.12).

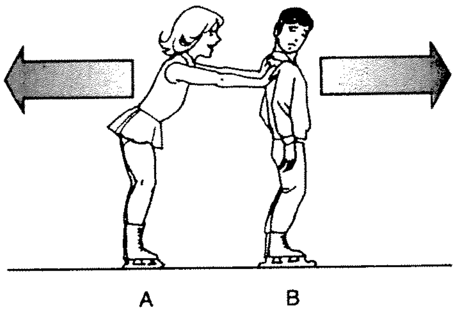


Figure 2.12
Skater A experiences a force equal in magnitude but opposite in direction to the force she exerts on skater B.

Note that the action and reaction forces always act on different objects. In the acceleration of a space shuttle into outer space, the rockets force the gas out of the ship (action force); the reaction force is the force of the exiting gas on the rocket, thus propelling the ship forward (Fig. 2.13).

WEIGHT VERSUS MASS In physics a distinction must be made between the weight of an object and its mass. Weight is a force and is a measure of the force of gravity on an object. Mass is an intrinsic property of a substance. Mass is a measure of the "inertia" of an object; it never changes. However, an object's weight depends on its position in a gravitational field. On the moon, the weight of an object is one sixth of that when it is on earth, but its mass is the same. From Newton's second law, $F = ma$, we

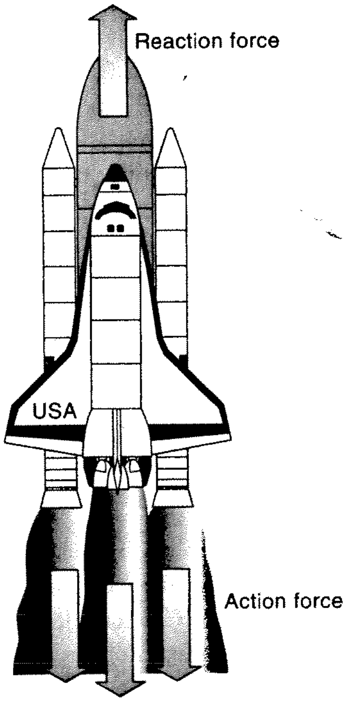


Figure 2.13
The reaction force of the exiting gases on the rocket accelerates it.

know that the weight w of an object is equal to its mass m times the acceleration due to gravity g (9.8 m/s^2 or 32 ft/s^2, at sea level): $w = mg$. For example, the weight of a 1 kg mass at sea level is equal to 1 kg × 9.8 m/s^2 = 9.8 N.

In the English system of measurement, the unit of mass is defined as the mass of a body whose acceleration is 1 ft/s^2 when the net force on the body is 1 lb. This unit of mass is called a slug. Therefore 1 lb = 1 slug × 1 ft/s^2. In everyday usage the pound is used to refer to a quantity of matter, but it really is a unit of force or weight. A useful fact is that an object with a mass of 1 kg will have a weight (at sea level) of 2.2 lb. (This won't be true on the moon.) An object with a mass of 1 kg does not weigh 1 kg—a common mistake.

Work and Energy and Units

Recall that the kinetic energy of an object is given by KE = $\frac{1}{2}mv^2$. From this expression, we can see that the units of energy are kg-m^2/s^2, which is defined as a joule (J). Note that since $W = F \times d$ and $F = ma$, the units for work are kg-m/s^2 × m, which is defined as a joule (J). The units for the terms of motion and energy are given in Table 2.4. Conversion factors between the English system and SI are also listed. A more complete set of conversions is found in Table 3.4.

Since KE and PE are both forms of energy, we can compare the amount of energy found in each of these forms, as the following example illustrates.

EXAMPLE

A cart with a mass of 10 kg is originally moving at a speed of 5 m/s. To what height above the ground would it have to be raised so that its potential energy there would have the same value as its KE?

SOLUTION

The cart's original kinetic energy is KE = $\frac{1}{2}mv^2 = \frac{1}{2} \times 10\text{ kg} \times (5\text{ m/s}^2) =$ 125 J. Recall that PE$_G$ = mgh. Setting the PE equal to the KE, we have 10 kg × 9.8 m/s^2 × h = 125 J. Therefore, the height is 125 J/98 N = 1.28 m.

Simple Machines

A machine is a device that multiplies a force at the expense of a distance. The word for "machine" comes from the Greek meaning "to help make things easier." Energy is still conserved for these devices in that a machine can't do more work than the energy put into it, but machines can reduce the force needed to perform a task. One of the simplest machines is the **lever,** which is a rigid bar pivoted at a point called the fulcrum (Fig. 2.14). A force F applied at one end of the bar lifts a load A (the output force) at the other end. The ratio A/F is called the "mechanical advantage" of the machine and is usually greater than 1. Ideally, the applied force $F \times h_1$ = output force $A \times h_2$. Levers have been used since prehistoric times to move heavy stones, lift water, and help in building construction.

