# Inelastic Collision

**Objectives**

To study the laws of conservation of linear momentum and energy in a completely inelastic collision.

**Introduction**

If no net external force acts on a system of particles, the total linear momentum of the system cannot change. This is known as the law of conservation of linear momentum. In other words, if the net external force on the system is zero, the total linear momentum of a system of particles before and after a collision is equal. If the total kinetic energy of the system is also conserved during the collision then it is called an elastic collision. If some of the kinetic energy is lost, for example in thermal energy, then it is called an inelastic collision. The energy loss is maximum when the particles stick together after the collision. This is known as completely inelastic collision.

In this lab, you will study the properties of completely inelastic collision between a ball and a pendulum. A schematic diagram is shown in Figure 1. A ball of mass m, moving with speed $v_1$, collides with a pendulum of mass M, which is at rest. Immediately after the collision, the ball and the pendulum move together with speed $v_2$. You will measure the masses m and M, and determine the speeds $v_1$ and $v_2$ in the following exercises.

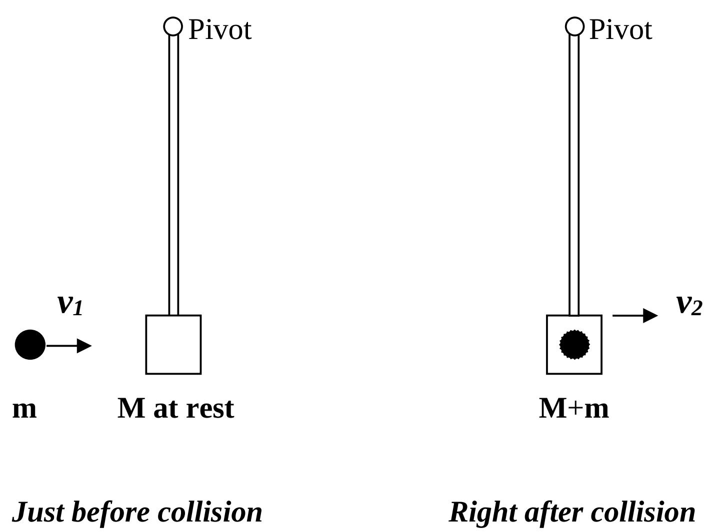



**Figure 1**

You will use a ballistic pendulum apparatus, shown in Figure 2. The apparatus consists of a launcher, a projectile ball, and a pendulum. Attached to the swinging end of the pendulum is a catcher designed to catch the ball and hold it, creating a completely inelastic collision. The pendulum rod is hollow to keep its mass low, and most of the mass is concentrated at the end so that the entire system approximates to a simple pendulum. The pendulum is initially at rest but acquires energy from the collision with the ball. The pendulum is attached to a Rotary Motion Sensor (RMS) at the pivot point. The RMS measures the angular position as a function of time as the pendulum swings. Measuring the maximum angular displacement enables us to find $v_2$ as you will see in Exercise 3. The horizontal speed of the projectile as it hits the pendulum ($v_1$) can be found by projectile motion analysis as done in Exercise 1.

