Verification of Law of Conservation of Mechanical Energy Using Air Track

Lab 14

Learning Objectives

In this laboratory activity you determine the kinetic and gravitational potential energy of an object and perform an experimental test of the principle of conservation of mechanical energy for the force of gravity.

Required Equipment

- Air track with one glider
- Two photogate accessories
- Science Workshop Interface box
- Ruler
- Two block (cylinders) of different height
- Vernier caliper
- Set of masses: 20 g and 50 g.

Learning Outcomes

You will be able to:

- *Understand the principle of conservation of mechanical energy.*
- *Apply the principle of conservation of mechanical energy to situation involving gravitational potential energy and kinetic energy for a glider that slides on an air track.*
- *Calculate the potential and kinetic energies of a glider that slides on an air track.*
- *Compare the kinetic energy gained by a glider with the loss in gravitational potential energy and, as a result, verify the principle of conservation of mechanical energy.*

Theoretical Background

The theoretical background for this experiment is the same as for Laboratory experiment 13. However, experimental procedure for verification of the law of conservation of energy in this laboratory activity is based on the study of frictionless motion using an air track.

Energy is one of the most fundamental concepts in science. Energy is defined as the ability of a body or a system of bodies to perform work. Energy can be subdivided into well-known forms, such as mechanical energy, thermal energy, electrical energy, atomic energy, and nuclear energy. There are two kinds of mechanical energy. The energy that an object possesses by virtue of its position and interaction with another body is defined as potential energy. The gravitational potential energy is the energy that an object of mass *m* has by virtue of its position above the surface of the Earth. If that position being measured by the height *h* relative to an arbitrary zero level, the potential energy of the object is

$$PE = mgy \ , \tag{14.1}$$

where g is the acceleration due to gravity. It is important to mention that potential energy is always associated with conservative forces. By definition, we call any force a conservative force if the work done by the force on the other object moving from one point to another depends only on the initial and final positions and it is independent of the particular path taken. In mechanics we have to deal with two conservative forces. They are the force of gravity $F = mg$ and the force $F = -kx$ associated with elastic materials.

In addition to having energy by virtue of its position, an object also possesses energy by virtue of its motion. The energy that an object possesses by virtue of its motion is the kinetic energy. The kinetic energy of the object with mass *m* and speed *v* is given by

$$KE = \frac{mv^2}{2} \ . \tag{14.2}$$

The sum of these two kinds of energies is called the total mechanical energy *E*, so

$$E = PE + KE = mgy + \frac{mv^2}{2} \ . \tag{14.3}$$

When we say that something is conserved we mean that the quantity is constant and does not change with time. It is a surprising aspect of nature that when an object is in motion, its position is changing with time, and its velocity is changing with time, yet certain characteristics of that motion still remain constant. One of the quantities that remain constant during the motion is the total energy of the object. ***In any isolated system, the total energy of the system remains constant.*** This is the law (principle) of conservation of energy. In other words, the principle of conservation of energy states that ***In any isolated system, the total mechanical energy remains constant along all paths between the initial and final points, never varying from the initial value.*** If we let v_1 and mgy_1 represent the velocity and the gravitational potential energy of the object, which possesses total energy E_1 at one instant, and v_2 and mgy_2 represent them, when the object possesses total energy E_2 at the second instant, then we can mathematically write the law of conservation of energy as

$$E_1 = E_2 \tag{14.4}$$

or

$$mgy_1 + \frac{mv_1^{\ 2}}{2} = mgy_2 + \frac{mv_2^{\ 2}}{2}. \tag{14.5}$$

We can get more information from this equation by rewriting it in the form

$$-\left(mgy_2 - mgy_1\right) = \frac{mv_2^{\ 2}}{2} - \frac{mv_1^{\ 2}}{2}. \tag{14.6}$$

But

$$\Delta PE = mgy_2 - mgy_1 = -mg\Delta h \ , \tag{14.7}$$

is the change in the potential energy of an object, and $\Delta h = y_2 - y_1$. Also

$$\Delta KE = \frac{mv_2^{\ 2}}{2} - \frac{mv_1^{\ 2}}{2} \tag{14.8}$$

is the change in the kinetic energy of an object. Substituting equations (14.7) and (14.8) back into equation (14.6) gives

$$-\Delta PE = \Delta KE. \tag{14.9}$$

Equation (14.9) says that the change in gravitational potential energy of an object will always be equal to the change in the kinetic energy of an object. In other words, the potential energy of position is converted into kinetic energy of motion, or the amount of gravitational potential energy of the object lost is equal to the gain in kinetic energy.

