Conservation of Linear Momentum

Purpose: To understand the concept of linear momentum conservation; to investigate whether momentum and energy are conserved in elastic and inelastic collisions. To ponder the concept of impulse in a real-life situation.

Apparatus: Pasco track, Pasco carts (two), LabPro interface and cables, motion sensors (two), mass weights (black, bar-shaped)

Introduction: In the last lab, you tested energy conservation when potential energy was converted to kinetic energy in a system (mass bucket + mass). That system was acted upon by a conservative external net force (gravity), as well as a non-conservative force (friction). This week you will examine a system in which there is again friction, but no conservative external net force. The changes in motion of the constituents of the system (two colliding masses) will arise from the internal forces between them. You will measure the momenta of each mass before and after the collision and then check whether momentum and energy are conserved.

Newton originally stated his second law using momentum, rather than acceleration:

$$\overrightarrow{F_{net}} = \frac{\Delta\vec{p}}{\Delta t} \quad \text{where } \vec{p} = m\vec{v} \qquad \text{(Eq. 1)}$$

For a **system** of N particles, we can rewrite this as

$$\overrightarrow{F_{net}} = \frac{\Delta\overrightarrow{p_{net}}}{\Delta t} \text{ where } \overrightarrow{p_{net}} = \sum_N \overrightarrow{p_i} = \overrightarrow{p_1} + \overrightarrow{p_2} + \overrightarrow{p_{3....}} + \overrightarrow{p_N} \qquad \text{(Eq. 2)}$$

In the case we are considering, namely where there are no external forces, the above equation reads

$$\frac{\Delta\overrightarrow{p_{net}}}{\Delta t} = 0 \qquad \text{or} \qquad \overrightarrow{p_{net}} = constant \qquad \text{(Eq. 3)}$$

which states that the linear momentum of a system is conserved, <u>for no external forces</u>.

For a system composed of two masses (carts) along a track, we can relate their momentum values before and after the collision as follows. Here we have dropped the vector notation, and adopted the convention that the only directional information needed comes from positive or negative velocity values:

$$m_1 v_1^i + m_2 v_2^i = m_1 v_1^f + m_2 v_2^f \qquad (4)$$

The experiment consists of colliding two carts along a track, while monitoring their velocities with two motion sensors mounted at opposite ends of the track. By weighing the masses beforehand, you will have Logger Pro output the real-time momentum value.

You may be thinking at this point: "*How do I get the masses to move if there aren't supposed to be any external forces on them? Doesn't my hand, which pushes the mass, represent an external force?*". You will indeed be providing an external force; however, the time interval that we are most interested in is the period *just before* the collision to *just after* the collision. During that interval there are no external forces on the system other than gravity, which we cannot eliminate in the lab. The only forces acting are internal, action-reaction ones, described by the Third Law: $\overrightarrow{F_{12}} = -\overrightarrow{F_{21}}$. In this lab we will examine two types of collisions: **elastic** collisions, in which energy is ideally conserved, and **inelastic** collisions, in which energy is not conserved. However, linear momentum is ideally conserved for both types of collisions.

Finally, you will be asked to consider (in the last Question) the concept of Impulse, which is defined as $J = \int_{t_1}^{t_2} F\,dt$

In calculus, this quantity is the area under the curve of the F vs. t graph and represents the change of momentum during a short collision between two objects. Since this is an algebra-based course, we will assume that the force is roughly constant with time, so that the above equation simplifies to:

$$J = F\Delta t = \Delta p$$

The impulse can then be thought of as the change in momentum of an object when acted on by a constant force over a short period of time. Note that a large force acting over a shorter period of time can impart the same impulse as a smaller force acting over a longer period of time. Each can be advantageous in different cases; for instance, the latter is desirable when it comes surviving a car crash – an air bag will lengthen the time of the impulse imparted during the collision, therefore decreasing the force that the passenger experiences, despite the fact that in both situations (with or without airbag), the impulse (the change of momentum) is the same (from velocity v before the collision to 0 after).

Sometimes impulse has the symbol I, which we won't use since it can easily be confused for Moment of Inertia, to be used in your next lab, which is also represented by I.

Procedure

You will be colliding two carts together, while simultaneously monitoring (using Logger

Pro) their momenta (calculated from their velocities). You will then identify points immediately before and after the collision, to determine the$p_{initial}$*and*p_{final}*values.* *<u>Note that friction will be present throughout the entire motion of the carts</u> (visible in both the momenta and energy plots) but that the effects of friction will be minimal during the brief time interval of the collision.*

<u>A. Preparations (0 pts)</u>

As usual, record all your data, observations and answers to questions in your Google Sheets lab report, shared with your lab partners, TA and LA.

