Chapter 2: Force, Energy, and Work

Time Required:

Text reading - 30 minutes
Experimental - 1 hour

Experimental Pre-setup:

NONE

Additional Materials:

Fresh fruit such as a banana, apple, or orange

Overall Objectives:

This chapter will introduce the students to the fundamental concepts of force, energy, and work. These concepts can be difficult to understand. It is not important that the students completely grasp everything about these concepts. This chapter is only a qualitative introduction and the students should be encouraged to think about them but not necessarily understand all of their subtleties.

2.1 Introduction

This section introduces the terms energy, work, and force.

Discuss with the students their own ideas about the terms work, energy, and force.

Ask them:

> What is energy?
> Can energy be created or destroyed?
> What happens to the energy in a battery when the battery dies?
> What is work?
> When you move bricks from the front yard to the back yard- is that work?
> Is lifting a book work?
> Is dropping a book work?
> What is force?
> Can you give some examples of force?

Most of their answers may not be correct and they may have some misconceptions about energy, work, and force. For example, the energy in a battery is not destroyed when it dies. The usable energy has only been converted into a form that cannot be used any longer. This is a common misconception; students will better understand the nature of energy by examining this misconception.

2.2 Force

This section examines the nature of force in more detail. By definition a force is something that:

> changes the position, shape, or speed of an object.

Using this definition, discuss with the students some of the forces they experience every day. For example:

> What happens when they jump?
> What happens when they collide with another player on the football field?
> What happens when they lift a heavy object?
> What happens when they drop a heavy object?
> What happens when they pull or push on a door?
> What happens to a marshmallow when they squeeze it?
> What happens to a steel ball when they squeeze it?

Explain to them that, in all of these examples, forces are acting.

Discuss gravitational force. Gravitational force is an attraction between any two bodies with *mass*.

Mass has two very important roles in physics. First, as in the paragraph above, any two bodies with mass will attract each other by gravitation. So, the amount of mass determines how strong gravitational forces are. Big objects with large masses attract each other much more than smaller objects with small masses. The *weight* of any object is the gravitational attraction between the object and the earh (as measured at the earth's surface). So *weight* is a force, not a mass. Note that the English unit of weight, pounds, is a unit of force while the metric unit, kilograms, is a unit of mass.)

Second, the mass of an object controls its inertia, the tendency of any body to resist movement when acted on by a force. A body with a large mass will accelerate slowly when acted on by a force, but a body with a small mass will accelerate quickly when acted on by the same force. At first glance, this seems like a completely different property than gravitational attraction and it is indeed a very strange fact that one property of matter, mass, controls two seemingly different things. The fact that *gravitational mass* and *inertial mass* are the same is called the Equivalence Principle. The equivalence principle is the basis for Einstein's theory of gravitation (also called General Relativity). Both inertia and gravitation arise from one thing -- the curvature of space itself!

The students will look at inertial mass in more detail in Chapter 4.

The force due to gravity is:

$$F = G * m_1 m_2 / d^2$$

where G is the universal gravitational constant, m_1 is the mass of the first body, m_2 is the mass of the second body, and d is the distance between the two bodies.

We can see from the equation that a body that has more mass will have a greater force. Explain to the students that because their mass is so much less than the mass of the earth their gravitational force is much smaller and so they cannot pull the earth towards them. This is why they come back to the earth when they jump rather than the earth shifting upwards to meet them. (Do they think it might be possible to shift the earth by having everyone jump at the same time? Why or why not?)

2.3 Balanced forces

Explain to the students that, when objects aren't moving, forces are balanced.

The most fundamental equation defining force is Newton's Third Law of Motion:

$$F = ma \text{ or } a = F/m$$

where F is force, m is mass and a is acceleration. This equation says that the force exhibited by an object is equal to its mass times its acceleration. This equation shows that if the acceleration of an object is zero, then the net force acting on that object is also zero. Or conversely, a force acting on an object causes it to accelerate. For a given force, an object of small mass will acclerate more than an object of large mass.

Explain to the students that, in the drawing, a ball is sitting on a shelf. You can see from the diagram that the arrows point in opposite directions. The ball is pushing down on the shelf but at the same time the shelf is pushing up on the ball. Point out to the students that the forces are equal but acting in opposite directions.

