LESSON 7: MOTION

7–1 LET'S GET MOVIN'
Content on the Energy of Motion

It Depends on How You Look at It

Look over at someone's desk in the classroom. Is it moving? Do you witness any motion from the desk? If you answered yes or no to those questions, you are right. This is because the motion of an object depends on the frame of reference you use to evaluate that object. The desk is at rest if you judge it relative to the floor or to yourself; but it is in motion relative to the sun. Since it is located on the earth, the desk is revolving around the sun continuously. Actually, no object on the earth is ever at rest relative to the sun.

For the purpose of our discussions on motion, we will use the earth rather than the sun as our frame of reference. When objects on the earth are placed in motion, they travel certain distances in a given time. The distance an object travels in a given time frame is called speed. Speed is determined by the following formula: speed = distance divided by time $(S = d/t)$.

Is It Speed or Is It Velocity?

There are two types of speed we need to consider in our discussion—instantaneous and average. Instantaneous speed is an easy concept to grasp if you think of a speedometer on a car. The speedometer is registering the speed at that particular instant you are looking at the dial. Unless the car has a cruise control monitor, there will be some fluctuations in the speed over time. Red lights and stop signs and slower motorists dictate that the instantaneous speed will vary. Average speed is the concept that we discuss more often when traveling. Average speed is the total distance an object travels over the total time span it took to achieve this distance. If you went on a trip across the country and wanted to figure your average speed, you could do this by watching your odometer (distance dial on the speedometer) and your watch. Let's say you went 80 miles in 90 minutes. What would your average speed be? Eighty miles divided by 90 minutes would give you speed in miles per minute. Your average speed was 0.89 miles/minute, or you could figure your answer in miles per hour by dividing 80 miles by 1.5 hours. Your average speed would be 53.33 miles/hour.

Most people think of speed and velocity as the same concept. And to everyone but the physicist, this may be true. In physics, velocity is the speed in a given direction. Velocity is determined by dividing the displacement by the time. Displacement is the length and direction of an object's path from its starting point straight to its ending point.

This means that the speed and velocity of an object may be different depending on the route you took to get to your destination. It might be easier to understand this if you pictured a walk with your beagle dog from your house to your grandmother's house. You would probably stay on the sidewalk and walk directly from your house to your destination by using the shortest route. Your beagle would probably veer off the sidewalk and sniff a few trees and run after a couple of rabbits on the trip. This would increase the distance the dog traveled but not his displacement. Therefore, the speed of the dog would be different from your speed, whereas the velocity for both of you would be the same if you both arrived at the house at the same time.

When computing velocity, you not only state the magnitude of the velocity but also the direction traveled. Magnitude and direction traveled are called vector quantities in physics, whereas magnitude without direction is called a scalar quantity. Speed is a scalar quantity and velocity is a vector quantity.

Let's return to our walk with the beagle to reinforce these concepts. It is 4 miles to your grandmother's house by the shortest route you can travel. She lives due west of your home. You and your dog, Doc, accomplished this mileage in 60 minutes. You took the straight path of 4 miles, but Doc logged in 6 miles as he veered off the path for some rabbit-hunting adventures. Your speed was 4 miles/hour. Your velocity was 4 miles/hour west. Doc's velocity was 4 miles/hour west, but his speed was 6 miles/hour (distance traveled divided by time).

There's No Cruise Control on Roller Coasters

Another vector quantity we need to mention is acceleration. Acceleration is the rate of change in velocity. Since acceleration is a vector quantity, it can involve a change in speed, a change of direction, or both. Have you ever experienced or felt acceleration? If you have braved the amusement park's roller coaster rides you have experienced acceleration. Changes in speed can be detected easily as you feel your body jarred about as the roller coaster slows down and speeds up. The formula for finding the magnitude of acceleration is as follows: acceleration equals change in velocity divided by time, or a = final velocity – initial velocity/time for change in velocity. Acceleration can be represented by either negative or positive numbers. When objects speed up, you have positive acceleration. When objects slow down, you have negative acceleration (known as deceleration). Think about the next three situations.

