Experiment 4: Projectile Motion
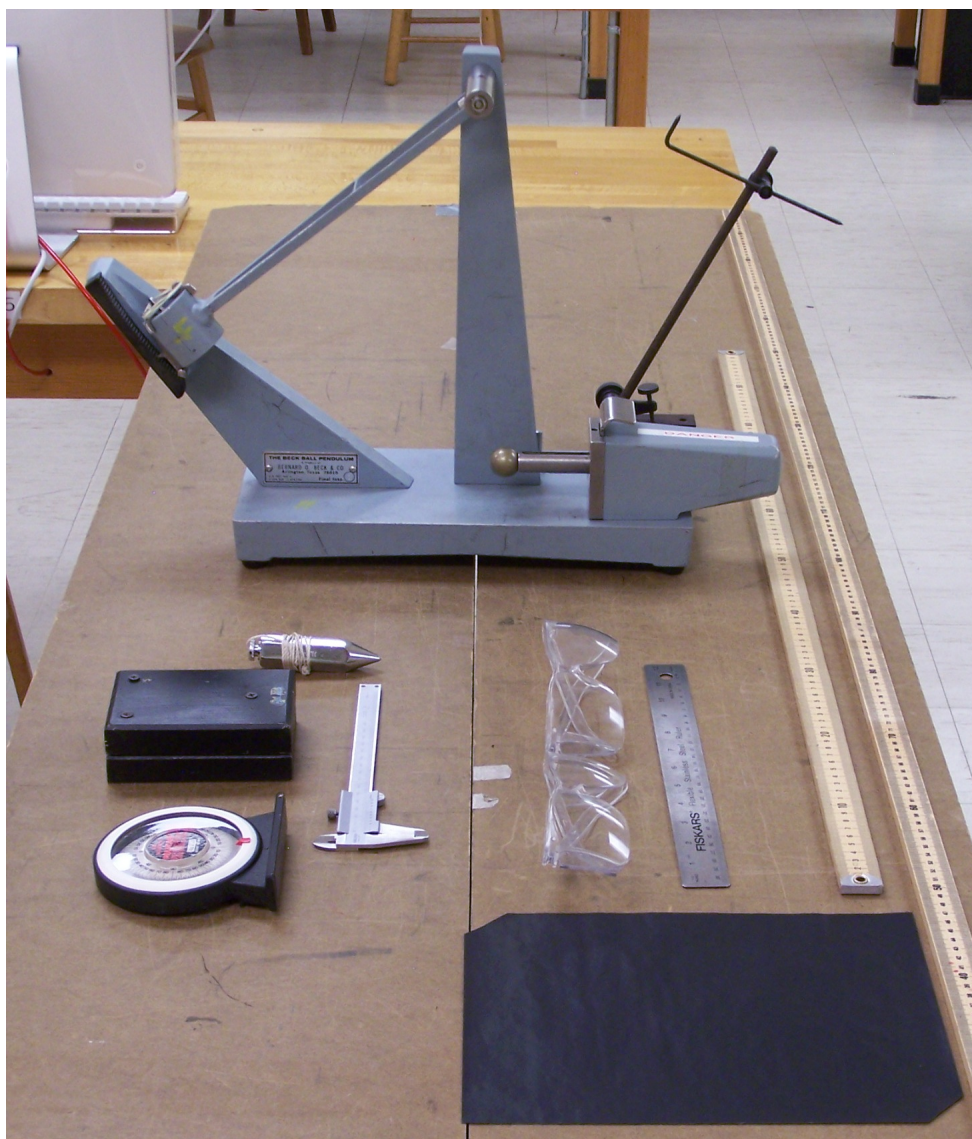

Figure 4.1: Ballistic Pendulum (Spring Gun)

EQUIPMENT

Beck Ballistic Pendulum (Spring Gun)
2-Meter Stick
Meter Stick
Ruler
Vernier Caliper
Height Gauge
Inclinometer

Block (to incline the spring gun)
Plumb Bob
Carbon Paper
Target Paper
Launch Platform & C-clamps
Wall Guards

Advance Reading

Text: Motion in two dimensions (2-D), projectile motion, kinematic equations.

Lab Manual: Appendix A, Appendix D.

Objective

To measure the initial velocity of a projectile when fired from a spring gun and to predict the landing point when the projectile is fired at a non-zero angle of elevation.

Theory

Projectile motion is an example of motion with constant acceleration when air resistance is ignored. An object becomes a projectile at the very instant it is released (fired, kicked) and is influenced only by gravity.

