Linear Motion and Collisions on an Air Track
An Experimental Verification of Mechanical Conservation Laws

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ABSTRACT: We aim to explore the laws of momentum conservation and energy conservation during 1-dimensional collisions between objects. The experiment involves two types of collisions: elastic, where objects bounce off each other after impact, and inelastic, where objects stick together after impact. We aim to determine if momentum and kinetic energy are conserved during these collisions. Position vs. time data were collected for four collision scenarios: elastic and inelastic collisions between initially moving carts, and elastic and inelastic collisions between a moving and a stationary cart. Elastic collisions were performed by placing a rubber attachments to carts which would collide with each other. Inelastic collisions were performed by placing a pin on one cart and a cork on the other, causing the two carts to stick together after the collision. Position data was collected using an ultrasound sensor. Pairing this data with time-series data, we determined the speeds of objects before and after the collisions. Using the mass of the objects, we calculated the momenta and kinetic energies of the masses. We observed the conservation of momentum in all cases except for the inelastic collision between a stationary and moving object. Additionally, kinetic energy was conserved in all elastic collisions, but never in inelastic collisions. Limitations in the experiment included unreliable ultrasound sensor readings at greater distances, potential tilt in the air track, and high cart launch speeds. Future improvements include increasing the wall size for ultrasound measurements, launching carts more slowly, and ensuring that the track is level.

I. INTRODUCTION

Some of the central principles in mechanics are the conservation of momentum and the conservation of energy. The conservation of momentum states that in a closed system, the total momentum of a system will always remain constant. The conservation of energy states that the total energy of an isolated system will always remain constant. These principles are very important in various scientific and engineering fields. In this experiment, we seek to verify the conservation of momentum after a collision, and also verify the conservation of energy in a certain class of collisions.

Momentum (p) is a quantity defined as the product of an object's mass (m) and its velocity (v):

$$p = mv$$

The conservation of momentum asserts that the total momentum of a system is conserved in the absence of external forces. In other words, if no external forces act on a system, the sum of momenta before a collision (ρ_{initial}) should be equal to the sum of momenta after the collision (ρ_{final}):

$$\rho_{\text{initial}} = \rho_{\text{final}}$$

Additionally, we also want to explore the concept of kinetic energy conservation, another fundamental aspect of mechanics. Kinetic energy (K) is the energy associated with an object's motion, and can be calculated from an object's mass (m) and velocity (v):

$$K = \frac{1}{2}mv^2$$

In elastic collisions, where no external forces dissipate energy, both momentum and kinetic energy are conserved. Thus, the total kinetic energy of the system before the collision (K_{initial}) should be equal to the total kinetic energy of the system after the collision (K_{final}):

$$K_{\text{initial}} = K_{\text{final}}$$

However, in inelastic collisions, where external forces or internal work dissipate energy, the total kinetic energy of the system may not be conserved. Therefore, the equation above may not be true in general.

In this experiment, we will investigate the behavior of objects on an air track, an environment that minimizes the influence of external forces such as air resistance and friction. With our experiments, we aim to determine whether the momentum of the system of objects remains constant before and after the collision as predicted by Newtonian mechanics. We also aim to determine whether the kinetic energy of the system of objects will remain constant in the elastic collisions.

We hypothesize that the total momentum of a system of objects will not change after a collision. Additionally, we hypothesize that the total kinetic energy of a system of objects will not change after an elastic collision. We can define the quantities system momentum loss and system kinetic energy loss, $\Delta\rho$ and ΔK respectively, as:

$$\Delta\rho = \rho_{\text{initial}} - \rho_{\text{final}}$$

$$\Delta K = K_{\text{initial}} - K_{\text{final}}$$

Then, our hypothesis will state that $\Delta\rho = 0$ in every collision, while $\Delta K = 0$ in elastic collisions. We will conduct experiments involving multiple elastic and inelastic collisions (in total, 4), and measure $\Delta\rho$ and ΔK in each of these collisions to test our hypothesis.

II. METHODS

A. Equipment List

- 2 - Arduino Uno
- 2 - HC-SR04 Arduino ultrasonic sensor
- 2 - HC-06 Bluetooth module
- 1 - Perforated air track glider
- 1 - Air Compressor
- 2 - Insertable rubber band holder
- 2 - Rubber bands
- 2 - Cardboard Sheets
- 6 - AA batteries
- 2 - Battery pack
- 2 - Arduino extension board
- 2 - Arduino mini breadboard
- 15 - Breadboard jumper wires
- 1 - Meter stick
- 1 - Roll of Tape
- 1 - Weighing scale
- 2 - Insertable pin

B. Arduino Setup

An Arduino Uno was configured to wirelessly obtain a stream of distance data. The means of measuring distance was ultrasonic sensing: using reflected sound waves to determine short distances in the range of 100 meters. An HC-SR04 ultrasonic sensor was used as the main data collection device. After being mounted to the Arduino, code was configured to translate its time readings to distance in meters. This was done using the speed of sound constant (v_s) and the equation:

$$d = \frac{tv_s}{2} \tag{1}$$

The Arduino was further configured with the HC-06 Bluetooth module, a portable module designed for short range wireless data, to quickly relay the distance data to the client server.

