Lab 6: Work and Energy (M6)

Objectives

- Understand the concepts of work and energy.
- Learn about the transfer of energy.
- Use graphing techniques to find the spring constant *k*.

Types of Energy

Kinetic energy is the energy of moving objects. It represents the capacity to do work by virtue of speed. The kinetic energy of an object with mass *m* and velocity *v* is: $\text{KE} = \frac{1}{2}mv^2$. Kinetic energy is always positive, but it is value is relative, depending on coordinate system in which we measure the velocity.

Potential energy is the energy due to position. It represents the capacity to do work by virtue of position. In this lab, we will examine two ways to store energy. In a spring, (elastic) potential energy is stored when the spring is stretched from the equilibrium length: $\Delta PE = \frac{1}{2}k(\Delta x)^2$, where Δx represents the change in length of the spring from equilibrium and k is the constant of proportionality. On an incline, the elevation of the cart above the table gives the cart gravitational potential energy: $PE = W = Fd = mgh$, where $F = mg$ and $d = h$. The ***change*** in potential energy ($\Delta PE = mg\Delta h$, $\Delta h = h_1 - h_2$) is the quantity that is useful because the zero of potential energy (where $h = 0$) is arbitrarily defined. The absolute value of the gravitational potential energy is relative – it depends where we define the zero potential energy level, but the change of potential energy does not depend on the choice of the coordinate system.

Work is the product of the force exerted (resulting in a displacement in the direction of the force) times the distance that the object is displaced ($W = Fd$ when the force is constant and is acting in a direction parallel to the displacement).

Work needed to change the length of a spring is equal to the change of its elastic potential energy (cf., the elastic potential energy equation $\Delta PE = \frac{1}{2}k(\Delta x)^2$). The formula: $W = Fd$ does not apply in this case, because the force is not constant!

Total (mechanical) energy of the system is the capacity to do work by virtue of speed and position ($\text{E} = \text{KE} + \text{PE}$). If only conservative forces are acting upon the system, then the mechanical energy is always conserved and will remain constant.

We measure PE, KE, work and total energy in Joules.

1 Joule = 1 Newton ∗ 1 meter. 1 J = 1 Nm

Average **Power** P_{AVE} is defined as the ratio of the work done to the time necessary to complete the work. $P_{AVE} = W/t$

The unit of power is Watt: 1 Watt = 1 W = 1 Joule/ 1 s 1 kW = 1000 W

The power of an automobile is traditionally given in old unit called horsepower (hp).

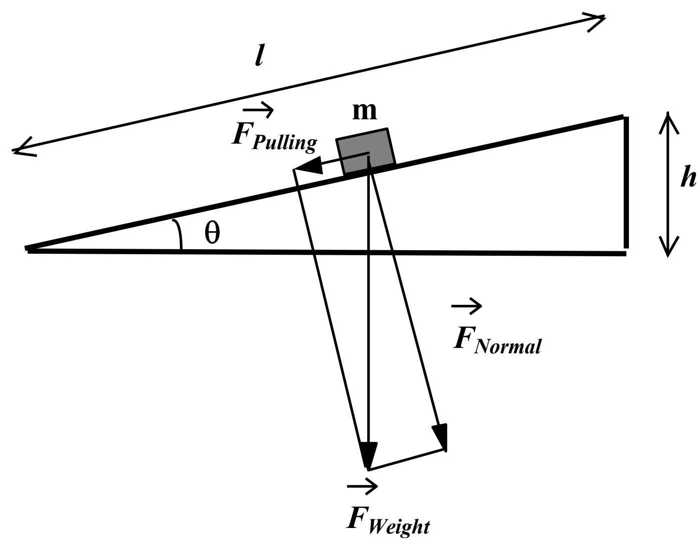
1 hp = 745.7 W = 0.7457 kW

Object with mass *m* on a frictionless incline

$$F_{Weight} = mg$$

$$F_{Normal} = W\cos\theta = mg\cos\theta$$

$$F_{Pulling} = W\sin\theta = mg\sin\theta = mgh/l$$



Procedure:

In Activities 1, 2 and 3 we will analyze what happens to the cart located in two locations: at the top of the incline and at the bottom of the incline. In Activity 1, we calculate the change of gravitational potential energy between these two locations. In Activity 2 we estimate the work needed to move the cart from the bottom location to the top of the incline. In Activity 3 we measure the kinetic energy of the cart at the bottom of the incline when it is released from the top of the incline. Potential energy change, work and kinetic energy are all forms of energy and are linked together by the conservation of energy principle. Activities 4 and 5 are about the potential energy stored in a stretched spring and its conversion into kinetic energy.

Activity 1: Potential Energy

Download files for experiment M6 from Brightspace lab folder.

