Accelerated Motion Down an Incline
Merrily We Roll Along

Purpose

To investigate the relationship between distance and time for a ball rolling down an incline.

Required Equipment and Supplies

2-meter ramp
steel ball bearing or marble
wood block
stopwatch
tape
meterstick
protractor

Optional Equipment

Apple II Series computer
interface box
3 photogates (light probes)
LabTools software
3 flashlights or other light sources
2 ring stands

Discussion

Measurement of the motion of a freely falling object is difficult because the speed constantly increases. In fact it increases by nearly 10 m/s every second. The distance that the object falls becomes very large, very quickly. Galileo slowed down the motion by using inclined planes, which make objects freely fall at an angle. Inclined planes make the change in speed easier to see because the change happens more slowly. The less steep the incline, the smaller or less the acceleration. The physics of free fall can be understood by first considering the motion of a ball on an inclined plane.

This experiment will require you to make many timing measurements using a stopwatch or, if available, a computer. If you use a stopwatch, develop good timing techniques so as to minimize errors due to reaction time. The computer-photogate system is a powerful stopwatch because it not only eliminates reaction time, but can be used in a variety of timing modes. Since the diameter of a ball can be measured directly, its *speed* can be found by dividing the diameter by the amount of time it takes to pass through the beam of a light probe. Strictly speaking, since the ball's speed is increasing as it rolls down the incline, the speed of the ball is *slightly* slower as it enters the beam than when it exits the beam. Therefore, the width of the ball divided by the time the ball eclipses the light beam gives the *average* speed of the ball through the light beam, not the *instantaneous* speed. But since the time that the ball eclipses the light is relatively small, the instantaneous speed and the average speed are practically the same.
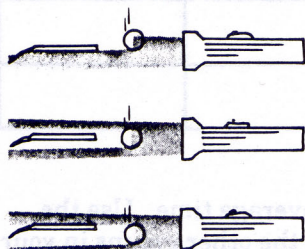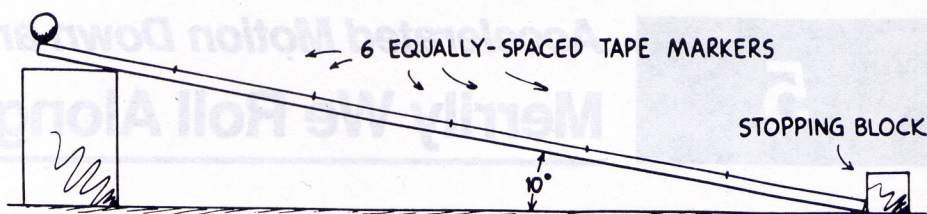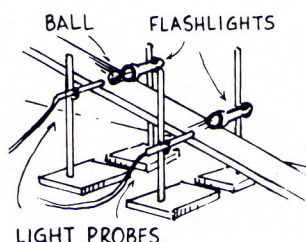
Figure 5.1

6 EQUALLY-SPACED TAPE MARKERS

STOPPING BLOCK

10°

Procedure

Step 1.   Set up a ramp with the angle of the incline at 10° to the horizontal, as shown in Figure 5.1.

Step 2.   Divide the ramp's length into six equal parts and mark the six positions on the board with pieces of tape. These positions will be your release points. Suppose your ramp is 200 cm long. Divide 200 cm by 6 to get 33.3 cm per section. Mark your release points every 33.3 cm from the bottom. Place a stopping block at the bottom of the ramp to allow you to hear when the ball reaches the bottom.

Step 3.   Use either a stopwatch or a computer to measure the time it takes the ball to roll down the ramp from each of the six points. If you use the computer, use the "Chronometer" program with one photogate (light probe) positioned at the release point and the other at the bottom of the ramp. Use a ruler or a pencil to hold the ball at its starting position, then pull it away quickly parallel to the incline to release the ball uniformly. Do several practice runs with the help of your partners to minimize error. Make at least three timings from each position, and record each time and the average of the three times in Data Table 5.1.

