Conservation of Energy and Efficiency

Introduction: Whenever a force is involved, there is the potential for energy.

$$F_{net} \cdot \Delta x = \Delta K$$

Equation 1

Theory: The work-energy theorem states that the work (the left side of the equation above) done on the object by the net force = the object's change in kinetic energy. There is an important qualification in that statement: work done by the net force causes a change in kinetic energy. Therefore, if the sum of all the forces in a mechanical system equals zero, there is no change in kinetic energy. This is a consequence of Newton's First Law of Motion. If the sum of all the forces is not zero, then there is an acceleration (from Newton's Second Law of Motion), a corresponding change in velocity (from kinematics), and therefore a change in kinetic energy:

$$\Delta K = \frac{1}{2}m(v_f^2 - v_i^2)$$

Equation 2

However, there is an elephant in the room: with all these forces, which force does what? In this case we must distinguish between work done by a system and work done on a system. While these definitions stem from thermodynamics, we can safely just state that work done *by* a system is positive and work done *on* a system is negative. Consider a block sliding down a hill. The component of the force of gravity that causes the block to accelerate downwards is opposed by the force of friction pointing up the hill, opposing the direction of motion. Since the distance down the hill is common to both forces, we can say the work done by gravity (positive) plus the work done on or against friction (negative) will produce a surfeit of energy which becomes the change in kinetic energy; thus we can say energy is conserved, meaning all of it is accounted for.

However, not all of it was useful for us. If the point to letting the block slide downhill was to get it moving fast, it did not attain the maximum possible speed suggested by its initial conditions. We can quantify how much useful energy we got out of the system by calculating its *efficiency*:

$$eff = \frac{Work_{out}}{Work_{in}}$$

Equation 3

In our example, the work in is the work done by gravity and the work out is the change in kinetic energy; the work done against friction was wasted as heat (assuming we don't need any heat!) but it is not gone from the universe; thus energy is conserved.

Task:

To examine the conservation of energy in an inclined plane system and calculate its efficiency

Equipment:

- Airtrack
- Lab jack
- Plastic laptop stand
- Pasco Capstone Interface (PCI)
- Level
- Tape measure

Procedure:

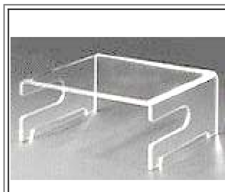	
Figure 1	Figure 2

Figure 3a

Figure 3b	Figure 3c

You will allow a cart (don't forget to mass it!) on an airtrack to slide downhill, finding its speed at the bottom with photogates. You will then observe how far back up the track it bounces. From this you can get the efficiency of the bumper at the bottom, and of the entire airtrack assembly.

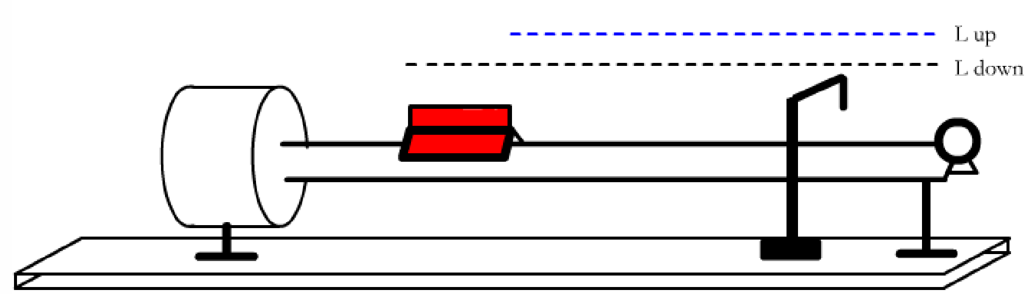

Figure 4

(N.B.: the animation is horizontal, but your airtrack will be slightly inclined)

1. Carefully acquire the airtrack and set it on the clear plastic laptop stand and closed lab jack. Adjust the lab jack so that the system is level.
   a. Use the benches on the sides of the classroom, not the center benches.
      i. Butt the end of the track that doesn't have the fan motor against the wall so that it doesn't shift when the cart hits the end.
   b. Leveling can be done quickly by placing the cart in the middle of the track and turning the air on.
      i. Caution: NEVER slide the cart on the track if the air is off!
      ii. The cart will slide to one side: adjust the jack level until the cart stays in the middle.

        iii. Confirm the horizontality of the track with the level.