In this case, the ball does not move and so the net force is zero.

F_{net} = [force of the ball pushing down] - [force of the shelf pushing up] = zero.

The forces are balanced, i.e., they cancel each other out.

Explain to the students that objects that are moving but not *accelerating* also have balanced forces. Discuss the diagram with the hockey puck and show them that, although the hockey puck is moving, it is not *accelerating*.

2.4 Unbalanced forces

When forces become unbalanced the object will accelerate. Acceleration is the change of an object's speed over time, like a car speeding up from a stop light or a ball speeding up when it is dropped. An object's speed also changes when it slows down, so slowing down is also a form of acceleration. Just as a massive object is hard to speed up, it is also hard to slow down.

Discuss with the students some examples of unbalanced forces:

> Does a ball thrown in the air have balanced or unbalanced forces? Why? *unbalanced because it speeds up and slows down.*
>
> Does an airplane when it takes off have balanced or unbalanced forces? *unbalanced - speeds up to take off*
>
> Does a car going from a stoplight have balanced or unbalanced forces? *unbalanced*

2.5 Work

The concept of work may be difficult to understand because when we hear the word "work," we think of mowing the lawn or doing the laundry. However, in physics, work is defined as:

work = distance x force

The illustration in the student text shows that, for the same amount of force, the work a short weight lifter does is less than the work a tall weight lifter does because the distance is less for the short weight lifter.

Discuss with the students other examples relating work, distance, and force. For example:

> If you carry a box of books up one flight of stairs and your brother carries the same box up two flights of stairs, who has done more work? (*your brother*) How much more work has he done? (*exactly twice the amount of work*)
>
> If you carry a box of books up one flight of stairs and your brother carries a box of books that has half the mass up one flight of stairs, who has done more work? (*you have*) How much more? (*exactly twice as much*)

Help the students think of some of their own examples. The more examples they can discuss the more they will understand the relationship between work, distance, and force.

2.6 Energy

Energy is another concept that can be difficult to grasp because when we hear the word "energy" many different ideas come to mind. Energy basically gives objects the ability to do work. The different kinds of energy, such as potential energy, kinetic energy, and heat energy, will be discussed in more detail in later chapters. What is important for the students at this point, is for them to begin thinking about where the ability for an object to do work comes from.

Ask the students to list some forms of energy that they are familiar with and discuss with them what kind of energy they think might be used.

What do you need to make a car run? *gasoline (chemical energy)*
What do you need for a flashlight? *batteries (chemical energy)*
What do you need for a CD player? plug into an outlet *(electrical energy)*
What do you need to carry books up a flight of stairs? *muscles (mechanical energy), food (chemical energy)*

2.7 Summary

Go over the summary statements with the students. Discuss with them any questions they might have.

NOTES:

Experiment 2: Fruit Works? Date: ______

Objective: ______________________________

Hypothesis: ______________________________

Materials:

- slinky
- paper clips (2)
- apple
- lemon or lime
- banana
- ruler
- balance or food scale

Experiment:

1. Try to decide, just by "weighing" each piece of fruit in your hands which piece will do the most work and which piece will do the least work on the spring.
2. Write down your prediction stated as the Hypothesis.
3. Now weigh each piece of fruit on the balance or food scale.
4. Record the weights on the chart below.

In this experiment the students will try to determine how much work a variety of fruit can do. Remind the students that:

work = distance x force

Have the students read the entire experiment and then help them think of possible objectives. For example:

> Using a slinky, we will find out if a banana can do more work than an orange.
>
> We will measure the work fruit can do.
>
> We will find out if two bananas do more work than one.

Have the students make a guess about which fruit can do more work. They should be able to tell just by weighing the fruit in their hands which one is the heaviest. Have them state these in the Hypothesis. For example:

> A banana is heavier than a lemon and will do more work.
>
> An orange is lighter than the apple and will do less work.
>
> Two bananas will do more work than one banana because two bananas weigh more.

Using a food balance or a small scale, have the students weigh each piece of fruit and record their weights in the chart.

Fruit	Weight (oz. or g.)

