

### General guidelines for experiment reports

- 1) Each person will write their own report. Include the names of everyone who contributed.
- 2) Reports will be typewritten and include tables and graphs, as appropriate, to demonstrate the work and support the conclusions.
- 3) There are no particular font, margins, or pages requirements.
- 4) A complete report should include the following sections:
  - Abstract States the main goal and the main results.
  - Introduction Describes why the experiment is being performed.
  - Methods & Data Describes the experimental setup in both words and with appropriate graphics. This section may also include formulae or derivations needed to demonstrate the objectives of the experiment, and tables of data or derived parameters.
  - Analysis Interprets the data. This section may also describe the precision of the results achieved and the main sources of error or uncertainty. This section should include graphs or figures that help interpret the data. Equations or derivations using basic data to compute other parameters may also be included here.
  - Results & Conclusions Summarizes the results and describes what worked well or what could have been changed to achieve better results.
  - Appendix Includes work performed but not essential to the main report, e.g., computer code for making plots or doing computations.
- 5) Feel free to include a photo of pertinent aspects of your setup or equipment. Drawings are often better as they can be labeled to show sizes, distances, etc.
- 6) The text should follow standard English grammar, punctuation, and sentence structure.
- 7) You should share data among the group but make your own tables and plots! Your report should be unique and reflect your own writing and thinking.

**Lab Report Grading Rubric**

	0	1	2	3	4
	Poor				Excellent
04% Signatures on Experimental Plan & Final Data					
08% Abstract: States the main goal and the main results.					
18% Introduction: Describes why the experiment is being performed.					
20% Methods & Data: Describes the experimental setup and execution. Includes tables of measurements and graphics/figures that demonstrate the methods and interpret the data.					
20% Analysis: Derives and interprets the results using equations and graphs that demonstrate the objectives of the experiment. Describes the precision of the results achieved and the main sources of uncertainty.					
20% Results and Conclusions: Summarizes the results and their uncertainties, and describes what worked well or what could have been changed to achieve better results.					
10% The report is neat and legible and shows original thought and understanding. The work is not copied from a friend or a solutions manual.					

# Experiment 999

## Measuring an Acceleration

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### Abstract

We measured the acceleration of a HotWheels car down an incline of constant slope. Observers recorded the distance traveled by the car at time intervals of 0.5 seconds over the four seconds required for the car to reach the bottom of the ramp. The position-time data were used to compute the average velocity in each of eight 0.5-second time intervals. We then used the change in velocity over each 0.5-second time interval to compute the acceleration. Our average acceleration over the eight intervals was  $0.469 \text{ m/s}^2$  with a standard deviation of  $0.099 \text{ m/s}^2$ .

### Introduction

Acceleration is a change in the velocity of an object. Generally, an average acceleration may be expressed as a change in velocity,  $\Delta v$ , over some time interval,  $\Delta t$ .

$$a_{avg} = \frac{\Delta v}{\Delta t}$$

Or, in the limit that  $\Delta t$  goes to zero,

$$a_{avg} = \frac{dv}{dt}$$

Measuring an acceleration, therefore, requires measuring a change in the position of an object and timing the duration required for each movement. In this experiment, we chose to measure the acceleration of a race car (really a HotWheels car) down an inclined road (really an orange track). Our goal was to measure the acceleration of the car to a precision of at least 0.01 meters per second squared by sing multiple measurements of the car's position over several seconds.

### Methods

We set up the race track on an inclined slope made by two metal tracks supported by bricks. Each metal track was two meters long, so that they form a solid surface four meters long when placed end-to-end. Upon this solid surface we placed several sections of HotWheels track connected together. The track drops roughly 18 inches over four-meter length. Although we could measure the incline angle to be roughly 15 degrees, it was not necessary for this experiment. Figure 1 below shows the experimental setup.

The metals ramps are marked with distance in cm along one edge, making it easy to measure the position of the car at any point along the ramp.

