Formal Lab
Measuring g

Physics 4A

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Contents

Chapter 1

Purpose

The purpose of this lab is to measure gravitational acceleration and compare it to the theoretical value of the gravitational value of Earth g found to be about $9.80\frac{m}{s^2}$. In this lab the goal is to attempt to measure an experimental g.

Chapter 2

Theory

Objects that fall freely near Earth will accelerate at approximately $9.80\frac{m}{s^2}$ if they:

- are near the surface of the Earth
- are at a geographic location where the Earth's radius is approximately its average value

When air friction is ignore, the acceleration of an object falling is independent of the mass, volume, and shape. For short distances and small objects it is not unreasonable to neglect air resistance, but for long distances and large objects, air resistance is significant Acceleration of gravity g can be calculated using kinematics

- Δy is the displacement
- t is the time
- v_0 is the initial velocity
- v_f is the final veolcity
- $a = g_{exp}$ a is the experimental acceleration due to gravity

Chapter 3

Procedure

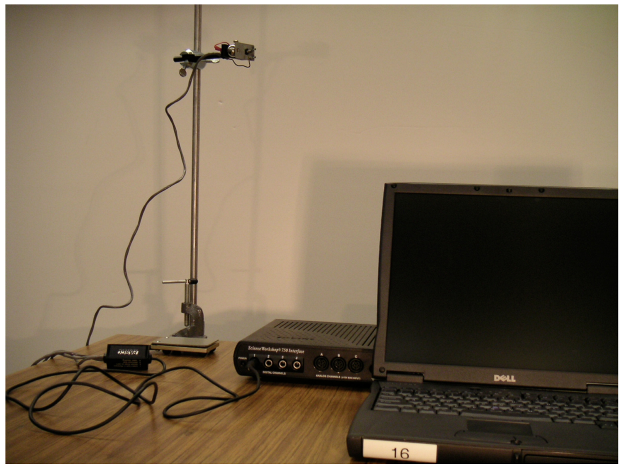
3.1 Procedure Equipment

The necessary equipment for this lab is as follows:

- 2 meter aluminum rod
- Table clamp
- Swivel clamp or 90° Offset Clamp
- Meter Stick
- $\frac{1}{2}$" and $\frac{3}{8}$" steel ball
- Freefall Adapter - PASCO #ME
- PASCO 750 Interface box
- PASCO Interface box power cord and SCSI Interface Card
- Laptop Computer w/ Data Studio

3.2 A. Apparatus Setup

Setup the apparatus as shown in the picture below. Make sure that the clamps are tight, but not over tight. The clamp holding the apparatus should be tight enough to not allow the apparatus to move around. Makre sure that the small thumb screw on the ball clamp is on top.



The apparatus consists of a small clamp that holds the metal ball and a steel rod; it is designed to complete a circuit when the ball is installed. There is a plunger that goes through the thin steel plate that has a retaining ring on both ends. This plunger places pressure on the steel plate and holds the ball in place.

Place the ball in the clamp, positioning it between the hole and the brass screw, pull on plunger so that the retaining ring is exerting pressure on the steel plate. When there is enough pressure on the plate to retain the ball, tighten the thumbscrew. The ball and apparatus are now ready to be used.

Position the floor plate directly beneath the ball clamp. Do a few test drops to make sure that the ball solidly strikes the plate.

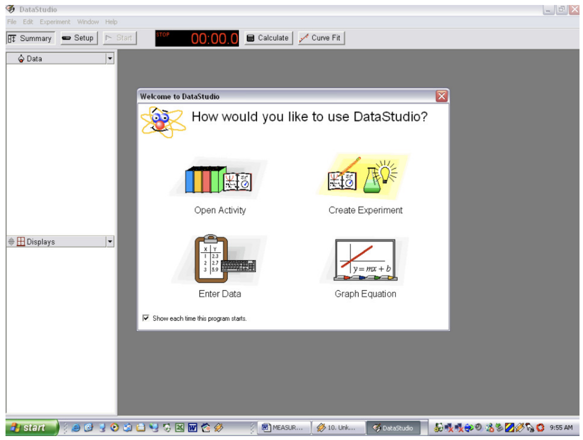
Possible Pitfalls:

Due to the age of the apparatus, the circuit may be easily broken. It is possible, however, to maneuver the ball so that the circuit remains closed. The thumbscrew must be tightly set; otherwise it will not hold the plunger. This means that the slightest turn on the thumbscrew will release the plunger.

