GALILEO'S KINEMATICS LAB

INTRODUCTION

In this experiment you will attempt to reproduce Galileo's results using the inclined plane. You will test three hypotheses relating to motion on an incline. You will learn to draw a"best fit" or regression line of experimental data.You will discover that reaching conclusions about motion is not as easy as it seems at first. Although you will be using an electronic stopwatch, it is not much more accurate than Galileo's water clock.

Galileo designed experiments to study accelerated motion using the inclined plane. His reasoning suggested that objects rolling down a ramp behaved similarly to objects in freefall so that he could understand freefall by studying ramps. This experiment is designed to reproduce a portion of Galileo's experiments. Galileo performed many more trials than you will, but did not have the sophisticated tools that you have to analyze the data.

He deduced that an object which is uniformly accelerated will travel a greater distance in each successive time interval such that the distance traveled is directly proportional to the square of the time.

He also discovered that the speed of a falling object depends only on the height from which it falls.

One of Galileo's contributions to the experimental method was the idea of holding one or more variable constant while noting the effect when another variable is changed.

In this experiment there are FOUR VARIABLES.

1. The distance along the ramp which the balls rolls.

2. The steepness of the incline which is measured by the ratio of height to length of the ramp.

3. The height from which the ball is released on the ramp.

4. The time required for the ball to roll a certain distance down the ramp.

NOTES ON DISTANCE AND TIME MEASUREMENT

Measuring distance and time require different skills as well as different instruments. There are unique problems associated with each type of measurement.

You should be able to make distance measurements to one digit more than the [least count] of the meter stick or ruler. Typically this will be 0.1 mm.(0.01 cm or 0.001m.) on a ruler with a least count of 1 mm. Try to estimate the decimal fraction "between the mm. marks" on the ruler. Be sure to measure and record all data to the [correct number of significant figures].

Time measurements require coordination between the event and the timer in a different way because an event happens only once in time. You get only one chance at a time measurement (not counting video tapes and other recordings.)

It is best to use a "starting gate" to avoid imparting to the can any uphill or downhill motion. The starting gate is a pencil or small ruler which holds the can in place, to be lifted when time starts. Think of how the gates at a parking garage operate. All of this is because we want to assure that the initial speed is zero, ie. stationary.

A countdown of "5, 4, 3, 2, 1" is a good way to begin the timing whether there is one person or two involved in the experiment.

To stop the timing it is best to use a flat object such as a ruler or the cover of a book as a physical stop. This allows you to use your sense of hearing along with sight to coordinate the stopwatch with the stopping point.

OBJECTIVES

1. Become familiar with the concept of hypothesis testing by experiment.

2. Observe and measure motion on an inclined plane.

3. Be familiar with Galileo's inclined plane.

4. Understand the relationships between distance, time, average speed, instantaneous speed, and acceleration.

5. Understand how to draw and interpret a "best fit" or regression line on a graph of experimental data.

6. Appreciate the difficulties in analyzing experimental data to make conclusions, even if the data is carefully and correctly collected.

EQUIPMENT

Ramp, meter stick. empty tin can, electronic stopwatch

RAMP CONSTRUCTION

See Figure 1

For the ramp you can use any flat, level object such as a board or a cardboard box. It should be about 1.25 meters (4.0 ft.) long If you don't have anything like that then you will have to improvise. You can by a 1 x 4 x 4 ft. board at a home improvement center such as City Mill or Ace Hardware for a few dollars. Be creative. It doesn't matter what the ramp is made of as long as it is flat and strong enough to support your tin can without bending.

To raise one end of the ramp, use a pile of books. You may not be able to get the top of the ramp at exactly the height given in the instructions. Get it as close as you can and record the actual height in data tables A and B.