BALL   FLASHLIGHTS

LIGHT PROBES

Data Table 5.1

DISTANCE (cm)	TIME (s)			
	TRIAL 1	TRIAL 2	TRIAL 3	AVERAGE

Step 4.   Graph your data by plotting distance vs. average time. Use the same scales on the coordinate axes of your graph as the other groups in your class so that you can compare results.

Step 5.   Repeat Steps 2 to 4 with the incline set at an angle 5° steeper. Record your data in Data Table 5.2. Graph your data as in Step 4.

Data Table 5.2

DISTANCE (cm)	TIME (s)			
	TRIAL 1	TRIAL 2	TRIAL 3	AVERAGE

1. What *is* acceleration?

2. Does the ball accelerate down the ramp? Cite evidence to defend your answer.

3. What happens to the acceleration if the angle of the ramp is increased?

Step 6. Remove the tape marks and place them at 10, 40, 90, and 160 cm from the stopping block as in Figure 5.2. Set the incline of the ramp to be 10°.
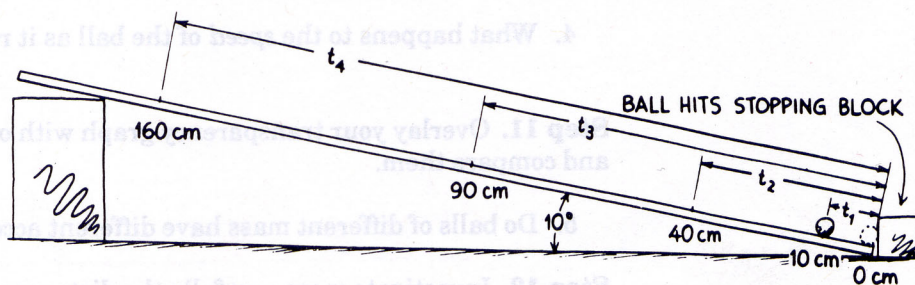

Figure 5.2

Step 7. Measure the time it takes for the ball to roll down the ramp from each of the four release positions. Make at least three timings from each of the four positions and record each time and the average of the three times in the second column of Data Table 5.3.

Data Table 5.3

COLUMN 1	COLUMN 2				COLUMN 3	COLUMN 4
DISTANCE TRAVELED (cm)	ROLLING TIME (s)				TIME DIFFERENCES BETWEEN SUCCESSIVE INTERVALS (s)	TIME IN "NATURAL UNITS"
	TRIAL 1	TRIAL 2	TRIAL 3	AVERAGE		
10				$t_1 =$		1
40				$t_2 =$	$t_2 - t_1 =$	
90				$t_3 =$	$t_3 - t_2 =$	
160				$t_4 =$	$t_4 - t_3 =$	

Step 8. Graph your data by plotting distance vs. time. To facilitate comparison with your classmates, use the same coordinate axes and scales as the other groups in your class.

Step 9. Look at the data in the second column a little more closely. Notice that the difference between t_2 and t_1 is approximately the same as t_1 itself. The difference between t_3 and t_2 is also nearly the same as t_1. What is the difference between t_4 and t_3? Record these time intervals in the third column of Data Table 5.3.

Step 10. If your values in column 3 are slightly different from one another, find their average by adding the four values and dividing by 4. Do as Galileo did in his famous experiments with inclined planes and call this average time interval one "natural" unit of time. Note that t_1 is already listed as 1 "natural" unit in column 4 of Data Table 5.3. Do you see that t_2 will equal—more or less—2 units in column 4? Record this, and also t_3 and t_4 in "natural" units, rounded off to the nearest integer. Column 4 now contains the rolling times as multiples of the "natural" unit of time.

4. What happens to the *speed* of the ball as it rolls down the ramp?

Step 11. Overlay your transparency graph with other groups in your class and compare them.