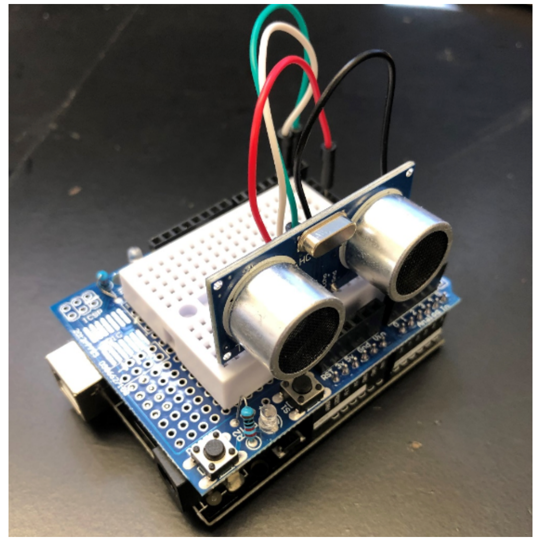


FIG. 1: Ultrasonic sensor mounted on Arduino motherboard.

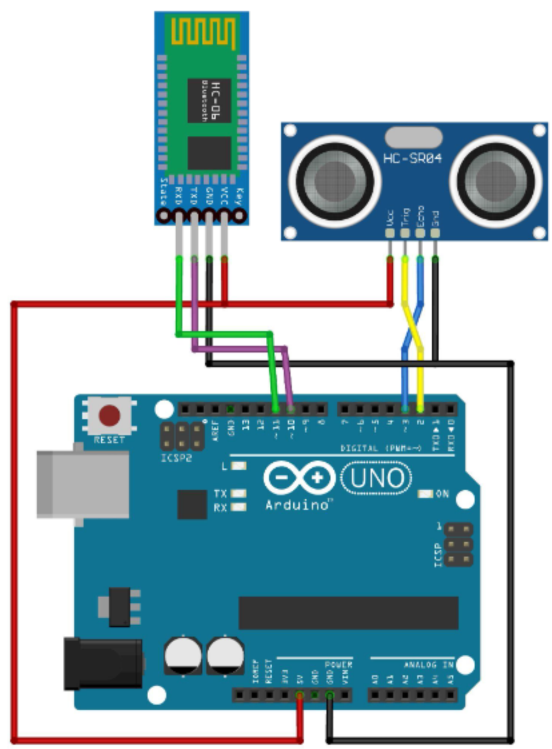


FIG. 2: Schematic of final circuit wiring.

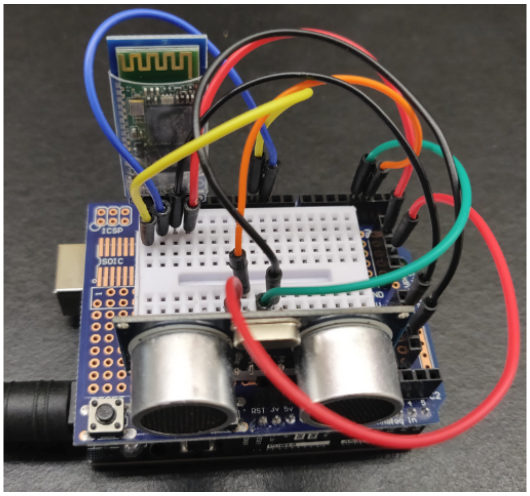


FIG. 3: Finished wiring of Arduino with sensor and Bluetooth module.

C. General Experiment Setup

To simulate and collect data about a number of collisions, a near frictionless air glider set-up was used. This perforated metal track would be supplied with air using an air compressor to allow a mounted plastic platform/-cart to slightly hover over the rails. The air compressor was used at its highest setting. This caused friction to be negligible in this environment. Cardboard sheets were mounted at each end of the rail using tape, at a distance of 100 cm from each other. These walls would allow the ultrasonic waves released by the Arduino module to be reflected back towards the device. While cardboard was used in this instance, any reflective surface would be a viable substitution. Lastly, the meter stick measuring device was laid in front of the rail to provide a frame of reference and easy measurements for the experiment.

FIG. 4: Cardboard sheets mounted on sides to created "walls."

The properly Arduino device would be mounted on the plastic platform which would travel linearly along the rail. The battery holder was taped under the board to improve stability. The ultrasonic sensor was facing towards the taped cardboard walls. This mounting process was repeated twice to finish with two Arduino devices on two separate plastic platforms.

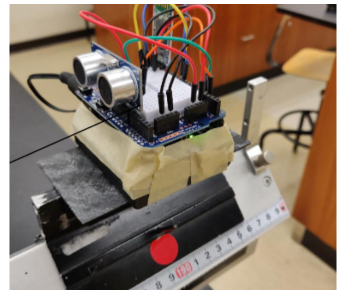


FIG. 5: Arduino module mounted on plastic platform.

