Lab Report 2 – ACCELERATION DUE TO GRAVITY

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PHYS 2125

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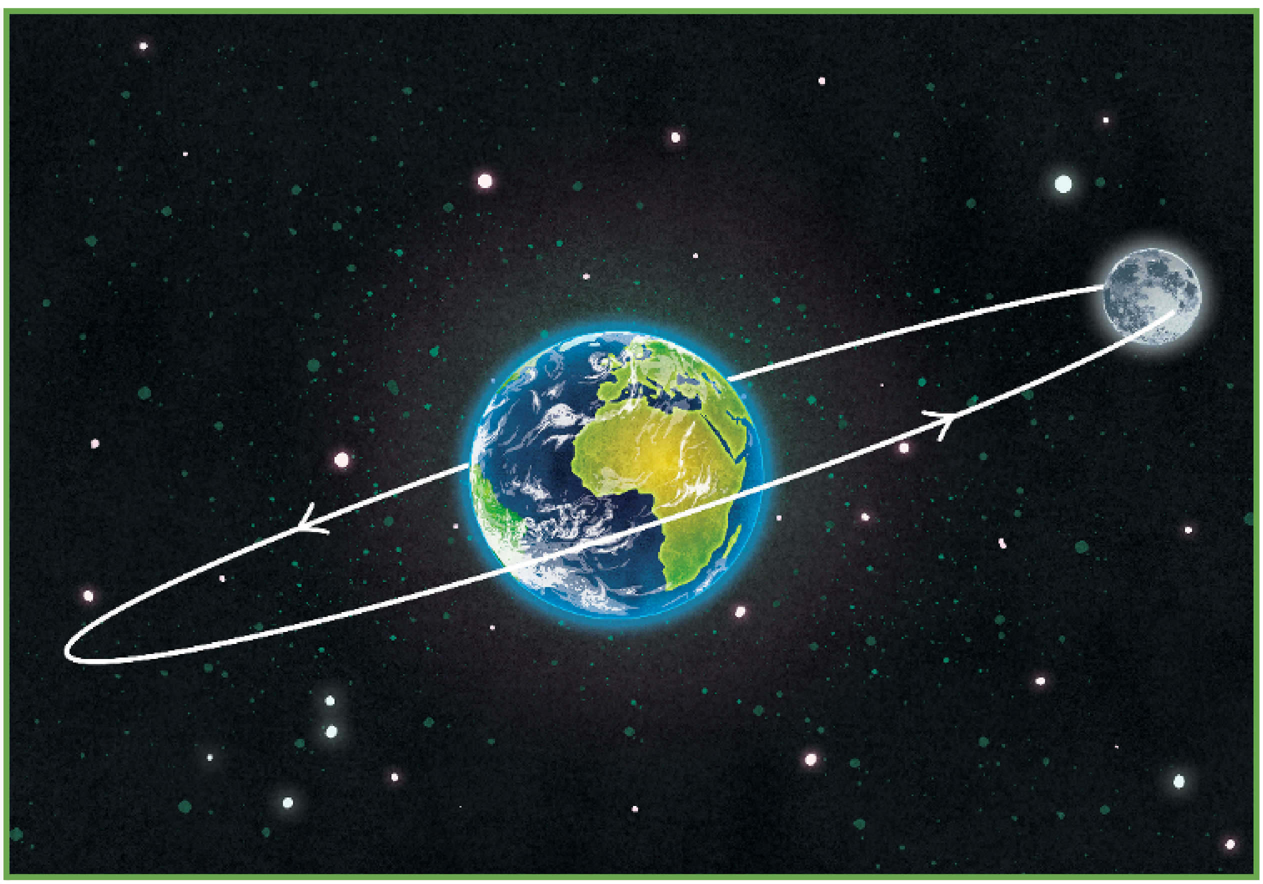


Objectives

To experimentally determine the magnitude of local acceleration due to gravity.

Equipments

The list of equipments used in this experiment is:

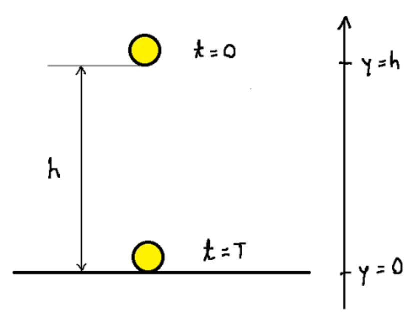
- Ball
- Meter Stick
- Stopwatch on iphone
- Motion Sensor
- “Picket Fence”
- Photogate
- Computer Interface
- Lab stand

Theory and Equations

To measure the acceleration of gravity, we use kinematics equations and calculus fundamentals.