5. Do balls of different mass have different accelerations?

Step 12. Investigate more carefully the distances traveled by the rolling ball in Table 5.4. Fill in the blanks of columns 2 and 3 to see the pattern.

6. What is the relation between the distances traveled and the squares of the first four integers?

Step 13. You are now about to make a very big discovery—so big, in fact, that Galileo is still famous for making it first! Compare the distances with the times in the fourth column of Data Table 5.3. For example, t_2 is 2 "natural" time units and the distance rolled in time t_2 is 2^2, or 4 times as great as the distance rolled in time t_1.

Table 5.4

DISTANCE TRAVELED (cm)	FIRST FOUR INTEGERS	SQUARES OF FIRST FOUR INTEGERS
	COLUMN 1	COLUMN 2	COLUMN 3
10	1	1
40	2	4
90	3	9
160		

7. Is the distance the ball rolls proportional to the square of the "natural" unit of time?

The sizes of your experimental errors may help you appreciate Galileo's genius as an experimenter. Remember, there were no stopwatches 400 years ago! Galileo concluded that the distance, d, is proportional to the square of the time, t.

$$d \sim t^2$$

Step 14. Repeat Steps 6 to 10 with the incline set at an angle 5° steeper. Record your data in Data Table 5.5.

8. What happens to the acceleration of the ball as the angle of the ramp is increased?

9. Instead of releasing the ball along the ramp, suppose you simply dropped it. It would fall about 5 meters during the first second. How far would it freely fall in 2 seconds? 5 seconds? 10 seconds?

Data Table 5.5

COLUMN 1	COLUMN 2				COLUMN 3	COLUMN 4
DISTANCE TRAVELED (cm)	ROLLING TIME (s)				TIME DIFFERENCES BETWEEN SUCCESSIVE INTERVALS (s)	TIME IN "NATURAL UNITS"
	TRIAL 1	TRIAL 2	TRIAL 3	AVERAGE		
10				$t_1 =$		1
40				$t_2 =$	$t_2 - t_1 =$	
90				$t_3 =$	$t_3 - t_2 =$	
160				$t_4 =$	$t_4 - t_3 =$	

Data Table 5.6

	TOTAL DISTANCE TRAVELED (cm)	ECLIPSE TIME (s)	INSTANTANEOUS SPEED (cm/s)	AVERAGE ROLLING TIME (s)
FIRST ANGLE	10			
	40			
	90			
SECOND ANGLE	10			
	40			
	90			

Going Further

Investigating the Speed of the Ball Down the Ramp

You can use the computer to investigate the speed the ball acquires rolling down the ramp. This can be accomplished several different ways using a timing program on *LabTools*. One way is to use the "Off Mode" of the "Chronometer" program and position three light probes 10 cm, 40 cm, and 90 cm from the release point on the ramp. The speed of the ball as it passes a probe can be determined by measuring the time interval between when the front of the ball enters the light beam and the back of the ball leaves it. The distance traveled during this time interval is just the diameter of the ball. Measure the diameter of the ball.

diameter of ball = _____ cm

Step 15. With the incline set at an angle of 10°, measure the respective eclipse times for each probe, and record your timings in Data Table 5.6. To compute the instantaneous speed of the ball at the three positions, divide the diameter of the ball by the eclipse time. Record the speeds in the table. Use the data from the table to record the average rolling time it took for the ball to travel from each release point, too.

Make a plot of instantaneous speed vs. rolling time.

Step 16. Repeat with the ramp at an angle 5° steeper. Use the rolling times recorded in Data Table 5.5.

10. How do the slopes of the lines in your graphs of speed vs. time relate to the acceleration of the ball down the ramp?

11. When you determined the speed of the ball with the light probes, were you really determining instantaneous speed? Explain.

12. As the angle of the ramp increased, the acceleration of the ball increased. Do you think there is an upper limit to the acceleration of the ball down the ramp? What is it?