Experiment No. 3:

Study of projectile motion and collision.

3.1 Objectives:

The main objective of this lab is to construct a projectile and study the basic quantities of the projectile motion. Also to study the elastic collision between a ball and fixed surface.

3.2 Prelab:

Student should read the lab manual and have clear idea about the objective, time frame and outcomes of the lab.

3.3 Outcomes:

After completing this lab work student will be able to answer the following questions:

- What is a projectile motion and how its horizontal and vertical components of velocities change with time?
- For a projectile how the quantities: velocity at any time (both value and direction), time of flight, range and maximum height can be calculated?
- How momentum and energy are conserved for an elastic collision?
- What is Impulse? How it could be calculated for a collision?

3.4 Timing and Length of Investigation (Total 3 Hours):

- **Lab Preparation (15 minutes):**
    - Students will sit for the lab class with preparations and class attendance will be taken.
- **Lecture on Theory (30 minutes):**
    - Teacher will clarify the objective and theory of the experiment.
- **Lecture on Procedure (15 minutes):**
    - Students will learn about the procedure of the experiment through a video lecture.
- **Experimental Work (90 to 100 minutes):**
    - A sample data will be provided to students and teacher will clarify every part of it.
    - Students will do all the calculations and complete the result part.
- **Post Lab Discussion (15 to 20 minutes):**
    - Teacher will summarize the total lab work and have a discussion with the students related with the questions given in the outcomes part.
- **Report Submission:**
    - After completing the lab reports students will upload their lab reports as groups in teams in the same day.

3.5 Theory:

Projectile Motion:

The motion of projectiles, known to mankind since the times of Archimedes, is an example of two-dimensional motion. This motion occurs in a vertical plane defined by the direction of launch. In the simplest case (when air resistance is neglected and motion occurs close to the surface of earth), the projected body experiences a uniform acceleration along the vertical direction and a uniform velocity along the horizontal direction.

The trajectory of a projectile is parabolic as the fig. 3.1 shows. A study on projectile motion helps in a thorough understanding of the basic concepts in kinematics like accelerated motion, uniform motion, equations of motion and so on.

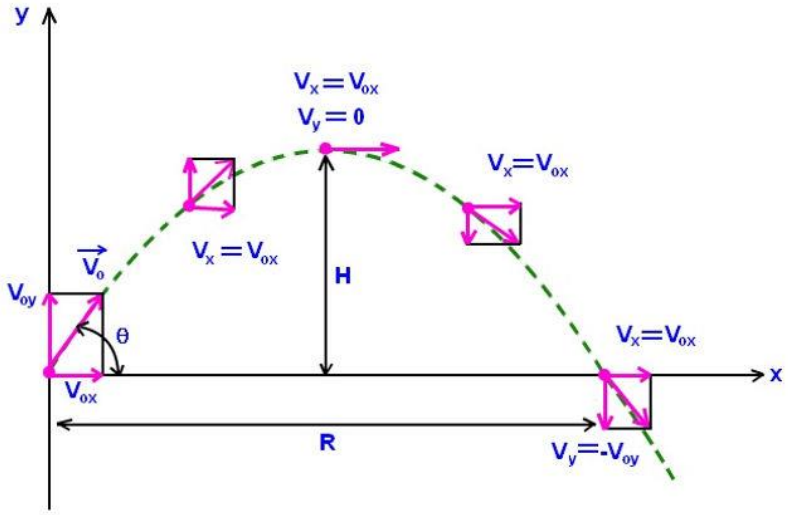

Figure 3.1: The parabolic trajectory of a projectile in the x-y plane. The projectile is thrown with an initial velocity v_0 and angle θ with the x axis. R and H represent the range and maximum height of the projectile, respectively.

Collision:

The elastic collision between a ball and a fixed smooth surface can be presented as the fig. 3.2 shows.