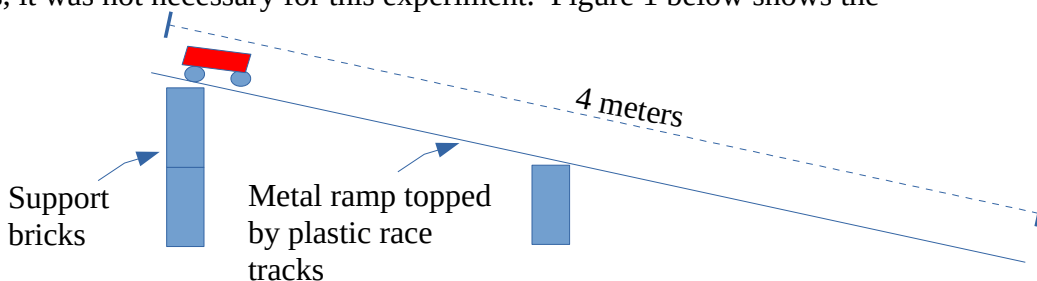


Figure 1: Schematic of the experimental setup

We released the car from rest at the top of the ramp with the rear end of the car at the zero mark. At each half second interval (e.g., 0 s, 0.5 s, 1.0 s, etc...) we measured the position of the rear edge of the car. Three or four people measured the position of the car at each time interval. We found that was possible to measure the position to an accuracy of at least 1 cm when the car was moving slowly, and each person estimated the position to 1.10 of a cm or 1 mm. However, once the car was moving more quickly, it became harder to measure the position with similar accuracy. We estimate that the positions are accurate to no more than 1 cm. Because several people took data at each time, we record all of their measurements, and we computed an average position at each time in order to help reduce random measurement errors. Table 1 below shows the measurement from each person and the average position of the car at each time.

**Table 1. Position, Velocity, Acceleration data**

	Measured Data					Calculated parameters	
	Distance	Distance	Distance	Distance	Distance	Avg. Velocity	Avg. Acceleration
Time	(m)	(m)	(m)	(m)	(m)	(m/s)	(m/s <sup>2</sup> )
(s)	Person 1	Person 2	Person3	Person4	Average		
<b>0.00</b>	0.000	0.000	0.000	0.000	<b>0.000</b>	0	
<b>0.50</b>	0.065	0.056	0.058	0.069	<b>0.062</b>	0.124	0.248
<b>1.00</b>	0.251	0.262	0.240	0.248	<b>0.250</b>	0.3765	0.505
<b>1.50</b>	0.562	0.540	0.578	0.569	<b>0.562</b>	0.624	0.495
<b>2.00</b>	1.051	1.011	0.980	0.991	<b>1.008</b>	0.892	0.536
<b>2.50</b>	1.569	1.530	1.630	1.590	<b>1.580</b>	1.143	0.502
<b>3.00</b>	2.256	2.267	2.244	2.239	<b>2.252</b>	1.3435	0.401
<b>3.50</b>	3.067	3.040	3.079	3.050	<b>3.059</b>	1.615	0.543
<b>4.00</b>	4.010	4.060	3.950	3.967	<b>3.997</b>	1.8755	0.521
						Average	<b>0.469</b>
						StdDev	<b>0.099</b>

## Analysis

Figure 2 shows a plot of the position of the car versus time. The plot shows that the car moved farther in any given time interval as the car moved along the ramp. The shape of the curve is roughly that of a parabola.

