Lab 8:
Conservation of Momentum

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In this lab you will learn

- how to determine if momentum is conserved during an elastic collision when a moving object collides into a stationary object of the same mass
- how to determine if momentum is conserved during an inelastic collision when a moving object collides with another object and comes to a complete stop
- how to determine if momentum is conserved during an elastic collision when a moving object collides with other moving objects of different masses. Use a velocity-time graph to find out the time of the collision

Activity 1: Pre-Assessment

1. What do you think might happen to the kinetic energy and momentum of one toy car that collides with another toy car in its path? Does the momentum of the first car change because of the collision? Does the momentum of the second car change because of the collision? Does the kinetic energy of the first car change because of the collision? What about the kinetic energy of the second car?
2. Think of ways to measure the time taken by the car to travel from one end of the table to another. Think of ways to measure the distance traveled by the car before and after the collision.
3. **Discuss the answers to questions 1 and 2 with the class.**

Activity 1: Elastic Collision

In most collisions, we assume there are no net forces acting from outside the system, and the total momentum is the same before and after the collision. An **elastic collision** is one in which the total kinetic energy is also unchanged by the collision. Billiard balls provide a good example. When billiard balls collide, the total momentum after the collision is the same as the total momentum before the collision. Even though one of the balls may slow down after the collision, thereby decreasing its own kinetic energy, this is almost entirely because it transfers kinetic energy to the other ball, which then travels with increased kinetic energy and momentum. We can take the total kinetic energy of both billiard balls to be unchanged, making it an example of a **perfect** or **near-perfect elastic collision**.

Safety Precautions

- Inform your teacher immediately of injuries caused by moving objects.
- Clean up and inform your teacher immediately about any broken objects to prevent people from being injured.
- Objects that can roll are hazardous to step on unexpectedly. If the floor is used to roll the carts, immediately remove any cart that rolls out of the temporary test area of the floor.

For this activity you will need the following:

- A rectangular table with a flat surface where the length of the table is longer than the width, or a large, clear floor surface
- Two lab carts of different mass
- One ruler
- Lab scale
- Three chalk pieces of different colors
- Three stopwatches, numbered 1–3, or video camera to record the actions

For this activity you will work *in pairs if using a video camera***,** or *groups of four if using stopwatches*.

Structured Inquiry

Step 1: The idea behind this experiment is to compare the total momentum after a collision with the total momentum before a collision by colliding one moving cart into a second cart at rest. You will determine the initial and final velocities of both carts to calculate the momentum of each cart. You will also use the data you collect to calculate and compare the initial and final kinetic energies.

To measure the velocity of each cart before and after the collision, place chalk marks on the table, one a short distance after the place where the first cart will be released, another where the second cart is at rest, and the third a distance after that. The chalk lines are distance markers for pressing the stopwatch as a cart passes the line. If stopwatches are used, choose one student to be in charge of each stopwatch and one in charge of setting the cart into motion. If a video camera is used, two lab partners can divide the tasks.

Step 2: Hypothesize/Predict: Predict what happens to the velocities and momenta of the two colliding carts when the first cart collides with a second cart of smaller mass in its path. In which direction do you predict each cart will move after the collision? What might happen to the velocity and momentum of the first colliding cart? What might happen to the velocity and momentum of the second colliding cart? What would be the total momentum of the two colliding carts before and after the collision? Will the total momentum be exactly the same or only approximately the same? Add your predictions to the data table you create.

Step 3: Weigh each colliding cart to determine its mass. For this experiment, the first cart should have greater mass than the second. If a video camera is not available, follow the steps below: Draw a chalk line that the first cart will cross after it has been pushed and is rolling on its own. Place the second chalk line where the stationary cart is located, and the third chalk line a distance after that.

