PHYSICS 4AL

EXPERIMENT 2: MEASUREMENT OF G

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Contents

PLOTS

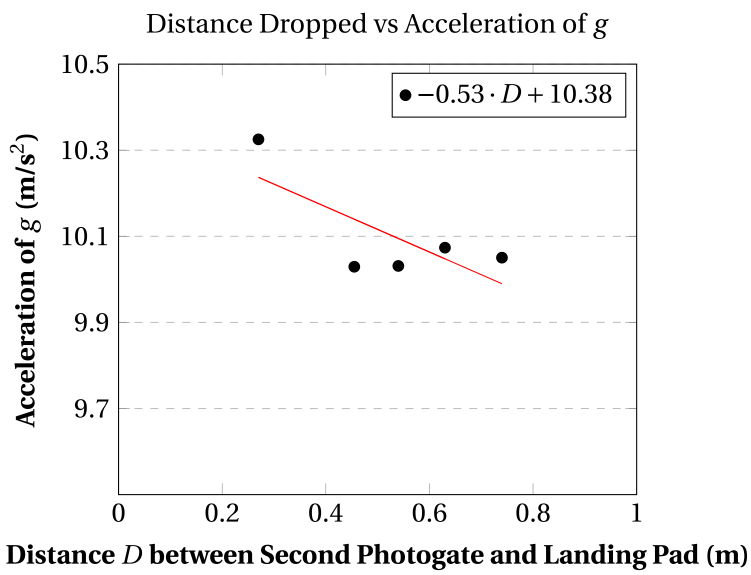

Figure 2.1 Graph of measured distance between second photogate and impact sensor. The dots on the graph depict acceleration g for heights .455 m, .54 m, .63 m, .27 m, and .72 m. The best fit line for this equation has the line $g = -0.53D + 10.38$, where g is acceleration due to gravity and D is height of fall.

For the ball drop experiment, I do not expect that g should depend on D, because acceleration due to gravity is constant everywhere on Earth. Thus, the trendline fitting g vs D should be completely horizontal. However, **Figure 2.1** indicates that there is a slight downward slope of -0.53D, showing acceleration decreases with greater dropped distance. Due to the placement of the data points, I can see that the datapoint at 0.27m has a much higher measured acceleration value of 10.31 m/s^2 compared to an average of 10.03 m/s^2 for the other data values. Thus, we can eliminate this linear dependence if we choose to ignore the acceleration at 0.27m as an outlier. Without that data point, it is clear that the resulting trendline will be much flatter, with a slight slope of 0.11D. We can see in **Figure 2.2** on the next page that without the acceleration for height 0.27m, the trendline for gravity is nearly flat and constant.

Figure 2.3 on the next page shows four quadratic trendlines of position vs time of a photocomb dropping through a photogate. Trial 3 was saved for a scientific plot at the end. Accelerations and uncertainties of these trials are shown in **Table 2.3**. The length of the comb was measured to be 30.5 cm, and we found length λ of each hole segment by dividing the total length by the number of holes, which was 35. Because of this method of calculating λ, our calculations of g included both systematic and statistical uncertainties, which are explained later in **Table 2.3**. The height of which the photocomb was dropped from is 85 cm.

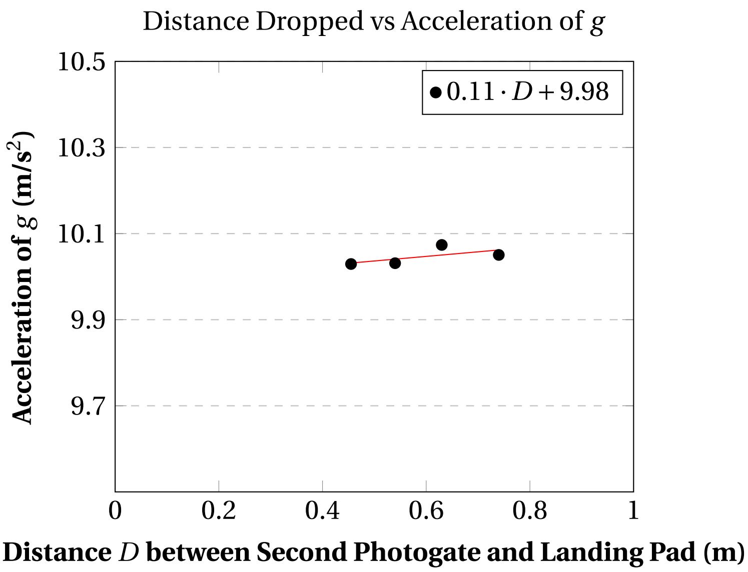

Figure 2.2 Second graph of measured distance between second photogate and impact sensor. The dots on the graph depict acceleration g for heights .455 m, .54 m, .63 m, and .72 m. We disregard the acceleration measured for height 0.27m. The best fit line for this equation has the line $g = 0.11D + 9.98$.