Situation 1—You have a new set of "wheels." You want to try them out to see what the new car can do. You begin at a stop sign and press the accelerator as you move south on Main

Street. You find that your speedometer reaches 60 miles/hour after 4 seconds. What was the acceleration of your new car?

Situation 2—You are out for your nightly jog. You are jogging along at a constant 3 meter/sec pace. A car turns sharply in front of you, and you have to stop suddenly to avoid being struck. Your sneakers skid to a dead stop in 0.9 seconds. What was your deceleration?

Situation 3—You go to the oval-shaped dirt race track to do a little practice driving. You keep your car at 90 miles per hour for 10 seconds without changing your speed. Was the car accelerating? If so, explain why.

You have jostled your brain cells to solve these problems. Let's see if your solutions were correct. In situation 1, you should have answered that the acceleration of the car would be 0.00417 miles per second square. In situation 2, your acceleration was negative. You should have come up with a negative 3.3 meters per second^2. Finally, in situation 3, the car was accelerating due to a change in direction on the oval track.

Solutions

Situation 1—To solve this problem, you must change miles/hour to miles/second or either change seconds to hours. Let's change miles/hour to miles per second. 60 miles/hour divided by 3600 sec = 0.01667 miles/sec. Now use the miles per second in the acceleration formula:

$$a = 0.01667 \text{ miles/sec} - 0/4 \text{ sec} = 0.00417 \text{ miles/sec}^2.$$

Situation 2—$a = 0 - 3$ miles/sec/0.9 sec = $-3/0.9 = -3.3$ miles/sec^2.

Situation 3—The car was accelerating even though the speed was not being changed, because acceleration is a vector quantity. Vector quantities are also affected by changes in direction, which occurred on the oval track.

Free Fall

The last concept we want to examine is free fall. Objects that fall downward toward the earth due to the pull of gravity fall with the same acceleration regardless of their mass. This is acceleration due to gravity, *g*. Ten meters per second squared is the acceleration due to gravity for objects falling toward the earth. If you were to climb to the highest building in your town and drop a tennis ball and a bowling ball off the building at the same time, they would both hit the ground at the same time. This is because they both maintain equal accelerations due to the pull of gravity and the effects of inertia. Later in this lesson we will work out some problems dealing with this concept.

Inertia and Newton

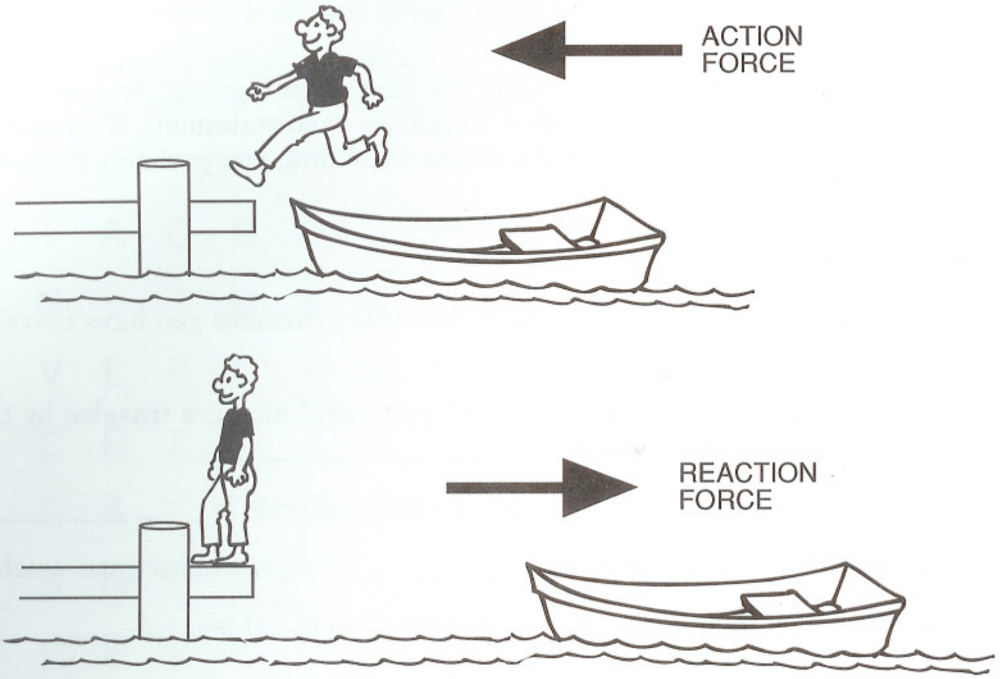
No discussion of motion is complete without the mention of Newton's three laws of motion. Newton's first law of motion is called the law of inertia. It states that an object at rest will remain at rest and an object in motion will remain in motion unless some outside force acts on it. The term *inertia* means "a resistance to change" and often is the measure of the mass of a substance. To understand the first law of motion, imagine a boulder on the edge of a cliff. It remains perched on the edge unless something or someone nudges it forward. This force could be a person pushing it or a vibration of the earth. Or imagine that your car hits the car in front of you and you lunge forward until the force of your seat belt stops your forward motion.

