Physics 200B
Lab 8: Conservation of mechanical energy

OBJECTIVES
- To understand the concept of potential energy.
- To understand the concept of mechanical energy of a system.
- To investigate situations where mechanical energy is conserved and those where it is not.

OVERVIEW
In Lab 7 on work and energy we defined the kinetic energy associated with the motion of a rigid object: $K = \frac{1}{2}mv^2$, where m is the mass of the object, and v is its speed. In this lab we will consider other forms of energy associated with gravitational and spring (elastic) forces.

It is useful to define the gravitational potential energy of an object at height y (relative to a height $y = 0$) as the amount of work needed to move the object away from the Earth at constant velocity through a distance y. If we use this definition, then the potential energy of an object is maximum when it is at its highest point. If we let it fall, then the potential energy becomes smaller and smaller as it falls toward the Earth while the kinetic energy increases as it falls. We can now think of kinetic and potential energy to be two different forms of energy. We define the *mechanical energy* as the sum of these two energies.

Is the mechanical energy constant during the time the mass falls toward the Earth? If it is, then the amount of mechanical energy doesn't change, and we say that mechanical energy is conserved. If mechanical energy is conserved in other situations, we might be able to hypothesize a law of conservation of mechanical energy as follows: *In certain situations, the sum of the kinetic and potential energy, called the mechanical energy, is a constant at all times. It is conserved.*

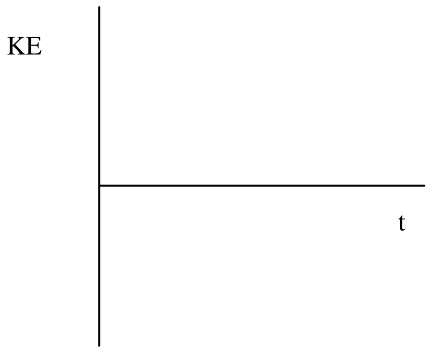
Can we apply a similar concept to masses experiencing other forces, such as those exerted by springs? Can we define a spring potential energy, and in that case could we say that mechanical energy will also be conserved for an object attached to a spring?

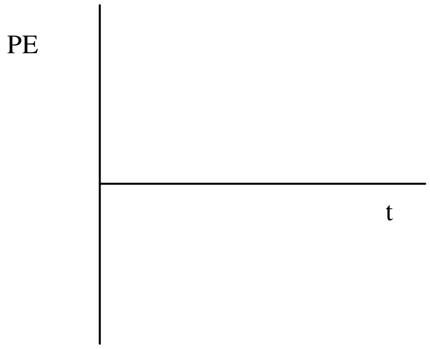
In this lab you will explore several different forms of potential energy, and will measure the *mechanical energy* to see if it is conserved in situations where the only forces doing work are gravity and springs.

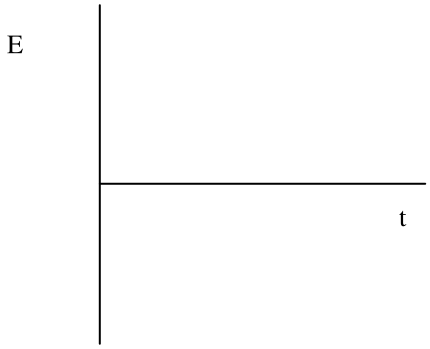
INVESTIGATION 1: GRAVITATIONAL POTENTIAL ENERGY
A system where the gravitational force is essentially the only force doing work is a cart moving on an inclined ramp with very little friction. You can easily investigate the mechanical energy for this system as the cart rolls down the ramp using a movie which you will make and analyze.

Activity 1-1: Potential, Kinetic, and Mechanical Energy of a Cart Moving on an Inclined Ramp
1. Set up a low-friction ramp so that it is inclined at an angle of about 15° above the horizontal. The friction pad on the cart should not be in contact with the ramp.

Prediction 1-1: As the cart rolls down the ramp, how will its kinetic energy change with time? How will the gravitational potential energy change? How will the mechanical energy change? Describe your predictions in words and then sketch your predictions on the three graphs located on the next page.







