Investigating the Relationship Between the Angle of Inclination of a Ramp and the Acceleration of a Rolling Object

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1 Introduction

In my investigation, I am captivated by the thrilling world of roller coasters and the exhilarating experiences they offer. As I have been fortunate enough to enjoy these gravity-defying rides, I have often marveled at the intricate design and the physics behind them. The heart-pounding anticipation as the coaster climbs to its highest peak, followed by the breathtaking descent at incredible speeds, has left an indelible impression on me.

It is this fascination and personal connection to roller coasters that have sparked my interest in exploring the relationship between the inclination of a ramp and the speed of a sliding object. Every twist, turn, and loop of a roller coaster ride relies on the precise manipulation of inclines to create thrilling moments of acceleration and gravity. It is an art that seamlessly blends engineering and physics to provide the ultimate adrenaline rush.

Through this investigation, I aim to measure and analyze how the angle of inclination affects the velocity of sliding objects. By conducting experiments and gathering data, I hope to reveal any underlying correlations that exist between these two variables, further fueling my passion for Roller coasters.

To enhance the clarity of my findings, I will utilize various tools and software such as Desmos, Microsoft Excel, and Microsoft Paint. These resources will enable me to visually represent the data and present a comprehensive picture of my research.

2 Research Question

How does the angle of inclination of a ramp affect the time it takes an object to slide down ?

3 Theory

The theory section of this investigation aims to provide a comprehensive understanding of the physics principles underlying the relationship between the angle of inclination of a ramp and the speed of a sliding object. By exploring these concepts, we can establish a theoretical basis for our hypothesis and elucidate the factors influencing the motion of the object.

One fundamental concept to consider is the force of gravity, which acts vertically downward. When an object is placed on an inclined plane, the force of gravity can be resolved into two components: one perpendicular to the ramp's surface and one parallel to it. The component parallel to the ramp's surface is crucial in determining the object's acceleration and speed.

According to the formula below , where a represents the acceleration, g is the acceleration due to gravity, and theta is the angle of inclination, we can see that the acceleration of the object is directly proportional to the sine of the angle of inclination. This implies that as the angle of inclination increases, the acceleration of the object also increases.

$$a = gsin(\theta) \tag{1}$$

To relate the acceleration to the speed of the object, we can refer to the equations of motion. Assuming no significant air resistance or friction, the speed of the object can be determined using the following:

$$v = u + at \tag{2}$$

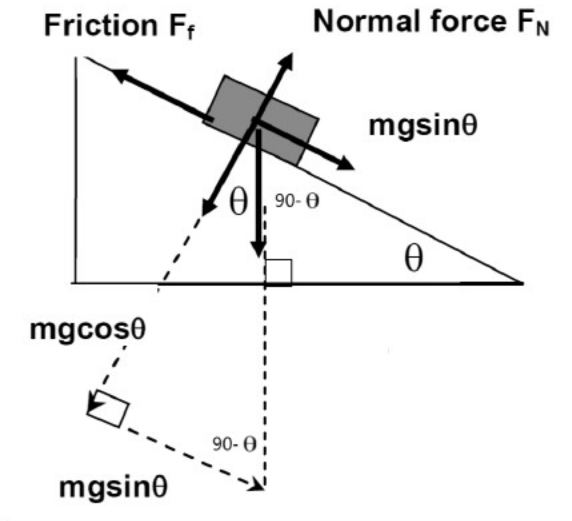

Figure 1: *Illustration of an object on an inclined plane with forces acting*

$$s = (\frac{u+v}{2})t \tag{3}$$

Subsituiting equation 2 into equation 3

$$s = (\frac{u+u+at}{2})t \tag{4}$$

$$s = (\frac{2u+at}{2})t \tag{5}$$

$$s = \frac{2ut+at^2}{2} \tag{6}$$

$$s = ut + \frac{1}{2}at^2 \tag{7}$$

where s represents the displacement (distance traveled) of the object, u is the initial speed (which can be considered negligible as the object starts from rest), a is the acceleration, and t is the time taken.

