General Physics I Lab (PHYS-2011)
INCLINED PLANE

Equipment

Equipment Required		
QTY	**ITEM**	**PASCO #**
1	1.2 m Track System	ME-9493
1	Smart Cart - Red	ME-1240
1	250 Mass Bars (Set of 2)	ME-6757A
1	Track Endstops (Set of 2)	ME-8971
1	Track Feet (Set of 2)	ME-8972
1	Pasco Capstone	
1	Meter Stick	

Objective:

Today's experiment involves using a cart accelerating down an incline, that explores: Position and time for an object with constant acceleration and then uses that relationship to derive a mathematical relationship between the two. Velocity and time for an object with constant acceleration and then uses that relationship to derive a mathematical relationship between the two.

Theory:

Galileo Galilei used an inclined plane with minimal friction to observe motion due to gravity. The track in this experiment is more technically sophisticated, but the idea is the same as it was 400 years ago. The height of the incline can be adjusted to change the angle of the slope.

Assuming friction is negligible, an object that slides down an inclined plane is subject to a constant acceleration (a). This acceleration is due to the gravitational acceleration (g) but the acceleration on the slide is reduced because the track is at an angle. Near the Earth's surface, the gravitational acceleration is $g = 9.8 \ m/s^2$.

$$a = g \ sin(\theta) \ = g\frac{h}{\ell} \qquad (1)$$

where $\ell = \Delta x$ is the distance

Conservation of Energy

The Work Energy theorem states that $W = \Delta KE$, work is the change of the kinetic energy. Work is also defined as $W = |\vec{F}||\vec{\Delta x}| \cos\theta$, the component of an applied force along the displacement Δx. We can divide work by the type of force that generates it:
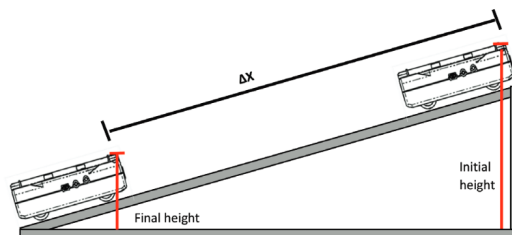
- **Conservative :** These are forces that do not remove energy from the *system*. They can be represented by a potential energy. Examples are springs, gravity, and the electromagnetic fields.

- **Non-conservative :** These are forces that do remove energy from the *system*. They cannot be represented as a potential energy. Examples are friction, heat, and sound.

When a force can be represented as a potential energy it means energy can be transferred between kinetic and potential without loss. This allows us to write the Work Energy theorem as

$$W_{nc} = \Delta KE + \Delta PE, \tag{2}$$

where W_{nc} is the work done by any non-conservative forces. In ideal situations $W_{nc} = 0$ and this becomes

$$0 = \Delta KE + \Delta PE,$$
$$KE_i + PE_i = KE_f + PE_f,$$

or the sum of the kinetic and potential energies must remain constant.

Today, we will test this relationship using a cart moving down an incline plane. The cart is started from rest from the top of the track and the speed is measured along the track using Capstone software. Potential energy (**PE**= mgh) is calculated by measuring the height and kinetic energy (**KE**= $1/2mv^2$) is calculated from the speed. Initially when the cart is not moving all of its energy is stored as PE but when the cart is released it rolls freely down the track and its stored PE is converted to KE.

If there is friction in the system this transfer of energy from PE to KE will not be complete. The work done by kinetic friction can be represented as

$$W_f = KE_f - PE_i,$$
$$-f_k \Delta x = KE_f - PE_i,$$
$$-\mu_k |n| \Delta x = KE_f - PE_i,$$
$$-\mu_k mg \cos \theta \Delta x = KE_f - PE_i,$$

where μ_k is the coefficient of kinetic friction, m is the mass of the cart, and θ in this equation is the angle at which the track is inclined. Notice that the sign of the work done by kinetic friction is negative. Recall that the frictional force opposes motion, so the displacement vector and force vector are in opposite directions. For today's experiment we will assume all energy losses are because of a *global* friction in the system, the sides wheels on the track groove, the axles rotating, air resistance, etc. Therefore, any losses will be attributed to a single μ_k parameter in the analysis.

Setup:

1. Use the bubble level provided and the adjustable feet on both ends to level the track.

2. Inspect the rubber bands at the end of the track. Make sure there are three bands in good shape strung across the downhill side of the gate.

3. Turn on the Bluetooth Smart Cart and open PASCO Capstone Software. Depress the black button on the side of the cart (the button is located below the power symbol). The LED's next to the Bluetooth and battery symbols should blink.