2. Hold the cart at the top of the ramp. Start video capture and release the cart. Edit the movie (instructions will be provided in lab) and save it.

3. Open VideoPoint. Open the movie you just saved. Click on the same part of the cart in each frame to get position vs. time data. Scale the movie by clicking on the ruler icon, and use the length of the calibration object to set the distance scale (follow the directions in Video Point).

4. Note that coordinate axes are shown in yellow on the movie. Click on the coordinate origin and drag it so that the origin is located at the bottom of the track.

5. Determine the mass of the cart. Click on Edit, then Edit Selected Series, and enter the mass with appropriate units.

6. Click on the Graph icon (or choose View, then New Graph) and change the Vertical Axis coordinate to "magnitude." Make graphs of Kinetic energy, Potential energy, and Total energy (KE + PE) vs. time. Graph all three on the same axes).

Question 1-1: Describe in words what happened to the kinetic energy and to the potential energy as the cart rolled down the track. How did the shape of these graphs compare to your predictions?

Question 1-2: Does the mechanical energy change significantly as the cart moved down the ramp? Did this agree with your prediction?

Question 1-3: What is the "system" for which mechanical energy is conserved in this experiment?

Question 1-4: Imagine that you set up another ramp so it went from the same initial to the same final height, but with a steeper slope, and let the cart roll down it. Would the cart's kinetic energy at the bottom of the ramp be larger, smaller, or the same? Explain your answer.

7. Go under Movie and select Half Size so you can see the graph and the video at the same time. Now click and drag the coordinate origin so that it's roughly at the center of the track.

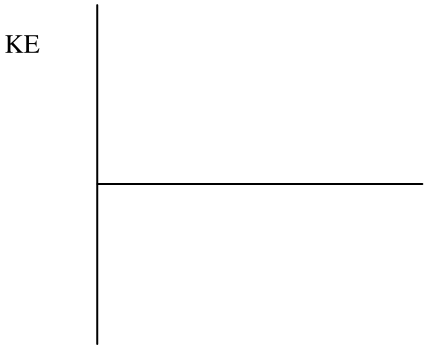
Question 1-5: How does the change in origin affect your graphs? Specifically, is KE the same as it was before? What about gravitational PE? What about the total mechanical energy?

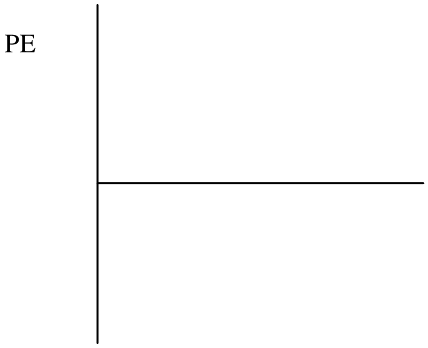
Question 1-6: Does changing the origin of your coordinate system affect whether or not total mechanical energy is conserved as the cart moves down the track? Explain.

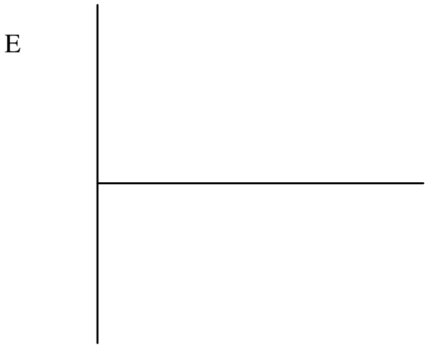
! Checkpoint 1

Activity 1-2: Energy of a Cart Moving up and down an Inclined Plane

Prediction 1-2: Suppose that the cart is given a push up the ramp and released. It moves up, reverses direction, and comes back down again. How will the kinetic energy change? How will the gravitational potential energy change? How will the mechanical energy change? Sketch your predictions below.







Test your predictions. Repeat the previous procedure (parts 2-6), but give the cart a quick push up the ramp and let it roll back down.