Make sure the left motion sensor is plugged into DIG/SONIC1 on the LabPro interface, and that the right motion sensor is plugged into DIG/SONIC2.

Feel free to position the motions sensors closer than what the pictures in the beginning of the manual indicates; you could try distances of 1/4 and 3/4 along the length of the track for the Sensor 1 and Sensor 2, respectively.

1. Weigh the carts and weights on the lab scale as you did in the last lab. If the masses are already labeled, you can use these figures. Make sure both motion sensors are adjusted for a horizontal orientation and set to narrow beam. Record the masses in your lab report. (0 pts)

2. Open the Logger Pro (LP) file "Momentum.CMBL", which is in the Linear Momentum experiment folder on your lab Mac. You will see a data table and graphs monitoring momentum data as well as energy data. By convention, the track on the left is mass **one** and the track on the right is mass **two**. Individual values such as P1 and P2 are be added to give **total** value P. The only values actually measured by the motion are t, Distance 1 and Distance 2 (neither is shown on LP plot); **everything else is calculated from these**.

3. Double-click on the **P1** column in the Table Window. You will see the definition of the momentum of mass 1. Change the default value of 0.490 to the actual mass of your mass 1. Do the same for the **P2.**

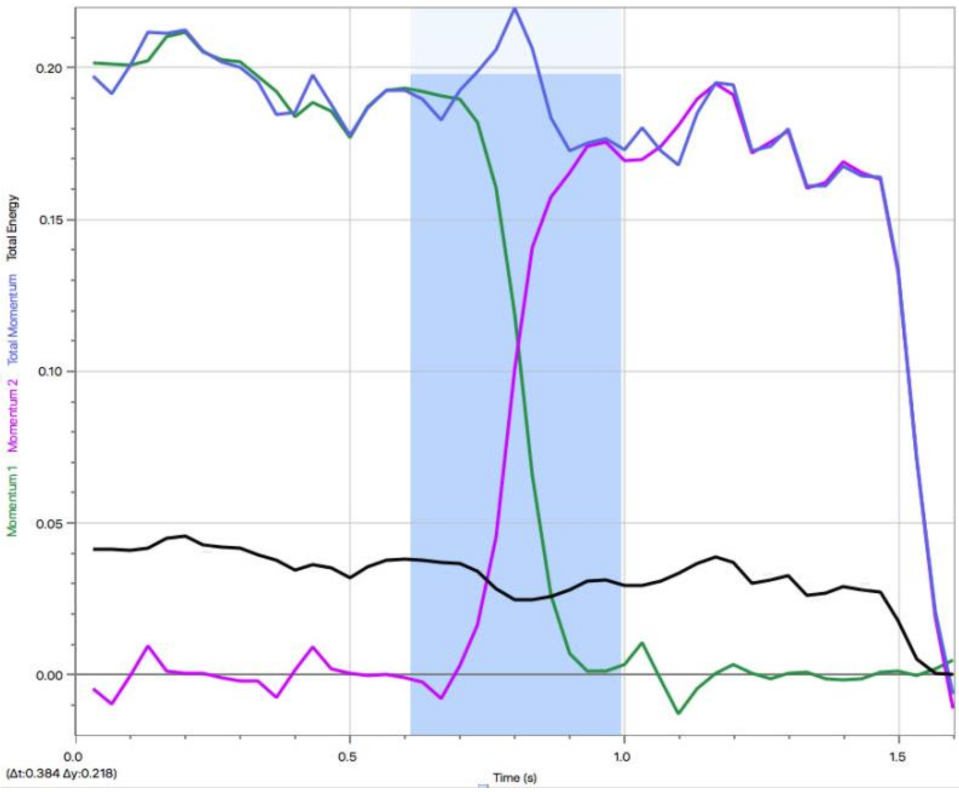
4. Examine your Pasco carts that you will collide with each other; there are 2 types:

- the older type (usually light gray metallic in color) has Velcro patches on one end while the other end doesn't. When the velcro end of one cart comes in contact with the velcro end of another cart, adhesion occurs and the masses are stuck together - this approximates an **inelastic collision.** Conversely, putting the non-velcro ends together puts internal magnets of each mass near each other to provide a repulsive force - this approximates an **elastic** collision.

