Lab Report 1: Acceleration due to Gravity

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Introduction:

The purpose of this lab is to experimentally determine acceleration due to gravity using a tennis ball and tracker software. The popular belief that gravity was discovered due to a falling apple is mimicked using a falling tennis ball. We use modern technology, a cellphone, in the lab and the tracker software in order to experimentally determine our acceleration due to gravity.

The theoretical value for g is -9.81 m/s^2. Other than determining our experimental value for g, we are evaluating if our measuring tools are effective in producing quality results. One aspect is the phone camera which operates using sensors that collect enough light to produce a clear image. When taking a video, this aspect of its operation causes motion blur when an object is recording while it is moving. Though, it is hard to see in a direct video, when going frame by frame by using tracker software, the motion blur of the tennis ball is visible. The amount of motion blur might limit our abilities to accurately calculate the acceleration due to gravity.

When determining acceleration due to gravity, the following equations are used based on the data we obtain. The comparison of position vs. time gives us a parabolic function which can be linearized as follows to obtain acceleration due to gravity as our slope:

$$y = y_0 - \frac{1}{2}gt^2,$$

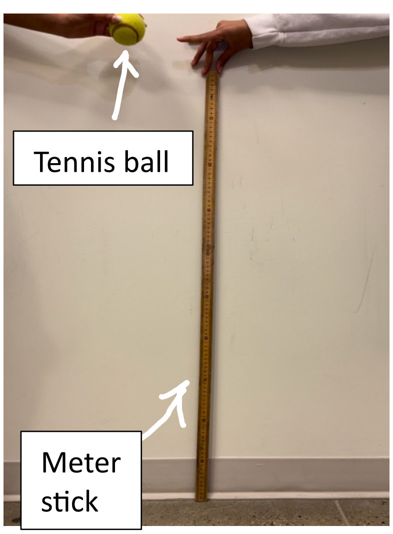
Where $\frac{1}{2}t^2$ gives us our x-values and the position, y, gives us our y-values. The slope of this equation gives us acceleration due to gravity, g. This formula was obtained from the EN PHYS Fa23 Lab manual [1].

The comparison of velocity vs. time gives us a linear function through the formula obtained from the EN PHYS Fa23 Lab Manual [1]:

$$v_y = v_{0,y} - gt,$$

Where t is our x-value and the velocity is the y direction is our y-value. Using this, we obtain our slope which is our experimentally determined value for acceleration due to gravity. The results of acceleration due to gravity from these equations can be used to be compared against the theoretical value of gravitational acceleration, g = 9.81 m/s^2.

Methods:



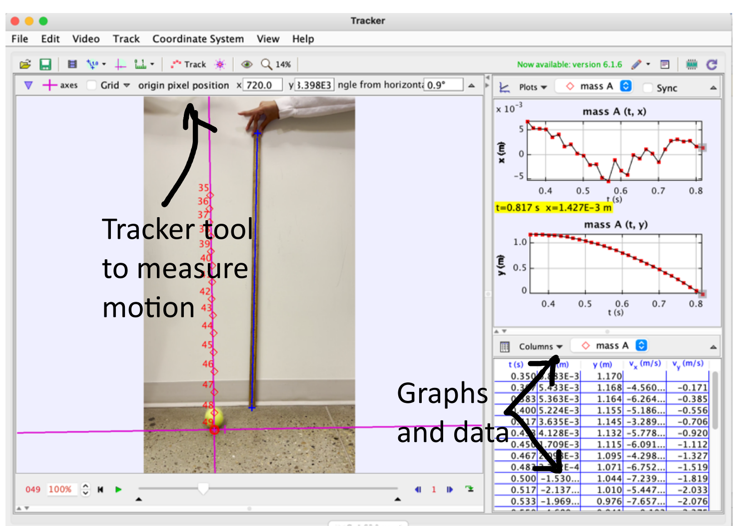


Fig.1 Fig.2

Fig.1. This shows the experimental set up used. The meter stick was used to be a standard measurement for our software while the tennis ball was held at the top of the screen and dropped with no initial velocity.