Another example of a lever (also shown in the figure) is one in which the load is between the fulcrum and the applied force, as in a wheelbarrow. To lift a heavy load,

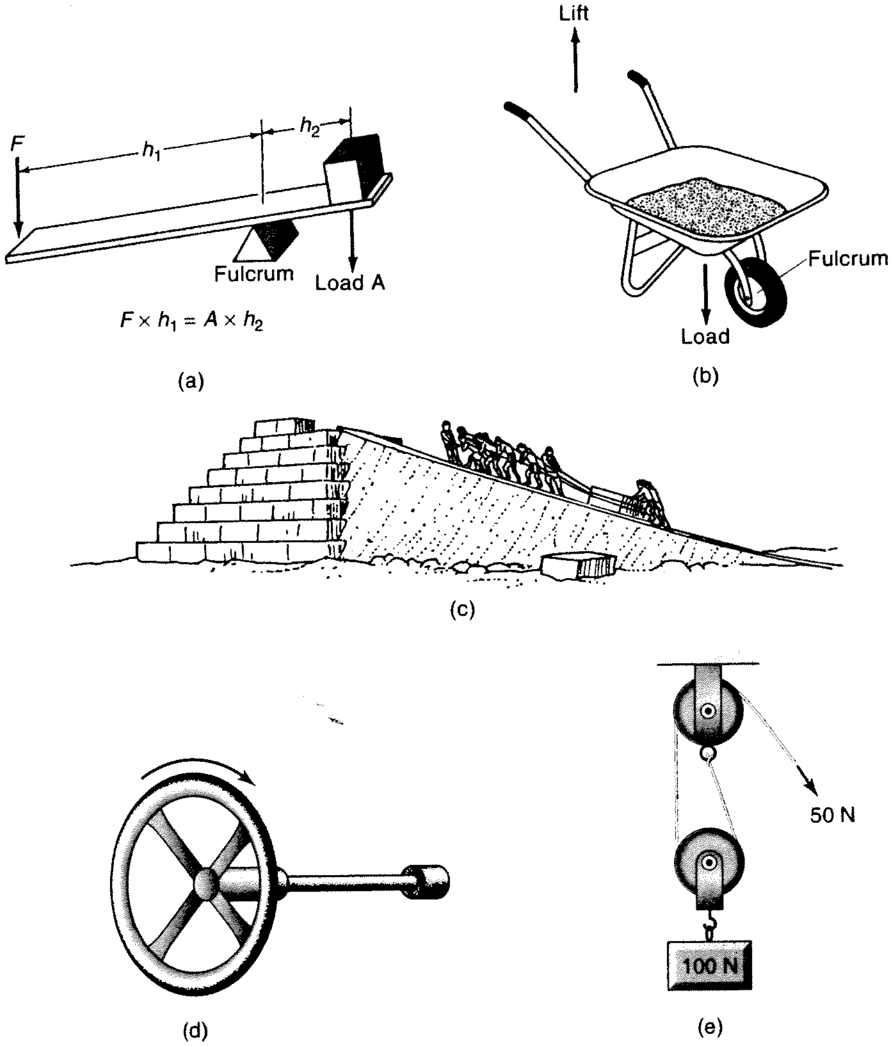


Figure 2.14
Several types of simple machines: (a) lever; (b) wheelbarrow; (c) inclined plane (pyramid construction); (d) wheel and axle; (e) pulley system.

you can apply a smaller force at the end of the handle; since energy is conserved, this force will be applied over a greater distance than the distance the load is raised. Other examples are a crowbar and a claw hammer.

Another very simple machine is the **inclined plane.** Pushing a cart up a plane is easier than carrying the same cart straight up to the top by a ladder, because the applied force is less; however, the work done in both cases is the same. Inclined planes or ramps were probably used during the construction of the Egyptian pyramids to move the large blocks of stone to the top.

Two other types of machines are the **wheel and axle** and the **pulley.** A wheel is like a circular lever. The wheel is much bigger than the axle, so it can be used to increase a force as it moves a much larger distance. In a turbine used to produce electricity, the blades act as the wheel and are turned by water or steam which causes the axle (connected to the generator) to turn. Another illustration of this machine is the screwdriver; a larger diameter handle usually works better. A gear is a wheel with teeth and is used to transfer a force to different parts of a machine; it also enables different parts to work at different speeds (as a clock). Pulleys can change the size and direction of a force. A system of pulleys, referred to as a block and tackle, can enable one to easily lift an engine out of a car. Fig. 2.14(e) shows a simple system than enables a 50-lb force to lift a 100-lb object.

PROBLEMS

1. How long does it take a car to travel 1 mile if its average speed is 40 mph?

2. If you shout across a canyon and the echoes return in 2 seconds, how far away is the other side? (Take the velocity of sound to be 330 m/s.)

3. In a television tube, an electron moves at a speed of 4×10^7 m/s. How long does it take to hit the screen 0.5 m away?

4. A ship can maintain an average velocity of 30 km/h on an ocean voyage. How far will the ship have traveled in 4 days?

5. A bird takes 2 minutes to travel 350 m. What distance would this bird cover in 10 seconds, assuming uniform motion?

6. A car accelerates at a constant rate of 4 m/s^2 from rest. Find its velocity after 6 seconds.

7. A net force of 10 N is applied to a 3-kg block at rest on a smooth, level surface. Find the block's velocity after 9 seconds. (*Hint:* Find the acceleration first.)

8. A 1300-kg car experiences a net force of 3900 N. After 100 meters, what is the car's kinetic energy and velocity?

9. An 80-kg man climbs a 6-m ladder in 12 seconds. What is his average power expended?

10. What must your car's average speed be if you wish to make a 500-mile trip in 8 hours?

11. If a car's acceleration is equal to the acceleration of gravity, then how long would it take to reach a speed of 60 mph, starting from rest?

12. If a 70 kg sprinter running at 10 m/s could convert all of his kinetic energy into upward motion, how high could he jump?

13. What is your weight in newtons? Your mass in kg?

14. A Corvette can accelerate from 0 to 60 mph in 4.8 seconds. What is its acceleration in m/s^2?

15. You wish to lift a 500-lb object with a lever. You can place a fulcrum under a long board a distance of 1.5 ft from the object. If you could only exert a force of 75 lb, then how long a board (total length) would you need to lift this object?