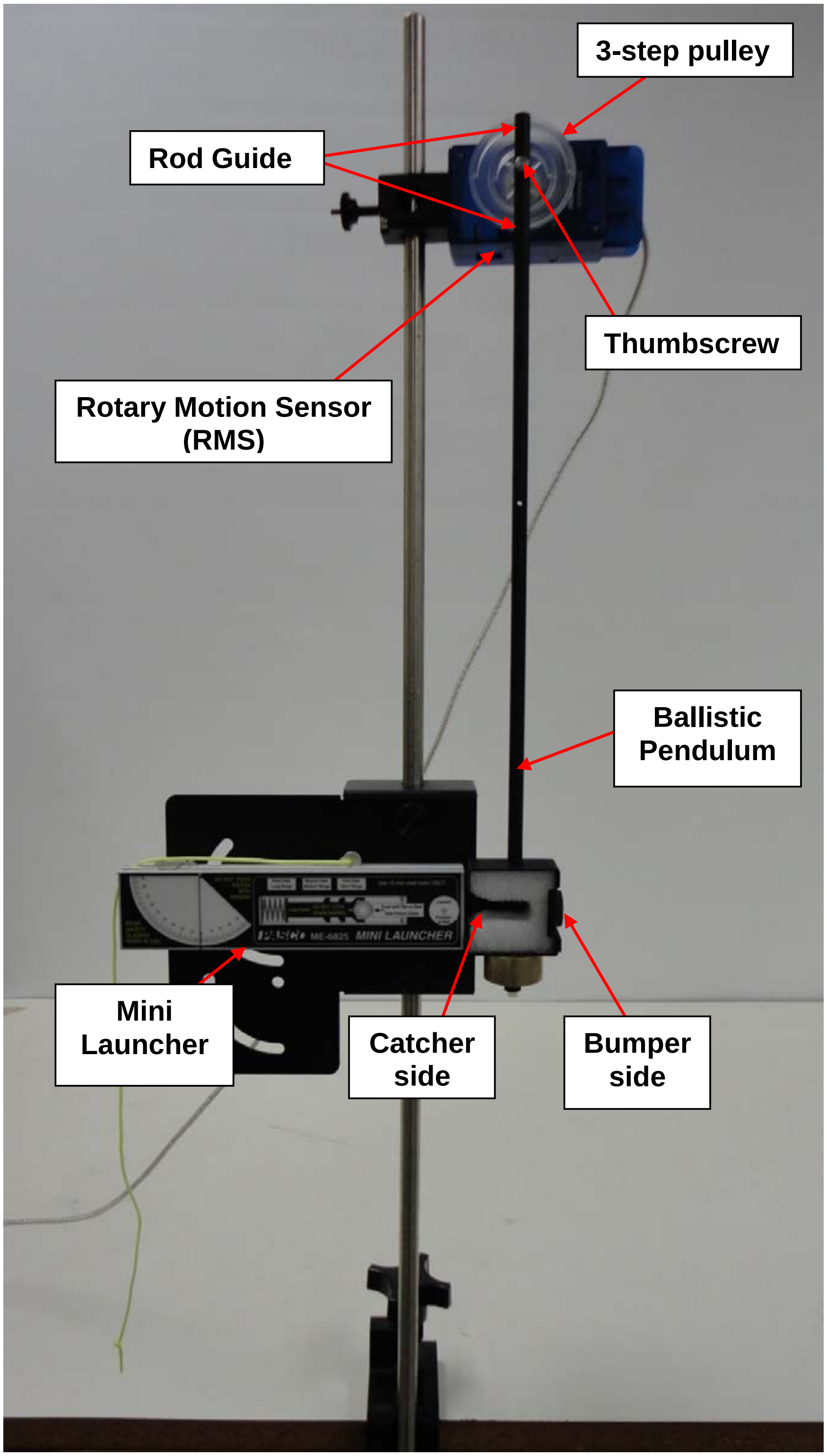



**Figure 2**

**Exercise 1 – Initial speed of the projectile**

In this exercise, you will determine the launching speed of the projectile from the range of the projectile as shown in Figure 3.

