Student Learning Outcome for lab reports

Students will be able to recognize, understand, and produce technical science writing.

General guidelines for lab 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:
    - **<u>Abstract</u>** States the main goal and the main results. Any main quantitative results should be included.
    - **<u>Introduction</u>** Describes why the experiment is being performed.
    - **<u>Methods & Data</u>** Describes the experimental setup in both words and with appropriate graphics. This section should include tables of data and derived parameters.
    - **<u>Analysis</u>** Interprets the data. This section should include formulas or derivations. Describe the precision of the results achieved and the main sources of error or uncertainty. Include graphs or figures that help interpret the data.
    - **<u>Results & Conclusions</u>** Summarizes the results and describes what worked well or what could have been changed to achieve better results. Like the abstract, any main quantitative results should be included.
    - **<u>Appendix</u>** Supplementary information, e.g., computer code for making plots or doing computations. See note below on AI!
5) Include a photo of pertinent aspects of your setup or equipment. Drawings are also often helpful, 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.

Incorporating Artificial Intelligence

1. Provide in the Appendix an AI-generated introduction to your lab report (and the prompt given!). Provide a *brief* critique of the AI-generated introduction, and how you modified it for your actual introduction to the lab report. One site is https://openai.com/
2. Provide in the Appendix an AI-generated image/sketch/drawing of your apparatus. Have fun! One site is https://hotpot.ai/

Uncertainty vs Error
I'm using the term "uncertainty" in the standard way: to reflect our confidence in a quantity. I'm using the term "error" to only reflect the percentage difference from expectations. Uncertainties should be provided for every number including the final result; errors should be additionally provided for the final result.

Example #1 for uncertainty
For something directly measured like the mass of a cube, the "uncertainty" is your best estimate about the accuracy of the scale, maybe $\pm$ 1 gram.

Example #2 for uncertainty
For something that relies on both measurements and an equation, like the average volume of the gardyloo, the uncertainty can be computed via

$$\varepsilon(\langle V\rangle) = \sigma/\mathrm{sqrt}(3),$$

in other words, the standard deviation of your individual volumes divided by the square root of the number of trials you carried out. One can also estimate the uncertainty via propagation of errors, like we did for Lab #1, but typically we'll use the statistical approach.

Example #1 for error
I expect to see an error provided for a lab's final result, like the molar mass. In this example, the error can be computed via the percent difference from expectations:

$$\mathrm{error}(M) = 100*|M- M_{known}|/M_{known}$$

For the Lab #2 report
There may not be sufficient time to carry out three independent trials for M, and because the propagation of errors is messy, I don't expect an uncertainty on M. And since we can't look up a reference value for $V_{gardyloo}$, I don't expect an error for $\langle V_{gardyloo}\rangle$. In short, I only expect an error for M and an uncertainty for $\langle V_{gardyloo}\rangle$.

Lab Report Grading Rubric

04% Approvals for Experimental Plan & theoretical interpretation.
08% Abstract: States the main goal and the main results.
15% 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.

15% 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.
06% The AI-generated introduction is provided and critiqued in the Appendix.
02% The AI-generated image/sketch/drawing of the apparatus is included in the Appendix.

Experiment 999

Measuring an Acceleration

Ima Genius
in collaboration with
B.A. Helper, M.Y. Partner, A. Dude

Abstract

Our goal was to measure acceleration to a precision of at least 0.01 meters per second squared. 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±0.052 m/s^2 with a standard deviation of 0.099 m/s^2 and thus an error of 0.035 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, Δv, over some time interval, Δt.

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

Or, in the limit that Δt goes to zero,

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

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 using 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 18±0.2 inches over four-meter length. Although we could measure the incline angle to be 15±1 degrees, it was not necessary for this experiment. Figure 1 below shows the experimental setup. The metals ramps are

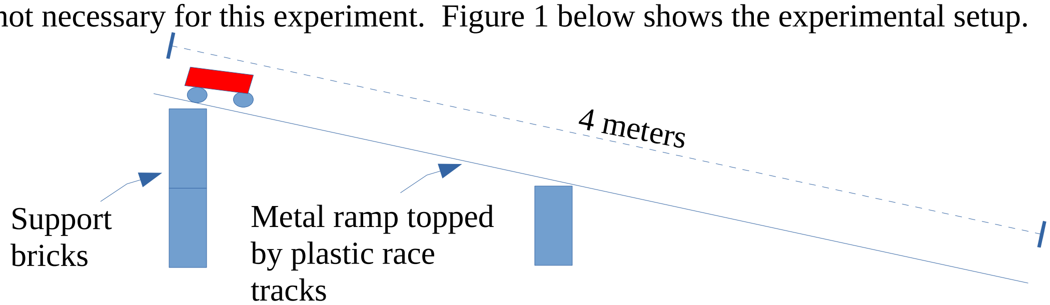

Figure 1: Schematic of the experimental setup

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

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

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, Δx, divided by the time interval, Δt.