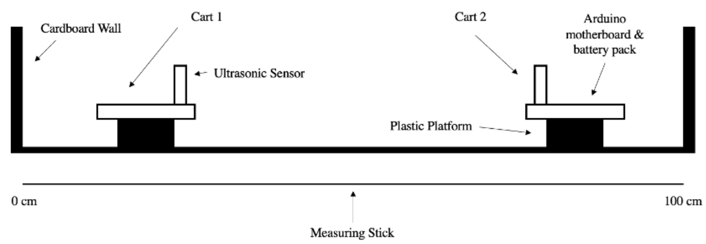


FIG. 6: Diagram of final air track setup.

D. Elastic Collision Process

Four data sets were collected in two forms of collisions: inelastic and elastic. To simulate an elastic collision, rubber band holders with rubber bands were placed at the forefront of each cart. Use the measuring scale to record the weights of each of the carts in grams. The two carts were placed at an x-axis marking of 20 cm and 80 cm respectively, placing them 60 cm apart. Begin recording data at this point, at a state of rest for both of the carts.

For the first variation, elastic collision with both objects moving towards each other, the two carts were pushed towards each other at approximately the same velocity. This push was done by hand. Data should be recorded until both carts return to a state of rest.

For the second variation, elastic collision with one object moving towards a stationary object, place Cart 1 at the 20 cm mark and Cart 2 at the 40 cm mark. This altered placement allows more room for Cart 2, the struck cart, to decelerate without hitting the cardboard wall. Begin recording data while both carts are at a state of rest. With a constant velocity, push Cart 1 by hand towards the direction of Cart 2. Collect data until both carts return to a state of rest. Better data conclusions can be made if Cart 2 does not hit the carboard barrier during its period of motion.

E. Inelastic Collision Process

Remove the rubber band holder insertion from the front of each of the carts. Replace this insertion with the pin collider insertion. The pin collider consists of two parts, and each cart receives one part. One part is a pin, and the other is a cork with a hole it. This allows the pin to lodge into the cork after the collision, and make the carts stick together. Repeat the procedures for the two variations of collisions previously discussed with the newly modified carts. Be sure to record the new weights of each of the carts before collisions take place, since the masses of the pin collider insertion and the rubber band holders are different.

F. Code for Data Extraction

Data was collected in the form of a text file containing pairs of time and distance. Python was used as the programming language to parse and reveal data insights. The ‘numpy’ and ‘matplotlib’ modules were imported as well. Snippets of code are included to give general insight for certain steps.
For each of the variations, time versus distance was plotted for each cart in a scatter plot:

Listing 1: Preliminary Scatter Plot

```
plt.scatter(time_m1, position_m1)
```

Array indices were arranged to remove periods of rest before and after the collision for each cart. From this scatter plot, a line of best fit and corresponding covariance matrix were extracted. These lines of best fit were calculated for the motion of both carts both before and after the collisions. Here, we calculate the line of best fit and covariance matrix for m_1's motion before a collision:

Listing 2: Determing the Covariance Matrix

```
coeff_linear_pre_m1, cov_pre_m1 =
    np.polyfit(time_m1_pre,
    pos_m1_pre,1,cov=True)
```

Entries in the best-fit line and the covariance matrix corresponded to the velocities of the cart before and after the collision, as well as their errors. Here, we calculate the velocity and error in velocity for m_1 before a collision:

Listing 3: Variable Correspondence

```
u1 = coeff_linear_pre_m1[0]
delta_u1 = np.sqrt(cov_pre_m1[0,0])
```

Predefined functions for momentum, energy, and their respective errors were used in conjunction with the values obtained from the best fit line and the matrix to produce insights regarding conservation of energy. We could calculate the momentum, error in momentum, kinetic energy, and error in kinetic energy for each cart in each collision, before and after the collision. An example of the momentum error function is shown below (this calculation is discussed more in Results):

Listing 4: Momentum Error Function

```
def delta_momentum(m , delta_m, v,
    delta_v):
    int1 = delta_m / m
    int2 = delta_v / v

    int1 = int1 ** 2
    int2 = int2 ** 2

    int3 = int1 + int2
    p = m * v
    return p * np.sqrt(int3)
```

Momentum and errors for each cart before and after collision were then recorded. Energy and errors for each cart were recorded as well. Finally, the change in system momentum $\Delta\rho$ and the change in system kinetic energy ΔK were calculated for each collision. If these values were within 2σ of zero, then we would be confident that momentum and/or kinetic energy would be conserved in the collision. Here, we calculate the system momentum loss and associated error for an elastic collision with both objects initially moving:

Listing 5: Momentum Error Function

```
# System momentum loss
p_loss = m1_p_i + m2_p_i - m1_p_f -
    m2_p_f
# Error in system momentum loss
d_p_loss = math.sqrt(dm1_p_i**2 +
    dm2_p_i**2 + dm1_p_f**2 +
    dm2_p_f**2)
print(p_loss)
print(d_p_loss)
```

G. Assumptions

A frictionless environment was assumed with the implementation of a gliding air track. Approximately equal (however, not necessarily exactly equal) initial velocities for both carts were assumed when simultaneously pushed by a hand. We also assumed the absence of gravity in this environment (the track was perfectly level and not tilted), which means that there were not external forces acting on either of the 2 carts. We also assumed that the cart would move a negligible amount during delay between when the ultrasound sensor sent and received its pulses, so its reading would be accurate to describe the position of the cart at a particular time.

