Experiment 3: Projectile Motion Part 1

**EQUIPMENT**

Computer capable of running html simulation
**Advance Reading**

*Text:* 2-D Projectile Motion (Serway and Vuille 3.1-3.2)

**Objective**

The objective of this lab is to investigate projectile motion, first when a projectile is fired horizontally, and then when a projectile is fired from a non-zero angle of elevation.

**Theory**

Projectile motion is an example of motion with a constant acceleration, with an initial velocity in any direction (horizontal, vertical, or at an angle). An object is considered to be a projectile when the only force acting on the object is gravity - so we are ignoring air resistance and starting our calculations the moment after the object has been launched and ending our calculations the moment before the object lands.

Gravity is a force between two objects with mass. The force of gravity on the projectile will be directed toward the center of the Earth - downward. The acceleration of the projectile will be due only to gravity and therefore the x-component of the acceleration will be zero and the y-component of the acceleration will be directed downward and have a magnitude of \( g = 9.80 \text{m/s}^2 \).

To predict where a projectile will land, one must know the object’s starting position, \( \mathbf{r}_0 \), initial velocity, \( \mathbf{v}_0 \), and the acceleration it experiences, \( \mathbf{a} \). Position as a function of time is then described as:

\[
a_x = 0 \\
a_y = -9.80 \text{m/s}^2
\]

Because the x-component of the acceleration is zero, the motion in the x-direction will be constant-velocity motion. Because the y-component of the acceleration is equal to a constant value of \(-9.80 \text{m/s}^2\), the motion in the y-direction will be constant-acceleration motion. Both of these motions are happening simultaneously - the projectile is moving forward in the x-direction with constant velocity while it is accelerated downward due to gravity.

**Experiment 3: Projectile Motion Part 1**

We will analyze the motion of the projectile using the kinematic equations, separated into x- and y-components. The only connection between the motion in the x-direction and the motion in the y-direction is that they both take place during the same time interval \( t \).

\[
v_x = v_{0x} + a_xt \\
x = x_0 + v_{0x}t + \frac{1}{2}a_xt^2 \\
v_x^2 = v_{0x}^2 + 2a_x\Delta x
\]

and

\[
v_y = v_{0y} + a_yt \\
y = y_0 + v_{0y}t + \frac{1}{2}a_yt^2 \\
v_y^2 = v_{0y}^2 + 2a_y\Delta y
\]
1. What is projectile motion?

2. Find the initial velocity, $v_0$, of a ball rolling off the table in the figure below. The launch position is the origin of the coordinate system, positive directions as specified.

3. Using the table height and launch speed from the previous question, predict the final landing distance in the x direction if the launcher is adjusted to an angle of $40^\circ$. 
Worksheet - Exp 4: Projectile Motion Part 1

**Objective:** The objective of this lab is to investigate projectile motion, first when a projectile is fired horizontally, and then when a projectile is fired from a non-zero angle of elevation.

**PROCEDURE**

**Part 1: Horizontal Launch ($\theta_0 = 0^\circ$)**

1. Open the Projectile Motion simulation in your browser and select the "Lab" option. Ensure gravity is set to 9.80 m/s$^2$ and the "air resistance" box is unmarked.

2. Set the initial height of the object as 5m by clicking and dragging the crosshairs at the back of the cannon.

3. Set the launch angle to $0^\circ$ by clicking and dragging the front of the cannon.

4. Choose the origin of your coordinate system. You will need to decide whether the origin is at the launch position or at the ground, and which direction is positive and which is negative. Record your decision below: (5 points)

5. Set the initial launch velocity to 10 m/s by clicking the arrows or dragging the slider under "Initial Speed".

6. Predict the time of flight and landing position using the kinematic equations and record them in the table on the next page (x(m) (calc) and t(s) calc)), show your work here. (15 points)

7. Fire the cannon by clicking the red fire button. Drag the investigation device from the the top right of the screen and measure the time of flight and landing position of the projectile by placing the crosshairs at the landing position. Record these values in the table.

8. Compare your calculated and experimental values for time of flight and landing position and record the percent error in the table.

9. Repeat steps 1 through 8 for initial velocities of 15 m/s and 20 m/s.
**Horizontal Fire Data** (10 points)

<table>
<thead>
<tr>
<th>$v_0$ (m/s)</th>
<th>x (m) (calc)</th>
<th>x (m) (meas)</th>
<th>x (m) (% error)</th>
<th>t (s) (calc)</th>
<th>t (s) (meas)</th>
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10. a) Does the time of flight change as the initial velocity is increased? b) Is this the result you would have expected? Why or why not? (5 points)

11. Mark the "air resistance" box and fire the projectile at the same three initial velocities and investigate changes. Does the time of flight change from no air resistance? Does the time of flight now differ when the velocity is increased from 10 m/s to 15 m/s and 20 m/s? (5 points)
**Part 2: Launch from non-zero angle of elevation**

12. Reset the Projectile Motion simulation in your browser by clicking the reset button on the bottom right of the screen. Ensure gravity is set to 9.80 m/s$^2$ and the "air resistance" box is unmarked.

13. Set the initial height of the object as 5m by clicking and dragging the crosshairs at the back of the cannon.

14. Set the launch angle to 30° by clicking and dragging the front of the cannon.

15. Choose the origin of your coordinate system. You will need to decide whether the origin is at the launch position or at the ground, and which direction is positive and which is negative. Record your decision below: (5 points)

16. Set the initial launch velocity to 10 m/s by clicking the arrows or dragging the slider under "Initial Speed".

17. Predict the time of flight and landing position using the kinematic equations and record them in the table on the next page (x(m) (calc) and t(s) calc), show your work here. (15 points)

18. Fire the cannon by clicking the red fire button. Drag the investigation device from the top right of the screen and measure the time of flight and landing position of the projectile by placing the crosshairs at the landing position. Record these values in the table.

19. Compare your calculated and experimental values for time of flight and landing position and record the percent error in the table.

20. Repeat steps 12 through 19 for initial velocities of 15 m/s and 20 m/s.
Non-horizontal Fire Data (10 points)

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21. a) Does the time of flight change as the initial velocity is increased? b) Is this the result you would have expected? Why or why not? (5 points)

22. Mark the "air resistance" box and fire the projectile at the same three initial velocities and investigate changes. Does the time of flight change from no air resistance? Does the time of flight now differ when the velocity is increased from 10 m/s to 15 m/s and 20 m/s? (5 points)
Part 3: Conceptual Questions

23. If a projectile has twice the mass but the same initial velocity, what effect would this have on its the horizontal range of the projectile? Ignore air resistance. (5 points)

24. When an archer fires an arrow at a target, should they aim directly at the bullseye? If not, where should they aim? Discuss whether your answer depends on the distance between the archer and the target. (5 points)

25. When firing from a non-zero angle of elevation at ground level, assuming zero air resistance, what angle will achieve maximum range? Explain your reasoning and test your answer using the simulation (5 points)

26. If air resistance is present, does the angle for maximum range increase or decrease? Explain your reasoning and test your answer using the simulation. (5 points)