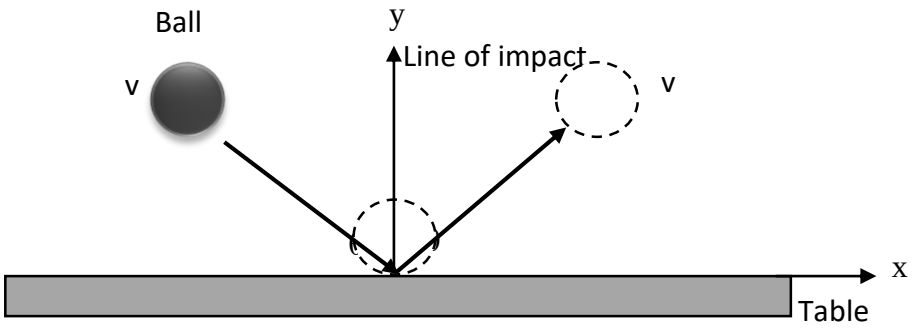

Figure 3.2: An elastic collision between a smooth ball and a table. The velocities just before and after the collision remain the same.

For an elastic collision, both the momentum and kinetic energy are conserved. The impulse in any dimension (x or y) can be defined as

$$\text{Impulse, } J = \text{Change in momentum, } \Delta p = p_f - p_i ,$$

where p_i and p_f are the initial and final momentum, respectively.

3.6 Apparatus:

Marble, ramp, clamp, recording paper, carbon paper, meter scale, weighing scale.

3.7 Procedure:

- Set up the apparatus as shown in fig. 3.3. Make sure that the end of the ramp looks level with the table. Lay down a piece of recording paper on the floor and place a sheet of carbon paper on top. Each bounce of the ball will leave a mark on the recording paper.
- Once the apparatus is fixed, do not move the recording paper until the data collection is completed. However, the carbon paper can be lifted at any time to inspect the collision points. Locate the position O on the floor using the marble ball and measure the distance from O to a reference point on the recording paper. This allows the paper to be moved after the data collection is completed to a more suitable location for the measurements of S_1 and S_2.

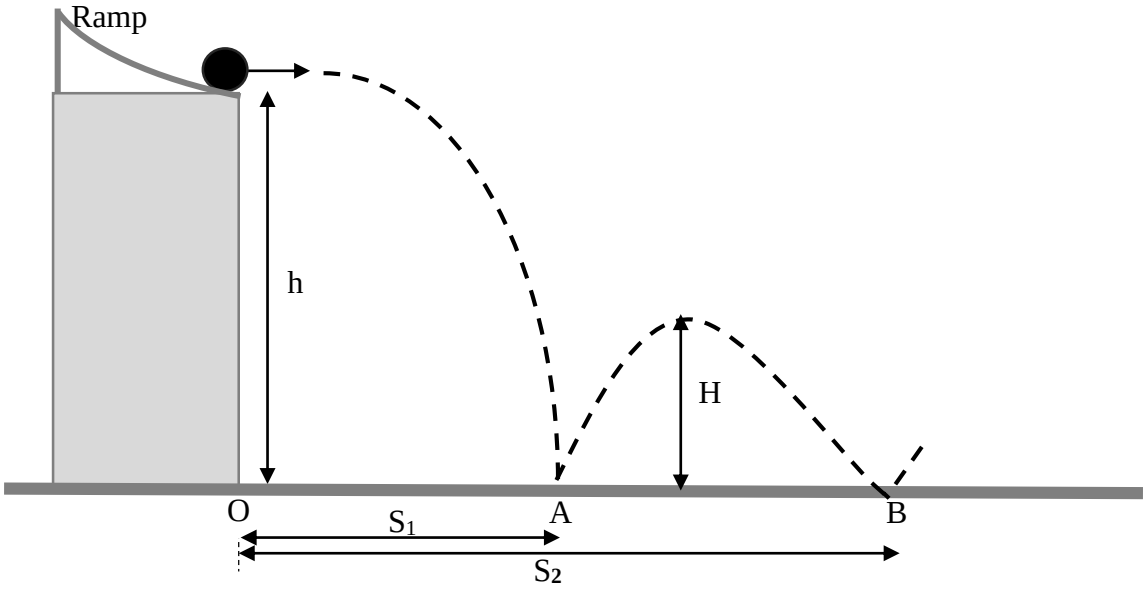

Figure 3.3: Set-up for the experiment.

- To collect the data, release the ball from a point near the top of the ramp, being careful not to impart spin on the ball. This allows the ball to roll down the ramp and bounce on the floor with minimal spin. Repeat the procedure 10 times always releasing ball from the same point on the ramp.
- Measure the heights h and H with a meter scale as accurately as possible.
- From the recording paper, obtain the average values of S_1 and S_2 in the following way. By eye, determine the circular region that include most of the marks on the paper (ignore any points that are obviously anomalous). Draw the circle around this region. Take the center of the circles for S_1 and S_2. The radius of the circles as the uncertainties in S_1 and S_2.
- Measure the mass of the marble.