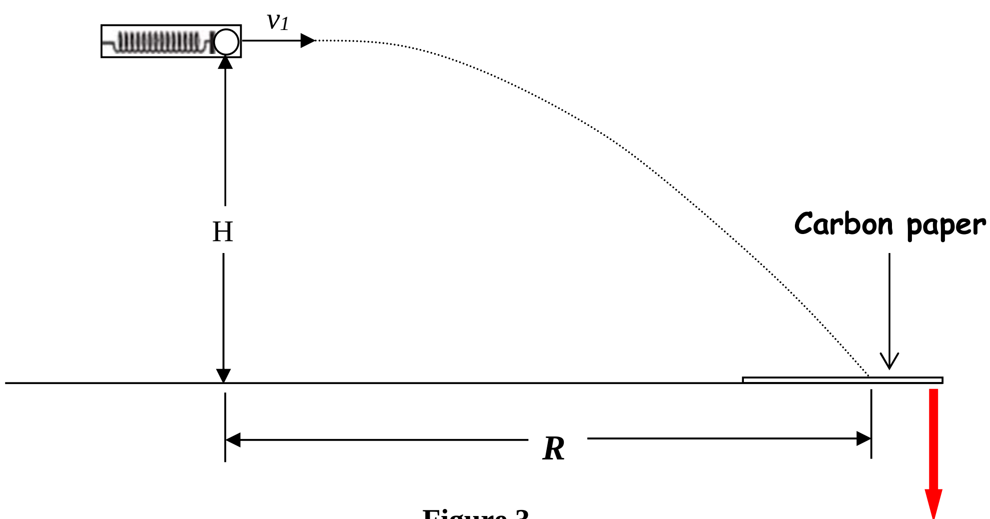
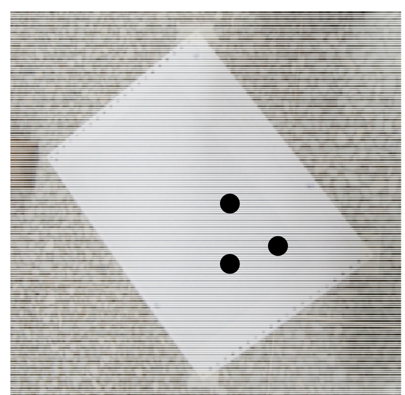



**Figure 3**



The horizontal launching speed $v_1$ is related to the range $R$ by

$$\boldsymbol{v_1 = R\sqrt{\frac{g}{2H}}} \qquad \textbf{(1)}$$

where $H$ is the vertical height through which the projectile fall and $g$ is the free-fall acceleration = 9.80 m/s$^2$.