Situation

We consider an object released from rest from a height (h) above the ground. It will accelerate downwards at a rate equal to g = 9.8 m/s^2. After a time T, the object will hit the ground.



Assumption

The initial speed of the object is 0 m/s^2.

We know the accepted value of the acceleration of gravity (g).

Equation

$$y = y_0 + v_0 t - \frac{1}{2} g t^2$$

$$0 = h + 0 - \frac{1}{2} g T^2$$

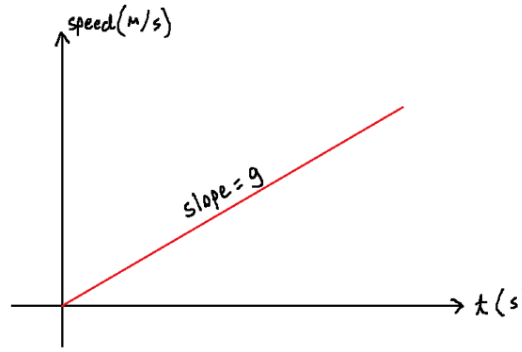
$$h = \frac{1}{2}gT^2 \qquad \text{(Eq. 0)}$$

In this lab, we want to measure the value of local acceleration of gravity (g) based on the time (T) and initial height (h). Thus, we have:

$$g = \frac{2h}{T^2} \qquad \text{(Eq. 1)}$$

Relationship between Object Speed and Acceleration of Gravity

When an object in free-fall, released from rest, will have its speed increase linearly. Particularly, a graph of speed and time will be a straight line with a slope equal to g.



In Calculus fundamentals, the derivative of an object's position with respect to time is considered to be speed; that is, the rate at which the object's position changes is its speed. Meanwhile, the derivative of its speed with respect to time is considered to be acceleration; that is, the rate at which the speed changes is what determines acceleration.

Taking the second derivative of the change in the object's position in (Eq. 0), we can obtain the value of g.

$$h'(T) = v(T) = (\frac{1}{2}gT^2)' = \frac{1}{2}(2)gT = gT$$

$$h''(T) = v'(T) = (gT)' = g$$

It conclusion, we have:

$$\boxed{g = h''(T) = v'(T) = \text{(Slope of Speed vs. Time graph)} \qquad \text{(Eq. 2)}}$$

Percentage Error

The percentage error is calculated based on the experimentally determined measure (exp) and the accepted value (acc). And there are 2 types of accepted values which are theoretical value which is predicted from theory and empirical value which is collected from a reliable source.

$$\text{Percentage Error} = \left|\frac{(exp) - (acc)}{(acc)}\right| * 100\% \qquad \text{units: } \%$$

Summary of Procedures

To calculate the gravitational acceleration, we conducted three different experiments, from a merely manual experiment performed by a human to an advanced experiment using software and motion sensors. For the first manual experiment, we placed a ruler vertically against the wall and perpendicular to the ground. Then, we choose a safe height to drop the ball at 1.6 m (h = 1.6 m). At the same time, we drop the ball from a height (h) and start the stopwatch. The stopwatch will stop as soon as the ball touches the ground. We repeat this process 12 times and record the dropping time of the ball.

We then set up a stable surface with some measuring tools for the last 2 experiment methods.

For the free-fall ball experiment with motion sensors, we dropped the ball from directly below the motion sensor and simultaneously pressed the record button in the software, allowing the ball to fall vertically to the ground. We then pressed the stop button in the software. We repeat this process 12 times and record the speed vs. time graph of the ball and the value of its slope (m).

For the experiment with the picket fence and photogate, we first place the photogate at the edge of the table so that the picket fence can drop over it. We also place foam on the ground to protect the picket fence when it hits the ground. We then hold the fence gently at one end. When we press the record button in the software, we immediately drop the picket fence linearly above the photogate, so that it passes over the sensor as it falls. We repeat this process 12 times and record the speed vs. time graph of the picket fence and the slope value (m).

Finally, we calculate the percent error based on the accepted value (acc) of g and the average experimental values (exp) of g in those different scenarios to see how much the accuracy improves when using different experimental methods.

