DUTCHESS COMMUNITY COLLEGE

Lab Report 10: Conservation of Momentum

PHY121

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Purpose

To demonstrate that momentum is conserved during a collision, by analyzing elastic and inelastic collisions.

Theory

Momentum is a measurement of mass in motion. Momentum can be calculated using the following equation:

$$p = mv$$

p : Momentum
m : Mass of object
v : Velocity of object

Unless there is an outside force, the amount of momentum must be the same at two points in time. This *Conservation of Momentum* law can be expressed in the following equation:

$$p_o = p_f \Longrightarrow m_1 v_1 o + m_2 v_2 o = m_1 v_1 f + m_2 v_2 f \tag{1}$$

$\mathbf{p_o}$: Initial Momentum
$\mathbf{p_f}$: Final Momentum
$\mathbf{m_1}$: Mass of object 1
$\mathbf{v_1 o}$: Initial Velocity of object 1
$\mathbf{v_1 f}$: Final Velocity of object 1
$\mathbf{m_2}$: Mass of object 2
$\mathbf{v_2 o}$: Initial Velocity of object 2
$\mathbf{v_2 f}$: Final Velocity of object 2

In *elastic collisions* both momentum **and** *kinetic energy* are conserved. In *inelastic collisions* only momentum is conserved.

Applying an external force to an object will change its momentum. The amount that momentum changes depends on the total time the force is applied. This relationship between force and time is called the *impulse*. Impulse is required to change an object's momentum and can be expressed using the following equation:

$$\text{Impulse} = \overline{F}(t_f - t_o) = \Delta p = m(v_f - v_o) \tag{2}$$

$\mathbf{\overline{F}}$: Average Force
$\mathbf{t_f}$: Final time
$\mathbf{t_o}$: Initial time
$\mathbf{\Delta p}$: Change in Momentum
$\mathbf{m}$: Mass of object
$\mathbf{v_f}$: Final Velocity of object 1
$\mathbf{v_o}$: Initial Velocity of object 1

Procedure

Part 1: Elastic Collisions

1. Opened *Physics Classroom - Momentum & Collision* simulation.
2. Set mode to "Elastic Collision".
3. Set **blue cart** *initial velocity* to 0 m/s and **red cart** *initial velocity* to 5 m/s.
4. Calculated *initial momentum* based off masses of 1 kg for **blue cart** and **red cart**.
5. Ran simulation.
6. Calculated and recorded *final momentum.*
7. Repeated steps 3-5 but set **blue cart** to 2 kg and **red cart** to 1 kg. Also calculated *initial kinetic energy.*
8. Calculated *final momentum* & *kinetic energy.*
9. Calculated *percent difference* between values from step 8 and the initial values calculated in step 7.
10. Repeated steps 7-9 with both masses of **blue cart** and **red cart** set to 1 kg, *initial velocity of* ***red cart*** set to 5 m/s, and *initial velocity* of **blue cart** set to -3 m/s.
11. Repeated steps 7-9 with **red cart** at 2 kg and **blue cart** at 0 m/s

Part 2: Inelastic Collisions

12. Set simulation mode to ”Inelastic Collision”
13. Set mass of both carts to 1 kg, *initial velocity* of **red car** to 6 m/s, and *initial velocity* of **blue car** to 0 m/s.
14. Calculated *initial momentum* and *kinetic energy* in simulation.
15. Ran simulation.
16. Calculated *final momentum* & *kinetic energy* of simulation. Also calculated *percent difference* between *initial values* calculated in step 14.
17. Set mass of **blue cart** to 3 kg and *initial velocity* to 0 m/s.
18. Repeated steps 14 - 16 for new setup.

Part 3: Force During a Collision

19. Opened *Logger Pro.*
20. Set *range switch* on **Force Sensor** to 10 N, and calibrated it using 500 g of mass.
21. Removed **second cart** from track.
22. Placed **clamp** mid way on track.
23. Set **Force Sensor** against **clamp** towards **first cart**.
24. Attached **elastic string** to **cart** and **Force Sensor**.
25. Zeroed all sensors.
26. Pushed **cart** away from **Force Sensor** using a gentle push.
27. Stopped **cart** on way back to **Force Sensor**.
28. Analyzed data using *Logger Pro.*

