Collision Lab

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Contents

Abstract

1 Theory

When objects come into contact while in motion (note that one may instead begin stationary), this interaction is commonly referred to as a *collision*, during which momentum and energy may be exchanged between them. We can categorize collisions into two primary types: elastic and inelastic.

Momentum is quantified by its velocity, which is the rate at which it covers distance relative to a point of reference over some period of time. We denote

$$v = \frac{\ell}{t} \tag{1}$$

Where ℓ is the length of the distance covered, and t is the time that it took to cover such distance.

Considering an object has mass, its momentum, denoted by p, is calculated by multiplying its velocity by its mass.

$$p = mv \tag{2}$$

In scenarios involving several objects, the total momentum is the sum of the individual momenta.

$$p_{\text{TOT}} = p_1 + p_2 + \ldots = m_1 v_1 + m_2 v_2 + \ldots \tag{3}$$

We first explore inelastic collisions, which is when two objects stick together and form a single entity after they collide. In this case, the momentum remains conserved, but kinetic energy does not.

$$\begin{gathered} K_i \neq K_f \\ K_{1,i} + K_{2,i} \neq K_{1,f} + K_{2,f} \\ \frac{1}{2} m_1 v_{1,i}^2 + \frac{1}{2} m_2 v_{2,i}^2 \neq \frac{1}{2} m_1 v_{1,f}^2 + \frac{1}{2} m_2 v_{2,f}^2 \end{gathered} \tag{4}$$

Thus, in these scenarios, only momentum is preserved from start to finish.

$$\begin{gathered} p_{\text{TOT},i} = p_{\text{TOT},f} \\ p_{1,i} + p_{2,i} = p_{1,f} + p_{2,f} \\ m_1 v_{1,i} + m_2 v_{2,i} = (m_1 + m_2)\, v_f \end{gathered} \tag{5}$$

Next, we have elastic collisions, where both kinetic energy and momentum remain conserved.

$$\begin{gathered} K_i = K_f \\ p_i = p_f \end{gathered} \tag{6}$$

Such collisions can be visualized with two billiard balls or hockey pucks gliding across ice, where they bounce off each other without sticking. Applying the known equations for momentum and kinetic energy, we get the following equations

$$\begin{gathered} \frac{1}{2} m_1 v_{1,i}^2 + \frac{1}{2} m_2 v_{2,i}^2 = \frac{1}{2} m_1 v_{1,f}^2 + \frac{1}{2} m_2 v_{2,f}^2 \\ m_1 v_{1,i} + m_2 v_{2,i} = m_1 v_{1,f} + m_2 v_{2,f} \end{gathered} \tag{7}$$

Ideally, these systems should not experience energy losses from friction, sound, or other energy transformations. However, this is not always the case when considering non-ideal systems, we measure this loss as a percentage, defined as the absolute difference between the initial and final values relative to the initial value, multiplied by 100%.

$$\%\,\text{Loss} = \frac{|\varphi_f - \varphi_i|}{\varphi_i} \times 100\% \tag{8}$$

Where φ denotes kinetic energy.

1.1 Procedure

In this experiment, we are going to test four scenarios, two elastic collisions and two inelastic collisions. These first steps are general steps that we will just get out of the way first.

1. Mass out the two carts and record them. If the carts are too heavy, we have 500 g cylinders that can hook onto the scale.
2. Mass out the extra weight that will go onto one of the carts and record.
3. Measure the length of the metal flag that goes on the carts. This will be the length that you use to find the velocity of each of the carts.
4. Place the flags on the carts such that the long edge is facing the side of the track and place the carts on the track.

1.2 Image of the setup

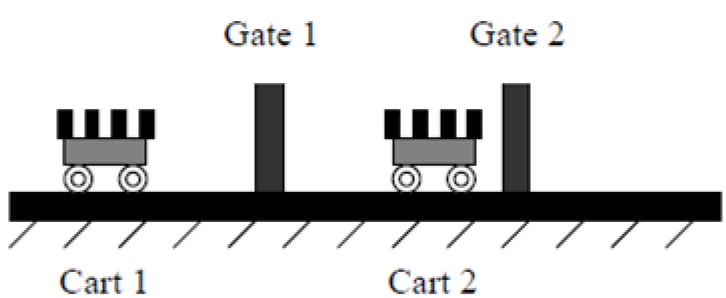

Figure 1: *Illustrates the setup of the carts and the photogates used in the experiment*

2 Data

Before we branch off to the specific cases, we record a few measurements that will remain constant throughout each trial. These measurements include the mass of the light cart (m_L), the mass of the heavy cart (m_H), and the length ℓ that will be used to compute the velocity, this length is the length of the flag above the cart.

Name	Measurement
m_L	0.565 kg
m_H	1.082 kg
ℓ	0.06 m

Table 1: *Displays the constants that will be used among all four trials*

2.1 Inelastic: Light cart stationary

We begin this trial but placing the light cart (m_L) inbetween the two photogates (see figure 1). We then send the heavy cart towards the light cart. The heavy cart passes through the first photogate, then collides with the stationary cart. The two carts will stick together after the collision.

Once the collided carts pass through the second photogate, we will have two time mesaurements, the time it took for the heavy cart to pass through the first photogate, and the time it took for the collided carts to pass through the second photogate. These measurements are displayed in the following table

Cart	Time difference (Δt s)
Heavy ($m_{i \to p_1}$)	0.13855
Joined ($m_{f \to p_2}$)	0.148

Table 2: *Shows the time it took for the objects to pass through each photogate*

The notation used in this table ($m_{i \to p_1}$), is used to denote the inital mass moving through photogate 1, and ($m_{f \to p_2}$) denoting final mass moving through photogate 2

Note:-

We denote the first time difference Δt_1, and the second time difference Δt_2

2.2 Inelastic: Heavy cart stationary

This second trial is similar to the previous, but this time the heavy cart is positioned in the middle (stationary).

Again, we display the time measurements in the following table

Cart	Time difference (Δt s)
Light ($m_{i \to p_1}$)	0.134
Joined ($m_{f \to p_2}$)	0.204

Table 3: *Shows the time it took for the objects to pass through each photogate*

2.3 Elastic: Light cart stationary

This trial will be similar to the first, where the light cart is placed in the middle. However, we flip the carts around such that the magnets of each cart do not face eachother. Hence, they will not stick together after the collision.

This trial will have three time measuremens, whereas the last two trials had two. The first will be the time it took for the leftmost cart to pass through the first photogate ($m_{i\to p_1}$). The second will be the time it took for the stationary (middle) mass to pass through the second photogate after collision ($m_{s\to p_2}$), and the third will be the time it took for the initial mass to pass through the second photogate after collision ($m_{i\to p_2}$).

Cart	Time difference (Δt s)
$m_{i\to p_1}$	0.085
$m_{s\to p_2}$	0.172
$m_{i\to p_2}$	0.645

Table 4: *Shows the time it took for the objects to pass through each photogate*

2.4 Inelastic: Heavy cart stationary

I regret to inform that this trial was not able to be conducted. Technical difficulties were experienced.

3 Results

Using the data found in the previous tables, we compute the velocities, momentums, and kinetic energys for each trial.

3.1 Inelastic: Light cart stationary

We start with the velocites. As discussed previously, we show these computations in this section and then simply display the results in the proceeding sections, without computations.

Using the length of the flag recorded at the start of the experiment ($\ell = 0.06m$), and the times found in table two, we find

$$v_{m_i\to p_1} = \frac{\ell}{\Delta t} = \frac{0.06m}{0.1385s} = 0.363\,m/s$$
$$v_{m_f\to p_2} = \frac{\ell}{\Delta t} = \frac{0.06m}{0.148s} = 0.405\,m/s.$$

Next, we use equation four to find the momenta

$$p_i = m_i v_{m_i\to p_1} = 1.08\,kg \cdot 0.363\,m/s = 0.392\,kg \cdot \frac{m}{s}$$
$$p_f = (m_i + m_f) v_{m_f\to p_2} = 1.645\,kg \cdot 0.405\,m/s = 0.667\,kg \cdot \frac{m}{s}.$$

Finally, we find the kinetic energys

$$K_i = \frac{1}{2} m_i v_{m_i \to p_1}^2 = \frac{1}{2}(1.08\,kg)(0.363\,m/s)^2 = 0.071\,J$$
$$K_f = \frac{1}{2} m_f v_{m_f \to p_2}^2 = \frac{1}{2}(1.645\,kg)(0.405\,m/s)^2 = 0.135\,J.$$

3.2 Results tables for all trials

The following table displays the results for the trial we just analyzed, as well as the remaining two.

