What You Need To Know:

The Physics  So far in lab you’ve dealt with an object moving horizontally or an object moving vertically. Now you are going to examine an object that is moving along both axes at the same time. We will deal with a special case: 2D motion where gravity is the only thing affecting the motion. This is called projectile motion.

Projectile motion is a challenging concept. The ideas, however, are no different from the ones you’ve been dealing with already. The key to projectile motion is to analyze the motion one axis at a time (either x-axis or y-axis). You are still going to be using the linear motion equations that you’ve been using in class (See Figure 1) but now you have to be clear on whether you are using horizontal information or vertical information. One common mistake is mixing up the equations for the horizontal motion (constant velocity) and vertical motion (free fall).

What You Need To Do:

The Equipment  The only lab equipment that you will be using is the computer which contains two photos. The photos are of a white ball flying through the air in front of a grid (that will represent a piece of graph paper). A strobe light was used to show multiple images of the ball as it flew through the air. The physical setup should be at the front of your lab. Your TA will show a demonstration of a ball launching in front of the grid. The photos were taken using very controlled conditions that cannot be reproduced in a lab class. This is why you are not taking your own pictures today and instead you are using photos on the desktop.

Unlike the graphs that you have been dealing with in recent labs, these graphs are not x vs. t graphs. They are y vs. x graphs. Along the vertical axis you will be taking measurements for “y” locations. Along the horizontal axis you will be taking measurements for “x” locations. In each photo the origin is at the lower left-hand corner of the grid. Also, positive directions will be assigned as up and to the right.

You will be analyzing two different types of launches of the ball. One is a horizontal launch and the other is an angled launch.

Horizontal Launch

Part 1 – Horizontal Motion  Open the file called PROJECTILE 1. This is a high resolution photo of a ball being launched horizontally. There are multiple images of the ball that are each 1/24 of a second apart. A white circle has been added that encircles each image of the ball so that it is easier to see some of the more faded images.
A) Make a chart like Chart 1 on the left. Make 12 rows since there are 12 images of the ball. This first image is considered to be at $t = 0$ s.

B) Using the right edge of each image of the ball as a reference, take data on the horizontal location of the ball, i.e. along the x-axis. The lines on the grid are 1 cm apart. Approximate your locations to an accuracy of multiples of 0.25 cm. (For example, 1.25, 1.50, or 1.75 cm.) You can zoom into the image by using the scroll wheel on the mouse. Put this data in the chart.

C) Using a spreadsheet and the data you just collected, make a graph of $x$ vs. $t$. Use all that you learned from the Graphical Analysis lab on how to graph properly. NOTE: In this case it is easier to graph the time data as the ratios instead of a decimal.

D) On your graph, draw in a best-fit-line for your data and calculate the slope of the line. Use all that you learned from the Graphical Analysis lab on how to do this process properly.

Question 1 Is the velocity of the ball constant or changing along the x-axis? How do you know this?

Question 2 What is the magnitude of the velocity of the ball along the x-axis? How do you know this?

Part 2 – Vertical Motion  Now you are going to do basically the same procedure you just did but with information from the vertical axis.

A) Make a chart like Chart 2 on the right. All the time data have been converted into decimal form for you to save time.
B) Using the *bottom* edge of each image of the ball as a reference, take data on the *vertical* location of the ball, i.e. along the y-axis. Put this data in the chart for “y”.

C) Open the program **GRAPHICAL ANALYSIS**. In the x-column enter your time data (in decimal form). In the y-column enter your vertical position data.

**Question 3** Based on your graph, what kind of motion does the ball have along the y-axis (constant or changing)? If you are having a difficult time determining this then use the “R=” button to see if the linear best-fit-line matches the data.

**Question 4** Why is the velocity along the y-axis changing while the velocity along the x-axis is remaining constant? (This is the most important question of the lab, so make sure you elaborate.)