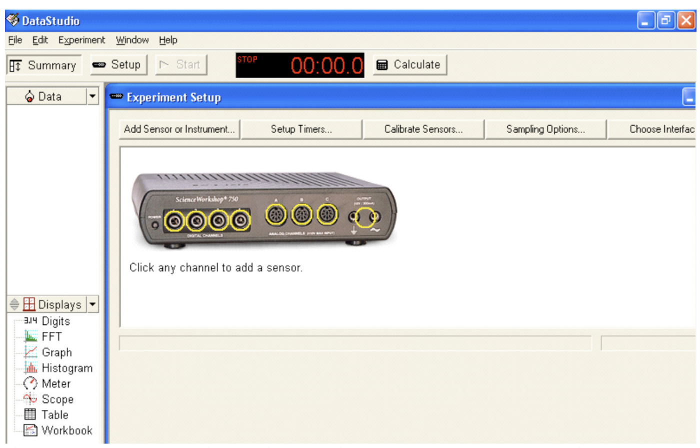
3.3 B. Computer Setup

Provide power to the PASCO 750 Interface box, connect the box to the computer with the SCSI cord and turn on the box, making sure the word "Honda" on the cord is facing upward when it gets plugged into the computer. **Only after you have turned on the PASCO 750 Interface box 750 and plugged it into the computer, can you turn on the computer. (If you do not perform these tasks in the above listed order, your computer will not recognize the PASCO 750 Interface box.)** When the computer is first turned on, it may have a Found New Hardware window open. If so, just ignore the window and proceed with the steps below.

Double-Click on the *Data Studio* icon on the desktop. The following screen should appear:



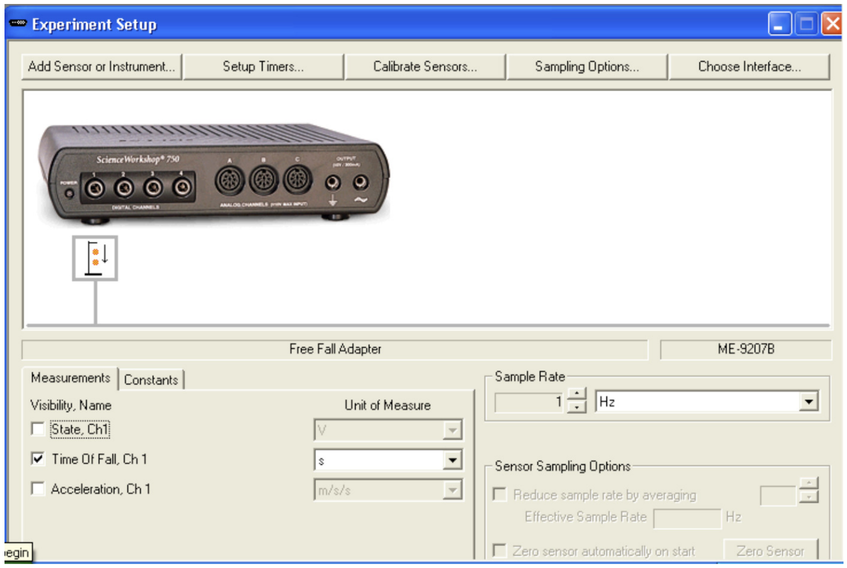
Click *Create Experiment*, if it cannot find the Interface box right away, click *Scan*. If it doesn't find it after you have clicked *Scan*, make sure that it is connected properly. If it is connected properly and everything seems to be in order, restart the computer and the Interface box should load proper.
Once the Interface box is found, the following screen will appear:



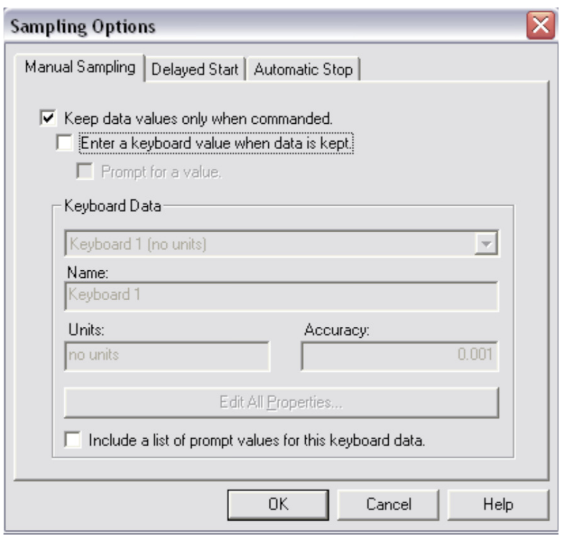
This is your main window. This window contains a picture of the interface box you currently have attached, access to a list of sensors that can be attached to the Interface box, a toolbar to *adjust* sensor options and other items.