Calculations & Graphs

Momentum

$$p = mv \tag{3}$$

p : Momentum
m : Mass of object
v : Velocity of object

Sample Calculation

using initial momentum of red cart in Part 1, trial 1

$$\begin{aligned} p &= mv \\ &= (1\text{ kg})(5\text{ m/s}) \\ p &= \boxed{5\text{ kg m/s}} \end{aligned}$$

Kinetic Energy

$$\text{KE} = \frac{1}{2}mv^2 \tag{4}$$

$\boldsymbol{m}$: mass
$\boldsymbol{v}$: velocity

Sample Calculation

initial kinetic energy of red cart, part 1 trial 2

$$\begin{aligned} \text{KE} &= \frac{1}{2}mv^2 \\ &= \frac{1}{2}(1\text{ kg})(5\text{ m/s})^2 \\ \text{KE} &= \boxed{12.5\,\text{J}} \end{aligned}$$

Percent Difference Between Change Calculated Momentum and Impulse From Graph

$$\text{PD} = \left| \frac{\text{measured - actual}}{\text{actual}} \right| \text{ x } 100\% \tag{5}$$

Sample Calculation
using values from part 3

$$\text{PD} = \left| \frac{\text{measured - actual}}{\text{actual}} \right| \text{ x } 100\%$$

$$\text{PD} = \left| \frac{0.4933 \text{ - } 0.4724}{0.4724} \right| \text{ x } 100\%$$

$$PD = \boxed{4.431\%}$$

Tables

Table 1: Part 1: Elastic Collisions - Pre Collision

Trial	1	2	3	4
Red Cart Mass (kg)	1	1	1	2
Blue Cart Mass (kg)	1	2	1	1
Red Cart V_o (m/s)	5	5	5	5
Blue Cart V_o (m/s)	0	0	-3	0
Total Momentum (kg m/s)	5	5	2	10
Total KE (J)	12.5	12.5	17	25

Table 2: Part 1: Elastic Collisions - Post Collision

Trial	1	2	3	4
Red Cart Mass (kg)	1	1	1	2
Blue Cart Mass (kg)	1	2	1	1
Red Cart V_f (m/s)	0	-1.7	-3	1.7
Blue Cart V_f (m/s)	5	3.3	5	6.7
Total Momentum (kg m/s)	5	4.9	2	10.1
Total KE (J)	12.5	12.3	17	25.3
Total Momentum % Difference (%)	0	2	0	1
KE % Difference (%)	0	1.32	0	1.34

Table 3: Part 2: Inelastic Collisions - Pre Collision

Trial	1	2
Red Cart Mass (kg)	1	1
Blue Cart Mass (kg)	1	3
Red Cart V_o (m/s)	6	6
Blue Cart V_o (m/s)	0	0
Total Momentum (kg m/s)	6	6
Total KE (J)	18	18

Table 4: Part 2: Inelastic Collisions - Post Collision

Trial	1	2
Red Cart Mass (kg)	1	1
Blue Cart Mass (kg)	1	3
Red Cart V_f (m/s)	3	1.5
Blue Cart V_f (m/s)	3	1.5
Total Momentum (kg m/s)	6	6
Total KE (J)	9	4.5
Total Momentum % Difference (%)	0	0
KE % Difference (%)	50	75

Table 5: Part 3: Force During a Collision

Mass (kg)	0.6523
V_o (m/s)	-0.4409
V_f (m/s)	0.3154
Δp (kg m/s)	0.4933
Impulse (kg m/s)	0.4724
Percent Difference (%)	4.431

Questions

1. **What do you notice about the velocity of the second car after the collision when both cars are identical and one starts from rest?**

   The velocity of the second car becomes the same velocity as the first car before collision. In an elastic collision, when both objects have the same mass, the moving object transfers their velocity to the stationary object.

2. **What can you say about the momentum of both cars before the collision and the momentum of the cars after the collision?**

   Before the collision, the red cart has momentum since it's moving, while the blue cart has 0 momentum since it's at rest. After the collision, since both carts have the same mass, the red cart has 0 momentum since its velocity gets transferred to the blue cart, which now has momentum.

3. **What do you notice about the heavy cart after the collision? Does it go faster or slower than the 5 m/s?**

   The heavier cart goes slower than 5 m/s after the collision.

4. **What do you notice about the lighter cart after the collision? Which way is it traveling after the collision?**

   The lighter cart goes slower in the opposite direction of its motion prior to the collision.