D) Now you are going to make a graph of $v_y$ vs. $t$ for the vertical motion of the ball. You are going to use the same procedure that you used in last week’s lab in the Free-Fall portion of the lab. You are going to calculate $v_y$ using $v_y = \Delta y / \Delta t$. In order to calculate $\Delta t$ and $\Delta y$ you will use **every other data point**. For example, in order to calculate the first change in time for the $\Delta t$ column you will use … $2/24 - 0/24$. In order to find the first $\Delta y$ you will subtract the corresponding y values. Do all of the calculations for $\Delta t$ and $\Delta y$ and place these values in the chart. (NOTE: When you calculate $\Delta y$ make sure you are subtracting the final value minus the initial value. You should get negative values.) Now, calculate $v_y$.

E) Use **Graphical Analysis** to graph your data. In the x-column enter your time data. (NOTE: You are not using $\Delta t$ here, you are using $t$. Start with your first time as $1/24 = 0.0417$ s.) In the y-column enter your vertical velocity data, $v_y$.

F) Use the “R=” button to determine the slope of your line.
**Question 5** Based on your graph, what kind of acceleration does the ball have along the y-axis (constant or changing)? How do you know this?

**Question 6** What is the magnitude of the acceleration of the ball along the y-axis? How do you know this?

**G)** Compare the acceleration of the ball along the y-axis that you calculated to its textbook value (−9.8 m/s²) by using a percent error. (NOTE: Make sure your units are in meters. NOTE: this is not a precise measurement, where we are estimating the actual measurement uncertainty. Instead, we’re just checking against the textbook value to see if the answer is plausible.)

**H)** At this point in the lab all of the work you have done should be showing you that the velocity of the ball along the y-axis is changing because along this axis gravity is acting on the ball. However, along the x-axis, gravity is not acting on the ball and therefore the velocity is constant. This is the single most important fact about projectile motion. Think about what this implies about the acceleration along each axis.

**I)** Make a chart like Chart 3 below. For the Horizontal Launch row, fill in the columns for the acceleration for each axis based on what you determined in H). NOTE: You will fill out the rest of the chart in Part 3 which begins on the next page.

<table>
<thead>
<tr>
<th>Type of Launch</th>
<th>x-axis</th>
<th>y-axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x₀</td>
<td>v₀x</td>
</tr>
<tr>
<td>Horizontal Launch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angled Launch</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Part 3 – Initial Positions and Velocities** Now you are going to determine what the initial conditions are for the ball along each axis. NOTE: Do not close out of your velocity graph on Graphical Analysis.

**A)** Go back to your photo and using the first image of the ball determine the initial position of the ball on each axis. This data should also be in Charts 1 & 2. Put this data in Chart 3 for the Horizontal Launch row.
B) In examining the graph you made on the graph you made in a spreadsheet and calculations that you made, determine what the initial velocity of the ball was along the x-axis. Put this value in Chart 3 in the appropriate location.

C) In examining the graph you made on Graphical Analysis, determine what the initial velocity of the ball was along the y-axis. You can do this by using information that is in the little window that comes up when you push the “R=” button. One of the bits of information is the y-intercept. This should give you the value on the vertical axis at t = 0 which also should be the initial velocity of the ball along the y-axis. Compared to the other velocity values in your chart, this initial velocity value for the y-axis is very small, so we will approximate it to zero. So, put zero in Chart 3 in the appropriate location.

Part 4 – Calculations Using the information you calculated for the motion of the ball along both axes, you are going to calculate the location of the ball along each axis. Make sure that your units are all consistent. You might want to have your TA check out the data in your Chart 3 before you continue.

A) Using information you gathered in Chart 3 as well as the three linear motion equations (in the appropriate form, i.e. using “x” or “y”), calculate the final location of the ball on the x-axis (at 11/24 s).

B) In examining the photo, determine the final location of the ball on the x-axis for 11/24 s. Is your calculated value close to the location in the photo?

C) Using information you gathered in Chart 3 as well as the three linear motion equations (in the appropriate form, i.e. using “x” or “y”), calculate the final location of the ball on the y-axis (at 11/24 s).