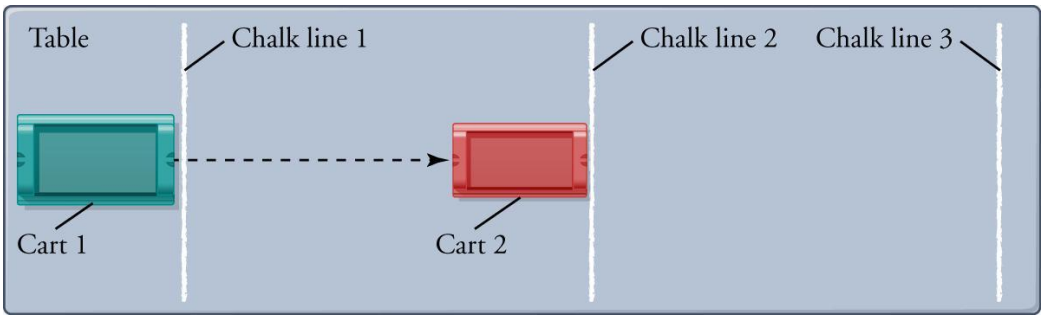


Figure 8.1: Arrangement for using stopwatches to measure the velocities and momenta of a more massive cart colliding elastically with a less massive cart.

Step 4: Student-Led Planning: What data will you need to find the velocity and momentum of each cart? How exactly will you measure the quantities needed, and calculate the intended results from the data collected? Discuss with your lab partner or partners, and describe your proposed method in your notebook. After you have collected your data, you will want to calculate the total kinetic energy of the carts before collision to compare with the total kinetic energy after collision. Describe in your notebook how you will use the data already collected to make that comparison. Decide on the positions of the student timing each part of the motion or operating the video recorder.

Step 5: Use the scale to determine the mass of each cart, and enter the masses into your notebook. Carry out your measurements for the case of a more massive cart colliding into a less massive one at rest. Determine the time and distance of travel for each cart before and after collision to find the velocity and momentum of each cart before the collision and of each cart after the collision. Record your data in the table created in your notebook.

Step 6: Critical Analysis: Based on the observations and calculations in your data table, were the predictions you made in Step 3 supported by your data? Why or why not? How did the total momentum of the two carts before collision compare with the total momentum of the two carts after collision? How accurate were your predictions about the directions in which the carts would move after collision? What methods could you have used to improve your results? Discuss with your partner and then write your answers in your notebook.

Step 7: Critical Analysis: Use your data to calculate the kinetic energy each cart had before collision and the kinetic energy each cart had after collision. How did the kinetic energy of each cart change? Calculate the total kinetic energy of both carts before collision, and the total kinetic energy after collision. Compare how well momentum was conserved with how well kinetic energy was conserved. Discuss with your lab partners and write your answers in your notebook.

Guided Inquiry

Step 1: Hypothesize/Predict: How do you think the results of the collision would be different if the less massive cart struck the more massive cart at rest? How do you think the directions and relative sizes of the velocities of the two carts after collision would depend on which has the larger mass? Write your ideas in your notebook.

Step 2: Student-Led Planning: How would you design an experiment to measure the total momentum before and after the collision? List the objects and lab equipment that you would need to conduct your experiment. Describe how you would measure important values, and what you would calculate from the collected data. Submit your list and research plan to your teacher. Once your teacher approves, carry out your experiment. Collect your data in your notebook, and determine the velocities, momenta, and total moment before and after collision. Write your results in your notebook.

Step 3: Critical Analysis: What differences did you notice when the less massive object was moving and struck a more massive stationary object? Did the results confirm your predictions? How well was total momentum conserved? Discuss your answers with your partner and write them in your notebook.

Step 4: Critical Analysis: Determine if your data shows conservation of total kinetic energy. Explain any significant loss or gain of kinetic energy that you found. Discuss your answers with your partner and write them in your notebook.