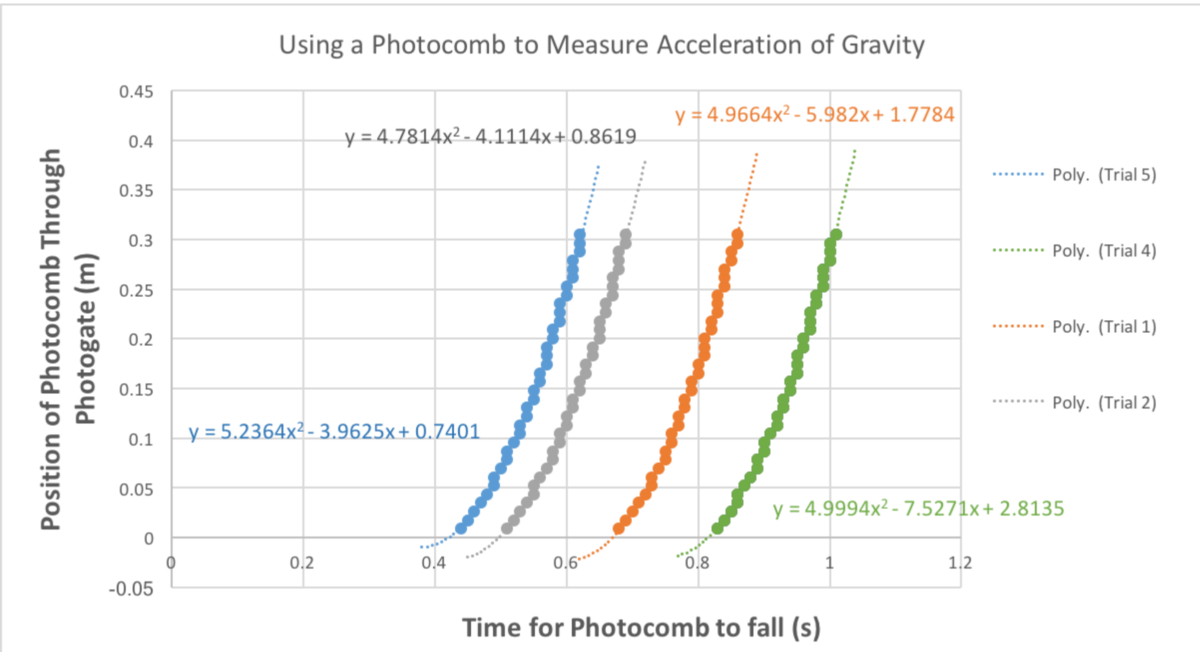

Figure 2.3 Position of Photocomb through a photogate vs. time of fall.

Where t stands for time and d for distance fallen:

For Trial 1, $d = (5.0 \pm 0.4)t^2 - (5.9 \pm 0.6)t + (1.8 \pm 0.2)$ in m.

For Trial 2, $d = (4.8 \pm 0.4)t^2 - (4.1 \pm 0.4)t + (0.9 \pm 0.1)$ in m.

For Trial 4, $d = (5.0 \pm 0.4)t^2 - (7.5 \pm 0.7)t + (2.8 \pm 0.3)$ in m.

For Trial 5, $d = (5.2 \pm 0.4)t^2 - (4.0 \pm 0.4)t + (0.7 \pm 0.1)$ in m.