Data and Observations

Part 1

The value of height is safely used to release the ball from:

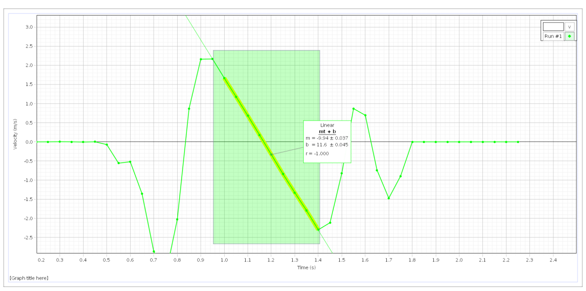
Height (m)	1.6

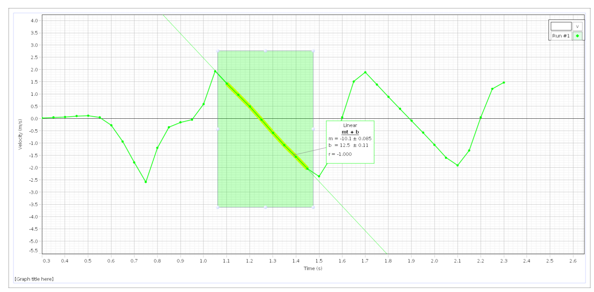
Record the falling time of 12 ball drops:

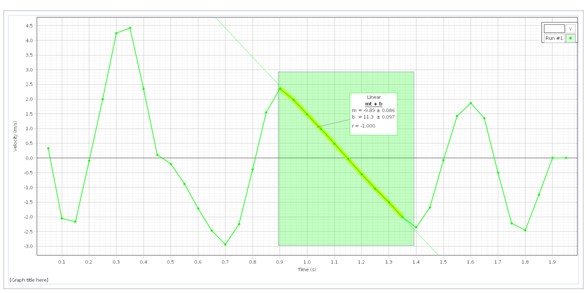
Dropping #	1	2	3	4	5	6	7	8	9	10	11	12
Falling Time (s)	0.46	0.51	0.54	0.54	0.49	0.49	0.46	0.65	0.66	0.59	0.53	0.49

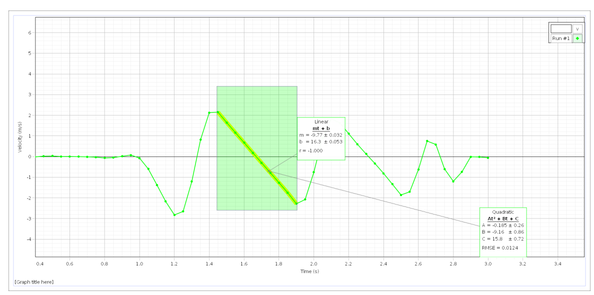
Part 2

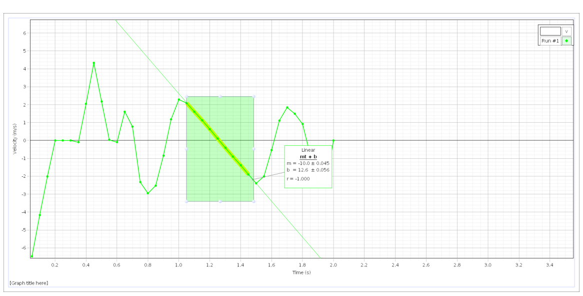
The records of speed vs time graph of the ball as it falls, and the graphs' slope (m) representing the gravitational acceleration value (g).