The x- and y-components of a projectile's motion are independent, connected only by time of flight, t. Consider two objects at the same initial elevation. One object is launched at an angle $\theta = 0°$ at the same moment the second object is dropped. The two objects will land at the same time. This allows the two dimensions to be considered separately.

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

$$\vec{r}(t) = \vec{r}_0 + \vec{v}_0 t + \frac{1}{2}\vec{a}t^2 \qquad (4.1)$$

Eq. 4.1 is a vector equation; it can be resolved into x- and y-components:

$$x = x_0 + v_{0_x}t + \frac{1}{2}a_x t^2 \qquad (4.2)$$

$$y = y_0 + v_{0_y}t + \frac{1}{2}a_y t^2 \qquad (4.3)$$

Velocity changes constantly in projectile motion. While horizontal acceleration is zero for the purposes of this experiment, the vertical component of a projectile's velocity can be described as follows, with $a_y = g$:

$$v_y = v_{0_y} + a_y t \qquad (4.4)$$

These are the **kinematic equations** for constant acceleration. Taken together, they describe the motion of projectiles and other constant-acceleration systems.

Part 2 of this experiment involves finding the components (v_{0_x} and v_{0_y}) of the velocity of a projectile fired at above the horizontal ($\theta > 0°$). To determine the components of an initial velocity vector, refer to Eq. 3.1 and Eq. 3.2 of *Experiment 3: Vector Addition.*

When measuring the change in position for the projectile in this experiment, measure from the bottom of the ball to the floor for Δy, and measure the end of the rod from which it is fired to where it lands for Δx.

The ballistic pendulum (spring gun) should be held firmly in place when fired to prevent loss of momentum.

Name: _____

1. What is projectile motion? (15 pts)

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. (25 pts)
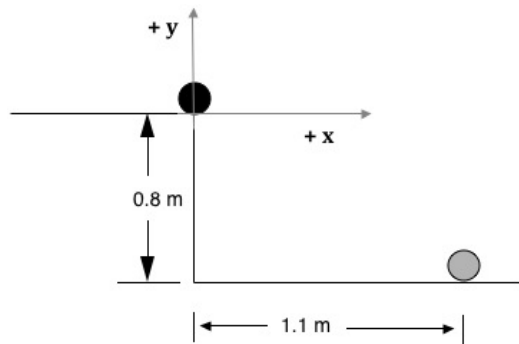
3. For a ball shot with an initial speed of 8.0 m/s at $\theta_0 = 30°$, find v_{0_x} and v_{0_y}. Always write the algebraic equations first, then write the equations with values inserted. (20 pts)

4. Given the information in *Question 3*, $y = -0.8$ m, use the quadratic formula to solve for t_1 and t_2. Note: It is unlikely that you will finish the experiment if you are not able to solve this type of quadratic equation. (20 pts)