It's a Matter of Mass

The second law of motion says that the acceleration produced by the net force on a body is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the body. Or, to shorten this explanation, think of this formula: acceleration = net force/net mass ($a = f/m$). You can turn this formula around and say that $F = m \times a$ or $m = F/a$. To understand this concept, think of a golf ball on a tee. The more force you use to strike the golf ball, the greater the acceleration of the ball. Now think of a lead ball on the tee. You might increase the force you use to hit the ball but not reach the acceleration you did before because of the great increase in mass of the object being moved. In other words, acceleration is directly proportional to force (if you increase one, you increase the other). Mass is inversely proportional to acceleration (if you increase the mass, you will decrease the acceleration if the force is not altered upward). The second law of motion might help to explain why race cars are built of light-weight materials like fiberglass to hasten acceleration. It is important to remember that forces applied to an object may be resisted by friction. Friction is a force that always acts in a direction to oppose motion. Greater masses may experience more friction when being moved than lighter masses. The surface on which the object is resting will dictate the amount of friction involved. Air resistance is also a type of friction. For objects that fall downward through the atmosphere, air resistance does not present a problem unless the mass of the object is so light that air currents can slow its progress (like feathers and pieces of paper).

Actions and Reactions

The third law of motion is the law that is mentioned most often. It states that whenever one body exerts a force on a second body, the second body exerts an equal and opposite force on the first. In laypeople's terms, for every action there is an equal and opposite reaction. Forces always occur in pairs. As you walk across the floor, you push down on the floor and the floor pushes back up on you. As a rocket fires out gases that push on the air molecules, the air molecules push back, propelling the rocket upward. The force that initiated the reaction is called the action force. The force that responded to the initial action is called the reaction force. You might have experienced this law of motion in a frightening way the first time you jumped from a row boat toward the bank of a pond. As you jumped forward off the front of the boat, the boat floated backward in response to your forward push. Hopefully, you took this into account as you leaped forward, or you might have gotten a little wet on your journey.



THIRD LAW OF MOTION

WORD FIND—VOCABULARY ACTIVITY ON *LET'S GET MOVIN'*

Directions

Read the following statements and determine the best word to complete each statement. Circle the word on the Word Find Puzzle that completes each statement. If you cannot find a word horizontally, vertically, or diagonally in the word find, you probably have an incorrect answer for the statement.

1. Distance divided by time is known as ______________________.
2. What device on a car registers the magnitude of the distance you have traveled on a trip? ______________________
3. What type of speed is determined by dividing the total distance traveled by the total time it took to travel that distance? ______________________
4. Another term for resistance to change or a measure of mass is ______________________.
5. The second law of motion is stated as ______________ equals mass times acceleration.
6. According to the second law of motion, the mass of an object is ______________________ proportional to the acceleration of that object.
7. When deciding if an object is in motion, it is important to determine your ______________________ by which to judge the relativity of that motion.
8. Velocity is defined as the ______________________ divided by the time.
9. When a quantity requires both the magnitude and the direction, it is classified as a(n) ______________________ quantity.
10. The change in velocity divided by the time required to achieve that is known as the ______________________ of that object.
11. The speed of an object at that moment in time only is called the ______________ speed.
12. 10 m/sec^2 is known as the acceleration of an object due to ______________________.
13. In the third law of motion, the force that is a response to the initial force is called the ______________________ force.
14. Negative acceleration is called ______________________.
15. The force that opposes motion when moving objects over a surface is called ______________________.
16. The quantity that expresses magnitude but does not express direction is called a ______________________ quantity.
17. The first law of motion explains that forces are required to initiate motion for objects at ______________________.