Derivation of Equation 2.1

Here we derive the equation used to calculate g for the ball drop experiment. We first set the velocity V_1 to be the distance d travelled between the first photogate and the second photogate over time T_1. Similiarly, the velocity V_2 is equal to the distance D over time traveled T_2 between the second photogate and the landing pad.

$$V_1 = \frac{d}{T_1} \qquad \text{and} \qquad V_2 = \frac{D}{T_2}$$

We substitute these velocities into the kinetic equation $V = V_o + g(t)$, where $V = V_2$, $V_o = V_1$, and t is equal to the average of the two times, or $t = \frac{T_1+T_2}{2}$.

$$V_2 = V_1 + g\left(\frac{T_1 + T_2}{2}\right)$$

By substituting in the values for V_1 and V_2, we get an equation that only contains the units that Equation 2.1 contained.

$$\frac{D}{T_2} = \frac{d}{T_1} + g\left(\frac{T_1 + T_2}{2}\right)$$

By rearranging the equation so that g is isolated, we end up with Equation 2.1.

$$g = \frac{2}{T_1 + T_2}\left(\frac{D}{T_2} - \frac{d}{T_1}\right), \text{ in terms of m/s}^2$$

Data Tables

Ball Drop Tables

Below are three tables, **Table 2.1** showing the measured acceleration and the uncertainties from the ball drop. **Table 2.2** shows the individual contributions to the uncertainty made by both statistical and systematic uncertainty for the ball drop. The uncertainties in **Table 2.1** were derived by adding together both the systematic uncertainty and statistical uncertainty in table **Table 2.2**. **Table 2.3** shows the measured acceleration and uncertainties of g calculated from dropping a photocomb through a photogate.

Trial	Photogate Spacing d(cm)	Gap to impact Sensor D(cm)	Measured Acceleration g(m/s^2)
1	8.00 ± 0.05	45.50 ± 0.05	10.03 ± 0.02
2	8.00 ± 0.05	54.00 ± 0.05	10.03 ± 0.03
3	8.00 ± 0.05	63.00 ± 0.05	10.07 ± 0.03
4	8.00 ± 0.05	27.00 ± 0.05	10.32 ± 0.01
5	8.00 ± 0.05	72.00 ± 0.05	10.05 ± 0.03

Table 2.1 Experiment Results and calculated acceleration values. The average calculated value of the acceleration due to gravity g is 10.10 ± 0.02 m/s^2. The systematic and statistical uncertainties are not the same. The following Table 2.2 lists out the contributions to uncertainty systematic and statistical uncertainty made.

Systematic and Statistical Uncertainty for Ball Drop

Trial	Photogate Spacing d(cm)	Gap to impact sensor D(cm)	Systematic Uncertainty in Measured Acceleration g(m/s^2)	Statistical Uncertainty in Measured Acceleration g(m/s^2)
1	8.00 ± 0.05	45.50 ± 0.05	± 0.02	± 0.003
2	8.00 ± 0.05	54.00 ± 0.05	± 0.02	± 0.01
3	8.00 ± 0.05	63.00 ± 0.05	± 0.02	± 0.01
4	8.00 ± 0.05	27.00 ± 0.05	± 0.01	± 0.003
5	8.00 ± 0.05	72.00 ± 0.05	± 0.02	± 0.01

Table 2.2 Uncertainty due to Statistical and Systematic Uncertainty Systematic uncertainty was calculated by calculating g on the upper and lower limits of the height's uncertainty. Uncertainty due to measurement in distances d and D was 0.05 cm, or 0.0005 m, because milimeters are the smallest unit on a meter stick. The best values for T_1 and T_2 were used along with the upper and lower limits of d and D to calculate g_{min} and g_{max}. We then subtracted the g_{min} and g_{max} and divided by two to get systematic δg.
Statistical uncertainty was found using Excel's regression analysis.

Uncertainty was derived by adding together both the statistical and systematic uncertainty. The uncertainty is dominated by statistical uncertainty, because the the average systematic uncertainty is ± 0.0072 m/s^2, while the average statistical uncertainty is ± 0.018 m/s^2, almost 2.5 times more contribution. Thus, statistical uncertainty dominates the uncertainty of the calculated acceleration. However, because statistical uncertainty was not 10 times greater than systematic uncertainty, we could not eliminate one form of uncertainty.

Photocomb Table

Trial	Measured Acceleration (m/s^2)
1	9.9 ± 0.4
2	9.56 ± 0.4
3	9.2 ± 0.3
4	10.0 ± 0.4
5	10.5 ± 0.3

Table 2.3 Acceleration Values From Photocomb Drop The photocomb was dropped from a height of 0.85 m, and the length of the comb was measured to be 0.305 m. With 35 holes in the comb, each λ was calculated to be 0.0087 m, where λ is the length of each hole in the photocomb.

