8 Energy

Energy is the most central concept that underlies all of science. Surprisingly, the idea of energy was unknown to Isaac Newton, and its existence was still being debated in the 1850s. The concept of energy is relatively new, and today we find it ingrained not only in all branches of science, but in nearly every aspect of human society. We are all quite familiar with it—energy comes to us from the sun in the form of sunlight, it is in the food we eat, and it sustains life. Energy may be the most familiar concept in science; yet it is one of the most difficult to define. Persons, places, and things have energy, but we observe energy only when something is happening—only when energy is being transformed. We will begin our study of energy by observing a related concept: work.

8.1 Work

The last chapter showed that changes in an object's motion are related both to force and to how long the force acts. "How long" meant time. The quantity "force × time" was called *impulse*. But "how long" need not always mean time. It can mean distance as well. When we consider the quantity "force × distance," we are talking about a wholly different quantity—a quantity called **work**.

We do work when we lift a load against the earth's gravity. The heavier the load or the higher we lift the load, the more work is done. Two things enter into every case where work is done:

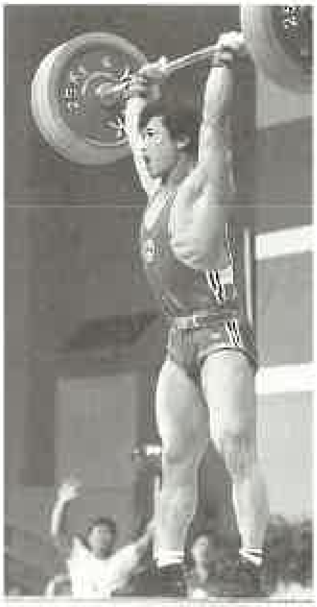

Fig. 8-1 Work is done in lifting the barbell. If the barbell could be lifted twice as high, the weightlifter would have to expend twice as much energy.

(1) the *exertion of a force* and (2) the *movement of something* by that force.

Let's look at the simplest case, in which the force is constant and the motion takes place in a straight line in the direction of the force. Then the work done on an object by an applied force is defined as the product of the force and the distance through which the object is moved.* In shorter form:

$$\text{work} = \text{force} \times \text{distance}$$
$$W = Fd$$

If you lift two loads one story up, you do twice as much work as you do in lifting one load, because the *force* needed to lift twice the weight is twice as great. Similarly, if you lift a load two stories instead of one story, you do twice as much work because the *distance* is twice as much.

Note that the definition of work involves both a force *and* a distance. A weightlifter who holds a barbell that weighs 1000 N overhead does no work on the barbell. He may get really tired doing so, but if the barbell is not moved by the force he exerts, he does no work on the barbell. Work may be done on the muscles by stretching and contracting, which is force times distance on a biological scale, but this work is not done on the barbell. Lifting the barbell, however, is a different story. When the weightlifter raises the barbell from the floor, he is doing work.

Work generally falls into two categories. One of these is work done to change the speed of something. This kind of work is done in bringing an automobile up to speed or in slowing it down.

The other category of work is the work done against another force. When an archer stretches her bowstring, she is doing work against the elastic forces of the bow. When the ram of a pile driver is raised, it is exerted against the force of gravity. When you do pushups, you do work against your own weight. You do work on something when you force it to move against the influence of an opposing force.

The unit of measurement for work combines a unit of force (N) with a unit of distance (m). The unit of work is the newton-meter (N·m), also called the **joule** (rhymes with pool). One joule (symbol J) of work is done when a force of 1 N is exerted over a distance of 1 m, as in lifting an apple over your head. For larger values we speak of kilojoules (kJ)—thousands of joules—or megajoules (MJ)—millions of joules. The weightlifter in Figure 8-1 does work on the order of kilojoules. The energy released by one kilogram of fuel is on the order of megajoules.

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* For more general cases, work is the product of only the component of force that acts in the direction of motion, and the distance moved.

8.2 Power

The definition of work says nothing about how long it takes to do the work. When carrying a load up some stairs, you do the same amount of work whether you walk or run up the stairs. So why are you more tired after running upstairs in a few seconds than after walking upstairs in a few minutes? To understand this difference, we need to talk about how fast the work is done, or **power**. Power is the rate at which work is done. It equals the amount of work done divided by the amount of time during which the work is done:

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

An engine of great power can do work rapidly. An automobile engine with twice the power of another does not necessarily produce twice as much work or go twice as fast as the less powerful engine. Twice the power means it will do the same amount of work in half the time. The main advantage of a powerful automobile engine is its acceleration. It can get the automobile up to a given speed in less time than less powerful engines.

We can look at power this way: a liter of gasoline can do a specified amount of work, but the power produced when we burn it can be any amount, depending on how *fast* it is burned. The liter may produce 50 units of power for a half hour in an automobile or 90 000 units of power for one second in a supersonic jet aircraft.

Fig. 8-2 The three main engines of a space shuttle can develop 33 000 MW of power when fuel is burned at the enormous rate of 3400 kg/s. This is like emptying an average-size swimming pool in 20 seconds!