2. Place the cart at the “top” end of the airtrack.
3. Place the photogate at the "bottom" so that the cart just clears the sensors when it hits the bumper at the bottom of the track.
4. Make sure that the cart blocks the photogate - it has a little hole that's just big enough to fool the sensor!
5. The Pasco Capstone Interface:
    a. Open the PCI and choose the photogate for your sensor.
    b. Set the timing to operate like this (down arrow on Pre-Configured Timer to get Build Your Own):

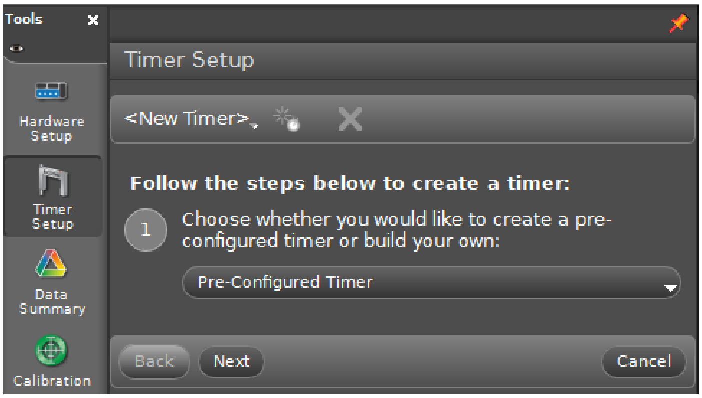

Figure 4

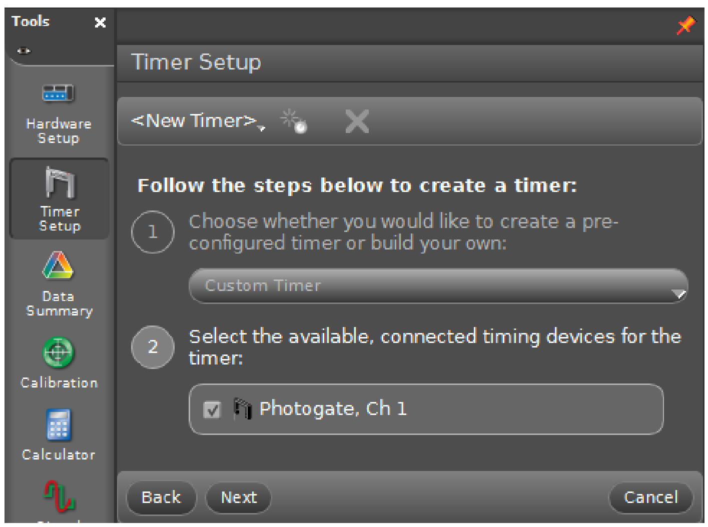

Figure 5

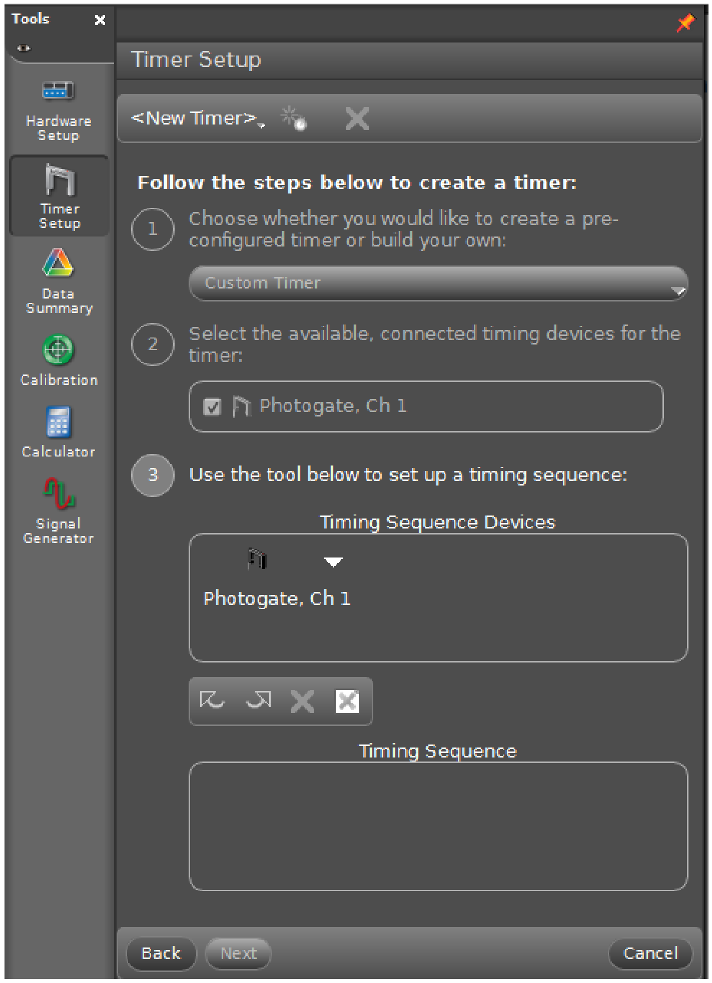
Tools
Hardware Setup
Timer Setup
Data Summary
Calibration
Calculator
Signal Generator
Timer Setup
<New Timer>
Follow the steps below to create a timer:
1
Choose whether you would like to create a pre-configured timer or build your own:
Custom Timer
2
Select the available, connected timing devices for the timer:
Photogate, Ch 1
3
Use the tool below to set up a timing sequence:
Timing Sequence Devices
Photogate, Ch 1
Timing Sequence
Back
Next
Cancel

