Impulse & Work

This lab is composed of two parts. In the first part, we will examine the relation between impulse and momentum and also test the law of conservation of momentum. In the second part, we will measure the kinetic energy of a moving cart then apply the law of conservation of energy to the data to determine the coefficient of kinetic friction.

Basis of the Set-up

Similar to how a bat navigates, the motion sensors used in the experiment measure the position of the carts by bouncing ultrasonic waves off them. If your position graphs are not smooth, check to see whether the motion sensors are picking up stray reflections from you or from other objects placed close to the track.

Part I – Experimental Procedure for Impulse and Momentum

Click on the icon "Impulse&Work_Pt1" in the folder "IntroI".

A. Sensor setup and calibration

1. Weigh the two carts and the extra bars. Record the values in the report sheet. Let the cables (from the force sensors) hang on the side of the scale; we do **not** want to count the mass of the cable.

2. Two **motion sensors** are attached to each end of the track. Check that the motion sensor at the left end is connected to the **Dig/Sonic 1 port** on the Vernier interface and that at the right end is connected to **Dig/Sonic 2**. It is very important that the track is horizontal – levels are available for you to check this.

3. There are also **force sensors**. Each looks like a black block and is attached to the top of each cart. Check that the force sensor on the left cart is connected to the **CH1** port, and the force sensor on the right cart is connected to the **CH2** port.

3. The motion sensors have a limited range, so all collisions should take place at the center of the track. In collisions where one cart is initially stationary, this is easily accomplished by placing that cart at the center of the track.

4. Place the two carts at rest at the center of the track, stuck together (there should be Velcros attached to the carts). Keep your hands clear of the track and click 🔵 Zero . Click on the two motion sensors to zero both motion sensors. This will establish the same coordinate system for both sensors. Check that the zeroing was successful by clicking ▶ Collect and rolling the still-linked carts back and forth on the track. The graphs for each motion detector should overlap for a 30-40 cm range near the center of the track. Again, we want to stick with right being positive. If either of the motion sensors detects the right direction as negative, you need to reverse the

direction. Click on "Experiment → Set up sensors → Show all interfaces". Click on the appropriate sensor (DIG/SONIC 1 or DIC/SONIC 2) and click "Reverse direction".

5. Calibrate the force sensors. Follow the same procedure as the "Forces between two carts" lab.
      a. Make sure you have the hooks attached to the force sensors, which is located on the black block near the front (as opposed to the rear) of the cart.
      b. Click on "Experiment → Calibrate → CH1:Dual Range Force".
      c. With the cart sitting still on the track, click "Calibrate now", input 0, and click "Keep".
      d. We will use a 500g weight to do the calibration. Pick the cart on the left, stand it vertically on its end on the edge of the table with the hook hanging down, and hang the 500g weight off the hook. When the weight is steady, input 4.9 N, and click Keep.
      e. Test the direction for the force sensor by pressing on it. Reverse the direction as appropriate. Note that the sensor to be changed here, if needed, is CH1.
      f. Repeat for the force sensor ("CH2") on the right cart.
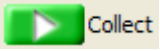   *Change the hooks to the bumpers before moving onto the next part.

B. Experimental procedure
We are going to test only elastic collisions, in which the total kinetic energy is conserved. (You will learn about this more in a later experiment.)
You should realize that the conclusions should be the same for inelastic collisions, in which the total kinetic energy is not conserved.

For trials 1-3, do not put any extra weight on the carts. For trials 4-5, put one or two weights on the left cart. Different scenarios for initial velocities of each cart are already given on the report sheet. (+ means positive initial velocity, - means negative velocity, "0" means at rest.)

For each trial, start the carts at least 30cm apart from each other.

Click [▶ Collect]. When the program starts collecting, put the carts in motion and clear your hands from the track.
Important: Make sure that the cables from the force sensors are relatively free to move, or it may produce bad data.
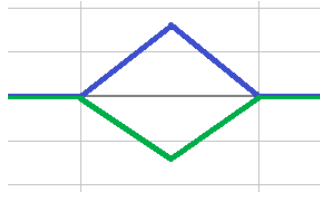You can stop collecting soon after the collision.
Please stop the carts from running into the motion sensors.

