RANGE AND THE DYNAMICS OF FREE FALL

Purpose

a. To measure the range of a projectile

b. To measure the time of flight of a projectile

c. To investigate vertical motion and determine the acceleration, g, due to gravity

Theory

In the previous two labs, we have studied the motion of a car along a horizontal track. In this lab we are going to study the motion of a ball as it flies off a horizontal track and into space. You may be surprised at how many questions we can ask about this process. For instance: What determines how far out it lands? How long does it take for it to hit the floor? Do different size/weights of balls fall differently? Does the point of release on the ramp matter? Does the length of the ramp or track matter? Etc.
In today's lab the first parameter to investigate is the distance from a point on the floor directly under the edge of the table out to the point where the ball hits the floor. This distance is called the *range* of the ball and is illustrated below in figure 1.

In the horizontal direction we measure position as x. In the vertical direction we measure position as y. The projectile motion in the vertical direction is independent of motion in the horizontal direction. This concept is called the superposition principle. In our experiment, (see figure 1) the projectile starts with the direction of the velocity all in the horizontal direction: $v_o = v_{ox}$. We will call v_o the exit speed. So there is no initial velocity in the vertical y direction. So we can say the object starts from rest in the vertical y direction. See figure 1 below.

The acceleration, a is all in the vertical direction recall free fall from experiment 2, $a = a_y = g$. So $a_x = 0\ m/s^2$. In the y direction we can use equation 4 of the previous experiment: $d_y = \frac{1}{2}\ g\ t^2$. When the object reaches the ground $d_y = h$, the vertical height, so

$$h = \frac{1}{2}\ g\ t^2 \quad eqn.\ \ (1)$$

Solving for t, the time of flight of the projectile, we get:

$$t = \sqrt{\frac{2h}{g}} \qquad eqn. (2)$$

Since there is no acceleration in the horizontal x direction, and recalling that the acceleration measures rate of change in velocity, then the velocity is constant in the x direction. So we can use equation 1 of experiment 2:

$$x = x_o + v_x t$$

We can take the position where the projectile starts as having $x = 0\ m$. So

$$x = v_x t \qquad eqn.\ \ (3)$$

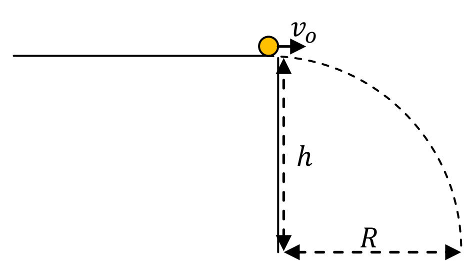

Figure 1: A projectile launched horizontally

When the projectile reaches the ground $x = R$, the range, and t is the time of flight. Using eqn. 2 for t, we get the range:

$$R = v_x \sqrt{\frac{2h}{g}} \qquad eqn. (4)$$

Running the experiment

The data sheet for the experiment is on page 3

Part 1: Dependence of the range, R on v_o the exit speed

1) Open the simulator https://www.walter-fendt.de/html5/phen/projectile_en.htm

Set the angle equal to zero. This will cause the projectile to be launched horizontally. See figure 1. Change the initial height to 4 m. Keep all other settings the same: Initial speed 5 m/s, mass 1 kg & gravitational acceleration 9.81 m/s^2.

2) Click start. After the projectile reach the ground click pause. Record the values of 'Maximum height', 'Horizontal distance' and 'Time' in table 1. These are h, R and time of flight t, respectively.

3) Using eqn. 1 and the value of time, calculate h. Compare with the value of h of the simulator.

4) Using eqn. 4 and the value of initial speed of the simulator and the value of h (from step 3), calculate the range, R. Compare to the value measured by the simulator.

5) Click reset. Change the initial speed to $5, 6, 7, 8,$ and $9\ m/s$. Repeat steps 2, 3 and 4 for each value of initial speed. Each time reset, adjust the initial speed, and start the simulator. Record the initial speed v_x, t time of flight, and R in the table 2 in the data sheet. Calculate t^2, and record in table 2.

6) Graph the range, R versus v_x, the exit speed. a) Calculate the slope. b) What does the slope represent? (Hint: see equation 3). c) Compare to the value of h and g. (Hint: see eqn. 4).

Part 2: Time of flight

From equation 2, we can see the time of flight depends only on h, and g. It neither depends on the exit speed v_o, nor on the range, R. But the range, R depends on both the initial speed, v_o and the fight time. See equation 3. Let's test these statements experimentally.

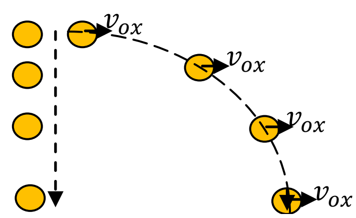

Figure 2: The time of flight depends only on h (and g) but does not depend on the range, R. The range R depends on the time of flight and the initial speed, v_o

1) In step 5 above, we changed the initial exit speed and recorded the flight time in table 2. a) Did the value of the flight time change? b) Did the value of the range, R change?

2) From the values recorded in the table in step 5 above, we saw that the time of flight does not depend on the initial speed, v_o, although the range, R does depend on the initial speed, v_o. a) Does the time of flight change if the range, R is zero (when $v_o = 0$. That is the object is dropped from rest)? Let's see. Click reset in the simulator and set the initial speed in the simulator equal to zero. Click start. Notice the motion, and record the flight time. b) Did the flight time change from the last value when v_o was 9 m/s?

Part 3: Vertical motion

We mentioned in the introduction that the horizontal and vertical motions are independent. That is, $v_x$and v_y are independent. If h changes, v_y changes but v_x remains unchanged. See figure 2.

1) In the simulator click reset and set the initial speed back to 5 m/s. change the initial height, h to 5, 6, 7, 8, and 9 m. Each time run the simulator and record the time of flight, t and compute t^2 . Record these values in table 3. Graph height, h versus the square of the time of flight, t^2.

2) Find the slope and compare to the value of g. (Hint: see eqn. 1).

Part 4: Effect of mass/size of the object

1) Set the initial height to 4 m, and set the mass to 2 kg. Run the simulator. Record the range R and time of flight t.

2) Repeat step 1 for mass = 3 kg. a) Does the range, R or time of flight t change? b) Explain. (Hint: see eqns. 4 and 2).

Data sheet

Name: **Group:** **Date experiment performed:**

Part 1: Dependence of the range, R on v_o the exit speed

Step 2, Table 1

Maximum height, h (m)	Horizontal distance, R (m)	Time: time of flight, t (s)

Step 3, Calculation of h: Step 4, Calculation of R:

Step 5: $h = 4\,m$, Table 2

v_x (m/s)	t (s)	t^2(s^2)	R (m)
5			
6			
7			
8			
9			

Step 6: a) Slope= b) The slope represents: c) The slope relates to h and g as:

Part 2: Time of flight

Answer to step 1, a) b)

Answers to: step 2, a) step 2, b)

Part 3: Vertical motion

Step 1: v_o= 5 m/s, Table 3

$d_y = h$ (m)	t (s)	t^2 (s^2)
5		
6		
7		
8		
9		

Step 2, Slope= The relation of the slope to g:

Part 4: Effect of mass/ size of the object

$h = 4\,m$	mass m (kg)	Range, R (m)	time of flight, t (s)
Step 1	2		
Step 2	3		

Answer to step 2 a: Answer to step 2 b: