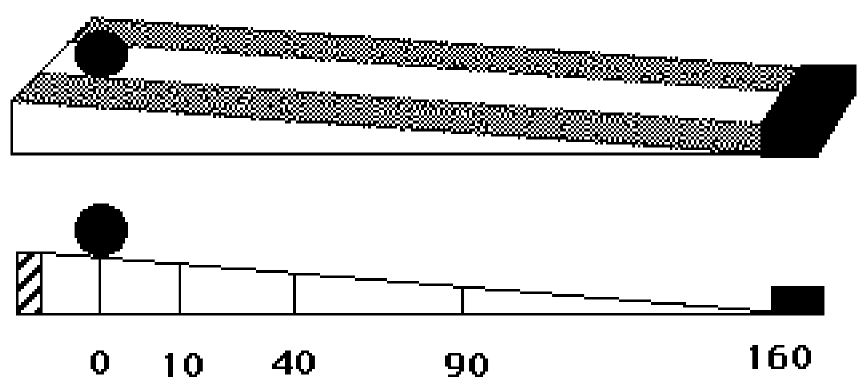
ACCELERATION (Inclined Plane)

PROBLEM PRESENTATION / EXPLORATION

A. In the experiment where we looked at the acceleration due to gravity the measurement of very short times was required because the acceleration due to gravity is pretty large. Hundreds of years ago Galileo found out that you could "slow down" the acceleration by not letting things fall straight down. Rather, he made them "fall" at an angle; in other words he let them fall down an inclined plane. In this way they didn't cover as much distance in a given time interval and the change in speed was slower. We are going to let a rubber ball roll down an inclined plane and measure the time and distance it requires to make the trip. As we saw in the domino experiment we can determine the average speed of a moving object by dividing the distance covered by the time required. In addition to computing the average speed we will want to examine the change in speed as the ball covers different parts of the trip. Just as a car accelerates, meaning that it goes slower in the first second of its trip than it does in the fifth second of its trip, we will want to examine the ball and compute its average speed during each successive part of the trip to confirm that the ball is accelerating as it moves down the inclined plane. Then as in the experiment on acceleration due to gravity we will compute the change in velocity and call this acceleration. The purpose of this experiment is to allow the students to learn how to determine acceleration, since we are going to need to know how to do this for the Newton's Second Law experiment that we will do later.

B. Setup

1. Set up a ramp (about two meters long) with the angle of incline at about 5° with respect to the table top. Put a block of wood at the bottom of the ramp to stop the ball. Lay down some old "Hot Wheels" track on top of the ramp.
2. Measure down from the top about 20 cm and draw a zero line. Place tape marks at 10 cm, 40 cm, 90 cm, and 160 cm measured down from the zero line.
3. Use a ruler or pencil to hold the ball at its starting position then pull it away quickly to release the ball.
4. Place a wooden block or book at the "finish" line to stop the ball from rolling off the ramp. You might also be able to hear when it hits the block and aid in knowing when to click the stopwatch.



5. Use a stopwatch to measure the time it takes the ball to cover the various distances.
6. Practice removing the ruler or pencil so that a smooth start can be carried out. Also practice using the stopwatch so that it can be reliably started and stopped at the beginning and finish of the trip.

C. Data Collection

1. Release the ball first from the zero position and time it to the 10 cm position, then to the 40 cm position, to the 90 cm, and finally to the 160 cm position.

Make at least three time determinations for each distance and enter them into TABLE 1. Average the three times and use this average in further calculations and graphs.

TABLE 1

Distance (cm)	Time (sec)			
	Trial 1	Trial 2	Trial 3	Average
10				t_1 =
40				t_2 =
90				t_3 =
160				t_4 =

2. Compute the amount of time needed for the ball to travel between each of the release points. What conclusion can you draw about the time interval between any two consecutive release points?

TABLE 2

Finish Point (cm)	Average Time (sec)	Time Differences Between Successive Intervals (sec)	Distance Covered in this Time Interval (cm)
10	t_1 =	t_1-t_o =	(10-0) = 10
40	t_2 =	t_2-t_1 =	(40-10) = 30
90	t_3 =	t_3-t_2 =	(90-40) = 50
160	t_4 =	t_4-t_3 =	(160-90) = 70

3. If the data were collected carefully, the time differences between successive intervals should be the same. Since for an equal amount of time, the ball is traveling farther as it rolls down the ramp (10 cm during the first interval, 30 cm more during the second interval, 50 cm more during the third interval, and 70 cm more during the last interval), the average speed must be getting greater. This is just another way of saying that the ball is accelerating down the ramp. Remember, acceleration is the rate of change of velocity or the change in velocity per change in time.

