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**Report Sheet for Experiment 4: Two Dimensional Motion**

Abstract

In this experiment, linear motion with constant velocity and constant acceleration as well as the collision of them are investigated to observe the velocity, momentum, kinetic energy, and their conservations or changes. First of all, simple linear relationship of displacement and time is acquired in the constant velocity with the root mean square error of the fitting above 0.99 for both axes. Furthermore, inclined surface makes the puck moves according to the gravity, letting us find the acceleration of the system and correlate to that of the gravity (9.81 m/s2). The obtained data is 9.334 0.068 m/s2, indicating a precise yet inaccurate experiment results from the blurred video recording therefore inaccurate length measurement. Also, the experiment shows that the momentum can be conserved in each of the axes. Finally,

the collision of two pucks is considered not elastic because both the system’s momentum and kinetic energy changed considerably after the collision. The changes are 8.56 percent decrease in momentum and 16.05 percent decrease in kinetic energy. This comes from the conversion of kinetic energy to other sources such as heat and sound.

Introduction

Two-dimensional motions are studied based on their acceleration into 2 groups of constant velocity (zero acceleration) and constant acceleration, the one with changing acceleration are not focused herein. The puck is objected to move on an air table where compressed air is blown up to the surface to imitate a frictionless movement for the puck. Positions of the puck are tracked with video recording and analyzed for velocities. The slope of velocity can be calculated for the acceleration occurring during the movement.

Theoretical Background

Part 1 – Linear motion in constant velocity of a puck

In two-dimensional movements, both the distance and velocity can be projected into each of the axes as shown in Figure 1. The time-derivative of distance in one particular axis will result in the velocity of that axis, therefore,

v→ =

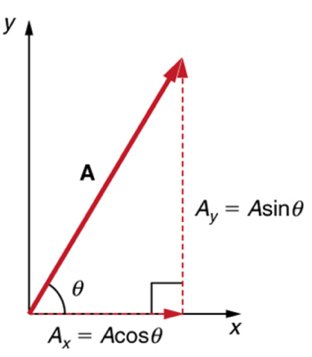


Figure 1 displays components of displacement in x and y axes.

Part 2 – Linear motion in constant acceleration of a puck

The puck is placed at an inclined angle of from the horizontal plane, making the acceleration of the puck be . With an initial velocity of 0, the relationship between displacement and time would be:

S = t2

Part 3 Two-dimensional collision of two pucks

Because of the frictionless air table, the momentum of the system (two of the pucks) is conserved. It is conserved separately in each component, given mass m1 with initial velocity u1 angled with the horizontal plane and mass m2 with initial velocity u2 angled 2 with the horizontal plane as depicted below. Their resulting velocities are v1 (angle ) and v2 (angle ), respectively.

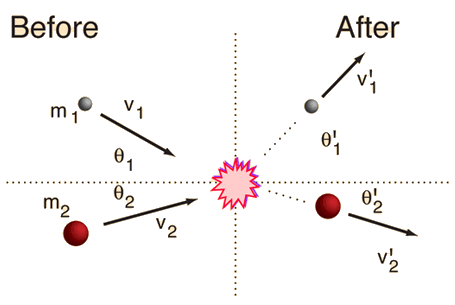


Figure 2 displays 2-dimensional collision of particles.

The conservation of momentum in x-axis can be derived as:

m1u1cos+ m2u2cos= m1v1cos+ m2u2cos

while that of y-axis is:

m1u1sin+ m2u2sin= m1v1sin+ m2u2sin

Finally, if the collision occurred elastically, the kinetic energy will be conserved as:

m1u1^2 + m2u2^2 = m1v1^2 + m2v2^2

Method

Set-up

1. Connect the air blower to the air table, adjust the level of the surface
2. Set length reference and camera for video recording

Part 1

1. Place a puck in the air table
2. Start recording and then track the movement of the puck just before it hits the edge of the table

Part 2

1. Tilt the air table up to 15 degrees from the horizontal plane.
2. Repeat method 3-4

Part 3

1. Place two pucks on the air table
2. Start recording and track the positions of two pucks before and after they collide each other but before each of them hits the edge of the table.