Fig.2. This shows the tracker software that was used to track the motion of the tennis ball to convert it into position and velocity information which was used in our calculations.

The equipment used in this lab is a meterstick, cellphone and a tennis ball. The cellphone was used to record the video where a tennis ball was dropped. A meter stick was held up to be used as a reference of known measurement to use in the software. One of my lab partners was recording while I held up the meter stick. My other lab partner held the ball a bit over meter above the ground. When the recording started, she simply dropped the ball ensuring no initial velocity was added. The video was recorded until the ball dropped to the floor and bounced a few times. This process was repeated a few times until a video that was aligned straight with a clear view of the tennis ball was recorded.

This video was transferred to all our computers and everyone computed their own results using the tracker software. I dragged the video into tracker and clicked on track as shown in Fig.2 to go on “New” and then “Point Mass”. This function allowed me to go frame by frame and place points as to where the ball was in its motion during that frame. I chose the bottom part of the ball as my reference point and continued placing points on the very bottom of the ball until the ball touched the ground. During frames of motion blur, I made a point at the very bottom of the dragged out blob as my “bottom of the ball”. Then, I chose calibration tools to click on calibration stick to provide the software with an object of known length that can be later used as a reference in video analysis [1]. I dragged the calibration stick which appeared as two blue points, one on top of the meter stick and the other on the bottom. Setting its length in the tool bar to 1m. My last step was clicking on the axis icon in the toolbar which showed me my axis which I placed at the very bottom of the balls motion. I placed it at the point where the ball made contact with the ground and tilted it to ensure the ball’s motion can be nearly a straight line with the y-axis. The data provided in the data rows was used in my calculations.

<u>Results:</u>

Time (s)	Position (m)	Velocity (m/s)	Manipulated Time, $\frac{t^2}{2} (s^2)$
0.00E+00	1.17E+00	0.00E+00	0
1.67E-02	1.17E+00	-1.71E-01	0.000138889
3.33E-02	1.16E+00	-3.85E-01	0.000555554
5.00E-02	1.16E+00	-5.56E-01	0.001250000
6.67E-02	1.15E+00	-7.06E-01	0.002222224
8.33E-02	1.13E+00	-9.20E-01	0.003472219

Fig. 3. This is sample table of raw data obtained from the tracker software. The table includes time set at zero, position of ball, velocity of ball, and manipulated time which was used in the

linearization of the position and time graph. The time was manipulated by first being raised to the power of two then being divided by 2. The full table can be found in the appendix.
Sample Calculation:
Manipulated time, $\frac{t^2}{2} = \frac{(1.67E-2)^2}{2} = 1.39E - 4\ s^2$. This was applied to all the time values using excel to get manipulated time.

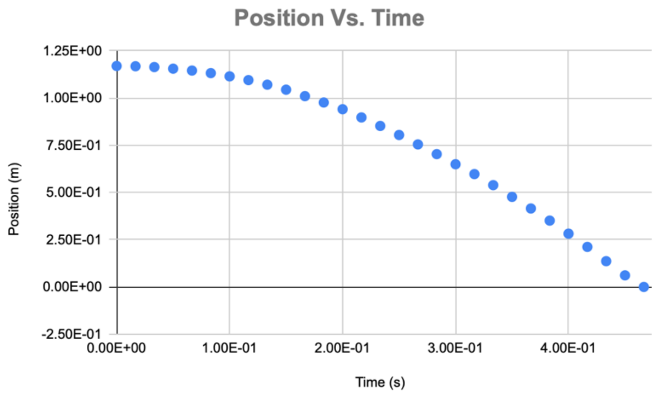


Fig. 4. This graph shows the relationship between position and time as a parabolic function. This data is linearized to obtain acceleration due to gravity as the slope.