1. Swing the pendulum out of the way to the other side of the barrel of the launcher, as shown in Figure 4.

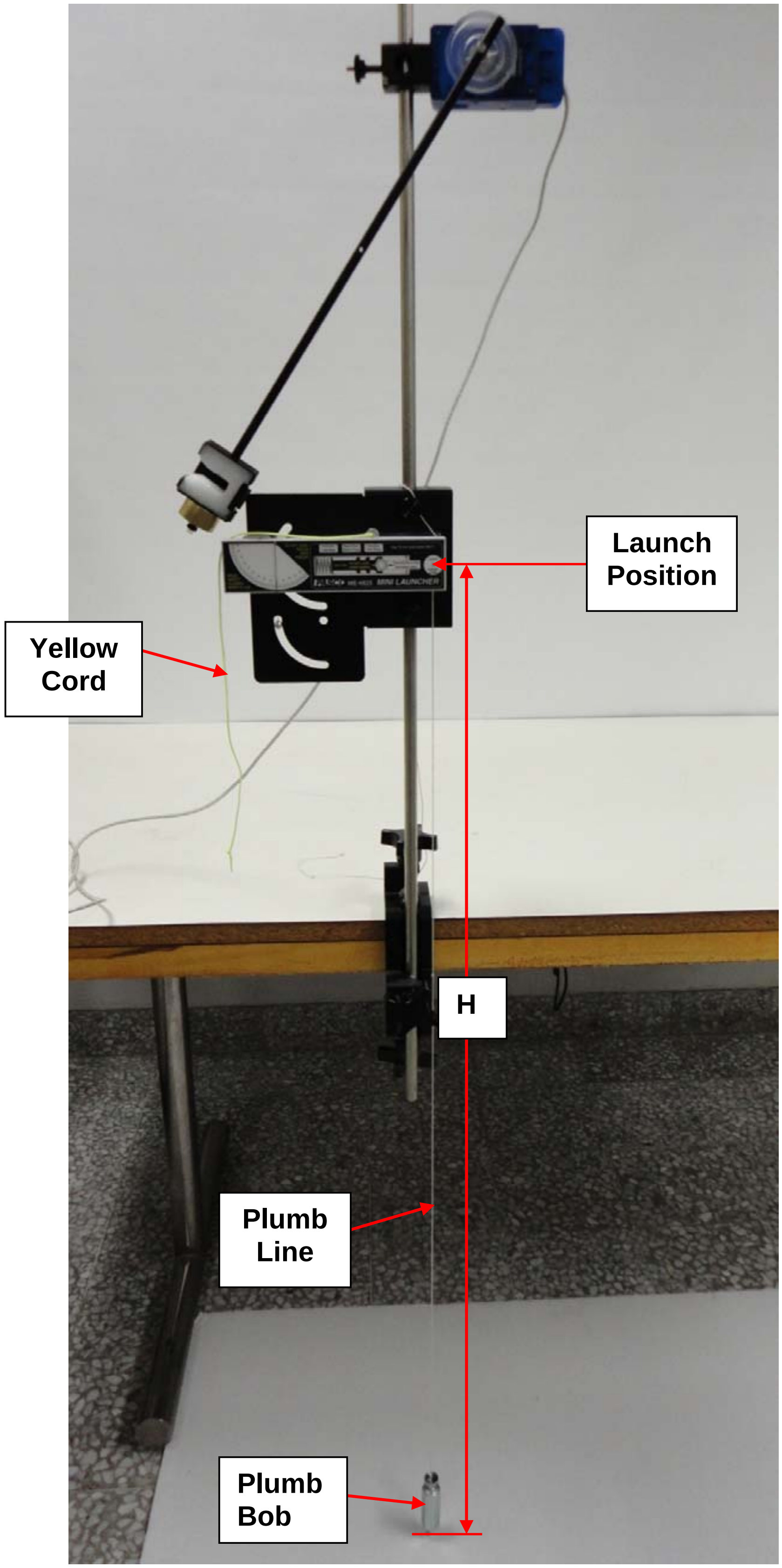



**Figure 4**

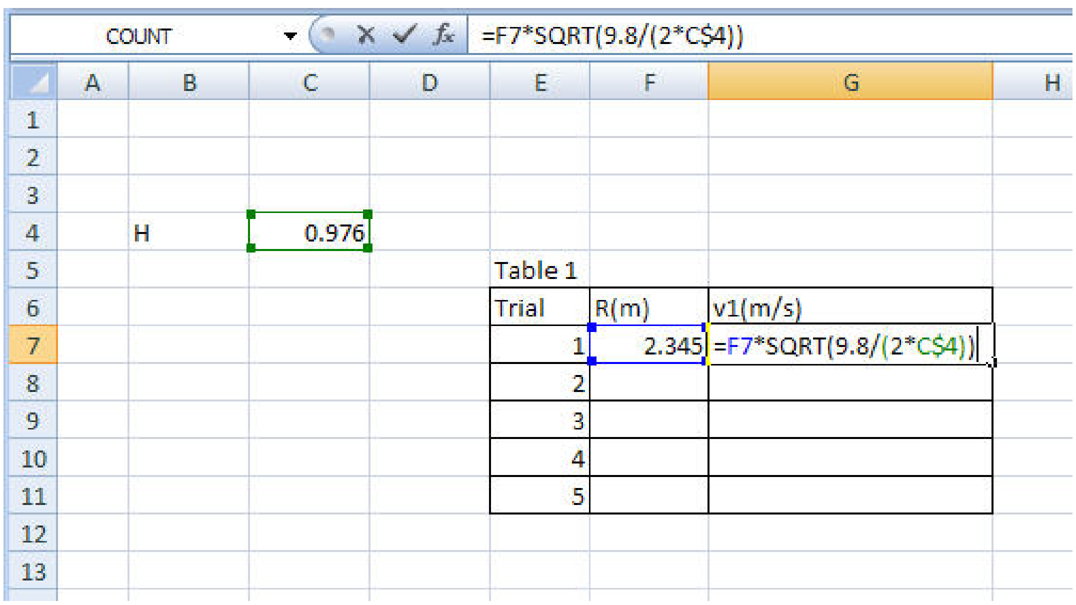
2. Place the projectile (steel ball) in the end of the barrel of the launcher. Use the pushrod (a plastic tube) to push the ball down the barrel until the trigger catches in the third position (fastest launch).