Assessments

1. A student records the distance traveled by object 1 as 10 cm before and 15 cm after the collision, and the time before and after the collision as 5.0 seconds each. If the 2 objects have a mass of 1.0 g each:
    a. Does this scenario describe a loss in kinetic energy for object 1 after the collision? Why or why not?
    b. Does this scenario describe a loss in momentum for object 1 after the collision? Why or why not?
2. How is the kinetic energy of an object changed if its momentum increases?
3. In an elastic collision, the total momentum of two objects before the collision is $20\ \mathrm{g \cdot cm/s}$. The mass of the first object is 2.0 g, and its velocity is $5.0\ \mathrm{cm/s}$ after the collision.
    a. What should be the total momentum of the two objects after a perfectly elastic collision?
    b. What is the momentum of the first object after the collision?

Activity 2: Pre-Assessment

1. What do you think might happen to the kinetic energy and momentum of a slowly moving train car when it meets and latches onto another train car that is free to roll but not moving? Do the momentum and velocity of the first car change because of the collision? How? Does the total momentum of both cars change because of the collision? Does the kinetic energy of the first car change because of the collision?
2. Think of how you can measure the kinetic energy and momentum of a small cart as it moves across the floor after it is pushed and released.
3. **Discuss the answers to questions 1 and 2 with the class.**

Activity 2: Inelastic Collisions

A perfectly **inelastic collision** occurs when two colliding objects stick together after a collision. One example of an inelastic collision is putty striking a wall. Upon hitting the wall, the putty stops and gets stuck. Both the momentum and kinetic energy it had have been reduced to zero. In this case, neither kinetic energy nor momentum is preserved. Most everyday collisions are inelastic (though not *perfectly* inelastic) because the kinetic energy of the colliding objects are converted into other forms of energy, such as that associated with producing sound.

Safety Precautions

- Inform your teacher immediately of injuries caused by moving objects.
- Clean up and inform your teacher immediately about any broken objects to prevent people from being injured.
- Avoid allowing any objects, especially those capable of rolling, to remain on the floor outside of the area being used for testing, to avoid anyone slipping and falling on them.

For this activity you will need the following:

- A rectangular table with a flat surface where the length of the table is longer than the width, or a large, clear floor surface
- Two lab carts with hook-and-loop fastener tape attached, or a mechanical clip, so that they stick together after collision
- A video camera to record the experiments, or a stopwatch
- One ruler
- Lab scale
- One chalk piece
- Two stopwatches

For this activity you will work *in pairs*.

Structured Inquiry

Step 1: We will now examine what happens in a perfectly inelastic collision, when one moving cart collides into another at rest with the same mass, and the two stick and move together. To do this, you will need to measure the velocity of the moving cart before colliding and the velocity of the two carts together after colliding.

Step 2: Hypothesize/Predict: When a moving cart collides into another of the same mass at rest, and the two stick together, do you predict that the total momentum will be conserved in the collision? How about the total kinetic energy? How will the velocity of the two carts moving together compare with the velocity the one cart had when it was moving? Discuss your predictions with your partner and write them in your notebook.

Step 3: Weigh each colliding cart to determine its mass in grams. For this experiment, both colliding carts should have the same mass. Assure that patches of hook-and-loop fastener tape, or a mechanical clip mechanism, are in place on the two carts so they will stick together upon collision.

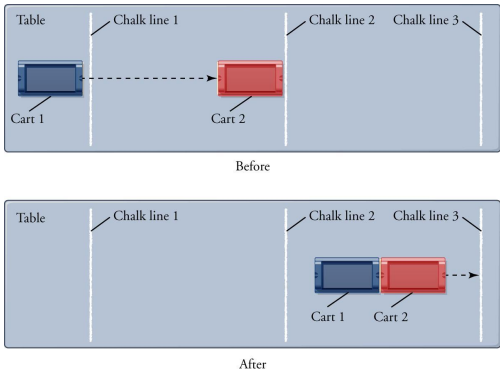


Figure 8.2: Arrangement for using stopwatches to measure the velocities and momenta of two carts undergoing a perfectly inelastic collision.