Insert the aluminum block under the two support legs at the end of the track. Choose that end of the track, which sits away from the wall. See Figure 2 below.

Place the collision cart onto the track so that its sail is facing towards the motion sensor at the bottom of the incline, opposite the aluminum block. Now, move the cart so that it just touches the bumper at the top of the incline. Using the plastic ruler provided, measure the vertical height of the track from the tabletop to the top of the track at this position (h_1). Always measure with respect to the front end of the collision cart (i.e., the end with the sail).

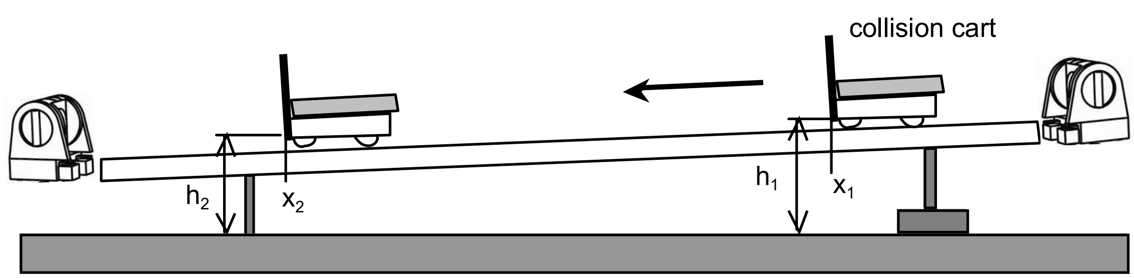


Figure 2. Illustration of position and height measurements on track.
(the lower end of the track should be closer to the wall)

Move the cart down the incline so that its front end just touches the lower bumper at the bottom of the incline. Using the ruler measure the vertical height of the track from the tabletop to the top of the track at this position (h_2).

Calculate the change in the potential energy of the cart as it travels from the bottom of the incline to the top of the incline and write it on the data sheets.

Activity 2: Work

Work is proportional to the change in distance along the incline multiplied by a force. Return the cart to the bumper at the top of the incline (as shown in Figure 2.) Using the ruler marked on the track, measure the position of the front end of the cart (x_1) and record this position on your data sheet. Now, move the cart so that its front end just touches the lower bumper at the bottom of the incline. Using the ruler marked on the track, measure the position of the same front end of the cart (x_2) and record this position on your data sheet. Calculate the absolute value of the change in position $|(\Delta x)|$, as the cart travels from the top to the bottom of the incline.

Download and then double-click on the "M6 Activity 2" icon. In this activity, you will use the force sensor to measure the force required to move the cart up the incline. On the side of the force sensor attached to the collision cart is a small button marked "TARE". This button will allow you to zero the sensor. Make sure that nothing is touching the hook and press the TARE button. You need to do this each time before collecting data. It will make your results more accurate.

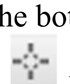
Attach the large loop of string to the hook on the force sensor. Place the collision cart on the track so that its sail is closest to the bottom motion sensor. Put the string over the pulley and pull it away from the bottom bumper. Hold the cart steadily and start data recording to measure the mean value of the force. Repeat the same procedure for five locations along the incline. Be sure to hold the string parallel to the incline, so that the force with which you pull is balancing the component of gravity along the incline alone. Write the results on the data sheets. Since the component of the gravity force that is parallel to the track ($F_P = mg \sin\theta$) depends only on m and θ, it should have a constant value along the incline.

Calculate the average of the five experimental force values (one for each location) and the standard deviation of the force. Because the force is applied in the same direction as the motion of the cart, calculate the work done by multiplying the average force by the change in the distance (Δx).

Calculate what should be the theoretical value of the force pulling the cart (neglecting friction). First, find the weight of the collision cart with the attached force sensor. The weight vector can be represented as a sum of two components: parallel and perpendicular to the incline. Calculate the component that is parallel to the incline. That component is equal to the pulling force. Does your average force agree with the theoretical value of the force within experimental error? **The work you have put into the system is now stored as potential energy.**

Activity 3: Kinetic Energy

Select "**Open Activity**" from the "**File**" menu. **Do not save any changes**! Next, select: "M6 Activity 3" and open it. Position and velocity graphs should appear on the screen.

You should start with the cart at the top of the incline. Make sure that the sail of the cart faces the sensor at the bottom of the incline. Release the cart. Record the velocity of the cart as it travels down the incline. Allow the cart to fall down the incline without pushing it. The cart will collide with the bottom bumper a couple of times before eventually coming to a stop. Use the "Smart Tool"  icon to read velocity values from the graph. On your data sheet, write down the velocity of the cart just before it collides with the bottom bumper (maximum velocity). Using this maximum absolute value of velocity, calculate the kinetic energy of the system. Remember that your velocity will be *negative* because the cart is moving towards the motion sensor.

