Laws of Conservation

Equipment

- Calculator, Computer, PASCO Interface
- Air Track, Air pump
- Air Track Carts (2 of one kind, 1 of the other kind)
- Photogate and Stand (2 of each)

Objectives

The objective of this experiment is to verify the Law of Conservation of Energy and the Law of Conservation of Momentum for collisions.

Introduction

Collisions and Laws of Conservation of Momentum and Energy

In this experiment we will measure the motion of two carts before and after a collision. The carts will glide on an air track to minimize the effects of friction. Based on the observed motion we will compute the linear momentum and kinetic energy of each object, both before and after the collision. The carts are equipped with springy metal "bumpers" on each end, so that collisions between the carts are elastic (very little energy is transformed into other forms, such as material deformation or heat). Based on our observations we will then verify that the total linear momentum and the total energy of the system are conserved for this type of collision.

This introduction gives some information on Momentum and Kinetic Energy, but it is certainly not comprehensive. For more information:

- Serway/Vuille, College Physics, 9th Ed, Chap 5&6, especially Ex 6.4.
- Serway/Jewett, Physics for Sci. & Engr., 9th Ed, Chap 7&9, especially Ex 9.5.
- http://www.physicsclassroom.com/class/momentum

Momentum

The linear momentum $\vec{p}$ of an object is defined as the product of the object's mass m and velocity $\vec{v}$. This definition is Equation 1 below. Linear momentum is a vector quantity that points in the same direction as the velocity vector. The units of momentum are kg·m/s.

Definition: $$\vec{p}_i = m\vec{v}_i \quad (1)$$

Note: As a vector, momentum on an air track can be positive or negative!

Linear momentum is changed by forces exerted over a period of time, similar to how the amount of water in a bucket is changed by the flow rate applied over a period of time. When two objects touch, their forces are equal and opposite, and each experiences the force for the exact same amount of time. So any momentum lost by one object is gained by the other.

The principle of **conservation of linear momentum** applies to the collision between two objects along a 1-dimensional track. The principle states:

> *The total linear momentum of an isolated system remains constant (conserved). An isolated system is one for which the vector sum of the external forces acting on the system is zero. (The forces between objects that interact within the system are internal.)*

$$\begin{gathered} \vec{p}_f = \vec{p}_i \\ \sum(m\vec{v})_i = \sum(m\vec{v})_f \\ m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f} \end{gathered} \tag{2}$$

Note that the last form of the equation is written in components where the v's are components, not magnitudes and, depending on the direction, can be + or −.

Kinetic Energy

The Kinetic Energy of an object, KE, is a positive, scalar (not vector) quantity. The important property of Energy is that it exists in different forms depending on how it is stored in a system and can be transformed from on kind to another during interactions. Kinetic energy is the kind that is stored in motion. Any moving object possesses Kinetic Energy and an object that has Kinetic Energy cannot be stationary.

$$\mathrm{KE} = \frac{1}{2}mv^2 \tag{3}$$

Kinetic energy can by transferred into none-mechanical form of energy by work of non-conservative force such as friction. A transfer of Kinetic Energy into Thermal Energy by a frictional force always results in a loss of speed by an object or slow down. When interaction happens in a closed system, the momentum is conserved (as described above), but, if non-conservative force is present, some kinetic energy can be lost due to deformation or transfer into sound or thermal energy. Such interaction is called **an inelastic collision** where the total kinetic energy after collision is less than total kinetic energy before collision due to energy transfer by none-conservative forces.

An **elastic collision** is the type of collision that doesn't involve none-conservative forces. In elastic collision, there is no transfer of kinetic energy and the total kinetic energy after the collision is the same as it was before the collision. So, in an elastic collision, not only is the momentum conserved, but the kinetic energy is conserved also:

$$\begin{gathered} \mathrm{KE}_f = \mathrm{KE}_i \\ \sum\left(\frac{1}{2}mv^2\right)_i = \sum\left(\frac{1}{2}mv^2\right)_f \\ \frac{1}{2}m_1 v_{1i}^2 + \frac{1}{2}m_2 v_{2i}^2 = \frac{1}{2}m_1 v_{1f}^2 + \frac{1}{2}m_2 v_{2f}^2 \end{gathered} \tag{4}$$

Note that in the last form of the equation, the v's are technically magnitudes, but components can be used because they are squared, and any negative sign gets cancelled out.