3.8 Experimental Data:

Table 3.1: Equations of motion for one dimensional and two dimensional (projectile) motion

Height h (cm)	Height H (cm)	Average Distance, S_1 (cm)	Uncertainty in S_1 (cm)	Average Distance, S_2 (cm)	Uncertainty in S_2 (cm)	Mass of Marble m (gm)

3.9 Analysis:

Keep in mind that the horizontal velocity v_x of the ball before impact at A equals the horizontal velocity immediately after the rebounds from A. This is a good assumption providing the working table-floor is smooth. Using table 3.2 according to the fig. 3.3 calculate the quantities in table 3.3 and 3.4.

Table 3.2: Equations of motion for one dimensional and two dimensional (projectile) motion.

Quantity	Straight line (one dimensional) motion	Projectile (two dimensional) motion	
		Horizontal component	Vertical component
Initial velocity	u	$v_{0x} = v_0\cos\theta_0$	$v_{0y} = v_0\sin\theta_0$
Acceleration	a	$a_x = 0$	$a_y = -g$
Velocity at any point	$v = u + at$ $v^2 = u^2 + 2as$	$v_x = v_{0x}$	$v_y = v_{0y} - gt$ $v_y^2 = v_{0y}^2 - 2gy$
Distance	$s = vt$ (constant velocity) $s = ut + \frac{1}{2} at^2$	$x = v_{0x}t$	$y = v_{0y}t - \frac{1}{2} gt^2$

3.10 Result:

Table 3.3: Some basic quantities related with projectile motion.

SN	Quantities	Corresponding Equations	Values with Units
1	Time for the ball to leave the ramp and hit the point A	$t = \sqrt{\frac{2h}{g}}$	
2	Constant Horizontal velocity of the ball	$v_x = \frac{s}{t}$	
3	Vertical velocity just before it strikes the point A	$v_y = -gt$ or $v_y = -\sqrt{2gh}$	
4	Velocity of the ball just before it strikes the point A in vector form	$\lvert v\rvert = \sqrt{v_x^2 + v_y^2}$, $\theta = tan^{-1}\left(\frac{v_y}{v_x}\right)$	
5	Range of the second projectile = Distance between point A and B	$R = \frac{v^2 sin2\theta}{g}$ or R= $S_2 - S_1$	
6	Time of the ball spends between point A and B	$t_{AB} = \frac{R}{v_x}$	
7	Maximum height for the projectile between point A and B	$H = \frac{g}{2}\left(\frac{t_{AB}}{2}\right)^2$	

Table 3.4: Some basic quantities related with elastic collision between ball and the fixed surface.

SN	Quantities	Corresponding Equations	Values with Units
1	Magnitude of the velocity before/after impact at point A	$\lvert v\rvert = \sqrt{v_x^2 + v_y^2}$	
2	The angle that the ball makes with the surface just before/after the collision at point A	$\theta = tan^{-1}\left(\frac{v_y}{v_x}\right)$	
3	Kinetic energy of the ball before the collision at A	$K.E_i = \frac{1}{2}m\lvert v\rvert^2$	
4	Kinetic energy of the ball after the collision at A	$K.E_f = \frac{1}{2}m\lvert v\rvert^2$	
5	Horizontal impulse that the floor gives to the ball	$J_x = P_{ix} - P_{fx}$	
6	Vertical impulse that the floor gives to the ball	$J_y = P_{iy} - P_{fy}$	

3.11 Resources:

For further understanding students may go through the following resources.

- **Fundamental of Physics (10th Edition):** Projectile motion (Chapter 4, page 70-75), Collision and Impulse (Chapter 9, page 266)
- **Video Links:**
  - Projectile motion: https://www.youtube.com/watch?v=rMVBc8cE5GU
  - **https://www.youtube.com/watch?v=pZZt357pk-I&list=RDCMUCX1Hh7CvEc3RCUd4NRBWJMw**
  - **https://www.youtube.com/watch?v=WtfVZdpHZ9o**
  - Collision: https://www.youtube.com/watch?v=hZm-DcO2JfA