Subsituting equation 1 into equation 7 to establish a relationship between an independent and a dependent variable, the equation below is valid:

$$s = ut + \frac{1}{2}gsin\theta t^2 \tag{8}$$

Since the object was released at rest

$$u = 0 \tag{9}$$

and the equation is reduced to

$$s = \frac{1}{2} g sin\theta t^2 \tag{10}$$

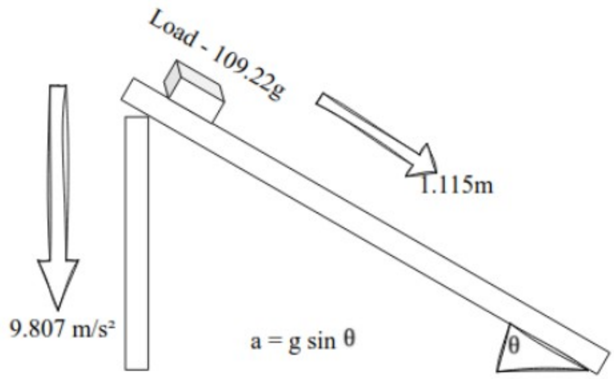

Figure 2: *Illustration of experiment set up*

4 Hypothesis

I hypothesize that as the angle of inclination of a ramp increases, the speed of a sliding object will also increase in a linear manner, indicating a direct positive correlation between these variables. I anticipate that a steeper ramp will result in a greater gravitational force component parallel to the ramp's surface, accelerating the object along the ramp and leading to a higher velocity.

I expect this relationship to exhibit linearity, with incremental increases in the ramp angle corresponding to proportional increases in the object's speed. By conducting carefully controlled experiments and analyzing the collected data, I aim to validate or challenge this hypothesis, contributing to our understanding of motion on inclined planes and the fundamental principles of physics.

5 Variables

5.1 Independent Variables

The independent variable in this experiment is the angle of inclination of the ramp. It represents the manipulated factor that we control and vary to observe its effect on the motion of the sliding object. The angle of inclination is measured in degrees and determines the steepness of the ramp.

To obtain the angle of inclination, we utilized the trigonometric relationship known as SOH CAH TOA. This relationship allows us to determine the angle by considering the ratios of the sides of a right triangle. Specifically, we used the SOH part of the relationship, which states that the sine of an angle is equal to the ratio of the length of the side opposite the angle to the length of the hypotenuse.

By measuring the length of the opposite side and the hypotenuse of the triangle formed by the ramp, we were able to calculate the angle of inclination using the inverse sine function. This method ensured accurate and consistent measurement of the angle for each trial.

Controlling and adjusting the angle of inclination within the range of 25 to 45 degrees in increments of 5 degrees allowed us to investigate how changes in this independent variable affect the motion of the sliding object.

5.2 Dependent Variables

The dependent variable in this experiment is the speed of the sliding object. It represents the observed and measured outcome that is influenced by the changes in the independent variable, which is the angle of inclination of the ramp. The speed of the object is directly affected by the angle of inclination and is therefore dependent on this factor.

To measure the speed of the sliding object, we timed the object as it traveled down the ramp over a fixed distance. By using a stopwatch, we recorded the time taken for the object to travel from the top of the ramp to a designated point at the bottom. The distance covered during the timing was kept constant for all trials to ensure consistency in measurements.

The speed of the sliding object was then calculated by dividing the distance traveled by the time taken. This allowed us to obtain the average speed for each trial. The speed was measured in units of distance per unit time, such as meters per second (m/s).

By observing and analyzing how the speed of the sliding object changes with varying angles of inclination, we can understand the relationship between these variables. This relationship helps us evaluate the impact of the angle on the motion of the object and provides insights into the physics principles governing the experiment.

5.3 Controlled Variables

In order to ensure the reliability and validity of our experiment, we controlled certain variables that could potentially affect the speed of the sliding object. These controlled variables include:

- Mass of the object: The mass of the sliding object was kept constant throughout the experiment. We used a plastic container with a block of wood to provide a consistent mass of approximately 109.22 grams (plus or minus one gram). By keeping the mass constant, we eliminate the influence of weight on the motion of the object.