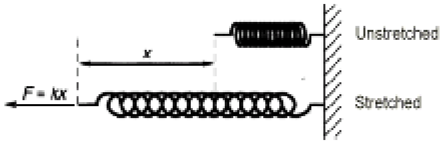
Question 1-7: How do the various forms of energy change as the cart rolls up and down the ramp? Does this agree with your prediction? Explain.

Question 1-8: Change the horizontal axis of your graphs to distance rather than time. Describe and explain the differences between the graphs of energy vs. time and energy vs. distance.

! Checkpoint 2

INVESTIGATION 2: ELASTIC POTENTIAL ENERGY

As mentioned earlier, it is useful to define other kinds of potential energy besides gravitational potential energy. In this investigation you will look at another common type, the *elastic(or spring) potential energy,* which is associated with the elastic force exerted by a spring that obeys Hooke's law. You have seen that the magnitude of the force applied by most springs is proportional to the amount the spring is stretched from beyond its unstretched length. This is usually written $|F| = kx$, where k is called the spring constant.

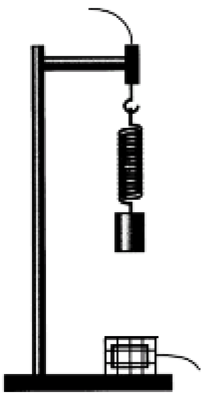


If we define the *elastic potential energy* of a spring to be the work done in stretching the spring, the definition will be analogous to the way we defined GPE. In this case, the *elastic potential energy* (EPE) would be EPE = $\frac{1}{2}kx^2$.

Activity 2-1: Spring Constant

To calculate the elastic potential energy of a stretched spring, you need first to determine the spring constant *k.* Since $F = kx$, this can be found by measuring a series of forces F and the corresponding spring stretches x.

1. Set up the force probe and motion detector as shown below. The motion detector should be on the floor, below the hanging mass.



2. Open the experiment file called **Spring Constant (L12A2-1)**. The software is set up in **prompted event mode.** When you begin graphing, force vs. position data will be displayed continuously. After you decide to **keep** a force value, the software will allow you to enter the value of the hanging mass.

3. With nothing hanging from the force probe, **zero** the force probe.

4. Hang the spring and the mass carrier from the force probe.

5. Click on **Collect.** When you are satisfied that the motion detector and force probe are reading properly, click **keep**, and **enter the value** of the hanging mass. Then add 50 g to the carrier, and again record this data point. Add another 50 g and record this data point. Then **stop** graphing.

6. Use the **fit routine** (Analyze/Linear Fit) to find the line that best fits your data, and determine the spring constant from the fit equation. (Remember that the spring constant is always positive.)

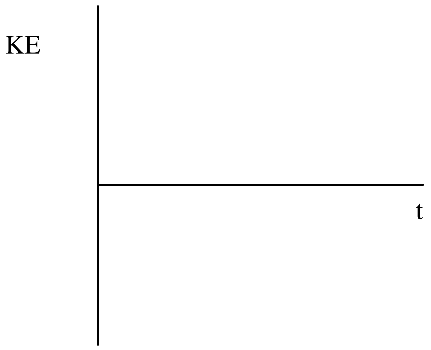
k = ________+/-________N/m

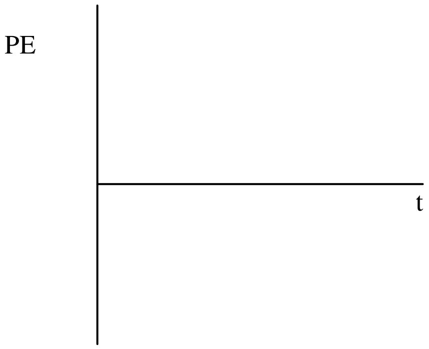
! Checkpoint 3

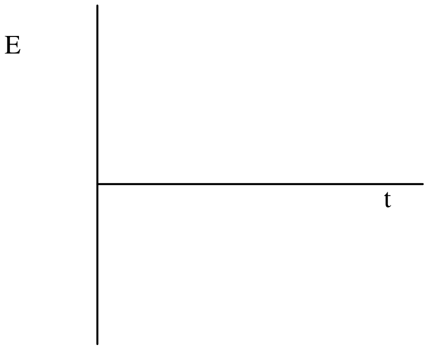
Activity 2-2: Mechanical Energy Too

Attach the mass carrier to the end of the spring. Hold the mass so that the spring has almost started to stretch, and then release it from rest. The potential energy in this case is the sum of the elastic (spring) potential energy and the gravitational potential energy.