PROCEDURES and HYPOTHESES

Figure 1 for procedures A & B

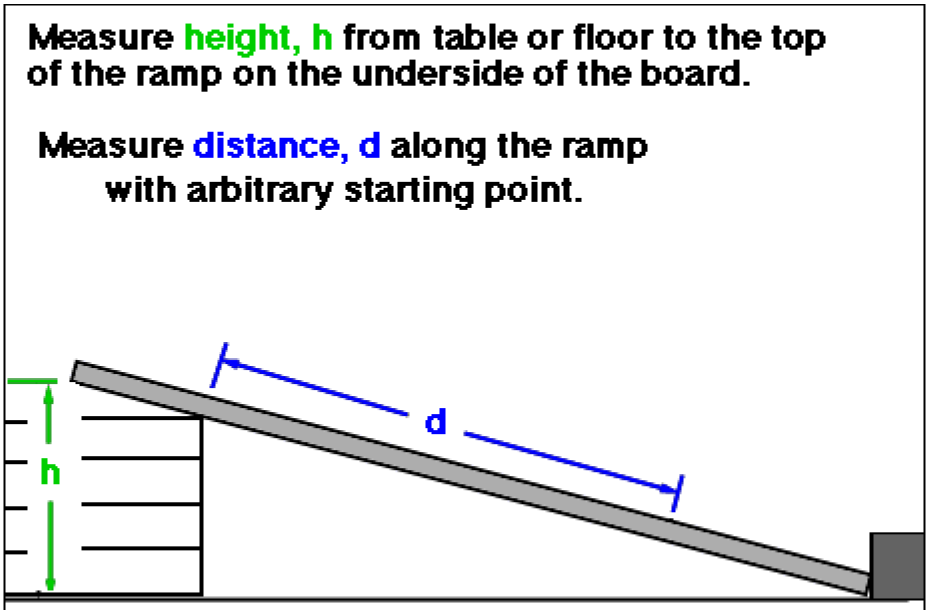

Figure 1

HYPOTHESIS A: Distance is directly proportional to the square of time if acceleration is uniform.

In this part the distance d down the ramp is the variable while the angle of slope is constant.

1. Set up the ramp with h= 0.10 m above the table, (as shown in Figure 1.)

2. Starting with the cylinder at rest, use the stopwatch to measure the time to roll distance d = 1.0 meter down the ramp. See "Making Measurements", above.

3. Take 6 time measurements, record in data table A. Cross out the highest and lowest times and determine the average of the remaining four times. (Sum four times and divide by four to find the average.)

4. Repeat steps 2 and 3 for distances of 0.80 m, 0.60, 0.40 m (see data table A).

HYPOTHESIS B: Rate of acceleration is proportional to incline of ramp.

In this part the distance rolled down the ramp and the angle of slope are both variables.

1. The steepness of the incline can be measured by the ratio of height to length. Measure the total length of the ramp and record in data table B as L.

2. Copy the data from the first set of measurements in hypothesis A into the data table for hypothesis B, unless you prefer to collect that data a second time. (Time to roll 1.0 m when h = 0.1 m)

3. Raise the top of the ramp to 0.15 m.

4. Starting with the cylinder at rest, use the stopwatch to measure the time to roll 1.0 meter down the ramp.

5. Take 6 time measurements, record in data.

6. Repeat steps 4 and 5 for heights of 0.20 m, 0.25 m.

HYPOTHESIS C: Objects will reach the same speed from a given height regardless of incline.

In this part the starting height is held constant while the distance rolled down the ramp and the angle of slope are varied.

Figure 2 for procedure C

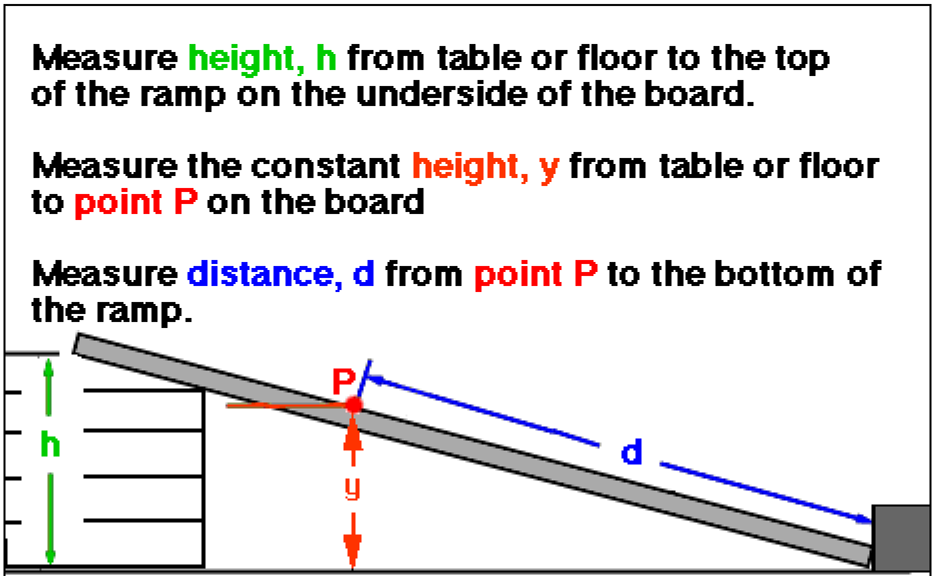

Figure 2

1. With the top of the ramp at h = 0.25 m as in part B, find the point P on the ramp that is y = 0.10 m above the table (see Fig 2).

2. Measure the length of the ramp from that point P to the BOTTOM of the ramp and record as d in data table (see Fig 2.)

3. Measure the time for the cylinder to roll from point P to the bottom of the ramp (start from rest as before).

4. Repeat steps 2 and 3 for ramp heights of h = 0.20 m, 0.15 m, and 0.10 m. NOTE THAT THE DISTANCE d, THE INCLINE OF THE RAMP, AND POINT P WILL BE DIFFERENT FOR EACH OF THE 4 TRIALS WHILE THE HEIGHT y REMAINS CONSTANT.

DATA TABLES

A. Acceleration vs. distance

Calculate the average time for six trials. Discard the highest and lowest in each trial so you will average the middle four values. Enter the average time in the data table. In each case use $t_{(avg)}$ for the times to calculate t squared. Draw a graph of distance versus average time squared for your data.

Table A

d (m)	t_1	t_2	t_3	t_4	t_5	t_6	$t_{(avg)}$	t^2
1.00	.	.	.	.	.	.	.	.
0.80	.	.	.	.	.	.	.	.
0.60	.	.	.	.	.	.	.	.
0.40	.	.	.	.	.	.	.	.

B. Acceleration vs. Slope

L is the total length of the board, to be recorded below. Distance rolled (d) is 1.0 meter. "t^2" means "t raised to the power of 2" or "t squared".

Height divided by length (h/L) is a measure of steepness of slope.

Distance divided by time squared (d/t^2) is proportional to acceleration.

The relationship will be linear if and only if acceleration is directly proportional to slope.

Table B

L = ______m	d = 1 m

h (m)	t_1	t_2	t_3	t_4	t_5	t_6	t_{avg}	t_{avg}^2	(d/t^2)	(h/L)
0.10	.	.	.	.	.	.	.	.	.	.
0.15	.	.	.	.	.	.	.	.	.	.
0.20	.	.	.	.	.	.	.	.	.	.
0.25	.	.	.	.	.	.	.	.	.	.

From data table B above, calculate the average time, the square of the average time, ratio d/t_{avg}^2 and the ratio h/L. For each of the four heights divide the two ratios from table B (divide d/t^2 by h/L) and enter the results in the table B1 below.

Table B1

h (m)	(d/t2)/(h/l)
0.10	.
0.15	.
0.20	.
0.25	.

Examine the ratios and decide whether or not they are constant. Then plot a graph of (d/t^2) vs. (h/L) with h/L on the horizontal axis.

C. Speed vs. Height

"y" is the constant height from which the ball is rolled. "h" is the measurement to the top of the ramp as before, "d" is the distance from point P along the ramp to the bottom. See figure 2. Be sure you understand the meaning of the variables before you begin.

You want the can to be rolled from the same height above the table each time. The point of release and the distance rolled down the ramp will be different for each trial.

Table C

y = 0.10 m

h (m)	d (m)	t_1	t_2	t_3	t_4	t_5	t_6	t_{avg}
0.10	.	.	.	.	.	.	.	.
0.15	.	.	.	.	.	.	.	.
0.20	.	.	.	.	.	.	.	.
0.25	.	.	.	.	.	.	.	.

For each height, calculate the average speed at the bottom of the ramp, d/t and enter the results in the data table C1 below. If the speed is the "same" then the ratios d/t should be equal.

Table C1

h (m)	(d/t)
0.10	.
0.15	.
0.20	.
0.25	.

Comparing the ratios of d/t decide whether or not you think the speeds are the same, then draw a graph of d vs. t for each of the four slope angles.

QUESTIONS

QUESTIONS FOR HYPOTHESIS A.

Using your data from part A, plot a graph of d (vertical axis) vs. t^2 (horizontal axis) . Draw a "best fit" straight line through the points.

A1. Is the graph linear?

A2. What does it mean if the graph is linear?

A3. What does a linear graph indicate about the acceleration of rolling objects?

A4. Does your data support hypothesis A? Briefly justify your answer.

QUESTIONS FOR HYPOTHESIS B

Using your data from part B calculate d/t^2 and h/L. Then plot a graph of d/t2 vs. h/L with h/L on the horizontal axis. Draw a "best fit"straight line through the points.

B1. Is the graph linear?

B2. What does it mean if the graph is linear?

B3. Does your data support hypothesis B? Briefly justify your answer

QUESTIONS FOR HYPOTHESIS C

The average speed of an object under constant acceleration is distance divided by time. Plot a graph of d vs. t with t on the horizontal axis. Draw a "best fit" straight line through the points.

C1. Is the graph linear?

C2. What does it mean if the graph is linear?

C3. Does your data support hypothesis C?

GENERAL QUESTIONS

G1. What are the variables in this experiment?

G2. How did you control the can to be sure it did not roll off the side of the board? Would this have any affect on the precision or accuracy of your measurements?

G3. How can you tell whether or not the points on the graph represent a linear relationship? Would you expect them to be perfectly linear? Why or why not?

G4. Briefly discuss the problems encountered in making kinematic conclusions from experimental data. Don't confuse the process of collecting data with the process of drawing conclusions from it.