III. RESULTS

Note: since m_1 is always initially moving in every collision, we will define the positive direction for position and velocity to be the direction that m_1 initially moves in.
To derive the error in momentum, $\rho = mv$, we use the error propagation equation for $Z = aXY$ for variables X, Y, and Z, and a constant a.

$$\frac{\delta Z}{|Z|} = \sqrt{\left(\frac{\delta X}{|X|}\right)^2 + \left(\frac{\delta Y}{|Y|}\right)^2}$$

$$\delta\rho = mv\sqrt{\left(\frac{\delta m}{|m|}\right)^2 + \left(\frac{\delta v}{|v|}\right)^2}$$

Similarly, we can derive the error in kinetic energy, $K = \frac{1}{2}mv^2$. However, we need to know the error in v^2, which is given by $Z = X^a \rightarrow \frac{\delta Z}{|Z|} = a\frac{\delta X}{|X|}$.

$$\frac{\delta\left(v^2\right)}{|v^2|} = 2\frac{\delta v}{|v|} \rightarrow \delta K = \frac{1}{2}mv^2\sqrt{\left(\frac{\delta m}{|m|}\right)^2 + \left(2\frac{\delta v}{|v|}\right)^2}$$

System momentum loss is the difference between the initial momentum and the final momentum of a system. We can calculate it using $\Delta\rho = \rho_{1,i} + \rho_{2,i} - \rho_{1,f} - \rho_{2,f}$. The error for system momentum loss is based on the error propagation equation $Z = X + Y \rightarrow \delta Z = \sqrt{\delta X^2 + \delta Y^2}$, so

$$\delta\Delta\rho = \sqrt{\delta\rho_{1,i}^2 + \delta\rho_{1,f}^2 + \delta\rho_{2,i}^2 + \delta\rho_{2,f}^2}$$

Similarly, system kinetic energy loss is the difference between the initial and final kinetic energies of a system. We can calculate it using $\Delta K = K_{1,i} + K_{2,i} - K_{1,f} - K_{2,f}$. Likewise, the error in system kinetic energy loss, $\delta\Delta K$ is given by:

$$\delta\Delta K = \sqrt{\delta K_{1,i}^2 + \delta K_{1,f}^2 + \delta K_{2,i}^2 + \delta K_{2,f}^2}$$

A. Elastic collision between 2 moving objects

The plots of position of the carts vs. time are shown in Figures 7a and 7b. Both m_1 and m_2 are initially moving.

Based on its best-fit lines for position vs. time before and after the collision, m_1 starts with velocity $u_1 = 28.3 \pm 0.521\,\mathrm{m/s}$, and it ends with velocity $v_1 = -23.4 \pm 0.119\,\mathrm{m/s}$.

Based on its best-fit lines for position vs. time before and after the collision, m_2 starts with velocity $u_1 = -29.7 \pm 1.16\,\mathrm{m/s}$, and it ends with velocity $v_1 = 34.4 \pm 0.400\,\mathrm{m/s}$.

m_1 has mass .434 $\pm$ .001 kg, and m_2 has mass .351 $\pm$ .001 kg. Thus, using the momentum and momentum error formulas, we have the quantities seen in Table I.

Momentum	Value in kgm/s
$\rho_{1,i}$	$.122 \pm 2.28 * 10^{-3}$
$\rho_{2,i}$	$-.104 \pm 4.08 * 10^{-3}$
$\rho_{1,f}$	$-.101 \pm 5.69 * 10^{-4}$
$\rho_{1,f}$	$.121 \pm 1.45 * 10^{-3}$
System momentum loss	$-3.43 * 10^{-4} \pm 4.93 * 10^{-3}$

TABLE I: Momentum for objects before and after an elastic collision, both objects move initially

Using the kinetic energy and kinetic energy error formulas, we also have the quantities seen in Table II.

Kinetic energy	Value in J
$K_{1,i}$	$.0174 \pm 6.41 * 10^{-3}$
$K_{2,i}$	$.0155 \pm 1.21 * 10^{-3}$
$K_{1,f}$	$.0119 \pm 5.31 * 10^{-4}$
$K_{1,f}$	$.0207 \pm 1.40 * 10^{-3}$
System KE loss	$1.74 * 10^{-4} \pm 2.03 * 10^{-3}$

TABLE II: Kinetic energy for objects before and after an elastic collision, both objects move initially

The system momentum loss and the system kinetic energy loss are both within σ of 0, so we are not confident that the system momentum or kinetic energy of the system changed after this collision. This means that both momentum and energy were conserved in this collision.

