



Conservation of Energy

Physics Lab VI

Objective

This lab experiment explores the principle of energy conservation. You will analyze the final speed of an air track glider pulled along an air track by a mass hanger and string via a pulley falling unhindered to the ground. The analysis will be performed by calculating the final speed and taking measurements of the final speed.

Equipment List

Air track, air track glider with a double break 25mm flag, set of hanging masses, one photogate with Smart Timer, ruler, string, mass balance, meter stick

Theoretical Background

The conservation principles are the most powerful concepts to have been developed in physics. In this lab exercise one of these conservation principles, the conservation of energy, will be explored.

This experiment explores properties of two types of mechanical energy, kinetic and potential energy. *Kinetic energy* is the energy of motion. Any moving object has kinetic energy. When an object undergoes translational motion (as opposed to rotational motion) the kinetic energy is,

$$K = \frac{1}{2}Mv^2. \quad (1)$$

In this equation, K is the kinetic energy, M is the mass of the object, and v is the velocity of the object.

Potential energy is dependent on the forces acting on an object of mass M . Forces that have a corresponding potential energy are known as *conservative forces*. If the force acting on the object is its weight due to gravity, then the potential energy is (since the force is constant),

$$P = Mgh. \quad (2)$$

In this equation, P is the potential energy, g is the acceleration due to gravity, and h is the distance above some reference position where the potential energy is set to zero. Notice the object's weight is $F = Mg$.

Conservation of energy states that the sum of kinetic and potential energy of the system at some initial time is equal to the sum of the kinetic and potential energy at some final time,

$$K_i + P_i = K_f + P_f. \quad (3)$$

In this experiment, a glider is connected to a hanging mass that is hung over a pulley. Figure 1 illustrates this geometry.

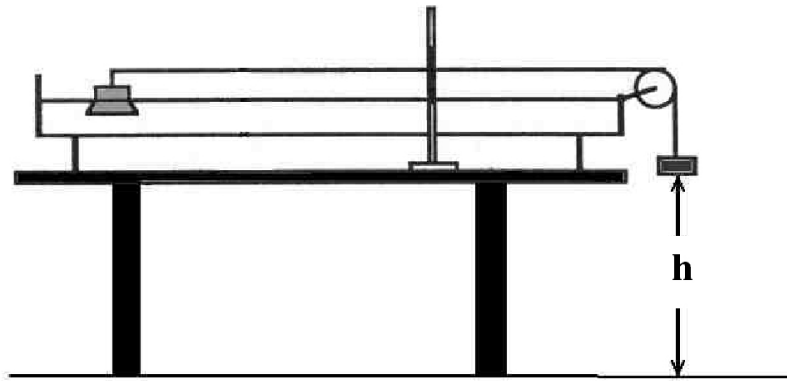


Figure 1: Conservation of Energy Experimental Arrangement

Combining Equations 1, 2, and 3, the conservation of energy for this experiment can be written as,

$$\frac{1}{2}M_c v_i^2 + \frac{1}{2}m_h v_i^2 + m_h g h_i = \frac{1}{2}M_c v_f^2 + \frac{1}{2}m_h v_f^2 + m_h g h_f \quad (4)$$

In this equation, M_c is the mass of the glider, m_h is the mass of the hanging weight, v_i is the initial velocity, which is the same for both the glider and the hanging mass since they are connected by a string which we assume does not stretch, v_f is the final velocity, h_i is the initial height of the hanging weight, and h_f is the final height of the hanging weight. In this experiment, the glider and hanging weight are released from rest so that the initial velocity is zero. The hanging weight is allowed to fall to the floor so that the final height is zero. Putting in these initial and final conditions in Equation 4, this equation reduces to,

$$m_h g h_i = \frac{1}{2}[M_c + m_h]v_f^2. \quad (5)$$

Solving Equation 5 for the final velocity, an expression for the theoretical velocity of the glider is obtained, based upon conservation of energy:

$$v_{theo} = \sqrt{\frac{2m_h g h_i}{M_c + m_h}}. \quad (6)$$

In this equation, h is the initial height from which the hanging weight is dropped.

