ACCELERATION (Free-Fall)

PROBLEM PRESENTATION / EXPLORATION

A. This activity begins with a DISCREPANT EVENT involving acceleration. It is designed to facilitate the students' understanding of the differences between velocity and acceleration. To an eleven meter string (CD) attach seven weights at various intervals. Holding the string by one end drop it from a height of about five meters into a metal wastebasket. As the weights hit the wastebasket a series of sounds will be heard at evenly spaced time intervals. A second string (AB), identical in length and number of weights, is dropped, but this time when the weights hit the wastebasket the sounds are not evenly spaced. When the strings are retrieved from the wastebaskets and laid on the floor, students (who were not allowed to see the strings before or as they were dropped) are asked to pick the string that made the evenly spaced sounds. Common sense would dictate choosing string AB because the weights are attached to the string at identical intervals. (This, however, is not the correct choice!) Upon repeating the drop for the class, string AB can be dropped from either the A or B end and will result in sounds of hitting the wastebasket with unequal time intervals. If you drop string CD from the opposite end (C) that it was dropped from in the first time, once again unequal time intervals between the washers hitting will result. Only when CD is dropped from the D end will there be equal time intervals.

A------------x-------------x-------------x-------------x-------------x------------B

C-x---x-------x--------------x---------------------x-------------------------------D

B. String AB should be prepared by attaching weights at even intervals of about 183 cm. String CD should be prepared by attaching weights at the following points along the string: 0 cm, 31 cm, 123 cm, 276 cm, 490 cm, 766 cm, and 1100 cm.

CLASS RESPONSE / CONCEPT INVENTION

A. To revitalize faulty memories and to eliminate unnecessary drops, have one or two of the student observers tape-record the two drops of each string. It would even be better if the tape-recorder was equipped to tape at two different speeds so that it could be taped at high speed and played back at the slow speed. In this way the intervals between the sounds will be more distinct, and the students will be sure of what they heard. [In real time there is 0.25 second between each plunk for string CD]. Have students try to explain what they have heard in terms of what they have seen concerning the spacing of weights on the strings.

B. Try to direct the students' thinking back to what we learned about velocity or speed. If the string was falling with uniform velocity, the one with the equally spaced weights would produce evenly spaced sounds, because each weight would be traveling the same distance in the same time. Since each weight on string AB travels the same distance before hitting the waste can (the weights are evenly spaced) and since each arrives in a shorter time interval (the tape-recording proves that), we need to get the students to conclude that each subsequent weight must be traveling faster. In other words, the velocity of the string is increasing as each weight falls through its 183 cm. This change in velocity per change in time is called ACCELERATION.

C. If the C end of the string was placed into the waste can so that washer #1 is just touching the bottom of the can when you let go, the second washer will have to fall 31 cm before it hits the bottom. As we have seen above, it takes 0.25 seconds for this to happen. The third washer hits 0.25 seconds later, the fourth washer hits 0.25 seconds later, etc. The following chart can be used to demonstrate the distances traveled by each of the washers at the end of each quarter second for a total time of 1.5 seconds.

	Washer #2 had traveled	Washer #3 had traveled	Washer #4 had traveled	Washer #5 had traveled	Washer #6 had traveled	Washer #7 had traveled
At the end of .25 sec	31 cm	31 cm	31 cm	31 cm	31 cm	31 cm
At the end of .50 sec		31+92 cm	31+92 cm	31+92 cm	31+92 cm	31+92 cm
At the end of .75 sec			31+92+ 153 cm	31+92+ 153 cm	31+92+ 153 cm	31+92+ 153 cm
At the end of 1.00 sec				31+92+153+ 214 cm	31+92+153+ 214 cm	31+92+153+ 214 cm
At the end of 1.25 sec					31+92+153+ 214+276 cm	31+92+153+ 214+276 cm
At the end of 1.50 sec						31+92+153+ 214+276+ 334 cm

D. Have students investigate the table above and determine the additional distance covered by each successive washer. They should find that between plunks the distance covered constantly increases at a rate of about 61 cm more than it covered in the last quarter of a second. This means that weight #3 travels 61 cm farther than weight #2 in the same amount of time; and weight #4 travels 61 cm farther than weight #3 in the same time interval, etc.. If they are having trouble seeing this from the above table, have them examine the table below.

	Washer #2	Washer #3	Washer #4	Washer #5	Washer #6	Washer #7
Distance traveled during 1st quarter of a second	31 cm	31 cm	31 cm	31 cm	31 cm	31 cm
Distance traveled during 2nd quarter of a second		92 cm	92 cm	92 cm	92 cm	92 cm
Distance traveled during 3rd quarter of a second			153 cm	153 cm	153 cm	153 cm
Distance traveled during 4th quarter of a second				214 cm	214 cm	214 cm
Distance traveled during 5th quarter of a second					276 cm	276 cm

