

LAB IV. ONE DIMENSIONAL COLLISION

1. Objectives

This experiment focuses on studying the conservation of linear momentum. By analyzing the collision of two pendulums, you will learn how momentum is transferred from one pendulum to the other.

2. Material

- 2 Ping-pong ball/ Golf ball/ Tennis ball/Playdough *etc*.
- A String
- A Meter stick/ruler
- A Scale (Kitchen scale)
- A Glue gun
- 2/3 Suction cups with hooks

Fig. 1: An example list of materials used in this lab.

3. Theory

3.1 Conservation of momentum

Linear momentum is one of the fundamental concepts in physics. In Newtonian mechanics it is proportional to the velocity and the mass of an object,

$$\boldsymbol{p} = m\boldsymbol{v}. \tag{1}$$

In the absence of an external force, the total linear momentum of a system is conserved. This means that the sum of the momenta of all objects of an isolated system at one instant ($P = p_1 + p_2 + \cdots$) is constant and will not change with time,

$$\boldsymbol{P_i} = \boldsymbol{P_j}, \tag{2}$$

where i and j refer to two different instances of time, and $\boldsymbol{P}$ is the total momentum of the system, respectively.

3.2 Conservation of total energy

For a closed, isolated system, the total energy of the system (E) remains constant. This means energy is not created or destroyed, but it can be converted from one form to another. So, at two instances *i* and *j*,

$$E_i = E_j. \tag{3}$$

For a system exposed to the gravitational force and in absence of any friction (dissipation of energy) or external forces (applied work on the system), the total energy must be the sum of **kinetic** (K) and **gravitational potential** (U) energy,

$$E_i = K_i + U_i = \frac{1}{2}mv_i^2 + mgh_i, \tag{4}$$

where v_i and h_i are velocity and height at an instant *i*, respectively. **Equation. 3** can be written as,

$$\frac{1}{2}mv_i^2 + mgh_i = \frac{1}{2}mv_j^2 + mgh_j. \tag{5}$$

3.3 Elastic collision

In addition to linear momentum, when the total kinetic energy of the system is conserved, the collision is called an *elastic* collision. For a system of two objects, the equations would be,

$$\begin{cases} K_{1i} + K_{2i} = K_{1f} + K_{2f} \\ \boldsymbol{p}_{1i} + \boldsymbol{p}_{2i} = \boldsymbol{p}_{1f} + \boldsymbol{p}_{2f} \end{cases}, \tag{6}$$

where K_{1i} , K_{2i} ($\boldsymbol{p}_{1i}, \boldsymbol{p}_{2i}$) are initial kinetic energies (momenta), and K_{1f} , K_{2f} ($\boldsymbol{p}_{1f}, \boldsymbol{p}_{2f}$) are final kinetic energies (momenta) of objects 1 and 2, respectively. Considering the motion to occur in 1D and writing the exact expression for the kinetic energies,

$$\begin{cases} \frac{1}{2}m_1v_{1i}^2 + \frac{1}{2}m_2v_{2i}^2 = \frac{1}{2}m_1v_{1f}^2 + \frac{1}{2}m_2v_{2f}^2 \\ m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f} \end{cases}. \tag{7}$$

One can then easily find the final velocities in terms of initial velocities for both objects,

$$\begin{cases} v_{1f} = \frac{m_1 - m_2}{m_1 + m_2} v_{1i} + \frac{2m_2}{m_1 + m_2} v_{2i} \\ v_{2f} = \frac{2m_1}{m_1 + m_2} v_{1i} + \frac{m_2 - m_1}{m_1 + m_2} v_{2i} \end{cases}. \quad (8)$$

4. Set-up Preparation

There are several instructional videos on the preparation of the lab. You need to watch

(1) **Preparing the Meterstick** video

(https://www.youtube.com/watch?v=67j4kJOiAQI)

(2) **Phone Setup** video

(https://www.youtube.com/watch?v=nHfeejFBe28)

(3) **Tracker Tutorial** video

(https://www.youtube.com/watch?v=BxplFubEVzQ)

Please make sure that you follow the detailed instructions to avoid potential errors in data analysis before attempting to perform the experiment.

A detailed video instruction on how to prepare and perform simple pendulum motion can be found at:

https://www.youtube.com/watch?v=ehEdYe43RHU

and follow the steps below to prepare the set-up:

4.1 Hang a ball from a suction hook according to the instruction for the pendulum lab. In brief, use a suction hook and wind a string attached to the ball around the hook.

4.2 Hang a second ball similar to the first ball

4.3 Note that the length of the string should be the same as the one for the first ball. This means their centers will be at the same level horizontally.

4.4 The horizontal distance between them should be adjusted so that both balls are touching. However, even if the balls are touching, you may still have an incorrect set-up. You must make sure the suction hooks are exactly separated by $r_{b1} + r_{b2}$, where r_{b1} and r_{b2} are the radius of ball 1 and 2, respectively.

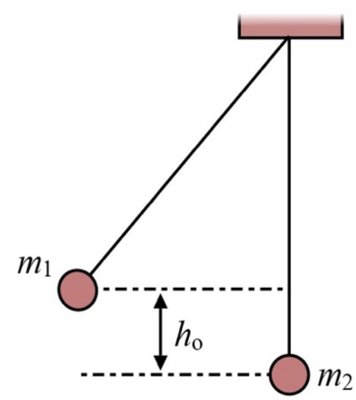

Fig. 2: The m_1 is initially at height h_0 with respect to m_2.

4.5 Move the ball with mass m_1 to a height h_0 relative to the second ball according to **Fig. 2** and release it. The m_1, as expected, swings downward and has an almost elastic (why?) collision with m_2.

4.6 The collision should occur in a plane parallel to the screen/camera. This means before releasing m_1, you need to make sure that m_1 and m_2 are in the same plane when viewed from the side. Neglecting this can seriously deteriorate the accuracy of the experiment

5. Experiment & Data Analysis Procedure

In the first part, the focus will be on the collision between two identical balls. You are asked to release the ball at different initial angles (heights) and check the conservation of momentum and kinetic energy. In the second part, you will look at two other scenarios for the collision. One is a light object colliding with a heavy object and the other is a heavy object colliding with a light object.

5.1 Identical balls

5.1.1 *Simplifying the equations*: Considering that both balls are identical and have same mass, simplify the **Eq. 8**.

5.1.2 *Initial velocity*: Use **Eq. 5** to find the velocity of ball 1 just before the collision in terms of the initial height of the object. It should be noted that when releasing the ball, the system has no kinetic energy.

5.1.3 *Performing the experiment*: Release the first ball at different initial heights at least 5 times and fill in the table. Determine the velocities just before and after the collision using conservation of energy. Then, measure the velocities just before and after the collision using the numerical estimation $v_r(t_i) = \frac{r(t_{i+m}) - r(t_{i-m})}{t_{i+m} - t_{i-m}}$ for $m = 2$. You can find the v_x and v_y and then find v_r ($\sqrt{v_x^2 + v_y^2}$). Fill in the **Table. 2**.

5.1.4 *Kinetic energy*: Find the kinetic energies before and after the collision and fill in the rest of the **Table. 2**.

5.2 Light-heavy collision

5.2.1 *Perform the experiment*: Use two balls with one being noticeably heavier than the other. An example would be a ping-pong ball as the first ball and a gulf ball as the second ball. Lift the light ball to a relative height of *h* with respect to the heavy ball and then release it. Perform the experiment at least 5 times.

5.2.2 *Simplifying the equations*: Measure the mass of each ball, then simplify the **Eq. 8** and find the final (just after the collision) velocities in terms of initial (just before the collision) velocities.

5.2.3 *Tracker analysis*: Use the numerical evaluation formula discussed in 5.1.3 to find the initial and final velocities of both light and heavy balls and fill in **Table. 3**. Then, use the initial velocities to calculate the final velocities again using the simplified equations in 5.2.2.

5.3 Heavy-light collision

5.3.1 *Perform the experiment*: Lift the heavy ball to a relative height with respect to the light ball and then release it. Perform the experiment at least 5 times.

5.3.2 *Simplifying the equations*: Follow the same steps as in Section 5.2 and fill in **Table. 4**

Lab IV Worksheet

Name of the Student: ______________________ **Date:** _____________________

Q.1 Identical balls

Mass of ball 1: ------------------ Mass of ball 2: ------------------

Q.1.1 Rewrite **Eq. 8** that ball 2 is initially stationary and both balls are identical.

Q.1.2 Find the initial velocity of ball 1 using conservation of energy.

Q.1.3 Describe your observation just after the first collision. What will happen to the first ball immediately after the collision?

Fill in table-1 according to the procedure:

Table 1

Trial	h_{1i}	v_{1i} $(Theory)$	$v_{1i}(Tracker)$	% Error
1				
2				
3				
4				
5				

Q.1.4 Why are the velocities calculated from conservation of energy and Tracker analysis different? Provide at least 4 reasons.

Fill in the table-2 according to the procedure:

Table 2

Trial	$v_{1i}(Tracker)$	$v_{2f}\ (Tracker)$	$v_{1f}(Tracker)$	K_{1i}	K_{2f}	$\frac{v_{1i}-v_{2f}}{v_{1i}}$	$\frac{K_{1i}-K_{2f}}{K_{1i}}$
1							
2							
3							
4							
5							

Q.1.5 Is the momentum conserved for these trials?

Q.1.6 Are these collisions elastic? If not, what are the reasons causing the collision not to be elastic?

Q.1.7 After the first collision, the second ball will reach swing and then collide with the first ball (2^{nd} collision). Briefly describe your observations for the 2^{nd} and 3^{rd} collisions.

Q.2 Light-to-Heavy collision

Mass of ball 1: ------------------ Mass of ball 2: ------------------

Q.2.1 Briefly describe your observation of how each ball moves after the collision.

Q.2.2 Rewrite **Eq. 8** according to the masses and find the final velocities in terms of the initial ones.

Fill in the table:

Table 3

Trial	$v_{light,i}$ (Tracker)	$v_{light,f}$ (Tracker)	$v_{heavy,f}$ (Tracker)	$v_{light,f}$ (Theory)	$v_{heavy,f}$ (Theory)
1					
2					
3					
4					
5					

Q.2.3 How do the predicted final velocities agree with the numerical estimation from "Tracker" ? For one of the trials, find the total initial and final total momentum and kinetic energy according to **Eq. 6** and **7**. Which one is better conserved?

Q.3 Light-to-Heavy collision

Q.3.1 Briefly describe your observation of how each ball moves after the collision.

Q.3.2 Rewrite **Eq. 8** according to the masses and find the final velocities in terms of the initial ones. Are they the same as what you got for Q8? Explain.

Fill in the table:

Table 4

Trial	$v_{light,i}$ (Tracker)	$v_{light,f}$ (Tracker)	$v_{heavy,f}$ (Tracker)	$v_{light,f}$ (Theory)	$v_{heavy,f}$ (Theory)
1					
2					
3					
4					
5					

Q.3.3 What are the main sources of error in this experiment? Can you design the collision experiment differently? (It should not be just pendulums).