For the lab exercise, the theoretical expression derived using conservation of energy will be compared to an experimentally determined velocity of the glider.

Procedure

Variation of Initial Height

In this exercise the variation of the final velocity of the cart and hanging mass as a function of the initial height will be measured experimentally.

1. Untie the mass hanger from the glider. Measure and record the mass of the glider as M_c .
2. Place the glider on the air track and turn the air supply on. Adjust the pitch of the air track so that the glider, when released remains stationary. After adjusting the pitch of the air track turn the air supply off.
3. Tie the mass hanger to the glider. Re-place the glider on the air track, and place the mass hanger over the pulley.
4. Position the glider on the track so that the mass hanger is 80 cm from the floor. Measure and record the height of the hanger as h_i .
5. Measure a 20 g disk and place it on the mass hanger. Record the total mass of the hanger as m_h (the hanger's mass is 5 g).
6. Using the measurements of M_c , m_h and h_i calculate and record the theoretical final velocity of the glider.

$$v_{theo} = \sqrt{\frac{2m_hgh_i}{M_c + m_h}} \quad (7)$$

7. Set the height of the photogate so that light sensor triggers the center region of the flag.
8. Set the horizontal position of the photogate so that the hanging mass hits the floor **before** the glider's flag passes through the photogate. If the hanging mass would hit the floor after the flag passes through the photogate, try moving the photogate or adjusting the length of the string.
9. Re-adjust the height of the hanging mass if necessary. Set the Smart Timer to **Speed: One Gate**. Depress the black key of the Smart Timer.
10. Turn the air supply on. Release the cart. ***Make sure that the hanging mass hits the floor before the cart goes through the gate.***
11. If the photogate and timer are set correctly, a speed should be displayed on the timer. Important note: The Smart Timer is designed to calculate velocity for distances of 1cm. The actual distance under observation is 2.5cm. Figure 2 illustrates the actual distance.

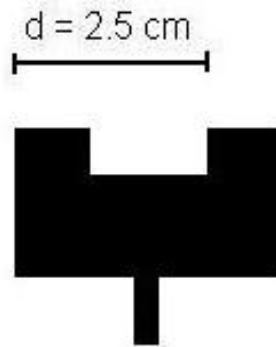


Figure 2: Description of actual distance travelled.

12. Multiply the experimental velocities v_{exp} by 2.5cm to account for the correction. Record the correct measurements on your data sheet.
13. Calculate and record the average value of v_{exp} . Calculate and record the square of the average of v_{exp} .
14. Calculate and record the percent variation of v_{exp} measurements.

$$\% \text{ variation} = 100 \times \frac{\text{Largest Value} - \text{Smallest Value}}{2 \times \text{Average Value}} \quad (8)$$

15. Repeat the process of measuring the final velocity for a total of five velocity measurements. ***For each measurement, make sure to release the cart from the same release point.***
16. Repeat steps 4-15 for h_i values of 70 cm , 60 cm , 50 cm , and 40 cm . For each h_i value you should have five speed measurements.

Variation of Mass of Hanging Weight

In this exercise the variation of the final velocity of the cart and hanging mass as a function of the hanging mass weight will be measured experimentally.

1. Record the previous measured value of the glider as M_c .
2. Position the glider on the track so that the mass hanger is 80 cm from the floor. Measure and record the height of the hanger as h_i .
3. Measure a 20 g disk and place it on the mass hanger. Record the total mass of the hanger as m_h (the hanger's mass is 5 g).
4. Using the measurements of M_c , m_h and h_i calculate and record the theoretical final velocity of the glider.