Step 4: Student-Led Planning: Discuss with your lab partner how you will collect data to determine the velocity of the single moving cart and then of the two carts moving together after collision. Place the second cart in the path of the first cart. Start the video camera and record the entire experiment. If you do not have a video camera, you will use stopwatches to measure the times of travel and the distances between three chalk lines drawn for this purpose. The first chalk line should be at a location where the first cart is moving but no longer being pushed, the second at the collision point, and the third a distance after the collision point. Record your data in your notebook. Calculate the initial velocity of the first cart and the final velocity of the two carts. Then calculate the total momentum before and after the collision.

Step 5: Critical Analysis: Based on the observations and calculations in your data table, were the predictions you made in Step 3 about the initial and final velocity supported by your data? Does your data support the law of conservation of momentum? Explain any causes you can think of for any observed disagreement. What methods could you have used that would improve your results? Discuss with your partner and then write your answers in your notebook.

Guided Inquiry

Step 1: Hypothesize/Predict: How do you think the results of the inelastic collision experiment would differ if the collision were between carts of unequal mass? Write a mathematical expression for the total momentum of Cart 1 and Cart 2 if Cart 1 has mass m_1 and velocity $\boldsymbol{v}_{1i}$ and Cart 2 has mass m_2 and is not moving. Then write an expression for the total momentum of Cart 1 and 2 stuck to each other and moving together at velocity **v**. Work with your partner to apply conservation of total momentum to equate the two expressions and to solve the equation that results to predict the final velocity in terms of the initial velocity and the two masses. Write your derivation and prediction in your notebook.

Step 2: Critical Analysis: Based on the observations and calculations in your data table, were the predictions you made in Step 3 about the initial and final velocity supported by your data? Does your data support the law of conservation of momentum? Explain any causes you can think of for any observed disagreement. What methods could you have used that would improve your results? Discuss with your partner and then write your answers in your notebook.

Guided Inquiry

Step 1: Hypothesize/Predict: How do you think the results of the inelastic collision experiment would differ if the collision were between carts of unequal mass? Write a mathematical expression for the total momentum of Cart 1 and Cart 2 if Cart 1 has mass m_1 and velocity $\boldsymbol{v}_{1i}$ and Cart 2 has mass m_2 and is not moving. Then write an expression for the total momentum of Cart 1 and 2 stuck to each other and moving together at velocity **v**. Work with your partner to apply conservation of total momentum to equate the two expressions and to solve the equation that results to predict the final velocity in terms of the initial velocity and the two masses. Write your derivation and prediction in your notebook.

Step 2: Student-Led Planning: Discuss with your partner how to test your prediction by collecting velocity data using methods and equipment from this lab. Carry out the experiment, and enter the masses and measured velocities in a data table in your notebook.

Step 3: Critical Analysis: Use your mass and velocity data in the expression for the final velocity you derived in Step 1 to find a numerical value of the predicted velocity. How well does your prediction compare with your measured final velocity of the two carts moving together? Comment on any reasons you can think of for any substantial disagreement. How could you improve the accuracy of your data? Discuss your answers with your partner and write them in your notebook.

Assessments

1. A student records data about a collision between two objects. Object 1 travels a total of 2 seconds before the collision while object 2 travels 5 seconds before the collision. If both objects have the same mass and object 1 traveled 10 cm and Object 2 traveled 25 cm before the collision,
    a. does this scenario describe object 1 with greater momentum than Object 2 before and after the collision? Why or why not?
    b. does this scenario describe object 2 with greater kinetic energy than Object 1 before and after the collision? Why or why not?
2. Is it possible for an object to have momentum but not kinetic energy, or kinetic energy without having momentum?
3. In an inelastic collision, where a ball hits a wall, the total momentum of the ball before the collision is $10\ \mathrm{g \cdot cm/s}$.
    a. If this collision is inelastic, will the momentum of the ball after the collision be the same, greater, or lesser?
    b. What is the momentum of the wall after the collision?