We computed the velocity of the car during each 0.5 s time interval by taking the distance traveled,  $\Delta x$ , divided by the time interval,  $\Delta t$ .

$$v(m/s) = \frac{\Delta x}{\Delta t} = \frac{(x_2 - x_1)}{(t_2 - t_1)}$$

For example, after the first 0.5-second time interval, the velocity is

$$\frac{\Delta x}{\Delta t} = \frac{(0.062 - 0.000)}{(0.5 - 0.0)} = 0.124 \text{ m/s}$$

The 6<sup>th</sup> column of Table 1 lists the velocities computed in this manner from each time intervals. Figure 3 below shows a plot of velocity versus time using the data from Table 1. The trend is a approximately a straight line with a positive slope, indicating increasing velocity. A straight line is consistent with a constant acceleration given by the slope of the line. The average velocity of the entire journey is

3.997 meters / 4.0 seconds = 1.00 m/s.

However, the instantaneous velocity is much smaller during the first portion of the experiment and much larger during the latter portion.

Finally, we used the velocity data to compute the acceleration during each time interval. The average acceleration was computed from

$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{(v_2 - v_1)}{(t_2 - t_1)}$$

For the first time interval this yields

$$\frac{(v_2 - v_1)}{(t_2 - t_1)} = \frac{(0.124 - 0.000)}{(0.5 - 0.0)} = 0.248 \text{ m/s}^2$$

Figure 3: Velocity of the car versus time.

The computed accelerations appear in Column 7 of Table 1. The values are relatively constant and fall near  $0.5 \text{ m/s}^2$ . At the bottom of Table 1 we compute the average acceleration over the eight time intervals to be  $0.469 \text{ m/s}^2$  and the standard deviation of this set of data to be  $0.099 \text{ m/s}^2$ .

## Results and Conclusions

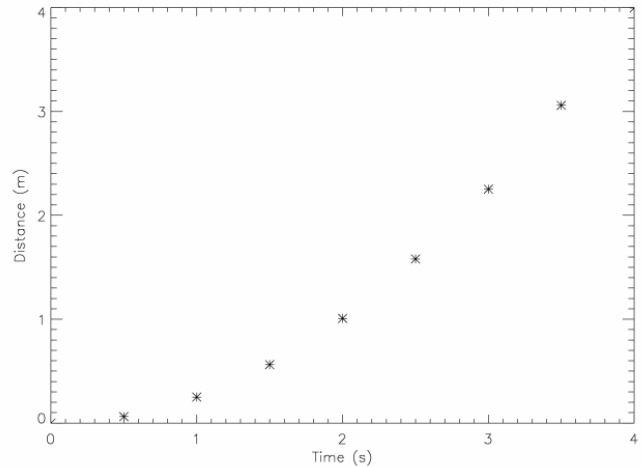
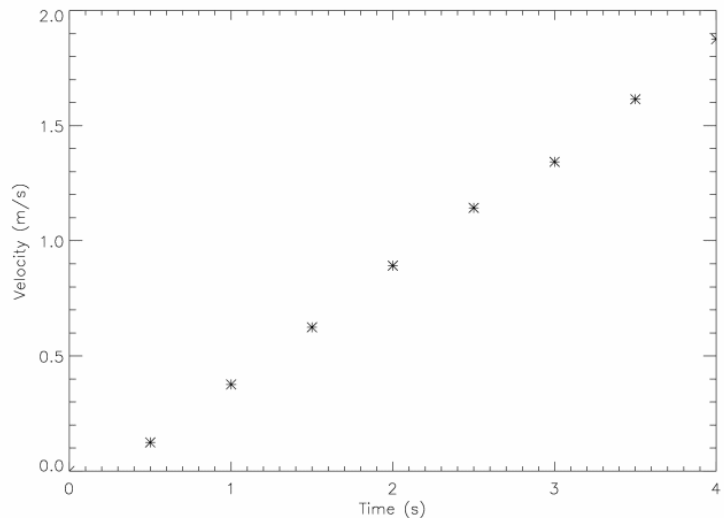


Figure 2: Position of the car in meters versus time using data from Table 1.