The unit of power is the joule per second, also known as the **watt** (in honor of James Watt, the eighteenth-century developer of the steam engine). One watt (W) of power is expended when one joule of work is done in one second. One **kilowatt** (kW) equals 1000 watts. One megawatt (MW) equals one million watts. In the United States we customarily rate engines in units of horsepower and electricity in kilowatts, but either may be used. In the metric system of units, automobiles are rated in kilowatts. (One horsepower is the same as 0.75 kilowatt, so an engine rated at 134 horsepower is a 100-kW engine.)

8.3 Mechanical Energy

When work is done by an archer in drawing a bow, the bent bow has the ability of being able to do work on the arrow. When work is done to raise the heavy ram of a pile driver, the ram acquires the property of being able to do work on an object beneath it when it falls. When work is done to wind a spring mechanism, the spring acquires the ability to do work on various gears to run a clock, ring a bell, or sound an alarm.

In each case, something has been acquired. This "something" which is given to the object enables the object to do work. This "something" may be a compression of atoms in the material of an object; it may be a physical separation of attracting bodies; it may be a rearrangement of electric charges in the molecules of a substance. This "something" that enables an object to do work is called **energy**.* Like work, energy is measured in joules. It appears in many forms, which will be discussed in the following chapters. For now we will focus on **mechanical energy**—the energy due to the position or the movement of something. Mechanical energy may be in the form of either potential energy or kinetic energy.

8.4 Potential Energy

An object may store energy by virtue of its position. The energy that is stored and held in readiness is called **potential energy** (PE), because in the stored state it has the potential for doing work. A stretched or compressed spring, for example, has the potential for doing work. When a bow is drawn, energy is stored in the bow. A stretched rubber band has potential energy because of its position, for if it is part of a slingshot, it is capable of doing work.

The chemical energy in fuels is potential energy, for it is actually energy of position when looked at from a microscopic point of view. This energy is available when the positions of electric charges within and between molecules are altered, that is, when a chemical change takes place. Any substance that can do work through chemical action possesses potential energy. Potential energy is found in fossil fuels, electric batteries, and the food we eat.

Work is required to elevate objects against earth's gravity. The potential energy due to elevated positions is called *gravitational potential energy*. Water in an elevated reservoir and the ram of a pile driver have gravitational potential energy.

The amount of gravitational potential energy possessed by an elevated object is equal to the work done against gravity in lift-

* Strictly speaking, that which enables an object to do work is called its *available energy*, for not all the energy of an object can be transformed to work.

ing it. The work done equals the force required to move it upward times the vertical distance it is moved ($W = Fd$). The upward force required is equal to the weight mg of the object, so the work done in lifting it through a height h is given by the product mgh:

$$\text{gravitational potential energy} = \text{weight} \times \text{height}$$
$$\text{PE} = mgh$$

Note that the height h is the distance above some reference level, such as the ground or the floor of a building. The potential energy mgh is relative to that level and depends only on mg and the height h. You can see in Figure 8-3 that the potential energy of the boulder at the top of the ledge does not depend on the path taken to get it there.

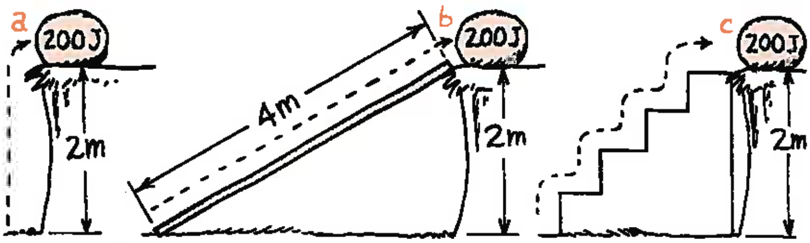

Fig. 8-3 The potential energy of the 100-N boulder with respect to the ground below is the same (200 J) in each case because the work done in elevating it 2 m is the same whether it is (a) lifted with 100 N of force, (b) pushed up the 4-m incline with 50 N of force, or (c) lifted with 100 N of force up each 0.5-m stair. No work is done in moving it horizontally (neglecting friction).

▸ **Questions**

1. How much work is done on a 100-N boulder that you carry horizontally across a 10-m room?
2. a. How much work is done on a 100-N boulder when you lift it 1 m?
   b. What power is expended if you lift it this distance in 1 s?
   c. What is its gravitational potential energy in the lifted position?

▸ **Answers**

1. You do no work on the boulder moved horizontally, for you apply no force (except for the tiny bit to start it) in its direction of motion. It has no more PE across the room than it had initially.
2. a. You do 100 J of work when you lift it 1 m (since $Fd = 100\ \text{N·m} = 100\ \text{J}$).
   b. Power = (100 J)/(1 s) = 100 W.
   c. It depends; with respect to its starting position, its PE is 100 J; with respect to some other reference level, it would be some other value.

8.5 Kinetic Energy

Push on an object and you can set it in motion. If an object moves, then by virtue of that motion it is capable of doing work. It has energy of motion, or **kinetic energy** (KE). The kinetic energy of an object depends on the mass of the object as well as its speed. It is equal to half the mass multiplied by the square of the speed.

$$\text{kinetic energy} = \tfrac{1}{2}\text{mass} \times \text{speed}^2$$
$$\text{KE} = \tfrac{1}{2}mv^2$$

When you throw a ball, you do work on it to give it the speed it has when it leaves your hand. The moving ball can then hit something and push against it, doing work on what it hits. The kinetic energy of a moving object is equal to the work required to bring it to that speed from rest, or the work the object can do in being brought to rest:*

$$\text{net force} \times \text{distance} = \text{kinetic energy}$$

or in shorthand notation,

$$Fd = \tfrac{1}{2}mv^2$$

Fig. 8-4 The potential energy of the drawn bow equals the work (average force × distance) done in drawing the arrow into position. When released, it will become the kinetic energy of the arrow.