Because we calculated λ by dividing by the length of the comb by the number of holes in the comb, we had to take into account systematic uncertainty in our calculations of g. The systematic values for acceleration were calculated by taking the top and bottom of the range of uncertainty for a measurement ruler (which was 0.0005 m), finding the values of g and subtracting them, and dividing by two. The statistical uncertanties were obtained by regression analysis on Excel.

Because the systematic uncertainty values were much smaller than the statistical uncertainty values, only the statistical uncertainty affected the final outcome of the calculated g, and so systematic uncertainty was excluded from the final calculation. On average, the systematic uncertainty was $\pm$ 0.02 m/s^2, whereas the average statistical uncertainty was $\pm$ 0.36 m/s^2, more than 10 times greater. Systematic uncertanty had too few significant digits to be considered in calculations. The uncertainties of acceleration from the photocomb drop were clealy dominated by statistical uncertainty.

Conclusion

The commonly accepted value of g is 9.80 m/s^2. The values of g calculated in my ball drop experiment had low error % compared to the real value regardless of the height, indicating that gravity is indeed constant and not affect by the height with which an object was dropped from. We can prove this by calculating the difference between calculated and real values of g. At .455 m, the percent of error was 2.3%, at .54 m the error was 2.3%, at .63 m the error was 2.8%, at .27 m the error was 5.3%, and at .72 m the error was 2.6%.

For the photocomb experiment, the error for Trial 1 was 1%, the error for Trial 2 was 2.4%, the error for Trial 3 was 6.1%, the error for Trial 4 was 2%, and the error for Trial 5 was 7%. All the error percentages are low and indicate our calculated values of g accurate relative to the true value of g. The average error percentage of the ball drop experiment was 3.06%. The average error percentage for the photocomb experiment was 3.7%.

The most precise method of calculating the value of g was the ball drop, which yielded more significant digits in the uncertainty calculations, which is more precise (2 decimal places vs 1 decimal place). Based on average error percentage, we can see the ball drop experiment is more accurate in calculating the value of g, because it yields the closest value to true g on average. However, it is interesting to note that Trial 1 of the photocomb experiment resulted in the calculated value that is closest to the real value of g, with an error percentage of only 1%. It could be said that the photocomb experiment is the most accurate way to get the closest value of real g, but this is not consistently replicable, so it cannot be said to be the most accurate on average. In fact, it also yielded the result with the greatest error percentage at Trial 5(7%), indicating its results are not entirely reliable.

For our uncertainty calculations, I went with the conservative route and added together both the systematic and statistical uncertainties for the ball drop, because neither uncertianty value was 10 times smaller than the other. This process was chosen because there was no plausible reason to omit either and it would increase the accuracy of our calculations. However, for the photocomb calculations, only the statistical uncertainties were used, because the systematic uncertainties were 10 times smaller than the statistical uncertainties.

We notice that all the accelerations calculated from the ball drop were greater than 9.8 m/s^2, and so we can conclude that when the experiment was being conducted, the ball was given a slight push when it was dropped through the photogates, explaining the higher than normal values for g. The next time this experiment is conducted, we must make sure to not give the ball any initial velocity when dropping the ball.

