Physics 101 Activity
6: Work and Energy

Doing Work

Suppose two objects (Object A and Object B) exert forces on each other. If Object A exerts a force on Object B, and Object B moves in the direction of this force, then we say that Object A *does work* on Object B. Similarly, Object B may do work on Object A. Perform each of the brief experiments described below and answer each question "Yes" or "No", and provide a brief explanation.

1. Push a large book across the surface of your table. Do you do work on the book?

2. Lift a large book up into the air. Do you do work on the book?

3. Roll a small metal ball across the table. Is any work done on the ball while it is rolling?

4. Push down on the table with your hand. Do you do work on the table?

We will now look at the quantitative definition of work. We will focus on the special case in which the motion of the object (if it moves) is in the same direction as the force exerted on the object. In this case the amount of work done on the object is equal to the force exerted on the object times the distance the object moves, or

$$\text{work} = \text{force} \times \text{distance} = Fd.$$

The metric unit of work is the Joule (J), where 1 J = 1 N·m.

5. If you lift a 17 N book at an unchanging speed, the net force on the book must be ____.
   (a) zero
   (b) a little less than 17 N
   (c) 17 N
   (d) a little more than 17 N

6. To lift a 17 N book at an unchanging speed, what magnitude force must you exert on the book?
   (a) zero
   (b) a little less than 17 N
   (c) 17 N
   (d) a little more than 17 N
7. Calculate how much work you do on the book in the previous question if you lift it from ground level to a height of 2 m. Note: it wouldn't hurt to go ahead and do the experiment, so that you get a physical sense of what doing this much work is like.
8. If you now allow the book to push your hand back down to ground level (at an unchanging speed), how much work does the book do on your hand?

Energy

We saw in the last section that a raised object (like the book) can do work. In what other situations can an inanimate object do work? Try the following experiment:

9. Throw the tennis ball on your table to another member of the group. Throw the ball fairly hard, but not so hard that they cannot catch it (and certainly not so hard that it might hurt them). Does the tennis ball do work on the hand of the person who catches it?
   (a) Yes, because they can feel it hit their hand.
   (b) No, because the ball does not exert a force on their hand.
   (c) No, because the their hand does not move at all when they catch the ball.
   (d) Yes, because the ball exerts a force on their hand and causes their hand to move.

The ability to do work is a special and useful thing, so we give it the special name *energy*. Quantitatively, the energy of a system is the maximum amount of work that it can do. Note: a *system* just means some particular part of the Universe, such as a particular collection of objects. We have just seen that raised objects and moving objects are both capable of doing work, so they must have energy. But their energy is in different forms. The energy of a raised object (which is caused by the object's gravitational attraction to Earth) is called *gravitational energy*. The gravitational energy of an object is defined to be the object's weight times its height above ground,

$$\text{gravitational energy} = \text{weight} \times \text{height}$$

or

$$\text{GravE} = wt \times ht.$$

10. Calculate the gravitational energy of a 17 N book that is 2 m above the floor. Show that the gravitational energy of the book is exactly equal to the amount of work that the book does in Question 8.

The maximum amount of work that can be done by a moving object, which we call the object's *kinetic energy*, is given by

$$\text{kinetic energy} = \frac{1}{2} \times (\text{object}'\text{s mass}) \times (\text{square of object}'\text{s speed})$$

or

$$\text{KinE} = \frac{1}{2}ms^2.$$

11. If the speed of a moving object is doubled, what happens to the object's kinetic energy?
    (a) it is decreased by a factor of 2
    (b) it does not change
    (c) it is increased by a factor of 2
    (d) it is increased by a factor of 4

12. Look back over the examples we have discussed where work was done on an object. Consider the object's gravitational and kinetic energy. When work is done *on* an object that object's energy _____. When work is done *by* an object that object's energy _______. This is known as the *work-energy principle.*
    (a) increases . . . increases
    (b) decreases . . . decreases
    (c) decreases . . . increases
    (d) increases . . . decreases

Conservation of Energy

Let's take a closer look at the situation of a falling book. If a 17 N book is released 2 m above the ground it will fall to the ground. As it falls it will accelerate at about 10 m/s^2 according to Galileo's Law of Falling.

13. What is the mass of this book?
    (a) 170 kg
    (b) 17 kg
    (c) 1.7 kg
    (d) 0.17 kg

14. How long will it take for the book to hit the ground? Recall that $d = (1/2)gt^2$ for a freely falling object, where $g = 10$ m/s^2.

    (a) 0.2 seconds
    (b) 0.4 seconds
    (c) 0.447 seconds
    (d) 0.632 seconds

15. The book is accelerating at 10 m/s^2 during this time, so we can calculate its change in speed (average acceleration equals change in speed divided by elapsed time). Since the book started from rest, the change in its speed is just its final speed before hitting the ground. What is the book's speed just before hitting the ground?

    (a) 2 m/s
    (b) 4 m/s
    (c) 4.47 m/s
    (d) 6.32 m/s

16. Calculate the book's kinetic energy just before it hits the ground. Compare this to the gravitational energy that the book started with (see Question 10).

Note that the book's final kinetic energy is equal to its initial gravitational energy. This is a consequence of the *law of conservation of energy*. This law states that energy is never lost or gained. Energy can be transfered from one object to another, or it can change from one type of energy to another, but it is never created nor destroyed.