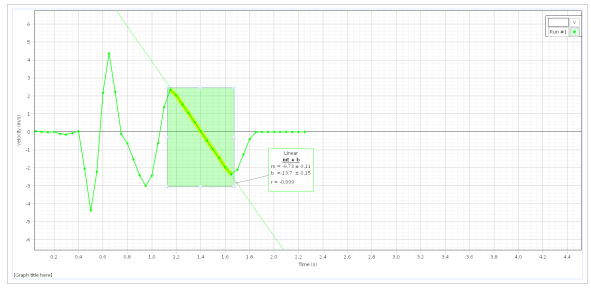


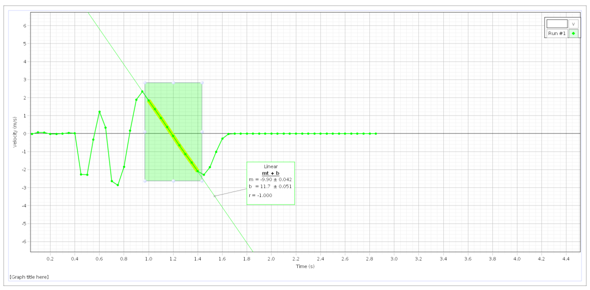


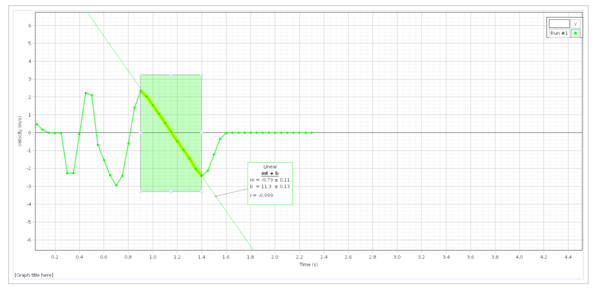


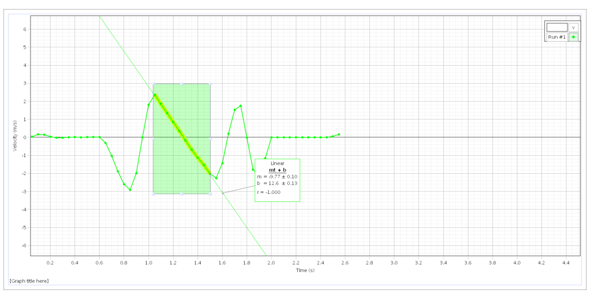


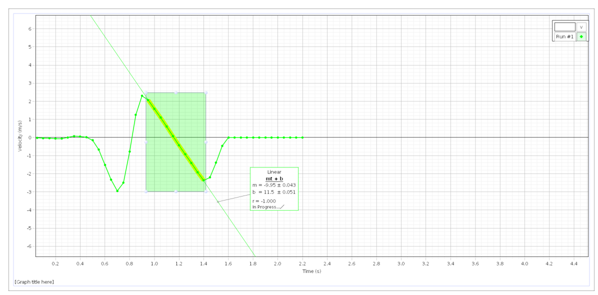










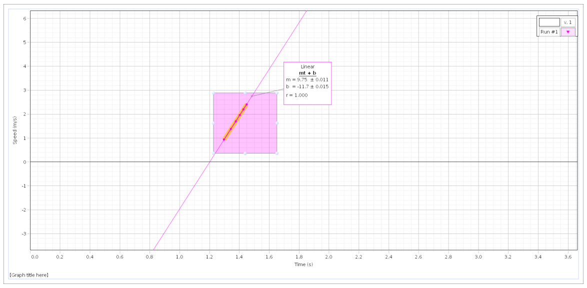


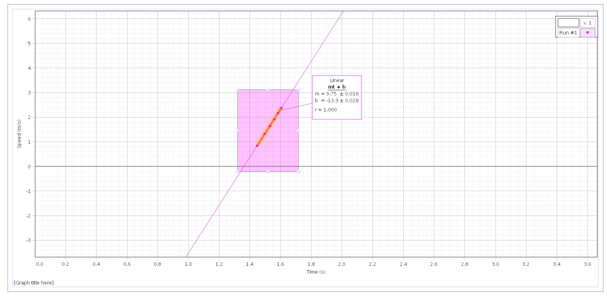
The table of recorded slope (g) value in those graphs above:

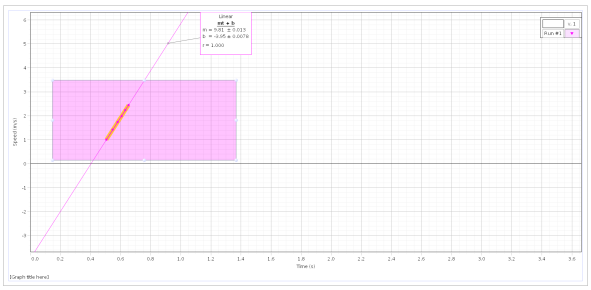
Graph #	1	2	3	4	5	6	7	8	9	10	11	12
Slope = g value (m/s^2)	-9.94	-10.1	-9.89	-9.77	-10.0	-9.80	-9.91	-9.73	-9.90	-9.79	-9.77	-9.95

