

# ENERGY OF A TOSSED BALL

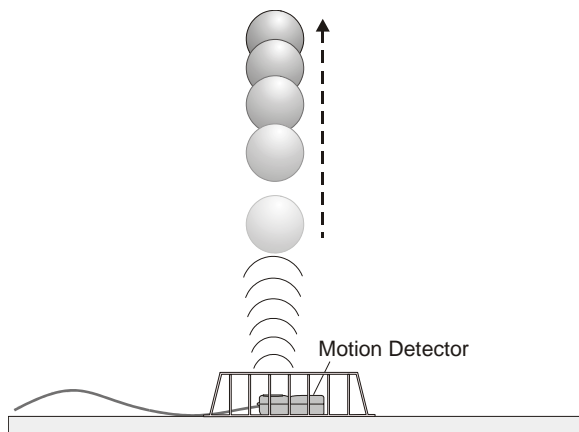
## LAB MECH 15. CALC (Version 2)

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### INTRODUCTION

When a juggler tosses a bean ball straight upward, the ball slows down until it reaches the top of its path and then speeds up on its way back down. In terms of energy, when the ball is released it has kinetic energy,  $KE$ . As it rises during its free-fall phase it slows down, loses kinetic energy, and gains gravitational potential energy,  $PE$ . As it starts down, still in free fall, the stored gravitational potential energy is converted back into kinetic energy as the object falls.

If there is no work done by frictional forces, the total energy will remain constant. In this experiment, we will see if this works out for the toss of a ball.



In this experiment, we will study these energy changes using a Motion Detector.

### PURPOSE

The purpose of this experiment is to measure the kinetic and potential energies of a ball moving vertically undergoing free-fall due to gravity and to study changes in these energies and the total energy during the free-fall.

### MATERIALS

LabPro or CBL 2 interface  
TI Graphing Calculator  
DataMate program  
Vernier Motion Detector

Volleyball, basketball, or other similar  
fairly heavy ball  
Wire basket

## PRELIMINARY QUESTIONS

For each question, consider the free-fall portion of the motion of a ball tossed straight upward, starting just as the ball is released to just before it is caught. Assume that there is very little air resistance.

1. What form or forms of energy does the ball have while momentarily at rest at the top of the path?
2. What form or forms of energy does the ball have while in motion near the bottom of its path?
3. Sketch a graph of velocity *vs.* time for the ball.
4. Sketch a graph of kinetic energy *vs.* time for the ball.
5. Sketch a graph of potential energy *vs.* time for the ball.
6. If there are no frictional forces acting on the ball, how is the change in the ball's potential energy related to the change in kinetic energy?

## PROCEDURE

1. Measure and record the mass of the ball you plan to use in this experiment.
2. Connect the Vernier Motion Detector to the DIG/SONIC 1 port of the LabPro or the DIG/SONIC port of the CBL 2 interface. Use the black link cable to connect the interface to the TI Graphing Calculator. Firmly press in the cable ends.
3. Place the Motion Detector on the floor and protect it by placing a wire basket over it.
4. Turn on the calculator and start the DATAMATE program. Press  to reset the program.
5. In this step, you will toss the ball straight upward above the Motion Detector and let it fall back toward the Motion Detector. This step may require some practice. Hold the ball directly above and about 0.5 m from the Motion Detector. Use two hands. Be sure to pull your hands away from the ball after it starts moving so they are not picked up by the Motion Detector. Select START to begin data collection. You will notice a clicking sound from the Motion Detector. Wait one second, then toss the ball straight upward. Be sure to move your hands out of the way after you release it. A toss of 0.5 to 1.0 m above the Motion Detector works well. You will get best results if you catch and hold the ball when it is about 0.5 m above the Motion Detector.
6. After data collection is complete press  to view the distance graph.
7. Examine the distance *vs.* time graph. Repeat Step 5 if your distance *vs.* time graph does not show a region of smoothly changing distance. Check with your instructor if you are not sure whether you need to repeat the data collection. To repeat data collection, press  to return to the SELECT GRAPH menu; select MAIN SCREEN and then START to repeat data collection.

