Exercise 8: Conservation of momentum

Purpose: Investigate conservation of momentum and mechanical energy in a collision.

Introduction

When objects collide, whether billiard balls, vehicles, shopping carts or football players, the results of their collision can be complicated. Yet even in the most chaotic of collisions, as long as there are no external forces acting on the colliding objects, conservation of linear momentum always holds and provides an excellent tool to study the dynamics of the collision. The conservation of momentum in these closed systems is simply

$$\vec{p}_i = \vec{p}_f \ .$$

In most cases, the collision time is short which means that the effect of external forces will be small in comparison to forces that the objects exert on each other.

For a collision between two objects in one dimension with no external forces acting on the objects, the conservation of linear momentum requires

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f} \ .$$

where we have used the definition of momentum, $\vec{p} = m\vec{v}$.

A collision is called <u>elastic</u> if both the linear momentum and kinetic energy conserve. A collision is called <u>inelastic</u> if only the linear momentum conserves. Perfectly elastic collisions have another conserved quantity, the kinetic energy. The <u>conservation of kinetic energy</u>, $\Delta K = 0$, for two objects undergoing a collision is stated as

$$\frac{1}{2} m_1 v_{1i}^2 + \frac{1}{2} m_2 v_{2i}^2 = \frac{1}{2} m_1 v_{1f}^2 + \frac{1}{2} m_2 v_{2f}^2 \ .$$

In this laboratory you will investigate the linear momentum and kinetic energy of some collisions.

Laboratory assignment

As a quick note setting up the experiment, we will be taking two measurements on a single photogate at times. The photogates will immediately show the first measurement although it will store a second measurement. To reveal the total time of both measurements, click the toggle switch down to the "read" option. *<u>Warning</u>, you must write down the first measurement prior to toggling this switch because it will erase the original value*. The value shown after toggling the switch will be the total time for both measurements, i.e., you will record t_1 and hit the toggle switch to see the value of $t_1 + t_2$. You can find t_2 by taking the difference between the two values.

<u>Part 1: elastic collisions</u>

1. Turn on the air track and level it until a glider moves in both directions with equal ease.
2. Measure the length of each glider's card, ℓ_1 and ℓ_2 to be used as a beam block. Assume negligible error in your measurement. Place these values in Table 1.
3. Determine the mass of each glider with a balance.
4. Place the elastic collision attachments on the gliders (rubber band accessories in your kit).
5. Place both gliders in the middle of the air track and move them so that the attachments on the gliders are touching (this is where the collision will take place).
6. Place an additional 200 g on one of the gliders.

7. Set up the photogates so that they are on either side the gliders. Leave about 5cm of space between the photogate and the beam blocks riding on the gliders.
8. Remove the lighter glider and place it near the end of the track.
9. Turn on both photogates and set them to the single pulse "gate" setting. Turn the "memory toggle to the middle position. Then hit "reset" on both photogates.
10. Push the light glider towards the center of the air track with a reasonable speed and watch the gliders collide.
11. Record the times that the gliders passed through the gates. Be sure to record both time measurements for the gate that recorded two passes, t_1 and t_2, in this experiment. Place these values in Table 1.
12. Analyze this data and fill out the rest of the boxes in Table 1. (Be sure to include the correct sign (positive or negative direction.)

Table 1: data from rubber band collision – heavy glider initially stationary.

		m (kg)	ℓ (cm)	t (s)	v (m/s)	p (kg·m/s)	K (J)
Before collision	Glider 1						
	Glider 2						
After collision	Glider 1						
	Glider 2						

13. Redo this experiment by leaving in the light glider and setting the heavier glider at the end of the track. Fill out Table 2 with the measured values and analysis.

Table 2: data from rubber band collision – light glider initially stationary.

		m (kg)	ℓ (cm)	t (s)	v (m/s)	p (kg·m/s)	K (J)
Before collision	Glider 1						
	Glider 2						
After collision	Glider 1						
	Glider 2						

Part 2: inelastic collisions

14. Repeat the same experiment with the heavy glider colliding with the stationary light glider, but this time replace the rubber band bumpers with the needle and wax bumpers. Fill out Table 3.

Table 3: data from needle/wax collision – light glider initially stationary.

		m (kg)	ℓ (cm)	t (s)	v (m/s)	p (kg·m/s)	K (J)
Before collision	Glider 1						
	Glider 2						
After collision	Glider 1 + glider 2						

Part 3: additional analysis

15. Fill in Table 4 identifying the total momentum and total kinetic energy, before and after the collision. Take the percent differences between the initial and final values to see how close each quantity is conserved.

Table 4: analysis of collision experiment.

	p_i (kg·m/s)	p_f (kg·m/s)	K_i (J)	K_f (J)	% diff$_K$ (%)	% diff$_p$ (%)
Case 1 (elastic)						
Case 2 (elastic)						
Case III (inelastic)						

16. In which cases is the momentum conserved? Explain if these results were expected or why the results are different than anticipated.

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17. In which cases is the kinetic energy conserved? Explain if these results were expected or why the results are different than anticipated.

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Equipment list: air track, glider (2), collision kit, photogates (2).