Distance traveled during 6th quarter of a second						334 cm

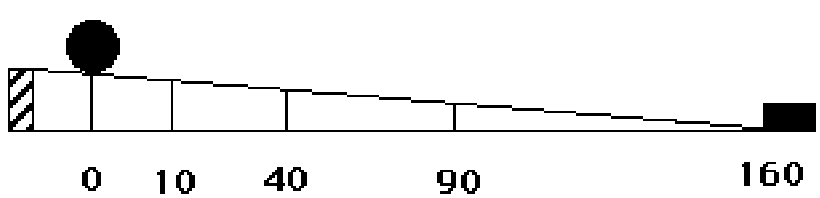
Since the time interval between plunks in the waste can for string CD is .25 second, the string is speeding up 61 cm per quarter second for every additional quarter second. Written another way 61 cm / .25 sec = 244 cm/sec. Remember the velocity is changing 244 cm/sec every .25 sec or in one whole second the velocity would have changed (4 x 244) a total of 976 cm/sec. This is written as 976 cm/sec/sec or 976 cm/sec^2. If they don't believe that the weight is accelerating, ask them from which height they would **not** want to catch a dropped baseball, from a height of one meter? from ten meters? or from 1000 meters? The ball weighs the same each time but the speed of the ball **is** increasing with time.

E. To facilitate the measurement of a falling body where the speed is constantly increasing, Galileo slowed down the motion by using an inclined plane. Because the change in speed occurs more slowly it is easier to measure accurately.

1. Set up a ramp with the angle of the incline at about 10° to the table.
2. Measure the length of the ramp and place a piece of tape at the half-way point.
3. Practice releasing a ball so that it can be released uniformly throughout the rest of the experiment. Using a stopwatch measure the time required for a ball to travel from the release point at the elevated end to the end of the ramp. Repeat this measurement two more times and determine the average time for this length.
4. Now determine the average time for the ball to roll from the same release point to the half-way mark.
5. What conclusion can be reached about the velocity of the ball through the first half of the trip and its velocity through just the second half of the trip? [The velocity for the first half of the trip is much less than for the last half of the trip. The ball is therefore accelerating.] Is the ball accelerating as it rolls down the ramp? What evidence do you have?
6. Repeat steps 3-5 with an angle of only 5° to the ramp. What happens to the acceleration as the angle is changed? [The acceleration is decreased with the smaller angle.]
7. Predict what will happen if a new ball (a heavier one) is allowed to roll down the ramp? Will its acceleration be greater, smaller, or the same as that of the lighter ball? [The mass of the ball has no effect on the acceleration, assuming all other factors remain the same.] What evidence do you have?

F. Readjust the inclined plane to an angle of 10°. This time mark off the ramp at 10 cm intervals, **starting from the bottom**. The plank should be at least 170 cm in length.

1. Release the ball from the 10 cm mark and record the amount of time it takes to roll to the end. Call this amount of time <u>one time unit.</u> (This should be done at least three times and an average value used in subsequent parts of the experiment.)



2. Predict from where the ball would have to be released to take twice as much time to roll down to the end of the plank. How does this distance needed for <u>two time units</u> compare with the distance required for only one time unit? [It is NOT twice as far. It will have to roll four times as far to take twice as much time.]

3. Predict from where the ball would have to be released to take three times as long as when released from the 10 cm mark to reach the end. How does this distance needed for <u>three time units</u> compare with the distance required for only one time unit? [It will have to roll nine times as far to take three times as much time.]
4. Predict from where the ball would have to be released to take four times as long as when released from the 10 cm mark to reach the end. How does this distance needed for <u>four time units</u> compare with the distance required for only one time unit? [It will have to roll sixteen times as far to take four times as much time.]

Time	Predicted Distance	Actual Distance	Ave Speed cm/sec	Change in Speed
	10 cm	10 cm		

5. Is there a constant change in speed for every subsequent time unit? In other words, did the speed increase the same amount in going from time #1 to time #2 as it did from time #2 to time #3, etc.? This constant change in speed per each time unit is the acceleration.

CONCEPT EXTENSION

A. If a ball were dropped from a cliff and had both an odometer and speedometer attached to it, by how much should its speed change each second? How far would it go each second? The acceleration due to gravity is about 10 m/sec^2.

Elapsed Time (sec)	Odometer (m)	Speedometer (m/sec)	Distance Covered During the Last Second (m)
0	**0**	**0**	**0**
1	**5**	**10**	**5**
2	*20*	*20*	*15*
3	*45*	*30*	*25*
4	*80*	*40*	*35*
5	*125*	*50*	*45*
6	*180*	*60*	*55*

1. Can you devise a way to check the numbers that you think should go in the table? Remember, there is a constant acceleration of 10 m/sec every second.
2. Do not encourage students to use canned formulas to arrive at the answers.

B. When a ball is thrown straight upward, by how much does the speed **decrease** each second? After it reaches the top and begins its return downward, by how much does its speed **increase** each second? How much time is required in going up compared to coming down? [It decreases at the same rate in an upward direction as it increases in a downward direction. It decelerates at -10 m/sec^2 upward and accelerates at +10 m/sec^2 downward.]

1. Devise an experiment to show that your answers make sense. Since it might be difficult to throw a ball with the same force each time, you might want to think of some other uniform way of projecting an object upward. [Ping pong ball guns are good; guns that shoot rubber darts; any kind of spring-loaded projection device that you can find at the toy store.]
2. If you are riding your bike along at 20 mile/hr and you put on your brakes,

what starts happening to your velocity? Are you accelerating? Are you decelerating? How are acceleration and deceleration related?

3. Experimentally determine what the acceleration is for a student riding his/her bike when they slam on the brakes and leave them locked until he/she comes to rest.