Under *Experiment Set-Up*, click *Add Sensor or Instrument* and a window will open. Then click on the small black arrow near the top of the window to open a drop-down menu and select *Scientific Workshop Digital Sensors*. Finally select *Free-Fall Adapter* and click *Ok*. See picture below.

In the *Experiment Set-Up* window, on the bottom left corner of the window, click the *Measurements* tab and de-select *Acceleration, Ch 1 box*. As seen below.



Plug the *Free Fall Adapter* into the channel indicated (here it is in Channel 1). Click the *Sampling Options* button (located on the top of the *Experiment Setup* window). Make the selections as below:



When you click on *"Keep data values only when commanded,"* you will have to uncheck *"Enter a keyboard value when data is kept."* Click *Ok*. The computer is now ready to collect data.

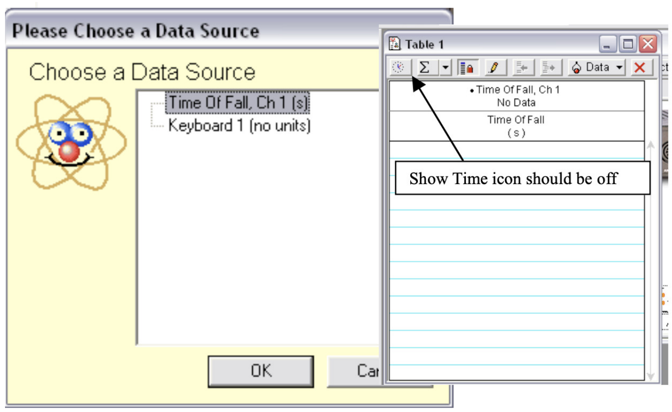
3.4 C. Data Collection Setup

On the left-hand side of the Data Studio program, there are two windows: *Data* and *Displays*.

Data shows you what you are going to collect. Here, you can see that the only data being collected is the *Time of Fall*, in seconds.

Displays gives you several choices and formats in which to display your captured data. In this lab, we are only going to be concerned with the *Table* display. We will explore other displays in subsequent labs.

Double-Click *Table* in Displays and select *Time of Fall, Ch 1 (s)*. Click *OK*. The following table will appear on your screen:



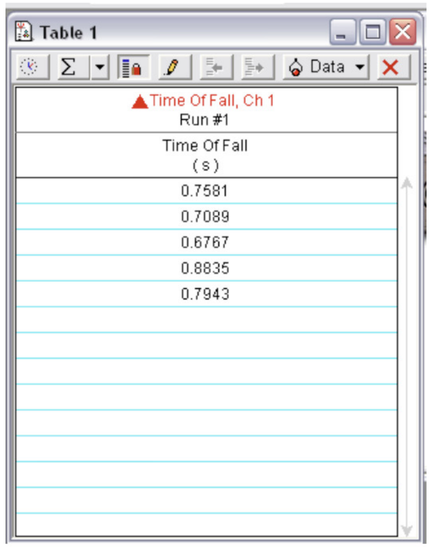
Make sure that the *Show Time* icon, on the top of your table, is **off**. You are now ready to begin the experiment.

3.5 D. Data Collection

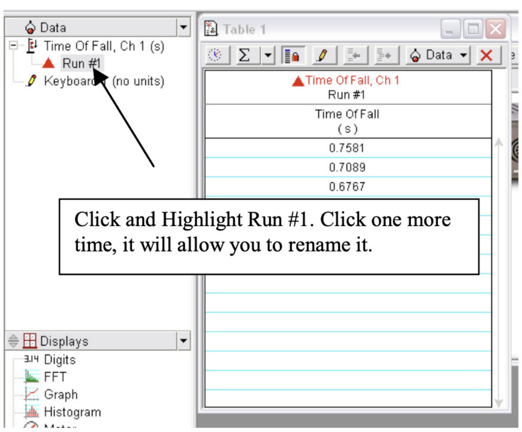
The goal of this experiment is to capture the time it takes the ball to fall a certain distance. We have set up the computer and apparatus to assist us in capturing the data required.

