Lesson 37: Work & Energy

The everyday definition of "work" and the one that we use in physics are quite different from each other.

- When most people think about "work" they think of the job that they have.
  - Although it is possible that a person might be doing the physics definition of work while at his or her job, it is not always the case.
- Like so many other things in physics we have to use an exact definition to really explain what work is. In fact, we have to use **two** definitions of work.

Definition 1:

Work is a transfer of energy.

This is probably the most basic definition possible, but it still has many ways of being interpreted.

- Let's say you are running up some stairs when you trip and fall back down the stairs.
  - At first the **chemical potential energy** in your muscles was being converted into **kinetic energy** as you moved *and* **gravitational potential energy** of being higher up.
  - When you fell, the **gravitational potential energy** of being high up changed into **kinetic energy** as you fell faster and faster down the stairs.
- In both cases, work was happening because energy was changing forms.
- This definition of work can also mean that energy is transferred from one object to another object.
- Can be written as $\mathbf{W = \Delta E}$

> ***For more information...***
> ...about the different kinds of energy mentioned here, you might want to refer back to what you learned about energy in Science 10. These different types of energy will also be discussed in more detail in later lessons on Physics 20.

Definition 2:

Work happens when a force causes an object to move through a displacement.

Be careful with this definition. Some people incorrectly assume that it means a force *is* work.

- Instead, what it really means is that a force exerted on an object can cause work to happen.
- We have to be careful that the object actually has a displacement, otherwise work has not happened.
  - The force and the displacement must point in the exact same direction.

Example 1: I am holding a 2 kg block of cheese in my hands. I walk 12 m to the other side of the room. **Explain** if I did any work.

Since I am holding the cheese up against the force of gravity (F_g), the force I must be applying (F_a) on it will be pointing up ***vertically***. I moved ***horizontally***, so the two vectors (force and displacement) are perpendicular to each other. I didn't do any work.

Example 2: I decide to get my pet frog to do a little weight lifting (but I'm going to start him off slow!). He lifts 10 kg up from the floor, over his head, and back down to the floor. Explain if he did any work.

Well, in this case the force must be pointing up when he lifts up the weights, and at first he's moving them up, so everything seems fine so far. But wait… I said that he then brings the weights back down to the floor. Overall, the displacement of those weights is zero!

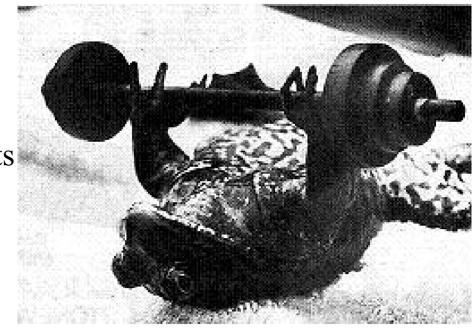

Illustration 1: Froggy!

Example 3: Last winter my car got caught in a snow bank. I promise one of my friends that if he comes over to do some work for me I'll buy him a Whopper (with extra onions… he really likes onions). We get behind the car and push it out of the snow. **Explain** if we did any work.

In this situation, both of us were pushing in the same direction (parallel to each other) and the car moved in that direction. So the answer would be "Yes!" I do owe him a whopper for the work he did… but I'll cut it in half and eat part of it myself since I did half the work.

Example 4: I am holding a 10kg book in my hand. I put it down on the floor. **Explain** if I did any work.

The force and displacement are parallel, but they do not point in the same direction. When I put the book down, I do NOT push the book down; instead, I am pushing upwards while the force due to gravity pulls down. My force is up, the displacement is down, so I didn't do any work. As a note, if you look at it in terms of gravity the Earth did work by pulling the book downwards.

Both of these definitions can be seen in the formulas on your data sheet:

$$W = \Delta E$$
$$W = Fd \cos \theta$$

W = work (Joules)
F = force (Newtons)
d = displacement (metres)
θ = the angle between the Force and Displacement vectors.

- Notice that both of the definitions are shown in the formulas.
  - A transfer of energy means a change in energy (ΔE) is happening.
  - The second formula shows that force and displacement are happening.

The reason for the angle in the work formula is because it is possible for work to be done when the vectors of force and displacement are not parallel.

- The only time that absolutely no work is done is when they are ***exactly*** perpendicular to each other.
- We basically calculate the component of the force vector that ***is*** parallel to the displacement.

- Look at the situation of a person pulling a box on the end of a rope that makes a 30° angle to the ground…

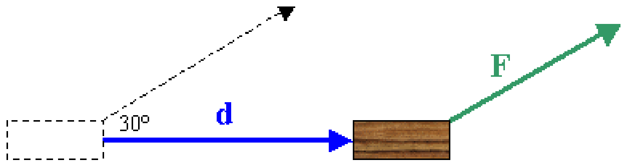

Illustration 2: A force at an angle causing displacement.

- The box moves to the right, and the force is pointing diagonally up. To figure out the x-component of the force, we need to draw a right angle triangle.
  - To figure out F_x we would use cosine, since we have the hypotenuse and we are trying to calculate the the side adjacent to the angle.

$$\cos\theta = \frac{adj}{hyp} = \frac{F_x}{F}$$
$$F_x = F\cos\theta$$

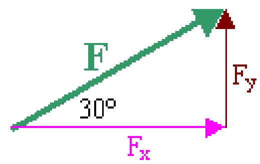

Illustration 3: The force broken into components.

- This just shows that the component of the force that points the same direction as the displacement can be quickly figured out as the the actual force multiplied by the cosine of the angle.
- The formula W = Fd cosθ takes care of that for us.
  - If the force and the displacement are actually parallel, then the angle is 0°...

    cos 0° = 1
    ∴ W = Fd cos 0°
    W = Fd

  - If the force and the displacement are exactly perpendicular to each other then the angle is 90°...

    cos 90° = 0
    ∴ W = Fd cos 90°
    W = 0 J

By definition, 1 Joule of work is done by applying 1 Newton of force to move an object 1 metre.

- Work has no direction, so it is a **scalar** quantity. Do not try to associate the numbers you calculate for work with a direction like “up.”
- But, keep in mind that force and displacement are both vectors, and we must always make sure that we are doing calculations for the two values that are parallel.

Example 5: When they were young, my daughter Katrien grabbed my son Niels by the leg and dragged him 2.3 m across the floor. If she exerted a force of 8.1 N to do this, **determine** how much work she did.

Since the angle between the force exerted and the displacement is zero, the cosine of the angle will be one.

$W = Fd\cos\theta = F\,d = 8.1\,(2.3) = 18.63 = 19\ J$

Illustration 4: Katrien and Niels.

When you look at the answer you just calculated, you'll also want to keep in mind the first definition of work.

- Since work is a transfer of energy it applies to the example above. Katrien is transferring chemical energy stored in her body into kinetic energy of Niels going across the floor.
- This definition is also useful if you know something about how energy is changing forms.

Example 6: You are pulling a box with a rope at a 30.0º angle from the ground (as shown in Illustration 2). The box moves 12.7 m when you pull along the rope with a force of 76.0 N. **Determine** how much work you did.

$$W = F\,d\cos\theta$$
$$= 76.0\,(12.7)\cos 30.0°$$
$$W = 835.8877 = 836\ J$$

Homework

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