- Surface of the ramp: The surface of the ramp was kept consistent by using the same material and ensuring its smoothness. This minimizes variations in friction between the object and the ramp's surface, allowing for more accurate and consistent results.

- Starting position: The starting position of the object at the top of the ramp was kept consistent for each trial. This was achieved by using a marked point on the ramp where the object was placed before each trial. This ensures that the object starts from the same initial position, minimizing any variations in the initial velocity.

- Timing method: The method of timing the object's motion down the ramp was standardized. We used a stopwatch to measure the time taken for the object to reach a designated point at the bottom of the ramp. By using the same timing method for all trials, we reduce potential errors associated with different timing techniques.

By controlling these variables, we can isolate the effect of the angle of inclination on the speed of the sliding object. This allows us to confidently attribute any observed changes in speed to the variation in the angle, strengthening the reliability of our results and supporting the validity of our conclusions.

6 Apparatus

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- Two pieces of wood: These pieces of wood are used to create a makeshift ramp. They should be long enough to provide a sufficient inclined surface for the sliding object. The angle of inclination can be adjusted by sliding the pieces of wood back and forth to increase or decrease the height of the ramp.
- Sliding object: A plastic container or a small cart that can slide smoothly on the makeshift ramp. The object should have a consistent mass and be easy to control and measure.
- Stopwatch: A stopwatch or a timer is used to measure the time it takes for the sliding object to travel a certain distance on the makeshift ramp. This allows for the calculation of the object's speed.
- Weighing scale: A weighing scale is used to measure the mass of the sliding object. It should be accurate and sensitive enough to provide precise measurements.
- Measuring tape or ruler: A measuring tape or ruler is used to measure the length and height of the makeshift ramp, as well as the distance traveled by the sliding object. This helps in calculating the angle of inclination and determining the speed of the object.

7 Risk concerns

During the conduction of the experiment, it is essential to address potential risks to ensure the safety of the individuals involved. In this particular experiment, there are no identified environmental or ethical concerns that would arise.

However, it is important to be aware of the risk of slipping and falling during the experiment. As the experiment involves sliding the object on the makeshift ramp and manipulating the apparatus, there is a slight risk of slipping or losing balance. To minimize this risk, ensure that the experiment is conducted on a stable and non-slippery surface. Take precautionary measures such as wearing appropriate footwear with good traction, maintaining a firm grip on the objects being used, and securing the experimental setup to prevent any accidental movements.

Additionally, be cautious when adjusting the angle of the ramp or moving around the experimental setup to avoid accidental falls or trips. It is recommended to perform the experiment in a well-lit area with ample space to move around, ensuring there are no obstacles or obstructions in the vicinity. Keep the experimental area tidy and organized to minimize the risk of falls.

To further ensure safety, the experiment should be supervised by an adult or conducted under the guidance of a responsible individual who can provide assistance and address any unforeseen risks or emergencies.

8 Method

- Set up the makeshift ramp using two pieces of wood, placing them on a flat surface in a sloping configuration.
- Adjust the position of the wood pieces to change the angle of inclination. Start with an angle of 5 degrees and increase it in increments of 5 degrees up to 20 degrees.
- Place the plastic container with the added weight at the top of the ramp.
- Take three measurements of the time it takes for the sliding object to travel a fixed distance down the ramp for each angle of inclination.
- Calculate the average time for each angle of inclination.
- Repeat steps 4-5 for all desired angles of inclination.
- Record the average time for each angle of inclination.
- Collect and record the data in a table or spreadsheet.
- Analyze the data to observe any trends or patterns between the angle of inclination and the speed of the sliding object.

9 Data table

In *Figure 3* the table includes Trial, Angle of Inclination, Hypotenuse Length, Time Taken (Trial 1), Time Taken (Trial 2), and Time Taken (Trial 3).

10 Proccessing Data

In *Figure 4* the table includes Trial Number, Inclination Angle, Sin of the Angle, Average Time, and 1 divided by Time squared.

The average for the following rows were calculated using this approach

$$average = \frac{1.57 + 1.60 + 1.67}{3}$$

which resulted in $1.61s$ for my first trial

The abosolute uncertainity for each row was calculated using this approach:

$$\Delta\bar{t} = \frac{1.67 - 1.57}{2}$$

Inclination angle (°) ± 0.5	Time taken to roll down(s) ± 0.2		
	Trial 1	Trial 2	Trial 3
25	1.57	1.60	1.67
30	1.18	1.16	1.25
35	0.68	0.68	0.67
40	0.55	0.52	0.53
45	0.46	0.44	0.48

Figure 3: *Presentation of Raw Data*

Trial	Inclination angle ($degrees$)	$sin(\theta)$	Average($\bar{s}$)	$1/t^2$
1	25	0.42	1.61	0.386
2	30	0.5	1.20	0.694
3	35	0.57	0.68	2.163
4	40	0.64	0.53	3.559
5	45	0.70	0.46	4.725

Figure 4: *Presentation of Processed Data*

$$\%t^2 = \frac{2 * 0.05}{1.61} * 100$$
$$\Delta\frac{1}{t^2} = \frac{6.2}{100} * 3.86$$
$$= 0.02$$

10.1 Graph Analysis

From the straight line graph, the line of best fit nearly passes through all the data points which may reflect a good precision of data. The coefficient of determination of 0.9563 for the line of best fit signifies a good correlation between the dependent and independent variables with minimal error margin.

Absolute uncertainity in gradient:

$$= \frac{16.996 - 13.996}{16.348}$$

Average($\bar{t}$)	Absolute Uncertainty in t	t^2 (s^2)	$1/t^2$(s^{-2})	Absolute Uncertainty in $\frac{1}{t^2}$	$sin(\theta)$
1.61	0.050	2.5900	0.386	0.02	0.42
1.20	0.050	1.4400	0.694	0.06	0.50
0.68	0.005	0.4624	2.163	0.03	0.57
0.53	0.020	0.2809	3.559	0.30	0.64
0.46	0.020	0.2116	4.725	0.40	0.70

Figure 5: *Processed Data with Error Analysis*

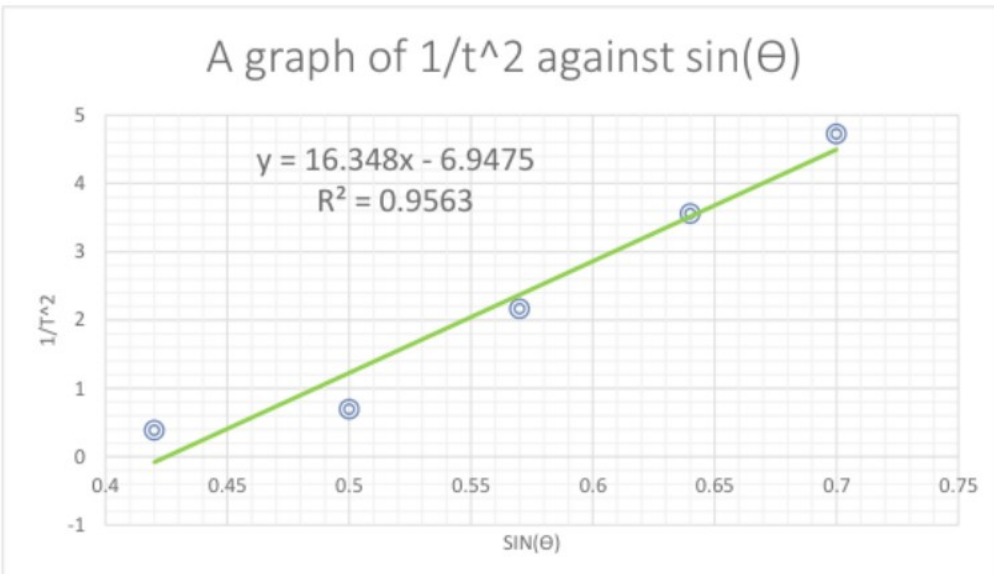

Figure 6: *Graph of* $1/t^2$

Percentage uncertainity in gradient:

$$= \frac{0.18}{16.348} * 100$$

$$= 1.10\%$$

A small percentage of 1.10% shows a good linear relationship.