Name ______________________________ Date ________________ (7–1)

WORD FIND—VOCABULARY ACTIVITY ON *LET'S GET MOVIN'*

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4. Another term for resistance to change or a measure of mass is ____________________.
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16. The quantity that expresses magnitude but does not express direction is called a ________________________ quantity.
17. The first law of motion explains that forces are required to initiate motion for objects at ________________________.

18. Which law of motion explains why football players who are running backs weigh less than linebackers due to the need for acceleration? ____________________

19. What object is used for the frame of reference if you were to say that a dead mosquito is in motion even though it is lying still on the ground? ____________________

20. Inertia is really a measure of the ____________________ of an object. Objects with greater inertia are often harder to move.

E	I	A	D	S	S	A	M	O	G	R	A	V	I	T	Y
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M	D	I	S	P	L	A	C	E	M	E	N	T	N	J	S
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F	F	R	I	C	T	I	O	N	J	R	A	L	A	C	S

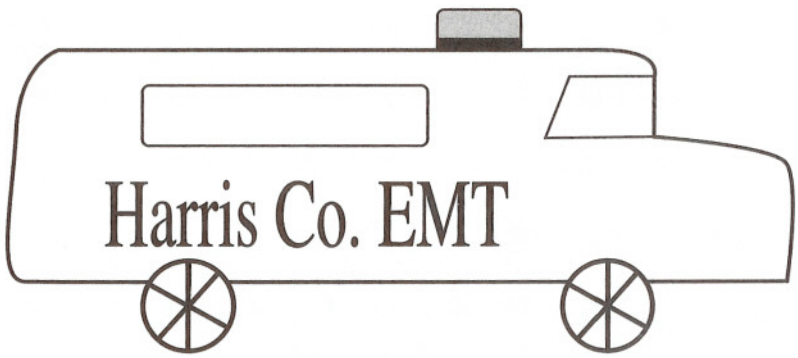
7–2 SOLVING YOUR PROBLEMS IN MOTION
Activity on the Energy of Motion

Objectives

Students will solve physics problems on speed, velocity, and acceleration using the appropriate formulas.

Teacher Notes

Students must read "Let's Get Movin' " to complete this activity. Students may find a calculator helpful. You might want to solve some sample problems on the board before making this assignment.



Solving Your Problems in Motion

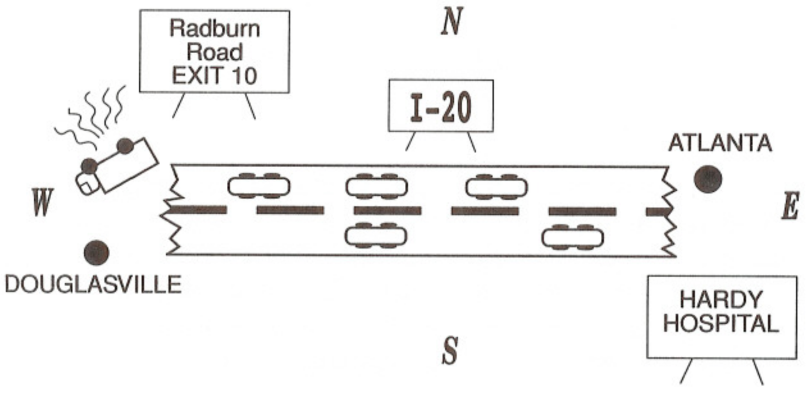
Activity on the Energy of Motion

Directions

Use the information and formulas discussed in the content of *Let's Get Movin'* to solve the following motion problems. Please show your work for each problem in addition to the final answer. If you need additional room for your computations, you may use the back of the worksheet.