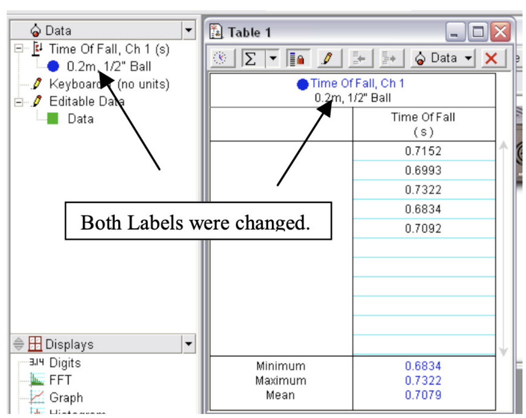
You will be dropping each ball over a minimum of 5 distances (0.2 m, 0.4 m, 0.6 m,0.8 m, 1.0 m, etc.). Drop the ball 5 times per height to get an average time.

Load the apparatus with the large ball, and set the apparatus at the correct height. Click the Start button; this will start the timer. Leave it on for the remainder of the experiment. When you drop the ball, the data will appear on the table. If it appears to be good data, click the *Keep* button



Repeat 5 times for the given height and press Stop. You can rename the run to help keep track of where you are in the process (ie. 0.2 m, $\frac{1}{2}$" Ball) by clicking on the *Run* # Label in the *Data* window.





This is your first set of times. Repeat the experiment at the same height with the smaller ball.

Set the apparatus at a new height and repeat.

Note: Every time you start and stop the timer, you create new runs.

It is possible to delete a run if necessary, Click Experiment then Delete Last Data Run. Caution In Data Studio you can only delete the last data run or

ALL data runs, however, once all of the runs have been completed, you will move the data from each table into Excel for analysis. In *Excel* you can delete any bad data runs that you were unable to delete in Data Studio.

You should have at least 5 tables of times per ball, each properly labeled and ready for transfer into *Excel*. If the data tables are not all open, then go to the left-hand side of the Data Studio program, where the *Data and Displays* windows are. Click (and hold) on your data run, then drag it to the *Table* icon under *Displays* and release the mouse button. A table of that data run should appear, showing the time of fall.

3.6 Data Collection Cont.

You should have at least 5 tables of times per ball, each properly labeled and ready for transfer into Excel. If the data tables are not all open, then go to the left-hand side of the Data Studio program, where the Data and Displays windows are. Click (and hold) on your data run, then drag it to the Table icon under Displays and release the mouse button. A table of that data run should appear, showing the time of fall.

The table below should give you an idea of what you are looking for, however using the method described here, you will have each data table in a separate window.

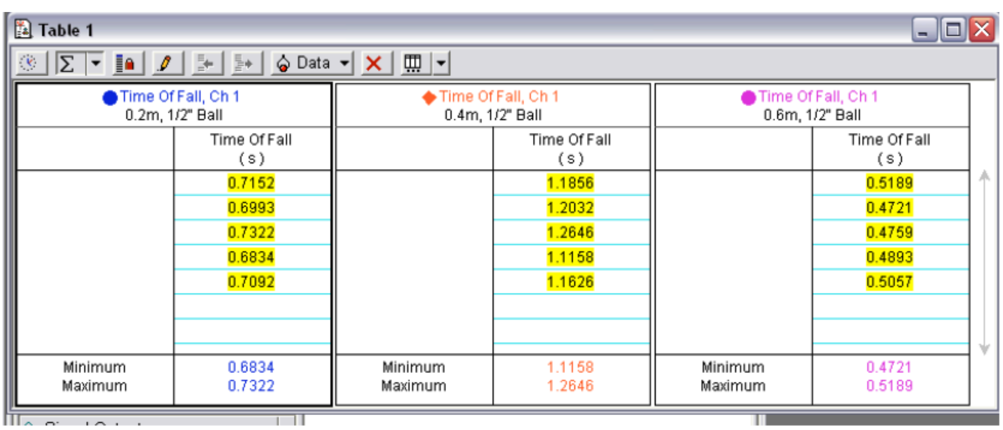


Table 1

Time Of Fall, Ch 1 0.2m, 1/2" Ball		Time Of Fall, Ch 1 0.4m, 1/2" Ball		Time Of Fall, Ch 1 0.6m, 1/2" Ball	
	Time Of Fall (s)		Time Of Fall (s)		Time Of Fall (s)
	0.7152		1.1856		0.5189
	0.6993		1.2032		0.4721
	0.7322		1.2646		0.4759
	0.6834		1.1158		0.4893
	0.7092		1.1626		0.5057
Minimum	0.6834	Minimum	1.1158	Minimum	0.4721
Maximum	0.7322	Maximum	1.2646	Maximum	0.5189