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

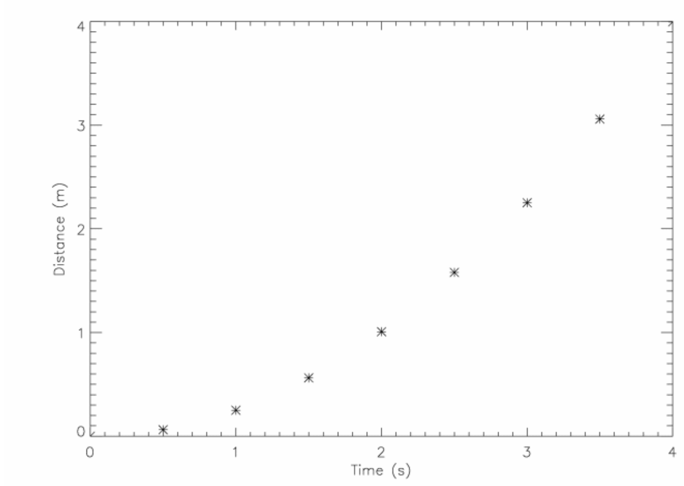

Figure 2: Position of the car in meters versus time using data from Table 1.

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

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

The 6th 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

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

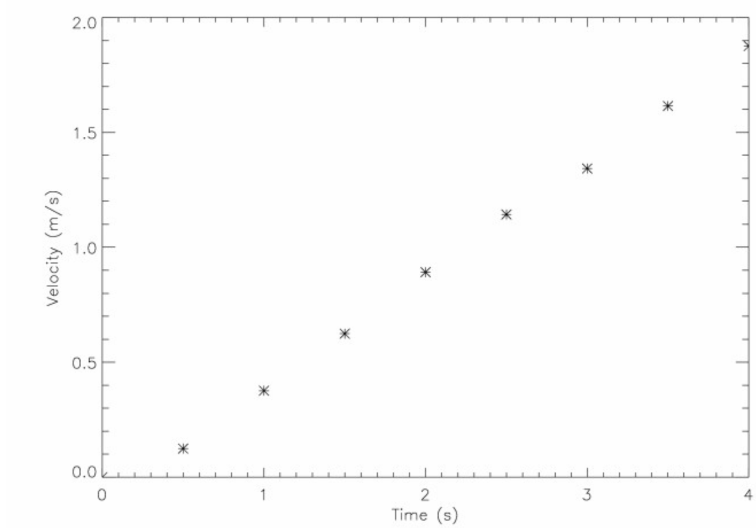

Figure 3: Velocity of the car versus time.

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

Results and Conclusions

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

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

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 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.

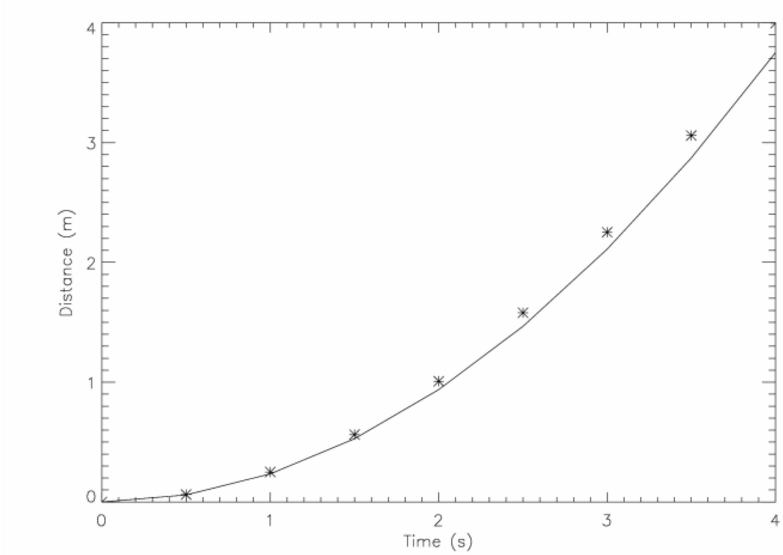

Figure 4: The position of the car versus time, showing the data (asterisks) and the theoretical curve computed using the average acceleration (solid line).

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)')
```