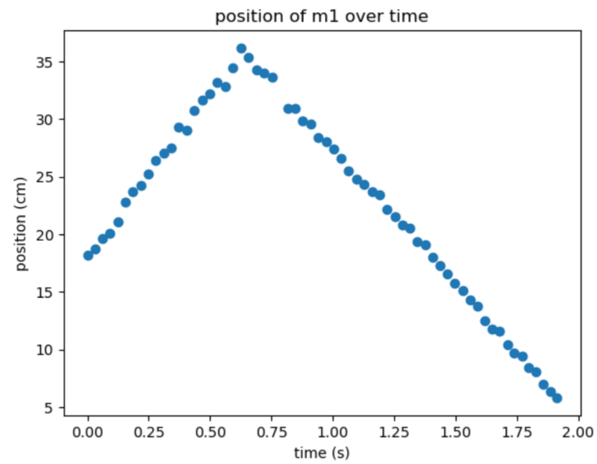
B. Inelastic collision between 2 moving objects

The plots of position of the carts vs. time are shown in Figures 7c and 7d. Both m_1 and m_2 are initially moving.

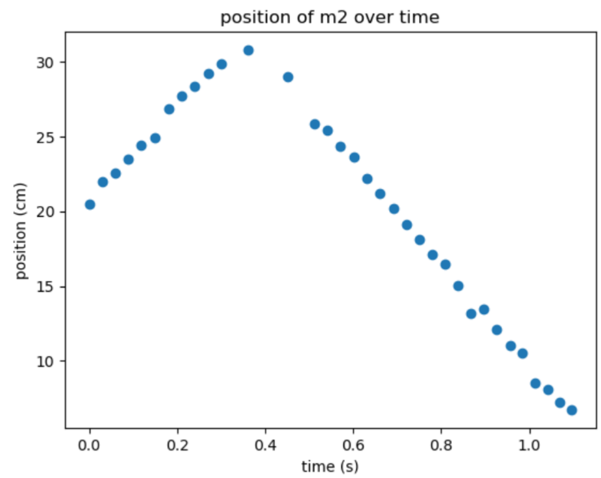
Based on its best-fit lines for position vs. time before and after the collision, m_1 starts with velocity $u_1 = 9.81 \pm 0.134\,\mathrm{m/s}$, and it ends with velocity $v_1 = 0.178 \pm 0.0525\,\mathrm{m/s}$.

Based on its best-fit lines for position vs. time before and after the collision, m_2 starts with velocity $u_1 = -11.3 \pm 0.132\,\mathrm{m/s}$, and it ends with velocity $v_1 = 0.245 \pm 0.0531\,\mathrm{m/s}$.

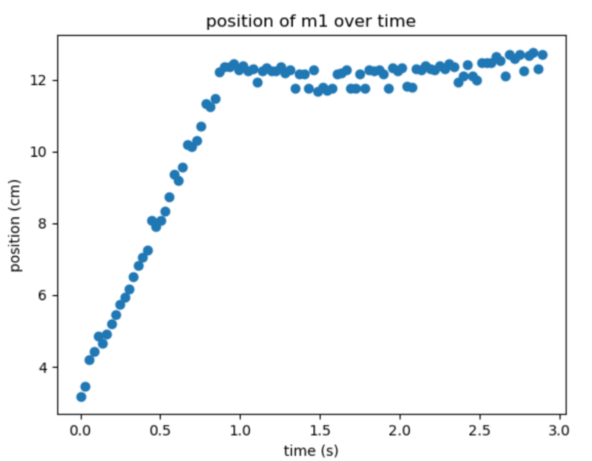
m_1 has mass .418 $\pm$ .001 kg, and m_2 has mass .335 $\pm$ .001 kg. Thus, using the momentum and momentum



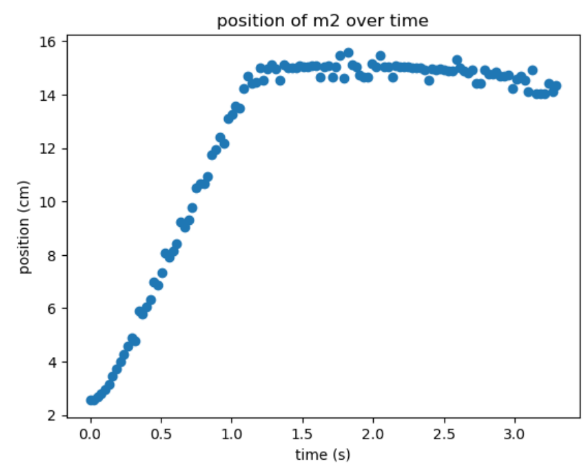
(a) Position of m_1 over time



(b) Position of m_2 over time



(c) Position of m_1 over time



(d) Position of m_2 over time

FIG. 7: Plots of distance vs. time for various collisions. Plots 7a and 7b represent the motion of objects during an elastic collision when they both begin moving. Note that they both start with velocity in one direction and reverse their velocities after the collision. Plots 7c and 7d represent the motion of objects during an inelastic collision when they both begin moving. Note that they both start moving with high velocity, but after the collision they move with a smaller, approximately equal in magnitude, velocity.

error formulas, we have the quantities seen in Table III.