5. **Is kinetic energy conserved? Is momentum conserved?**

   Yes, both kinetic energy and momentum were conserved.

6. **Write a statement as to what you think should happen to reach cart's motion after the collision.**

   I predict that the red cart's velocity will decrease, and it'll go back in the opposite direction.The blue car's velocity will increase and it'll go towards the right.

7. **Now seeing what you saw, were you right? What can you say about the momentum before the collision and the momentum after the collision?**

   I was correct. Momentum was conserved after the collision.

8. **Write what you expect to happen to the carts after they collide. Which will be traveling fasterslower and in what direction?**

   I expect the red cart to go slower in the opposite direction, and the blue cart to go faster and towards the right.

9. **How right were you in your hypothesis of what you thought would happen? Explain why the carts behaved the way they did after the collision using terms like inertia, force, and momentum.**

I thought the red cart would be slower, so I was correct in that aspect, but I was incorrect in regards to the direction it'd be travelling. I thought the blue cart would go faster, which was correct, and I was also correct about its direction after the collision. Inertia is the tendency of an object to stay in its current state, and is directly correlated with the mass of an object. The red cart keeps moving forward, because of inertia, and the blue cart, since its mass is smaller, moves along with the red cart when the red cart's force is applied to it.

10. **How did the total momentum compare to the total momentum after the collision? How did the total kinetic energy after the collision compare to what it started with?**

    The total momentum after the collision was the same, but the total kinetic energy was cut in half.

11. **How did the total momentum compare to the total momentum after the collision? How did the total kinetic energy after the collision compare to what it started with?**

    Once again, the momentum was the same, and the total kinetic energy was reduced by 75 %.

12. **What do you think the major differences are between an elastic and inelastic collision?**

    The biggest difference between an elastic and inelastic collision is the conservation of kinetic energy.

13. **What is the impulse as calculated by the graph?**

    The impulse as calculated by the graph was 0.4724 kg m/s.

14. **What is the change in momentum, Δp as calculated from the graph?**

    The change in momentum was calculated by the graph to be 0.4933 kg m/s.

15. **Based on your answers from question 14 and 15, would you say that the impulse-momentum theorem is approximately verified? Why or why not?**

    Based on my answers, I'd say that the impulse-momentum theorem is approximately verified since the change in momentum was calculated to be approximately equal to the impulse.

16. **How might the force vs. time graph be different for a more stiff rubber band?**

    A stiffer rubber band would result in the impulse being greater since the tension force would increase.

Conclusion

The purpose of this lab was to demonstrate that momentum is conserved during a collision. By analyzing the momentum of carts through simulation and physical means, we were able to confirm the *Conservation of Momentum* law (see equation 1).

In Part 1, we simulated the motion of the elastic collision of two carts and calculated the total momentum and kinetic energy before and after collision. In an elastic collision, both momentum and kinetic energy are conserved. Our results show that that is true. Across all our simulations for Part 1, the percent difference between the total momentum and kinetic energy, after the collision was less than 3% (see table 2).

An interesting effect occurred in Part 1 when the red and blue carts had equal mass. Under such circumstances the velocities of the two carts swapped. As an example, in Part 1 trial 3 (see tables 1 and 2) the red cart swapped velocities with the blue cart after collision. The same effect also occurred in trial 1 (see tables 1 and 2).

For Part 2, we simulated the motion of the inelastic collision of two carts. Once again, we calculated the total momentum and kinetic energy before and after collision. During inelastic collisions, while momentum is conserved, kinetic energy is not. Based on our results, we can confirm that statement. We conducted two trials: one where both carts were equal in mass, and one where they were different (see tables 3 and 4). In both trials, the percent difference in momentum before and after collision was 0% (see 4). However the percent difference in both trials was much more than 10%, with trial 1 having a 50% difference in total kinetic energy post collision, and trial 2 having a 75% difference (see 4). Since these were inelastic collisions, the results are to be expected.

In Part 3, we analyzed the difference in momentum physically using a cart on a track. After tying a rubber band to a Force Sensor and a cart, we measured the force and velocity of the cart after release. An analysis of the graph generated from Logger Pro, allowed us to determine both the change in momentum and the impulse of the cart's motion. Using equations 2 and 5, we found the percent difference between the impulse and momentum to be 4.431% (see 5). Since this difference is less than 10%, we can confirm that impulse is indeed a change in momentum as described in equation 2.