5.1 Do You Know the Meaning of Work?

Warm Up

Bounce a rubber or tennis ball up and down several times. List all the different forms of energy you observe.

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What is Energy?

Energy appears in a variety of forms. Some forms you are familiar with include light, sound, thermal energy, electrical energy, elastic potential energy, gravitational potential energy, chemical potential energy, nuclear energy, and mechanical energy. What is energy? Your experience tells you it is associated with movement or with the potential for motion. Energy is what makes things move. The usual definition of energy says that energy is the capacity to do work.

In physics, **work** has a specific meaning. If work is to be done on an object, two things must happen: (1) a force must act on the object and (2) the object must move through a distance in the direction of the force. The amount of work done is equal to the product of the force exerted and the distance the force causes the object to move, measured in the direction of the force.

work = force × distance

$$W = Fd$$

Since force is measured in newtons (N) and distance in metres (m), work can be measured in newton-metres. One newton-metre (N·m) is called a **joule (J)** after James Joule (1818–1889), an English physicist.

$$1\ \text{J} = 1\ \text{N·m}$$

Sample Problem 5.1.1 — Calculating Work

How much work does a golfer do lifting a 46 g golf ball out of the hole and up to his pocket (0.95 m above the ground)?

What to Think About	How to Do It
1. Find the correct formula.	$W = Fd$
2. Find the force in newtons.	$F = mg = (0.046\text{kg})(9.81\ \text{m/s}^2)$ $F = 0.45\ \text{N}$
3. Find work done.	$W = Fd = (0.45\ \text{N})(0.95\ \text{m})$ $= 0.43\ \text{J}$ The golfer does 0.43 J of work lifting the golf ball from the hole to his pocket.

Practice Problems 5.1.1 — Calculating Work

1. How much work will you do if you push a block of concrete 4.3 m along a floor, with a steady force of 25 N?

2. If your mass is 70.0 kg, how much work will you do climbing a flight of stairs 25.0 m high, moving at a steady pace? (g = 9.81 N/kg)

3. Your car is stuck in the mud. You push on it with a force of 300.0 N for 10.0 s, but it will not move. How much work have you done in the 10.0 s?

Power

A machine is powerful if it can do a lot of work in a short time. **Power** is the measure of the amount of work a machine can do in one second.

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

$$P = \frac{W}{\Delta t}$$

Power could be measured in joules per second (J/s), but one joule per second is called one **watt (W)**, after James Watt (1736–1819), a Scottish engineer.

1 W = 1 J/s

Power can be measured in kilowatts (kW) or megawatts (MW).

1 kW = 1000 W (10^3 W)
1 MW = 1 000 000 W (10^6 W)

Sample Problem 5.1.2 — Calculating Power

The power of a small motor in a toy can be calculated by the amount of work it does in a period of time. What is the power rating of a toy motor that does 4200 J of work in 70.0 s?

What to Think About	How to Do It
1. Find the correct formula.	$P = \frac{W}{\Delta t}$
2. Calculate the power.	$P = \frac{4200\text{ J}}{70.0\text{ s}} = 60\text{ W}$ The power rating of the toy motor is 60 W.

Practice Problems 5.1.2 — Calculating Power

1. An airport baggage handler lifts 42 pieces of luggage, averaging 24 kg each, through a height of 1.6 m onto a baggage cart, in a time of 3.6 min. In this situation, what is the power of the baggage handler?

2. How much work or energy (in J) does a 150 W light bulb convert to heat and light in 1.0 h?

3. A mechanical lifting system is approximately 25% efficient. This means that only 25% of the energy used to lift a mass is converted into useable energy. The rest is mostly lost as heat. If 1.5×10^8 W is used for 2.0 h, how much energy (in J) of useable work is produced? How much heat is produced?

What's Watt?

Power is commonly measured in **horsepower**. Eventually, horsepower may be replaced by the **kilowatt**, which is a metric unit, but the horsepower (non-metric) will persist for some time because it is firmly entrenched in our vocabulary.

The Scottish engineer James Watt is famous for his improved design of a steam engine, invented earlier by Thomas Newcomen. Watt's new engine was used at first for pumping water out of coal mines, work that previously had been done by horses. Customers wanted to know how many horses Watt's new engines would replace. So that he could answer their questions, Watt did the following:

1. He measured the force, in pounds, exerted by the average horse over a distance, measured in feet.
2. He calculated the amount of work the horse did, in a unit he called foot-pounds.
3. He measured the time it took the horse to do the work.
4. He calculated how much work the horse would do in one second, which is the average power of the horse. He found this to be 550 foot-pounds per second. This was taken to be the average power of one horse equal to one horsepower.

$$1 \text{ horsepower} = 550 \frac{\text{foot-pounds}}{\text{second}}$$

The modern unit for power is the watt (W). One horsepower is equivalent to 746 W, which is almost 3/4 kW. The following example finds the power in an electric motor and them shows how to convert watts to horsepower.

Sample Problem 5.1.3 — Calculating Horsepower An electric motor is used, with a pulley and a rope, to lift a 650 N load from the road up to a height of 12 m. This job is done in a time of 11 s. What is the power output of the motor?	
What to Think About	**How to Do It**
1. Find the correct formula.	$P = \frac{work}{time} = \frac{W}{\Delta t}$
2. Calculate the power in watts.	$P = \frac{Fd}{\Delta t} = \frac{(650\ N)(12\ m)}{11\ s}$ $= 7.1\ 10^2\ W$
3. Calculate the horsepower.	The often-used unit of power, 1 horsepower, is equivalent to 7.5×10^2 W. The motor in this question would have a horsepower of $\frac{7.1 \times 10^2\ W}{7.5 \times 10^2\ W/HP} = 0.95\ HP$