Momentum	Value in kgm/s
$\rho_{1,i}$	$.0410 \pm 5.67 * 10^{-4}$
$\rho_{2,i}$	$-.0379 \pm 4.55 * 10^{-4}$
$\rho_{1,f}$	$7.45 * 10^{-4} \pm 2.20 * 10^{-4}$
$\rho_{1,f}$	$8.20 * 10^{-4} \pm 1.78 * 10^{-4}$
System momentum loss	$1.54 * 10^{-3} \pm 7.80 * 10^{-4}$

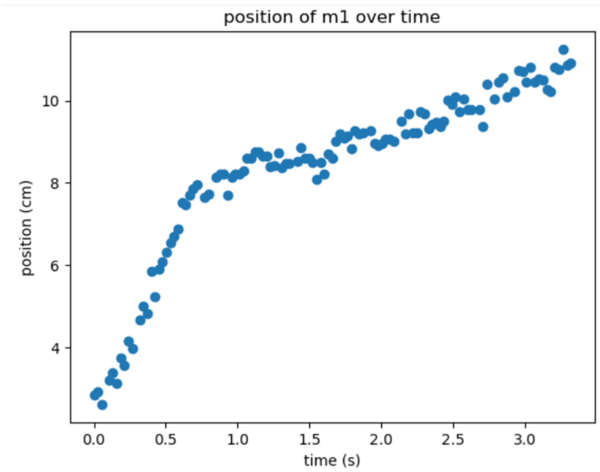
TABLE III: Momentum for objects before and after an inelastic collision, both objects move initially

Using the kinetic energy and kinetic energy error formulas, we also have the quantities seen in Table IV.

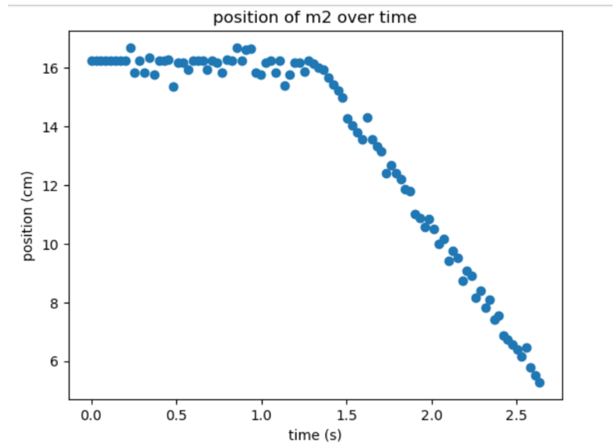
Kinetic energy	Value in J
$K_{1,i}$	$2.01 * 10^{-3} \pm 5.00 * 10^{-5}$
$K_{2,i}$	$2.15 * 10^{-3} \pm 5.03 * 10^{-5}$
$K_{1,f}$	$6.65 * 10^{-7} \pm 9.96 * 10^{-7}$
$K_{1,f}$	$1.00 * 10^{-6} \pm 1.08 * 10^{-6}$
System KE loss	$4.16 * 10^{-3} \pm 7.46 * 10^{-5}$

TABLE IV: Kinetic energy for objects before and after an elastic collision, both objects move initially

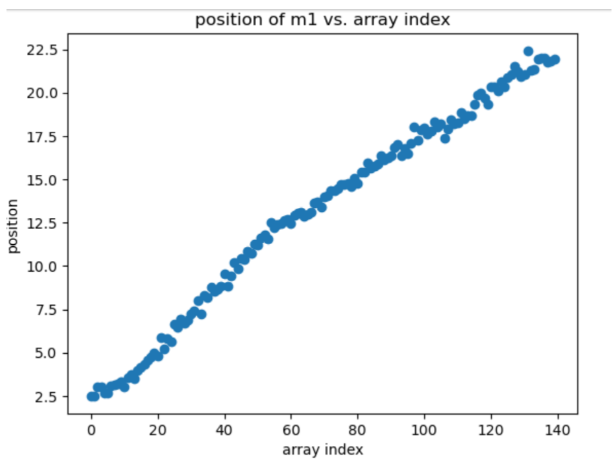
The system momentum loss is within 1.98σ of 0, so we are not confident that the system momentum changed after this collision. This means that momentum was conserved in this collision. However, the system KE loss is greater than 2σ, so are confident that the system energy changed (specifically, it decreased). This means that this collision did not conserve energy.



