# conservation of momentum

Structured

Driving Question | Objective

How is the total linear momentum and kinetic energy of a two-object system affected by a collision? Experimentally demonstrate that linear momentum and kinetic energy are conserved in an elastic collision, and that linear momentum is conserved but kinetic energy is not conserved in an inelastic collision.

NOTE: The word “linear” is used to differentiate momentum from angular momentum. It is often omitted for simplicity.

Materials and Equipment

|  |  |
| --- | --- |
| * Data collection system | * PASCO Cart Masses, 250-g (2) |
| * PASCO Smart Cart, blue, with magnetic bumper1 | * PASCO Dynamics Track End Stop (2)3 |
| * PASCO Smart Cart, red, with magnetic bumper1 | * Balance, 0.1-g resolution, 2,000-g capacity |
| * PASCO Dynamics Track with feet2 | (1 per class) |

|  |  |  |
| --- | --- | --- |
| 1[www.pasco.com/ap37](http://www.pasco.com/ap37) | 2[www.pasco.com/ap08](http://www.pasco.com/ap08) | 3[www.pasco.com/ap11](http://www.pasco.com/ap11) |
|  |  |  |
| PASCO Smart Cart | PASCO PAStrack | PASCO Dynamics Track End Stop |

Background

The momentum of an object is equal to the product of its mass m and velocity :

 (1)

For a system that is not influenced by outside forces, the total momentum of the system is conserved. This extends to objects experiencing two types of collisions: elastic and inelastic.

Elastic collisions occur when two objects bounce off each other perfectly (without the loss of kinetic energy), like two billiards balls colliding. Momentum is transferred from one object to the next, and if the two objects are the same mass, all of the momentum of the first is transferred to the second.

Inelastic collisions occur when two objects don’t bounce off each other perfectly. Examples include objects that collide and stick to each other, like two clay balls colliding and then moving as one object; or two objects colliding and deforming as a result of the collision, like a two-car accident.

In this activity, you will use an experimental procedure to demonstrate that the total momentum of a system consisting of two carts on a flat track is conserved in both elastic and inelastic collisions (implying that the total momentum of the system does not change in either collision type), but the total kinetic energy of the system is only constant in elastic collisions.

Relevant Equations

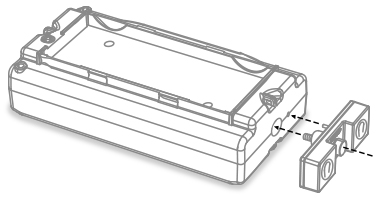
 (1)

 (2)

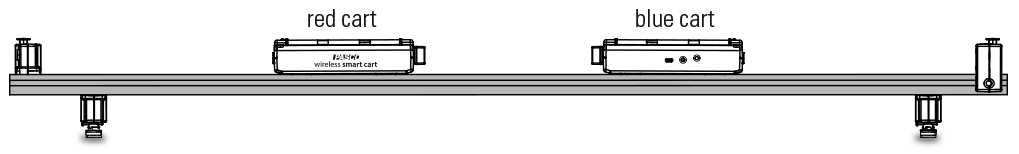
Procedure

Part 1 – Elastic Collision

Set Up

1. Set the track on a level surface with one end stop at each end of the track. Adjust the track feet to make sure the track is as level as possible. 

2. Attach a magnetic bumper to the front of each smart cart, and then set the red cart on the left side of the track, and the blue cart on the right, with both magnetic bumpers facing each other.



3. Power-on both Smart Carts and connect them wirelessly to your data collection system.

NOTE: The Smart Carts are pointed in opposite directions. In this orientation, the red cart by default will measure positive velocity for motion to the right, while the blue cart by default will measure negative velocity to the right. This must be corrected within your data collection system so that both carts report positive velocity for motion to the right. The following step addresses this.

3. In the data collection system, use the built-in “Change Sign” function, or create the calculation “Velocity\_Blue = –[Velocity (m/s)]” (where [Velocity (m/s)] is velocity data measured by the blue Smart Cart) to change the sign of the default velocity measurements made by the blue cart.

4. Create two graph displays: one graph display of velocity versus time for the red cart, and one graph display of the corrected velocity of the blue cart versus time.

Collect Data

5. Measure the mass of each cart. Record the mass of the red cart into Table 1 next to Trial 1, and the mass of the blue cart into Table 2 next to Trial 1 in the Data Analysis section below.

6. Place the blue cart in the middle of the track with its bumper facing left, and the red cart at the left-side end of the track with its bumper facing right.

7. Start recording data, and then gently push and release the red cart toward the blue cart, allowing them to collide. Stop recording data once the carts have collided.

8. Repeat the same data collection steps two additional times, each time adding one of the 250-g cart masses to the blue cart; keep the mass of the red cart the same in all three trials.

NOTE: When measuring cart mass, be sure to measure the mass of the cart plus any masses that you’ve added. Record the red cart’s mass in Table 1 and the blue cart’s mass in Table 2.

9. Use the tools in your graph to find the velocity of both carts just before the collision (initial velocity) and just after the collision (final velocity) in each trial. Enter the red cart velocity values in Table 1, and the blue cart velocity values in Table 2.

Part 2 – Inelastic Collision

Set Up

10. Remove the cart masses from the blue cart.

11. Remove the magnetic bumpers from both carts, and then swap the positions of the carts on the track so that the blue cart is now on the left side of the track and the red cart is on the right with the Velcro® bumpers facing each other.



Collect Data

12. Repeat the same data collection steps from Part 1. However, in this part you will place the red cart in the middle of the track and push the blue cart into the red cart. When the carts collide, they will hit Velcro bumper to Velcro bumper and stick together, resulting in an inelastic collision.