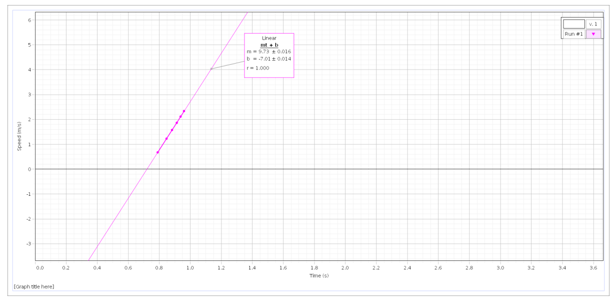
Part 3

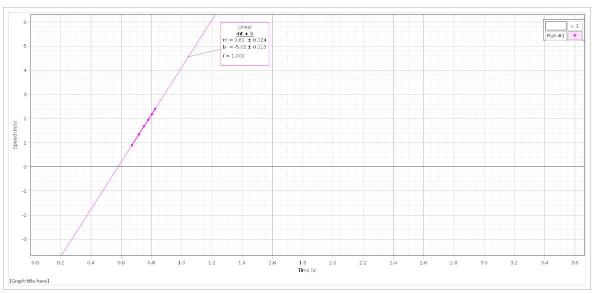
The records of speed vs time graph of the picket fence as it falls through the photogate, and the graphs' slope (m) representing the gravitational acceleration value (g).

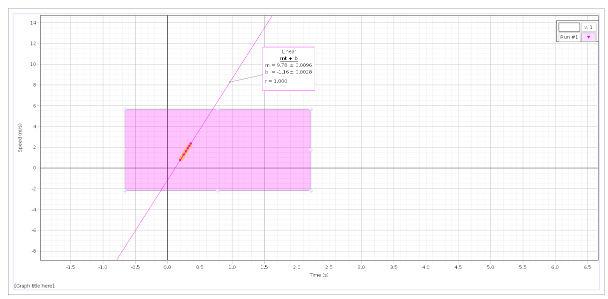

Linear
mt + b
m = 9.75 ± 0.011
b = -11.7 ± 0.015
r = 1.000
Speed (m/s)
Time (s)
Run #1
[Graph title here]

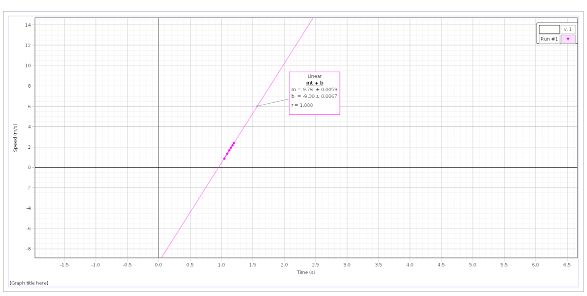

Linear
mt + b
m = 9.75 ± 0.018
b = -13.3 ± 0.028
r = 1.000
Speed (m/s)
Time (s)
Run #1
[Graph title here]

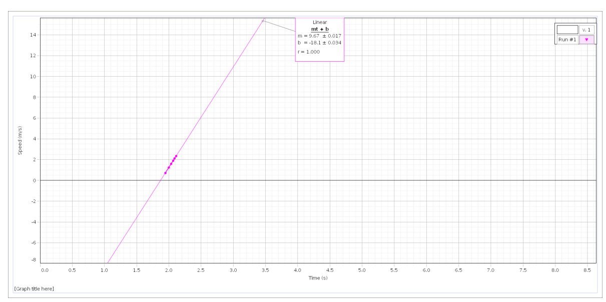

Linear
mt + b
m = 9.81 ± 0.013
b = -3.95 ± 0.0078
r = 1.000
Speed (m/s)
Time (s)
Run #1
[Graph title here]

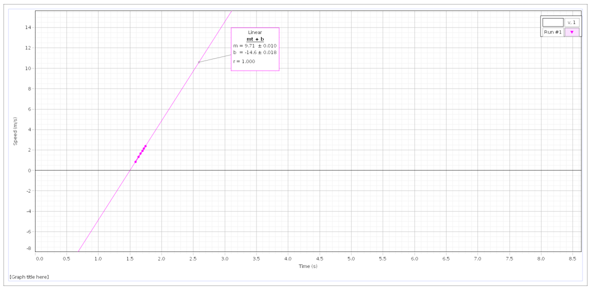

Linear
mt + b
m = 9.73 ± 0.016
b = -7.01 ± 0.014
r = 1.000
Speed (m/s)
Time (s)
Run #1
[Graph title here]

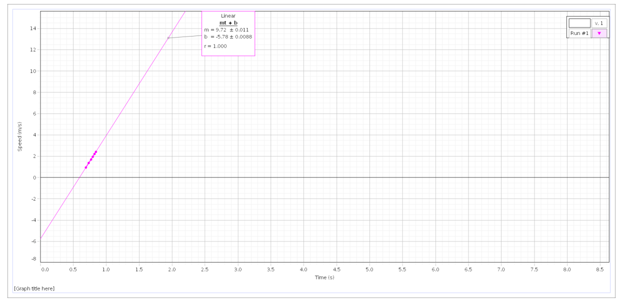

Linear
mt + b
m = 9.81 ± 0.024
b = -5.68 ± 0.018
r = 1.000
Speed (m/s)
Time (s)
Run #1
[Graph title here]

