Galileo's Ramp Lab

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1 Observations

Table 1: Height and Angle Data⋆

Height #	Track Height (m)	Average Time (s)	Angle of Incline (°)
Height #1	0.132m	2.56s	5.07°
Height #2	0.200m	1.98s	7.66°
Height #3	0.269m	1.66s	10.1°
Height #4	0.334m	1.38s	13.0°
Height #5	0.406m	1.30s	15.7°

⋆ *All values rounded to 3 significant digits*

Length of Ramp ($\boldsymbol{\Delta d}$) = 1.50 metres

2 Analysis

1. Calculating Acceleration of the Ball:

Sample Calculation for Height #1:

$$\vec{a} = \frac{2\Delta d}{t^2}$$
$$\vec{a} = \frac{2(1.50)}{2.56^2}$$
$$\vec{a} = 0.458 \text{ m/s}^2[\text{downhill}]$$

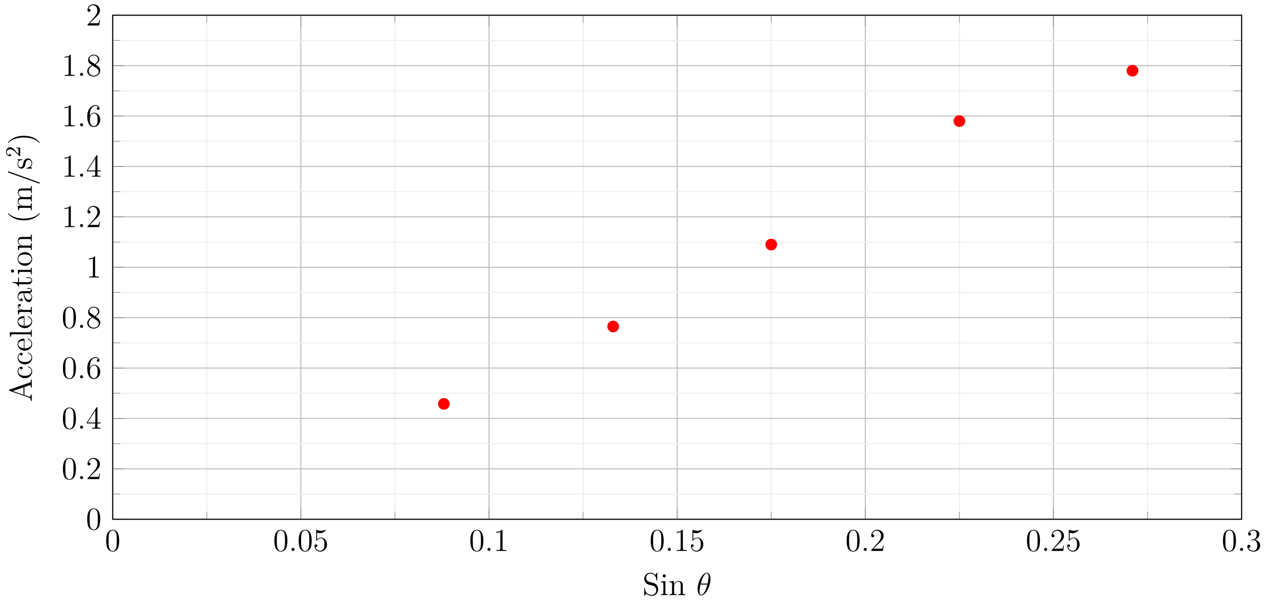
Table 2: Angles and Acceleration Data⋆

Height (m)	Angle (°)	Sin θ	Acceleration (m/s²)
Height #1: 0.132 m	5.07°	0.0880	0.458 m/s²
Height #2: 0.200 m	7.66°	0.133	0.765 m/s²
Height #3: 0.269 m	10.1°	0.175	1.09 m/s²
Height #4: 0.334 m	13.0°	0.225	1.58 m/s²
Height #5: 0.406 m	15.7°	0.271	1.78 m/s²