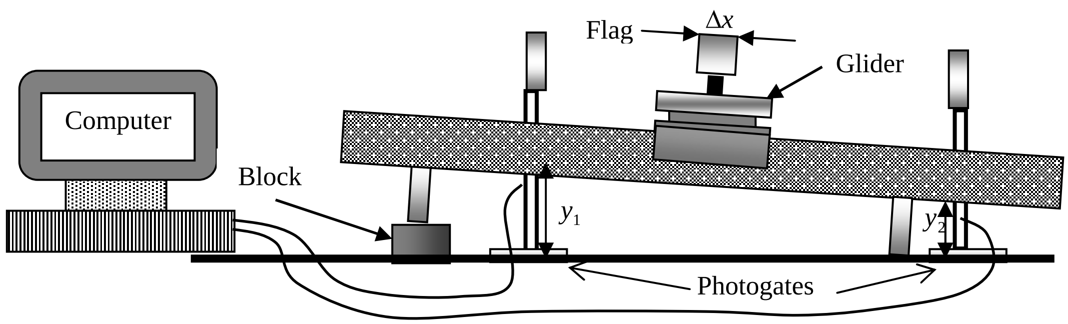

Fig.14.1. Setup of an air track with photogate accessories for verification of the principle of conservation of mechanical energy.

It is not easy to experimentally verify the law of conservation of mechanical energy. If an object is sliding down on an inclined plane, for example, it is constantly converting gravitational potential energy into kinetic energy, and also into thermal energy (heat energy) due to the friction between it and the inclined plane. It also loses energy due to the air resistance acting against its motion. When the object moves, it is striking the air molecules along the way and imparts to them a certain portion of its kinetic energy. In other words, we have the transformation of the mechanical energy of the object into the other forms of energy. This kind of difficulty exists throughout experiments and we have to create the simplest situation in which we can neglect all of these effects and focus on a particular aspect of the transformation of the gravitational potential energy to kinetic energy. In this experiment we will examine the transformation of energy that occurs as an air track glider slides down an inclined track, as it is shown in Fig. 14.1. We use the air track since there are no objects to interfere with the motion and there is negligible friction between the track and the glider. So we can consider this system to be an isolated system. Therefore, the loss in gravitational potential energy, as the glider slides down the track, should be equal to the gain in kinetic energy of the glider.

Procedure

1. Place the block or cylinder under the support leg of the air track.
2. Set up two Photogate accessories as shown in Fig. 14.1. Keep the distance between the photogates about 1.1 m.
3. Measure the vertical distances y_1 and y_2 between the tabletop and the points of the inclined air track, where the photogate accessories are located as shown in Fig.14 1. Record y_1 and y_2.
4. Measure and record the length of the flag on the glider Δx and the mass of the glider.
5. Connect the Science Workshop interface box to the computer, turn on the interface, and turn on the computer.
6. Connect the **Photogate accessories** stereo phone plugs into **Digital Channel 1** and **Digital Channel 2** on the Science Workshop Interface.
7. **Set up the sensors in the software.**
   - Open *DataStudio* Window. Click "Create Experiment".
   - Find the "Photogate" in the Sensors list in the Experiment Setup window. Double-click the "Photogate", and as a result the "Photogate" icon appears below Digital Channel 1 of the Interface box 750. Double-click the "Photogate" again, and as a result the "Photogate" icon appears below Digital Channel 2 of the interface.
   - In the Experimental Setup Window click "Timers", and as a result the "Timer Setup" window appears. According to equation (14.5), to measure the kinetic energy of a glider you need to know the velocities v_1 and v_2, when the glider passes Photogate 1 and Photogate 2, respectively. To measure the velocities v_1 and v_2, we will use the same techniques as in Experiment 5 and determine the velocities as
   $$v_1 = \frac{\Delta x}{\Delta t_1}, \qquad \text{and} \qquad v_2 = \frac{\Delta x}{\Delta t_2}. \tag{14.10}$$
   To measure the initial velocity v_1 of the glider you need to measure the time Δt_1 the glider's flag requires to pass through Photogate 1, when the Photogate 1 is first blocked by the flag and when it is unblocked as the back end of the flag moves away from the Photogate 1. In the timing sequences choices click **Ch. 1** and select "Blocked". Click once again and select "Unblocked".
   - Now in the "Timer Setup" window click **+New** and Timer 2 appears. To measure the final velocity v_2 of the glider you need to measure the time Δt_2 the glider's flag requires to pass through Photogate 2, when Photogate 2 is first blocked by the flag and when it is unblocked as the back end of the flag moves away from Photogate 2. In the timing sequences choices click **Ch. 2** and select "Blocked". Click once again and select "Unblocked".
   - To record your measurements of time, double-click the Table icon in the Display window, and as a result the "Choose a Data Source" window appears. Choose "Timer 1" and click OK. (You can also click-and-drag the Table icon from the Display window to the Data window for Timer 1). Repeat this procedure for Timer 2. For your measurements you only need "Elapsed time". Click on the "Clock" icon in each table menu, and as a result you will record just "Elapsed time". Resize the tables to fit your screen.
8. Put the glider at the starting point and turn on the air supply. Hold the glider steady. The glider must be released from the same point for each trip. Click the "**Start**" button and then release the glider from the starting point so it glides freely through the photogates. Timing begins when the beams of the photogates are blocked and ends when the beams are unblocked. The time intervals Δt_1 and Δt_2 that the flag of length Δx takes to pass between the photogates will be immediately displayed. Record the value of Δt_1 and Δt_2 in Data Table. 14.1. Catch the glider, put it at the same starting point and release again. Repeat this step a few times.
9. Click the **Statistics** button and take the mean value of Δt_1 and Δt_2. Record the mean value of Δt_1 and Δt_2 in Data Table 14.1.
10. Click the **Stop** button to end data recording.
11. Change the mass of the glider by adding 20 g and repeat steps 8 and 10. Then do this for a mass 50 g.
12. Change the block or cylinder under the support leg of the air track and repeat steps from 7 through 11.