Figure 6

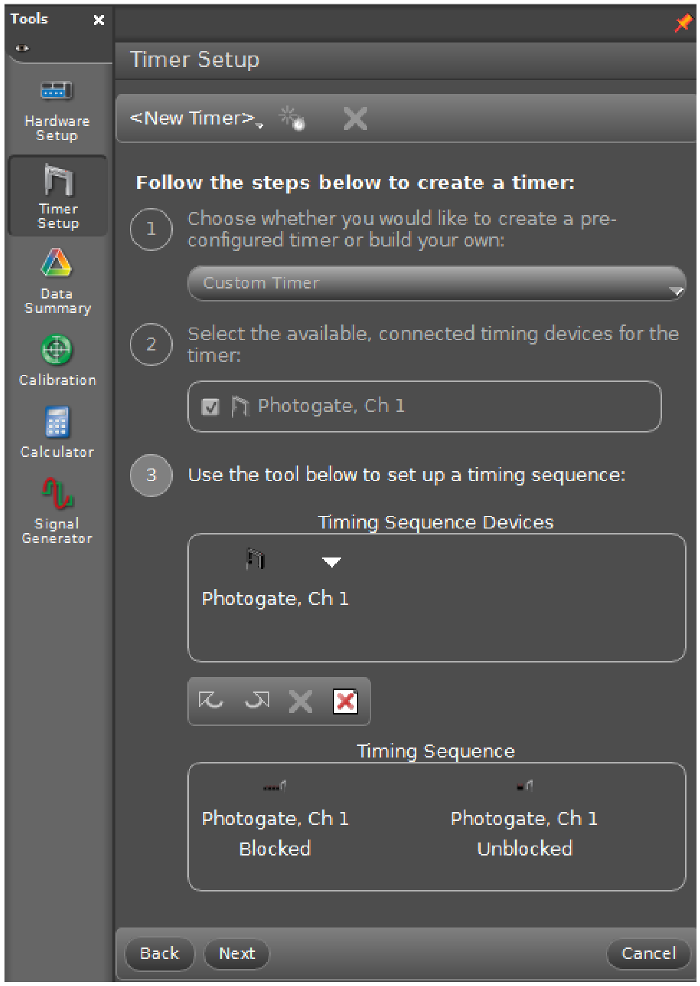

Figure 7

   d. Use the little down arrow in the lower left for blocked, then again for unblocked.

6. Here's how you will find the speed of the cart at the bottom of the airtrack:
   a. The PCI will time how long the photogate is blocked while the cart is moving right and also when it rebounds and moves left. That's why it is important that the "unblocked" interval at the bottom is as brief as possible.
   b. Knowing the length of the cart and the time the photogate is blocked will allow you to find its speed. (Actually, it's the average speed over that brief blocked interval, not quite the final speed of the cart.)
7. Raise the labjack so that the top of the airtrack is 0.5 cm higher than the bottom.
8. Place the cart at the top end,.
   a. Note the initial position of the cart and how far it can travel before it hits the bumper. This is *L down* in the animation. Hint: place the cart as far up the track for best results.
      i. The airtrack has markings on the side - are these the best you can use for *L down* and *up*?
   b. While holding the cart, start the data studio, then release the cart.
   c. Note how far back up the ramp the cart travels. This is *L up* in the animation. Use the tape measure for this distance, but be careful not to scratch the track with the metal tape.
9. Repeat at 0.5 cm intervals until the height of the top of the track is 6 cm higher than the bottom.
10. From the *L down* and *L up* of the cart find the overall efficiency of the system for each height (remember 'Happy' and ' Sad'?), and from the initial and final speeds at the bumper find its efficiency each for each collision. Present your results clearly in a table.
    a. Don’t forget to calculate your uncertainties!

Questions:

1. Was the overall efficiency constant as the height changed? Statistically quantify the *variations*. What happened to the missing energy
2. Did the efficiency of the bumper change as the height increased? Statistically quantify the *variations*. What happened to the missing energy
3. Why is it legitimate to use *L down* and *L up* for efficiency calculations? Does that cart actually descend 0.5 cm more each time?
4. How much error was introduced by using the average velocity rather than the actual final velocity in 6b?