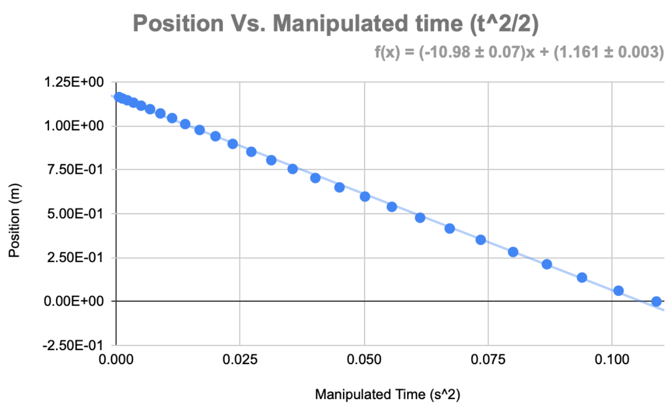


Fig. 5. This graph shows the relation between position and manipulated time. The graph was linearized using the formula, $y = y_0 - \frac{1}{2}gt^2$, where position is the y-value and manipulated time is the x-value. The slope of this graph gives us negative acceleration due to gravity while the y-intercept is the initial position. This graph is described by the function shown in the figure with our value for acceleration due to gravity being -10.98 m/s^2 with an error interval of ± 0.07 m/s^2. While the initial position is 1.161 ± 0.003 m. These numbers were obtained using LINEST.

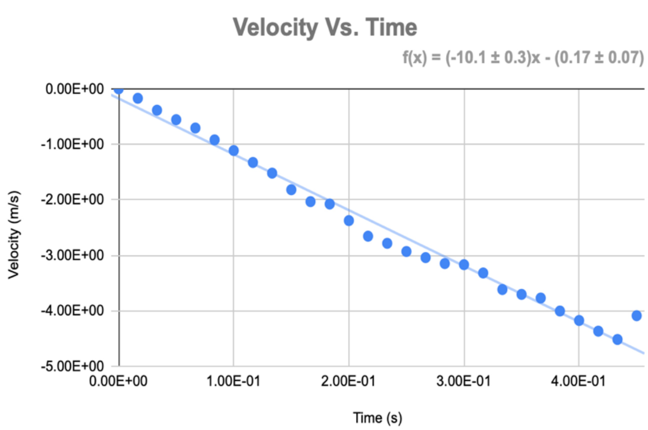


Fig. 6. This graph shows the relation between velocity and time which gives us a linear function. The following equation was used to find acceleration due to gravity as the slope this graph, $v_y = v_{0,y} - gt$, where position is the y-value and time is x-value of the graph. Using LINEST, we find our slope being negative acceleration due to gravity of -10.1 m/s^2 with an error interval of ± 0.3 m/s^2. This value can be used to be compared against the theoretical value for gravitation acceleration. The y-intercept is the initial velocity which should be close to zero. Our experimental value was -0.17 ± 0.07m/s.

The experimentally determined acceleration due to gravity using the equation, $y = y_0 - \frac{1}{2}gt^2$, of position and manipulated time is -10.98 ± 0.07 m/s^2.

The experimentally determined acceleration due to gravity using the equation, $v_y = v_{0,y} - gt$, of velocity and time is -10.1 ± 0.3 m/s^2. Compared to the theoretical value using the equation, $(g_{theory} - g_{experimental})$ / δg = (-9.81 – -10.1)/ 0.3 = 0.97; the number of error intervals between theory and experiment.

Discussion:

The experimental value for acceleration due to gravity obtained through the velocity vs. time graph is -10.1 ± 0.3 m/s^2. Comparing this with the theoretical value for acceleration due to gravity of -9.81 m/s^2, we can see that our experimental value is within one error interval of theory. This indicates that there is good agreement between theory and experiment. The initial velocity obtained through the y-intercept is -0.17 ± 0.07m/s. This is within two error intervals from the theoretical value of 0 which means there is modest agreement between the two values. The experimental value for acceleration due to gravity obtained through the position vs. manipulated time graph is -10.98 ± 0.07 m/s^2, this is in poor agreement with theory as it is more than three error intervals away.