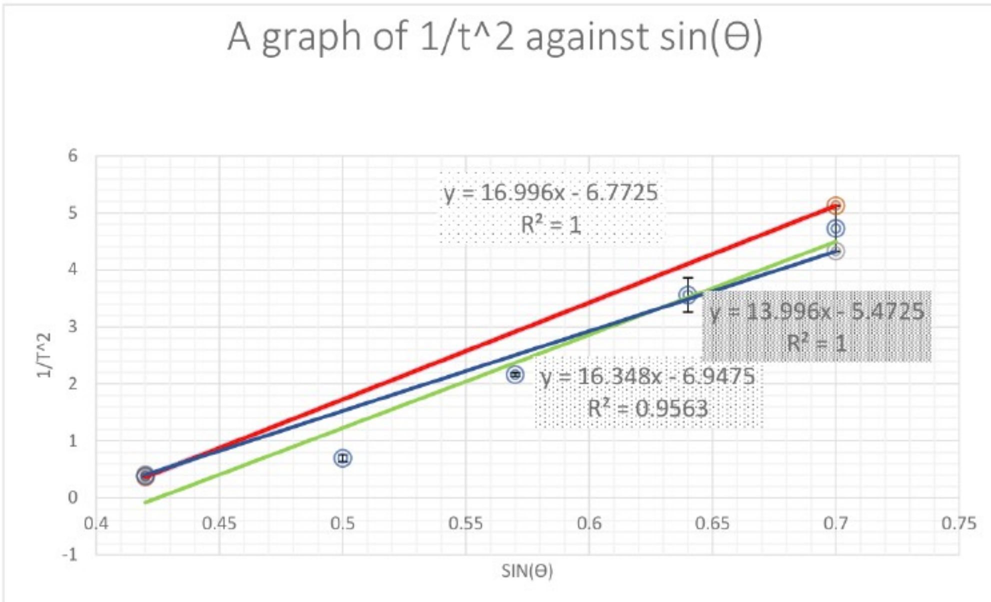

Figure 7: *Graph of* $1/t^2$ *with uncertainty*

11 Conclusion

In response to my original research question: ***How does the angle of inclination of a ramp affect the time it takes an object to slide down ?***, the conducted experiment provided valuable insights. By varying the angle of inclination and measuring the time taken for the object to travel, it was possible to observe a clear relationship between the two variables.

The results of the experiment demonstrated that as the angle of inclination increased, the acceleration of the sliding object also increased. This aligns with the understanding that a steeper incline leads to a greater force component along the ramp, contributing to a higher acceleration. Furthermore, the recorded times indicated that as the angle of inclination increased, the time taken for the object to travel the fixed distance decreased. This supports the hypothesis that a steeper ramp allows the object to reach higher speeds in a shorter amount of time.

These findings highlight the significance of the angle of inclination in determining the motion of a rolling object on a ramp. By manipulating this variable, it becomes possible to control and predict the acceleration for the object to travel. Understanding the relationship between the angle of inclination, acceleration, and time enhances our knowledge of the fundamental principles of motion.

12 Evaluation

In conducting this study, utmost care was taken to ensure accurate and reliable results. The experimental setup was carefully arranged, and the measurements were recorded meticulously. However, there are certain limitations to consider that may have influenced the outcomes of the study.

12.1 Limitations

Source of Error	Significance	Improvements
Manual angle measurement	Inaccurate angle readings in experiment	Use inclinometer or electronic angle tool
Stopwatch timing	Human reaction time and errors	Incorporate light gate or electronic timing system
Inability to release the object	Potential for inconsistent start of motion	Implement a release mechanism, such as electromagnets for consistent and controlled start of motion

Figure 8: *Limitations and Potential Improvements for the Experimental Setup*

Overall, despite these limitations, the study was conducted with great care and attention to detail. The findings provide valuable insights into the relationship between the angle of inclination and the motion of a sliding object. By recognizing the limitations and areas for improvement, future studies can further refine the experimental setup and data collection methods to obtain more accurate and reliable results.

Works Cited

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