3. Use the plumb line to locate the point vertically below the launch position of the ball.

4. Make sure the launcher is placed horizontally and you have sufficient open space in front of the set-up so as to measure the range *R* of the projectile.

5. After alerting all nearby persons, pull the trigger using the yellow cord to fire the ball. This is only a trial run to gauge the distance at which the ball will strike the floor. Place a carbon paper at this point on the floor and tape it down so that the landing point of the ball can be seen on the paper.

6. Fire the ball five times. Measure and record the five values of *R* in **Excel** (see Figure 5 for example).



COUNT =F7*SQRT(9.8/(2*C$4))

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | |
| 2 | | | | | | | | |
| 3 | | | | | | | | |
| 4 | | H | 0.976 | | | | | |
| 5 | | | | | Table 1 | | | |
| 6 | | | | | Trial | R(m) | v1(m/s) | |
| 7 | | | | | 1 | 2.345 | =F7*SQRT(9.8/(2*C$4)) | |
| 8 | | | | | 2 | | | |
| 9 | | | | | 3 | | | |
| 10 | | | | | 4 | | | |
| 11 | | | | | 5 | | | |
| 12 | | | | | | | | |
| 13 | | | | | | | | |

**Figure 5**

7. Measure and record the value of *H*.

8. Determine the launching speed $v_1$ for each value of *R*. Use EXCEL to do all your calculations. Note the "absolute reference" to the cell C4 as C$4, so when you fill down the formula it doesn't change. But F7 will change to F8 and so on as needed. Round the calculated value of $v_1$ to right number of significant figures. Take $g$ as 9.80 m/s$^2$, correct to three significant figures.

9. <u>Copy your Table 1 from Excel worksheet in your report</u>.

Table 1

| H = | (m) |
|---|---|

| R(m) | $v_1$(m/s) |
|---|---|
| | |
| | |
| | |
| | |
| | |

**Exercise 2 – Find the Mass and Center of Mass**

In this exercise, you will measure the mass of the pendulum M using a triple-beam balance, determine the mass of the ball m, and locate the center of mass of the pendulum-ball system.

1. Bring back the pendulum to face the launcher barrel. Make sure that the catcher side of the pendulum is facing the launcher and aligned with the launcher. See Figure 2. The alignment of launcher with the foam catcher of the pendulum is very important. Fire the ball and catch the pendulum near the top of its swing with your hand so it does not swing back and hit the launcher (this will prevent the ball from falling out or shifting).

2. Remove the pendulum from the RMS.

3. Remove the thumbscrew from the pendulum shaft (rod).

4. With the ball still in the catcher, place the pendulum at the edge of a table with the pendulum shaft perpendicular to the edge and the counterweight hanging over the edge. Push the pendulum out until it just barely balances on the edge of the table. The balance point is the center of mass (see Figure 6).

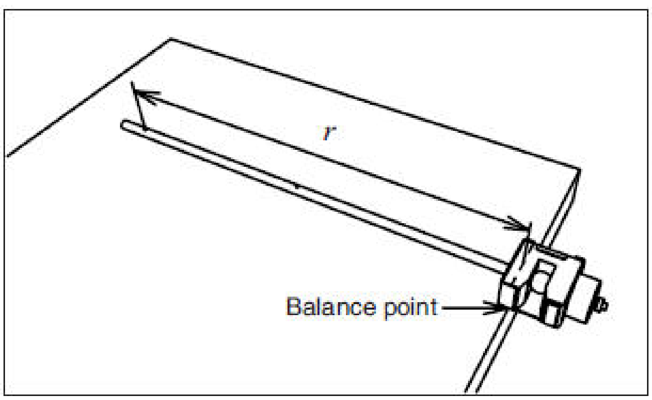



**Figure 6**

5. Measure and record the distance **r**, from the center of rotation (where the pendulum was attached to the RMS) to the center of mass.