Prediction 2-1: As the mass carrier oscillates up and down, how will its kinetic energy change with time? How will the potential energy change? How will the total energy (the sum of KE and PE change)? Sketch your predictions on the axes below.







Before taking data, you will need to find how far the mass carrier is from the motion detector when the spring is at equilibrium. This equilibrium position, along with the mass and spring constant, will be used by the computer to determine where the unstretched position of the spring is so that it can calculate potential energy correctly.

1. Suspend the mass holder from the spring, and let it hang <u>at rest</u> at its equilibrium position.

2. Open the experiment file **Distance Graphs (L01A1-1a)** to display Position vs. time axes. Begin graphing, and then determine the equilibrium position (as measured from the motion detector) using the **analysis and statistics features** in the software.

Equilibrium distance: ________+/-___________m

Now calculate (using the measured spring constant) the distance Δx between the unstretched position and the equilibrium position.

Distance Δx: ________+/-_________m

3. Open the experiment file called **Mech-energy-too-modified**.

4. Under Data/Column Options, choose **mass**. Replace the number there value that's there with the mass of your weight carrier. Next, choose **spring constant** and enter your measured value of the spring constant. Finally, choose **equilibrium position** and enter your measured equilibrium position. Mechanical energy will then be calculated by the computer as KE + gravitational PE + elastic PE, using these values.

5. Hold the mass so the spring is almost at the point of stretching (keep your hands out of the way of the motion detector!). Begin graphing, and then release the mass from rest.

Question 2-1: Describe how the kinetic energy, potential energy, and total mechanical energy changed with time. How did the graphs compare to your predictions?

Question 2-2: At what point in the motion (e.g. at equilibrium, at the lowest point, at the highest point) is the kinetic energy largest? Explain briefly how you determined this.

6. Using the equation you derived for the prelab, calculate how fast the mass carrier will be moving when it reaches the equilibrium position, that is, after it has fallen a distance Δx equal to the difference between the unstretched and the equilibrium distances.

7. Using the graph that shows position vs. time and velocity vs. time, and the Analyze|Examine feature, find a point on the position graph that corresponds to the mass holder passing through the equilibrium position, and determine what the speed was there. Take several measurements and find an average and uncertainty.

speed: ______________ m/s ± _________________ m/s

Question 2-3: How well does this measured value of the speed compare to what you calculated in part 6 of this activity?

! Checkpoint 4

Activity 2-3: Mechanical Energy With Air Resistance
Suppose you attach a large cardboard "sail" to the bottom of your mass holder so that there is significant air resistance acting on the mass as it oscillates up and down.
Prediction 2-2: How will the elastic potential energy change with time? How will the mechanical energy change? Compare your predictions to the case you just examined where the air resistance was very small.

1. Measure the mass of the hanging mass with sail attached.

Total of hanging mass and sail: ____________+/-________kg

2. Enter (Data/Column Options) the new mass.

3. Attach the cardboard sail securely to the bottom of the mass holder.

4. Determine the new equilibrium position and enter it.

5. Hold the mass holder and sail so the spring has just started to stretch, begin graphing, and release the mass and sail from rest.

Question 2-4: Is the mechanical energy constant for the motion of the mass *with air resistance?* Is mechanical energy conserved?

Question 2-5: If you found mechanical energy was not conserved, where did the energy go?

Question 2-6: Can you tell from your graphs whether the mechanical energy decreased at the same rate throughout the motion, or whether more was lost during certain parts of the motion than others?

! Checkpoint 5