4. Go to the Hardware Setup and connect to the Smart Cart. In the Hardware Setup the smart cart should appear with a six digit number, *e.g.* 483-589. Make sure this number matches the number on your cart. If it doesn't you've connected to a nearby group's cart.

5. Click on "File" and then "Open Experiment". Select the *inclined_plane* file. This file may need to be downloaded from the course D2L or will be in a 2011/Experiments folder. The data panel will show four plots shown in Fig.1. The plots are:

   - **Upper Left :** Speed [m/s] vs. Time [s]
   - **Upper Right:** Kinetic and Potential Energy [J] vs. Time [s].
   - **Lower Left :** Linear Position [m] vs. Time[s].
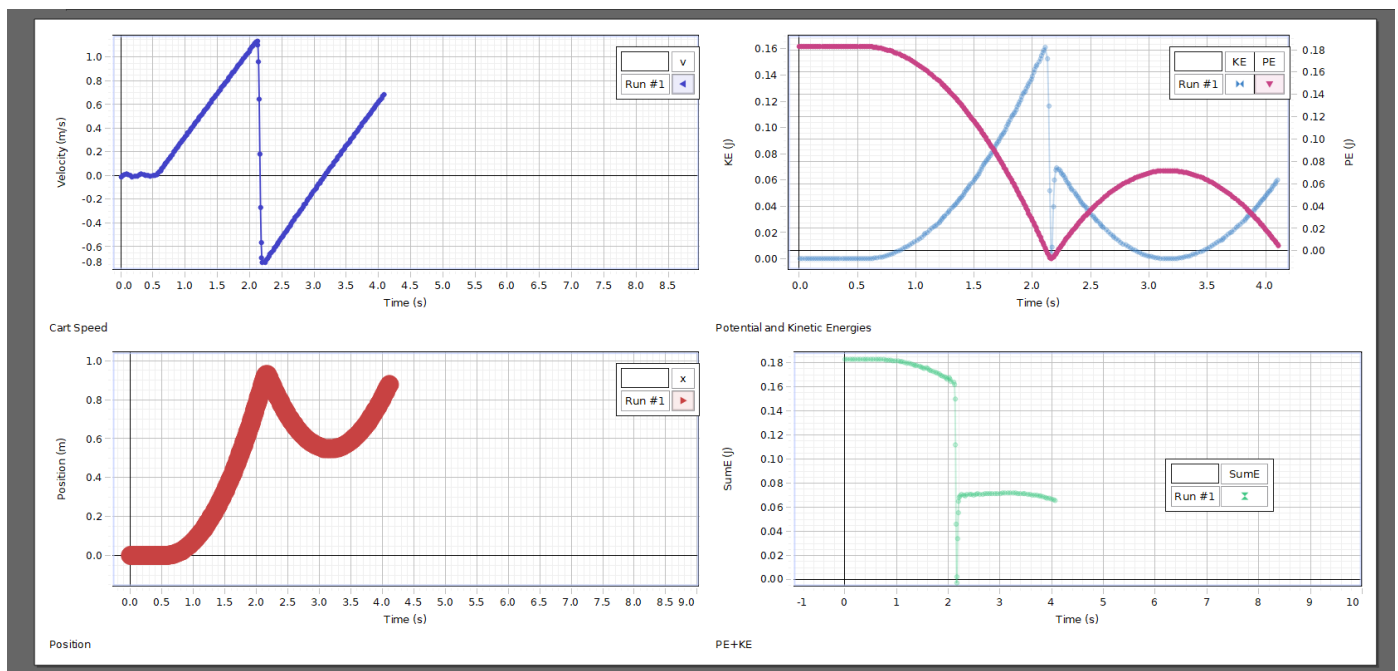   - **Lower Right:** Total energy [J] vs. Linear Position [m].

Figure 1: The inclined plane data panel should look like this after opening the experiment file. Notice on the plot of KE and PE, the y-axis for PE is on the left and KE on the right.

6. In Capstone at the bottom of the screen click on the words "Smart Cart Force Sensor" or "Common Rate." A drop down menu should appear. Select "Common Rate" if its not already selected. Once selected, use the up arrow button in the window to the right to increase the sampling rate to 100.0 Hz if it does not already read 100 Hz.
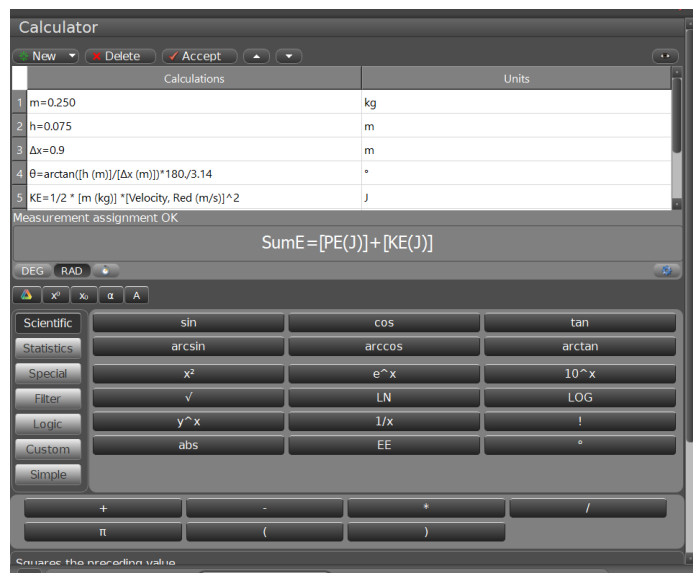
Figure 2: Equation Editor Screen. The parameters m, h, and Δx are shown as lines 1, 2, and 3 of the editor. Note that the mass is in kg and the distances are in m.

7. Click on the "Calculator" icon on the left of the Capstone screen. Under the Calculations column will be three constants: m, Δx, and h. You will need to adjust these variables during the experiment.

Procedure:

1. Use the balance to find the mass of the cart (M_c). Record this mass in the Calculator tab as the variable m. (See fig. 2)

2. On the track is a ruler. Note the position of the rubber bands. Place the cart on the track near the elevated end. Ensure both sets of wheels are on the track. Note the position of the front of the cart. In the calculator tab enter the difference of the carts position and the rubber bands as the variable Δx, e.g. if the front of the cart is at 101 cm and the bands are at 8 cm then $\Delta x = 93$ cm.

3. Use a labjack or provided equipment to adjust the elevation of the track so that the starting position of the cart is approximately 5 cm above the rubber bands. Record the height in the Calculator tab as the variable h.

4. When everything is ready, have one lab partner start recording data. Wait for data points to appear on your graphs and then release the cart (without pushing it). After the cart hits the bands click the stop button. In Fig.1 the cart is moving from about 0.7 s to 2.2 s. After 2.2 s the cart is bouncing off the bands and this data can be ignored.

5. Click on the graph of the velocity versus time. In the toolbar that appears click on the black down arrow next to the button that looks like a red Σ. Select "Maximum" and click on the arrow again. Now click on the Σ.

6. Now click on the data highlighter button, it looks like a yellow pen drawing on three blue points. This will create a "Region of interest" box, ROI for short. The ROI can be moved by clicking

on its center and dragging and resized by clicking and dragging its edges. Data that is in the ROI will be high-lighted. Move the ROI to include the peak of the velocity graph. Record the maximum speed.

7. Repeat Steps 5 and 6 on the kinetic and potential energy graphs and the position plot. Record the maximum Kinetic and Potential energies. Verify that the distance from the position graph matches the Δx variable in the equation editor.

8. **Possible extra step :** Click on the energy sum plot in the lower right. Use high-lighting tool to select the data during the carts motion. Click on the "Fitting tool", this looks like a dark blue line between a few red points. Select linear from the drop down menu and click on the plot again. A fit line and information box should appear. Record the slope of the fit line, the parameter "m" in the information box.

9. Repeat steps 4-6 two more times. For a total of 3 measurements at this mass and height.

10. Add one of the 250g masses to the cart. Record the total mass (M_1) = (250g + Cart Mass) of the cart in your Data Table. Open the calculator and change the mass variable m.

11. Repeat step 4-6 3 times at this mass and height. **Make sure to use the same starting position of the cart every time.**

12. Add a second 250g mass to the cart for a total of 500g. Record the new total mass (M_2) of the cart in your Data Table. Open the calculator and change the mass variable m.

13. Repeat step 4-6 3 times at this mass and height. **Make sure to use the same starting position of the cart every time.**

14. You will now have 9 measurements, 3 at each mass.

15. Repeat this procedure with heights of 10 cm and 15 cm. **Make sure to change the h and m variable in the Calculation Editor as the experimental parameters change.** You will have a total of 27 data points, 3 for each mass at each height.

Data Analysis:

Record Data Here.

