**ACCELERATION DOWN AN INCLINE**

SPH 3U LAB EXPERIMENT

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**ABSTRACT**

In this experiment, the acceleration of a cart travelling down an incline was determined to be (1.98 .05) m/s2 [N]. When compared to the theoretical acceleration of (2.04.09) m/s2 [N], the experimental value was found to deviate by only 3%. When experimental error was considered, the experimental and theoretical values were found to agree. As a result of these findings, it was concluded that the kinematic equations that govern the motion of objects are valid in predicting the value of certain kinematic quantities. It was further determined that both position-time and velocity-time graphs are useful tools for studying kinematics.

**THEORY**

The motion of a cart down an incline is non-uniform since the cart accelerates as it travels down the ramp. As a result of this acceleration, the position-time graph will not be linear. Instead, the position-time graph will be curve resembling Figure 1.0 below.



***Figure 1.0: The position-time graph showing non-uniform motion.***

In accelerated motion, the displacement in each time interval is not uniform. Hence the motion is describe as non-uniform. This gives rise to the curved shape of the position-time graph. Since the displacement in each time interval is different from the displacement in the previous time interval, the position-time graph is curved. The slope of tangent lines to this curved position–time graph gives instantaneous velocities.

The velocity-time graph for accelerated motion, however, is linear with the slope being equal to the acceleration of the cart as depicted in Figure 2.0.



***Figure 2.0: The velocity-time graph showing non-uniform motion.***

The slope of the line in the velocity time graph is given by the following equation.

 … [1]

The theoretical value of the magnitude of the acceleration of a cart, ***a***, can be determined by finding the vector component of the acceleration due to gravity, ***g***.

 … [2]

where a is the magnitude of the theoretical acceleration

g is the magnitude of the acceleration due to gravity, 9.8 m/s2

 is the angle of the ramp and the horizontal

**METHOD**

The apparatus used in this experiment are:

* a 2.0 m long ramp
* a 1.0 kg cart
* a PASCO motion sensor model PS-2103A
* a large protractor
* a computer with the following software
  + - dataSTUDIO
    - Regression analyzer
    - Equation Grapher

1. The ramp was setup as shown in Figure 3.0



***Figure 3.0: The setup of the apparatus used in this experiment.***

1. The cart was then released and allowed to travel down the complete length of the ramp. At the same time the play button on dataSTUDIO was clicked so that the motion sensor recorded the position of the cart as it travelled down the ramp. The results from the motion sensor are shown in Table 4.0.

1. Using the position data form dataSTUDIO, regression analyzer was used to create a position-time graph. This graph is shown in Graph 1.0. A 2nd quadratic function fit was used to determine the equation of motion for the position data.
2. The equation of motion was then used in equation grapher to determine the instantaneous velocity at five different points in time. The tangent option was used to determine the equation of the tangent lines so that the slope, which yields the instantaneous velocity, could be determined. The results of the five instantaneous velocities are shown in Table 2.0 and Graph 2.0.
3. The five instantaneous velocities were then plotted in regression analyzer to produce a velocity-time graph of the moving cart as it travelled down the ramp. This velocity-time graph is shown in Graph 3.0. The line of best fit was then fitted to the velocity-time graph data points and the slope of the line of best fit was recorded as the experimental acceleration of the cart.

**DATA**

The following table is the results from dataSTUDIO as described in part 2 of the method.

|  |  |  |
| --- | --- | --- |
| Index | Time (t)  (±.01 s) | Position (d)  (±.001 m) |
| 0 | 0 | 0 |
| 1 | .10 | .010 |
| 2 | .20 | .040 |
| 3 | .30 | .100 |
| 4 | .40 | .158 |
| 5 | .50 | .240 |
| 6 | .60 | .371 |
| 7 | .70 | .500 |
| 8 | .80 | .635 |
| 9 | .90 | .820 |
| 10 | 1.00 | .995 |

***Table 1.0: The results from the motion sensor as displayed by dataSTUDIO.***

**ANALYSIS**

The data in table 1.0 was plotted and a 2nd polynomial was fitted to produce Graph 1.0 as

described in part 3 of the method.



*Graph 1.0: The position-time graph of the cart as it travelled down the ramp.*

The results of the fit are shown below.

2nd Poly REGRESSION

Y = -0.000804 + 0.0141A + 0.987A^2

Correlation (R) = 0.9997782364

R-sq = 99.95565219%

Standard Deviation = 0.331662479

The fitted function in Graph 1.0 was then used in equation grapher to determine the slope of five tangent lines. These slopes are the instantaneous velocities at the specific time interval.



