7.3 Efficiency and Power

One day your science teacher declares, "Today we are going to do our work with greater *efficiency* and greater *power*." That sounds like a good idea, but what does your teacher mean? Read on and you will find out.

VOCABULARY

work input - the work that is done on an object.

work output - the work that an object does as a result of work input.

Work input and output

Input work and output work

Every process that transforms energy can be thought of as a machine. Work or energy goes in one end and work or energy comes out the other end. The "machine" might be a toaster heating bread, which transforms electrical energy into heat, or even a human consuming food in order to have the energy to exercise. Using this concept, the **work input** is the work or energy supplied to the process (or machine). The **work output** is the work or energy that comes out of the process (or machine).

A rope and pulley example

As an example, consider using a rope and pulley machine to lift a load weighing 10 newtons (Figure 7.19). If you lift the load a distance of 1 meter, the machine has done 10 joules of work and the work output is 10 joules. For this particular machine, you need to pull with a force of only 5 newtons, but you need to pull the rope a distance of 2 meters. Your work input is 5 newtons × 2 meters or 10 joules.

How work input and output are related

The example of a rope and pulley machine illustrates a rule that is true for all machines and all processes that transform energy. The total energy of work output can never be greater than the total energy of work input.

The energy output of a process or machine can never exceed the energy input.

You might recognize this statement as just another way of saying the law of conservation of energy. You are right! If you carefully account for all the work and energy in any process, you find that the total work and energy output of the process is exactly equal to the total work and energy input.

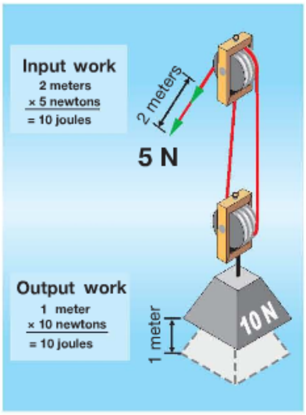


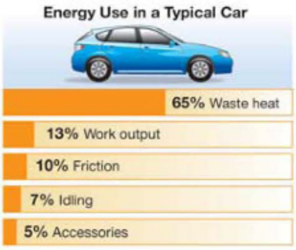
Figure 7.19: *Assuming no friction, the work input of the rope and pulley machine is the same as the work output.*

Efficiency

Real machines

Suppose you measure the forces on an actual rope and pulley machine. Figure 7.20 shows what you find. Notice that the work input is a little more than the work output. It took 11 joules of input work applied to the rope to produce 10 joules of output work lifting the weight. This kind of behavior is true of all real machines. The work output is less because some work is always converted to heat and other kinds of energy by friction.

Everyday machines



The diagram at the left shows how the chemical energy (input) released by burning gasoline is used in a typical car. Only 13 percent of the energy in a gallon of gas is transformed into output work! Car engines in use get hot. That's because 65 percent of the energy in gasoline is converted to heat. In terms of moving the car, this heat energy is "lost." The energy doesn't vanish, it just does not appear as useful output work.

Efficiency

The **efficiency** of a machine is the ratio of usable output work divided by total input work. Efficiency is usually expressed in percent. The car in the diagram has an efficiency of 13 percent. That means 13 out of every 100 joules released from gasoline go to making the car move. A "perfect" car would have an efficiency of 100 percent. Since all real machines have some friction, perfect machines are technically impossible.

Calculating efficiency

You calculate efficiency by dividing the usable output work by the total input work. The rope and pulley machine in Figure 7.20 has an efficiency of 91 percent. That means that 1 joule out of every 11 (9 percent) is "lost" to friction. The work isn't really "lost," but it is converted to heat and other forms of energy that are not useful in doing the job the rope and pulley machine is designed to do.

VOCABULARY

efficiency - the ratio of usable output work divided by total input work. Efficiency is often expressed as a percent, with a perfect machine having 100 percent efficiency.

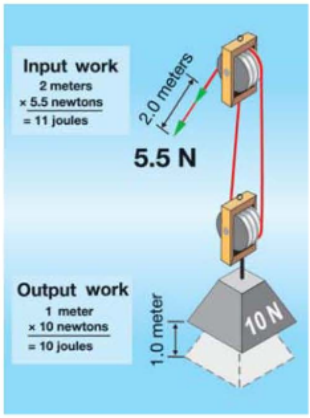
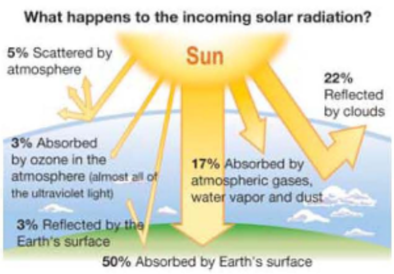


Figure 7.20: *If the input work is 11 joules, and the output work is 10 joules, then the efficiency is 91 percent.*

Efficiency in natural systems

The meaning of efficiency

Energy drives all the processes in nature, from winds in the atmosphere to nuclear reactions occurring in the cores of stars. In the environment, efficiency is defined as the fraction of incoming energy that goes into a process. For example, Earth receives energy from the Sun. Earth absorbs this solar energy with an average efficiency of 78 percent. The energy that is not absorbed is reflected back into space.



Earth's temperature

Earth's efficiency at absorbing solar energy is critical to living things. If the efficiency decreased by a few percent, Earth's surface would become too cold for life. Some scientists believe that many volcanic eruptions or nuclear war could decrease the absorption efficiency by spreading dust in the atmosphere. Dust reflects solar energy (Figure 7.21). On the other hand, if the efficiency increased by a few percent, Earth would get too hot to sustain life. Adding carbon dioxide (and other greenhouse gases) in the atmosphere increases absorption efficiency. Scientists are concerned that the average annual temperature of Earth has already warmed 1°C degree since the 1880s mostly as a result of carbon dioxide released by human activities (Figure 7.22).