$$y = y_0 + v_{0_y}t + .5a_y t^2$$
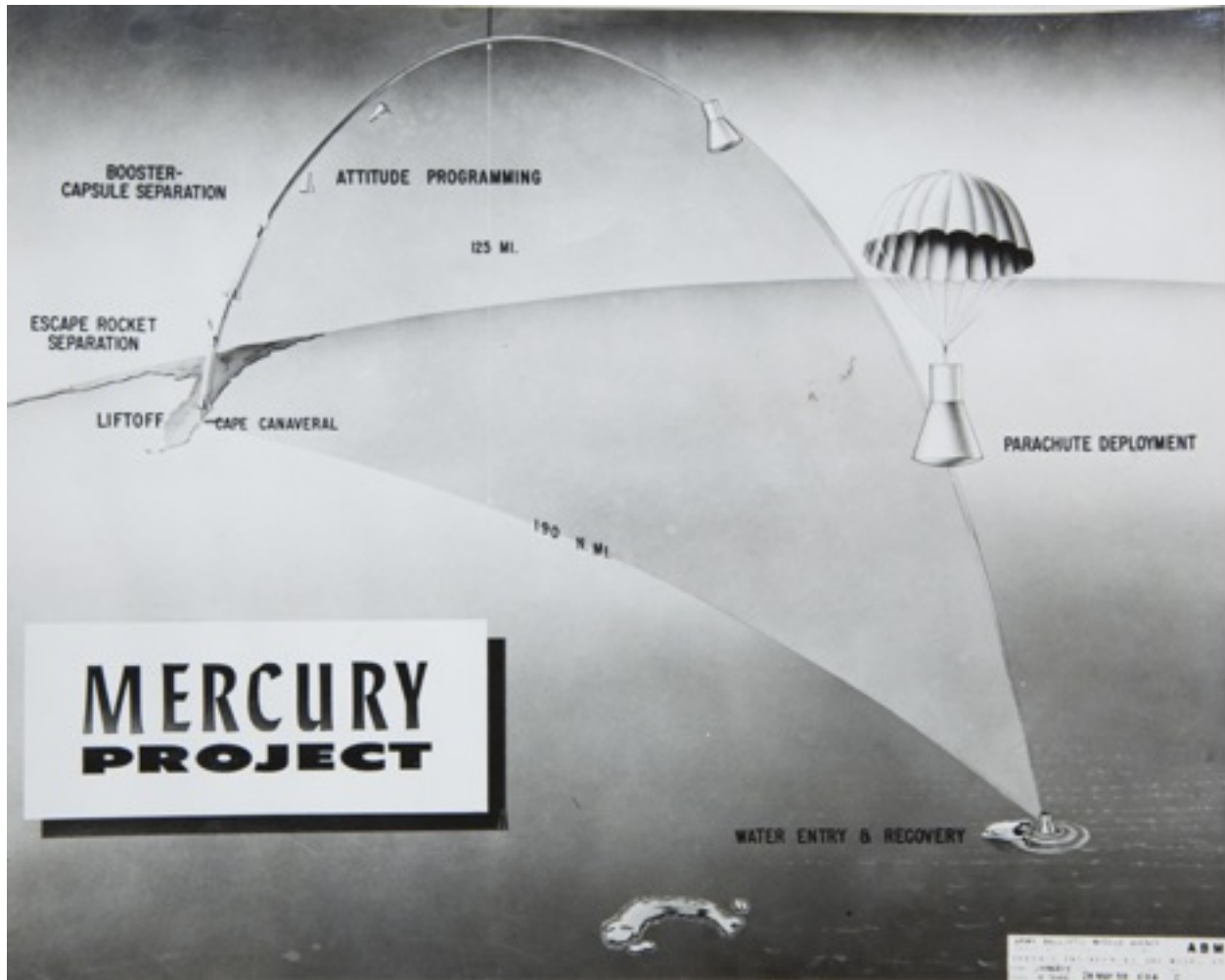
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Figure 4.2: The Trajectory

On May 5, 1961, only 23 days after Yuri Gagarin of the then-Soviet Union became the first person in space, NASA astronaut Alan Shepard launched at 9:34 a.m. EDT aboard his Freedom 7 capsule, powered by a Redstone booster, to become the first American in space. His historic flight lasted 15 minutes, 28 seconds. Image Credit: NASA

6. Calculate the initial velocity in m/s, ignoring air resistance. Show work. (20 pts)
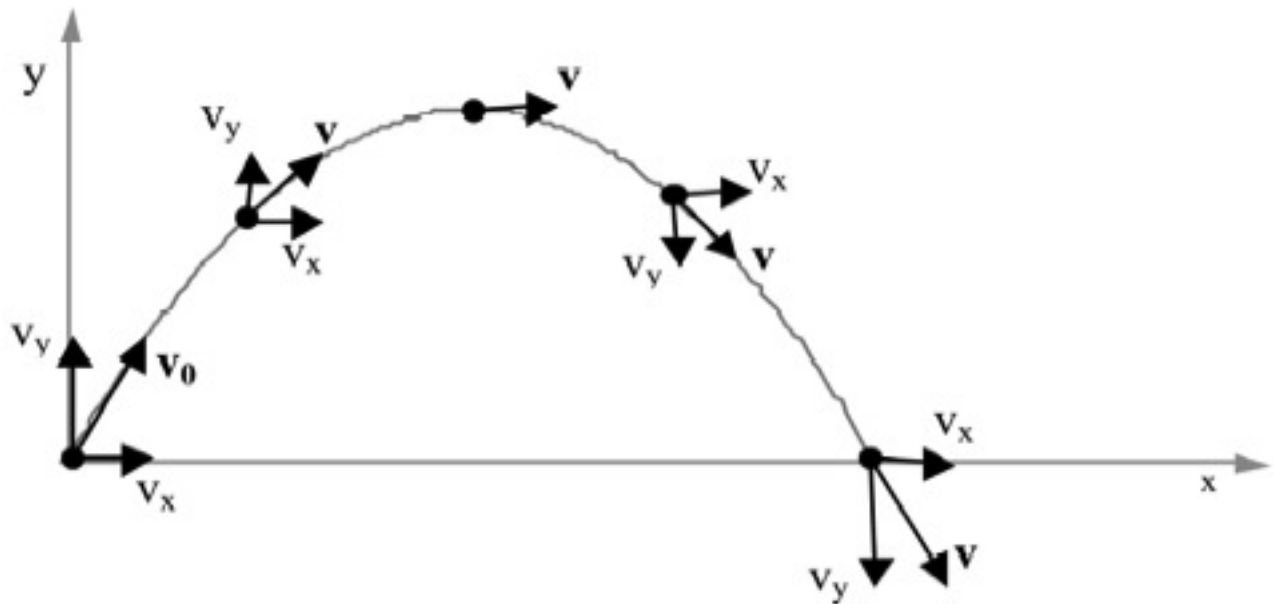
Figure 4.3: Projectile Motion. The trajectory (path) is a parabola.