It is important to notice that the speed is squared, so that if the speed of an object is doubled, its kinetic energy is quadrupled ($2^2 = 4$). This means that it takes four times as much work to double the speed of an object, and also that an object moving twice as fast as another takes four times as much work to stop. Accident investigators are well aware that an automobile traveling at 100 km/h has four times as much kinetic energy it would have traveling at 50 km/h. This means that a car traveling at 100 km/h will skid four times as far when its brakes are locked as it would if traveling 50 km/h. This is because speed is squared for kinetic energy.

Kinetic energy underlies other seemingly different forms of energy such as heat, sound, and light.

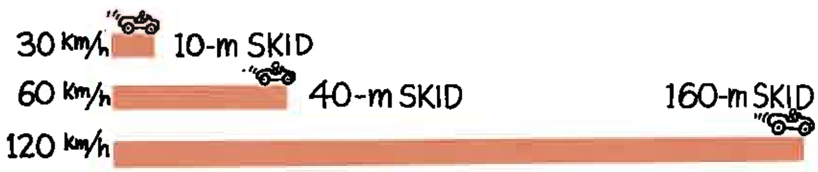

Fig. 8-5 Typical stopping distances for cars traveling at various speeds. Notice how the work done to stop the car (friction force × distance of slide) depends on the square of the speed. (The distances would be even greater if reaction time were taken into account.)

* This can be derived as follows. If we multiply both sides of $F = ma$ (Newton's second law) by d, we get $Fd = mad$. Recall from Chapter 2 that for motion in a straight line at constant acceleration $d = \tfrac{1}{2}at^2$, so we can say $Fd = ma(\tfrac{1}{2}at^2) = \tfrac{1}{2}maat^2 = \tfrac{1}{2}m(at)^2$. Substituting $v = at$, we get $Fd = \tfrac{1}{2}mv^2$.

▶ **Question**

When the brakes of a motorcycle traveling at 60 km/h become locked, how much farther will it skid than if the brakes locked at 20 km/h?

8.6 Conservation of Energy

More important than being able to state *what energy is* is understanding how it behaves—*how it transforms*. You can understand nearly every process or change that occurs in nature better if you analyze it in terms of a transformation of energy from one form to another.

As you draw back the stone in a slingshot, you do work in stretching the rubber band; the rubber band then has potential energy. When released, the stone has kinetic energy equal to this potential energy. It delivers this energy to its target, perhaps a wooden fence post. The slight distance the post is moved multiplied by the average force of impact doesn't quite match the kinetic energy of the stone. The energy score doesn't balance. But if you investigate further, you'll find that both the stone and fence post are a bit warmer. By how much? By the energy difference. Energy changes from one form to another. It transforms without net loss or net gain.

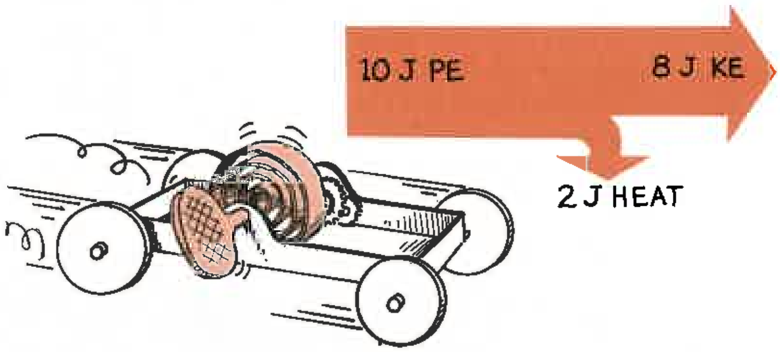

Fig. 8-6 Part of the PE of the wound spring changes into KE. The rest turns into heating the machinery and the surroundings due to friction. No energy is lost.

The study of the various forms of energy and their transformations from one form into another has led to one of the great-

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▶ **Answer**

Nine times farther: the motorcycle has nine times as much energy when it travels three times as fast: $\frac{1}{2}m(3v)^2 = \frac{1}{2}m9v^2 = 9(\frac{1}{2}mv^2)$. The friction force will ordinarily be the same in either case; therefore, to do nine times the work requires nine times as much sliding distance.