CLASS RESPONSE / CONCEPT INVENTION

A. Computing Acceleration

1. As we have already seen average speed can be computed by dividing the distance traveled by the time it took. (We will call this Method A.)
2. Another way of finding the average speed for a certain portion of the trip is to take how fast something is going at one point of the trip add it to how fast it is going at some point later in the trip and divide it by 2. In other words, we find the average speed by finding the sum of the initial speed and final speed and then dividing by two. (We will call this Method B)
3. For the ball rolling down the entire ramp, the average speed can be determined by either of the methods above, in fact they are the same because the .$speed_{(initial)}$ is zero.
4. The second method does have another feature that is sometimes useful. Lets look at the formula that represents this method.

$$\frac{speed_{(final)} + speed_{(initial)}}{2} = \text{Average speed}$$

If we use a little simple algebra to rearrange it, we get:

$$2\ (\text{Average speed}) - \text{speed}_{(\text{initial})} = \text{speed}_{(\text{final})}$$

5. We now can calculate the speed at the end of any distance interval for which we know the following: how fast it was going at the beginning of the interval, and what its average speed was through that interval.
6. Since we know how much time it takes to travel the first 10 cm (see TABLE 1) and that it takes the same amount of time to travel the next 30 cm and that it takes the same amount of time to travel the next 50 cm and that it takes that same amount of time to travel the last 70 cm (see TABLE 2), we can start to fill in the TABLE 3.

TABLE 3

Time (sec)	Total Distance Traveled (cm)	Average Speed (cm/sec)	Speed$_{(\text{final})}$ (cm/sec)	Acceleration by Method #1* (cm/sec^2)
	10			
	40			
	90			
	160			

7. Acceleration is the change in speed divided by the change in time. In TABLE 3 above we have calculated the velocity of the ball when passing by the 10 cm mark as well as its velocity when passing by the 40 cm, the 90 cm, and the 160 cm marks. With this information there are two methods for calculating the acceleration.

<u>*Method #1</u> says that the speed of the ball when crossing one of the tape marks minus the speed of the ball at the starting line divided by the amount of time need to reach the tape mark gives us the acceleration

$$\frac{\text{speed}_{(\text{final})} - \text{speed}_{(\text{initial})}}{\text{time}} = \text{Acceleration}$$

Since the speed$_{(\text{initial})}$ is always zero we can find the acceleration of the ball by dividing its speed going past one of the tape marks by how long it took to reach that spot. The units for acceleration will be (cm/sec) / sec. We read these units as cm per sec^2. Now calculate the acceleration for the ball going from the starting line to each of the tape marks and enter your calculation into the TABLE 3.

<u>Method #2</u> uses the same formula as was used in Method #1. However, initial speeds other than zero can be inserted into the formula. If we wanted to calculate the acceleration through each of the distance intervals between tape marks, all we would need to know was the speed the ball had when crossing each mark.. From TABLE 3 we have the speed$_{(\text{initial})}$ at the beginning of each interval. Notice that if we start from the top of the ramp, the speed$_{(\text{final})}$ for the first interval is the speed$_{(\text{initial})}$ for the second interval. In turn the speed$_{(\text{final})}$ for the second interval will be the speed$_{(\text{initial})}$ for the third interval, and so on. Now calculate the acceleration for the ball traveling between each of the tape marks.

TABLE 4

Distance Interval (cm)	Time Differences Between Successive Intervals (sec)	$Speed_{(final)}$ (cm/sec)	Acceleration by Method #2 (cm/sec^2)
(10-0) = 10	$t_1 - t_o$ =		
(40-10) = 30	$t_2 - t_1$ =		
(90-40) = 50	$t_3 - t_2$ =		
(160-90) = 70	$t_4 - t_3$ =		

8. You should get roughly the same acceleration for all of the distance intervals regardless of whether you used method #1 or method #2. In other words **the acceleration that the ball experiences is a constant throughout the whole trip**. This is an extremely difficult concept for most students to accept. The mix up the fact that the velocity is constantly increasing but the acceleration is remaining constant. The reason is that they forget that acceleration is the change in velocity per unit time. This change is remaining constant throughout the entire trip down the ramp.

B. Will balls of different mass roll down the ramp with different accelerations?
1. Obviously the way to answer this question is to have some of the students use balls with different masses.
2. Before you do this, however, ask them what they think will be the answer. I bet most of them will tell you that the heavier ball will have a greater acceleration.
3. **The mass of the ball has no effect on the acceleration**. Many students will not believe this is true before testing it out. Some will even not accept this after the experiments have been done.

CONCEPT EXTENSION

A. What happens to the acceleration if the angle of the ramp is increased?
1. Repeat the same experiment with only one change. Have one group raise the ramp so that the angle that the board makes with the table is 10°. Have another group raise it to 15°.
2. The acceleration increases as the angle increases.
3. Ask the students whether they think that there is an upward limit to the acceleration that the ball could reach. If someone relates this experiment back to the one on acceleration due to gravity and they picture the angle of the board getting steeper and steeper so that it is straight up and down, they might see that the upward limit is the acceleration due to gravity (9.8 m/sec^2).

B. If you consult your physics book you will find another formula with acceleration, distance, and time in it. If you have students who have had algebra, they could invent this formula from the ones we used to fill in our tables.
1. The standard formula is $d = \frac{at^2}{2}$
2. See if any of your students can come up with this equation from the ones we used.

$$\frac{d}{t} = \text{Average speed}$$

$$\frac{\text{speed}_{(\text{final})} + \text{speed}_{(\text{initial})}}{2} = \text{Average speed}$$

$$2\ (\text{Average speed}) - \text{speed}_{(\text{initial})} = \text{speed}_{(\text{final})}$$

$$\frac{\text{speed}_{(\text{final})} - \text{speed}_{(\text{initial})}}{t} = \text{Acceleration}$$