Conservation of Mechanical Energy

Materials: *Simple pendulum suspended from the ceiling rail, photogate and hardware, 2*[m] *meterstick, vernier caliper, triple-beam or electronic balance*

Purpose

The goal of this laboratory is to test the law of conservation of energy using a simple pendulum.

Introduction

The total mechanical energy of an object with mass m, moving at speed v and positioned at a height of y above some reference point is the sum of the kinetic and potential energies

$$E = \frac{1}{2}mv^2 + mgy \tag{1}$$

Here the only relevant potential energy is the near-Earth gravitational potential ($PE_{\text{grav}} = mgh$)

The Law of Conservation of Energy states that energy cannot be created nor destroyed but may be converted within a system. So we may **hypothesize** that *if the work done by non-conservative forces in a system (e.g. no air resistance, no friction) then the total mechanical energy E remains constant throughout the motion.* For an object in motion between points 1 and 2 with no non-conservative forces doing work on the system (e.g. $W_{\text{nc}} = 0$), we can write this hypothesis (law of conservation of energy) as

$$W_{\text{nc}} = 0 = E_2 - E_1 \tag{2}$$

Consider the pendulum system shown in Fig 1 where the points of interest are (1) the initial position of the pendulum starting from rest and (2) the pendulum at the bottom of its path. The total energy for states 1 and 2 are expressed as

$$E_1 = \frac{1}{2}m\underbrace{v_1^2}_{=0} + mgh_0 \quad \text{and} \quad E_2 = \frac{1}{2}mv_2^2 + mgh \tag{3}$$

So the conservation of energy expression can be written as

$$\begin{gathered} 0 = \left(\frac{1}{2}mv_2^2 + mgh\right) - (mgh_0) \\ \downarrow \\ \underbrace{\left[\frac{1}{2}mv_2^2\right]}_{\text{Y}} = \underbrace{(1)}_{\text{slope}}\underbrace{[mgh_0]}_{\text{X}} + \underbrace{(-1)mgh}_{\text{y-int}} \end{gathered} \tag{4}$$

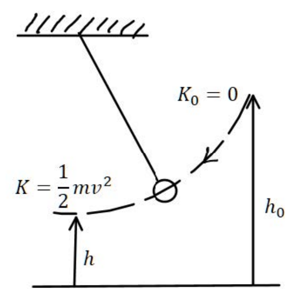

Figure 1: Pendulum with measurements identified.

where the square brackets demonstrate which quantities will vary in this experiment: that is, the initial potential energy (by varying h_0) and the final kinetic energy (measuring the resulting v_2). Rearranging the conservation of energy expression (Eqn. 4) results in a model that is linearized and testable.

Procedure

Configure the photogate at the bottom of the pendulum swing to measure the speed as the pendulum passes through. Choose an initial height (h_0), release the pendulum from rest and measure the speed at the bottom of the swing. Repeat for several different initial heights. Plotting the final kinetic energy (Y in Eqn. 4) as a function of the initial potential energy (X in Eqn. 4) enables the use of a linear fit to verify this model.

Scientific method

If the hypothesis is good, then according to the model (eqn 4), a plot of $\frac{1}{2}mv_2^2$ versus mgh_0 should yield a straight line with a

$$\text{slope} = 1 \quad \text{and} \quad \text{y-intercept} = -mgh$$

If a straight line is not produced, the hypothesis and model should be modified.
If a straight line is produced, the extent to which the model agrees will be checked using a percent difference calculation for the slope and height above the floor (h).

Experiment Details

- Record the bob mass, the bob diameter and the bob height at the bottom of the swing (h).
- Create a data table with the following columns (record raw data on a hard copy before entering into a spreadsheet)

h_0 [m]	Gate time 1, t_1 [s]	Gate time 2, t_2, [s]	Avg time, $\bar{t}$ [sec]	Speed, v [m/s]	KE [J]	PE$_0$ [J]
⋮	⋮	⋮	⋮	⋮	⋮	⋮

- Collect data (as described in the Procedures section) for $h_0 = 1.20$ m $\rightarrow$ 1.80 m in 10 cm increments.
- Use a two-meterstick with zero on the floor to set the release height (h_0) at the center of the bob
- Practice releasing the bob without giving it any push. It will help to hold it between two fingers that are horizontally opposed from each other. The bob will always pass through the photogate if you release it from rest.
- Before recording anything, do a few test runs to confirm that the Capstone timer is working reliably and you are able to release the bob from rest. Only record times when you feel confident about how it functions.
- The speed of the bob at the bottom (v_2) is 'bob diameter'/'average gate time'
- The kinetic energy KE is determined with $\frac{1}{2}mv_2^2$
- The total energy at the top (potential energy at the top, PE_0) is determined by mgh_0.
- Record all digits reported on the instruments; determining the final significant figures to report should be done based on the estimated uncertainty and/or reported tolerance of the equipment.
- Make notes on your estimated uncertainty for all measured parameter types

References

- *Physics* 10th Edition, Serway and Jewett
- OpenStax College, *College Physics*, 21 June 2012 <http://cnx.org/content/col11406/latest>.

Responses and submission

Complete this section and attach (as required) the specified materials in the following order

- This *response and submission* section
- On a single page, a neatly formatted data table with plot of kinetic energy vs initial potential energy

1. Slope of your graph (with units) = _____________

2. Percentage difference between your slope and the theoretical (expected) value = _____________
   Show work here
   $\%\text{Diff} = \frac{\text{slope}_{\text{exp}} - \text{slope}_{\text{theory}}}{\text{slope}_{\text{theory}}} \times 100\% =$

3. Height of bob at bottom of swing as measured with the meterstick h = _____________

4. Height of bob at bottom of swing as determined from the linear fit's y-intercept value h = _____________
   Show work here ↓

5. Percentage difference for h values = _____________
   Show work here ↓

6. The total estimated experimental uncertainty for this apparatus = _____________
   Show work here ↓