PHY 123 Lab 4 - Conservation of Energy

The purpose of this lab is to verify the conservation of mechanical energy experimentally.

Important! You need to print out the 1 page worksheet you find by clicking on this link and bring it with you to your lab session.

If you need the .pdf version of these instructions you can get them here.

Video

Equipment

- air track (with picket fence)
- glider
- photogate (mounted on top of the glider)
- interface box (photo gate – computer)
- computer
Introduction

To prepare for this lab, you should review the material in Chapter 10 of *Knight, Jones and Field (2nd ed.)*, (abbreviated KJF2), which is our recommended textbook for PHY 121. Pay particular attention to section 10.6, *Using the Law of Conservation of Energy*, including the worked-out examples in that section.

For an isolated system, the total energy must be conserved. (You earlier met the concept of an “isolated” system in the discussion of and labs on angular momentum and linear momentum. Make sure you understand precisely what an isolated system is.) In this experiment you will examine the law of the conservation of the total mechanical energy by observing the transfer of gravitational potential energy to kinetic energy, using a glider on an air track that is pulled by the weight of a falling mass. The apparatus is is called an air track because an air “cushion” reduces the friction. We consider the system, glider + mass, along with the string-and-pulley system that connects them, to be isolated from friction. The position of the glider as a function of time can be accurately recorded by means of a photogate device. From previous labs you are already familiar with the use of photogates and the computer.

In this experiment the glider on the air track gains kinetic energy as the falling mass $m$ loses potential energy.
When it is moving with velocity \( v \), the kinetic energy of the mass-plus-glider system is given by

\[
\frac{1}{2} (M + m) v^2 \tag{4.1}
\]

The change in the potential energy \( \delta PE \) of the system, (as we have been doing previously in this course, \( \delta \) denote a change in a quantity and \( \Delta \) denotes the uncertainty in a quantity), when the height \( h \) of the small mass \( m \) changes by \( \delta h \), is given by

\[
m g (\delta h) \tag{4.2}
\]

Note that \( \delta h \) will be negative in this experiment, i.e., the gravitational potential energy of the system should be reduced as the mass falls. The principle of conservation of energy leads one to expect that this decrease in the potential energy of the system should result in an equal and opposite increase in the kinetic energy of the system.

\[
\delta KE = -\delta PE \tag{4.3}
\]

You can also use Newton’s second law to calculate what you expect the acceleration of this system to be and then check that with our experiment.

\[
F_{net} = mg = (M + m)a \Rightarrow a = \frac{m}{M + m} g \tag{4.4}
\]

**Experimental Procedure**

A battery-powered photogate is mounted on the glider. When activated with the small push button on the side of the glider, the photogate turns on a bright light emitting diode (LED) whenever the picket fence over the air track blocks the photogate. A light sensor at the end of the air track receives the LED signals, and the timing program in the computer measures and records the times when the light beam of the photogate is blocked. **Of course you need to make sure the LED on the base of the glider is facing the receiver on the track.**

A small mass is attached to the glider via a string on a level air track. When you drop the small mass, you can measure the change in height of the small mass as well as the velocity of the glider-mass system. This will allow you to compute the sum of kinetic and potential energies before and after the mass falls and, thereby, verify (or dismiss!) the law of the conservation of mechanical energy as a useful concept.

1. Your lab TA has a list of the masses for all the gliders. Get the number of your glider and obtain its mass, \( M \), from your lab TA. Assume a 1 gram uncertainty for this mass and record this mass and the error on your worksheet.
2. You need to determine the distance \( d \) from one “picket” to the next and enter it into the computer later on. Instead of measuring \( d \), measure \( 10d \) and estimate the absolute uncertainty for it. You might remember that we did a similar thing in Lab 2. From this measurement determine the distance \( d \) and its uncertainty according to expression (E.11) from the Lab 1 manual, *Uncertainty, Error and Graphs.*
3. Level the air track by carefully adjusting the single leveling screw at one end of the track. When the track is level, the glider should remain nearly stationary at any point on the track. Be sure to tighten the wing nut on the leveling screw when your track is level.