Computations and Data Analysis

1. Use equations (14.10) and calculate velocities $v_1 = \frac{\Delta x}{\Delta t_1}$ and $v_2 = \frac{\Delta x}{\Delta t_2}$ for each trial based on the parameter Δx, the length of the flag you measured and time intervals Δt_1 and Δt_2 the flag takes to pass through each of the photogates. Record the values of v_1 and v_2 in Data Table 14.1.
2. Use equation (14.2) to calculate the kinetic energy of the glider as it passed through photogate 1 and photogate 2. Then determine the change in kinetic energy of the glider $\Delta KE = \frac{m{v_2}^2}{2} - \frac{m{v_1}^2}{2}$ for each trial.
3. Calculate the gravitational potential energy of the glider at the positions where the photogate 1 and photogate 2 are located. Find the change in gravitational potential energy of the glider $\Delta PE = mgy_2 - mgy_1$ for each trial.
4. Calculate the total mechanical energy of the glider at the position 1, E_1 and position 2, E_2.
5. Compare the total mechanical energy E_1 with the total mechanical energy E_2 by computing the percent difference. Make a conclusion.
6. Compare the kinetic energy gained with the loss in gravitational potential energy by computing the percent difference. Make a conclusion.

Questions

1. Was the mechanical energy of the glider in motion conserved? Discuss the possible sources of error.
2. A glider released from a starting height at an inclined air track bounces to one-half its original height. Discuss the energy transformations that take place.
3. Analyze the data Table 14.1. Does the velocity of the sliding glider depend on the sliding mass? Explain why. Does the kinetic energy remain the same?
4. If you perform the same experiment on the Moon where the acceleration due to gravity is six times less than on the Earth will the value of the kinetic and potential energies stay the same as in this experiment?

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Data Table 14.1. **Data and results of calculations**

Length of the flag Δx =_____m
Mass of the glider _____kg

First Trial
Height y_1 =_____m
Height y_2 =_____m

Second Trial
Height y_1 =_____m
Height y_2 =_____m

Trial	Photogate 1 mean Δt_1, s	Photogate 2 mean Δt_2, s
First Trial		
Second Trial		

Mass m, kg	Position 1				Position 2				% difference
	Velocity v_1, m/s	Kinetic energy $KE_1 = \frac{mv_1^2}{2}$, J	Potential energy $PE_1 = mgy_1$, J	Total energy $E_1 = KE_1 + PE_1$, J	Velocity v_2, m/s	Kinetic energy $KE_2 = \frac{mv_2^2}{2}$, J	Potential energy $PE_2 = mgy_2$, J	Total energy $E_2 = KE_2 + PE_2$, J	
+0.02									
+0.05									
+0.02									
+0.05									

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Data Table 14.2. **Results of calculations**

Mass *m, kg*	Kinetic energy gain $\Delta K = \frac{mv_2^2}{2} - \frac{mv_1^2}{2}$, *J*	Loss in potential energy $-\Delta U = -(mgy_2 - mgy_1)$, *J*	% difference
+0.02			
+0.05			
+0.02			
+0.05			