Energy of a Tossed Ball

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 remains constant. In this experiment, we will see if this is true for the toss of a ball. We will study these energy changes using a Motion Detector.

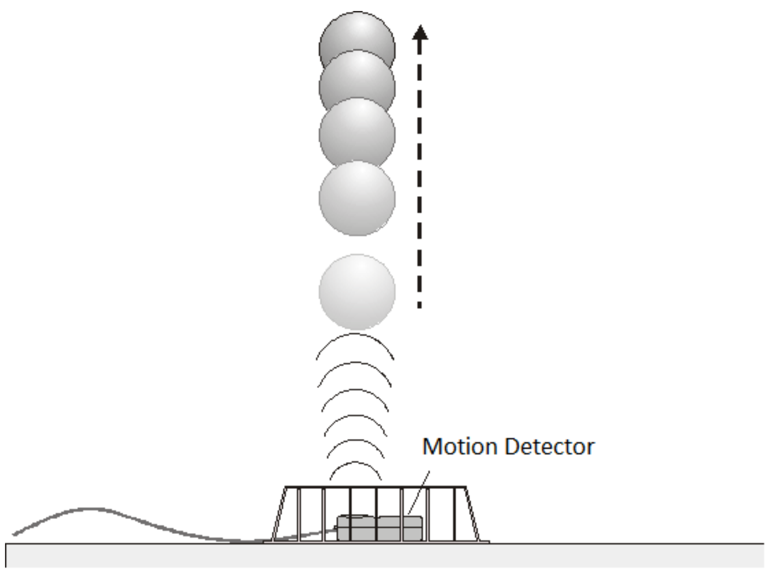


Figure 1

OBJECTIVES

- Measure the change in the kinetic and potential energies as a ball moves in free fall.
- See how the total energy of the ball changes during free fall.

MATERIALS

LabQuest
LabQuest App
Vernier Motion Detector
volleyball, basketball, **or** other similar fairly heavy ball
wire basket

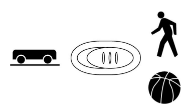
PRELIMINARY QUESTIONS

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. Set the Motion Detector sensitivity switch to Ball/Walk. Connect the Motion Detector to a digital (DIG) port on LabQuest and choose New from the File menu.



3. Place the Motion Detector on the floor and protect it by placing a wire basket over it.
4. 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.
   a. Hold the ball directly above and about 0.25 m from the Motion Detector. Use two hands.
   b. Start data collection.
   c. Wait one second, then toss the ball straight upward. 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 the best results if you catch and hold the ball when it is about 0.5 m above the Motion Detector.
5. After data collection is complete, graphs of position *vs.* time and velocity *vs.* time are displayed. Repeat Step 4 if your position *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 data collection. To repeat data collection, start data collection when you are ready to toss the ball.

DATA TABLE

Mass of the ball (kg)	

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

1. To analyze only the free-fall portion of the data you must zoom in on the graph.
   a. It is easiest to select the proper region using the velocity graph.
   b. To select the free-fall portion of the data, tap and drag across the straight-line, negative-slope region that corresponds to free fall.
   c. Choose Zoom In from the Graph menu to display just that portion of your graph.
   d. To explore the energy of the ball (kinetic and potential) at various moments during the motion, you can examine the graph by tapping any data point. As you tap each data point, time and velocity values are displayed to the right of the graph. Record the following times and velocities in your data table: Tap the point at 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 time and velocity data pairs.
   e. Using the position graph, determine the position of the ball at the same five times you used in the previous step. Record the position values in the data table.
   f. 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.

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

   You can also graph the ball's energy at all the measured times, instead of just the five in the data table. Using the position data in the equation *mgh*, you can store gravitational potential energy at each moment in a new column. Using the velocity data in the equation

$$KE = \frac{1}{2}mv^2,$$

   you can store the ball's kinetic energy in another new column. Finally, you can find the total mechanical energy at each moment by finding the sum of the potential and kinetic energies and storing the data in a third new column. You will do this in the upcoming steps.

3. Display a single graph by choosing Show Graph from the Graph menu and selecting Graph 1.

4. Calculate the ball's kinetic energy, storing the result in a new column.
   a. Tap Table to display the data table.
   b. Choose New Calculated Column from the Table menu.
   c. Enter the Name (KE) and Units (J).
   d. Select the equation, ABX^C, because this has the same form as
   $$KE = \frac{1}{2}mv^2.$$
   e. Select Velocity as the Column for X.
   f. For the A value, enter **0.5**.
   g. For the B value, enter the mass of your ball in kilograms.
   h. For the C value, enter **2**.
   i. Select OK to display the graph of kinetic energy (*KE*) *vs.* time.

   Inspect your kinetic energy *vs.* time graph for the free-fall flight of the ball. Explain its shape and then print or sketch the graph.

5. Calculate the ball's gravitational potential energy (*PE*) using *mgh*, where the height, *h*, comes from your distance data, storing the result in a new column.
   a. Tap Table to display the data table and choose New Calculated Column from the Table menu.
   b. Enter the Name (PE) and Units (J).
   c. Select the equation, ABX, because this has the same form as *mgh*.
   d. Select Position as the Column for X.
   e. For the A value, enter the mass of the ball in kilograms.

f. For the B value, enter **9.8**.

g. Select OK to display the graph of potential energy (*PE*) *vs*. time.

Inspect your potential energy *vs.* time graph for the free-fall flight of the ball. Explain its shape and then print or sketch the graph.

6. Compare your energy graph predictions (from the Preliminary Questions) to the real data for the ball toss.
7. Calculate the ball's total energy, *TE* = *KE* + *PE*, and store the result in a third new column.
   a. Tap Table to display the data table and choose New Calculated Column from the Table menu.
   b. Enter the Name (TE) and Units (J).
   c. Select the equation, X + Y.
   d. Select KE (J) as the Column for X.
   e. Select PE (J) as the Column for Y.
   f. Select OK to display the graph of total energy (*TE*) *vs.* time.
8. Display all three energy plots on the same graph.
   a. Choose Graph Options from the Graph menu.
   b. Select PE, KE, and TE for the Graph 1 Y-Axis.
   c. Select OK to display a graph of *PE*, *KE*, and *TE*.
9. Tap and drag across the free-fall portion of the data. Choose Zoom In from the Graph menu to display just that portion of your graph.
10. What do you conclude from the total energy *vs.* time graph 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. Mount the Motion Detector high and pointed downward so it can follow the ball through several bounces.