⋆ *All values rounded to 3 significant digits*

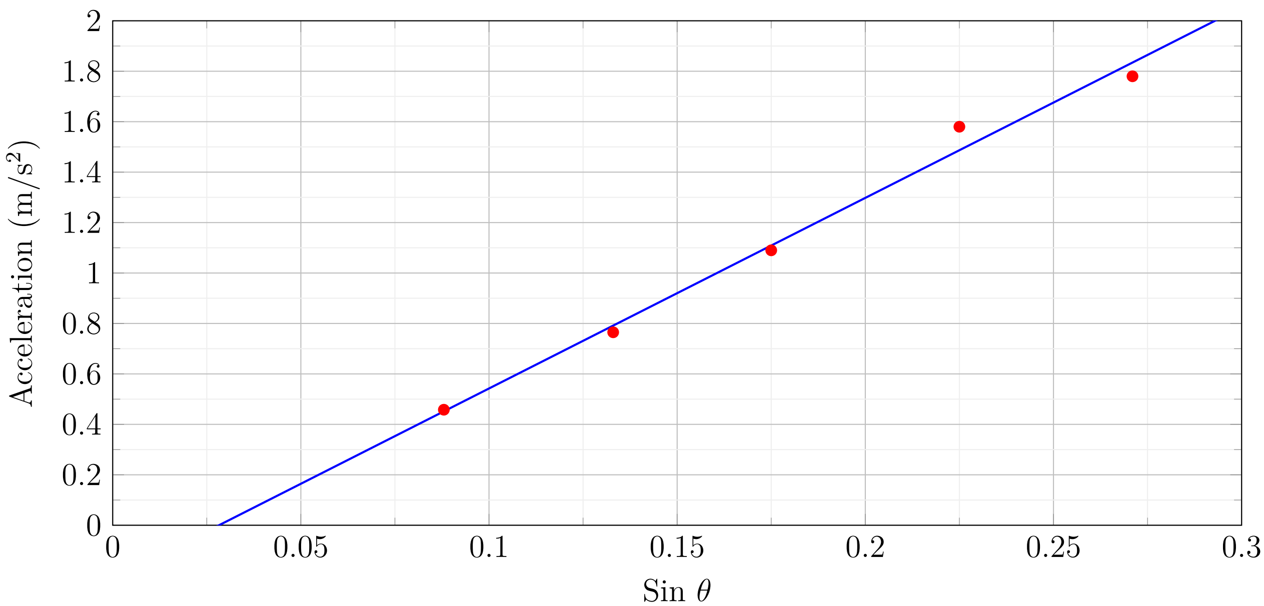
2. Acceleration Vs. Sin θ Graph Without Line of Best Fit:

Figure 1: Acceleration Vs. Sin θ



3. Acceleration Vs. Sin θ Graph With Line of Best Fit:

Figure 2: Acceleration Vs. Sin θ



a) Relation between Acceleration and Sin θ:

There is a linear relationship between acceleration and sin θ, where acceleration is directly proportional to sin θ ($\vec{a} \propto \sin\theta$), and the slope of best fit line should represent the acceleration due to gravity.

b) Calculating Slope of the Best Fit Line:

Two points on the best fit line are: $(0.24, 1.6)$ and $(0.11, 0.60)$

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$
$$m = \frac{1.6 - 0.60}{0.24 - 0.11}$$
$$m = 7.69 \text{ m/s}^2$$

$\therefore$ The calculated slope of the best fit line is 7.69 m/s^2.

c) Equation of the Line:

Let $\boldsymbol{x}$ represent $\boldsymbol{\sin\theta}$

Equation based on Excel trendline: $\boldsymbol{y = 7.5563x - 0.2134}$

Equation from calculations: $\boldsymbol{y = 7.69x - 0.246}$

d) Acceleration of the Ball if $\boldsymbol{\theta = 90°}$:

Calculated using equation provided by Excel:

$$y = 7.5563 \sin\theta - 0.2134$$
$$y = 7.5563 \sin 90° - 0.2134$$
$$y = 7.5563(1) - 0.2134$$
$$y = 7.34 \text{ m/s}^2$$

$\therefore$ The acceleration of the ball at 90° would be 7.34 m/s^2[down].

