# Modern Galileo Experiment

When Galileo introduced the concept of uniform acceleration, he defined it as equal increases in speed in equal intervals of time. This experiment is similar to the one discussed by Galileo in his book, *Dialogues Concerning Two New Sciences*, in which he assumed that a ball rolling down an incline accelerates uniformly. Rather than using a water clock to measure time, as Galileo did, you will use a Motion Detector connected to a computer. This makes it possible to very accurately measure the motion of a ball rolling down an incline. From these measurements, you should be able to decide for yourself whether Galileo's assumption was valid or not.
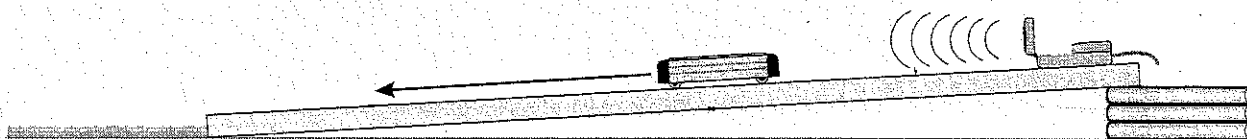
Galileo further argued in his book that balls of different sizes and weights would accelerate at the same rate down a given incline or when in free fall. This was contrary to the commonly held belief of the time that heavier objects fall at a greater rate than lighter objects.

Since speed was difficult for Galileo to measure, he used two quantities that were easier to measure: total distance traveled and elapsed time. However, using a Motion Detector it is possible to measure much smaller increments of time, and therefore calculate the speed at many points down the incline. The data you will be able to gather in one roll of a ball down an incline, is more than Galileo was able to acquire in many trials.

OBJECTIVES

- Use a Motion Detector to measure the speed of a ball down an incline.
- Determine if Galileo's assumption of uniform acceleration is valid.
- Analyze the kinematic graphs for a ball on an incline.
- Model uniformly accelerated motion with algebraic equations.

MATERIALS

Power Macintosh or Windows PC
LabPro or Universal Lab Interface
Logger *Pro*

Vernier Motion Detector
incline (1 – 3 m long)
balls (5 – 10 cm diameter)

PRELIMINARY QUESTIONS

1. List some observations that led people of Galileo's time to believe that heavier objects fall faster than lighter objects.

2. Drop a small ball and a large ball from the same height at the same time. Did the larger one hit first, last, or at the same time?

3. What would happen if you again simultaneously dropped the two balls, but this time held the small ball about 30 cm above the larger one. Would the distance between the two balls

increase, decrease, or remain the same as they fall? Since the fall time is short, it is hard to tell just what happens by eye. You will see why Galileo and the people of his day had a difficult time answering the questions of motion. Try to answer this question using Galileo's assumption of constant acceleration.

[handwritten: BOOT UP PC ; START LOGGER PRO ; file, open]

PROCEDURE

1. Connect the Motion Detector to DIG/SONIC 2 of the LabPro or PORT 2 of the Universal *[handwritten: FOLDER]* Lab Interface.

   [handwritten: PHYSICS w/]

2. Place the Motion Detector at the top of a 1 to 3 m long incline. The incline should form an angle between 5° and 10° of horizontal.

3. Open the file in the Experiment 3 folder of *Physics with Computers*. Two graphs will appear *[handwritten: OPENED]* on the screen. On the top graph, the vertical axis has distance scaled from 0 to 3 meters. The second graph will have velocity scaled from 0 to 2 m/s. The horizontal axis of both graphs has time scaled from 0 to 3 s. *[handwritten: CART ON RAMP]*

4. Position a ball about 0.4 m down the incline from the Motion Detector.

5. Click [▶Collect] to begin data collection. Release the ball when you hear the Motion Detector start to click. *[handwritten: SPACE BAR = COLLECT; CLICK "EXPERIMENT"; "CLEAR LATEST RUN"]*

6. Print or sketch the graphs of distance *vs.* time and velocity *vs.* time. *[handwritten: COPY/PASTE INTO WORD; GMAIL YOURSELF.]*

7. Click on the velocity *vs.* time graph. Click on the Examine tool, 🔍, on the toolbar. Move the cursor to a point about one-fourth of the way down the incline. Record in the data table below the value of time and velocity for that point. Starting from that point, record time and velocity data for every 0.2 s until you have recorded 10 points, or until you reach the point that corresponds to the end of the acceleration. *[handwritten: At² + Bt + C ; RECORD A, b, C]*

8. Does the distance *vs.* time graph appear to follow a simple algebraic curve? Which curve or line? Try fitting various functions to the portion of the data corresponding to free-rolling by dragging across that time interval and clicking the Curve Fit button, 📈. Select a function from the scrolling list and click [Try Fit] to see how the function fits the data. Choose the simplest function that still fits the data well, click [Try Fit] to re-plot the fit, and click [OK] to place the fit on the main graph window. Record both the equation and the parameters of the fitted equation. Print or sketch your graph. Include the curve fit information.

9. Similarly, does the velocity *vs.* time graph follow a simple algebraic curve? Using the process above, choose the simplest function that still fits the data well and record the parameters of the fitted equation. Print or sketch your graph. Include the curve fit information.