I. Read the information below and consult the map to answer the following questions about this paragraph:

Joe works for the Emergency Medical Technician (EMT) team in Atlanta. He is often called on to use his superior driving skills when rushing to the scene of an accident and then delivering the patient back to Hardy Hospital in Atlanta. On May 14, Joe received a call that a car collision had occurred on Radburn Road in Douglasville. Joe knew he must cover the 25-mile distance in as little time as possible. He jumped into his car at 10:00 P.M. and arrived at the scene of the accident at 10:15 P.M. He spent from 10:15 to 11:00 P.M. getting the patient ready to transport. At 11:00 P.M., Joe jumped into his EMT vehicle and started back toward Atlanta with his patient. As he started the engine to leave the scene of the accident, he went from 0 to 60 miles per hour in 2.5 seconds. He had almost made it back to the hospital when a green Volkswagen darted in front of him. Joe slammed on the brakes and went from his 120-mile-per-hour speed to stop in 4 seconds, barely avoiding an accident. Finally at 11:20, Joe arrived safely at Hardy Hospital with his patient.



Questions

1. Give the speed of the trip from Atlanta to Douglasville in (A) miles/min, and (B) miles/hour.

2. Give the speed of the trip from Douglasville back to Atlanta in (A) miles/min, and (B) miles/hour.

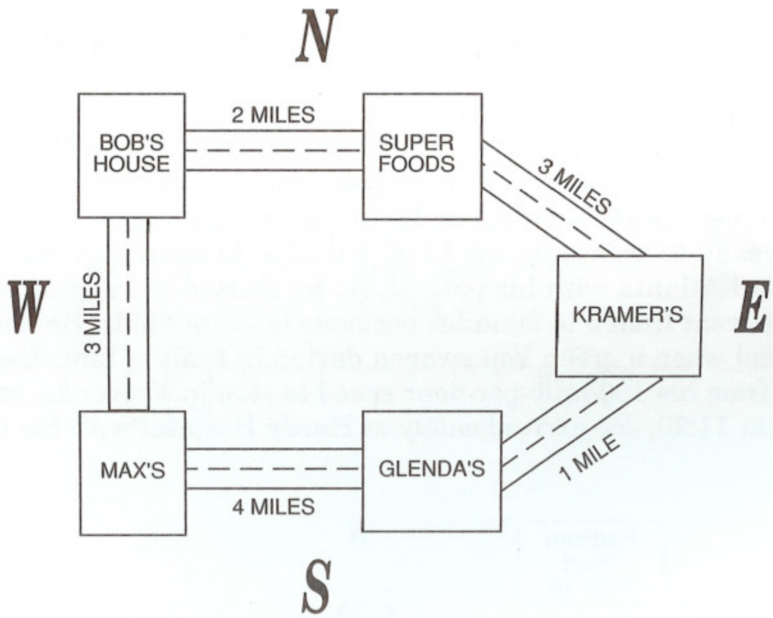
3. Give the velocity of the trip from Hardy Hospital in Atlanta to Douglasville in miles per hour (be sure to include both magnitude and direction).

4. Give the velocity of the trip from Douglasville back to Hardy Hospital in miles/hour (be sure to include magnitude and direction).

5. Give Joe's acceleration in that 2.5-second period when he started from the scene of the accident in Douglasville. Give your answer in (A) miles/hour^2, and (B) miles/sec^2.

6. Give Joe's deceleration as he slowed to avert the accident with the Volkswagen as he returned to the hospital. Give the answer in miles/hour^2.

II. Look at the drawing below and answer the following questions:



Information: Bob leaves home at 9:00 A.M. to run some errands on his bike. He goes directly from his house to Super Foods to pick up some jelly beans. He leaves Super Foods and travels to Kramer's to return some plastic bags for recycling which he received on his last shopping trip. He goes directly from Kramer's to Glenda's clothing store to pick up some black socks. And finally he leaves Glenda's and goes directly to Max's. He arrives at Max's at 11:00 A.M. Now answer the following questions as you look at the map above.