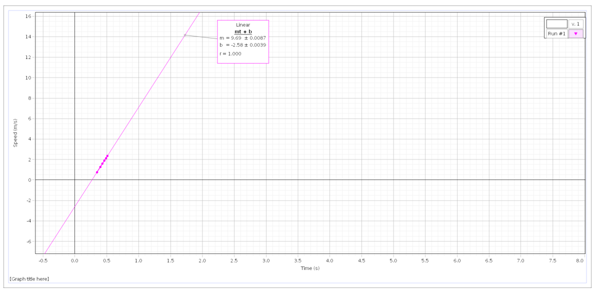

Linear
mt + b
m = 9.78 ± 0.0096
b = -1.16 ± 0.0028
r = 1.000
Speed (m/s)
Time (s)
Run #1
[Graph title here]

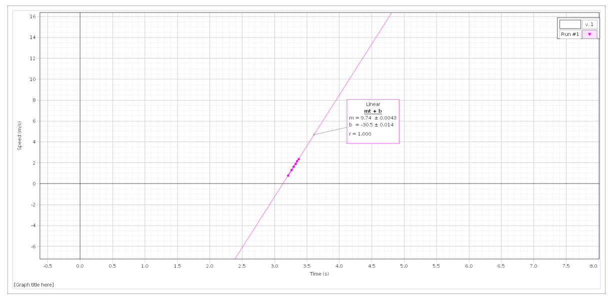

Linear
mt + b
m = 9.76 ± 0.0059
b = -9.30 ± 0.0067
r = 1.000
Speed (m/s)
Time (s)
Run #1
[Graph title here]


Linear
mt + b
m = 9.67 ± 0.017
b = -18.1 ± 0.034
r = 1.000
Speed (m/s)
Time (s)
Run #1
[Graph title here]









The table of recorded slope (g) value in those graphs above:

Graph #	1	2	3	4	5	6	7	8	9	10	11	12
Slope = g value (m/s^2)	9.75	9.75	9.81	9.73	9.81	9.78	9.76	9.67	9.71	9.72	9.69	9.74

Data Analysis

Calculation for Part 1

Average of Falling Time =

$$\frac{0.46 + 0.51 + 0.54 + 0.54 + 0.49 + 0.49 + 0.46 + 0.65 + 0.66 + 0.59 + 0.53 + 0.49}{12} = 0.534166 = 0.53\ (s)$$

Height (m)	1.6

From the Eq. 1 formula, we have: $g = \frac{2h}{T^2}$

Experimental Gravitational Acceleration (g) = $\frac{2 * 1.6m}{(0.53s)^2} = 11.21\ (m/s^2)$

Average of g value (m/s^2)	11.21

Calculation for Part 2

Average of slope value = g =

$$\frac{|-9.94| + |-10.1| + |9.89| + |-9.77| + |-10.0| + |-9.80| + |-9.91| + |-9.73| + |-9.90| + |-9.79| + |-9.77| + |-9.95|}{12} = 9.88\ (m/s^2)$$

Thus, we have:

Average of g value (m/s^2)	9.88

Calculation for Part 3

Average of slope value = g =

$$\frac{9.75 + 9.75 + 9.81 + 9.73 + 9.81 + 9.78 + 9.76 + 9.67 + 9.71 + 9.72 + 9.69 + 9.74}{12} = 9.74\ m/s^2$$

Thus, we have:

Average of g value (m/s^2)	9.74

Results

Formula of Percentage Error = $\left|\frac{(exp) - (acc)}{(acc)}\right| * 100\%$ units: %

Accepted Value:

Accepted Value of g (units: m/s^2)	9.80

Part 1:

