LAB 6

Work & Mechanical Energy

OBJECTIVES
1. Compare the work done on an object and the change in the kinetic energy of the object.
2. Measure the spring constant of a dynamics cart.
3. Observe energy as it transforms between potential and kinetic and verify that mechanical energy is conserved.

EQUIPMENT
Force Sensor, Motion Sensor, Dynamics Cart and Track, mass and hanger set, and digital scale.

THEORY
1. Work-Energy Theorem
For an object with mass \( m \) that experiences a net force \( F_{\text{net}} \) over a distance \( x \) that is parallel to the net force, the work done is:
\[ W = \int F_{\text{net}} \cdot dx \]
The object’s kinetic energy changes according to the Work-Kinetic Energy theorem:
\[ W = \Delta K = K_f - K_0 = \frac{1}{2} mv_f^2 - \frac{1}{2} mv_i^2 \]

2. Conservation of Mechanical Energy
The elastic potential energy of a spring compressed a distance \( x \) from its equilibrium position is given by
\[ U_{\text{spring}} = \frac{1}{2} kx^2 \]
where \( k \) is the spring constant. As described by Hooke’s Law, the force exerted by the spring is proportional to the distance the spring is compressed or stretched from equilibrium, \( F = -kx \), where \( k \) is the spring constant. The spring constant can be experimentally determined by applying different forces to compress the spring different measured distances. If force is plotted versus distance, the slope of the resulting straight line is equal to \( k \). If energy is conserved, the spring potential energy in the compressed spring will be completely converted into kinetic energy when the spring pushes an object of mass \( m \).

PROCEDURE

Part 1: Work-Energy Theorem

The purpose of this laboratory activity is to compare the total work done on an object to the change in kinetic energy of the object. You will use the Force Sensor to measure the force applied to the cart and the Motion Sensor to measure the speed of the cart as it is pulled by the weight of the hanging mass. Finally, you will use Capstone to plot and analyze the data.

(a) Level the Dynamics Track, and setup the apparatus as shown below. Place a motion sensor at the opposite end of the track so that the cart moves away from the sensor.
(b) Use a string that is 10 cm longer than the length needed to reach the floor when the cart is next to the pulley. Attach one end of the string to the hanging mass (50 g total) and the other end to the Force Sensor’s hook. Place the string in the Pulley’s groove.

(c) Open DataStudio and create a new activity. You will need to set up the Force Sensor and the Motion Sensor. Use Capstone to create two plots: Force vs. Position and Velocity vs. Time.

(d) Pull the cart away from the pulley until the hanging mass is just below the pulley.
   - Start data recording. **Release the tension on the string (so it is zero) and push the tare button on the Force Sensor to zero it.** Restore the tension and then release the cart so it moves away from the motion sensor.
   - End data recording just before the cart reaches the end stop.
   - Record the value of the maximum speed for the data run. This should occur just as the weight hits the ground (and the tension becomes zero).

Analysis of Data

(e) From the maximum speed and the mass of the cart, find the maximum value for KE. Call this $K_f$.

(f) In the Force vs. Position Graph display, click and drag the cursor to highlight the region of data that corresponds to the motion. Integrate to find the area under the curve (i.e. the work $W_{done}$) of the Force vs. Position Graph using Capstone.

(g) Compare $K_f$ and $W_{done}$ using a percent difference. What are some possible reasons for the difference?

(h) Using Newton’s 2nd law, calculate the theoretical tension $T_{thy}$ in the string using the known masses from the experiment. Compare $T_{thy}$ to your experimental result (use your average tension for $T_{exp}$) using a percent difference.

(i) Repeat steps (d) – (g) for two different values of the hanging mass (for a total of three).

Part 2: Calculate the Spring Constant $k$

Use the Force Sensor to measure the force that compresses the plunger spring in the Dynamics Cart. Measure the distance that the spring compresses and use EXCEL to plot the force vs. distance. The slope of the best-fit line of a graph of force versus distance is the spring constant $k$.

(a) Level the Dynamics Track and set it up as shown by the instructor.

(b) Open DataStudio and create a new activity. Set up DataStudio to display the force exerted on the cart.

(c) Press the tare button on Force Sensor to zero the Force Sensor. Start data recording.

(d) Push the Dynamics Track against the stopper so the plunger spring is compressed 5 millimeters (0.005 m). Record the Force value.
(e) Continue to slide the Dynamics Track to the right in 5 mm increments until the plunger spring has been compressed 20 millimeters. Record a Force value at each new position.

(f) Using EXCEL, plot Force vs. Position (in meters) and determine the slope of the graph. The slope is equal to the spring constant of the spring.

**Part 3: Conservation of Mechanical Energy**

Use a Motion Sensor to measure the motion of a cart as its plunger spring de-compresses. Next, use Capstone to calculate and display the velocity (speed) of the cart. Compare the measured kinetic energy to the calculated elastic potential energy.

(a) Remove the Force Sensor from the Dynamics Cart and make sure the Dynamics Track is still level. Attach a Motion Sensor at the opposite end of the track as the end stopper. Open DataStudio and create a new activity. Set up DataStudio to display Velocity vs. Time.

(b) Put the cart on the Dynamics Track so the end of the plunger bar is pressed against the end stop, but the plunger spring is not compressed. Measure the length of the plunger relative to the end cap of the Dynamics Cart. Record the plunger length \(x\).

(c) Completely compress the plunger spring on the cart and lock the spring in position. Launch the cart along the track and use the motion sensor to measure the maximum speed of the cart (before it slows down due to friction).

(d) Do five trials and find the average kinetic energy of the launched cart

(e) Use your value of \(k\) from part 2 to calculate the elastic potential energy stored in the fully compressed plunger (compressed a distance \(x\)). **Compare the average kinetic energy of the cart with the elastic potential energy stored in the spring.**

(f) Do five more trials with a weight on the cart and repeat the same analysis.

(g) *What is the percent difference between the average kinetic energy and the elastic potential energy for your two different cases (with and without added weight)? What are some possible reasons for the differences, if any?*