*Graph 2.0: The position-time graph of the cart as it travelled down the ramp with the tangent lines representing the instantaneous velocities.*

The results from equation grapher are shown in the table below.

|  |  |  |
| --- | --- | --- |
| Index | Time (t)  (±.01 s) | Velocity (v)  (±.01 m/s) |
| 0 | 0 | 0 |
| 1 | .20 | .41 |
| 2 | .40 | .80 |
| 3 | .60 | 1.20 |
| 4 | .80 | 1.59 |
| 5 | 1.00 | 1.99 |

***Table 2.0: The instantaneous velocity results from Equation Grapher.***

Using Table 2.0, the velocity-time graph of the cart was constructed. The graph is shown below.



*Graph 3.0: The velocity-time graph of the cart as it travelled down the ramp.*

The results of the fit are shown below.

2nd Poly REGRESSION

Y = 0.00671 + 1.98A

Correlation (R) = 0.9999828223

R-sq = 99.99656499%

Standard Deviation = 0.0494165738

From the results of the fit we see that the slope of the velocity-time graph, which is the experimental acceleration of the cart, is 1.98 m/s2. The uncertainty in this acceleration is given by the standard deviation of the data points, + .05 m/s2, to one significant digit. Therefore an experimental acceleration of the cart as it moved down the incline is **(1.98 + .05) m/s2 [N]**.

The theoretical acceleration is given by eq [2]:



The uncertainty in this theoretical acceleration is given by:



Therefore the theoretical acceleration of the cart down the ramp is **(2.04 + .09) m/s2 [N]**.

The percent difference between the experimentally determined acceleration and the theoretical acceleration is:



So, an excellent result was obtained since the experimental acceleration and the theoretical acceleration deviated by only 3%.

**SOURCES OF ERROR**

In this experiment, most of the uncertainties are a result of instrumental error. There are certain limitations of the equipment used to obtain the data. However, these affects did not have a significant impact on the results as the experimentally determined acceleration differed from the theoretical acceleration by only 3%.

The first instrumental error was a limitation in the PASCO motion sensor. The manufacture of the sensor claims that the resolution of the motion sensor is 1 mm. Therefore an experimental error of + 0.001 m was used for all position data. As for velocity, a more conservative value of

+ .01 m/s was used. Although the manufacturer claims better accuracy, it was the concluded that 1 mm/s was pushing the limits of the device. Therefore a more conservative value was chosen using the error in the slope of the tangent lines to the position-time graph. Each slope had a standard deviation of + .01 m/s, so this was assigned to be the experimental error in the instantaneous velocities. The second instrumental error was in the protractor used to measure the angle of incline of the ramp. Since the graduation on the protractor was 1o, the midpoint between graduations was chosen as the error. Therefore, the instrumental error in the protractor was determined to be + .5o.

Although the results of this experiment were excellent, there are always ways to improve the results of any experiment. One major flaw in the method for this experiment is that the experiment was only conducted one time. To improve on the experiment, more samples should be taken. In order to draw valid conclusions, the results of any experiment must be repeatable. Therefore, the experiment should have been repeated multiple times in order to ensure accuracy in the measurements. This would eliminate any argument in how such an excellent result was obtained. If multiple results of similar accuracy were reproduced, then it could be solidly concluded that the results of this experiment truly reflect the acceleration of a cart down an incline.

**CONCLUSION**

The purpose of this experiment was to use graphical techniques to measure the acceleration of a 1.0 kg cart down an incline and compare it to the theoretical acceleration predicted by kinematic equations. The acceleration of the cart was found to be (1.98 .05) m/s2 [N]. When compared to the theoretical acceleration of (2.04.09) m/s2 [N], the experimental value was found to deviate by only 3%. When experimental error was considered, the experimental and theoretical values were found to agree.

The process used in this experiment proved to be very well suited. First, the motion senor was used to obtain position data of the cart as it travelled down the ramp. This data was displayed on dataSTUDIO and then entered into regression analyzer for analysis. A graph of position vs time was created in regression analyzer so that a function relating position and time could be determined. A quadratic function proved to be the best fit, since the correlation coefficient was closest to one at 0.9997782364. This is in total agreement with the theory, which predicts that the position-time graph of constant accelerated motion is a quadratic function. The equation describing the quadratic function was then entered into equation grapher so that tangent lines could be drawn to determine instantaneous velocities at various time intervals. This was done so that a velocity-time graph could be constructed in regression analyzer. The velocity-time graph was linear, yielding a correlation coefficient of 0.9999828223, again in perfect agreement with the theory. The velocity-time graph of constant acceleration is a straight line. The slope of the velocity-time graph gave us the acceleration of the cart. Due to the very low percent difference between the experimentally determined and the theoretically predicted acceleration, it was concluded that using graphical techniques to analyze motion proved to be correct and appropriate.

In the experiment, the PASCO motion senor PA-2103A proved to be very accurate, contributing to the very low percent difference between the experimentally determined and theoretical predicted acceleration of just 3%. The dataSTUDIO, regression analyzer, and, equation grapher software’s all proved to be very useful tools in analyzing the data from the motion sensor. These programs allowed us to draw all of our conclusions.

**SOURCES**

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