3.2.1 Velocity table: Inelastic trials

Trial	$v_i\ m/s$	$v_f\ m/s$
1	0.363	0.405
2	0.448	0.294

Table 5: *Displays the velocities found during the first two inelastic trials*

3.2.2 Velocity table: Elastic trial

Trial	$v_{m_i \to p_1}\ m/s$	$v_{m_s \to p_2}\ m/s$	$v_{m_i \to p_2}\ m/s$
3	0.705	0.349	0.0938

Table 6: *Displays the velocities found during the elastic trial*

3.2.3 Momenta and Energy table

Trial	$P_i\ kg \cdot \frac{m}{s}$	$P_f\ kg \cdot \frac{m}{s}$	$K_i\ J$	$K_f\ J$
1	0.392	0.667	0.071	0.135
2	0.253	0.484	0.057	0.071
3	0.7614	0.298	0.268	0.039

Table 7: *Shows the momentum and energy found in each trial*

3.3 Percent loss: Momenta

We now find the percent loss among each trials initial and final momentum. For this, we use equation 6. We show this computation for the first trial, and then report the remaining findings in a following table

$$\begin{aligned}
\%\,\text{Loss} &= \frac{|\varphi_f - \varphi_i|}{\varphi_i} \times 100\% \\
&= \frac{|0.667kg/s - 0.392kg \cdot m/s|}{0.392kg \cdot m/s} \times 100\% \\
&= 70\%.
\end{aligned}$$

3.4 Percent loss: Energy

$$
\begin{aligned}
\%\,\text{Loss} &= \frac{|\varphi_f - \varphi_i|}{\varphi_i} \times 100\% \\
&= \frac{|0.135J - 0.071J|}{0.071J} \times 100\% \\
&= 90\%.
\end{aligned}
$$

3.5 Percent loss data table

Trial	Momentum percent loss	Energy percent loss
1	70%	90%
2	91%	24%
3	61%	85%

4 Discussion

In this experiment, we explored how momentum and energy behave during collisions, focusing on the difference between elastic and inelastic collisions. We showed the principle of momentum conservation, which holds regardless of the collision type. Our procedures ranged from measuring the mass of moving carts to recording their velocities after the collision, which allowed us to look into the nuances of kinetic energy behavior and momentum transfer.

However, things didn't always go as smoothly as we hoped. We noticed some inconsistencies in our momentum calculations. For instance, in inelastic collisions where the carts stuck together, it looked like we ended up with more momentum than we started with, which shouldn't happen. We think this might have been due to errors in how we measured the time it took for the carts to pass through the sensors, which affected our velocity calculations. It's a good reminder that even small mistakes in measurement can lead to big discrepancies in results, and it's important to be as accurate as possible.

When initial and final momentum measurements don't match up in experiments, several factors can be at play, beyond just measurement errors. Friction between the moving objects and the surfaces can lead to a loss of kinetic energy, affecting the final momentum measurement. Any external force acting on the system can introduce additional momentum. In a perfectly isolated system, momentum would be conserved, but external forces can add or subtract from the system's total momentum.

5 Conclusion

In conclusion, this lab's look into the types of collisions has not only deepened our understanding of the concepts of momentum and energy conservation but has also provided a look at the challenges of capturing these principles in real-world scenarios. Despite setting up our experiments to explore both elastic and inelastic collisions, we encountered unexpected outcomes that were vastly different from the theoretical predictions. These discrepancies show us the complexities of experiments, where factors such as measurement errors in timing and velocity determinations can influence the results. The apparent momentum gain in some inelastic collisions hinted at underlying inaccuracies in our measurement techniques. How we computed the final velocity for the inelastic collisions most likely contained some fatal errors, which caused the resulting momentum to be greater than the initial.