

Chapter 7

Energy

Name: _____ Lab Partner: _____ Section: _____

7.1 Purpose

In this experiment, energy and work will be explored. The relationship between total energy, kinetic energy and potential energy will be observed.

7.2 Introduction

Energy is loosely defined as a scalar quantity that is associated with the ability to do work (see the definition of work below). Energy comes in many forms but one form that is very apparent is the energy associated with an object's motion. Energy associated with an object because of its motion is called **kinetic energy**. For an object of mass m , the kinetic energy, KE, is:

$$KE = \frac{1}{2}mv^2 \quad (7.1)$$

where v is the velocity of the object. The SI unit is $kg \frac{m^2}{s^2}$, which is called a joule (J).

Besides kinetic energy, there is also potential energy. When we speak of energy associated with a mass in a gravitational field or of the energy of a compressed spring, we are referring to **potential energy**. Potential energy is energy of an object because of its position or configuration. It is simply another form of (mechanical) energy. For a mass, m , in a constant gravitational field the gravitational potential energy of an object is given by:

$$PE = mgh \quad (7.2)$$

where g is 9.8 m/s^2 and h is the height of the object relative to some reference position. As in the case for kinetic energy, the unit of potential energy is the joule. We have assumed

an origin (zero point) for the height and thus an origin for the potential energy. Often we are only interested in the change in potential energy so that the above equation becomes $\Delta PE = mg\Delta h$, where ΔPE is the change in potential energy and Δh is the change in height.

When a spring is stretched or compressed, the force required to stretch or compress the spring is given by Hooke's Law:

$$F = -kx \quad (7.3)$$

where F is the force, x is the distance the spring is stretched or compressed from its undisturbed position and k is the spring constant measured in N/m. The negative sign in equation 7.3 is to remind us that the force is opposite to the direction we stretch or compress the spring. The potential energy stored in a spring is given by:

$$PE = \frac{1}{2}kx^2 \quad (7.4)$$

The displacement, x , in equation 7.4 is the displacement of the spring from its undisturbed position to the final position ($x_f - x_o$).

The total (mechanical) energy, E , of a system is the sum of the kinetic and potential energies:

$$E = KE + PE \quad (7.5)$$

If there are no dissipative forces like friction, the total energy is constant (the law of energy conservation). Since E is a constant we can relate the change in kinetic and potential energy as:

$$\Delta KE = -\Delta PE$$

Work is a measure of energy transfer. In the absence of friction, when positive work is done on an object, there will be an increase in its kinetic or potential energy. In order to do work on an object, it is necessary to apply a force along or against the direction of the object's motion. If the force is constant and parallel to the object's path, work, W , is defined as:

$$W = F \cdot x$$

where F is the constant force and x is the displacement of the object.

If the force is not constant, the work can still be found with calculus or using a graphical method. If we divide the overall displacement into short segments, Δx , the force is nearly constant during each segment. The work done during that segment can be calculated using the previous expression. The total work for the overall displacement is the sum of the work done over each individual segment (see Figure 7.1):

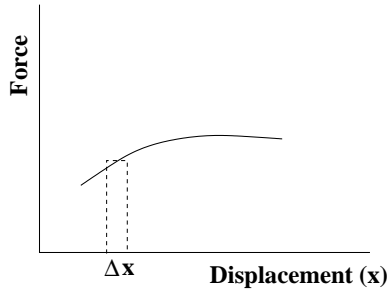


Figure 7.1: The area under the force vs. displacement plot is the work even if the force is not constant.

$$W = \Sigma F(x)\Delta x$$

This sum can be determined graphically as the area under the plot of force vs. distance. (For students with a knowledge of calculus, this can be expressed as an integral: $W = \int F(x)dx$).

Since work is a measure of energy transfer, we can relate the work done on an object to the **change** in the total energy of the object:

$$W = \Delta E$$

7.3 Procedure

7.3.1 Energy Stored in a Spring

In this section the energy stored in a spring will be studied. The force constant of a spring, k , will be measured. After compressing the spring a known distance, the energy will be used to send a cart up an inclined plane when the energy will be measured as gravitational potential energy.

Measuring the Spring Constant, k

In the first part of this section, the spring constant, k , of the spring will be measured. The experimental setup is shown in Figure 7.2.