7. Give the distance Bob traveled.

8. Give the displacement of Bob's journey.

9. Give the average speed of Bob's trip in miles/hour.

10. Give the velocity of Bob's trip in miles/hour (be sure to include both magnitude and direction).

III. For the problem below, use this formula to find final velocity: final velocity = initial velocity + (acceleration) (time). Also remember that acceleration of an object that is falling toward the ground due to gravity is 10 m/sec^2.

11. An amateur cliff diver plans to jump off a cliff into the river below. She realizes that injury can result from too high a dive. She needs to know the velocity with which she will strike the water below to judge the danger of the dive. She makes this judgment by dropping a heavy rock off the cliff to the water below. It takes the rock 2.5 seconds to reach the water. Now give her final velocity just before she struck the water.

IV. For the following questions, use the speed = distance/time formula to figure the distance traveled.

12. An airplane travels at 250 miles/hour for 90 minutes. Give the distance the plane traveled in miles.

13. A car travels at 60 miles per hour for 20 miles. Give the time it took for the trip in minutes.

7–3 THE BALL DROP
Lab on the Energy of Motion

Objectives

Students will apply the physics formula relating acceleration, time, and distance in determining the height of a structure by dropping a tennis ball.

Teacher Notes

The structure you select to have the ball dropped from should allow this to be performed without any obstructions to the ball prior to it reaching the ground. Suggestions include the top of the football stadium steps (off the side), top of the basketball bleachers (off the side), from the press box, etc. You will need to do some looking around to find the best location. It is also wise to choose a location that has some data on its actual height when it was constructed. Your administrators might be able to help with this. In this lab the students use tennis balls, but any object heavy enough to overcome air resistance can be used. It's a good idea to work out some problems in class using the distance formula before conducting this lab.

Extension

Give students the actual value of the structure they measured in the lab and have them figure out their percent of error. They should use this formula: observed value – accepted value ÷ accepted value × 100%. For example, if the student found the stadium to be 225 meters tall and you were told by the administration that it was really 260 meters tall, this formula could be used: 225m – 260m/260m × 100% = –35/260 × 100% = –0.142 × 100% = –14.2% error. A discussion could then follow about what caused the error and how to make the measurement more exact.

THE BALL DROP

Lab on the Energy of Motion

Introduction

Formula use is an integral part of physics. It is very important not only to be able to learn formulas and use them in solving word problems, but to be able to apply them to real-life situations. Sometimes distances cannot be measured easily using basic measurement tools (such as the tape measures, rulers, etc.) because measurements can be very inconvenient to make. Let's say you were asked to measure the height of the tallest building in Atlanta, Georgia. You would look pretty funny using a tape measure to achieve that task. But if you knew a little physics, you could achieve a fairly accurate measurement in a matter of seconds. You may be saying, "That's impossible." Let's look at how it might be done. You would need to take the elevator (or stairs) to the roof of the building. You also would need an object such as a golf ball or tennis ball, a stop watch, and a calculator. To conduct your measurement, you would drop the ball off the top of the building and start the stop watch at exactly the same time. As soon as you see the ball strike the ground below, you hit stop on the stop watch. You have just measured the time it took the ball to fall from the building to the ground under the influence of gravity.

This time can then be used in a physics formula that gives you distance. The following formula is used: displacement = 1/2 (acceleration due to gravity) (time) (time), or $\Delta X = 1/2\ (gt^2)$. In this formula, displacement represents the distance from the top of the building to the ground (that is what you are trying to find!). In addition, *g* represents acceleration due to gravity. As we mentioned earlier, all objects fall toward the earth at the same acceleration due to the pull of gravity if they can overcome air resistance. This *g* value is always about 10 meters/sec/sec. Time is the number of seconds it took to complete the fall. When using this formula your answer will come out in meters.