5. Next, take the paper clip and stretch one side out to make a small hook.
6. Place the hook in one of the pieces of fruit.
7. Hold the slinky up to the level of your chest and allow 10 to 15 coils to exist below. You will have to hold most of the slinky in your hand.
8. Measure the distance from the floor to the bottom of the slinky with the tape measure. Record your result below.

Distance from floor to slinky

____

9. Now place the piece of fruit that has the hook in it on the slinky and allow the slinky to be pulled out by the fruit.
10. Measure from the end of the slinky to the floor with the tape measure and record your results below.
11. Repeat with each piece of fruit. Record your results below.

After the students have recorded the weights of the fruit, have them use the paper clips to create hooks for the fruit. We found the paper clips worked fairly well, but the younger kids found tape more effective. The fruit can be fixed to the slinky in any manner.

The students will have to experiment with the slinky and number of coils. We found that having the students hold most of the coils in their hands and allowing only a few to fall below worked fairly well. Also, instead of holding the slinky, it can be attached to the branch of a tree or some other fixed ledge. Just make sure the slinky is free to extend and does not contact any other surface.

Have the students first measure the distance from the end of the slinky to the floor without a piece of fruit on it. The distance should be around 2 or 3 feet. Make sure that once this distance is measured, the number of coils allowed to extend is not altered. If the distance is too short (that is the fruit extends the slinky to the ground) reduce the number of coils used and remeasure the distance to the floor.

Have the students fix the fruit to the last coil in the slinky and allow the coils to extend. Have them measure the distance from the ground to the bottom of the piece of fruit.

Fruit	Distance from floor to slinky	Distance extended

11. Subtract the distance you recorded in step 8 from each of the distances you measured and recorded above. This gives you the distance each piece of fruit has extended the slinky.

12. Calculate the work each piece of fruit has done. Record your answers in the chart below

Fruit	Work

13. What would happen if you put two pieces of fruit on the slinky? Test your prediction and record your answer below.

(2)Fruit	Distance from floor	Distance extended	Work

Have the students subtract the distance the slinky extended without any fruit on it from the distance it extended with the fruit on it. This will give the net displacement. Have them record this in the column marked "Distance extended."

Have the students calculate the work each piece of fruit has done. They calculate this by using the equation;

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

Force is the weight of the fruit.

Now have them predict what would happen if they placed two bananas or two oranges on the slinky. They should predict that two pieces of fruit will do exactly twice the amount of work. Have them test this prediction by fixing two pieces of fruit to the slinky and measuring the distance the slinky extends. Have them record their results.

14. Make some conclusions about your results and record them below.

Conclusions:

Help the students make valid conclusions about their results. Also help them record any problems they may have encountered. For example:

The banana did more work than the orange.

Two bananas did twice the work of one banana.

Two bananas did not do twice the work of one banana.

The slinky extended too far and we could not measure two piecees of fruit.

The apple and orange weighed the same and did the same amount of work.

Challenge question:

In the Review there is a challenge question. Have the students think about whether this would be possible and then help them do a rough calculation.

The mass of the earth is 5.98×10^{24} kg.

The mass of an average human is 66 kg.

According to the US Census the world population is 6,341,930,833. *http://www.census.gov/cgi-bin/ipc/popclockw*

Total mass of people = # people x mass per person = (6,341,930,833)(66kg) = 418,567,434,978 kg $\approx 4 \times 10^{11}$ kg.

Answer = *NO*- there are not enough people.

Review

Define the following terms:

force — something that changes position, shape, or speed of an object

work — work = distance x force

energy — gives objects the ability to do work

Circle the correct answer:

Which object has the greater gravitational force:

a banana or a (bowling ball)
a (car) or a bicycle
the moon or the (earth)
the earth or the (sun)

Answer the following questions:

Is a book sitting on a shelf doing work? *No*
Is a bowling ball crashing into the pins doing work? *Yes*
How much work is done if you lifted a 3 lb box 2 feet? *6 lb-feet*
How much work is done if you lifted a 2 lb box 3 feet? *6 lb-feet*

List some forms of energy

potential energy *chemical energy* *electrical energy*

Challenge:

Do you think if we could get every person on the earth to jump all at once we could move the earth? Why or why not? Can you do a rough calculation?

NOTES: