

## **Uniform Acceleration on a Toy Race Car Track.**

(Adopted from Physics Laboratory Manual by David H. Loyd -Laboratory 4. Uniformly Accelerated Motion on the Air Track)

### **Objectives**

In this laboratory a toy racetrack will be used to approximate a one dimensional low friction surface. The track will be tilted to form an inclined plane, and a toy racecar will be released and allowed to move down the track. The study of the motion of the car will be used to accomplish the following objectives:

1. Verification that the displacement of the car down the inclined plane is directly proportional to the square of the elapsed time.
2. Determination of the acceleration of the car from an analysis of the displacement versus time data
3. Determination of an experimental value for  $g$  the acceleration due to gravity by interpretation of the cart's acceleration as a component of  $g$

### **Equipment List**

1. 18-25 lengths of Hot Wheels™ Race Track (60.5cm per section)
2. Laboratory timer or stopwatch
3. A ramp for approximately 10 meters of track. Inclined from 5° to 10°
4. 10-15 track connectors
5. One or Two toy die-cast metal cars (Hot Wheels™ or Matchbox™) Toys based on real automobiles tend to work the best.

### **Theory**

When an object undergoes one dimensional uniformly accelerated motion its velocity increases linearly with time. If it is assumed that the initial velocity of the object is zero at time  $t=0$ , then its velocity at any later time  $t$  is given by

$$(1) \quad v = at$$

where  $a$  is the acceleration which is assumed to be constant in magnitude and direction.

Consider a time interval between  $t=0$  and any later time  $t$ . The velocity is zero at  $t=0$ , and the velocity is  $v$  at time  $t$ . Therefore, the average velocity  $v_{\text{avg}}$  during the time interval is

$$(2) \quad v_{\text{avg}} = (0 + v)/2 = v/2$$

The displacement  $x$  of the object during the time interval  $t$  is given by

$$(3) \quad x = v_{\text{avg}} t = v_{\text{avg}} t/2$$

Substituting equation (1) for  $v$  in equation (3) gives

$$(4) \quad x = at^2/2$$

Thus equation (4) states that if an object is released from rest its displacement is directly proportional to the square of the elapsed time. Figure 1 shows graphs of both  $x$  versus  $t$  and  $x$  versus  $t^2$  for uniformly accelerated motion.

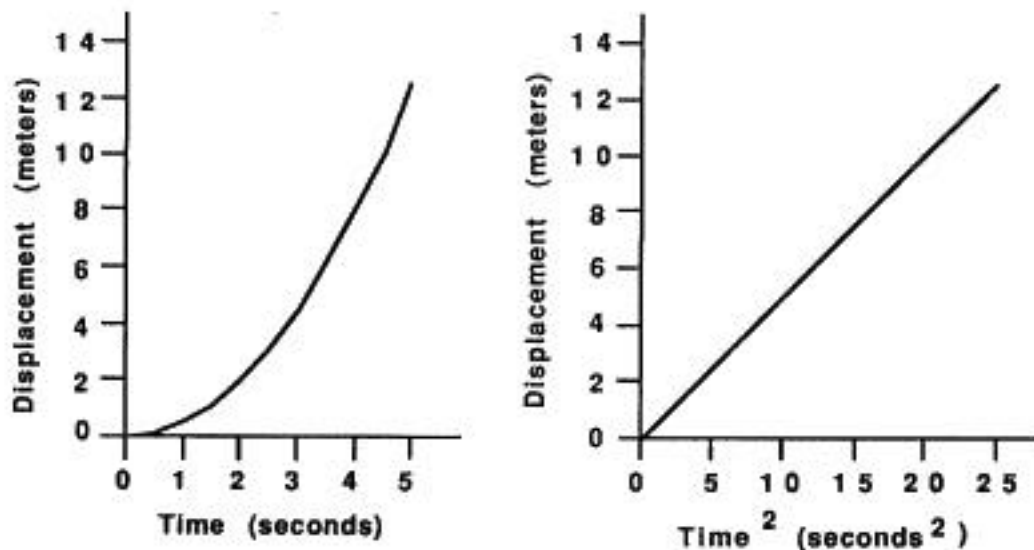


Figure 1. Graphs of displacement versus time and displacement versus the square of the time for uniformly accelerated motion. Note that displacement is linear with time squared.

Consider a car that is placed on a racetrack which is raised at one end to form an inclined plane whose angle of inclination is  $\theta$ . The car moves down the inclined plane with an acceleration  $a$  that is simply a component of the acceleration due to gravity  $g$ . The acceleration due to gravity points directly downward, but it can be resolved into components that are perpendicular and parallel to the plane. Figure 2. shows a car on a raised racetrack. The

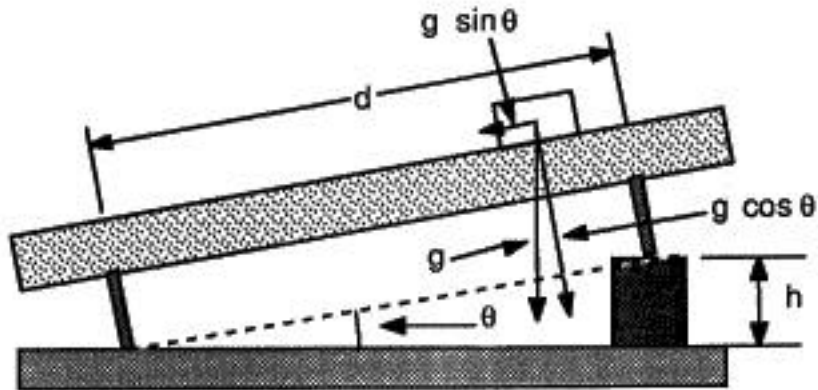


Figure 2. Components of  $g$  the acceleration due to gravity on a car on a raised racetrack.

component perpendicular to the plane is seen to be. The component parallel to the plane is equal to the acceleration  $a$  and is given by

$$(5) \quad a = g \sin \theta$$

### Experimental Procedure

1. Link and place approximately 18 sections of track on the ramp in the Science Wing hallway. Measure the height  $h$  (“drop”) of the ramp. Attempt to estimate the value of  $h$  to the nearest 1.0 mm. Have five members of the class perform this measurement independently and record those five trials in the Data Table.

2. Have five members of the class independently measure the distance  $(d)$  down the ramp to the point where the height of the ramp was measured. ( $d =$  hypotenuse) Note that the angle of inclination  $\theta$  is defined by  $\sin \theta = h(\text{height})/d(\text{hypotenuse})$ . Record the five trials for  $d$  in the Data Table.

3. Have one member of the class release the cart from rest at the top of the incline, while another lab member simultaneously starts a timer. Stop the timer when the cart has traveled two sections of track (1.21 m) down the ramp. Have four other members of the class repeat this measurement, each one taking one trial for a total of five trials at this distance. Record all times in the Data Table.

4. Repeat step 2 for distances of four sections of track (2.42 m), six sections of track (3.63 m), eight sections of track (4.84 m), ten sections of track (6.05 m), twelve sections of track (7.26 m), fourteen sections of track (8.47 m), and sixteen sections of track (9.68 m). At each distance have five different members of the class perform a measurement. Record all times in the Data Table.

### Calculations

1. Calculate the mean  $h$  and the standard error  $\sigma_h$  for the five trials of the ramp height. Record the results in the Calculations Table.

2. Calculate the mean  $d$  and the standard error  $\sigma_d$  for the five trials of the distance  $d$ . Record the results in the Calculations Table.

3. Calculate the mean time  $t$  and the standard error  $\sigma_t$  for the five trials of the time at each distance. Record the results in the Calculations Table.

4. Calculate the square of each of the mean times  $t^2$  for the eight distances and record the results in the Calculations Table.

5. Perform a linear least squares fit to the data of  $x$  versus  $t^2$  with  $t^2$  as the abscissa and  $x$  as the ordinate. In that fit make (0,0) one of the points that is included. According to equation (4) the slope of this fit should be equal to  $a/2$  where  $a$  is the car's acceleration. From the value of the slope obtained in the least squares fit calculate the acceleration  $a$  of the car and record it in the Calculations Table.

6. Calculate the value of  $\sin \theta = h/d$  and record it in the Calculations Table.

7. Using equation (5) calculate an experimental value for the acceleration due to gravity  $g_{\text{exp}}$  from the measured values of “a” and  $\sin \theta$  and record it in the Calculation Table.

8. Calculate the percentage error in your value of  $g_{\text{exp}}$  compared to the accepted value of  $9.80 \text{ m/sec}^2$  and record it in the Calculations Table.

### **Graphs**

1. According to equation (4) a graph of  $x$  versus  $t^2$  should be a straight line. Construct a graph of the  $x$  versus  $t^2$  data with  $x$  as the ordinate and  $t^2$  as the abscissa. Also show on the graph the straight line from the linear least squares fit.

## Questions

1. According to the standard error, how many significant figures are there in the values of  $h$  and  $d$ ?

2. According to the standard error, how many significant figures are there in each of the values of  $t$ ?

3. Consider the difference between your measured value of  $g$  and the true value of  $9.80 \text{ m/sec}^2$ . Would friction produce an error in the direction of the error you observed for your data? In other words, could friction be the cause of the observed difference? What else might be a problem in the experiment?

4. Calculate the correlation coefficient  $r$  for the least squares fit. Using the correlation coefficients in Appendix 1, state the probability that the level of correlation is accidental.

5. What was the instantaneous velocity of the cart at  $x=4.00$  meters assuming your value of the acceleration " $a$ " is correct?

6. Does your graph of  $x$  versus  $t^2$  seem to “flatten” out at higher value of  $t$  and  $x$ . What might this indicate? What causes this “flattening” to happen?

7. What was the main purpose or goal in this lab? State your opinion of how well the purpose of this laboratory met. Does your data show the expected results?

Name \_\_\_\_\_ Section \_\_\_\_\_ Date \_\_\_\_\_

Lab Partners \_\_\_\_\_

Laboratory 4. Uniformly Accelerated Motion on the *Toy Russian Track*

### Laboratory Report

Data Table

	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
h					
d					

x	t1	t2	t3	t4	t5

Calculations Table

$\bar{h} =$  \_\_\_\_\_  $\alpha_h =$  \_\_\_\_\_  $\bar{d} =$  \_\_\_\_\_  $\alpha_d =$  \_\_\_\_\_  $\sin \theta = \bar{h}/\bar{d} =$  \_\_\_\_\_

x								
$\bar{t}$								
$\alpha_t$								
$\bar{t}^2$								

slope = \_\_\_\_\_ a = \_\_\_\_\_  $g_{exp} =$  \_\_\_\_\_ % error = \_\_\_\_\_

### Appendix I Correlation Coefficients\*

This table shows the probability to obtain a given correlation coefficient  $r$  for two variables for which there is in fact no correlation. This probability is a strong function of the number of data pairs  $N$ . As an illustration of the table, consider the case of  $N=12$ . There is a 10% probability of obtaining a value of  $r \geq 0.497$ , a 2% probability of obtaining a value of  $r \geq 0.658$ , and a 0.1% probability of obtaining a value of  $r \geq 0.823$  for data for which no actual correlation exists. For many cases in this laboratory manual, you will take data which produces values of  $r$  greater than the 0.1% probability for the particular value of  $N$ . In those cases one can conclude that the data are strong evidence for a linear relationship between the variables.

N	Probability (%)				
	10	5	2	1	0.1
3	0.988	0.997	0.999	1.000	1.000
4	0.900	0.950	0.980	0.990	0.999
5	0.805	0.878	0.934	0.959	0.992
6	0.729	0.811	0.882	0.917	0.974
7	0.669	0.754	0.833	0.874	0.951
8	0.621	0.707	0.789	0.834	0.925
9	0.582	0.666	0.750	0.798	0.898
10	0.549	0.632	0.716	0.765	0.872
11	0.521	0.602	0.685	0.735	0.847
12	0.497	0.576	0.658	0.708	0.823
15	0.441	0.514	0.592	0.641	0.760
20	0.378	0.444	0.516	0.561	0.679

\*This table is adapted from Table VI of Fisher and Yates, "Statistical Tables for Biological, Agricultural, and Medical Research," published by Longman Group Ltd. London (previously published by Oliver & Boyd Ltd. Edinburgh) and by permission of the authors and publisher.