13. Perform three trials, adding one of the 250-g cart masses to the red cart in trial 2, and two cart masses in trial 3.

14. Record the red cart's mass, initial velocity, and final velocity for each trial into Table 4; Record the blue cart's mass, initial velocity, and final velocity for each trial into Table 5.

Data Analysis

Part 1 – Elastic Collision

Table 1: Red cart elastic collision data

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Trial | Mass (kg) | Initial Velocity (m/s) | Final Velocity (m/s) | Initial Momentum (kg·m/s) | Final Momentum (kg·m/s) | Initial Kinetic Energy (J) | Final Kinetic Energy (J) |
| 1 |  |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |  |
| 3 |  |  |  |  |  |  |  |

Table 2: Blue cart elastic collision data

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Trial | Mass (kg) | Initial Velocity (m/s) | Final Velocity (m/s) | Initial Momentum (kg·m/s) | Final Momentum (kg·m/s) | Initial Kinetic Energy (J) | Final Kinetic Energy (J) |
| 1 |  |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |  |
| 3 |  |  |  |  |  |  |  |

1. Calculate the initial and final momentum of each cart in each Part 1 trial. Record the values for the red cart into Table 1 and the values for blue cart into Table 2.

2. Calculate the initial and final kinetic energy of each cart in each Part 1 trial. Record the values for the red cart into Table 1 and the values for blue cart into Table 2.

3. Calculate the total momentum and total kinetic energy of the two-cart system before and after each Part 1 collision. Record the results into Table 3 below.

Table 3: Total system momentum and kinetic energy before and after the elastic collision

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Trial | Initial Momentum  of System (kg·m/s) | Final Momentum  of System (kg·m/s) | Initial Kinetic Energy  of System (J) | Final Kinetic Energy  of System (J) |
| 1 |  |  |  |  |
| 2 |  |  |  |  |
| 3 |  |  |  |  |

Part 2 – Inelastic Collision

Table 4: Red cart inelastic collision data

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Trial | Mass (kg) | Initial Velocity (m/s) | Final Velocity (m/s) | Initial Momentum (kg·m/s) | Final Momentum (kg·m/s) | Initial Kinetic Energy (J) | Final Kinetic Energy (J) |
| 4 |  |  |  |  |  |  |  |
| 5 |  |  |  |  |  |  |  |
| 6 |  |  |  |  |  |  |  |

Table 5: Blue cart inelastic collision data

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Trial | Mass (kg) | Initial Velocity (m/s) | Final Velocity (m/s) | Initial Momentum (kg·m/s) | Final Momentum (kg·m/s) | Initial Kinetic Energy (J) | Final Kinetic Energy (J) |
| 4 |  |  |  |  |  |  |  |
| 5 |  |  |  |  |  |  |  |
| 6 |  |  |  |  |  |  |  |

4. Calculate the initial and final momentum of each cart in each Part 2 trial. Record the values for the red cart into Table 4 and the values for blue cart into Table 5.

5. Calculate the initial and final kinetic energy of each cart in each Part 2 trial. Record the values for the red cart into Table 4 and the values for blue cart into Table 5.

6. Calculate the total momentum and total kinetic energy of the two-cart system before and after each Part 2 collision. Record the results into Table 6 below.

Table 6: Total system momentum and kinetic energy before and after inelastic collision

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Trial | Initial Momentum  of System (kg·m/s) | Final Momentum  of System (kg·m/s) | Initial Kinetic Energy  of System (J) | Final Kinetic Energy  of System (J) |
| 4 |  |  |  |  |
| 5 |  |  |  |  |
| 6 |  |  |  |  |

Analysis Questions

* 1. What experimental evidence do you have showing that momentum is conserved in inelastic and elastic collisions?

* 2. How does your data support that kinetic energy is conserved in elastic collisions?

* 3. How does your data support that kinetic energy is NOT conserved in inelastic collisions?

* 4. Why is kinetic energy not conserved in inelastic collisions? Where is the energy lost?

Synthesis Questions

* 1. Two locomotives, each weighing 100,000 kg and having a speed of 100 km/hr, race toward each other and have a completely inelastic collision. What is the final momentum of the system? Justify your answer.

* 2. A 10.0-kg bowling ball sliding across a frictionless surface, with a velocity of 3.00 m/s, collides head-on with a stationary 9.00-kg bowling ball. The collision is perfectly elastic, sending the 9.00-kg ball sliding away and leaving the 10.0-kg ball with a velocity of 0.158 m/s. What is the speed of the 9.00-kg ball after the collision? What is the total kinetic energy of the system after the collision?

* 3. A mother (mass 60.0 kg) skates across an ice rink with negligible friction toward her child (mass 20.0 kg), who is standing still on the ice. If the mother moves at 4.0 m/s before she picks up her child, what is her new speed after she picks up her child and holds onto him? What is the total energy of the mother-child system after she picks up the child?
* 4. A 25.0-kg dog is trapped on a rock in the middle of a narrow river. A 66.0-kg rescuer has assembled a swing with negligible mass that she will use to swing down and catch the trapped dog at the bottom of her swing, and then continue swinging to the other side of the river. The ledge that the rescuer swings from is 5.0 m above the rock, which is not high enough so the rescuer and dog together can reach the other side of the river, which is 3.0 m above the rock. However, the rescuer can use a ladder to increase the height from which she swings. What is the minimum height of the ladder the rescuer must use so both dog and rescuer make it to the other side of the river? Assume that friction and air resistance are negligible.