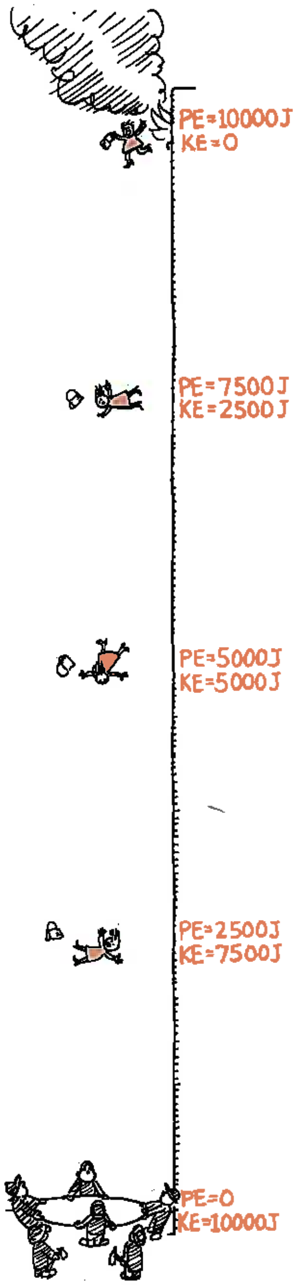

Fig. 8-7 When the lady in distress leaps from the burning building, note that the sum of her PE and KE remains constant at successive positions $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and all the way down.

est generalizations in physics, known as the **law of conservation of energy**:

> Energy cannot be created or destroyed; it may be transformed from one form into another, but the total amount of energy never changes.

When you consider any system in its entirety, whether it be as simple as a swinging pendulum or as complex as an exploding galaxy, there is one quantity that does not change: energy. It may change form, or it may simply be transferred from one place to another, but the total energy score stays the same.

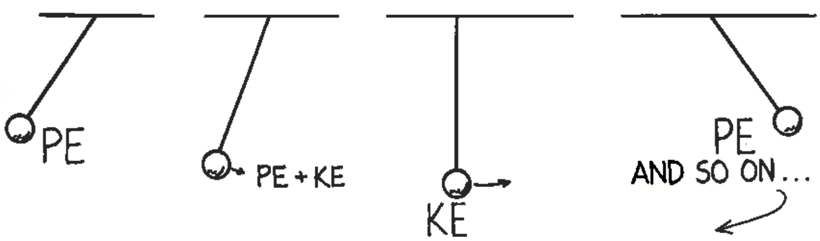

Fig. 8-8 Energy transformations in a pendulum. The PE of the pendulum bob at its highest point is equal to the KE of the bob at its lowest point. Everywhere along its path, the sum of PE and KE is the same. (Because of the work done against friction, this energy will eventually be transformed into heat.)

This energy score takes into account the fact that the atoms that make up matter are themselves concentrated bundles of energy. When the nuclei (cores) of atoms rearrange themselves, enormous amounts of energy can be released. The sun shines because some of this energy is transformed into radiant energy. In nuclear reactors much of this energy is transformed into heat.

Powerful gravitational forces in the deep hot interior of the sun crush the cores of hydrogen atoms together to form helium atoms. This welding together of atomic cores is called *thermonuclear fusion*. This process releases radiant energy, some of which reaches the earth. Part of this energy falls on plants, and part of this later becomes coal. Another part supports life in the food chain that begins with plants, and part of this energy later becomes oil. Part of the energy from the sun goes into the evaporation of water from the ocean, and part of this returns to the earth as rain that may be trapped behind a dam. By virtue of its position, the water in a dam has energy that may be used to power a generating plant below, where it will be transformed to electric energy. The energy travels through wires to homes, where it is used for lighting, heating, cooking, and to operate electric toothbrushes. How nice that energy is transformed from one form to another!

> ▶ **Question**
>
> Suppose a car with a miracle engine is able to convert 100% of the energy released when gasoline burns (40 million joules per liter) to mechanical energy. If the air drag and overall frictional forces on the car traveling at highway speed is 2000 N, what is the upper limit in distance per liter the car could cover at highway speed?

8.7 Machines

A **machine** is a device for multiplying forces or simply changing the direction of forces. Underlying every machine is the conservation of energy concept. Consider one of the simplest machines, **the lever** (Figure 8-9). At the same time we do work on one end of the lever, the other end does work on the load. We see that the direction of force is changed, for if we push *down*, the load is lifted *up*. If the heat from friction forces is small enough to neglect, the work input will be equal to the work output.

$$\text{work input} = \text{work output}$$

Since work equals force times distance, then input force × input distance = output force × output distance.

$$(\text{force} \times \text{distance})_{\text{input}} = (\text{force} \times \text{distance})_{\text{output}}$$

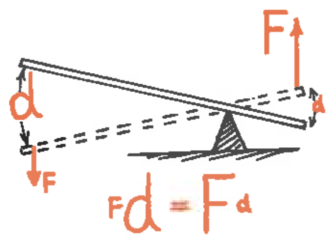

Fig. 8-9 The lever. The work (force times distance) you do at one end equals the work done to the load at the other end.

A little thought will show that the pivot point, or **fulcrum**, of the lever can be relatively close to the load. Then a small input force exerted through a large distance will produce a large output force over a correspondingly short distance. In this way, a lever can multiply forces. But no machine can multiply work nor multipy energy. That's a conservation of energy no-no!

Consider the idealized case of the weightless lever shown in Figure 8-10. The child pushes down with a force of only 10 N and is able to lift a load of 80 N. The ratio of output force to input

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▶ **Answer**

From the definition of work as force × distance, simple rearrangement gives distance = work ÷ force. If all 40 million joules of energy in one liter were used to do the work of overcoming the air drag and frictional forces, the distance would be:

$$\text{distance} = \frac{\text{work}}{\text{force}} = \frac{40\ 000\ 000\ \text{J}}{2000\ \text{N}} = 20\ 000\ \text{m} = 20\ \text{km}$$

The important point here is that even with a perfect engine, there is an upper limit of fuel economy dictated by the conservation of energy.

force for a machine is called the **mechanical advantage**. Here the mechanical advantage is (80 N)/(10 N), or 8. Note that the load is lifted only one eighth the distance that the input force moves. In the absence of friction, the mechanical advantage can also be determined by considering the relative distances through which the forces are exerted.