D) In examining the photo, determine the final location of the ball on the y-axis for 11/24 s. Is your calculated value close to the location in the photo?

Angled Launch

Part 1 – Horizontal Motion Open the file PROJECTILE 2. This is a high resolution photo of a ball being launched at an angle. As before, there are multiple images of the ball that are each 1/24 of a second apart.

A) Make a chart like Chart 4 on the left. Make 17 rows since there are 17 images of the ball. The first image will be at t = 0 even though the ball has already left the launch tube.

B) Using the right edge of each image of the ball as a reference, take data on the horizontal location of the ball. Put this data in the chart.

C) Re-open GRAPHICAL ANALYSIS, if needed. In the x-column enter your time data (in decimal form). In the y-column enter your horizontal position data.

D) Determine the velocity of the ball along the x-axis.
**Question 7**  Is the velocity of the ball constant or changing along the x-axis? How do you know this?

**E)** In examining the graph you made on Graphical Analysis and calculations that you made, determine what the initial velocity of the ball was along the x-axis. Place this value in Chart 3 in the appropriate location.

**Part 2 – Vertical Motion**

A) Make a chart like Chart 5 on the right.

B) Using the bottom edge of each image of the ball as a reference, take data on the vertical location of the ball, i.e. along the y-axis. Put this data in the chart for “y”.

C) Re-open GRAPHICAL ANALYSIS, if needed. In the x-column enter your time data. In the y-column enter your vertical position data.

**Question 8** Based on your graph, what kind of motion does the ball have along the y-axis (constant or changing)?

**Question 9** Why is the velocity along the x-axis constant while velocity along the y-axis is not constant?
D) Again, you are going to make a graph of $v_y$ vs. $t$ for the vertical motion of the ball. Use the same procedure as you did in the horizontal launch. Find your deltas using every other piece of data. Make sure that you are calculating final minus initial on your delta calculations. Put these values in Chart 5 and then calculate $v_y$.

E) Use Graphical Analysis to plot your data. In the x-column enter your time data. In the y-column enter your vertical velocity data.

**Question 10** Based on your graph, what kind of acceleration does the ball have along the y-axis (constant or changing)?

F) Determine the acceleration of the ball along the y-axis.

G) Compare the acceleration of the ball along the y-axis that you calculated to its true value by using a percent error.

H) In examining the graph you made on Graphical Analysis, determine what the initial velocity of the ball was along the y-axis. Do this in the same way that you did in the horizontal launch section. Place this value in Chart 3 in the appropriate location.

I) You already determined the initial vertical position of the ball. It’s in Chart 5. Take this value and place it in Chart 3 in the appropriate location.

Part 3 – Calculations  Using the information you calculated for the motion of the ball along both axes, you are going to do more calculations on the motion of the ball. Make sure that your units are all consistent. You might want to have your TA check out the data in your Chart 3 before you continue.

A) Using information you gathered in Chart 3 as well as the three linear motion equations (in the appropriate form, i.e. using “x” or “y”), calculate how long it takes for the ball to reach its peak. In the photo the ball reaches its peak right between the 6th and the 7th image. (You know this because those two images are at the same height.) Compare (using a percent error) your calculated value to this time value that is right between 6th and the 7th image. (Yes, you have to calculate this time value.)

B) Calculate the vertical location of the maximum height that the ball reaches. Compare (using a percent error) this value to the height it reaches in the photo.

C) Using information you gathered on the motion of the ball along the y-axis, the x-axis, and trigonometry, calculate the launch angle of the ball. Compare (using a percent error) this value to the true value of 55°.
**Bonus question:** the lab says it's not practical for you to take the photos yourself, even though modern smartphones have “burst” or “strobe” modes and slow-motion video capture. Speculate on what sources of measurement uncertainty would you have to account for if you tried this yourself.

**What You Need To Turn In:**

On this report (attach extra paper) answer all of the questions and include all of the charts that you are asked to draw. Also, turn in (email the prof) the graph with your plot from your spreadsheet.