The potential energy of the system was converted into kinetic energy. The change in potential energy (calculated in *Activity 1*) leads to the change of kinetic energy. However, because friction is a non-conservative force, part of the potential energy will not be converted into kinetic energy. Instead, it will dissipate as a small amount of heat.

Calculate the amount of energy lost (dissipated) on your data sheet. What percentage does this loss represent? Since all the energy lost is due to work done by the friction force, we may use the following equation:

$$|\Delta PE| - KE = F_{FRICTION}\,\Delta x$$

to estimate the average friction force $F_{FRICTION}$.

Activity 4: The Spring Constant k

Select "**Open Activity**" from the "**File**" menu. **Do not save any changes**! Next, select: "M6 Activity 4" and open it. Force vs. time axes should appear on your screen.

Remove the block from beneath of the track, i.e., level the track.

Attach the two springs (one on each side) to the cart and to the bumpers. Coil one end of each spring through the hole on the cart (or the small metal hook on the cart - **not** the one on the force sensor) and loop the other end onto the screw on top of the bumper. Make sure that the sail on the cart is closer to the same motion sensor as for the previous activities. After a brief moment, the cart system should come to a steady equilibrium.

Make sure the nothing is touching the hook on the force sensor and zero it again by pushing the "TARE" button.

Using the ruler on the track (which measures in centimeters), record the position of the front end of the cart. This position will be known as the origin or the equilibrium position, and all displacement measurements will be relative to the equilibrium position. Always use the same end of the cart when recording position.

Attach the small loop of string to the hook on the force sensor. Pull on the string so that the cart maintains the new position (make sure that the probe and the string connected to the probe are **parallel to the track**). Do not touch the cart with your hand.

Pulling the force probe, gently displace the cart a small distance away from its equilibrium position (5, 10, 15, 20, and 25 centimeters) and hold it there. Do **not** displace the cart so far that it causes the springs to sag and go limp. The **potential energy** is now stored in the springs.

Use the computer to record the force values. On your data sheet, write down the value of the force (applied **parallel** to the track) needed to maintain the displacement. Repeat this process for four other displacements. Do not allow the force probe or the loop of string to interact with the springs.

Because $F(x) = -kx$ (and so $k = {-F(x)}/{x}$) for a spring system, determine the spring constant k for the two-spring system by plotting the negative force (-F) vs. the absolute value of the displacement (|x|) using your five sets of measured values. You may use any graphing program like MS Excel, and then add a linear trend line to your data. The slope of this best-fit line on your graph should be positive and will give the value for the spring constant *k*. Record the value of the spring constant on the data sheets. Pay attention to the units on your graph when recording the value for *k* on your analysis sheet.

Activity 5: Elastic Potential Energy vs. Kinetic Energy

In this activity, you are going to observe how the elastic potential energy (the potential energy of a compressed or elongated spring) converts into kinetic energy of a moving object.

Select "**Open Activity**" from the "**File**" menu. **Do not save any changes**. Next, select: "M6 Activity 5" and open it. Position and velocity axes should appear on your screen.

In this system, displacement from the equilibrium position gives the cart potential energy. When released, this potential energy is transformed into kinetic energy.

Gently displace (displacement = 20 cm) the cart from the equilibrium position. Write down the **initial displacement** on your data sheets. Make sure that the springs are not limp or sagging. Using the computer, record data for the cart as you release it. Measure and write down the maximum absolute value of the cart's velocity (i.e., the maximum speed). **Print** that graph.

Using the spring constant *k* from Activity 4, calculate the **potential energy** of the system just before the release. Then, using the **first maximum speed** value, calculate the **kinetic energy** of the system. *Note*: The velocity could be negative in that case, but since $KE = ½mV^2$ we are interested in the absolute value of the velocity. What percentage of the available potential energy was not converted into kinetic energy due to friction? *Note*: Up to 30% is acceptable.

To determine the values of the kinetic and potential energy, you will need to use the mass of the cart with the force sensor from *Activity 1* and the value of the spring constant k found during the analysis of *Activity 4*. If the system experiences an energy gain (the KE is greater than the PE), your value for the spring constant (k) may not be correct (usually - too low).

When you finish - quit the program by selecting **Quit** from the **File** menu. **Do not save changes**.

Complete the lab report and return it to the lab TA.

Make sure to complete the following tasks:

You must submit the answers to the prelaboratory questions online. (3.5 points)

1. Your completed Data Sheets. (5 points)
2. Your plot of (-F) vs. |Δx| from the *Activity 4*. (1 point)
   (Title and write your name and those of your partners on each graph.)
3. Your plot of position and velocity vs. time from *Activity 5*. (0.5 points)
   (Title and write your name and those of your partners on each graph.)
4. Return the completed lab report to your lab TA.