3.7 Procedural Analysis and Results

In order to do the analysis of the data, you are going to transfer this data into *Excel*. In order to properly transfer it, move the mouse over to the cell that says *Time Of Fall*, your cursor will change into a down arrow. **Click** once to select the data in the table, **click** *Edit* in the *menubar*, then click *Copy*; OR, type *Ctrl-C* to copy. Once copied, open *Excel* and start a new workbook. Click cell *A1*, go to *Edit* on the *menubar*, click *Paste*; OR, type *Ctrl-V* to paste. Two columns and a header will appear in *Excel* as shown below

Time Of Fall, Ch 1, 0.2m, 1/2" Ball	
Time (s)	Time Of Fall (s)
5.478	0.7152
10.885	0.6993
16.333	0.7322
25.586	0.6834
31.525	0.7092

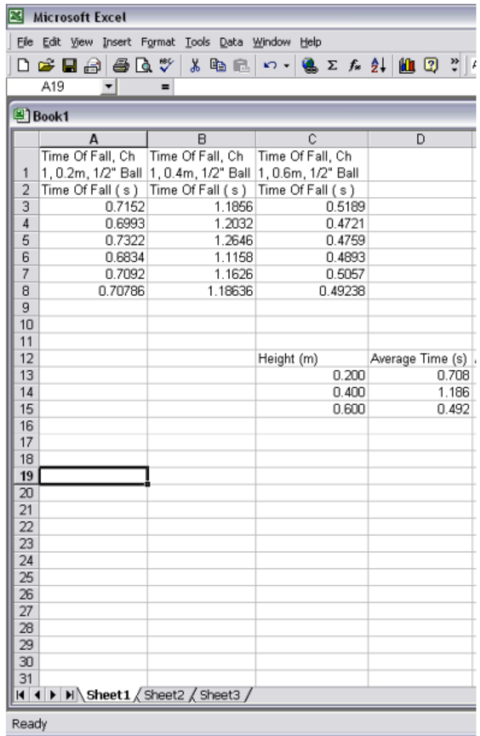
Copy or move the header (Time Of Fall, Ch 1, 0.2m, $\frac{1}{2}$" Ball) one cell to the left and then **delete** the first column. The first column is basically meaningless, it shows you when you took the measurement based on the elapsed time on the timer.

Repeat for each table of data you collected. By the time you are done with the copying, pasting and deleting, your *Excel* table should look like this:

Time Of Fall, Ch 1, 0.2m, 1/2" Ball	Time Of Fall, Ch 1, 0.4m, 1/2" Ball	Time Of Fall, Ch 1, 0.6m, 1/2" Ball
Time Of Fall (s)	Time Of Fall (s)	Time Of Fall (s)
0.7152	1.1856	0.5189
0.6993	1.2032	0.4721
0.7322	1.2646	0.4759
0.6834	1.1158	0.4893
0.7092	1.1626	0.5057

Using *Excel*, you will now find the average time for each run. To find the average, type in the following command into the cell directly below the 1st run of data. =AVERAGE(A3:A7), where A3:A7 is the range of cells over which you are calculating the average. After you have found the average times for each run, you are now ready to begin the calculation for g. In a cell away from the runs, begin a new table, with headers "*Height*" and "*Average Time*." In the *Height* column, type in each height that you used. In the *Average* Time column, type in the average time for each run (or you can reference the cell in which you made that calculation).

See example below



	A	B	C	D
1	Time Of Fall, Ch 1, 0.2m, 1/2" Ball	Time Of Fall, Ch 1, 0.4m, 1/2" Ball	Time Of Fall, Ch 1, 0.6m, 1/2" Ball	
2	Time Of Fall (s)	Time Of Fall (s)	Time Of Fall (s)	
3	0.7152	1.1856	0.5189	
4	0.6993	1.2032	0.4721	
5	0.7322	1.2646	0.4759	
6	0.6834	1.1158	0.4893	
7	0.7092	1.1626	0.5057	
8	0.70786	1.18636	0.49238	
9				
10				
11				
12			Height (m)	Average Time (s)
13			0.200	0.708
14			0.400	1.186
15			0.600	0.492

Looking once again at the formula: $=(2*(\text{first height cell})/((\text{first average time cell})^2))$, notice that the "first height cell" here is C13, the first average time cell is D13, and the formula itself is in E13. When you type this formula into the E13 cell, you can then copy and paste it into E14, E15 etc. The cell references will automatically be updated; you should not have to fix them.