	Δx (m)	M (kg)	v_{max} $\left(\frac{m}{s}\right)$	KE_{max} (J)	PE_{max} (J)
Data Table (1): Inclined Plane raised by 5 cm					
1					
2					
3					
4					
5					
6					
7					
8					
9					

	Δx (m)	M (kg)	v_{max} $\left(\frac{m}{s}\right)$	KE_{max} (J)	PE_{max} (J)
Data Table (2): Inclined Plane raised by 10 cm					
1					
2					
3					
4					
5					
6					
7					
8					
9					

	Δx (m)	M (kg)	v_{max} $\left(\frac{m}{s}\right)$	KE_{max} (J)	PE_{max} (J)
Data Table (3): Inclined Plane raised by 15 cm					
1					
2					
3					
4					
5					
6					
7					
8					
9					

Analysis Tasks

1. Calculate the mean and variance of the maximum velocities, kinetic energy, and potential energies measured in this lab.

2. Using the mean values calculate the difference of the KE_{max} and PE_{max} for each measurement. Is it different than you expected? If so, why?

3. Use the difference in the initial and final energies to estimate the work done by friction.

4. Estimate the coefficient of kinetic friction using your answer to the previous question.

5. **Optional :** How is the slope total energy versus time plot relate to the friction in the system?

Questions and Answers

1. What form of energy does the cart have while at rest at the top of the track?

2. What form of energy does the cart have while in motion near the bottom of the track?

3. How did the maximum velocity change with mass and height in this experiment? Is it what you expected?

4. How did the final kinetic energy change with mass and height in this experiment? Is it what you expected?

5. Compare the calculated value for velocity with the measured value for velocity.
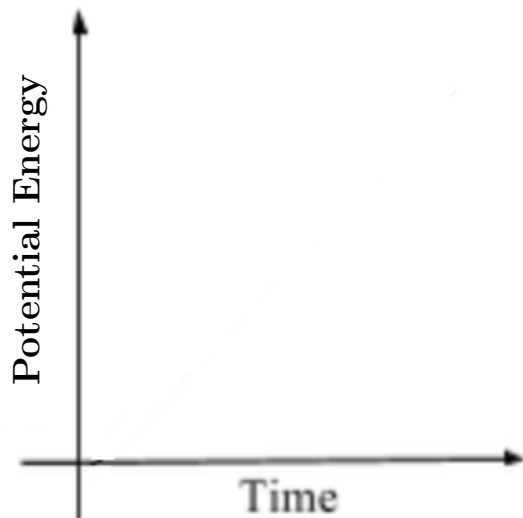
$$v_{max} = \sqrt{2gh} \tag{3}$$

6. Using v from the previous question calculate the expected value for Kinetic Energy K.

$$KE_{max} = \frac{1}{2}mv_{max}^2 \tag{4}$$

7. Sketch a graph of Position and Velocity vs Time.
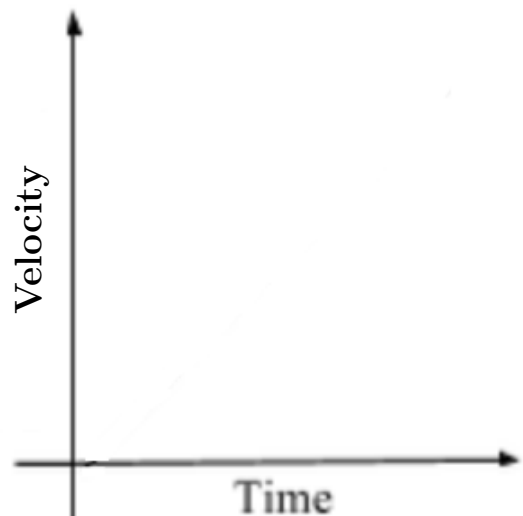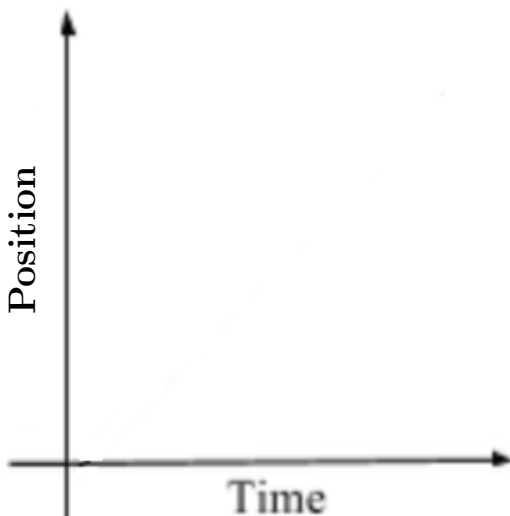
8. Sketch a graph of Potential Energy vs Time.

Potential Energy

Time

9. Sketch a graph of Kinetic Energy vs Time.

Kinetic Energy

Time