There are some points that appear "bad" and skew the line of best fit such as the very last point on the graph as well as the set of data points between time 2E-2 to 3E-1. Removing these points gives us an experimental value of -10.0 ± 0.2 m/s^2 and a y-intercept of -0.11 ± 0.05 m. Though the error intervals are the same, the values have gotten closer to the theoretical. The data is a relatively good fit with the line of best fit and no data needs to be removed. Some factors that could affect my results is the quality of the camera and the points to track motion on the tracking software. While the camera makes clear frames in the beginning when the velocity of the ball is low, it struggles to make the same clear images as the ball speeds up causing a lot of motion blur. A higher quality video camera can be used to minimize this. When using this video in the tracking software, it is hard to mark points with precision. This experiment yielded good results in agreement with the theory so our technological tools can be used to determine gravity. However, results could be improved if some changes to experiment set up were made such as placing the phone on a table for stability to ensure no further motion blur is added due to human shaking. When tracking the ball on the software, since I used the bottom of my ball as my reference point, the motion blur being predominantly on the bottom impacted the accuracy of my points. If I had chosen the top of the ball as my reference point, it is possible I could make more accurate measurements for the software to calculate yielding better results with a better agreement with theory.

Conclusion:

In this experiment, we recorded a video of a tennis ball being dropped to measure our experimental acceleration due to gravity. The camera absorbs light when recording to produce a clear image and this becomes harder as an object starts moving faster causing motion blur. The video recorded was analysed using tracker software by plotting dots on the bottom of the ball for every frame recorded. Using an object of known quantity, a metre stick, as reference, axis was added and this data was converted into velocity, position and time which was used to graphically calculate our experimental results. Our experimental value, from velocity vs. time, of -10.1 ± 0.3 m/s^2 was in good agreement, one error interval away, with the theoretical value for gravitational acceleration of -9.81 m/s^2 and an initial velocity of -0.17 ± 0.07m/s was in modest agreement with theoretical value of 0m/s. The experimental values from our position vs. time graph was -10.98 ± 0.07 m/s^2 was in poor agreement with the theoretical value.

References: [1] EN PHYS 131 Fa23 Lab Manual

Acknowledgements: Akhil Velagapudi (worked together to obtain raw data)
Arshiya Huq (worked together to obtain raw data)
Zeeshan Mustafa (worked together to obtain raw data)

Appendix:

Time (s)	Position (m)	Velocity (m/s)	Manipulated time, $\frac{t^2}{2}$ (s^2)
0.00E+00	1.17E+00	0.00E+00	0
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3.33E-02	1.16E+00	-3.85E-01	0.000555554
5.00E-02	1.16E+00	-5.56E-01	0.001250000
6.67E-02	1.15E+00	-7.06E-01	0.002222224
8.33E-02	1.13E+00	-9.20E-01	0.003472219
1.00E-01	1.11E+00	-1.11E+00	0.005000000
1.17E-01	1.09E+00	-1.33E+00	0.006805559
1.33E-01	1.07E+00	-1.52E+00	0.008888884
1.50E-01	1.04E+00	-1.82E+00	0.011250000
1.67E-01	1.01E+00	-2.03E+00	0.013888894
1.83E-01	9.76E-01	-2.08E+00	0.016805549
2.00E-01	9.41E-01	-2.37E+00	0.020000000
2.17E-01	8.97E-01	-2.66E+00	0.023472229
2.33E-01	8.52E-01	-2.78E+00	0.027222214
2.50E-01	8.04E-01	-2.93E+00	0.031250000
2.67E-01	7.54E-01	-3.04E+00	0.035555564
2.83E-01	7.03E-01	-3.15E+00	0.040138879
3.00E-01	6.49E-01	-3.17E+00	0.045000000
3.17E-01	5.97E-01	-3.32E+00	0.050138899
3.33E-01	5.39E-01	-3.62E+00	0.055555544
3.50E-01	4.77E-01	-3.70E+00	0.061250000
3.67E-01	4.15E-01	-3.77E+00	0.067222234
3.83E-01	3.51E-01	-4.00E+00	0.073472209
4.00E-01	2.82E-01	-4.18E+00	0.080000000
4.17E-01	2.12E-01	-4.37E+00	0.086805569
4.33E-01	1.36E-01	-4.52E+00	0.093888874
4.50E-01	6.14E-02	-4.09E+00	0.101250000
4.67E-01	-2.32E-05		0.108888904