- For each ball, plot $|\Delta y|$ verses $\frac{t^2}{2}$ using the xy *scatter* chart and insert a *best-fit linear trendline* with its equation to show the experimental g, which will be the slope of the trendline
- For each ball, calculate the percent difference between g_{exp}, the slope of your trendline, and the theoretical result ($g_{theoretical} = 9.80\frac{m}{s^2}$).

Chapter 4

Data

4.1 Raw Data

Raw Untouched Data

Time Of Fall, 0.2m, 1/2" large	Time Of Fall, 0.2m, 3/8" small
Time Of Fall (s)	Time Of Fall (s)
0.2021	0.2028
0.2032	0.2021
0.2009	0.2028
0.2004	0.2029
0.2005	0.2017

Time Of Fall, 0.4m, 1/2" large	Time Of Fall, 0.4m 3/8" small
Time Of Fall (s)	Time Of Fall (s)
0.2849	0.2862
0.2843	0.2866
0.284	0.2866
0.2851	0.2872
0.2845	0.2874

Time Of Fall, 0.6m, 1/2" large	Time Of Fall, 0.6m, 3/8" small
Time Of Fall (s)	Time Of Fall (s)
0.3476	0.3487
0.3476	0.3494
0.3494	0.3498
0.3491	0.3489
0.3487	0.3491

Time Of Fall, 0.8m, 1/2" large	Time Of Fall, 0.8m, 3/8" small
Time Of Fall (s)	Time Of Fall (s)
0.402	0.4049
0.4036	0.4034
0.4025	0.4036
0.4048	0.4037
0.4034	0.4043

Time Of Fall, 1.0m, 1/2" large	Time Of Fall, 1.0m, 3/8" small
Time Of Fall (s)	Time Of Fall (s)
0.4508	0.4531
0.4498	0.4512
0.4501	0.452
0.4517	0.452
0.4519	0.451

4.2 Formatted Raw Data

Raw Data Fromatted in a Data

Small Ball (3/8" steel ball)

Height (cm)	Uncertainty (+- cm) based on meter stick	Height (m)	Uncertainty (m)	Time of Fall (s)	Uncertainty (+- s) based on photogate timer
20.0	0.05	0.200	0.005	0.2028	0.00005
				0.2021	
				0.2028	
				0.2029	
				0.2017	
40.0	0.05	0.400	0.005	0.2862	0.00005
				0.2866	
				0.2866	
				0.2874	
				0.2872	
60.0	0.05	0.600	0.005	0.3487	0.00005
				0.3494	
				0.3498	
				0.3489	
				0.3491	
80.0	0.05	0.800	0.005	0.4049	0.00005
				0.4034	
				0.4036	
				0.4037	
				0.4043	
100.0	0.05	1.000	0.005	0.4531	0.00005
				0.4512	
				0.4520	
				0.4520	
				0.4510	

Large ball (1/2" steel ball)

Height (cm)	Uncertainty (+- cm) based on meter stick	Height (m)	Uncertainty (m)	Time of Fall (s)	Uncertainty (+- s) based on photogate timer
20.0	0.05	0.200	0.005	0.2021	0.00005
				0.2032	
				0.2009	
				0.2004	
				0.2005	
40.0	0.05	0.400	0.005	0.2849	0.00005
				0.2843	
				0.284	
				0.2851	
				0.2845	
60.0	0.05	0.600	0.005	0.3476	0.00005
				0.3476	
				0.3494	
				0.3491	
				0.3487	
80.0	0.05	0.800	0.005	0.402	0.00005
				0.4036	
				0.4025	
				0.4048	
				0.4034	
100.0	0.05	1.000	0.005	0.4508	0.00005
				0.4498	
				0.4501	
				0.4517	
				0.4519	

Chapter 5

Analysis

5.1 Average Time Calculated

In the following data tables, the average time of the fall for each ball at each height is calculated