6. Measure and record the mass of the pendulum with the ball inside it, **M+m**.

7. Remove ball from the catcher.

8. Measure and record the mass of the pendulum without the ball, **M**.

9. Calculate the mass of the ball, **m** and record it in your report.

**Exercise 3 – Center of mass speed of ballistic pendulum immediately after the collision**

During the collision, some of the ball's kinetic energy is converted into thermal energy. But after the collision, as the pendulum swings freely upwards, we can assume that energy is conserved and that all of the kinetic energy of the pendulum-ball system is converted into the increase in the gravitational potential energy.

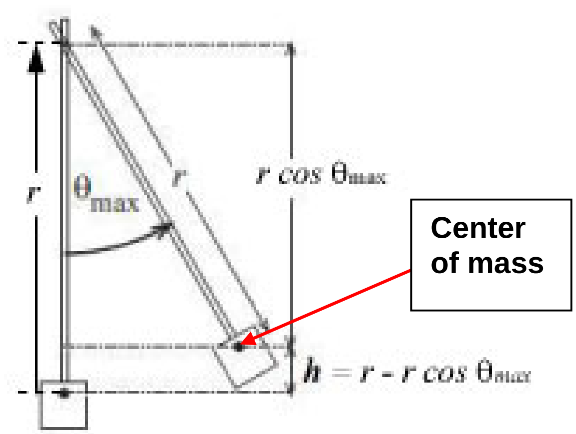



**Figure 7**

Energy conservation requires $K_i + U_i = K_f + U_f$

or $K_i - K_f = U_f - U_i$

That is,

$$\frac{1}{2}(m+M)v_2^2 = (m+M)g\,h$$

This leads to

$$v_2 = \sqrt{2g\,h} \qquad \textbf{(2)}$$

1. Save the DataStudio file *ballistic.ds* from phys101 homepage into your computer.

2. Open DataStudio and open the activity *ballistic.ds*.

3. Make sure RMS (rotary motion sensor) is connected to your computer via the interface.

4. Load the launcher and push the ball in to the third (fastest) position.

5. Attach the pendulum back to the RMS using the thumb screw. Make sure the pendulum shaft fits into the groove of the RMS pulley. Also make sure the catcher side of the pendulum is facing the launcher and aligned with the launcher as shown in Figure 2. The alignment of launcher with the foam catcher of the pendulum is very important.

6. **Start** data collection in DataStudio.

7. Launch the ball so that it is caught in the pendulum. Wait for the pendulum to reach its highest point and swings down towards the launcher. **Stop** the data collection.

8. If the foam catcher failed to catch the ball, **Delete All Data Runs** and repeat steps 4 through 7 until you get it right.

