5.14: Conservation Laws

Name: ____

Date: ________________________

Partners:____

Equipment

• *LabPro* Interface • Two motion detectors • Force sensor • *Force* software file	• Dynamics track • Dynamics cart • Pulley • Hanging masses

Introduction

Newton's Second Law directly relates the net force acting on an object to its acceleration. However, the force acting on an object can also be related to the other kinematic parameters of the system (the time, position, velocity, and changes in these variables). The Work-Energy and Impulse-Momentum relations directly relate force to these other parameters. More importantly, in closed systems, these relations generalize to the Laws of Energy and Momentum Conservation. These fundamental laws of physics provide an alternative to Newton's Laws for the study of motion.

I. An Alternative to Newton's Laws

Open the file *Force.*

Set the sensor to the ±10 N setting and securely attach it to the top of the cart.

Measure the mass of your cart and sensor. Record it below.

mass of cart and sensor, m = _____________ kg

Select **Experiment/Calibrate** and select the Force sensor. Select **Calibrate Now**. You will now perform a two-point calibration of the force sensor:

- For the first calibration point, do not apply any force to the sensor, enter 0 N, and hit **Keep.**
- For the second calibration point, attach a 200 g mass to the sensor by means of a string passing over the pulley. Enter the weight of this mass (1.96 N) and hit **Keep.**

You are going to repeat the same series of experiments you conducted while exploring Newton's Laws. However, rather than focusing on the relationship between force and acceleration, you will focus of the interrelationships between force and the other kinematic variables.

Attach 200 g to the sensor via a string passing over the pulley. Hold the cart in place about 20 cm in front of the motion detector, press **Collect**, and then release the cart. Make sure that the track is clean, the wheels of the cart turn freely, and the force sensor cord does not drag behind the cart. The resulting graphs of force and acceleration vs. time should look familiar.

To see a graph of momentum vs. time, you have to "teach" the program how to calculate momentum. To do this,

- Select **Data/New Calculated Column** and enter the appropriate name and units for a momentum column.
- In the equation box, enter the appropriate equation to calculate momentum. (You do not need to enter an equal sign in your equation.) Use the **Variables** pull-down menu to select the appropriate variable in your equation. Press **Done**.
- Replace the graph of acceleration vs. time with a graph of momentum vs. time.

Select the same large region of "good" data on both graphs and complete the first row of the table below. Directly measure the initial and final momentum from your momentum vs. time graph and determine the impulse acting on the cart during this time interval by determining the area under the force vs. time graph. Although the software does not automatically calculate an uncertainty for these measurements, this does not mean that the data is exact. Estimate and record an uncertainty for each measurement.

To see a graph of kinetic energy, you have to "teach" the program how to calculate kinetic energy. To do this,

- Select **Data/New Calculated Column** and enter the appropriate name and units for a kinetic energy column.
- In the equation box, enter the appropriate equation to calculate kinetic energy.
- Since work as the product of the force applied to the cart and the displacement of the cart, change the force vs. time graph to a force vs. position graph and replace the lower graph with a kinetic energy vs. position graph.

Select a large region of “good” data on both graphs and complete the first row of the second table below.

Hanging Mass (g)		**P_{final} (kg m/s)**	**$P_{initial}$ (kg m/s)**	**P (kg m/s)**	**Impulse (N s)**
200				±	±
150				±	±
100				±	±
50				±	±

Hanging Mass (g)		**KE_{final} (kg m^2/s^2)**	**$KE_{initial}$ (kg m^2/s^2)**	**KE (kg m^2/s^2)**	**Work (N m)**
200				±	±
150				±	±
100				±	±
50				±	±

Complete both of the above tables.

Question: Describe and defend your method for estimating the uncertainties in your data.

Question: Is there a relationship, within measured uncertainties, between impulse and change in momentum?

Question: Is friction small enough to be reasonably ignored? Would including friction make the agreement between your data and the impulse-momentum relation better or worse? Explain.

Question: Is there a relationship, within measured uncertainties, between work and change in kinetic energy?

Question: Is friction small enough to be reasonably ignored? Would including friction make the agreement between your data and the work-energy relation better or worse? Explain.

II. Collisions

Remove the force sensor from the interface and connect a second motion detector. Place the motion detectors at opposite ends of the track. Configure *LoggerPro* to display a single graph of both velocities.

Since “away” is considered the positive direction for a motion detector, the two motion detectors have conflicting coordinate systems. To fix this problem, select **Experiment/Set Up Sensors/Show All Interfaces**. Right-click one of your motion detectors and select **Reverse Direction**. Now both motion detectors will refer to the same direction as positive.

A. Velcro-Velcro Collisions

Arrange your two carts such that when they collide they will stick together.