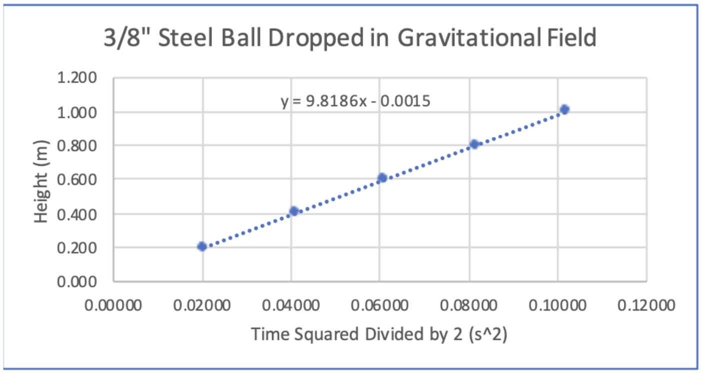
Height (m)	3/8" Small Ball	Time of Fall (s)
0.200		0.2028
		0.2021
		0.2028
		0.2029
		0.2017
	Average	0.2025
0.400		0.2862
		0.2866
		0.2866
		0.2874
		0.2872
	Average	0.2868
0.600		0.3487
		0.3494
		0.3498
		0.3489
		0.3491
	Average	0.3492
0.800		0.4049
		0.4034
		0.4036
		0.4037
		0.4043
	Average	0.4040
1.000		0.4531
		0.4512
		0.4520
		0.4520
		0.4510
	Average	0.4519

Height (m)	1/2" Large Ball	Time of Fall (s)
0.200		0.2021
		0.2032
		0.2009
		0.2004
		0.2005
	Average	0.2014
0.400		0.2849
		0.2843
		0.284
		0.2851
		0.2845
	Average	0.2846
0.600		0.3476
		0.3476
		0.3494
		0.3491
		0.3487
	Average	0.3485
0.800		0.402
		0.4036
		0.4025
		0.4048
		0.4034
	Average	0.4033
1.000		0.4508
		0.4498
		0.4501
		0.4517
		0.4519
	Average	0.4509

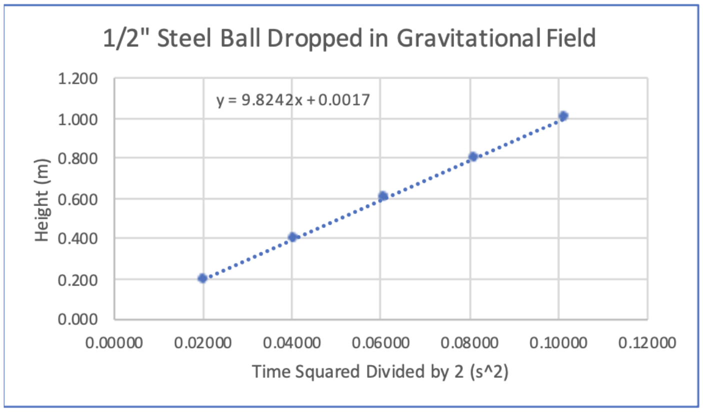
5.2 Graphed Data

The following graphs for the small and large ball and their avaerge fall times at each height squared then divided by 2, are plotted on a scatter plot and given a linear line with a calculated slope.

Height (m)	Average Time of Fall (s)	Time Squared Divided by 2 (s^2)
0.200	0.2025	0.02050
0.400	0.2868	0.04113
0.600	0.3492	0.06097
0.800	0.4040	0.08161
1.000	0.4519	0.10211



Height (m)	Average Time of Fall (s)	Time Squared Divided by 2 (s^2)
0.200	0.2014	0.02028
0.400	0.2846	0.04050
0.600	0.3485	0.06073
0.800	0.4033	0.08133
1.000	0.4509	0.10166



5.3 Answers to Questions Posed by Lab

1. How is average velocity different from average speed? Tell the definition of each.
   ANSWER: Average speed only shows how fast an object is going which is the total distance over a total time. Average velocity shows both the direction and the magnitude of an object over a time.

2. When, if at all, is the magnitude of the average velocity of an object moving in one-dimension:

   (a) equal to that object's average speed? Explain
   ANSWER: The average velocity of an object moving in one-dimension is only equal to that object's average veolcity when dispalcement is equal to the distance i.e. an object is moving in one direction

   (b) greater than that object's average speed? Explain.
   ANSWER: The average velocity of an object moving in one-dimension is **never** greater than that object's average speed. The displacement is always less than or equal to the direction.

   (c) less than that objects average speed? Explain.
   ANSWER: The average velocity of an object moving in one-dimension is less than the average speed of that object when it changes direction. For example when an object moves then returns to wher it started.

3. In the absence of air resistance, should the values of g_{exp} be the same or different for the two balls? Explain your answer.
   ANSWER: Due to the absence of air resistance and the equation $F = ma$, values of g_{exp} for the two different balls should be the same. This is because the gravitational force of acceleraton is not dependent on mass.