Average of g value = 11.21 m/s^2

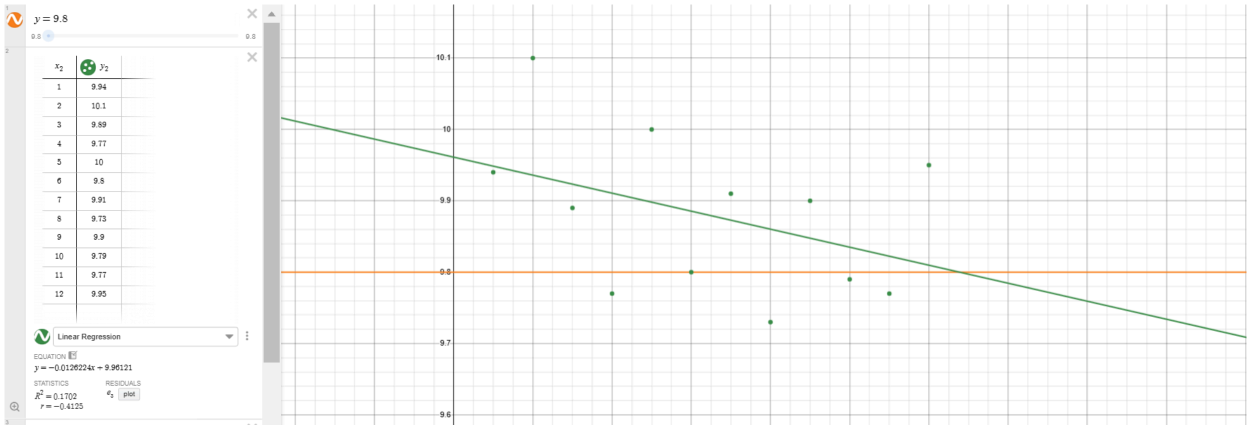
Percentage Error: = $\left|\frac{11.21 - 9.80}{9.80}\right| * 100\% = 14.4\ (\%)$

Part 2:

Average of g value = 9.88 m/s^2

Percentage Error: = $\left|\frac{9.88 - 9.80}{9.80}\right| * 100\% = 0.808\ (\%)$

To observe the distribution of different (g) values we get from dropping the ball underneath the motion sensor, we draw a scatter plot (green scatter points) and find their linear regression function (green line). Then compare those scatter points and their linear function with the accepted (g) value (orange line) to determine its accuracy.



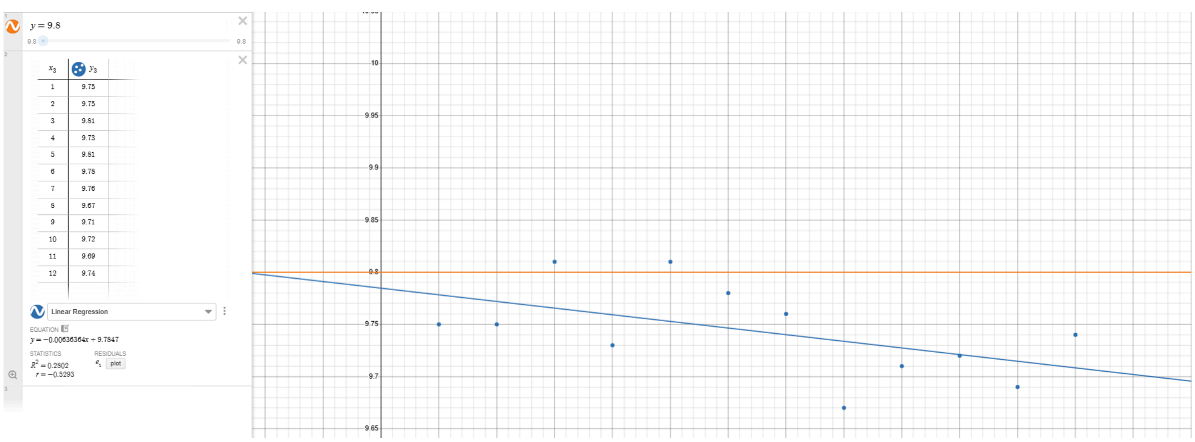
$R^2 = 0.1702$

Part 3:

