Special Review

Work and Power

As per Newton's second law, to get an object to change how it's moving requires a *force*, which we can think of as a push or a pull. If the object is at rest and you want it moving, you need to apply a force. If the object is already moving and you want it to speed up or slow down, again, you need to apply a force. This should be intuitive from your everyday experiences—to get things moving, you apply a force

A force may be applied, but here's a key question: For "how long" is that force being applied? Earlier we talked about how long in terms of *time*, which gives what we learned to be *impulse*:

Impulse = force x time

An impulse results in a *change in the object's momentum*. Let's now explore a different sort of "how long", which is in terms of not time but *distance*. For example, you might lift a heavy box to a height of 1 meter, which is a distance. This leads to a quantity known as **work**:

Work = force x distance

We do work when we apply a force to lift a load against Earth's gravity. The heavier the load or the higher we lift it, the more work we do. The amount of work done on an object depends on (1) how much force is applied and (2) how far the force causes the object to move. Note: An assumption here is that the force and distance are in the same direction. For example, you push upward on the load and it is lifted upward in the same direction.

Reading Check
What two things does the amount of work done depend upon?

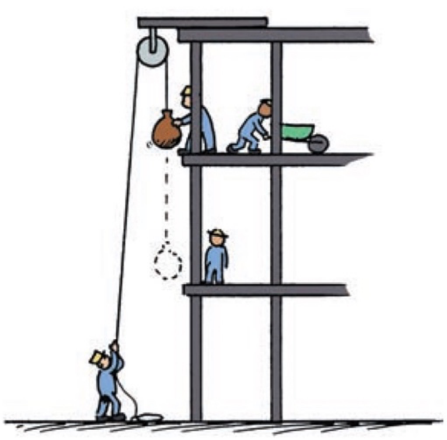

Figure A
Compared with the work done in lifting a load one story high, twice as much works is done in lifting the same load two stories high. Twice the work is done because the distance is twice as much.

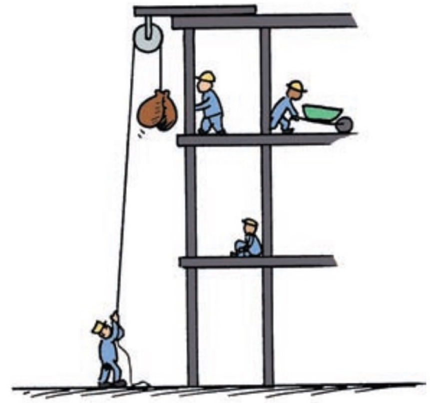

Figure B
When twice the load is lifted to the same height, twice as much work is done because the force needed to lift it is twice as much.

When a weight lifter raises a heavy barbell, he does work on the barbell. Interestingly, when a weight lifter simply holds a barbell overhead, he does no work on it. He may get tired holding the barbell still, but if the barbell is not moved by the force he exerts, he does no work on the barbell. Work may be done on his muscles as they stretch and contract, which is force × distance on a biological scale. But this work is not done on the barbell. Lifting the barbell is different than holding the barbell.

Figure C
Work is done in lifting the barbell. Lifting it twice as high requires twice as much work.

The unit of work combines the unit of force (N) with the unit of distance (m), the newton-meter (Nm). We call a newton-meter the **joule** (J) (rhymes with cool). One joule of work is done when a force of 1 newton is exerted over a distance of 1 meter, as in lifting an apple over your head. For larger values we can speak of kilojoules (kJ), thousands of joules, or megajoules (MJ), millions of joules. The weight lifter in Figure C does work in kilojoules. The work done to vertically raise a heavily loaded truck can be in megajoules.

Figure D
He may expend energy when he pushes on the wall, but if the wall doesn't move, then no work is done on the wall.

Concept Check

1. How much work is needed to lift an object that weighs 500 N to a height of 4 m?
2. How much work is needed to lift it twice as high?
3. How much work is needed to lift a 1000 N to a height of 8 m?

Check Your Answers

1. $W = F \times d = 500 \text{ N} \times 4 \text{ m} = 2000 \text{ J}$.
2. Twice the height requires twice the work. That is, $W = F \times d = 500 \text{ N} \times 8 \text{ m} = 4000 \text{ J}$.
3. Lifting twice the load twice as high requires four times the work. That is, $F \times d = 1000 \text{ N} \times 8 \text{ m} = 8000 \text{ J}$.

Lifting a load quickly is more of a challenge than lifting the same load slowly. If equal loads are lifted to the same height, one quickly and the other slowly, the work done is the same. What's different is the *power*. **Power** is equal to the amount of work done per the time it takes to do it:

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

By analogy, if you think of work as money, then power is the rate at which you spend that money. Consider two cars, one with an engine twice as powerful. Both cars can reach a speed of 50 mph. However, the car with the doubly powerful engine can reach that speed in half the time. Car racing fans are impressed with the "power" of the race car engines. Likewise, fans of the 100-meter dash are impressed by the "power" of the sprinter's muscles. In each case, greater power means the *same* amount of work can be performed more quickly.

Figure E

A space rocket burns fuel at an enormous rate to generate the power needed to lift it against gravity.

The unit of power is the joule per second, called the **watt**. This is in honor of James Watt, the eighteenth-century developer of the steam engine. One watt (W) of power is consumed when one joule of work is done in one second. One kilowatt (kW) equals 1000 watts. One megawatt (MW) equals one million watts.

Concept Check

1. You do work when you do push-ups. If you do the same number of push-ups in half the time, how does your power output compare?
2. How many watts of power are needed when a force of 1 N moves a box 2 m in a time of 1 s?

Check Your Answers

1. Your power output is twice as much.
2. The power expended is 2 watts:

Reading Check

What do work and time have to do with power?