- Start Capstone and open the file 'Energy_cart'. A graphs of force vs position and position vs time will be displayed. If the track is sitting on the wood block, remove the wood block. Level the track if necessary.
- Place the cart so the spring is just touching the black end stop. Place the motion detector at the opposite end of the track and pointed at the cart. The plastic rod of the cart launcher will extend through the hole in the end stop. Attach the pin to the hole in the plastic rod. Attach the string to the hook on the force sensor. Push the 'tare' button on the force sensor.

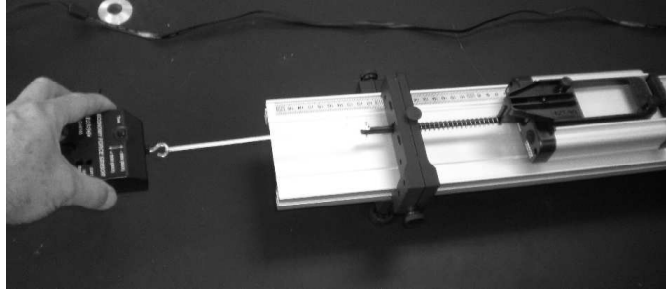


Figure 7.2: The setup for measuring the spring constant of the cart launcher. The force sensor is connected to the spring launcher. The force sensor measures the force. The distance is measured by the motion detector at the other end of the track.

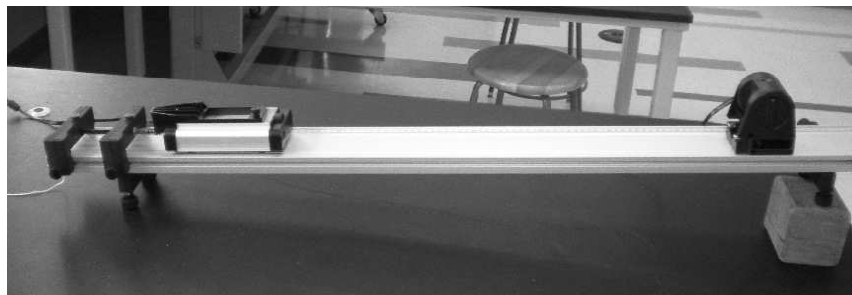


Figure 7.3: The setup for launching the cart up the inclined track. The cart with the launcher and compressed spring is on the left. The wood block and motion detector is on the right.

- Click 'record' on Capstone. Pull the force sensor horizontally so the spring is compressed most of the way. Click 'stop' in Capstone and gently release the force on the spring. Remove the force sensor and set it aside.
- Use a 'linear fit' to fit the data in the force vs position plot. The slope of the line is the force constant, k . Record the value below. (Note because of the orientation of the force sensor hook, the force will register as negative and the slope of the line will be negative. The spring constant, k , is a positive number)

Spring constant k _____

A Compressed Spring Pushing the Cart Up an Inclined Plane

The setup for this part of the experiment is shown in Figure 7.3. First the energy stored in the compressed spring will be calculated from the spring constant and how much the spring is compressed. This will then be compared to how much gravitational potential energy the cart has when it momentarily stops and turns around after being launched up the track.

- Clear the data from Capstone. Weigh the cart and cart launcher and record the value of the mass.

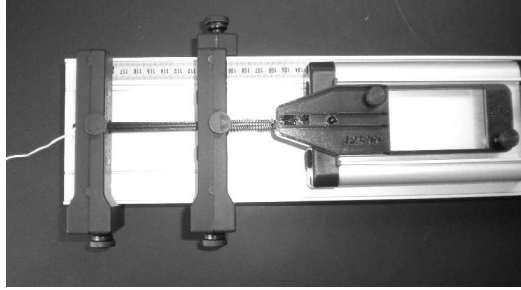


Figure 7.4: The cart launcher spring is compressed and being held by the pin on the second (left) end stop.

Mass of cart and cart launcher _____

- Measure the distance between the feet, d , of the track. Measure the thickness of the wood block, t . Record both values below.

Distance between feet of the track (d) _____

Thickness of wood block (t) _____

- The elevation angle of the track, θ , is $\sin^{-1}(t/d)$. Calculate θ and record it below.

Elevation angle (θ) _____

- Attach the second end stop to the track about 6 to 8 cm from the first end stop. Replace the cart on the track and push the cart so the rod on the cart launcher goes through the hole in the first end stop with the spring just touching the first end stop. Using the scale on the side of the track, measure the position of the back edge of the cart. Push the cart so the rod goes through the second end stop and push the pin into the hole of the cart launcher rod so the spring is compressed. Measure the position of the back edge of the cart. Refer to Figure 7.4. Record the initial position of the back edge of the cart, the final back edge position the cart and the difference, Δx . The difference in position, Δx , is the distance the spring has been compressed.