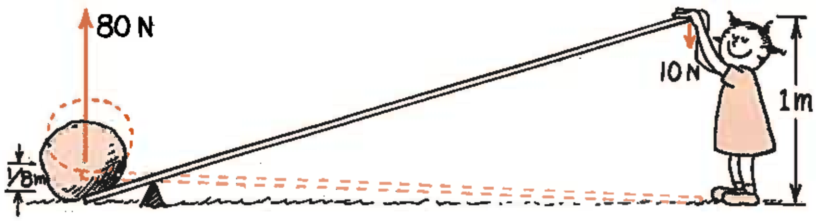


Fig. 8-10 The output force (80 N) is eight times the input force (10 N), while the output distance ($\frac{1}{8}$ m) is one eighth the input distance (1 m).

There are three different ways to set up a lever (Figure 8-11). Type 1 is the kind of lever commonly seen in a playground with children on each end—the seesaw. The fulcrum is between the input and output ends of the lever. Push down on one end, and you lift a load at the other. You can increase force at the expense of distance.

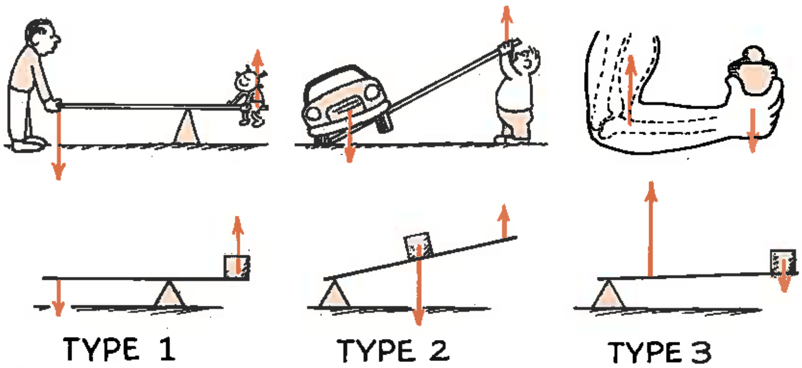


Fig. 8-11 The three basic types of lever.

With the type 2 arrangement, the load is between the fulcrum and the input end. To lift a load, you lift the end of the lever. An example is the placing of one end of a long steel bar under an automobile frame and lifting on the free end to raise the automobile. Again, force is increased at the expense of distance.

In the type 3 arrangement, the fulcrum is at one end and the load is at the other. The input force is applied between them. Your bicep muscles are connected to your forearm in this way. (The fulcrum is your elbow and the load is your hand.) The type

3 lever increases distance at the expense of force. When you move your bicep muscles a short distance, your hand moves a much greater distance.

A **pulley** is basically a kind of type 1 lever that is used to change the direction of a force. Properly used, a pulley or system of pulleys can multiply forces as well.

The single pulley in Figure 8-12 left changes the direction of the applied force. Here the load and applied force have equal magnitudes, since the applied force acts on the same single strand of rope that supports the load. Thus, the mechanical advantage equals one. Also, the distance moved at the input equals the distance the load moves.

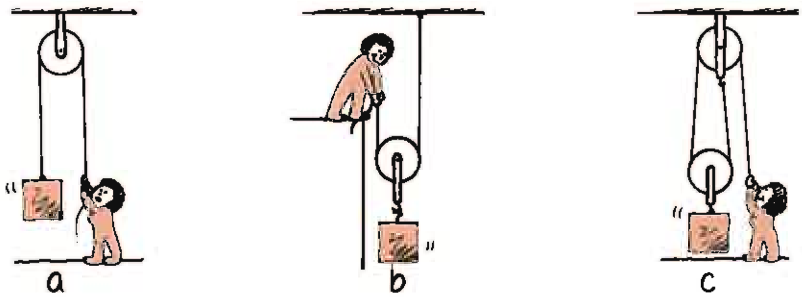


Fig. 8-12 A pulley can (a) change the direction of a force as effort is exerted downward and load moves upward; (b) multiply force as effort is now half the load, and (c) when combined with another pulley both change the direction and multiply force.

In Figure 8-12 center, the load is now supported by two strands. The force the man applies to support the load is therefore only half the weight of the load. The mechanical advantage equals two. The fact that there is only a single rope does not change this. Careful thought will show that to raise the load 1 m, the man will have to pull the rope up 2 m (or 1 m for each side).

The pulley system in Figure 8-12 right combines the arrangements of the first two pulleys. The load is supported by two strands of rope; the upper pulley serves only to change the direction of the force. Try to figure out the mechanical advantage of the pulley system. Actually experimenting with a variety of pulley systems is much more beneficial than reading about them in a textbook, so do try to get your hands on some pulleys, in or out of class. They're fun.