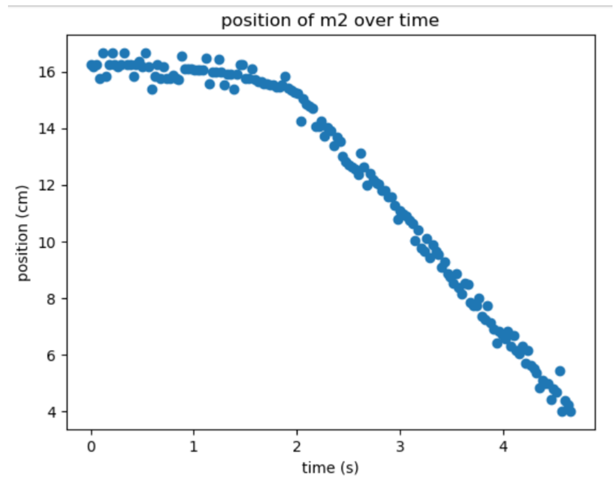
(e) Position of m_1 over time



(f) Position of m_2 over time



(g) Position of m_1 over time



(h) Position of m_2 over time

FIG. 7: Plots of distance vs. time for various collisions. Plots 7e and 7e represent the motion of objects during an elastic collision when m_1 begins and m_2 begins stationary. Note that m_1 starts with high velocity and ends with low velocity, while m_2 starts with low velocity and ends with high velocity. Plots 7g and 7g represent the motion of objects during an inelastic collision when when m_1 begins and m_2 begins stationary. Note that m_1 and m_2 have different velocities before the collision, but the magnitude of their velocities is approximately equal after the collision.

C. Elastic collision between a stationary and a moving object

The plots of position of the carts vs. time are shown in Figures 7e and 7f. m_1 is initially moving, but m_2 is initially stationary.

Based on its best-fit lines for position vs. time before and after the collision, m_1 starts with velocity $u_1 = 7.34 \pm 0.260\,\text{m/s}$, and it ends with velocity $v_1 = 1.11 \pm 0.0404\,\text{m/s}$.

Based on its best-fit lines for position vs. time before and after the collision, m_2 starts with velocity $u_1 = 0.135 \pm 0.111\,\text{m/s}$, and it ends with velocity $v_1 = 8.20 \pm 0.0872\,\text{m/s}$.

m_1 has mass .434 ± .001 kg, and m_2 has mass .351 ± .001 kg. Thus, using the momentum and momentum error formulas, we have the quantities seen in Table V.

Momentum	Value in kgm/s
$\rho_{1,i}$	$.0319 \pm 1.13 * 10^{-3}$
$\rho_{2,i}$	$4.73 * 10^{-4} \pm 3.91 * 10^{-4}$
$\rho_{1,f}$	$4.81 * 10^{-3} \pm 1.75 * 10^{-4}$
$\rho_{1,f}$	$0.0288 \pm 3.17 * 10^{-4}$
System momentum loss	$-1.28 * 10^{-3} \pm 1.25 * 10^{-3}$

TABLE V: Momentum for objects before and after an elastic collision, one object is initially stationary

Using the kinetic energy and kinetic energy error formulas, we also have the quantities seen in Table VI.

Kinetic energy	Value in J
$K_{1,i}$	$1.17 * 10^{-3} \pm 8.30 * 10^{-5}$
$K_{2,i}$	$3.19 * 10^{-7} \pm 5.27 * 10^{-7}$
$K_{1,f}$	$2.67 * 10^{-5} \pm 1.25 * 10^{-5}$
$K_{1,f}$	$1.18 * 10^{-3} \pm 3.22 * 10^{-5}$
System KE loss	$-3.80 * 10^{-5} \pm 8.99 * 10^{-5}$

TABLE VI: Kinetic energy for objects before and after an elastic collision, one object is initially stationary

The system system momentum loss is within 1.02σ of 0, and the system kinetic energy loss is within σ of 0, so we are not confident that the system momentum or kinetic energy of the system changed after this collision. This means that both momentum and energy were conserved in this collision.

D. Inelastic collision between a stationary and a moving object

The plots of position of the carts vs. time are shown in Figures 7g and 7g. m_1 is initially moving, but m_2 is initially stationary.

Based on its best-fit lines for position vs. time before and after the collision, m_1 starts with velocity $u_1 = 7.03 \pm 0.120\,\text{m/s}$, and it ends with velocity $v_1 = 4.26 \pm 0.0511\,\text{m/s}$.

Based on its best-fit lines for position vs. time before and after the collision, m_2 starts with velocity $u_1 = 0.309 \pm 0.0711\,\text{m/s}$, and it ends with velocity $v_1 = 4.16 \pm 0.0317\,\text{m/s}$.

m_1 has mass .418 $\pm$ .001 kg, and m_2 has mass .335 $\pm$ .001 kg. Thus, using the momentum and momentum error formulas, we have the quantities seen in Table VII.

Momentum	Value in kgm/s
$\rho_{1,i}$	$.0294 \pm 5.06 * 10^{-4}$
$\rho_{2,i}$	$1.03 * 10^{-3} \pm 2.38 * 10^{-4}$
$\rho_{1,f}$	$0.0178 \pm 2.18 * 10^{-4}$
$\rho_{1,f}$	$0.0139 \pm 1.14 * 10^{-4}$
System momentum loss	$-1.33 * 10^{-3} \pm 6.11 * 10^{-4}$

TABLE VII: Momentum for objects before and after an inelastic collision, one object is initially stationary

Using the kinetic energy and kinetic energy error formulas, we also have the quantities seen in Table VIII.