Roll cart 1 in the positive direction, colliding with a stationary cart 2. Roll cart 1 fast enough so that after the collision the two carts roll to the end of the track, but slow enough so that the carts don’t “jump” slightly off the track on contact.

1. Tracking Momentum during a Collision

Measure the mass of each cart and record it below.

mass of cart 1, $m_{cart\ 1}$ = ____________ kg

mass of cart 2, $m_{cart\ 2}$ = ____________ kg

To visualize how momentum behaves during the collision,

- Create a data table with columns for Momentum1, Momentum2, and Total Momentum using **Data/New Calculated Column** and entering the appropriate name and units. In the equation box, enter the appropriate equation to calculate each momentum.
- Create a single full-screen graph of Momentum1, Momentum2, and Total Momentum vs. time.

Question: Is the momentum of cart 1 conserved (i.e. constant) during the collision? If not, does it gain or lose momentum? Explain.

Question: Is the momentum of cart 2 conserved during the collision? If not, does it gain or lose momentum? Explain.

Question: Is the total momentum in the system of the two carts conserved during the collision? Should it be? Explain.

2. Tracking Kinetic Energy during a Collision

To examine the same collision in terms of kinetic energy, rather than momentum, *LoggerPro* can also be "taught" how to measure kinetic energy.

Using the technique described above, create calculated columns for Kinetic Energy1, Kinetic Energy2, and Total Kinetic Energy. Create a single full-screen graph of Kinetic Energy1, Kinetic Energy2, and Total Kinetic Energy vs. time.

Question: Is the kinetic of cart 1 conserved (i.e. constant) during the collision? If not, does it gain or lose kinetic energy? Explain.

Question: Is the kinetic energy of cart 2 conserved during the collision? If not, does it gain or lose kinetic energy? Explain.

Question: Is the total kinetic energy in the system of the two carts conserved during the collision? Should it be? Explain.

Question: If the total kinetic energy in the system of the two carts decreased during the collision, where did this energy go?

Add a second graph to your display. Make the top graph Momentum1, Momentum2, and Total Momentum vs. time and the bottom graph Kinetic Energy1, Kinetic Energy2, and Total Kinetic Energy vs. time. Adjust the scales on your graphs so that they are easy to read. Print this page and attach it to the end of the activity. Note that your graph may look better in landscape mode.

3. Other Types of Collisions

Imagine different types of collisions. For example, what if cart 1 was twice as massive (i.e. carrying a 500 g black bar)? What if cart 2 was moving and cart 1 stationary? What if both carts were moving? Would momentum and kinetic energy behave the same way they did in the simple collision just studied?

For the following three collisions, add a 500 g black bar to cart 1 (and alter your *LoggerPro* equation for Momentum 1 and Kinetic Energy 1):

- Cart 1 colliding with a stationary cart 2.
- Cart 2 colliding with a stationary cart 1.
- Cart 1 and cart 2 in a head-on collision.

For each collision, prepare and print the momentum and kinetic energy graphs described above and attach them to the end of the activity. Below each graph, clearly describe the collision and your findings regarding momentum and kinetic energy conservation for that collision.

Question: What conclusion(s) can you draw about the amount of momentum present before and after each collision? Do all 4 collisions (including the one analyzed in the previous section) support the same conclusion?

Question: What conclusion(s) can you draw about the amount of kinetic energy present before and after each collision? Do all 4 collisions support the same conclusion?

B. Magnet-Magnet Collisions

Arrange your two carts such that they repel each other when they get close together.

Roll cart 1 in the positive direction, colliding with a stationary cart 2. Roll cart 1 fast enough so that after the collision cart 2 rolls to the end of the track, but slow enough so that the carts don't actually touch during the interaction.

Prepare, print, and attach this graph to the end of the activity.

Question: Is the total momentum in the system of the two carts approximately constant during the collision? Should it be? Explain.

Question: Is the total kinetic energy in the system of the two carts approximately constant during the collision? Should it be? Explain.

Question: If the total kinetic energy in the system of the two carts decreased during the collision, did it decrease by a smaller amount than in the velcro-velcro collision?

Repeat the remaining two collisions you analyzed earlier, except using the magnet-magnet interaction.

- Cart 2 colliding with a stationary cart 1.
- Cart 1 and cart 2 in a head-on collision.

For each collision, prepare and print the momentum and kinetic energy graphs described above and attach them to the end of the activity. Below each graph, clearly describe the collision and your findings regarding momentum and kinetic energy conservation for that collision.

Question: What conclusion(s) can you draw about the amount of momentum present before and after each collision? Do all 3 collisions support the same conclusion? Compare these conclusions to the conclusions drawn from the velcro-velcro data.

Question: What conclusion(s) can you draw about the amount of kinetic energy present before and after each collision? Do all 3 collisions support the same conclusion? Compare these conclusions to the conclusions drawn from the velcro-velcro data.