## DATA TABLE

Mass of the ball	(kg)
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Position	Time (s)	Height (m)	Velocity (m/s)	PE (J)	KE (J)	TE (J)
After release						
Between release and top						
Top of path						
Between top and catch						
Before catch						

## ANALYSIS

- To analyze only the free-fall portion of the data you must discard all other data:
  - Press **ENTER** to return to the GRAPH menu.
  - It is easiest to select the proper region using the velocity graph. Use the **▲** and **▼** cursor keys to select VELOCITY.
  - Select SELECT REGION.
  - Using the cursor keys move the flashing cursor to the beginning of the straight-line, negative-slope region. This portion corresponds to free fall.
  - Press **ENTER** to select the left (lower) bound.
  - Use the cursor keys **◀** and **▶** to move the flashing cursor to the end of the straight-line section, corresponding to free fall.
  - Press **ENTER** to select the right (upper) bound.
  - Press **ENTER** again to see your selected data.
- To explore the energy of the ball (kinetic and potential) at various moments during the motion, you can trace across the graph using the cursor keys and read positions and velocities at certain times. Record the following times and velocities in your Data Table: Trace to the moment just after the ball was released into free fall, then when the ball was at the top of the path (where velocity was about zero), and then just before the free-fall motion ended. Choose two more points approximately halfway in time between the three recorded so far. You should now have five times and velocities.
- Now read the position of the ball at the same five times. Press **ENTER** and choose DISTANCE to see the distance graph. Trace across the graph to the same five times you used in the previous step and record the corresponding distances in the Data Table.
- For each of the five points in the Data Table, calculate the Potential Energy ( $PE$ ), Kinetic Energy ( $KE$ ), and Total Energy ( $TE$ ). Use the position of the Motion Detector as the zero of your gravitational potential energy.

5. How well does this table you have just completed show conservation of energy? Explain.

6. You can also graph the ball's energy at all the measured times, instead of just the five in the Data Table. Using the distance data in L6 and  $mgh$ , you can store gravitational potential energy at each moment in L3. Using the velocity data in L7, you can use  $\frac{1}{2}mv^2$  to store the ball's kinetic energy at each moment in L2. Finally, you can find the total mechanical energy at each moment by finding the sum of the potential and kinetic energies in L2 and L3, storing the result in L4. To do these calculations will require manipulating the data outside of the DATAMATE program, so press  $\boxed{\text{ENTER}}$ , MAIN SCREEN, and then QUIT to leave DATAMATE. To calculate the kinetic energy  $KE$  using  $\frac{1}{2}mv^2$ , storing the data in L2:

- The velocity data are stored in list L7. Where  $m$  is the mass of your ball in kg, press  $0.5 \boxed{\times} m \boxed{\times} L7^2 \boxed{\text{STO}} L2$ . (On the TI-83 and 83 Plus, to enter L7 you must press  $\boxed{2\text{nd}}$  [LIST], and then choose L7 from the list. It will be entered as L7. To enter L2 or any of the first six lists, press  $\boxed{2\text{nd}}$  and then the corresponding digit. On the TI-73, access lists by pressing  $\boxed{2\text{nd}}$  [STAT]. You will then see a list of available lists. You will need to scroll down using the cursor keys to see all the lists. On other calculators directly enter the list name using the alphanumeric keys.)

7. In a similar way you can calculate the ball's gravitational potential energy ( $PE$ ) using  $mgh$ , where the height  $h$  comes from your distance data, storing the result at each time in L3:

- The distance data are stored in list L6. Where  $m$  is the mass of your ball in kg, press  $9.8 \boxed{\times} m \boxed{\times} L6 \boxed{\text{STO}} L3$ .

8. Finally, calculate the ball's total energy  $KE + PE$  and store the result in L4:

- Press  $L2 \boxed{+} L3 \boxed{\text{STO}} L4$ .

9. Plot the  $KE$ ,  $PE$ , and total energy on your calculator:

**TI-73, TI-83, and TI-83 Plus, TI-84 Plus**

- a. Press  $\boxed{2\text{nd}}$  [STAT PLOT] and select Plot 1. (On the TI-73 press  $\boxed{2\text{nd}}$  [PLOT].)
- b. Use the arrow keys to position the cursor on each of the following Plot1 settings. Press  $\boxed{\text{ENTER}}$  to select any of the settings you change: Plot1 = On, Type =  $\boxed{\text{I}}$ , Xlist = L1, Ylist = L2, and Mark =  $\boxed{\square}$ . This is the kinetic energy.
- c. Press  $\boxed{2\text{nd}}$  [STAT PLOT] and select Plot 2.
- d. Use the arrow keys to position the cursor on each of the following Plot2 settings. Press  $\boxed{\text{ENTER}}$  to select any of the settings you change: Plot2 = On, Type =  $\boxed{\text{I}}$ , Xlist = L1, Ylist = L3, and Mark =  $\boxed{+}$ . This is the potential energy.
- e. Press  $\boxed{2\text{nd}}$  [STAT PLOT] and select Plot 3.
- f. Use the arrow keys to position the cursor on each of the following Plot3 settings. Press  $\boxed{\text{ENTER}}$  to select any of the settings you change: Plot3 = On, Type =  $\boxed{\text{L}}$ , Xlist = L1, Ylist = L4, and Mark =  $\boxed{\bullet}$ . This is the total energy.
- g. Press  $\boxed{\text{ZOOM}}$  and then select ZoomStat (use cursor keys to scroll to ZoomStat) to draw a graph with the x and y ranges set to fill the screen with data.