4. Attach a 20 gram mass (NOT more than 20 grams!), to the glider with a piece of string and rest the string on the groove on the pulley at the end of the air track so that the mass hangs over the edge of the table and can fall freely. Record the value of this mass and an assumed uncertainty of 0.2 grams on your worksheet. Make sure the string with the weight attached is long enough so that you can reach the far end from the pulley and can start the motion with the photogate in front of the first “picket”. The string should not be too long. “Not too long” means that the weight should not hit the floor before the glider is ~ 10 pickets from the end of the air track on the pulley side.

5. Get the computer ready for data taking: Double click the icon “Exp4_xv_t2”. A window with a spreadsheet on the left (having “Time, Distance, Velocity” columns) and an empty graph on the right with velocity and time axes comes up. On top is a window “Sensor Confirmation”. Click “Connect”, again “Connect”.

6. Enter your value for the distance $d$ in Fig. 2 above from step 2) into the program: Click Data→User Parameters: the window “User Parameters” comes up and should show:

| Name: PhotogateDistance1 | Value: your value of $d$ | Units: | Places: 4 | Increment: 1.0000 | Editable: ✔ |

Click OK. You are ready to take data now. Click Experiment→Start Collection.

Hold the glider on the air track at the far end from the pulley with the photogate ~ 3 cm in front of the first picket. Release the glider and hit the space bar (which stops the data taking) when the glider is ~ 10 pickets from the end at the pulley side. (You may want to practice this a few times.) After a good run you should have ~13 velocity-time pairs in the spreadsheet and a straight line velocity vs. time graph. If you do not get a linear graph, repeat the measurement. If your final graph still has a kink at the beginning use only data after the kink. Copy the first 8 data points (rows which contain a velocity) from your spreadsheet into Table 1 on you worksheet. The first point you enter is your data point “1” in the analysis below. Don’t skip any points after point “1”.

Analysis

Enter in the table below your value for $d$ and $\Delta d, m$ and $\Delta m, M$ and $\Delta M$ and then the eight velocity and time values you wrote in your table. When you click submit the computer will produce a table and a graph from your values. To calculate the change in potential energy, the calculation tool works out $\delta h$ and then multiplies it by $mg$ to get $\delta PE$, the change in potential energy from the value at the first measurement point. The change in the height $\delta h$ in Eq. (4.2) is the same (in magnitude, not sign) as the distance traveled by the weight from the data point 1 to 2, 1 to 3, 1 to 4, ..., etc. Thus, for data point 2, $\delta h = -(2 - 1)d$, for data point 3, $\delta h = -(3 - 1)d$, etc.

In the calculations of uncertainties, the uncertainty in the time is neglected because we assume the computer measures time accurately, or at least much more accurately than you can measure a distance or a mass, and, therefore, the relative uncertainty in the time is much less than the relative uncertainty in either $d, m$ or $M$. Some of the questions in the Lab 4 pretest deal with how the uncertainties in the various quantities are calculated from the uncertainties in the values you measure.

The computer calculates the kinetic energy at each velocity measurement by using Eq. (4.1). Then it makes a plot of $\delta PE$ vs $KE$. What do you expect the slope of this graph to be? Are your results consistent with this expectation? Answer these questions in the appropriate place on your worksheet.

It also makes a second plot, one of velocity vs. time. The slope of this graph is, of course, the acceleration. Check whether the value of acceleration matches the value you expect from Eq. (4.4). Answer the relevant
questions in the appropriate place on your worksheet.

Be prepared to discuss your results with your Lab TA(s) as part of the exit interview process. Finally, make sure your Primary TA collects your worksheet before you leave the lab.

d= +/- [___] m
m= +/- [___] kg
M= +/- [___] kg

Time and Velocity Values

| t1 | s | v1 | m/s |
| t2 | s | v2 | m/s |
| t3 | s | v3 | m/s |
| t4 | s | v4 | m/s |
| t5 | s | v5 | m/s |
| t6 | s | v6 | m/s |
| t7 | s | v7 | m/s |
| t8 | s | v8 | m/s |