3.2: Work- The Scientific Definition

Learning Objectives

- Explain how an object must be displaced for a force on it to do work.
- Explain how relative directions of force and displacement determine whether the work done is positive, negative, or zero.

What It Means to Do Work

The scientific definition of work differs in some ways from its everyday meaning. Certain things we think of as hard work, such as writing an exam or carrying a heavy load on level ground, are not work as defined by a scientist. The scientific definition of work reveals its relationship to energy—whenever work is done, energy is transferred.

For work, in the scientific sense, to be done, a force must be exerted and there must be motion or displacement in the direction of the force.

Formally, the **work** done on a system by a constant force is defined to be *the product of the component of the force in the direction of motion times the distance through which the force acts*. For one-way motion in one dimension, this is expressed in equation form as

$$W = F_{||}d$$

Where W is work, d is the distance the force acts, and $F_{||}$ is the force parallel to the direction of motion. We can also write this more simply as

$$W = Fd$$

as long as one keeps in mind that the force is in the same direction as the distance.

To find the work done on a system that undergoes motion that is not one-way or that is in two or three dimensions, we would divide the motion into one-way one-dimensional segments and add up the work done over each segment.

WHAT IS WORK?

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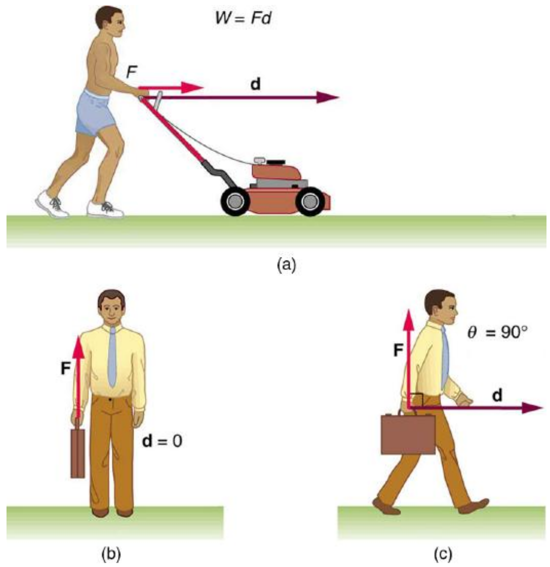

Figure 3.2.1: Examples of work. (a) Note that the force is in the direction of motion. (b) A person holding a briefcase does no work on it, because there is no motion. No energy is transferred to or from the briefcase. (c) The person moving the briefcase horizontally at a constant speed does no work on it, and transfers no energy to it. The force acting on the briefcase (against gravity) is perpendicular to the direction of motion.

To examine what the definition of work means, let us consider the other situations shown in Figure 3.2.1. The person holding the briefcase in Figure 3.2.1(b) does no work, for example. Here $d = 0$, so $W = 0$. Why is it you get tired just holding a load? The answer is that your muscles are doing work against one another, *but they are doing no work on the system of interest* (the "briefcase-Earth system"). There must be motion for work to be done, and there must be a component of the force in the direction of the motion. For example, the person carrying the briefcase on level ground in Figure 3.2.1(c) does no work on it, because the force is perpendicular to the motion.

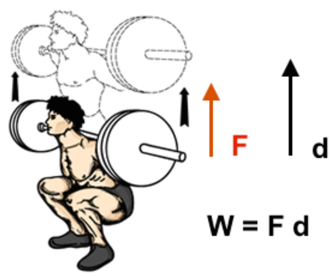

Figure 3.2.2: Work done when lifting a mass. Work is positive on the way up because force and displacement point in the same direction. On the way down work is negative due to force and displacement pointing in opposite directions (force up and displacement down).

Work can be positive or negative. In Figure 3.2.2 work done lifting the mass is positive because both force and displacement are in the same direction. Likewise, when the mass is lowered the work done is negative because the force and displacement are in *opposite* directions. We will soon see that positive work adds energy to the system and negative work removes energy from a system.

Calculating Work

Work and energy have the same units. From the definition of work, we see that those units are force times distance. Thus, in SI units, work and energy are measured in **newton-meters**. A newton-meter is given the special name **joule** (J), and $1\ \text{J} = 1\ \text{N} \cdot \text{m} = 1\ \text{kg} \cdot \text{m}^2/\text{s}^2$. One joule is not a large amount of energy; it would lift a small 100-gram apple a distance of about 1 meter.

Example 3.2.1: Calculating the Work You Do to Push a Lawn Mower Across a Large Lawn

How much work is done on the lawn mower by the person in Figure $3.2.1$(a) if he exerts a constant force of 75.0 N and pushes the mower 25.0 m on level ground? Compare it with this person's average daily intake of 10,000 kJ (about 2400 kcal) of food energy.

Strategy

We can solve this problem by substituting the given values into the definition of work done on a system, stated in the equation $W = Fd$. The force and displacement are given, so that only the work W is unknown. Note that force and displacement are in the same direction.

Solution

The equation for the work is

$$W = Fd.$$

Substituting the known values gives

$$W = (75.0 \text{ N})(25.0 \text{ m}) = 1875 \text{ J} = 1.88 \times 10^3 \text{ J}.$$

The ratio of the work done to the daily consumption is

$$\frac{W}{1.00 \times 10^4 \text{ kJ}} = \frac{1.88 \times 10^3 \text{ J}}{1.00 \times 10^7 \text{ J}} = 1.88 \times 10^{-4}.$$

Discussion

This ratio is a tiny fraction of what the person consumes, but it is typical. Very little of the energy released in the consumption of food is used to do work. Even when we "work" all day long, less than 10% of our food energy intake is used to do work and more than 90% is converted to thermal energy or stored as chemical energy in fat.

Example 3.2.2: Calculating the Work Done Lifting a Mass

The 60.0 kg mass shown in Figure $3.2.2$ is raised at a constant speed through a vertical distance of 0.800 m. What is the force that must be exerted? How much work is done lifting the mass?

Strategy

Constant speed tells us that the upward force must have the same magnitude as the downward force of gravity $F = mg$ (to have a zero net force). Using that information, along with the given values for mass and displacement, we can determine work using $W = Fd$.

Solution

The force is given by

$$F = mg = (60.0 \text{ kg})\left(9.80 \text{ m/s}^2\right) = 588 \text{ N}.$$

The work done is

$$W = Fd = (588 \text{ N})(0.800 \text{ m}) = 470 \text{ J}.$$

Discussion

Note that the work done lowering the mass back to its starting position would be -470 Jbecause force and displacement point in opposite directions. The total work done raising and lowering the mass is $470 \text{ J} - 470 \text{ J} = 0 \text{ J}$.

Section Summary

- Work is the transfer of energy by a force acting on an object as it is displaced.
- The work W that a force F does on an object is the product of the magnitude F of the force parallel to the motion, times the magnitude d of the displacement. In symbols,

$$W = Fd.$$

- The SI unit for work and energy is the joule (J), where $1\ \mathrm{J} = 1\ \mathrm{N} \cdot \mathrm{m} = 1\ \mathrm{kg} \cdot \mathrm{m}^2/\mathrm{s}^2$.
- The work done by a force is zero if the displacement is either zero or perpendicular to the force.
- The work done is positive if the force and displacement have the same direction, and negative if they have opposite direction.

Glossary

energy

the ability to do work

work

the transfer of energy by a force that causes an object to be displaced; the product of the component of the force in the direction of the displacement and the magnitude of the displacement

joule

SI unit of work and energy, equal to one newton-meter

Contributions and Attributions