Average of g value = 9.74 m/s^2

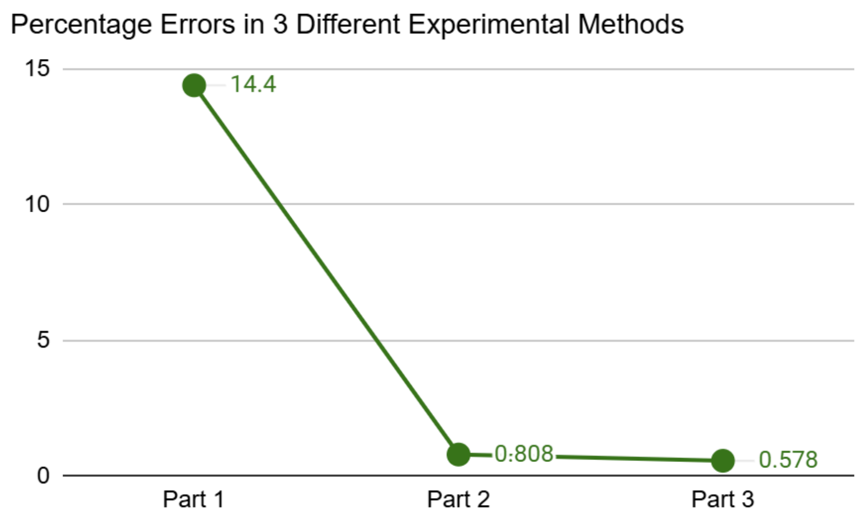
Percentage Error: = $\left|\frac{9.74 - 9.80}{9.80}\right| * 100\% = 0.578\ (\%)$

Again, to observe the distribution of different (g) values we get from dropping the picket fence through the photogate, we draw a scatter plot (blue scatter points) and find their linear regression function (blue line). Then compare those scatter points and their linear function with the accepted (g) value (orange line) to determine its accuracy.



$R^2 = 0.2802$

Also, we have the graph of percentage errors in those 3 different experimental methods:



Discussion / Conclusion

We can determine the gravitational acceleration using three different methods: Ball with Ruler/Meter Stick, Ball with Motion Sensor, and Picket Fence with Photogate. By calculating the percentage errors and graphing the distribution of value of g, we gain insights into their accuracy and precision.

From the percentage error results, it can be obviously seen that Part 1 method produces the most inaccurate (g) value with an error of 14.4%. While other 2 methods produce quite high accuracy with an error of under 1%. To explain the inaccuracy of the Part 1 method, it could be due to human error because we have to do everything manually, such as dropping the ball, pressing the stopwatch and observing when the ball hits the ground. Importantly, the Meter Stick is not a sensor, so it cannot measure the change in velocity during each individual drop to build a linear graph and calculate the acceleration due to gravity like the later methods. Basically, the formula it uses in Equation 1 is an estimated average value of (g). Moreover, in Part 1, the g value is also calculated based on the average time value of 12 drops. Therefore, it reduces the accuracy and reliability of the g value taken by the Part 1 method by taking too many calculations of average values.

Between the last 2 methods, the Part 3 method seems to produce more accurate value with the less-scatter graph with a higher value of R^2 (0.2802 > 0.1702). It means the Part 3 method can produce a better fit for a regression model in estimating the value of g. Also, the slope of the linear function in the Part 3 method is smaller (|-0.0064| < |-0.013|) with more points distributed closer to the accepted value of g (orange line on the graph). Interestingly, it seems that most of the values of g in the Part 2 method lie above the accepted value, while most of the value of g in the Part 3 method lie below the accepted value.

To explain the higher accuracy of the Part 3 method, it could be due to the dark stripes on the picket fence and the technology used in the photogate. In the Part 2 method, the ball has to travel a long distance with many environmental disturbances such as wind and noise that can affect the sound sensor. While in the Part 3 method, the fence travels a shorter distance (equal to the length of the picket fence) which reduces the environmental disturbance. Each time the fence passes through the infrared beam of the photogate, it can measure the time the fence travels between each stripe, thus calculating the g value. Additionally, infrared is generally known to have faster response times than sound sensors (IndMALL, n.d.).

In summary, the nature of the measurement method and the technology used in that method will determine the accuracy of the measured value. In particular, a method that can reduce environmental noise and increase the response time in the measurement is likely to produce a more accurate g value.

Post-Lab Question

As the ball is not dropped from the rest, but was launched vertically upwards at a speed of 5.0 m/s. It means we have v_0= 5.0 m/s. This will make Eq. 1 become invalid. We need to adjust the new formula which shows as below.

$$y = y_0 + v_0 t - \frac{1}{2} g t^2$$

$$0 = h + v_0 T - \frac{1}{2} g T^2$$

$$\boxed{g = \frac{2(h + v_0 T)}{T^2}}$$

If the ball was launched in this way from a height of 2.009 m and took 1.34 seconds to reach the ground, based on the new formula of g, we have:

$$g = \frac{2 * (2.009m + 5.0m/s * 1.34s)}{(1.34s)^2} = 9.7 \text{ (m/s)}$$

References

IndMALL. (n.d.). Which is best for measuring distance? IndMALL. Retrieved January 30, 2025, from https://www.indmall.in/which-is-best-for-measuring-distance/