Initial position of back edge of cart _____

Final position of back edge of cart _____

Spring compression distance Δx _____

- Calculate the potential energy stored in the spring from Equation 7.4 and record it below.

Potential energy stored in the Spring _____

- Place the motion sensor at the far end of the track so the motion sensor points down the track towards the cart. Place the wood block under the feet at the end of the track with the motion sensor.
- Click 'record' in Capstone. After about 1 second, use the string to pull the pin from the cart launcher rod. The cart will travel up the track and then return. Click 'stop' after the cart reaches its highest point.
- Use the 'smart tool' ('Add a coordinate tool' ) on the position vs time graph to determine the initial position of the cart (the flat part of the graph before the spring was released) and the final position of the cart (the bottom of the curve after the cart was released before it falls back.). The difference between the two positions is how far the cart traveled up the track, x_{\parallel} . Record the values below:

Initial position of the cart _____

Final position of the cart _____

Distance cart traveled up the track, x_{\parallel} _____

- The change in height of the cart and cart launcher, Δh , is given by $\Delta h = x_{\parallel} \sin\theta$. Calculate Δh and record it below.

Change in height Δh _____

- Calculate the change in gravitational potential energy of the cart from Equation 7.2. Record it below:

Change in Gravitational PE _____

- If energy is conserved, the potential energy stored in the spring before the cart was launched and the change in gravitational potential energy should be the same. Are the two values the same? Calculate the percentage difference between the two values

% difference _____


7.3.2 Energy of a Tossed Ball

When a ball is tossed straight upward, the ball slows down until it reaches the top of its path, stops and then speeds up on its way back down. In terms of energy, when the ball is released it has kinetic energy. As the ball rises it slows down, thus losing kinetic energy. The kinetic energy is converted to gravitational potential energy. As the ball starts down, still in free fall, the stored gravitational potential energy is converted back into kinetic energy. If there is no energy lost to air friction, the total energy will remain constant.



Figure 7.5: Ball and motion detector used in this lab.

This part of the experiment will observe the interplay of kinetic, potential and total energy of a tossed ball. A motion detector will be used to study these energy changes much as was done in the previous kinematics experiment.

- Open the file 'energy_ball_toss'. A graph of the position vs time will appear along with two energy graphs. One energy graph window contains a plot of kinetic energy (KE) and gravitational potential energy (PE). The other energy graph is a plot of the total energy (KE+PE).
- Measure and record the mass of the ball. 'Click' on the Calculator icon (). Change the experimental constant 'm' (mass) on the first line to the measured value for the ball's mass. Click on the Calculator icon again to close the calculator window.

Mass of ball _____

- One lab partner should click 'record' while the other partner tosses the the ball straight up about one meter above the motion detector. Use two hands to toss the ball. Move your hands out of the area after you toss the ball. You may have to practice this a few time to get good data.
- Using the position vs time plot, locate the parabola which is the data region where the motion of the ball was captured by the motion detector. Zoom in on the region of the parabola.
- Locate the time region of the kinetic and potential energy plot that corresponds to the motion of the ball through the air. Also locate this time region on the total energy plot.
- At what time on the horizontal scale is the kinetic energy of the ball a minimum? Where is the potential energy a maximum?

Time KE is minimum _____

Time PE is maximum _____

- Label these points on the graph using the note ('A') icon (button) on the plot tool bar.
- Does your data show that the total energy of the ball is approximately constant while in the air? If the value of the total energy is approximately constant while the ball is in free fall, record the value below.

Total energy while in free fall _____

- Save the data and plots as a '.cap' file and send the appropriately labeled file to your TA.

7.3.3 Questions

1. For the ball toss, what type of curve is the position vs. time graph? What type of curve is the kinetic energy vs. time graph? What type of curve is the potential energy vs. time graph? What type of curve is the total energy vs. time graph?
2. Show that equation 7.4 follows from equation 7.3 by finding the area under a plot of force vs distance.
3. If a force is applied to an object and the object does not move, is any work done?

7.4 Conclusion

Write a detailed conclusion about what you have learned. Include all relevant numbers you have measured with errors. Sources of error should also be included.