REPORT: SCIENTIFIC PLOTS

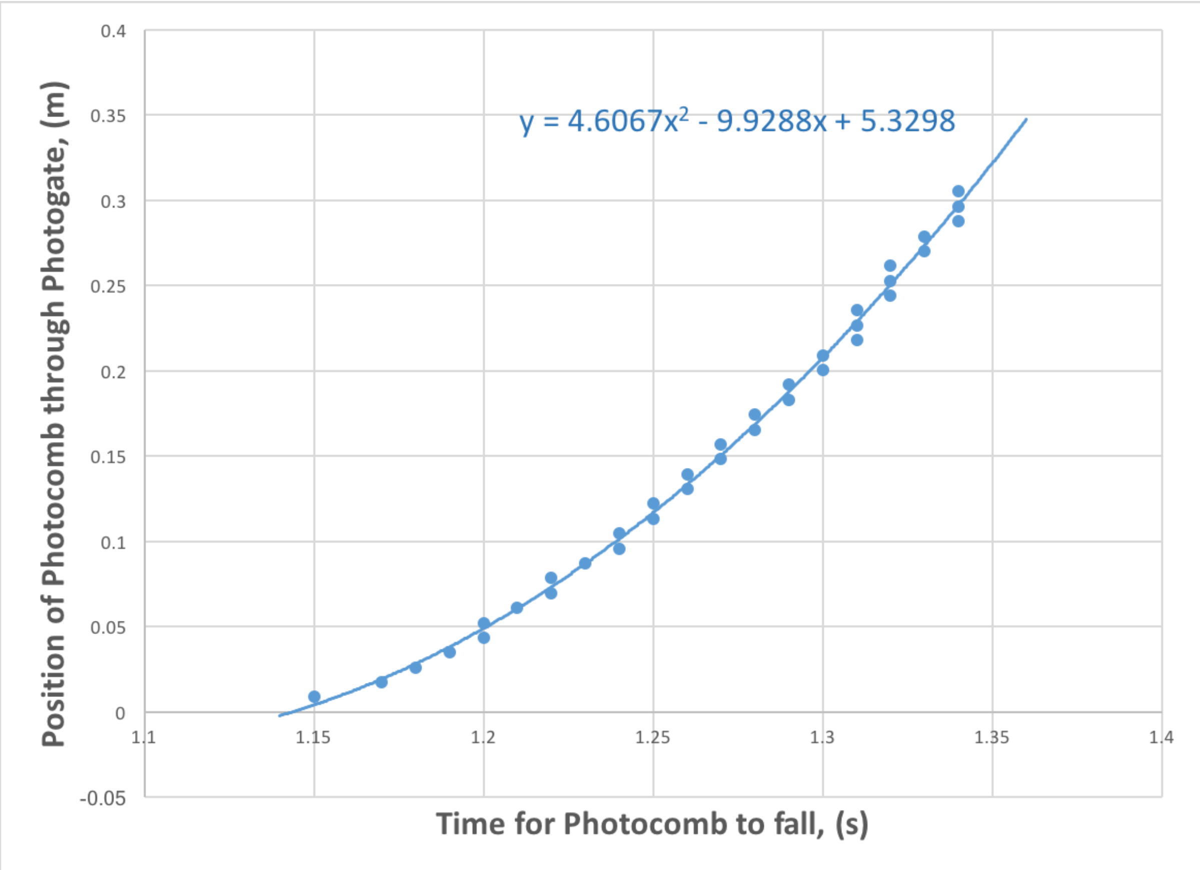

Figure 2.4 Measuring value of acceleration by tracking the time a photocomb takes to fall through a photogate. The data is a fit line to the quadratic curve $y = ax^2 + bx + c$, which shows that distance the photocomb falls per second increases as time and that it is accelerating. The fit line is $y = (4.6 \pm 0.3)x^2 - (9.9 \pm 0.8)x + (5.3 \pm 0.5)$, where y stands for distance fallen and x stands for time passed. The curves of the graph have been extended slightly to show that the fit line is indeed a parabola, which supports our decision to fit this data to a quadratic equation.

Figure 2.4 above depicts the position of a photocomb dropped from rest and accelerated by gravity over time. By fitting the quadratic equation to our position vs time graph, we can find the value of the photocomb's acceleration due to gravity g. Because the slope of the position vs time graph is not constant but instead increasing, we determine that the photocomb is speeding up and accelerating positively. Because acceleration is position differentiated twice, we can see the value of g in this fit line is $(9.8 \pm 0.6)\mathrm{m/s^2}$, or twice the value of the constant before the x^2.

The uncertainty of this calculated value comes wholly from statistical uncertainty. Systematic uncertainty would stem from differences in measurements, and turned out to be 10 times smaller than statistical uncertainty. The length of the photocomb used in this experiment was measured to be 30.5 cm. The uncertainty of the ruler was 0.05 cm, or half the smallest measurement unit, which was a millimeter. Systematic uncertainty was calculated by taking the upper and lower bounds of the measured length of the photocomb and finding g for those values, subtracting g_{max} and g_{min} and dividing by two. Statistical uncertainty was calculated using Excel's quadratic regression analysis.

Our calculated value of g is very accurate. The real value of g is accepted to be 9.80 $\mathrm{m/s^2}$, which matches our calculated value of g. However, the precision of our calculation has a large range, from 10.4 $\mathrm{m/s^2}$ to 9.2 $\mathrm{m/s^2}$. Thus, our calculations are not precise. Future improvements of this experiment would focus on increasing the precision of the calculation and reducing the uncertainty range to less significant digits. This could be achieved by using machines that could track more precise measurements and thus produce less statistical error, which accounts for most uncertainty and error.

Word count: 303