The system momentum and KE loss are both greater than 2σ, so are confident that the system momentum and energy changed (specifically, they decreased). This means that this inelastic collision did not conserve energy or momentum.

Kinetic energy	Value in J
$K_{1,i}$	$1.03 * 10^{-3} \pm 3.53 * 10^{-5}$
$K_{2,i}$	$1.60 * 10^{-6} \pm 7.35 * 10^{-7}$
$K_{1,f}$	$3.79 * 10^{-4} \pm 2.14 * 10^{-5}$
$K_{1,f}$	$2.89 * 10^{-4} \pm 9.93 * 10^{-6}$
System KE loss	$3.64 * 10^{-4} \pm 4.24 * 10^{-5}$

TABLE VIII: Kinetic energy for objects before and after an inelastic collision, one object is initially stationary

IV. CONCLUSIONS

In this experiment, we investigated the behavior of two types of collisions: elastic and inelastic. Elastic collisions were executed using rubber bands between the carts, while inelastic collisions involved cork and a pin designed to stick together post-collision. Our primary objective was to examine how collisions within a system impact both momentum and energy.

We measured position vs. time for 4 different types of collisions: elastic collisions with two initially moving carts, inelastic collisions with two initially moving carts, elastic collisions between a moving and a stationary cart, and inelastic collisions between a moving and a stationary cart. We hypothesized that in all collisions, momentum would be conserved, and in elastic collisions, kinetic energy would be conserved.

We observed that in every collision except the inelastic collision between a stationary and a moving object, momentum was conserved (specifically, the system momentum loss was less than 2σ from 0, which was our prediction if momentum was conserved). However, this did not occur in the inelastic collision between a stationary and moving object. In this exceptional case, the system's momentum slightly deviated from our prediction (2.18σ from 0 rather than 2σ) - see Table VII. While this does not agree with our hypothesis it is noteworthy that 3/4 of our experiments did agree with our hypothesis. Therefore, we cannot say whether momentum is conserved or not in every collision. However, with more experimentation and better techniques, a more definitive answer to this question may be reached.

We also observed that kinetic energy is conserved in elastic collisions, but not in inelastic collision (specifically, the system kinetic energy loss was less than 2σ from 0, which was our prediction if kinetic energy was conserved). This result supports our hypothesis that kinetic energy is only conserved in a certain class of collisions (elastic collisions), and these collisions are between elastic bodies that are free to move in any way after colliding (as opposed to 2 objects that stick together after a collision). Therefore, we can conclude that these elastic collisions conserve energy.

Overall, our experiment and subsequent data analysis failed to confirm our first hypothesis (momentum is conserved in every collision), but they did confirm our second hypothesis (kinetic energy is conserved in elastic collisions). Further experimentation may be needed to determine the validity of the first hypothesis.

A. Potential Issues

Some potential issues with our experimental setup is that the ultrasound sensor was fairly inaccurate when measuring position. Specifically, after a certain distance from the wall where sound waves reflect back to sensor, the reading of the sensor is dominated by noise. Oftentimes during this experiment, we would observe this noise when the object went too far into the middle and away from either boundary. This could prevent good readings from the sensor and cause very imprecise results for the initial and final velocities. In fact, this happened in several of our experiments and we had to use the TA's data for them, since ours did not clearly show the collision.

Additionally, the air track could have been slightly tilted downwards or upwards. This would mean that momentum and energy could not be conserved in any collision, since gravity would add some momentum to the system over time regardless. This error would directly affect our hypothesis, as we would observe that momentum isn't conserved even though the only outside source of momentum may just be gravity. For example, this could have occurred during our inelastic collision between a stationary and moving object, where the system had a statistically significant greater momentum after the collision than before. This may be because gravity imparted momentum to the system steadily after the collision. Without gravity, we may have observed a system momentum loss within 2σ of 0, but we instead observed a system momentum loss more than 2σ from 0.

B. Further Recommendations

Finally, when we analyzed our data, we observed that we often launched our carts too quickly towards each other. This means that the time we have to measure position data decreases, and the collision occurs more quickly. This will generally add more error to our velocity measurements, since we have less data for both the pre- and post-collision velocities.

In the future, we could use a more reliable ultrasound sensor that does not get dominated by noise at larger distances from a wall. Additionally, we could increase the size of the wall that the ultrasound sensor uses in order to ensure that the ultrasound reading is purely from the distance to the wall and no other external objects. We could also launch the carts towards each other more slowly to increase the amount of data collected and decrease error. Additionally, in order to ensure that gravity did not have an effect on the experiment, we could ensure that a cart stays stationary on a track before launching them; this would mean that gravity is not changing the momentum of the cart and thus would not change the momentum of the 2-cart system.

Further experimentation could focus on the change of system momentum and kinetic energy during collisions in the presence of an external force (such as a gravitational field). These forces could be conservative, like gravity, or nonconservative, like friction. Additionally, collisions in 2 or 3 dimensions could also be explored.