6 Conservation of Energy

Introduction
In this lab there are two parts, both of which will measure how energy is conserved in a system. In **Part I**, you will measure the potential and kinetic energies of a roller coaster rolling down a track, using those values to find the total energy of the roller coaster over time. You will use the World In Motion software for your data. **Part II** will involve measuring the velocity and position of a cart on an inclined track in its path up and back down a dynamics track. These measurements are taken so that potential and kinetic energies and therefore total energy, may be calculated.

Materials
Part I: World In Motion software, Excel
Part II: Data Studio, Excel, dynamics track, cart, motion sensor (see Figure 1)

Reference
Giancoli, Physics 6th Edition: Chapter 6, Sections: 3, 4, 6, and 7

Theory
Conservation principles play a very important role in physics. If the value of a physical quantity is conserved, then the value of that quantity stays constant. The total energy of a system is the sum of its kinetic energy and potential energy. In today's lab, the potential energy is gravitational potential energy given by \( PE = mg \). Thus:

\[
Total \ Energy = Kinetic \ Energy + \text{Gravitational Potential Energy} \quad 1
\]

\[
E = KE + PE = \text{constant} \quad 2
\]

\[
E = \frac{1}{2}mv^2 + mg \quad 3
\]

If the total energy is conserved, a graph of \( E \) vs. time should be a horizontal line. Gravity is a conservative force, so if it is the only force involved we expect the total energy to be conserved. (For this lab, we will assume that the force of friction is negligible.) Ideally the motion would be measured at the center of mass. For Part I, this will be possible but for Part II, the measurement taken by the motion sensor will be from the front of the cart.

**Theory for Part II**: You will use a coiled-spring launcher to launch a dynamics cart at the bottom of an inclined track and the cart will go up the track, reverse its motion and come back
down. If the friction is essentially zero, then energy should be conserved, and you can analyze the data from the standpoint of energy conservation.

![Experimental Setup showing launcher](image)

**Figure 1: Experimental Setup showing launcher**

The motion sensor is mounted on the track so the position it records is the distance from the top of the track. The position data are therefore taken *along* the track which makes the calculation of the velocity of the cart straightforward. However, it complicates the calculation of the *vertical displacement*, \( h \), which is necessary to calculate the potential energy.

![Diagram](image)

**Figure 2**
In Figure 2, \( P \) is the distance to the cart as measured by the position sensor and \( Z \) is the distance the front of the cart has moved up the track. You can calculate \( Z \) by the equation:

\[
Z = L - P_0
\]

The vertical height of the cart, \( h \), above the level of \( P_0 \) is given by:

\[
h = Z \sin \theta
\]

Where \( \theta \) is the angle of the track's incline. The reference point, \( P_0 \), is the point where the cart leaves the launcher. This will correspond to your reference height, \( h_0 \). In the procedural section you will receive more detailed instructions on how to determine values of \( h \) from your data.

The graph of position vs. time that you plot will be parabolic. The minimum value of the curve corresponds to the maximum height of the cart, where potential energy is at a maximum, and \( P_0 \) will represent your maximum for kinetic energy.

Procedure

**Part I: Frictionless Roller Coaster.** This measurement will be made from the analysis of a video file of Valleyfair Amusement Park's "Wild Thing", one of the five tallest roller coasters in the world.

1. Open the **World in Motion** software and follow your instructor's directions to open file "10.avi". The program will also load a data file with calibration data so that your measurements will be in meters and the software will know the mass of the coaster and the number of frames per second.
2. In order to verify conservation of energy you should mark the mid-point of the coaster. (If you examine the video, you will see that the coaster is segmented into six cars and the mid-point is between two segments.) Mark the mid-point of the coaster on each frame as you did in the projectile motion lab and then save your data with a unique file name.
3. When you have marked all the points, press the “Graphs” button on the lower right corner of the screen. Answer the questions and request graphs of energy versus time and acceleration versus time.
4. Discuss the energy versus time graph. Is energy conserved?
5. Discuss the acceleration versus time graph. Does the acceleration of the coaster approach free fall?

**Part II: Conservation of Energy in the Laboratory**

1. To take data using the setup shown in Figure 1, set up the ScienceWorkshop interface with a motion sensor set to take data at 40 Hz and the switch at the top of the motion sensor set to record motion at short distances. Hold the track firmly so it will not recoil when the cart is launched.
2. Press the **Start** button and launch the dynamics cart up the track so that it will reverse its direction of motion before getting too close to the motion sensor. You may need to do this a couple of times to practice. If it goes too high, the launcher can be adjusted.

3. Press the **Stop** button after the cart has bounced off the launcher.

4. Make graphs in Data Studio of the velocity and position vs. time and inspect the data. You want to have a position graph that looks somewhat like Figure 3 which shows the cart bouncing off of the launcher. The horizontal line shows the position of the part when it is sitting on the launcher after it has been sprung.

![Figure 3](image)

On the far left part of the graph, the data traces a horizontal line, because the cart is at rest on the coiled spring launcher. When the cart is launched it moves toward the motion sensor, it then reverses its course and moves away from the sensor. (Remember, the motion sensor records itself as position zero so when you move toward it, you get closer to zero, and as you move away, you get larger numbers. The minimum value of the curve corresponds to the maximum height of the cart, where potential energy is at a maximum, and $P_0$ is your maximum for kinetic energy.) The points reached a minimum as indicated by the arrow in Figure 3. At this minimum, the vertical height of the cart was at a maximum and it began to reverse its direction back down the ramp.
5. In order to calculate $Z$, you must find the first point after the cart just leaves the launcher. This is indicated by $P_0$ in Figure 3. This is your initial position and it corresponds to your reference height, $h_0$, shown in Figure 2. To do this you can take some data with the cart sitting on the launcher with the spring extended.

6. After you have found $P_0$, highlight the data points for all points below it, giving you a cut-off parabola. Make sure you don't choose any points that are higher than $P_0$ on either side of the parabola.

7. Copy the data to Excel and create a table with the following format:

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>$P$ (m)</th>
<th>$Z$ (m)</th>
<th>$h$ (m)</th>
<th>$v$ (m/s)</th>
<th>$PE$ (J)</th>
<th>$KE$ (J)</th>
<th>$E$ (J)</th>
</tr>
</thead>
</table>

8. Calculate and record $Z$ for each point by the following equation (equivalent to using Equation 4 with an appropriate sign correction):

$$Z = P_0 - P$$

9. Multiply the values of $Z$ by the sine of the angle of the incline to find and record the height, $h$, at each point in time. (See Equation 5 and Figure 2)

10. Use your original position data ($P$) to calculate the velocities of the cart along the track in Excel. (Remember, because the motion sensor records along the track, there is no need to find $x$ or $y$ components.)

11. With the heights and velocities that you calculated in Steps 8 and 9, use Equations 1-3 to determine the potential energy, the kinetic energy and the total energy in Excel.

12. Create a single graph of $E$, $KE$, and $PE$ versus time in Excel. Do your results indicate that energy is conserved?

For your Lab Report
Include a sample calculation of finding the uncertainty in $E$ for Part II by estimating the uncertainty of your measurements of the angle of the track and the position of the cart. Perform the calculation for a data point where the cart is halfway up the track. You need not worry about the uncertainty for the mass of the cart because mass can be canceled out in the energy equation. Make sure you include your calculation of $h$ from the position data.
For both parts of the experiment, we assumed no friction. In writing your lab report, look for evidence of friction.