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, and to ascertain graphically whether the total mechanical energy 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 from the previous experiment, using the Behr Free Fall apparatus, will be used.

THEORY

Kinetic energy of a mass *m* moving with speed *v* , is defined as:

$$KE = \frac{mv^2}{2} \qquad (1)$$

The potential energy of this mass relative to some origin is:

$$PE = mgy \qquad (2)$$

where *y* is the height above the origin and *g* is the acceleration due to gravity.

For a mechanical system where there are no energy losses due to frictional forces, the total mechanical energy, E_m, is constant:

$$KE + PE = E_m = E_{total} \qquad (3)$$

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

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

PROCEDURE for part II

In the previous experiment at each spark position (except the first one and the last one), the speed of the falling object was determined. In this part of the experiment these data will be used, to calculate the potential (*PE*) and kinetic energy (*KE*) at each point. The formulae for this calculation are given above. For the potential energy we will use *PE*=0 at y= 0 cm. So at point #31 *PE*=0.

Open the spreadsheet *Free fall 2_empty*, which is prepared for this lab. Transfer the values of y, Δy and v from the previous lab's spreadsheet, using the "copy and paste" procedure. Do this by retrieving your old spreadsheet from the folder "Results/Your section".

Program the spreadsheet to calculate *PE* and *KE*. This is done in the following way: click on the first cell (F22), where you want to calculate *PE*. You can now type in the formula for calculating *PE*. For the spreadsheet to recognize it as a formula it has to start with a '=' sign. *PE* is defined as *PE* =mgy, and this is programmed as ' = m * g* C22'. The variables 'm' and 'g' are defined in the spreadsheet as G7 and G10 and their values have to be given. After you enter the formula hit ‘return’ or ‘enter’. The spreadsheet will now execute it and show you the result in F22. Check the result by hand and turn in your manual calculation.

Once the formulae is correct, “fill-down” the column using **⌘-C** and **⌘-V**. The spreadsheet will put the formula into all of the cells in that column and pick up the correct *y* position for each calculation. Check the formula in some of the boxes.

Repeat the same steps for the calculation of the kinetic energy. Remember, now you have to use the speed. The term v^2 can be programmed as ‘v*v’ or as ‘v^2’, where “v” refers to the cell that has velocity in it (i.e. the first one 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 formulas used can be found in the appendix for this experiment.

Make one 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.

With the help of Your graph answer the following questions:

- ♦ Is the total energy conserved at all times ? If yes, how well is it conserved ? To answer this, draw a straight line through the points describing the total energy and calculate its slope. HINT: A slope equal to zero indicates that the total energy does not depend on time.
- ♦ 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.
- ♦ Discuss the point $PE = E_{total}$ and the point $KE = E_{total}$. What happens at these points, i.e. what is the position, speed and acceleration?

Formulas, 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 -i- (for example i=6) you determine:

$$\Delta y_i = y_{i+1} - y_{i-1} \text{ in our particular example: } \Delta y_6 = y_7 - y_5$$

from your measurements. On your data sheet this is labeled as Δy(i). The speed at point -i- is now determined by dividing the distance Δy_i (=Δy(i))by the time elapsed between the two points: 2τ. So the speed V_{y_i} is given by:

$$V_{y_i} = \frac{\Delta y_i}{\Delta t} = \frac{\Delta y_i}{2\tau} \quad \text{[cm/sec}^2\text{]}$$

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

$$PE = mgh = mgy_i \qquad KE = \frac{mv^2}{2} = \frac{mV_{y_i}^2}{2} \qquad \text{[gm cm}^2\text{ / sec}^2\text{]}$$

The errors for these quantities are defined as follows:

For each measured y_i you assign an error based on how accurate you can measure that point. This error is called δy. This error determines all other errors in this lab. For the following formulas it is assumed that the error in -τ- and -*m*- are zero. Here are the definitions:
The error in Δy at each point -i- is the same and is given by $\delta(\Delta y) = 2\delta y$
The error in the speed at each point -i- is:

$$\delta(V_y) = V_y \frac{\delta(\Delta y)}{\Delta y} = V_y \frac{2\delta y}{\Delta y} = \frac{V_y}{\Delta y} 2\delta y = \frac{2\delta y}{2\tau} = \frac{\delta y}{\tau}$$

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

$$\frac{\delta(KE)}{KE} = \frac{2\delta(V_y)}{V_y} = \frac{4\delta y}{\Delta y} \quad \text{which means} \quad \delta(KE) = KE\frac{2\delta(V_y)}{V_y} = KE\frac{4\delta y}{\Delta y}$$

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

$$\frac{\delta(PE)}{PE} = \frac{\delta y}{y} \quad \text{which means} \quad \delta(PE) = PE\frac{\delta y}{y} = mgy\frac{\delta y}{y} = mg\delta y$$

and as you will see, it is the same for every point.
The error in E_{total} is just the sum of the errors in the kinetic and potential energies.

FIT VIEW

Free Fall with Behr apparatus

Partner:

Name:

Section:

	value	units
Falling mass m=	0.01	[grams]
Error in mass is assumed to be zero.		
Time Interval between sparks:	0.017	[seconds]
Gravitational acceleration -g-:	980	[cm/sec**2]
Error in -y- : $\delta(y)$	xxx	[cm]
Error in -Δy- : $\delta(\Delta y) = 2\,\delta(y)$	xxx	[cm]

Key:
Blue = measured values
Yellow = calculated values

$\Delta y(i)=y(i+1) - y(i-1)$

Etot = KE+PE

Dot	Time	y(i)	Δy(i)	Vy(i)	PE	δ(PE)	KE	δ(KE)	Etot	δ(Etot)
i	[sec]	[cm]	[cm]	[cm/sec]						
						!!!!put units here !!!!!				
1	0.000	0.0								
2	0.017	0.0								
3	0.033	0.0								
4	0.050	0.0								
5	0.067	0.0								
6	0.083	0.0								
7	0.100	0.0								
8	0.117	0.0								
9	0.133	0.0								
10	0.150	0.0								
11	0.167	0.0								
12	0.183	0.0								
13	0.200	0.0								
14	0.217	0.0								
15	0.233	0.0								
16	0.250	0.0								
17	0.267	0.0								
18	0.283	0.0								
19	0.300	0.0								
20	0.317	0.0								
21	0.333	0.0								
22	0.350	0.0								
23	0.367	0.0								
24	0.383	0.0								
25	0.400	0.0								
26	0.417	0.0								
27	0.433	0.0								
28	0.450	0.0								
29	0.467	0.0								
30	0.483	0.0								
31	0.500	0.0								