# Momentum Lab from Carolina Kits

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04/18/2024

**Activity 1: Elastic Collision with Equal Masses Data Table 1**

**Table 1A. Cart A before collision.**

| Cart A mass, m (kg) | Distance, d (m) | Time, t (s) | Average time, t (s) | Velocity = d/t (m/s) $v_A$ |
|---|---|---|---|---|
| *0.0743* | *0.5* | Trial 1: .57 | *0.58* | *0.86* |
| | | Trial 2: .60 | | |
| | | Trial 3: .57 | | |

**Table 1B. Cart A after collision.**

| Cart A mass, m (kg) | Distance, d (m) | Time, t (s) | Average time, t (s) | Velocity = d/t (m/s) $v_A'$ |
|---|---|---|---|---|
| *0.0743* | *0.0* | Trial 1: .03 | *.03* | *0* |
| | | Trial 2: .04 | | |
| | | Trial 3: .03 | | |

**Table 1C. Cart B after collision.**

| Cart B mass, m (kg) | Distance, d (m) | Time, t (s) | Average time, t (s) | Velocity = d/t (m/s) $v_B'$ |
|---|---|---|---|---|
| *0.0768* | *0.5* | Trial 1: .57 | *.57* | *.88* |
| | | Trial 2: .57 | | |
| | | Trial 3: .56 | | |

**Calculations for Activity 1. Elastic Collision with Equal Masses**

Apply the law of conservation of momentum to the two-cart system by calculating the momentum before and after the collision.

Helpful equations:

Momentum before the collision = $m_A\boldsymbol{v}_A + m_B\boldsymbol{v}_B$

Momentum after the collision = $m_A\boldsymbol{v}_A' + m_B\boldsymbol{v}_B'$

$$m_A\boldsymbol{v}_A + m_B\boldsymbol{v}_B = m_A\boldsymbol{v}_A' + m_B\boldsymbol{v}_B'$$

$$Percent\ difference = \left| \frac{\text{first value} - \text{second value}}{\frac{\text{first value} + \text{second value}}{2}} \right| x\ 100\%$$

1. Calculate the momentum of the system before the collision (the left side of the equation) and after the collision (the right side of the equation).
   a. $Before: m_A v_A + m_B m_B \ \rightarrow\ .0743 * .86 + .0768 * 0 =\ .0639\ kg\frac{m}{s}$
   b. $After: m_A v_A + m_B m_B \ \rightarrow\ .0743 * 0 + .0768 * .88 =\ .0676\ kg\frac{m}{s}$

2. Calculate the percent difference between the two values.

a. $Percent\ difference = \left|\frac{.0639 - .0676}{\frac{.0639 + .0676}{2}}\right| x\ 100\% \rightarrow 5.6\%$

3. Explain any difference in the values before and after the collision.
    a. The first activity required me to begin the observation by weighing both carts. Cart B's mass was slightly more because of the attached spring. Following the instructions, the foam board was placed at a ~9-degree angle and marks were inscribed at 10cm intervals on a 70 cm strip of masking tape.
    b. Cart A was placed at the release point on the foam board and I recorded its displacement from the release to the end point. After three trials, Cart B was placed at the designated start point to observe a collision.
    c. Momentum equations attempt to quantify motion. OpenStax mentions that Newton originally stated his Second Law in terms of Momentum. Where the net force is equal to the change in momentum over the change in time.
    d. Combined, Cart A and Cart B become a constant mass system. The equation for momentum $[\Delta p = \Delta(mv)]$ becomes $m\Delta v = m\Delta v$. Considering Newton's second law, we can find the net force by dividing both sides by the change in time, $\boldsymbol{F}_{net} = \frac{m\Delta \boldsymbol{v}}{\Delta t} = \frac{m\Delta \boldsymbol{v}}{\Delta t}$.
    e. In the first week, we learned that the vector quantity acceleration is equal to the change in velocity divided by the change in time. Thus, we arrive at Newton's Second Law, $\boldsymbol{F}_{net} = m\boldsymbol{a}$.
    f. The motion of the system could be described as a one-dimensional Kinematics application along the horizontal axis. Where, the total momentum of the system before the collision is equal to the total momentum after the collision. Mathematically, we can describe this phenomenon with $m_{A_{t_0}} v_{A_{t_0}} + m_{B_{t_0}} v_{B_{t_0}} = m_{A_{t_1}} v_{A_{t_1}}{}' + m_{B_{t_1}} v_{B_{t_1}}{}'$.
    g. To find the momentum of the system before the collision, I added the mass times velocity of Cart A plus the mass times velocity of Cart B. Cart B had a zero velocity. Thus, the kinetic energy before the collision is based on the mass of Cart A.
    h. The momentum of the system before the collision was .0639 $kg\frac{m}{s}$. After the collision, the calculated momentum was .0676 $kg\frac{m}{s}$. My observation had a 6% difference. This is well within the margin of error.
    i. Most of the deviation was caused by human error, friction, and environmental conditions. The recording software was able to analyze movement at 3/100th intervals. A more precise recording device would net a closer approximation.

**Activity 2: Elastic Collision: Mass Added to Cart A Data Table 2**

**Table 2A. Cart A before collision.**

| Cart A mass, m (kg) | Distance, d (m) | Time, t (s) | Average time, t (s) | Velocity = d/t (m/s) $v_A$ |
|---|---|---|---|---|
| .1938 | 0.5 | Trial 1: 0.53 | 0.53 | 0.9375 |
| | | Trial 2: 0.54 | | |
| | | Trial 3: 0.53 | | |

**Table 2B. Cart A after collision.**

| Cart A mass, m (kg) | Distance, d (m) | Time, t (s) | Average time, t (s) | Velocity = d/t (m/s) $v_A$' |
|---|---|---|---|---|
| 0.1938 | 0.2 | Trial 1: 0.4 | 0.41 | 0.4839 |
| | | Trial 2: 0.4 | | |
| | | Trial 3: 0.44 | | |

**Table 2C. Cart B after collision.**

| Cart B mass, m (kg) | Distance, d (m) | Time, t (s) | Average time, t (s) | Velocity = d/t (m/s) $v_B$' |
|---|---|---|---|---|
| 0.0768 | 0.5 | Trial 1: 0.34 | 0.36 | 1.4019 |
| | | Trial 2: 0.36 | | |
| | | Trial 3: 0.37 | | |

**Calculations for Activity 2. Elastic Collision: Mass Added to Cart A.**
Apply the law of conservation of momentum to the two-cart system by calculating the momentum before and after the collision.

Helpful equations:
Momentum before the collision = $m_A\boldsymbol{v}_A + m_B\boldsymbol{v}_B$
Momentum after the collision = $m_A\boldsymbol{v}_A' + m_B\boldsymbol{v}_B'$

$$m_A\boldsymbol{v}_A + m_B\boldsymbol{v}_B = m_A\boldsymbol{v}_A' + m_B\boldsymbol{v}_B'$$

$$Percent\ difference = \left|\frac{\text{first value} - \text{second value}}{\frac{\text{first value} + \text{second value}}{2}}\right| x\ 100\%$$

1. Calculate the momentum of the system before the collision (the left side of the equation) and after the collision (the right side of the equation).
    a. $Before: m_A v_A + m_B m_B \rightarrow .1938 * .94 + .0768 * 0 = .1822\ kg\frac{m}{s}$
    b. $After: m_A v_A + m_B m_B \rightarrow .1938 * .48 + .0768 * .88 = .1606\ kg\frac{m}{s}$

2. Calculate the percent difference between the two values.

a. $Percent\ difference = \left|\frac{.1822 - .1606}{\frac{.1822 + .1606}{2}}\right| x\ 100\% \rightarrow 12\%$

3. Explain any difference in the values before and after the collision.
   a. Now that we defined the relevant terms and established a baseline with two carts of equal mass, the second activity required me to add 5 large weights to Cart A. Cart A was placed at the release point and I observed the unimpeded velocity. Then, Cart B was placed at the starting point and I recorded the time at collision, time it took for Cart A to move 20 cm and the time for Cart B to move 50cm.
   b. The momentum of the system before and after the collision was .1822 $kg\frac{m}{s}$ and .1606 $kg\frac{m}{s}$ respectively. My observation for the second activity had a 12% difference. This is well within the margin of error.
   c. In a constant mass system, momentum is the product of mass times acceleration. After weight was added to Cart A, the kinetic energy of the system at the release point was greater.
   d. As I stated previously, most of the deviation was caused by human error and friction. The foam board had a lower coefficient of friction than the wooden surface used for the start and end point. The additional weight of Cart A created more heat (friction) with the axles and wood after the collision.

**Activity 3: Elastic Collision: Mass Added to Cart B Data Table 3**

**Table 3A. Cart A before collision.**

| **Cart A mass, m (kg)** | **Distance, d (m)** | **Time, t (s)** | **Average time, t (s)** | **Velocity = d/t (m/s) $v_A$** |
|---|---|---|---|---|
| *.1048* | *0.35* | Trial 1: 0.36 | *0.36* | *0.96* |
| | | Trial 2: 0.37 | | |
| | | Trial 3: 0.36 | | |

**Table 3B. Cart A after collision.**

| **Cart A mass, m (kg)** | **Distance, d (m)** | **Time, t (s)** | **Average time, t (s)** | **Velocity = d/t (m/s) $v_A$'** |
|---|---|---|---|---|
| *.1048* | *0.1* | Trial 1: 0.44 | *0.42* | *-0.23* |
| | | Trial 2: 0.43 | | |
| | | Trial 3: 0.41 | | |

**Table 3C. Cart B after collision.**

| Cart B mass, m (kg) | Distance, d (m) | Time, t (s) | Average time, t (s) | Velocity = d/t (m/s) $v_B$' |
|---|---|---|---|---|
| *0.3427* | *0.35* | Trial 1: 1.00 | *1.00* | *0.34* |
| | | Trial 2: 1.03 | | |

| Cart B mass, m (kg) | Distance, d (m) | Time, t (s) | Average time, t (s) | Velocity = d/t (m/s) $v_B$' |
|---|---|---|---|---|
| | | Trial 3: 0.98 | | |

**Calculations for Activity 3. Elastic Collision: Mass Added to Cart B.**
Apply the law of conservation of momentum to the two-cart system by calculating the momentum before and after the collision.

Helpful equations:
Momentum before the collision = $m_A\boldsymbol{v}_A + m_B\boldsymbol{v}_B$
Momentum after the collision = $m_A\boldsymbol{v}_A' + m_B\boldsymbol{v}_B'$

$m_A\boldsymbol{v}_A + m_B\boldsymbol{v}_B = m_A\boldsymbol{v}_A' + m_B\boldsymbol{v}_B'$

$$Percent\ difference = \left|\frac{\text{first value} - \text{second value}}{\frac{\text{first value} + \text{second value}}{2}}\right| x\ 100\%$$

1. Calculate the momentum of the system before the collision (the left side of the equation) and after the collision (the right side of the equation).
    a. $Before: m_A v_A + m_B m_B\ \rightarrow\ .1048 * .96 + .3427 * 0 =\ .1\ kg\frac{m}{s}$
    b. $After: m_A v_A + m_B m_B\ \rightarrow\ .1048 * -.23 + .3427 * .34 =\ .09\ kg\frac{m}{s}$

2. Calculate the percent difference between the two values.
    a. $Percent\ difference = \left|\frac{.1 - .09}{\frac{.1 + .09}{2}}\right| x\ 100\%\ \rightarrow 10.5\%$

3. Explain any difference in the values before and after the collision.
    a. The final activity required me to add 11 large weights to Cart b and 5 small washers to Cart A. Cart A was placed at the release point and I observed the unimpeded velocity over 35 cm. Then, Cart B was placed at the starting point and I recorded the time at collision, the time it took for Cart A to move 10 cm and the time for Cart B to move 35 cm.
    b. The momentum of the system before and after the collision was .1 and .09 respectively. My observation for the second activity had a 10.5% difference. This is well within the margin of error.
    c. In a constant mass system, momentum is the product of mass times acceleration. The purpose of activity is to demonstrated negative acceleration or Cart A's motion in the opposite direction after the collision.
    d. We learned that an object will stay at rest or in motion unless acted upon by a net external force. At the point of impact, Cart A travels in the

negative direction with a velocity of -.23 $\frac{m}{s}$. The momentum of Cart A is subtracted from the system.

j. As I stated previously, most of the deviation was caused by human error and friction. The foam board had a lower coefficient of friction than the wooden surface used for the start and end point. The additional weight of Cart B created more heat (friction) with the axles and wood after the collision. A more precise recording device would net a closer approximation.