e) Calculating the Percentage Error:

δ = Percentage Error $\quad$ $\mathcal{V}_A$ = Accepted Value $\quad$ $\mathcal{V}_M$ = Measured Value

$$\delta = \left|\frac{\mathcal{V}_A - \mathcal{V}_M}{\mathcal{V}_A}\right| \cdot 100\%$$
$$\delta = \left|\frac{9.81 - 7.34}{9.81}\right| \cdot 100\%$$
$$\delta = 25\%$$

$\therefore$ The calculated percentage error is 25%.

f) Discussing Two (2) Sources of Error:

1) With the ball rolling on a surface, there are other forces acting on the ball during its motion besides the gravitational force. The most notable forces acting on the ball were kinetic friction and air resistance. Since kinetic friction opposes the motion of the ball, it also reduced the ball's acceleration. The effects of kinetic friction were most notable with smaller values of θ as the force of friction increases with smaller angles. Meanwhile, air resistance increased with larger angles since the ball has more speed. Additionally, the coefficient of friction between the ball (rubber) and ramp (plastic), is generally higher than for example metal on wood. For these reasons, the measured acceleration was lower than the accepted value of 9.81m/s^2 since friction opposed the ball's motion. This error could be regarded as a systemic error because the rubber ball and plastic ramp were the only available resources to use.

2) Our experiment also had random errors which caused variations in our data. The most common random error that occurred was the ball not rolling down the ramp in a straight line. Often the ball would hit the sides of the ramp, which first changes the direction of the balls motion often and caused the ball to lose energy through its collision with the ramp walls. The collisions caused a decrease in acceleration because the ball lost kinetic energy, and its change in directions resulted in an inaccurate time to reach the bottom of the ramp. Potential reasons for the ball's behaviour could include a faulty release and slight bumps/grooves in the plastic ramp. However, unlike the first error source, we were able to somewhat minimize the impact of the random errors by repeating trials, allowing us to average out results and reduce the effects of the random error.

4. After performing his experiments using inclined ramps and balls of different masses, Galileo concluded that the acceleration of various balls down a ramp was independent of mass.

a) Modifying The Experiment to Test Galileo's Conclusion:

To test Galileo's conclusion that the acceleration of balls down a ramp being independent of mass, the experiment can be modified by using balls of varying masses using the same five angles. However, despite these balls having different masses, they should share other physical properties such as similar material and surface area. By keeping those properties, the same, the effects of forces like friction on acceleration are minimized when analysing the data for different balls. By keeping the material, the same, all the balls should share a similar coefficient of friction and by keeping the surface area the same, the balls should all make a similar amount of contact with the ramp itself. These factors help to focus on testing Galileo's conclusion, as there are more controlled variables.

When graphing acceleration vs $\sin\theta$ graphs for the balls, the graphs should look similar in terms of their slope and overall equation. Due to Galileo's conclusion, the ball's different masses should not affect their accelerations at varying angles, therefore the equations of the line of best fit should not differ either, apart from minor random errors.

b) Explaining Why the Feather and Bowling Ball Result does not Contradict Galileo's Result:

The result does not contradict Galileo's result because his conclusion proved that all falling objects **accelerate** towards Earth at the same rate, **in the absence of other forces**. In the example of dropping a feather and a bowling ball, the two objects have other forces acting on them, where air resistance is most notable. Although the bowling ball likely receives more air resistance than the feather due to its larger surface area, the feather will reach terminal velocity much quicker than the bowling ball due to its lower mass. As a result the bowling ball will not reach terminal velocity and will hit the ground before the feather.

However, if both objects were placed inside a vacuum chamber such as NASA's Space Power Facility (SPF), air resistance becomes negligible. As a result, the feather and bowling ball would reach the ground at the same time if dropped from the same height and speed/at rest, because the only force acting on the objects is the acceleration due to gravity. To better demonstrate this concept, the BBC made a video showcasing the experiment in a vacuum chamber, which also shows the feather and bowling ball landing at the same time.

Galileo's conclusion is not contradicted as the acceleration due to gravity is independent to mass.