The pulley system shown in Figure 8-13 is a bit more complex, but the principles of energy conservation are the same. When the rope is pulled 10 m with a force of 50 N, a 500-N load will be lifted 1 m. The mechanical advantage is (500 N)/(50 N), or 10. Force is multiplied at the expense of distance. The mechanical

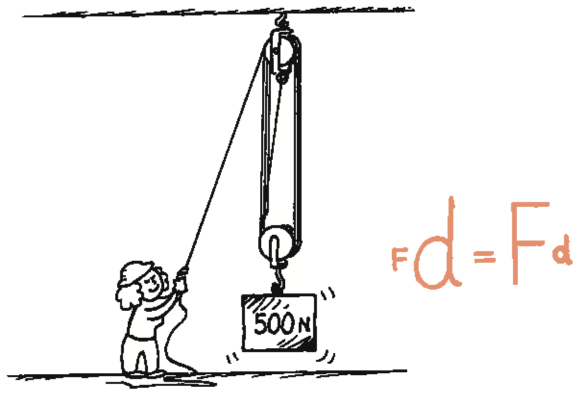


Fig. 8-13 In an idealized pulley system, applied force × input distance = output force × output distance.

advantage can also be found from the ratio of distances—that is, (input distance) ÷ (output distance)—which is also 10.

No machine can put out more energy than is put into it. No machine can create energy; a machine can only transfer it from one place to another, or transform it from one form to another.

8.8 Efficiency

The previous examples of machines were considered to be ideal; 100% of the work input was transfered to work output. An ideal machine would operate at 100% efficiency. In practice, this does not happen, and we can never expect it to happen. In any machine, some energy is dissipated to atomic or molecular kinetic energy—which makes the machine warmer.

Even a lever rocks about its fulcrum and converts a small fraction of the input energy into heat. We may do 100 J of work and get out 98 J of work. The lever is then 98% efficient, and we waste only 2 J of work input on heat. In a pulley system, a larger fraction of input energy goes into heat. If we do 100 J of work, the forces of friction acting through the distances through which the pulleys turn and rub about their axles may dissipate 40 J of energy as heat. So the work output is only 60 J and the pulley system has an efficiency of 60%. The lower the efficiency of a machine, the greater is the amount of energy wasted as heat.

Efficiency can be expressed as the ratio of useful work output to total work input:

$$\text{efficiency} = \frac{\text{useful work output}}{\text{total work input}}$$

An inclined plane serves as a machine. Sliding a load up an incline requires less force than lifting it vertically. Figure 8-14

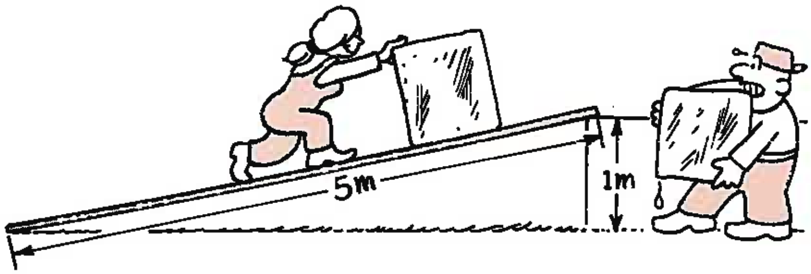


Fig. 8-14 Pushing the block of ice 5 times farther up the incline than the vertical distance lifted requires a force of only $\frac{1}{5}$ its weight. Whether pushed up the plane or simply lifted, it gains the same amount of PE.

shows a 5-m inclined plane with its high end elevated 1 m. If we use the plane to elevate a heavy load, we will have to push it five times farther than if we simply lifted it vertically. A little thought will show that if the plane is free of friction, we need apply only one fifth the force required to lift the load vertically. The inclined plane provides a *theoretical* mechanical advantage of 5. A block of ice sliding on an icy plane may have a near theoretical mechanical advantage and approach 100% efficiency, but when the load is a wooden crate and it slides on a wooden plank, both the actual mechanical advantage and the efficiency will be considerably less. Efficiency can also be expressed as the ratio of actual mechanical advantage to theoretical mechanical advantage:

$$\text{efficiency} = \frac{\text{actual mechanical advantage}}{\text{theoretical mechanical advantage}}$$

Efficiency will always be a fraction less than 1. To convert it to percent we simply express it as a decimal and multiply by 100%. For example, an efficiency of 0.25 expressed in percent is 0.25 × 100%, or 25%.

The jack shown in Figure 8-15 is actually an inclined plane wrapped around a cylinder. You can see that a single turn of the handle raises the load a relatively small distance. If the circular distance the handle is moved is 500 times greater than the pitch (the distance between ridges), then the theoretical mechanical advantage of the jack is 500.* No wonder a child can raise a loaded moving van with one of these devices! In practice there is

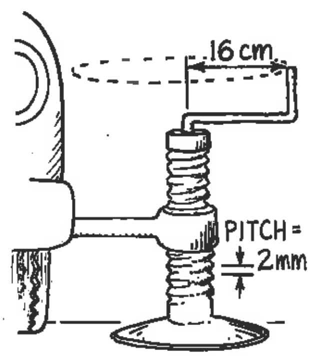
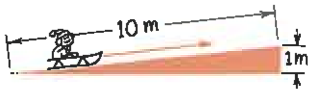


Fig. 8-15 The auto jack is like an inclined plane wrapped around a cylinder. Every time the handle is turned one revolution, the load is raised a distance of one pitch.

