Determining *g* on an Incline

During the early part of the seventeenth century, Galileo experimentally examined the concept of acceleration. One of his goals was to learn more about freely falling objects. Unfortunately, his timing devices were not precise enough to allow him to study free fall directly. Therefore, he decided to limit the acceleration by using fluids, inclined planes, and pendulums. In this lab exercise, you will see how the acceleration of a cart depends on the ramp angle. Then, you will use your data to extrapolate to the acceleration on a vertical "ramp"; that is, the acceleration of a cart dropped in free fall.

If the angle of an incline with the horizontal is small, a cart rolling down the incline moves slowly and can be easily timed. Using time and distance data, it is possible to calculate the acceleration of the cart. When the angle of the incline is increased, the acceleration also increases. The acceleration is directly proportional to the sine of the incline angle, (θ). A graph of acceleration versus $\sin(\theta)$ can be extrapolated to a point where the value of $\sin(\theta)$ is 1. When $\sin(\theta) = 1$, the angle of the incline is 90°. This is equivalent to free fall. The acceleration during free fall can then be estimated from the graph.

Galileo was able to measure acceleration only for small angles. You will collect similar data. Can these data be used in extrapolation to determine a useful value of *g*, the acceleration of free fall? We will see how valid this extrapolation can be. Rather than measuring time, as Galileo did, you will use a Motion Detector to determine the acceleration. From these measurements, you should be able to decide for yourself whether an extrapolation to large angles is valid.

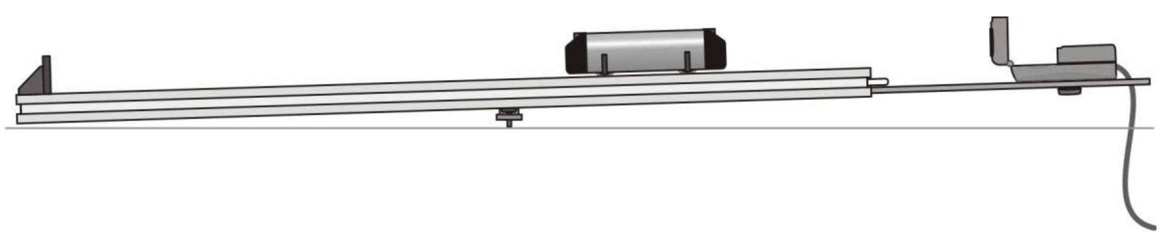


Figure 1

OBJECTIVES

- Use a Motion Detector to measure the speed and acceleration of a cart rolling down an incline.
- Determine the mathematical relationship between the angle of an incline and the acceleration of a cart down the ramp.
- Determine the value of free fall acceleration, *g*, by extrapolating the acceleration *vs.* sine of track angle graph.
- Determine if an extrapolation of the acceleration *vs.* sine of track angle is valid.

MATERIALS

LabQuest	dynamics cart
LabQuest App	meter stick
Motion Detector	books
ramp	Logger *Pro* software or graph paper
rubber ball	MacBook Lab

PRELIMINARY QUESTIONS

1. Galileo sometimes used his pulse to time motions. Drop a rubber ball from a height of about 2 m and try to determine how many pulse beats elapsed before it hits the ground. What was the timing problem that Galileo encountered?

2. Now measure the time it takes for the rubber ball to fall 2 m, using a wrist watch or wall clock. Did the results improve substantially?

3. Roll the ball down a ramp that makes an angle of about 10° with the horizontal. First use your pulse and then your wrist watch to measure the time of descent.

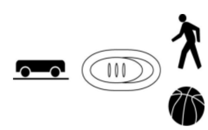
4. Do you think that during Galileo's day it was possible to get useful data for any of these experiments? Why?

PROCEDURE

1. Place a single book under one end of a 1–3 m long board or track so that it forms a small angle with the horizontal. Adjust the points of contact of the two ends of the incline, so that the distance x in Figure 1 is between 1 and 3 m.

2. Place the Motion Detector at the top of an incline. Place it so the cart will never be closer than 0.15 m.

3. If your Motion Detector has a switch, set it to Track. Connect the Motion Detector to DIG 1 port of LabQuest and choose New from the File menu.



4. Hold the cart on the incline about 0.5 m from the Motion Detector.

5. Start data collection; release the cart after the Motion Detector starts to click. Get your hand out of the Motion Detector path quickly.

6. Examine the graph of velocity vs. time.

7. You may have to adjust the position and aim of the Motion Detector several times before you get a useful run. Adjust and repeat the process until you get a good run showing approximately constant slope on the velocity *vs.* time graph during the rolling of the cart. To collect more data, start data collection when you are prepared to release the cart. Repeat Steps 5 and 6 until you get a useful run.

8. Fit a straight line to a portion of your data. First you must indicate which portion of the graph is to be used.

   a. Tap and drag your stylus across all data points in the linear region of the graph.
   b. Choose Curve Fit ► Velocity from the Analyze menu.
   c. Select Linear as the Fit Equation.
   d. Record the slope of the fitted line (the acceleration) in the data table. Select OK.

9. Measure the length of the incline, *x*, which is the distance between the two contact points of the ramp. See Figure 1. Record the length in your data table.

10. Measure the height, *h*, the height of the book(s). These last two measurements will be used to determine the angle of the incline. Record the height in your data table.

11. Raise the incline by placing another book under the end.

12. Repeat Steps 4–10 for the new incline.

13. Repeat Steps 4–11 for 3, 4, and 5 books.

DATA TABLE

Number of books	Height of books, *h* (m)	Length of incline, *x* (m)	Acceleration (m/s^2)	sin (θ)
1				
2				
3				
4				
5				

ANALYSIS

1. Open a New file in Logger Pro. Edit the data table to contain the data table you have above. (Mr. Duhrkopf will show you how to complete this step)

2. Using trigonometry and your values of *x* and *h* in the data table, calculate the sine of the incline angle for each height in a new calculated column. Note that *x* is the hypotenuse of a right triangle.

3. Plot a graph of the average acceleration (*y* axis) *vs*. sin(θ).

   a. Click on the y-axis variable for the graph and make it Acceleration.
   b. Click on the x-axis variable and make it sin(θ).
   c. Double click on a value on the x-axis. Change the values for Top and Right to 1.

4. Draw a best-fit line by hand or use the linear-regression feature of your software and determine the slope. The slope can be used to determine the acceleration of the cart on an incline of any angle.
   a. Choose Curve Fit ► Velocity from the Analyze menu.
   b. Select Linear as the Fit Equation.

5. On the graph, carry the fitted line out to sin(90°) = 1 on the horizontal axis, and read the value of the acceleration.

6. How well does the extrapolated value agree with the accepted value of free-fall acceleration (g = 9.8 m/s^2)?

7. Discuss the validity of extrapolating the acceleration value to an angle of 90°.

EXTENSIONS

1. Use the Motion Detector to measure the actual free fall of a ball. Compare the results of your extrapolation with the measurement for free fall.

2. Compare your results in this experiment with other measurements of *g*. For example, use the Picket Fence Free Fall experiment in this book.

3. Use a free-body diagram to analyze the forces on a rolling cart. Predict the acceleration as a function of ramp angle, and compare your prediction to your experimental results.