[handwritten: M·t + b ; RECORD m, b]

[handwritten: X TOOL → | ← CURSOR; READ speed ↑ ↕ velocity]

[handwritten: COLLECT 5 OR MORE]

[handwritten: MOVE TOOL]

[handwritten: time]

[handwritten: COLLECT POINTS ∆t = 0.2 s]

Physics with Computers
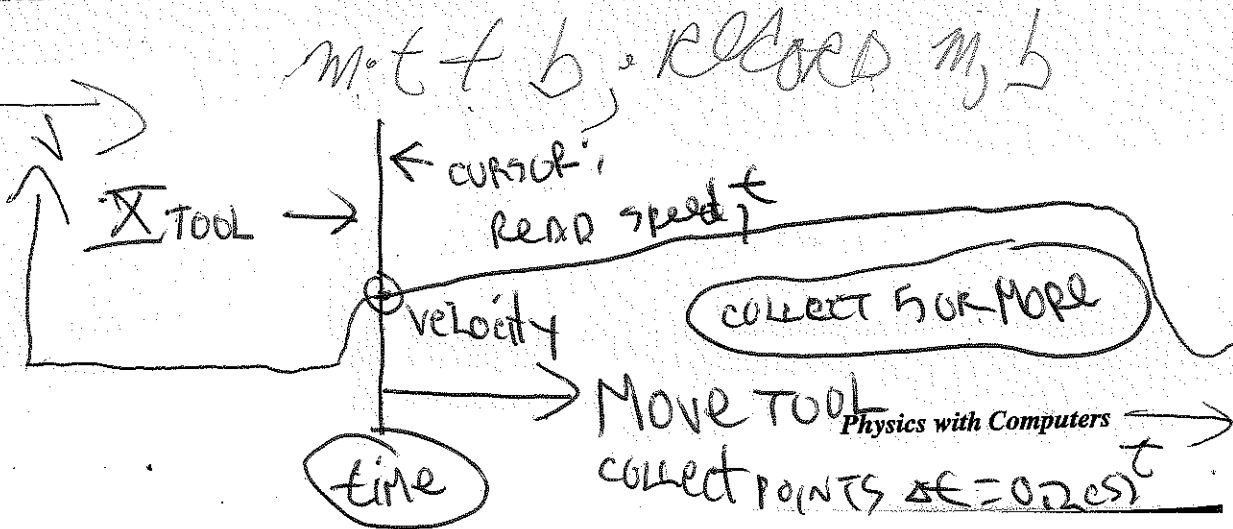
DATA TABLE

Data point	Time (s)	Speed (m/s)	Change in speed (m/s)
1		V_1	
2		V_2	$\Delta V_1 = V_2 - V_1$
3		V_3	ΔV_2
4		V_4	ΔV_3
5		V_5	ΔV_4
6		V_6	ΔV_5
7		V_7	ΔV_6
8		V_8	ΔV_7
9		V_9	ΔV_8
10			
slope of v-t graph	m (curve fit) ← ⑥		
average acceleration	$\dfrac{V_L - V_F}{t_L - t_F}$ ← Ⓐ		

ANALYSIS

new data sheet

1. Calculate the change in speed between each of the points in your data table above. Enter these values in the right column of the data table.

2. As stated earlier, Galileo's definition of uniform acceleration is *equal increases in speed in equal intervals of time.* Do your data support or refute this definition for the motion of an object on an incline? Explain.

3. Was Galileo's assumption of constant acceleration for motion down an incline valid? How do your data support your answer?

4. Calculate the average acceleration of the ball between the first and the last time recorded (t_1 and t_{last}) using your data and the definition of average acceleration:

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_{last} - v_1}{t_{last} - t_1} \qquad A$$

5. Look at the curve fit equation for the distance *vs.* time graph. How does the constant C in this curve fit relate to the slope of the velocity *vs.* time graph?

6. Look at the curve fit equation for the velocity *vs.* time graph. Does the fitted function have a constant slope? What does that slope mean? What are its units? Record the slope in the data table. m

EXTENSIONS

1. Repeat the experiment using a different size ball or a dynamics cart. Is there a difference in the results? How does the acceleration of a dynamics cart compare with the acceleration of the balls?

2. Use the Motion Detector to examine the acceleration of a rubber ball in free fall. Relate your findings to the Galileo experiment.

3. Roll the ball up the incline so that it slows to a stop and then rolls back down without coming within 0.4 m of the Motion Detector. Compare the up and down motion to the down only motion that you examined in the lab. Is the acceleration the same during the whole motion? Is the velocity always the same sign? How could you change the coordinate system of your experiment so the acceleration changes sign?

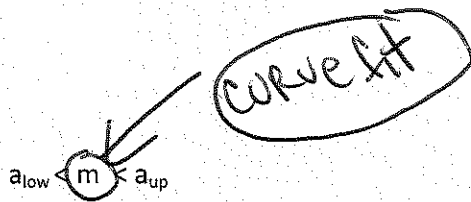| GALILEO LAB (EXPERIMENT 4)				
Analysis #2 and #3 combined				
$\Delta t = 0.2$ s or ___	Δv	Acceleration=$\Delta v/\Delta t$		
1	$\Delta v1$	$a_1 = \Delta v_1/\Delta t$		
2	Δv_2			
3	Δv_3	:		
4	Δv_4	'		
5	Δv_5			
6	Δv_6	$a_6 = \Delta v_6/\Delta t$		
7				
8				
9				
10				
11				
12				

Average acceleration: a_{AV} show work

$$a_{AV} = \frac{a_1 + \cdots a_6}{6}$$

Error = (Max –Min)/2 (6 or less data points) or uncertainty of the mean(University of Penn)

$$\frac{a_{MAX} - a_{MIN}}{2}$$

OR STDM

Check Is this true?

curve fit

a_{low} < (m) > a_{up}

m is from the curve fit for v vs t

a_{low} = average acceleration - error = a_{AV} - error

a_{up} = average acceleration + error = a_{AV} + error

Explain errors

Use attached sheets if needed