Chapter 6

Error Analysis and Procedural Errors

6.1 Front-End Error - RSS

$$RSS = \sqrt{\left(\frac{0.005m}{0.200m}\right)^2 + \left(\frac{0.005m}{0.400m}\right)^2 + \left(\frac{0.005m}{0.600m}\right)^2 + \left(\frac{0.005m}{0.800m}\right)^2 + \left(\frac{0.005m}{1.000m}\right)^2 + \left(\frac{0.00005s}{0.2025s}\right)^2 + \left(\frac{0.00005s}{0.2868s}\right)^2 + \left(\frac{0.00005s}{0.3492s}\right)^2 + \left(\frac{0.00005s}{0.4040s}\right)^2 + \left(\frac{0.00005s}{0.4519s}\right)^2} \cdot 100\% = 3.0\%$$

$$RSS = \sqrt{\left(\frac{0.005m}{0.200m}\right)^2 + \left(\frac{0.00005s}{0.2025s}\right)^2} \cdot 100\% = 2.5\%$$

These values are chosen because they are the greatest contributors to error in this lab experiment

6.2 Back-End Error

In this case, percent error should be used because this is an experimental result being compared to the accepted known value of $g = 9.8\frac{m}{s^2}$ With the following percent error calculated, none of the data points were over the Front-End Error percentage. In general the calulated gravitational acceleration was very close to the theoretical value of Earth's $g = 9.8\frac{m}{s^2}$

$$3/8\text{" } ball: \qquad \%error = \frac{|E-K|}{K} \cdot 100\%$$

$$= \frac{|9.8186\frac{m}{s^2} - 9.80\frac{m}{s^2}|}{9.80\frac{m}{s^2}} \cdot 100\% = 0.19\% \ (0.189\%)$$

$$1/2\text{" } ball: \qquad \%error = \frac{|E-K|}{K} \cdot 100\%$$

$$= \frac{|9.8242\frac{m}{s^2} - 9.80\frac{m}{s^2}|}{9.80\frac{m}{s^2}} \cdot 100\% = 0.25\% \ (0.246\%)$$

6.3 Potential Cause of Error

There are a number of potential causes to the error presented in this lab experiment. The two most notable causes of error are as follows:

- Miscalculated height - although we were aiming for 0.005m within each labeled drop height. There is possibilty that, that was not achieved for every drop due to changing heigts for different points of data collection. Additionally, it is possible, that the surface the ball was dropped on was not perfectly level which could cause additional error in the experiemnt
- Timing limitations - the timing mechanism is only accurate a few decimal places

A third cause to error is the disregarded air resistance. Although it is stated that air resistance only has significant impact on large objects falling far distances, air resistance could be a factor for some error.

Chapter 7

Conclusion

In conclusion, the purpose of this lab was to measure an experimental g and comapre that value with the accepted theoretical value of Earth's gravitational acceleration $9.80\frac{m}{s^2}$. After collecting 25 points of data for each steel ball the $\frac{1}{2}$" and $\frac{3}{8}$" ball, it is clear that the theory of an object freely falling will accelerate at this theoretical value. With both calculations of g_{exp} being approximately $9.82\frac{m}{s^2}$ and $9.81\frac{m}{s^2}$ respectively.

The g_{exp} for the $\frac{1}{2}$" ball was $9.8242\frac{m}{s^2}$ and

The g_{exp} for the $\frac{3}{8}$" ball was $9.8186\frac{m}{s^2}$

Though these g_{exp}'s are not exactly $9.80\frac{m}{s^2}$, the error allowed could account for this deviation from the theoretical value. With the RSS error being 3.0% and the greatest contributors RSS error being 2.5%

Furthermore, the backend error implementing %error for the $\frac{1}{2}$" ball was 0.25% and the %error for the $\frac{3}{8}$" ball was 0.19%

Considering the purpose of the lab, the result, and factors of possible error, the goal of this lab was accomplished.

Chapter 8

Suggestions for Improvement

Due to the age of this lab, over the years the professors of the Saddleback College Physics faculty have implemented almost all of the improvements that can be used for the lab.

Despite this, if I were to improve the lab experiment in any way, it would be to make sure the student is setting up their equiqment on a level surface.

During my lab I know that I found it difficult to gage whether or not my experiment was setup in the most accurate way. I also did not take into account the height of the sensor the ball was being dropped onto so I wasted precious time re-doing drops to get an accurate measure. Therefore, I think that the procedure section should add a note to consider this.