We measure the car's acceleration to be  $a=0.469\pm 0.099 \text{ m/s}^2$ . We use this value to compute the theoretical distance versus time curve using

$$x_1 = x_0 + v_0 t + \frac{1}{2} a t^2 ,$$

where  $v_0=0$  is the car's initial velocity and  $x_0=0$  is the car's initial position. Figure 4 shows the position-time plot of the data (asterisks) and the theoretical position-time curve (solid line). There is good agreement between the data and the curve, suggesting that the stated acceleration is a good representation of the car's motion overall. However, the curve falls increasingly below the data at later times, suggesting that we have underestimated the acceleration. We notice that our first computed acceleration in Table 1 is about half of the other values. If we reject this one measurement and compute an average of the remaining data, we find an average acceleration of 0.501, which would provide a better fit to the data. We don't have a good explanation for why our first acceleration value is low compared to the others, but it may have to do with difficulties in timing the very first measurement at  $t=0.5 \text{ s}$ . We conclude that we have measured the acceleration reasonably well.

In order to make a better measurement we might use a longer track so that we would have even more data points and a longer time over which to conduct the experiment. We could also have more people time the car at various points along the track so that, with more measurements, our data would be more accurate over each time interval. We could also try using a steeper track. We suspect that perhaps friction in the car's wheels would prevent the car from accelerating as quickly as it might otherwise if the track were steeper.

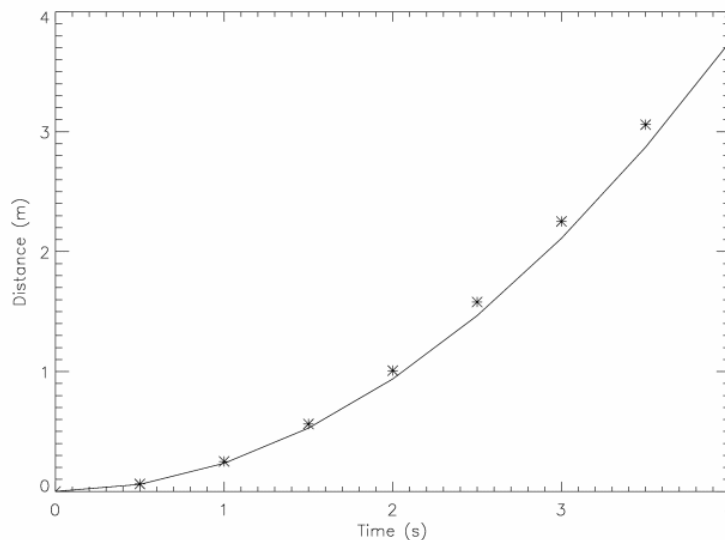


Figure 4: The position of the car versus time, showing the data (asterisks) and the theoretical curve computed using the average acceleration (solid line).

### Appendix

Below we show the Matlab code used to make the plots in Figures 2,3,4.

```
% make distance time plot in Figure 2
t=[0.0,0.5,1.0,1.5,2.0,2.5,3.0,3.5,4.0]
x=[0.000,0.062,0.250,0.562,1.008,1.580,2.252,3.059,3.997]
plot(t,x,'bs')
```

```
xlabel('Time (s)')
ylabel('Distance (m)')
% make velocity-time plot for Figure 3
t=[0.0,0.5,1.0,1.5,2.0,2.5,3.0,3.5,4.0]
v=[0.0,0.124,0.376,0.624,0.892,1.143,1.343,1.615,1.876]
plot(t,v,'rs')
xlabel('Time (s)')
ylabel('Velocity (m/s)')
% make distance-time plot for Figure 4 with theoretical curve overplotted
t=[0.0,0.5,1.0,1.5,2.0,2.5,3.0,3.5,4.0]
x=[0.000,0.062,0.250,0.562,1.008,1.580,2.252,3.059,3.997]
plot(t,x,'rs')
hold on
a=0.469
plot(t,0.5*a*t.^2)
xlabel('Time (s)')
ylabel('Distance (m)')
```