**Questions for Momentum**:

1. The law of conservation of momentum states that the total momentum before a collision equals the total momentum after a collision provided there are no outside forces acting on the objects in the system. What outside forces are acting on the present system that could affect the results of the experiments?
   a. Non conservative work forces are acting on the present system and affecting the results of the experiments. Friction is a non-conservative force that creates non-conservative thermal energy. I mentioned that the foam board has a smoother surface than wood. However, the static and kinetic friction on both surfaces causes an increase in thermal energy.
   b. The friction between the surface, wheels, axles, and cart increases as weight is added to the carts. An increase in mass will lead to increase in resistance to motion in the form of friction.

2. What did you observe when Cart A containing added mass collided with Cart B containing no mass? How does the law of conservation of momentum explain this collision?
   a. In the second activity, the mass of Cart A and B was .1938 $kg\frac{m}{s}$ and .0768 $kg\frac{m}{s}$ respectively. The unimpeded velocity of Cart A over a .5 m distance was .93 $\frac{m}{x}$.
   b. After Cart A collided with Cart B, the velocity of Cart A and B was .48 and 1.4 respectively. Additionally, I visually observed Cart B being displaced from the start point to the end point at a greater velocity than Cart A.
   c. The law of conservation of momentum states that energy cannot be created nor destroy. It can only be stored or transformed. Relative the first activity, the added mass in the second activity of Cart A times the acceleration increases the kinetic energy before the collision.
   d. The momentum before the system causes by the kinetic energy of Cart A can be represented mathematically as $m_{A_{t_0}} v_{A_{t_0}} + m_{B_{t_0}} v_{B_{t_0}}$ where the velocity of Cart B is zero. Thus, we have the equation $p = m_{A_{t_0}} v_{A_{t_0}}$ for momentum before the collision.
   e. Cart B had a lighter mass than Cart A. After the collision, the kinetic energy of Cart A was shared with Cart B. This can be represented

mathematically as $m_{A_{t_1}} v_{A_{t_1}}{}' + m_{B_{t_1}} v_{B_{t_1}}{}'$. After plugging in the known values before and after the collision for momentum, we arrive at $m_{A_{t_0}} v_{A_{t_0}} + m_{B_{t_0}} v_{B_{t_0}} = \ m_{A_{t_1}} v_{A_{t_1}}{}' + m_{B_{t_1}} v_{B_{t_1}}{}' \rightarrow .1822\ kg \frac{m}{s}_{before} = .1606\ kg \frac{m}{s}_{after}$ with a 12% difference due to outside forces.

f. Cart A moves at slower velocity after the collision. However, the net force of the system remains relatively unchanged. This is represented by the decrease in velocity of Cart A and the increase in velocity of Cart B.

3. In one of the experiments, Cart A may reverse direction after the collision. How is this accounted for in your calculations?
   a. In the third activity, the motion of Cart A was from East to West. After the collision, Cart A travel West to East. This represents motion in the negative direction. We were instructed to observe Cart A's possible negative displacement over .1 meters. We used the equation $s = \frac{\Delta d}{\Delta t}$ to final the final velocity of both carts after the collision. Mathematically, Cart A's velocity was determined by $V_f = \frac{d_f - d_i}{t_f - t_i}$ or $V_f = \frac{-0.1m - 0m}{0.42s - 0s}$.
   b. The negative in front of the recorded distance represents the negative displacement of Cart A. The momentum from Cart A is subtracted from the momentum of Cart B, $\left[m_{B_{t_1}} v_{B_{t_1}}{}' - \ m_{A_{t_1}} v_{A_{t_1}}{}' \ \rightarrow \ 1048 * -.23 + .3427 * .34 = \ .09\ kg \frac{m}{s}\right]$.
   c. From the above calculation, we can see that I have accounted for the reverse in direction, after the collision, for Cart A.