Experiment
9

Energy Storage and Transfer: Gravitational Energy

PART 3 – GRAVITATIONAL ENERGY

In the first of this series of labs exploring the role of energy in change, you found that the energy stored in an elastic system was proportional to the square of the change in the length of the spring or rubber band deformed by the applied force. We called the energy stored in this way *elastic energy*.

In the previous experiment you found that this energy could be transferred to a cart to produce a change in its speed. We said that the moving cart stored energy in an account called *kinetic energy*. Suppose that, instead of moving horizontally, the cart were to move up an incline. Gradually, the cart would come to a stop before it began to roll back down the incline. Let's examine for a moment the energy of the system when the object reaches its maximum height and its velocity is zero. While kinetic energy has diminished to zero, the energy of the system isn't "lost." It must be stored in some other account, which we call *gravitational energy*. This is the energy stored in the Earth-cart system as a function of its new height. Consider for a moment what system variables might affect the gravitational energy of the Earth-cart system.

While it is not a simple matter to measure this quantity directly, determining the *change* in the gravitational energy is straightforward. We can simplify this discussion if we arbitrarily assign a value of *zero* to both the gravitational energy of the system and the height of the object when it is as close to the Earth as it will get during the course of our investigation. Your goal is to determine a quantitative relationship between the gravitational energy and the height of an object above the zero-reference position.

OBJECTIVES

In this experiment, you will

- Recognize that the energy stored in an elastic system (spring, rubber band) can be transferred to another object, resulting in a change in the state of that object.
- Determine an expression for the gravitational energy as a function of the height of an object above the Earth.

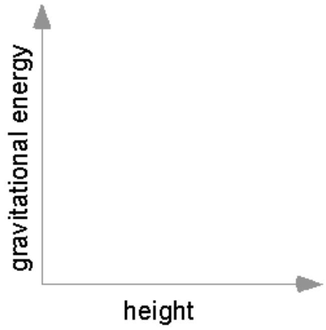
MATERIALS

Vernier data-collection interface
Logger *Pro* or LabQuest App
Vernier Dynamics Track
standard cart
standard lab masses (100 g increments)
Vernier Bumper and Launcher Kit (recommended) **or** heavy rubber band
Vernier Photogate (Extension only)
Cart Picket Fence (Extension only)

PRE-LAB INVESTIGATION

Examine the apparatus for this experiment. Assume that after you released the cart, all the elastic energy was transferred completely, first to kinetic energy, and then to gravitational energy as the cart reached its maximum height.

On the axes to the right, predict what a graph of the gravitational energy *vs.* the height would look like. Compare your graph to those sketched by other students in your class.



PROCEDURE

1. Attach the same spring you used in the last experiment to the Dynamics Track Bracket, then mount the bracket on the end of a Dynamics Track.

2. Obtain the value of the spring constant, *k*, for the spring you used in the previous experiment.[1]

3. Let *D* represent the distance between the leveling feet and *H* the height you have elevated one end of the track. By measuring the distance, *d*, the cart moves up the track, you can use similar triangles to determine the cart's height, *h*, above its zero position.

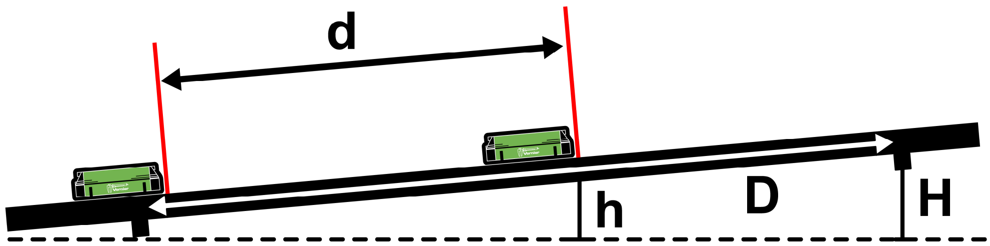


Figure 1

4. Before you elevate the track, recall the need to minimize the effect of friction on the transfer of energy from elastic to gravitational accounts. Use the leveling screws on one of the feet to raise that end of the track slightly. After you have made the necessary adjustment, place a block of height, *H*, under the other foot. Be sure to record these parameters.

[1] If you used a rubber band to store energy in the previous lab, you will need to quickly collect *F* vs. *x* data again to make sure that the band's effective "spring constant" has not changed since the last use.

5. Position the cart so that it just touches the hoop spring without deforming it. It is helpful to adjust the position of the bracket so that one end of the cart falls on a "convenient" value on the scale. Note this value as the zero reference position, x_0, for the spring.

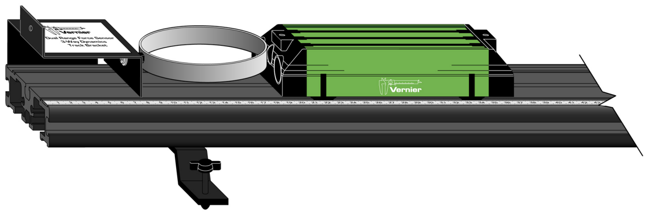


Figure 2

6. For this experiment, you will measure the distance, *d*, the cart travels before stopping as you vary the compression of the spring. This value, along with *H* and *D* (see Figure 1) will help you determine the height the cart reaches. Later, you will create a file (or use one your instructor provides) to analyze the data you have collected.

7. Consult with your instructor about appropriate values of change in length, *x*, for your apparatus. Begin data collection. Perform several trials for each change in length, *x*, and average the three most consistent values of distance. As before, it is important that you sight the scale from a position directly above the cart so as to avoid parallax error. Keep in mind that the initial position of the cart changes as you increase the extent to which you compress the spring

EVALUATION OF DATA

1. To evaluate the relationship between gravitational energy, E_g *vs.* height, set up a Logger *Pro* or LabQuest App file with the columns of **x** and **d,** where **x** is the change in length of the spring, and **d** is the average distance the cart moved up the inclined track. You will enter these data manually. You also need two calculated columns, **h** (the change in height of the cart) and $\mathbf{E_{el}}$ (elastic energy). Your instructor may guide you in the design of this file.

2. Discuss how the system energy is stored once the spring returns to its original shape. Make a new manual column for $\mathbf{E_g}$ (gravitational energy) and then fill in the $\mathbf{E_g}$ column with the appropriate values.

3. Create a graph of gravitational energy *vs.* change in height. If the relationship between gravitational energy, E_g, and the change in height, *h*, appears to be linear, fit a straight line to your data. If possible, print a copy of your data table and graph.

4. Write a statement that describes the relationship between the gravitational energy and the height of the cart. Keep in mind any assumptions made in the design of the file for this experiment.

5. Examine the slope of the graph (units as well as numerical value). Recall that the SI unit of energy, joule, is defined as a N m. Simplify the units of the slope, then compare the value that you obtained with that obtained by other groups.

6. Now write the general equation describing the relationship between the gravitational energy and the height of an object (above the zero-reference position).

EXTENSIONS

1. Suppose that you used a spring with a *k* value half as great as the one you used in your experiment to launch the dynamics cart. How would this change have affected the values of distance, *d*, you would have obtained? Describe the effect of this change on the graph of E_g *vs*. *h*. Explain.

2. Suppose that you had used a more massive dynamics cart (mass = 750g) in your experiment. How would this change have affected the values of distance, *d*, you would have obtained? Describe the effect of this change on the graph of E_g *vs*. *h*. Explain.

3. Suppose that the block that you used to elevate your track were 50% higher than the one that you used in your experiment. How would this change have affected the values of distance, *d*, you would have obtained? Describe the effect of this change on the graph of E_g *vs*. *h*. Explain.

4. Suppose that you had been able to perform your experiment on Mars where the acceleration due to gravity is about one third that on Earth. How would this change have affected the values of distance, *d*, you would have obtained? Describe the effect of this change on the graph of E_g *vs*. *h*. Explain.

EXTENSION ACTIVITY

Suppose you released a cart on the Dynamics Track at some height, *h*, above a zero-reference position. Assuming that you made an adjustment to minimize frictional losses, the principle of Conservation of Energy should lead you to predict that the kinetic energy (E_k) at the zero reference position would equal the gravitational energy (E_g) at the point of release. The following activity will enable you to test this prediction.

1. As you did in the experiment, raise the left end of the track slightly by adjusting the leveling screws on the left foot so as to minimize frictional losses. After you have made the necessary adjustment, place a block of height, *H*, under the right foot. Use the same value of *D*, (distance between feet) as you did in the experiment. Be sure to record these parameters.

2. Place the cart picket fence on the cart, then position a photogate near the lower end of the track so that the leading edge of the flag interrupts the beam when the front end of the cart falls on some "convenient" value on the scale, as shown in Figure 3.

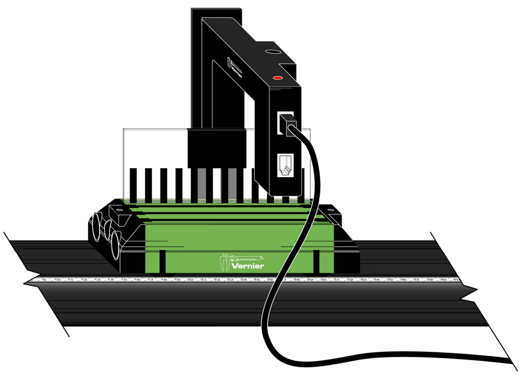


Figure 3

3. Start the data-collection program. Set up the photogate for Gate Timing. The length of the flag passing through the photogate is 0.05 m. The GateState should read **Blocked** when the flag interrupts the sensor and **Unblocked** when it has moved beyond the sensor.

4. You will first collect velocity data for 5–6 distances, *d*, and record these manually in your lab notebook. Later, you will create a file (or use one your instructor provides) to analyze the data you have collected. From the distance, *d*, the cart travels before the flag blocks the beam, you can determine the value of *h*. Using this, you can determine the value of the gravitational energy, E_g, in the system before you released the cart. With the cart mass and velocity, you can determine the kinetic energy, E_k, of the cart at the zero-reference position.

5. Produce a graph of kinetic energy *vs.* gravitational energy for your data. If the relationship appears linear, fit a straight line to the data. What can you conclude from the value of the slope?