Two photogates are set up at about 1/3 and 2/3 of the length of an air track. The PASCO software will record the time it takes for the silver flag on the top of each cart to blocks a photogate while the car is passing through the photogate. The software will then calculate the average speeds of the carts using these measured gate-blockage times. The measured values of the speed and mass of the carts are essential to compute the linear momentum and the kinetic energy of each cart before and after the collision. It is expected that the ratio of the total linear momentum after and before collision would be close to 90% but due to inelastic nature of the collisions, the ratio of the total kinetic energy after and before collision could be as low as 50%.

Three different initial conditions of the collision will be investigated in the experiment:

Condition 1: Carts with Different Masses, the light cart is originally at rest. Heavy Cart is moving to the right and collides with Light Cart, which is at rest.

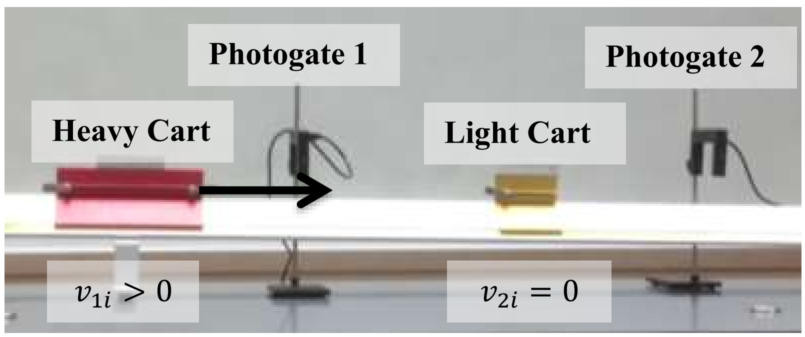

Figure 1. Rough experimental setup for Condition 1.

Condition 2: Carts with Different Masses, the heavy cart is originally at rest. Light Cart is moving to the right and collides with Heavy Cart, which is at rest.

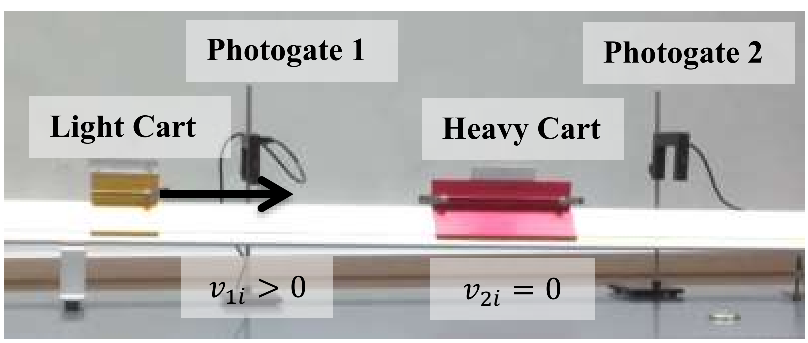

Figure 2. Rough experimental setup for Condition 2.

Condition 3: Two Identical Carts, initially moving toward each other. One cart is moving to the right and collides with the other cart, which is moving to the left. Either two light carts or two heavy carts can be used.

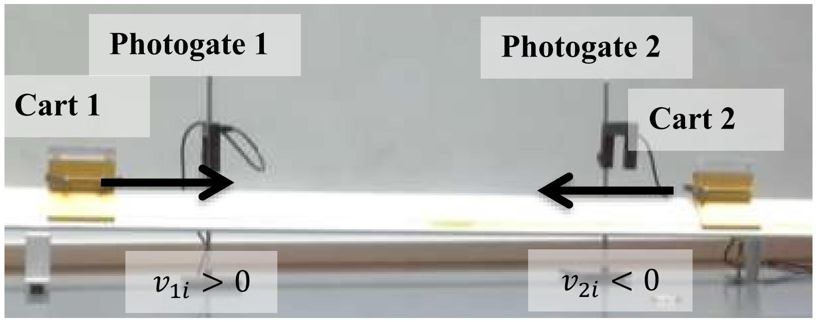

Figure 3. Rough experimental setup for Condition 3.