Conservation of energy

In any system, all of the energy goes somewhere. Another way to say this is that energy is conserved. For example, rivers flow downhill. Most of the potential energy lost by water moving downhill becomes kinetic energy in the motion of the water. Erosion takes some of the energy and slowly changes the land by wearing away rocks and dirt. Friction takes some of the energy and heats up the water. If you could add up the efficiencies for every single process in which this water is involved, that total would be 100 percent.

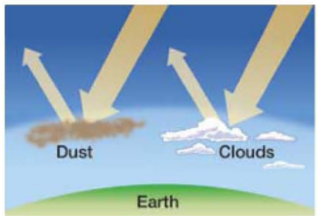


Figure 7.21: *Dust and clouds reflect light back into space, decreasing the efficiency with which Earth absorbs energy from the Sun.*

Figure 7.22: *Human activities have increased the amount of carbon dioxide and other greenhouse gases in Earth's atmosphere. These gases increase the absorption efficiency of Earth's atmosphere.*

Power

Energy vs. power If you lift a book over your head, the book gets potential energy from your action. Even if you lift the book faster, it has the same amount of potential energy. This is because the height is the same. But it feels different to transfer the energy to the book at different speeds. *Power* describes how fast energy is transferred to an object.

What is power? **Power** is the rate at which work is done. Here's an example. Suppose Michael and Jim each lift a barbell weighing 100 newtons from the ground to a height of 2 meters (Figure 7.23). Michael lifts quickly and Jim lifts slowly. Michael and Jim do the same amount of work (100 N × 2 m = 200 joules of work). However, Michael's power is greater because he gets the work done in less time.

Watts and horsepower Power is calculated in watts. One **watt** (W) is equal to 1 joule of work per second. One kilowatt equals 1,000 watts. The watt was named after James Watt, the Scottish engineer who invented the steam engine. Another unit of power is **horsepower** (hp) Watt expressed the power of his engines as the number of horses an engine could replace. One horsepower equals 746 watts or 746 joules of work per second.

POWER

Power (W) $P = \frac{W}{t}$ Work (J) / Time (s)

Calculating power Now, let's calculate and compare the power output of Michael and Jim. Michael's power is 200 joules divided by 1 second, or 200 watts. Jim's power is 200 joules divided by 10 seconds, or 20 watts. Jim takes 10 times as long to lift the barbell, so his power is one-tenth as much. The maximum power output of an average person is a few hundred watts.

VOCABULARY

power - the rate of doing work or moving energy. Power is equal to energy (or work) divided by time.

watt - a unit of power equal to 1 joule per second.

horsepower - a unit of power equal to 746 watts.

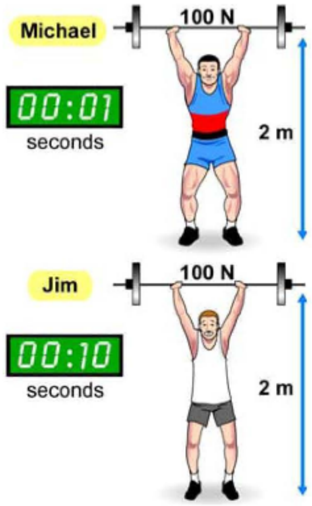


Figure 7.23: *Michael and Jim do the same amount of work but do not have the same power.*

Section 7.3 Review

1. You read about a rope and pulley machine that was able to produce equal amounts of output work and input work. Was this a realistic example? Why or why not?
2. What do you need to do to calculate the efficiency of any machine?
3. A car's efficiency is only 13 percent.
   a. If the input work for a car is 200 joules, what is the output work?
   b. List two things that car manufacturers do to improve a car's efficiency.
4. A simple machine produces 25 joules of output work for every 50 joules of input work. What is the efficiency of this machine?
5. How is work related to power?
6. If you know the power for a machine and the amount of time it was running, what value can you calculate?
7. How does 1 horsepower compare to 1 watt of power?
8. A gallon of gasoline contains about 36 kilowatt-hours of energy. Suppose a gallon of gas costs two dollars and a kilowatt-hour of electricity costs 8 cents. Which form of energy is less expensive?
9. A 100-newton object is lifted 100 meters in 100 seconds. What is the power generated in this situation?
10. Which situation would produce 200 watts of power?
    a. 100 J of work done in 2 s
    b. 400 J of work done in 2 s
    c. 2,000 J of work done in 5 s
    d. 2 J of work done in 100 s
11. An average car engine can produce about 100 horsepower. How many 100-watt light bulbs does it take to use the same amount of power?
12. A half-cup of ice cream contains about 200 food Calories. How much power can be produced if the energy in a cup of ice cream is expended over a period of 10 minutes (600 seconds)? Each food Calorie is equal to 4,184 joules. Write your answer in watts and then in horsepower.

JOURNAL

Are You Really Doing Work When You Do Your Homework?

Answer this question in your own words, based on what you know about work.

Think about this question from different angles before you answer it.

KEYWORDS

Energy-Efficient Technologies

Engineers are always trying to improve the efficiency of the machines we use every day. Do an Internet search using the key phrase "energy efficient technologies" and see what you find. Or, you might want to go directly to the U.S. government website www.energystar.gov. Pick a topic and present your findings to your class.

Extension: Be a reporter within your home and see how many energy-efficient appliances you can find.