* To raise a load by 2 mm the handle has to be moved once around, through a distance equal to the circumference of the circular path of radius 16 cm. This distance is 100 cm (since the circumference is $2\pi r = 2 \times 3.14 \times 16$ cm = 100 cm). A simple calculation will show that the 100-cm work-input distance is 500 times greater than the work-output distance of 2 mm. If the jack were 100% efficient, then the input force would be multiplied by 500 times. The theoretical mechanical advantage of the jack is 500.



▶ Questions

A child on a sled (total weight 500 N) is pulled up a 10-m slope that elevates her a vertical distance of 1 m.

a. What is the theoretical mechanical advantage of the slope?

b. If the slope is without friction, and she is pulled up the slope at constant speed, what will be the tension in the rope?

c. Considering the practical case where friction *is* present, suppose the tension in the rope were in fact 100 N. Then what would be the actual mechanical advantage of the slope? The efficiency?

a great deal of friction in this type of jack, so the efficiency may be around 20%. Thus the jack actually multiplies force by about 100 times. The actual mechanical advantage therefore approximates an impressive 100. Imagine the value of one of these devices during the days when the great pyramids were being built!

An automobile engine is a machine that transforms chemical energy stored in fuel into mechanical energy. The molecules of the petroleum fuel break up when the fuel burns. Burning is a chemical reaction in which atoms combine with the oxygen in the air. Carbon atoms from the petroleum combine with oxygen atoms to form carbon monoxide, and energy is released.

The converted energy is used to run the engine. It would be nice if all this energy were converted to mechanical energy, but a 100% efficient machine is not possible. Some of the energy goes into heat. Even the best designed engines are unlikely to be more than 35% efficient. Some of the energy converted to heat goes into the cooling system and is wasted through the radiator to the air. Some goes out the exhaust, and nearly half is wasted in the friction of the moving engine parts. In addition to these inefficiencies, the fuel does not even burn completely—a certain amount goes unused. We can look at inefficiency in this way: in

▶ Answers

a. The ideal or theoretical mechanical advantage is (input distance) ÷ (output distance) = (10 m)/(1 m) = 10.

b. 50 N. With no friction, ideal mechanical advantage and actual mechanical advantage would be the same—10. So the input force, the rope tension, will be 1/10 the output force, her 500-N weight.

c. The actual mechanical advantage would be (output force) ÷ (input force) = (500 N)/(100 N) = 5. The efficiency would then be 0.5 or 50%, since (actual mechanical advantage) ÷ (theoretical mechanical advantage) = 5/10 = 0.5. The value for efficiency is also obtained from the ratio (useful work output) ÷ (useful work input).

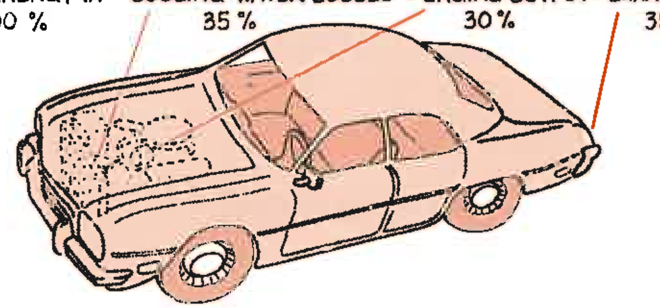


Fig. 8-16 Only 30% of the energy produced by burning gasoline in a typically efficient automobile becomes useful mechanical energy.

any transformation there is a dilution of the amount of *useful energy*. Useful energy ultimately becomes heat. Energy is not destroyed—it is simply degraded. Heat is the graveyard of useful energy.

8.9 Energy for Life

Every living cell in every organism is a living machine. Like any machine, it needs an energy supply. Most living organisms on this planet feed on various hydrocarbon compounds that release energy when they react with oxygen. Like the petroleum fuel previously discussed, there is more energy stored in the molecules in the fuel state than in the reaction products after combustion. The energy difference is what sustains life.

The principle of combustion in the digestion of food in the body and the combustion of fossil fuels in mechanical engines is the same. The main difference is the rate at which the reactions take place. In digestion the rate is much slower, and energy is released as it is required. Like the burning of fossil fuels, the reaction is self-sustaining once started. Carbon combines with oxygen to form carbon dioxide.

The reverse process is more difficult. Only green plants and certain one-celled organisms can make carbon dioxide combine with water to produce hydrocarbon compounds such as sugar. This process is *photosynthesis* and requires an energy input, which normally comes from sunlight. Sugar is the simplest food; all others—carbohydrates, proteins, and fats—are also synthesized compounds of carbon, hydrogen, and oxygen. How fortunate we are that green plants are able to use the energy of sunlight to make food that gives us and all other food-eating organisms our energy. Because of this there is life.

8 Chapter Review

Concept Summary

When a constant force moves an object in the direction of the force, the work done equals the product of the force and the distance through which the object is moved.

- Power is the rate at which work is done.

The energy of an object enables it to do work.

- Mechanical energy is due to the position of something (potential energy) or the movement of something (kinetic energy).

According to the law of conservation of energy, energy cannot be created nor destroyed.

