EXPERIMENT: ANALYSIS OF A FREELY-FALLING BODY

Part II: Conservation of Energy

OBJECTIVE

- to observe the changes in potential energy, kinetic energy, and total mechanical energy of a freely-falling body
- to ascertain graphically whether the total mechanical energy of a freely-falling body remains constant
- to determine, both theoretically and experimentally, the form of the
- variation of the potential energy and the kinetic energy with time

APPARATUS

The data collected using the Behr Free-Fall Apparatus in the previous experiment will be used.

THEORY

The kinetic energy of a mass m moving with speed v , is defined as

$$KE = \frac{mv^2}{2}. \tag{1}$$

The potential energy of this mass relative to some (arbitrarily chosen) origin is

$$PE = mgy, \tag{2}$$

where y is the height above the origin and g is the acceleration due to gravity. For a mechanical system where there are <u>no energy losses due to frictional forces</u>, the total mechanical energy, E_m, is constant:

$$KE + PE = E_m = E_{total} = constant \tag{3}$$

This is a special case of the general principle of conservation of energy.

The kinetic energy (KE) can be calculated directly from equation (1) using the speed that was measured in the previous lab. However, in order to use equation (2) to calculate potential energy (PE) it is necessary to first *define* or *chose* an origin from which to measure y. We will discuss the origin that will be used in the experiment in the procedure.

PROCEDURE

In the previous experiment the speed of the falling object was determined at each spark position (except for the first and last spark positions). In this second part of the experiment this data will be used to calculate the potential energy and kinetic energy at each point. The formulae for these calculations are given above. For the potential energy we will choose the point where potential energy is zero at y = 0 cm. That is, at point #31 PE = 0.

Open the spreadsheet *Free fall 2_empty*, which is prepared for this lab. Transfer your saved values for y, Δy, and v from the previous lab's spreadsheet using the "copy and paste" procedure.

Program the spreadsheet to calculate PE and KE by entering the formula for each in the first cell of the appropriate column. Remember that for the spreadsheet to recognize a formula it must begin with an equals (=) sign. For example, PE is defined as PE =mgy, and this is programmed as "= m * g* C19." You can simply use "m" for mass and "g" for gravitational acceleration in your formulae because the cells on your spreadsheet where these values go are <u>already named</u> for you. However, do not forget to enter the appropriate <u>values</u> into these cells, or your formulae will not work. When you have the correct formula for PE you can use the fill-down method to calculate the energies for all of your values. Check one of the computer's results for PE and turn it in on a "Manual Calculations" page with your lab write-up.

Repeat the same steps for the calculation of the kinetic energy. The term v^2 in the equation for KE can be programmed as "v*v" **or** as "v^2," where for "v" you must actually type in the coordinates of the cell that has velocity in it. For example, the first velocity cell is E22.

Calculate the total energy (E_{total}) by adding KE and PE at each point.

Finally, calculate the errors in PE, KE and E_{total}. The formulae used can be found in the appendix for this experiment. Note that the cells containing the values for error in y and error in delta y are already named for you, just like the cells containing the values for mass and gravitational acceleration are.

Do not forget to do a manual calculation for <u>each type</u> of quantity calculated and hand it in on your "Manual Calculations" page.

Make <u>one</u> graph showing PE, KE and E_{total} as functions of time. Select a range for the x-axis (time) such that it extends somewhat beyond your data points. Have the computer fit the plot of E_{total} with a best-fit line and make sure the equation for the line is somewhere on your graph.

<u>QUESTIONS</u>

1) Is the total energy conserved at all times? If yes, how well is it conserved? HINTS: A slope equal to zero indicates that the total energy does not depend on time. The formula for the error in your slope is given in the appendix to this lab.
2) One of the student's reports contained the following argument: "I think that the total energy is conserved because its graph is a straight line." Do you agree or disagree with this student? Explain your position.
3) Discuss the time PE = E_{total} and the time KE = E_{total} for an object in free fall. What happens at these points? That is, what are the position, speed and acceleration of the object at these points?

<u>CHECKLIST</u>

Your lab report should include the following four items:

1) spreadsheet with the data and *Excel*-computed calculations
2) a "Manual Calculations" sheet with a sample done by you of each type of calculation
3) one graph of the three energies with a best-fit line and equation of best-fit line for E_{total}
4) answers to the questions

Formulae, Definitions, and Errors for the Free Fall Experiment

DEFINITIONS

In this experiment you measure the position of a falling mass, m, at fixed time intervals. The fixed time interval is determined by a high-voltage spark source. Read off the time between sparks (τ) from the setting on the spark source.

You will measure the positions at each spark as y_1, y_2, y_3, y_4, etc. in centimeters [cm]. These positions will be referred to as y_i.

To measure the speed at point a particular point "i" first calculate

$$\Delta y_i = y_{i+1} - y_{i-1}.$$

For example for the sixth point

$$\Delta y_6 = y_7 - y_5.$$

On your data sheet this is labeled as Δy(i). You are now ready to calculate the speed at point i by dividing the distance Δy_i by the time elapsed between the two points, or 2τ. So the speed V_{y_i} is given by

$$V_{y_i} = \frac{\Delta y_i}{\Delta t} = \frac{\Delta y_i}{2t} \quad \text{[cm/s]}.$$

The potential energy (PE) and kinetic energy (KE) at each point y_i are defined as follows:

$$PE = mgh = mgy_i \qquad\qquad KE = \frac{mv^2}{2} = \frac{mV_{y_i}^2}{2}$$

ERRORS

For each measured y_i you assign an error based on how accurately you can measure that point. This error is called dy. This error determines all other errors in this lab. For this lab and for the following formulae it is assumed that the error in τ and m are zero.

The error in Δy at each point i is the same and is given by

$$d(\Delta y) = 2\,dy.$$

The error in the speed at each point i is

$$d(V_y) = V_y \frac{d(\Delta y)}{\Delta y} = V_y \frac{2dy}{\Delta y} = \frac{V_y}{\Delta y} 2dy = \frac{2dy}{2t} = \frac{dy}{t}.$$

The error in the kinetic energy at each point i is determined by:

$$\frac{d(KE)}{KE} = \frac{2d(V_y)}{V_y} = \frac{4dy}{\Delta y}$$

which means that

$$d(KE) = KE\frac{2d(V_y)}{V_y} = KE\frac{4dy}{\Delta y}.$$

The error in the potential energy at each point is determined by:

$$\frac{d(PE)}{PE} = \frac{dy}{y}$$

which means that

$$d(PE) = PE\frac{dy}{y} = mgy\frac{dy}{y} = mgdy.$$

As you will see, the error in PE is the same for every point.

The error in E_{total} is just the sum of the errors in the kinetic and potential energies.

The error in the slope of your E_{total} graph is

$$d\ (slope) = (dE_{totalf} + dE_{totali})\ /\ time$$

where δE_{totalf} is the error in the total energy of your final point used, δE_{totali} is the error in the total energy of your first or initial point used, and time is the total time elapsed between those two points.