The Roller Coaster and the Cannonball

To get a better feel for how conservation of energy works, your group should look at the two animations listed in the online components for Activity 6. First watch the Roller Coaster Animation. You can click on the animation to make it play again. Watch the bars that show the coaster's kinetic energy (orange), gravitational energy (blue), and total energy (green). Notice how the kinetic and gravitational energies change, but the total energy (which is the sum of the kinetic and gravitational energies) does not change.

17. When does the roller coaster have its maximum kinetic energy?

    (a) When it is at ground level.
    (b) When it has its minimum gravitational energy.
    (c) When it gets to the bottom of the initial downhill section.
    (d) All of the above.

Now watch the Cannonball Animation. Again notice how the kinetic energy (red) and gravitational energy (blue) go up and down, but the total energy (green) stays the same.

18. The minimum kinetic energy of the cannonball in this animation _____.
    (a) is zero and occurs when the cannonball returns to ground level
    (b) is zero and occurs when the cannonball is at its peak
    (c) is greater than zero and occurs when the cannonball returns to ground level
    (d) is greater than zero and occurs when the cannonball is at its peak

19. Note that in this case the cannonball starts off with a great deal of some other type of energy (shown in yellow) which quickly turns into kinetic energy when the cannon is fired. What do you think this third type of energy might be? In other words, what is it that does work on the cannonball to give it the kinetic energy it has when it emerges from the cannon?

Bouncing Tennis Balls

Now we are going to perform a little experiment. One member of your group should hold a meter stick so that the zero marking is at ground level and the meter stick extends straight up. Another member of your group should hold a tennis ball so that the bottom of the ball is level with the top of the meter stick, then release the ball and let it fall to the floor. Try to determine the maximum height reached by the bottom of the ball on its rebound from the floor. You may need to do this a couple of times to get a good measurement.

20. What height did the bottom of the ball reach after it bounced from the floor?

21. How much gravitational energy did the ball have before it was released? You may assume that the ball has a mass of 1 kg.

22. How much gravitational energy did the ball have when it reached its maximum height after bouncing from the floor?

23. How much kinetic energy did the ball have when it reached its maximum height after bouncing from the floor?

24. How much energy was lost by the ball when it bounced on the floor?

Types of Energy

Does the previous experiment violate the law of conservation of energy? Before we answer this question we need to discuss the different forms of energy. These are listed below.

Kinetic Energy (KinE) Energy due to the motion of an object.

Gravitational Energy (GravE) Energy due to gravitational forces.

Elastic Energy (ElastE) Energy in an elastic object (like a rubber band or a spring) that is stretched.

Thermal Energy (ThermE) The energy of a hot object. Recall that the temperature of an object is really a measure of the speed at which the molecules that compose the object move. So thermal energy is really just kinetic energy on a microscopic scale. For convenience, we'll keep microscopic and macroscopic motion separate in out discussion of energy.

Electromagnetic Energy (ElectmagE) Energy due to electromagnetic forces (more on this later).

Radiant Energy (RadE) Energy of light (more on this later).

Chemical Energy (ChemE) Energy due to the structure of molecules.

Nuclear Energy (NuclE) Energy due to the structure of the atomic nucleus (more on this later).

25. Place a piece of paper on your table and use your hand to rub the paper back and forth across the table's surface. Press down hard, rub vigorously, and keep it up for a little while. Then have another member of the group touch spot on the table that you just rubbed as well as a spot on the table that is far away from where you rubbed. You did work on the paper (you exerted a force on it and it moved), but the paper did not gain any kinetic energy or gravitational energy. We have said that when you do work on an object you increase its energy. What energy did you increase?

    (a) The nuclear energy of the paper.
    (b) The thermal energy of the paper and the table.
    (c) The elastic energy of the table.
    (d) The chemical energy of the paper and the table.

26. In light of the previous experiment, where do you think the energy that was "lost" in Question 24 actually went?

    (a) The lost energy went toward increasing the chemical energy of the ball.
    (b) The lost energy went toward increasing the nuclear energy of the ball.
    (c) The lost energy went toward increasing first the elastic energy of the ball, and eventually the thermal energy of the ball and the floor.
    (d) The lost energy was really lost. It just disappeared altogether.

Reflecting on the Law of Conservation of Energy

27. If you only consider the kinetic energy and gravitational potential energy of the tennis ball that you dropped earlier, then you would have to conclude that the ball's energy is not conserved. In the previous question, though, you may have argued that in fact the energy was not lost but rather was converted into another form of energy. Does this make it impossible to falsify the Law of Conservation of Energy? For example, if you did an experiment in which you kept track of every type of energy you knew about and still found that energy was not conserved could you always explain this away by proposing that there is some new form of energy of which you were not keeping track?[1]

28. In Imre Lakatos' view of science there are *core theories* that scientists are unwilling to modify, and then there are other theories or models that scientists are more willing to modify. The other theories or models form a *protective belt* that keeps the core theories from ever being falsified because any failure is blamed on the protective belt ideas rather than on the core theories. Which of the following would constitute a core idea, and which would be part of the protective belt. Explain your answer.

    - The idea that the total energy is always conserved in a closed system.
    - The idea that the total energy is the sum of the types of energy listed in the previous section.

[1]As you will read about in Section 6.5 of the text, this is an important issue. The refusal to believe that the Law of Conservation of Energy could be wrong led physicists to postulate the existence of an unknown particle called a *neutrino*. This particle was later detected experimentally and the 2005 Nobel Prize in physics was awarded to people who pioneered "neutrino astronomy."