**TI-86**

- a. To plot the kinetic energy, press  $\boxed{2\text{nd}}$  [STAT] PLOT, PLOT1.
- b. Use the arrow keys to position the cursor on On and press  $\boxed{\text{ENTER}}$ .
- c. Press  $\boxed{\nabla}$  to position the cursor on the graph type. Press SCAT.
- d. Press  $\boxed{\nabla}$  to position the cursor on the Xlist Name. Press L1.
- e. Press  $\boxed{\nabla}$  to position the cursor on the Ylist Name. Press L2.
- f. Press  $\boxed{\nabla}$  to position the cursor on the Mark. Press  $\boxed{\square}$ .

- g. To plot the potential energy, press  $\text{2nd}$  PLOT2.
- h. Use the arrow keys to position the cursor on On and press  $\text{ENTER}$ .
- i. Press  $\blacktriangledown$  to position the cursor on the graph type. Press SCAT.
- j. Press  $\blacktriangledown$  to position the cursor on the Xlist Name. Press L1.
- k. Press  $\blacktriangledown$  to position the cursor on the Ylist Name. Press L3.
- l. Press  $\blacktriangledown$  to position the cursor on the Mark. Press + (use the + in the menu, not the  $\text{+}$  key).
- m. To plot the total energy, press  $\text{2nd}$  PLOT3.
- n. Use the arrow keys to position the cursor on On and press  $\text{ENTER}$ .
- o. Press  $\blacktriangledown$  to position the cursor on the graph type. Press xyLINE.
- p. Press  $\blacktriangledown$  to position the cursor on the Xlist Name. Press L1.
- q. Press  $\blacktriangledown$  to position the cursor on the Ylist Name. Press L4.
- r. Press  $\blacktriangledown$  to position the cursor on the Mark. Press  $\square$ .
- s. Press  $\text{GRAPH}$  and select ZOOM; next select ZDATA (use  $\text{MORE}$  to reveal ZDATA) to draw a graph with the x and y ranges set to fill the screen with data.

**TI-89, TI-92, and TI-92 Plus**

- a. Press  $\text{APPS}$ , select Data/Matrix Editor, then Current. Press  $\text{F2}$  to select the Plot Setup menu.
  - b. Using the cursor keys, highlight Plot 1 and press  $\text{F1}$  to select it.
  - c. Choose Scatter for the Plot Type, and then Box for the Mark.
  - d. Use the cursor keys to move to the x line. Press  $\text{L}$   $\text{1}$  to enter the x-axis. Similarly enter  $\text{L}$   $\text{2}$  for the y-axis. Press  $\text{ENTER}$  twice. This is the kinetic energy.
  - e. Highlight Plot 2 and press  $\text{F1}$  to select it.
  - f. Choose Scatter for the Plot Type, then Plus for the Mark.
  - g. Press  $\text{L}$   $\text{1}$  to enter the x-axis and  $\text{L}$   $\text{3}$  to enter the y-axis. Press  $\text{ENTER}$  twice. This is the potential energy.
  - h. Highlight Plot 3 and press  $\text{F1}$  to select it.
  - i. Choose xyline for the Plot Type, then Dot for the Mark.
  - j. Press  $\text{L}$   $\text{1}$  to enter the x-axis and  $\text{L}$   $\text{4}$  to enter the y-axis. Press  $\text{ENTER}$  twice. This is the total energy.
  - k. Press  $\blacklozenge$  [WINDOW]. Press  $\text{F2}$  to access the Zoom menu.
  - l. Select ZoomData to fill the graph with your data.
10. Inspect your kinetic energy vs. time graph (marked with  $\square$ ) for the free-fall flight of the ball. Explain its shape.
  11. Inspect your potential energy vs. time graph (marked with +) for the free-fall flight of the ball. Explain its shape.
  12. Record the three energy graphs by printing or sketching.
  13. Compare your energy graphs predictions (from the Preliminary Questions) to the real data for the ball toss.
  14. What do you conclude from the total energy vs. time graph (marked with  $\bullet$  and plotted as a line plot) about the total energy of the ball as it moved up and down in free fall? Does the total energy remain constant? Should the total energy remain constant? Why? If it does not, what sources of extra energy are there or where could the missing energy have gone?

**EXTENSIONS**

1. What would change in this experiment if you used a very light ball, like a beach ball?
2. What would happen to your experimental results if you entered the wrong mass for the ball in this experiment?
3. Try a similar experiment using a bouncing ball. You should mount the Motion Detector high and pointed downward so it can follow the ball through several bounces.