C. Data analysis
You will get a force-time graph on the top and a velocity-time graph at the bottom of the screen.

(i) *Force-time graph*
First, highlight the peak in the force-time graph. Right click on it, and select Zoom Graph In (you need to highlight the peak vertically as well as horizontally). This roughly represents when the collision happens. It should look something like this:

*This is actually a bad representation of the actual force-time graph. What happens is that the data collection rate of our setup is very low, so we only collect 1 point (that's why the graph is a straight line up, then a straight line down).

Remember how impulse and force are related? $\text{Impulse} = \int \vec{F} dt$ = Area under the F-t graph. So we need to calculate the area under the curve in this graph to find the impulse.
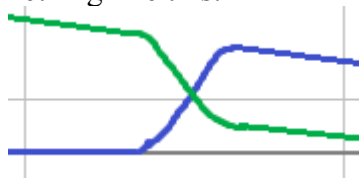
Highlight from the beginning to the end of the bump, then select "Analyze → Integral", which will calculate the area under the graph in the highlighted region. Make sure both Force 1 and Force 2 are checked, and press OK.
Remember to keep track of the positive and negative signs. Both the force and the momentum are vectors!
Record these values on your report sheet.

(ii) *Velocity-time graph*
Remember the form for the momentum? $p = mv$. Now let's look at velocity before and after the collision. Look at the time of the collision in the force-time graph, and zoom in around that time frame. Your graph should look something like this:

*Note that the lines are not purely horizontal. This is because there's friction between the cart and the track. If your graph does not look similar to this, please see your lab instructor. You may need to collect new data.

You will realize that this feature makes discrete jumps. Click on the Examine button ( ).
Look at the data point just before the beginning of the collision, and the data point just after the end of the collision (according to the time from the force-time graph).
Record the velocity values at these points in Table 1 of your report sheet.

Warning: The data from this lab will most likely be very inaccurate due to many factors. Make sure you followed the directions very well to minimize any errors. Think about what different factors may cause this "faulty" data. Write your answer on your report sheet.

Part II – Energy and Work

For this part of the lab, you will use a different program. Close the program you used in Part I. Open the folder "IntroI" and click on the icon "Impulse&Work_Pt2".

      In this experiment, you will use only one cart and one motion sensor (that is, the one on the left end of the track). Check that the direction of the motion sensor is correctly set by clicking [▶ Collect] and moving the cart to the right. You should see that the value of the data collected down the "Distance" column increasing with time. If not, reverse the direction of the motion sensor by clicking "Experiment" → "Calibrate" → "Details" → "DIG/SONIC 1" → "Reverse direction" → OK. If you want the program to collect the data for a longer period of time, click "Setup" → "Data Collection" → "Sampling" and key in "1" (second), for example, for "Experiment Length".

      Input a correct value for the mass of the cart in the formula of the Kinetic Energy, which is of the form, K = 0.5*m*v*v. Click on the column "KE" in the data window then the "Definition" tag and modify the "Equation" as appropriate.

      When everything in the program is properly set up, you may start the experiment. Give a push to the cart to set it into motion then quickly click [▶ Collect] to begin collecting the data. You will observe that the cart slows down with both time and position. This is because of the work done by friction.

      Question 1: We expect only one of the graphs (K vs. time, or K vs. position) to be linear. Which one should be linear? Do you observe it to be approximately linear? (Hint: You may put a ruler on top of the graph to help determine if it follows a straight line.)

      Question 2: With the aid of the graphs, determine the effective coefficient of kinetic friction associated with the cart moving on the track. (Hint: You will need to use one of the tool buttons [M=] [STAT] [⋀] [R=] [f(x)=] on the top manual to analyze your graph. To find out what each button does, put the cursor over the button. A message will show telling you the function of that button.)

      Question 3: Suppose the track is tilted as such that it makes an angle θ with the horizontal (see the figure below). In the report sheet, describe clearly how differently you will analyze the data to determine the effective coefficient of kinetic friction. (Hint: The cart's height relative to the origin is given by h = xsinθ.)