Here is some sample data to help you learn this formula. When you went to the top of the building, let's say it took 15 seconds for the ball to drop to the ground. You would use the formula like this: $\Delta X = 1/2\ (10\ \text{m/sec/sec})\ (15\ \text{sec})\ (15\ \text{sec}) = 5\ \text{m/sec}^2\ (225\ \text{sec})^2 = 1125$ meters. You have thus determined the height of the building using this simple method. You need to remember when performing such an experiment that you cannot use objects like a feather or piece of paper because air resists this acceleration. Obviously, that is an important fact for a person who parachutes out of airplanes. But if you could eliminate air resistance in a container such as a vacuum, you would see that all objects fall at an acceleration of 10 m/sec^2 toward the earth in response to gravity and the inertia of the object. This is certainly a different value on different planets because of the factor of gravity.

Now that you know a little more about height, let's practice using this formula.

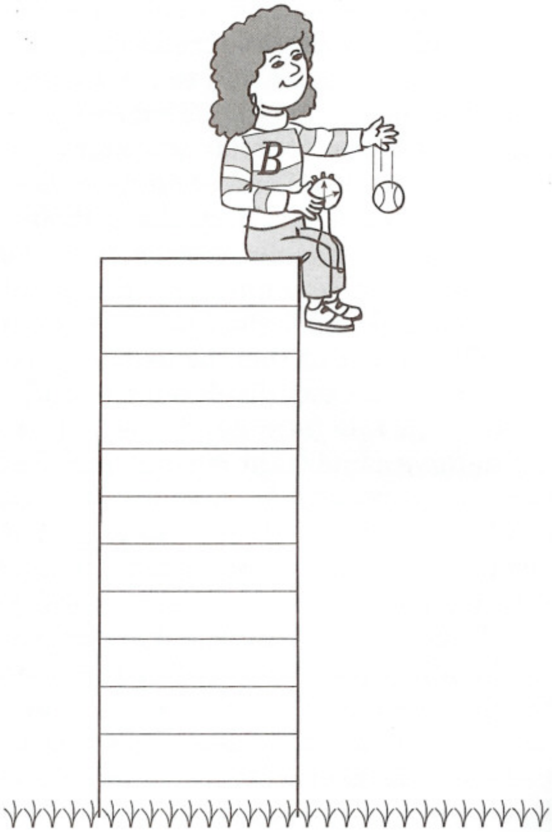
Prelab Questions

1. A diver is planning a dive from a cliff into the river below. He knows that dives are safe only from certain heights. He does not know the height of this cliff, but he knows his physics. He drops a large rock from the top of the cliff into the water below. It takes 8 seconds for the rock to hit the water. Give the height of the cliff in meters.

2. Explain why a feather cannot be used in question 1.
3. Explain what acceleration is.
4. Why is the *g* value different on Earth than on Jupiter?
5. Explain why using this formula is only moderately accurate. What are some problems you might encounter when using this formula that would cause some error?
6. List three professions that might use this physics formula, and explain how they would do so.

Materials needed

Stop watch
Tennis ball or golf ball
Calculator
A tall structure



Procedure

1. Go to the top of your tall structure (such as the top of the stadium steps) with a tennis ball and stop watch.
2. Standing on the top step, drop the ball off the side of the steps so it can fall toward the ground without being obstructed during its fall.
3. As you release the ball, start your stop watch. Stop it as the ball hits the ground below. Enter this value in the chart that follows.
4. Repeat this process three more times and enter each time in the chart.
5. Find the average number of seconds from your four trials and enter it in the chart.
6. You will use the average number of seconds to determine the height of the steps above the ground.
7. Answer the postlab questions.

CHART FOR DATA

Trial number	*Number of seconds required for fall*
1	
2	
3	
4	
Average	

Postlab Questions

1. Take the average number of seconds and use your formula to determine the height of your structure.
2. Cite any problems you encountered in this lab and explain how they might have skewed your results.
3. Do you think the use of this formula is more accurate on fairly short structures or on taller structures? Explain why.
4. You are standing at the base of a tree with a ball. You want to know how tall the tree is. You have a stop watch and a calculator. You toss the ball straight up in the air to almost exactly the height of the tree and time the number of seconds it takes to go up and return to the ground below. You note that it took 8 seconds from the time the ball left your hand until the time it returned to the ground. You remember that time going up will be equal to time coming down. With this in mind, figure out the height of the tree.