SAFETY PRECAUTIONS:
A minimum of 4 members per team for this experiment, with the following responsibilities:

- **2 members will block access to flight path from either side.**

- **1 member will cock the ballistic pendulum.**

- **1 member will fire the ballistic pendulum.**

Put on safety glasses!
They must remain on for the entire experiment. Rotate responsibilities as you progress through the experiment.

Failure to follow safety precautions will result in your dismissal from lab, zero grade.

PROCEDURE

PART 1: Horizontal Launch ($\theta_0 = 0°$)

1. Align the back edge of the spring gun with the back edge of the table. The initial position of the projectile is defined to be the origin of your coordinate system, as shown above in Fig. 4.3. Measure Δy.

2. Calculate the time of flight, t.

3. Teams (spring guns) are numbered from front of lab to back. Write your value for y and t in the table on the board before proceeding. (You do not need to record this data table.)

4. Read this step and the next step before proceeding. When the spring gun is fired for the first time, you will need to note where the ball lands. This is the location for your target. A target is a sheet of white paper taped to the floor with a sheet of carbon paper placed on top. Do not tape the carbon paper.

5. Team members must choose their responsibilities as noted in the safety precautions. Place the wastebasket against the wall where you expect the ball to hit. Do not allow the ball to hit the wall. When the

flight path is secure, cock, then fire the spring gun to determine the target location. Place the target.

6. Place the wastebasket against the wall, in the line of fire; do not allow the ball to hit the bare wall. Fire the spring gun once and measure x.

7. Determine v_0.

8. Record your value for v_0 in the table.

9. Fire the spring gun 5 more times. Measure and record x_i for each trial. Remember that x_i means x_1, x_2, x_3, etc.

10. Calculate the average displacement, x_{avg}, for all 6 trials.

11. Use x_{avg} to calculate v_{0-avg}.

12. Record your value for v_{0-avg} in the table.

13. Determine the class average, v_0 class avg.

PART 2: Inclined Launch ($\theta_0 > 0°$)

14. Elevate the front of your spring gun using a wood block or a book. Be certain that the back edge of the spring gun is aligned with the back edge of the table. Adjust the wastebasket at the wall if necessary.

15. After measuring the necessary quantities, use the kinematic equations and the quadratic formula to calculate the displacement of the ball when fired from this angle and height. Note that v_{0_y} is not equal to 0.0 m/s.

16. Write your values for θ, y, t, and x in the table on the board. (You do not need to record this data table.)

17. Place your target at the predicted location. Fire the spring gun a total of six times.

18. Determine x_{avg}. Write this value in the chart on the board.

19. Compare the theoretical and experimental values of x for *Part 2*. If the values are substantially different, check your calculations or measurements.

QUESTIONS

1. If a ball has twice the mass but the same initial velocity, what effect would this have on its displacement (neglect air resistance)?

2. Consider the following statement: When a rifle is fired horizontally, the bullet leaves the barrel and doesnt drop at all for the first 75 meters of flight. Is this statement true?

3. What is the acceleration of a projectile fired vertically upwards? Is it positive or negative? Sketch your coordinate system.

4. What is the acceleration of a projectile fired vertically downwards? Is it positive or negative? Use the same coordinate system you used for *Question 3*.

5. Determine the standard deviation, σ, for x_i for *Part 1*. (Refer to *Appendix A*)

6. Determine σ for x_i for *Part 2*.