9. You should get a graph of angular displacement in radians versus time in seconds similar to shown in Figure 8.

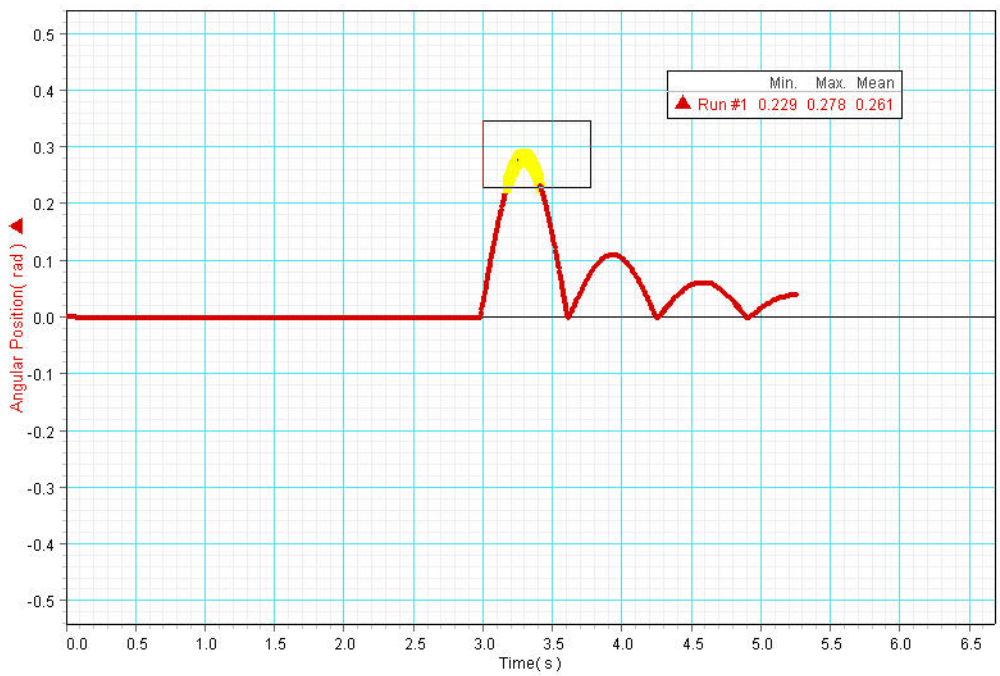



**Figure 8**

10. Note down the maximum angular displacement measured in radians by the RMS as the pendulum swings to the top at the very first instance. Prepare Table 2 in EXCEL and record this value.

Table 2

| Trial | $\theta_{max}$ (rad) | $h$ (m) | $v_2$ (m/s) |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |

11. **Delete All Data Runs** in DataStudio. Take out the ball from the foam catcher and place it safe in the box provided.

12. Repeat steps 4 through 11 four more times to get five values of $\theta_{max}$ in table 2.

13. For each value of $\theta_{max}$ in Table 2, calculate the maximum height ($h$) the center of mass rises as the pendulum swings up (see Figure 7). The equation to be used is:
$$h = r(1 - \cos(\theta_{max}))$$
Round the answer to the right number of significant figures.

14. Use your value of $h$ and equation 2 to calculate the center of mass speed of the pendulum-ball system right after collision ($v_2$). Round the answer to the right number of significant figures.

15. Copy your completed Table 2 from Excel worksheet in your report.

**Exercise 4 – Verifying the conservation laws**

In this exercise, you will verify that the total linear momentum is conserved while the kinetic energy is not conserved in the inelastic collision between the ball and the pendulum.

1. Calculate the five values for each of the following:

   Total linear momentum before collision, $P_1 = m\, v_1$

   Total kinetic energy before collision, $K_1 = \frac{1}{2} m\ v_1^2$

   Total linear momentum after collision, $P_2 = (m+M)\, v_2$

   Total kinetic energy after collision, $K_2 = \frac{1}{2}(m+M)\ v_2^2$

   Round the answer to the right number of significant figures and record these values in Excel as shown below (Table 3), where 1 and 2 in the first column (B/A) stand for before and after collision, respectively.

Table 3

| B/A | P(kg.m/s) | K (J) |
|---|---|---|
| 1 | | |
| 1 | | |
| 1 | | |
| 1 | | |
| 1 | | |
| | | |
| 2 | | |
| 2 | | |
| 2 | | |
| 2 | | |
| 2 | | |

2. Select the values in the first three columns including the labels B/A, P and K, and insert scatter plot. Copy your Table 3 and the graph from Excel and paste them in your report

3. From your graph:
   a. Can you conclude that momentum is conserved? Justify your answer.
   b. What can you conclude about the conservation of energy? Explain your answer.
   c. Why the kinetic energy after collision is smaller than that before collision?