Name: **Section:** **Date:**

Physics 223
General Physics Lab
<u>Experiment 5: Projectile Motion Theory and Procedure</u>

THEORY

Purpose

After measuring the parameters of a horizontally launched steel ball, we will exercise our knowledge of projectile motion to predict the landing point of that same steel ball when it is fired at an inclined angle. Random Error will be introduced and used in our analysis.

Projectile Motion

Projectile motion is the motion observed when an object near the Earth's surface is influenced only by gravity. This gravitational influence causes the object to accelerate towards the Earth's surface at approximately $g = 9.8\ \frac{m}{s^2}$ (or, approximately $g = 32\ \frac{feet}{s^2}$). **An object becomes a projectile at the very instant it is released (dropped, kicked, fired, etc.) and is influenced only by gravity.** We will assume that air-resistance is negligible (and consequently ignored) which makes this is an example of motion with constant acceleration.

Given any constant acceleration, the following equations will describe an object's motion (in a general, undefined coordinate system):

Couples Velocity and Time: $$\vec{v} = \vec{v}_o + \vec{a}t \qquad \textit{(Equation 1)}$$

Couples Position and Time: $$\vec{r} = \vec{r}_o + \vec{v}_o t + \frac{1}{2}\vec{a}t^2 \qquad \textit{(Equation 2)}$$

Couples Velocity and Position: $$v^2 = {v_o}^2 + 2\vec{a}\cdot(\vec{r} - \vec{r}_o) \qquad \textit{(Equation 3)}$$

Note that the vectors and scalars need to be clearly noted when working in a general coordinate system! The variables in the above equations are defined as follows:

Initial Position:	$\vec{r}_o$	(pronounced "r-naught")
Final Position:	$\vec{r}$	
Initial Velocity:	$\vec{v}_o$	(pronounced "v-naught")
Final Velocity:	$\vec{v}$	
Acceleration:	$\vec{a}$	
Time:	t	

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When working with two-dimensional projectile motion specifically, the most convenient coordinate systems to choose are ones in which our x-axis is parallel to the ground, and our y-axis is perpendicular to the ground. This choice perfectly aligns the y-axis with the acceleration an object undergoes due to Earth's gravity (g), and eliminates ALL components of g along the x-axis.

Because the x-axis and y-axis are perpendicular to each other, this kind of "axis-independence" is true of ALL the vector quantities listed above! In other words, **if you are dealing with a vector quantity, what happens in the x-dimension doesn't affect what happens in the y-dimension and vice-versa!** Mathematically, the only thing that connects (couples) the two dimensions is the time-of-flight, t (the only scalar in our list of kinematic variables).

Knowing this, we can break our general kinematic equations into x and y component equations and variables like so:

x-dimension	y-dimension
$v_x = v_{ox} + a_x t$	$v_y = v_{oy} + a_y t$
$x = x_o + v_{ox} t + \frac{1}{2} a_x t^2$	$y = y_o + v_{oy} t + \frac{1}{2} a_y t^2$
${v_x}^2 = {v_{ox}}^2 + 2a_x(x - x_o)$	${v_y}^2 = {v_{oy}}^2 + 2a_y(y - y_o)$
$x_o =$	$y_o =$
$x =$	$y =$
$v_{ox} =$	$v_{oy} =$
$v_x =$	$v_y =$
$a_x =$	$a_y =$
$t =$	$t =$

When solving kinematic problems, it is very useful to write all of the equations and variables in columns such as this so that you can begin filling in everything you know about the physical situation before beginning to do calculations (and continue to fill things in as you move through the calculations).

Random Error

In this experiment, you will first be introduced to the concept of "random errors". These random errors arise when the same measurement is taken multiple times, and small differences in that measurement manifest as a result of tiny differences in the experimenter's technique, the way a measuring device behaves, etc. The way we will account for these random errors is to take a large number of measurements, and then average them together. In this course, when random errors need to be quantified, we will usually do average over six measurements.

The **average** of a group of values is the sum of those values divided by the number of values in the group. Mathematically, for a number of values $(x_1,\ x_2,\ x_3,\ \ldots\ x_N)$ this is written:

$$\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N}$$

where N is the number of total x values.

To determine a reasonable uncertainty of this average, we must first calculate the standard deviation.

The **standard deviation** of a group of values $(x_1,\ x_2,\ x_3,\ \ldots\ x_N)$ is an estimate of the average uncertainty of *each* value. It is calculated:

$$\sigma_x = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

To determine a reasonable uncertainty of the average itself, we must then calculate the **standard deviation of the mean (SDOM)**, by dividing the standard deviation by the square root of the number of measurements:

$$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{N}}$$

The factor $\sqrt{N}$ in the denominator ensures that the SDOM slowly decreases as the number of measurements are increased.