Data Recording:

1. **Level the track**
2. Adjust the photogates height so that only the flag (the strip of aluminum on the top of a cart) blocks the photogate infrared beam.
3. Connect one Photogate to Channel 1 and another to Channel 2.
4. In the same location as your lab instructions, open "Photogates for Collisions.cap".
5. Turn on the Air Source to lift the carts slightly above the air track and minimize the effect of friction. Practice pushing the cart(s) gently from the ends of the air track so that they collide in the middle of the air track. **Make sure that the collision happens in between the photogates!** Adjust the photogates or your pushing technique.
6. Once you have practiced with collisions between the two carts, proceed to replicate **four collisions for each** one of the conditions described in pictures 1, 2 and 3. For each collision, place the carts according to the corresponding condition/picture and push one or both carts (depending on the condition) such that they collide with each other.
7. After each collision, allow the carts to pass back through the photogates (if appropriate) but grab them from the track before they strike the end bumpers.
8. **Important:** keep track of which cart passed which photogate, and in which direction. The computer won't do this for you.
9. When you record your data, carefully use the measured speeds and your knowledge of the collision to determine each cart's velocity (+ or –) before and after the collision.

ANALYZING THE DATA:

1. Again, the computer only records speed. You must choose the sign (+ or –) of the velocities from your notes about the direction of the motions.
2. Calculate the total momentum before the collision (Equation 2, left side).
3. Calculate the total kinetic energy before the collision (Equation 4, left side).
4. Calculate the total momentum after the collision (Equation 2, right side).
5. Calculate the total kinetic energy after the collision (Equation 4, right side).

According to the law of conservation of energy the total kinetic energy before the elastic collision should be equal to the total kinetic energy after the collision it the collision is elastic. For each collision, compare the kinetic energy before and the kinetic energy after the collision (% diff) for each collision, and then average the calculated values.

Avg. % Diff =____

According to the law of conservation of momentum the total momentum before the collision should be equal to the total momentum after the collision. For each collision, compare the momentum before and the momentum after the collision (% diff) for each collision, and then average the calculated values.

Avg. % Diff =____

Note: The lines above are provided for you to record your results for yourself. Your lab report should include the information either in sentences in the Abstract or in a separate Data Table.

Trial	M (kg)	m (kg)	$V_{i\,M}$(m/s)	$V_{i\,m}$(m/s)	∑p (kgm/s)	∑K (J)
1						
2						
3						
4						

Table 1a, 2a, 3a: Condition … initial values; the light cart is originally …. and the heavy cart is originally.

Trial	M (kg)	m (kg)	$V_{f\,M}$(m/s)	$V_{f\,m}$(m/s)	∑p (kgm/s)	∑K (J)	∑p %diff	∑K %diff
1								
2								
3								
4								
Average % Difference								

Table 1b, 2b, 3b: Condition … final values (the light cart is originally at rest)

Requirements for the Report (also consult the rubric):

Save your Excel files through your Blackboard Group File Exchange.

- The **abstract section** must contain the following explanations in paragraph form:
  - The purpose of the experiment: what did you try to verify and why? Make sure to define elastic vs inelastic collisions with respect to conservation of momentum and kinetic energy.
  - The description of the experimental set up, including the effect of the air cushion and the explanation on the design of the sensor used in the measurements (REM: the sensor measures speed not velocity, humans interpreted the direction).
  - Data collection and calculation for Tables 1a, 2a, 3a: what was measured and how the measured values were used for the calculation of the momentum and kinetic energy.
  - Data collection and calculation for Tables 1b, 2b, 3b: what was measured and how the measured values were used for the calculation of the momentum and kinetic energy including the calculation of the % Difference.
  - Use AVERAGE ratios for each condition to state if kinetic energy and/or momentum was conserved in the experiment. Make sure to identify the type of collision in each case.
  - Discuss the reasons for the difference between the initial and final values of the total kinetic energy and momentum. Could different design of the experiment improve the results? If yes, what should be different?

- The **data section** must include:
  - 6 Tables (labeled and captioned)