- the newer type (which are usually red in color) has Velcro patches **and** magnets on both ends, which means you can achieve both an **elastic collision** if you collide them without touching – or an **inelastic collision** if you collide them hard enough such that they stick together.

5. Do a few practice runs - put Cart 2 halfway along the track, then position Cart 1 about 15cm to the right of the left motion sensor. Press Collect in Logger Pro and push Cart 1 hard enough – to hit Cart 2, but not violently so. However, when you are doing an elastic collision **make sure the carts don't actually make physical contact, and only experience the magnetic repulsive force,** otherwise the collision will be partially inelastic. In all cases be prepared to catch any carts before they hit the right motion sensor – hold your left and right hands near the sensors, without obstructing them, as precautions.

NOTE: You will probably see a small bump in the Total Momentum graph (and a small dip in the Total Energy graph) during the time that the carts are colliding. This is a spurious (false) bump introduced by the software. The software tells the two sensors not to fire at the same time, to prevent interference, causing a lag between left and right sensors. Since the collision takes place over a very short time, the software incorrectly calculates the total momentum before both sensors are actually read. It is important to note this slight glitch, but it should not affect your measurements - in subsequent parts of this lab, you will be asked to identify and note values of v, p and K.E. *before* and *after* the collision, at points *outside* this spurious hump.



Elastic Collision between two masss of equal masses, with one initially at rest.

B. Inelastic collision, Cart 1 roughly equal to Cart 2, Cart 2 initially at rest (20 pts)

1. Try to produce a good clean run for an **inelastic** collision, with no added masses on the carts and pushing Cart 1 into Cart 2 which is initially at rest. Note on the graph:

a) the point at which the collision began
b) the point at which the collision ended
c) the region where the carts exerted forces on each other

2. Using the Analyze-->Examine feature, or by examining data in the Table, identify the velocities right **before** the interaction and right **after** the interaction. **IMPORTANT: rather than visually identify these points, look at the data table to see how the momenta values change – you can then more easily decide when the collision starts or ends in this way.** Record these in your lab report. Also record initial and final momenta and kinetic energies; just read them from Logger Pro. One good run is sufficient. Screen capture or photograph the plot for this run and also mark on the plot (a), (b) and (c) from question (1) above.

(8 values x 2 pts each) + (4 pts for graph markings) = 20 pts total)

C. Elastic collision, Cart 1 roughly equal to Cart 2, Cart 2 initially at rest (20pts)

Repeat Part B for an **elastic** collision, with no added masses on the Carts. Remember that the carts shouldn't physically touch each other and should only interact via the magnetic forces between them. Again, only one good run is required. Record pre/post velocities as well as pre/post momenta and kinetic energies. Submit plot for a good run. Mark on plot (a), (b) and (c). (20 pts)

D. Elastic collision, Cart 1 less than Cart 2, Cart 2 initially at rest (20 pts)

Add two mass weights (total 1kg) to Cart 2. Push Cart 1 into M Cart 2, initially at rest. **Don't forget to change the value for Cart 2 in the Logger Pro column definitions.** Again, only one good run is required. Record pre/post velocities as well as pre/post momenta and kinetic energies. Submit plot for a good run. Mark on plot (a), (b) and (c). (20 pts)

E. Elastic collision, Cart 1 about equal to Cart 2, both initially heading towards each other (20 pts)

Remove mass weights from Cart 2. Remember **to change back the value for Cart 2 in the Logger Pro column definitions.** Push both carts towards each other, at close to the same speed. Again, only one good run is required. Record pre/post velocities as well as pre/post momenta and kinetic energies. Submit plot for a good run. Mark on plot (a), (b) and (c). (20 pts)

Questions (20pts)

1. For an inelastic collision, and from analyzing percentages, was momentum conserved, considering your cart momenta immediately before and after the collision? What about kinetic energy? (4 pts)

2. For an elastic collision, and from analyzing percentages, was momentum conserved, considering your cart momenta immediately before and after the collision? What about kinetic energy? (4 pts)

3. For an elastic collision, why do the carts start interacting even though they never physically touch? (2 pts)

4. For an inelastic collision, into what other forms of energy is kinetic energy converted? (4 pts)

5. Looking at your graphs, what is the main source of energy loss during the entire run? (2 pts)

6. Can you think of an example where a larger force over a shorter time interval is preferable to a smaller force over a larger time interval? What about an example where a smaller force over longer time interval is preferable? (4 pts)