PROCEDURE

Safety Precautions

- **Closed Toed Shoes MUST be worn!**
- **Eye protection MUST be worn!**
- **From the time that the spring-gun is cocked to after the projectile lands, the flight path MUST be clear of ALL students!**
- **During Data Collection:**
    - **One Team Member should take responsibility for cocking the spring-gun.**
    - **One Team Member should take responsibility for firing the spring-gun.**
    - **Two Team Member should take responsibility for maintaining a safe flight-path. (Responsibilities should be alternated.)**
- **Failure to follow safety precautions will result in your dismissal from lab, and a grade of "zero".**

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

1) We will choose our coordinate system's origin to be on the floor of the lab directly under the point at which the ball becomes a projectile, with the $+x$-direction in the direction the projectile will fire, and the $+y$-direction skyward. Armed with this information (and our knowledge of kinematics), what 5 entries into *Data Table 1* can we immediately make? Check the "Step 1?" box in the cells you fill in now!

2) Ensure that the spring-gun is securely mounted to its surface via "c-clamp". Ensure that the spring gun is pointed perpendicular to the edge of this surface. Use the inclinometer on the side of the spring gun to ensure that it is level.

3) Carefully Measure y_o and record it in *Data Table 1*. Measure from the floor to the bottom of the projectile (at the instant at which it becomes a projectile).

4) Calculate the time of flight (t) and record it in *Data Table 1*.

5) When the spring-gun is fired for the first time, you will need to note where the ball lands. This is the location of your *target*.

   A *target* is a sheet of white printer paper taped to the floor with a sheet of carbon paper placed on top. DO NOT TAPE THE CARBON PAPER.

   Team members should choose their responsibilities as noted in the Safety Precautions. WHEN THE FLIGHT-PATH IS SECURE, fire the spring-gun to determine the location of your target. Place the target.

6) Fire the spring-gun six times onto the target. **USE THE SPRING GUN'S 3rd DETANT**.

   The spring-gun should be fired by pulling *gently* and consistently on the trigger mechanism.

   Below the carbon paper, the six landing marks will be recorded. Measure and record the six x_i distances in *Data Table 2* using the metersticks. Use the plumb-bob to ensure accurate distances. The x_i distances should be measured from the point that the object becomes a projectile to each landing mark.

7) Calculate the average of the x-components of the landing points ($\bar{x}_{hztl}$) and record it in *Data Table 1*.

8) Calculate the average initial velocity ($\bar{v}_{ox}$) and record it in *Data Table 1*.

9) There should be one cell left empty in *Data Table 1*. Write "N/A" in that cell.

   == YOUR T.A. SHOULD NOW INITIAL YOUR DATASHEET AND ADJUST YOUR SPRING-GUN TO A NON-ZERO ANGLE. ==

Part 2: Inclined Launch ($\boldsymbol{\theta_o > 0^\circ}$)

10) Using your knowledge of kinematics, the data in *Data Table 1,* and any new measurements that you deem necessary, calculate where the projectile will land when it is fired at the angle your TA has chosen. (Fill in *Data Table 3* as you work.)

11) Measure your predicted x distance using the metersticks, and place your target so that its center is where you predict the projectile will land.

12) HAVE YOUR TA WITNESS your first attempt at hitting your target by firing the spring-gun. If you hit your target, your T.A. will again initial your datasheet. You may fire the spring-gun 5 more times and record your six x_i distances in *Data Table 4.*

13) If you miss, you must review your calculations and try again (also under your T.A.'s supervision). Once you have a successful hit on your target, you may fire the spring-gun 5 more times and record your six x_i distances in *Data Table 4.*

14) Calculate the average and standard deviations of the inclined x_i values ($\bar{x}_{incl}$ and $\sigma_{\bar{x}}$). (This does not need to be done while in your lab session.)

POST LAB QUESTIONS

1) Discuss how your data and results would be affected if an aluminum ball were used instead of the steel ball. (Assume that the aluminum ball has half the mass of the steel ball that you actually used. Ignore air-resistance.)

2) What was the magnitude and direction of the steel ball's acceleration at the instant that it became a projectile? Answer the same question about when the ball is at the vertical peak of its trajectory and when the ball is infinitesimally close to striking the ground. (Ignore air-resistance.)

3) If we were able to "improve" these spring-guns with much stiffer springs so that horizontally fired steel balls traveled in the x-dimension 10 times farther than they currently do, by what factor would that increase or decrease the time-of-flight? (Ignore air-resistance.)

LAB REPORT SPECIFICS

- For your "Theoretical Analysis", you should neatly transcribe (by hand *or* equation software) Procedure Steps 4, 8, and 10. If you do this by hand, it should be submitted with your hardcopy, but does not need to be submitted to Safe-Assign. If you do this using equation software, it must be submitted to Safe-Assign. Careful tracking of sig-figs should be observed, as this will be the only record of theoretical uncertainty ($\delta_{theo.}$) that we keep!

- No "Data Plots/Charts" are needed for this report. The 10 points associated with this section will be applied to your "Discussion of Results".

- Your "Results" section should include a table similar to the one shown in the datasheet's "Sample Results" along with the two requested Result Statements.

- Your "Raw Data/Sample Calculations" should include your calculations of averages and standard deviations. This must be submitted in hardcopy, but does not need to be submitted to Safe-Assign. Your T.A. Initialed datasheet must be stapled to the back of your hardcopy report.