$$v_{theo} = \sqrt{\frac{2m_hgh_i}{M_c + m_h}} \quad (9)$$

5. Set the height of the photogate so that light sensor triggers the center region of the flag.
6. Set the horizontal position of the photogate so that the hanging mass hits the floor **before** the glider's flag passes through the photogate. If the hanging mass would hit the floor after the flag passes through the photogate, try moving the photogate or adjusting the length of the string.
7. Re-adjust the height of the hanging mass if necessary. Set the Smart Timer to **Speed: One Gate**. Depress the black key of the Smart Timer.
8. Turn the air supply on. Release the cart. ***Make sure that the hanging mass hits the floor before the cart goes through the gate.***
9. Multiply the experimental velocities v_{exp} by 2.5cm to account for the flag's actual distance. Record the correct measurements on your data sheet.
10. Calculate and record the average value of v_{exp} . Calculate and record the square of the average of v_{exp} .
11. Calculate and record the percent variation of v_{exp} measurements.

$$\% \text{ variation} = 100 \times \frac{\text{Largest Value} - \text{Smallest Value}}{2 \times \text{Average Value}} \quad (10)$$

12. Repeat the process of measuring the final velocity for a total of five velocity measurements. ***For each measurement, make sure to release the cart from the same release point.***
13. Repeat steps 2-12 for m_h values of 35 g, 45 g, 55 g, and 65 g. For each m_h value you should have five speed measurements.

- Estimate the uncertainty in the mass and height measurements. Use these estimates, together with the smallest value for each measurement, to calculate the uncertainty in each quantity.

$$\% \text{ uncertainty} = 100 \times \frac{\text{Measurement Uncertainty}}{\text{Smallest Measured Value}} \quad (11)$$

- Use the largest value in the percent variation in the experimental velocity as the percent uncertainty in the velocity. Record this value on your data table.
- Record the largest percent uncertainty in the experiment in the space provided.

Data Analysis

Variation of Initial Height

- Calculate the percent difference between the average experimental and theoretical velocities.

$$\% \text{ difference} = 100 \times \frac{\text{Theoretical Value} - \text{Experimental Value}}{\text{Theoretical Value}} \quad (12)$$

- Calculate the final kinetic energy using

$$K_f = \frac{1}{2}(M_c + m_h)v_{exp,ave}^2. \quad (13)$$

- Calculate the initial potential energy using

$$P_i = m_hgh_i. \quad (14)$$

- Calculate the ratio of the final kinetic energy, obtained above, to the initial potential energy, also obtained above, (i.e. calculate K_f/P_i). For this experiment, another way to express the conservation of energy is that all of the initial potential energy was converted into kinetic energy. If this is true, then the ratio of the kinetic energy to the potential energy should be equal to one.
- Plot** the square of the experimental velocity, $v_{exp,ave}^2$, as a function of the initial height of the hanging weight, h . Draw the straight line that passes closest to your data points and determine the slope and y-intercept of this line.

Variation of Mass of Hanging Weight

- Calculate the percent difference between the experimental and theoretical velocities of the cart.

$$\% \text{ difference} = 100 \times \frac{\text{Theoretical Value} - \text{Experimental Value}}{\text{Theoretical Value}} \quad (15)$$

2. Calculate the final kinetic energy using

$$K_f = \frac{1}{2}(M_c + m_h)v_{exp,ave}^2. \quad (16)$$

3. Calculate the initial potential energy using

$$P_i = m_hgh_i. \quad (17)$$

4. Calculate the ratio of the kinetic energy to the potential energy.
5. **Plot** the square of the experimental velocity, $v_{exp,ave}^2$, as a function of $\frac{m_h}{M_c+m_h}$. Draw the straight line that passes closest to your data points and determine the slope and y-intercept of this line.

Selected Questions

1. What effect would a tilt in the air track have on the kinetic energy/potential energy ratio? Explain why you think so.
2. What effect would friction have on the ratio? Explain why you think so.
3. What effect would variation in the release point have on the experimental value of the velocity? Explain why you think so.
4. This experiment ignored the rotation of the pulley. How does the rotation of the pulley affect the kinetic energy/potential energy ratio? Why is the rotation of the pulley negligible? Explain your reasoning for both questions.