- Energy can be transformed from one form to another.

A machine is a device for multiplying forces or changing the direction of forces.

- Levers, pulleys, and inclined planes are simple machines.
- Normally, the useful work output of a machine is less than the total work input.

Important Terms

efficiency (8.8)
energy (8.3)
fulcrum (8.7)
joule (8.1)
kinetic energy (8.5)
law of conservation of energy (8.6)
lever (8.7)
machine (8.7)
mechanical advantage (8.7)
mechanical energy (8.3)
potential energy (8.4)
power (8.2)
pulley (8.7)
watt (8.2)
work (8.1)

Review Questions

1. A force sets an object in motion. When the force is multiplied by the time of its application, we call the quantity *impulse*, which changes the *momentum* of that object. What do we call the quantity *force × distance*, and what quantity does this change? (8.1)

2. Work is required to lift a barbell. How many times as much work is required to lift the barbell three times as high? (8.1)

3. Which requires more work—lifting a 10-kg sack a vertical distance of 2 m, or lifting a 5-kg sack a vertical distance of 4 m? (8.1)

4. How many joules of work are done on an object when a force of 10 N pushes it a distance of 10 m? (8.1)

5. How much power is required to do 100 J of work on an object in a time of 0.5 s? How much power is required if the same amount of work is done in 1 s? (8.2)

6. What is mechanical energy? (8.3)

7. a. If you do 100 J of work to elevate a bucket of water, what is its gravitational potential energy relative to its starting position?
   b. What would it be if it were raised twice as high? (8.4)

8. If a boulder is raised above the ground so that its potential energy with respect to the ground is 200 J, and then it is dropped, what will its kinetic energy be just before it hits the ground? (8.5)

9. Suppose an automobile has a kinetic energy of 2000 J. If it moves with twice the speed, what will be its kinetic energy? Three times the speed? (8.5)

10. What will be the kinetic energy of an arrow shot from a bow having a potential energy of 50 J? (8.6)

11. What does it mean to say that in any system the total energy score stays the same? (8.6)

12. In what sense is energy from coal actually solar energy? (8.6)

13. Why is there an upper limit on how far an automobile can be driven on a tank of gasoline? (8.6)

14. In what two ways can a machine alter an input force? (8.7)

15. In what way is a machine subject to the law of energy conservation? Is it possible for a machine to multiply energy or work input? (8.7)

16. What does it mean to say that a certain machine has a certain mechanical advantage? (8.7)

17. What are the three basic types of levers? (8.7)

18. What is the efficiency of a machine that requires 100 J of input energy to do 35 J of useful work? (8.8)

19. Distinguish between theoretical mechanical advantage and actual mechanical advantage. How will these compare if a machine is 100% efficient? (8.8)

20. What is the efficiency of the body when a cyclist expends 1000 W of power to deliver mechanical energy to her bicycle at the rate of 100 W? (8.8)

Think and Explain

1. When a rock is projected with a slingshot, there are two reasons why the rock will go faster if the rubber is stretched an extra distance. What are the two reasons? Defend your answer.

2. A certain engine is capable of bringing a car from 0 to 100 km/h in 10 s. All other things being equal, if the engine has twice the power output, how many seconds would be required to accelerate it to this speed?

3. If a car that travels at 60 km/h will skid 20 m when its brakes are locked, how far will it skid if it is traveling at 120 km/h when its brakes are locked?

4. A hammer falls off a rooftop and strikes the ground with a certain KE. If it fell from a roof twice as tall, how would its KE of impact compare?

5. Most earth satellites follow an oval shaped (elliptical) path rather than a circular path around the earth. The PE increases when the satellite moves farther from the earth. According to energy conservation, does a satellite have its greatest speed when it is closest or farthest from the earth?

6. Why will a lighter car generally have better fuel economy than a larger car? Will a streamlined design improve fuel economy?

7. Does an automobile consume more fuel when its air conditioner is turned on? When its lights are on? When its radio is on while it is sitting at rest in the parking lot? Explain in terms of the conservation of energy.

8. How many kilometers per liter will a car obtain if its engine is 25% efficient and it encounters an average retarding force of 1000 N at highway speed? Assume the energy content of gasoline is 40 MJ per liter.

9. The pulley shown on the left in Figure A has a mechanical advantage of 1. What is the mechanical advantage when it is used as shown on the right? Defend your answer.

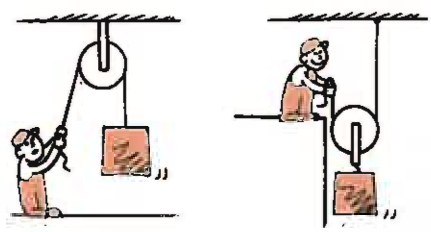


Fig. A

Fig. B

10. What is the theoretical mechanical advantage of the three lever systems shown in Figure B?

11. You tell your friend that no machine can possibly put out more energy than is put into it, and your friend states that a nuclear reactor puts out more energy than is put into it. What do you say?

12. The energy we require for existence comes from the chemically stored potential energy in food, which is transformed into other forms by the process of digestion. What happens to a person whose work output is less than the energy consumed? When the person's work output is greater than the energy consumed? Can an undernourished person perform extra work without extra food? Defend your answers.