Result

Chart, scatter chart

Description automatically generated

Figure 3 displays the x and y positions versus time of the puck in a constant velocity

Chart, line chart

Description automatically generated

Figure 4 displays the x positions versus time of the puck in constant acceleration of 3 trials

|  |  |  |  |
| --- | --- | --- | --- |
| Trial | Coefficient of x2 | Calculated acceleration due to gravity | %Error compared to 9.81m/s^2 |
| 1 | 1.20229 | 9.290584 | -5.29476 |
| 2 | 1.20337 | 9.298929 | -5.20969 |
| 3 | 1.21812 | 9.412909 | -4.04782 |
| Average | | 9.334141 | -4.85076 |
| Standard deviation | | 0.068343 |  |

Table1 summarizes the fitted parameters, calculated acceleration due to gravity, and their corresponding error.

In the collision experiment, the x and y positions of green and orange puck are displayed below in Figure 5. The dot scatter plot represents x-axis velocity and square scatter one represents y-axis velocity. The scatter plots are fitted linearly.

Chart, scatter chart

Description automatically generated

Figure 5 displays the y and x positions versus time of the two pucks colliding

Chart, scatter chart

Description automatically generated

Figure 6 displays the y and x positions of the two pucks colliding

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Puck | Mass (kg) | velocity | | | | | |
| Before | | | After | | |
| Vy | Vx | V | Vy | Vx | V |
| Green | 0.0275 | 0.4257 | -0.3600 | 0.5575 | 0.4257 | 0.2995 | 0.5205 |
| Orange | 0.026 | 0.3021 | 0.3700 | 0.4777 | 0.3021 | -0.2995 | 0.4254 |

Table2 summarizes the velocities and their components and the momentum with its change before and after the collision

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Momentum | | | Kinetic Energy | | |
| Before | After | %Change | Before | After | %Change |
| 0.02775 | 0.02537 | -8.56 | 0.00724 | 0.00608 | -16.05 |

Table3 summarizes the combined momentum and kinetic energy of both green and orange pucks before and after the collision

Discussion

In a constant velocity part, both x and y positions depend linearly on time which the slopes in the Figure 3 can be referred to the velocity in each axis – 0.318m/s and -0.257m/s for x and y respectively. The root mean square error are more than 0.99 for both axes, meaning that the change in velocity(acceleration) is negligible.

Furthermore, in a constant acceleration as expected, the x distances have a quadratic dependence on time. According to equation 2, the coefficient of x2 as half the acceleration value or half the acceleration due to gravity time cosine of 15 inclined degrees. The obtained acceleration due to gravity are summarized in Table1 with an average and a standard deviation. The mean value is 9.33 m/s2 and very accurate with S.D. only 0.06 m/s2, also, the precision is calculated compared to the theoretical 9.81 m/s2 value. It resulted in only -4.85 percent error. This might come from the systematic error, for instance, displacement measurement and blurred image, since the standard deviation is quite low.

Finally, the displacements of both pucks are plotted with time to find the derivative as velocities of the movement. The velocities in y axis are constant for both pucks before and after the collision. However, in x axis, the velocities change direction and little drop in their magnitude, as summarized in Table2. The combined velocity is calculated by the root of sum of velocities in both axes squared.

Since there is only a sharp change in displacement, therefore, the velocity is constant before and after the collision as depicted in Figure 5, meaning that it is not necessary to observe its dependence over time. On the other hand, the calculation of change of momentum and kinetic energy results in an 8.56 percent decrease in momentum and 16.05 percent decrease in kinetic energy. This comes from the conversion of kinetic energy to other sources like heat and sound, also the air friction from the air table, making the drop of the momentum of the system as well. We can conclude that the collision is not elastic which makes both momentum and kinetic energy are not conserved.

Conclusion

In a nutshell, pucks with constant velocity and acceleration are both experimented. The displacements versus time are linear and quadratic, respectively, meaning there is no acceleration in a constant velocity movement as the theory suggests. There is little to no error on the first experiment as confirmed by the root mean square error from the fitted lines. Moreover, the inclined air table makes the puck moves with the gravitational force, thereby, the acceleration due to gravity can be calculated from the displacement-time relationship. The three trials go along well yet not well with the theoretical value, suggesting an error from the set-up or the measurements. Lastly, the collision of two pucks is considered not elastic because both the system’s momentum and kinetic energy changed considerably after the collision.

Reference

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