LAKE FOREST COLLEGE
Department of Physics

PHYS 114 **Experiment 4: Projectile motion** Fall 2024

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Preliminary Instructions
Create a folder for you and your lab partner. Save a copy of these instructions for each student to that folder. Include your name in the filename. Save one copy of the Excel template with both your and your partner's name included in the filename. **Include descriptive captions for every derivation (explanation), drawing, picture, table, and graph.**

Experimental purpose of today's experiment
Observe a projectile in two-dimensional freefall, and measure the acceleration due to gravity of the object.

Pedagogical purpose of today's experiment
Study the motion of a projectile.

Background:
When an object is in freefall, the only force acting on it is gravity. The horizontal and vertical components of the projectile's motion are independent. There is zero horizontal acceleration and there is a constant downward acceleration. Therefore, we may use all our mathematical machinery for motion with constant acceleration. We treat the two components of motion separately: one set of equations for each of the components (the x direction and y direction).

We will launch a projectile and record video of its flight. By recording the position of the object in each frame of the video we will analyze both the x and y components of the particle's position as functions of time, and measure the projectile's acceleration.

Procedure

1. Position the spring gun such that it fires upwards at an angle of approximately 75° above the horizontal. The strength of the spring gun is determined by a series of latches along the side of the tube. Use the center latch (medium range) of the spring gun. Check the angle after cocking the gun. The ball should shoot over the top of the half-meter stick. *Ensure that the half-meter stick is in the plane of the ball's flight. This is crucial! Check from several directions.* The ball should land in the cardboard box with the foam.

2. Camera setup and recording
   (a) Turn on the camera. The camera should be set to "shutter priority," which is the "S" on the top knob. Press the black "set" button and select a shutter speed of 1/2000 s and press "set." Then go to the "menu" and choose the "quality" tab and select HS30-240 mode.
   (b) Aim the camera perpendicularly to the plane of the ball's motion (not tilted).
   (c) The ring around the shutter release controls the zoom. Zoom the camera lens to fill the screen with relevant features of the experiment. Check that the half-meter stick and projectile starting point are clearly visible in the camera frame. The entire range of the motion should be visible.
   (d) Start the camera in video mode (button on back, with a red dot) and launch the projectile. Press the button again to stop recording.
   (e) Turn off the camera. Attach the camera to the computer using the special USB cable. It has an unusual small connector with a little arrow (a triangle) on one side. That arrow must be adjacent to a similar arrow on the camera. Don't force the connector! Turn the camera on. The camera will show up as an external device, similar to a flash drive. Copy the file on to the desktop or into your folder for this experiment.
   (f) Open Logger Pro and choose 'insert' → 'movie.' Enlarge the movie window to be as large as possible.
   (g) Play the movie and ensure that the entire flight of the projectile is captured. Take a new video if necessary.

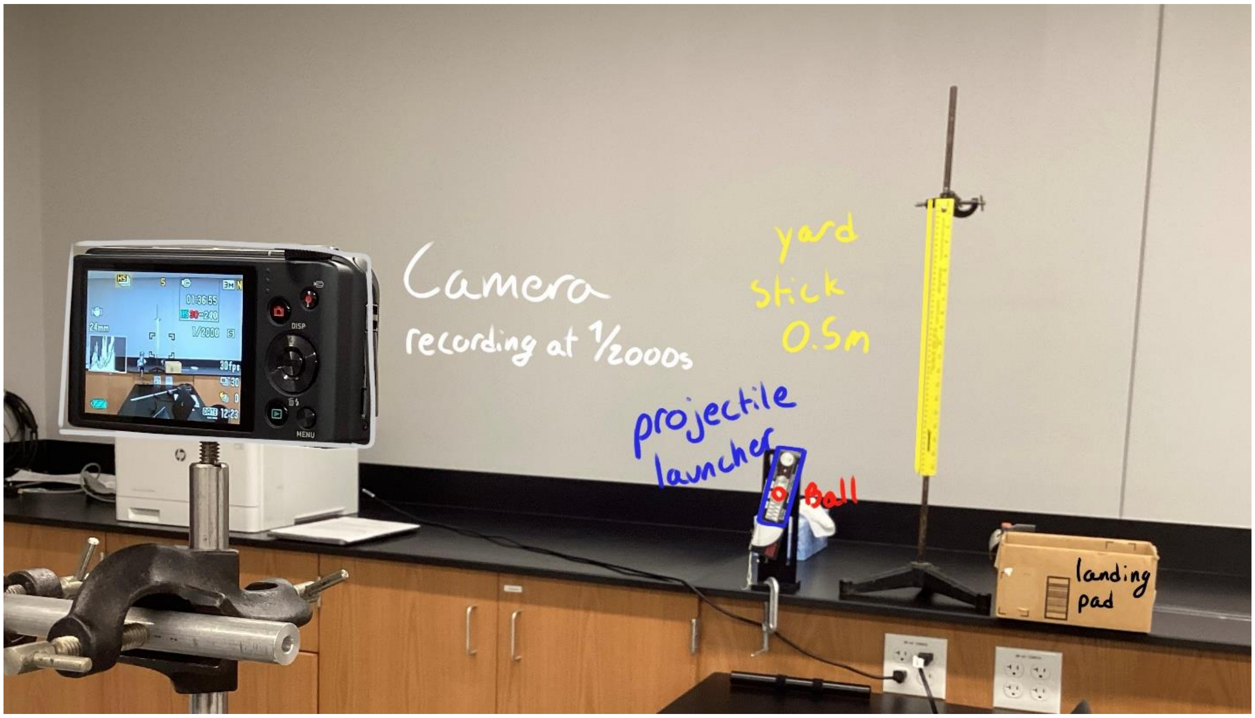

Figure 1. Experiment setup for projectile motion. Ball, marked in red, was launched out of short range projectile launcher (marked in blue) at an angle of 76° from horizontal. Yard stick, marked in yellow, provided scale for analysis.

3. Video Analysis in Logger Pro
   (a) Click on the 'Enable video analysis' button (3 red dots) at the bottom right of the movie frame to open the data analysis buttons along the right-hand edge of the window.
   (b) Advance the video past the initial shaking caused by pushing the record button.
   (c) In order to set the scale of the images click on the “Set Scale” button (picture of the ruler). In the image, ***precisely*** click on the top of the left edge of the yellow half-meter stick and drag to the bottom of the left edge. Set this length to be 0.5 meters.
   (d) Click on the “Set Origin” button and then click on the top of the left edge of the yellow half-meter stick. You may need to rotate the axes slightly to align the *y* axis with the edge of the half-meter stick. Do this by clicking on the yellow circle that is on the *x* axis and dragging. The axis with the yellow dot will be the *x* axis. Once the axes are correctly aligned, reposition the origin by clicking on the middle of the white circle at end of the spring gun.
   (e) Advance and/or rewind the film frame by frame until the first frame after the projectile has left the gun.
   (f) Click on the “Add Point” button, and *carefully* select the position of the center of the projectile in this frame of the movie. The movie will automatically advance to the next frame. Again, click on the position of the object. Repeat for the entire flight of the projectile. If you need to delete or re-do a point from the data set, click on “Select” button and pick the point you would like to delete. Press the delete button on your keyboard. Alternatively, you can clear all data and start over.

(g) **Copy the final video image with your dots using the Snipping Tool and paste it here.**

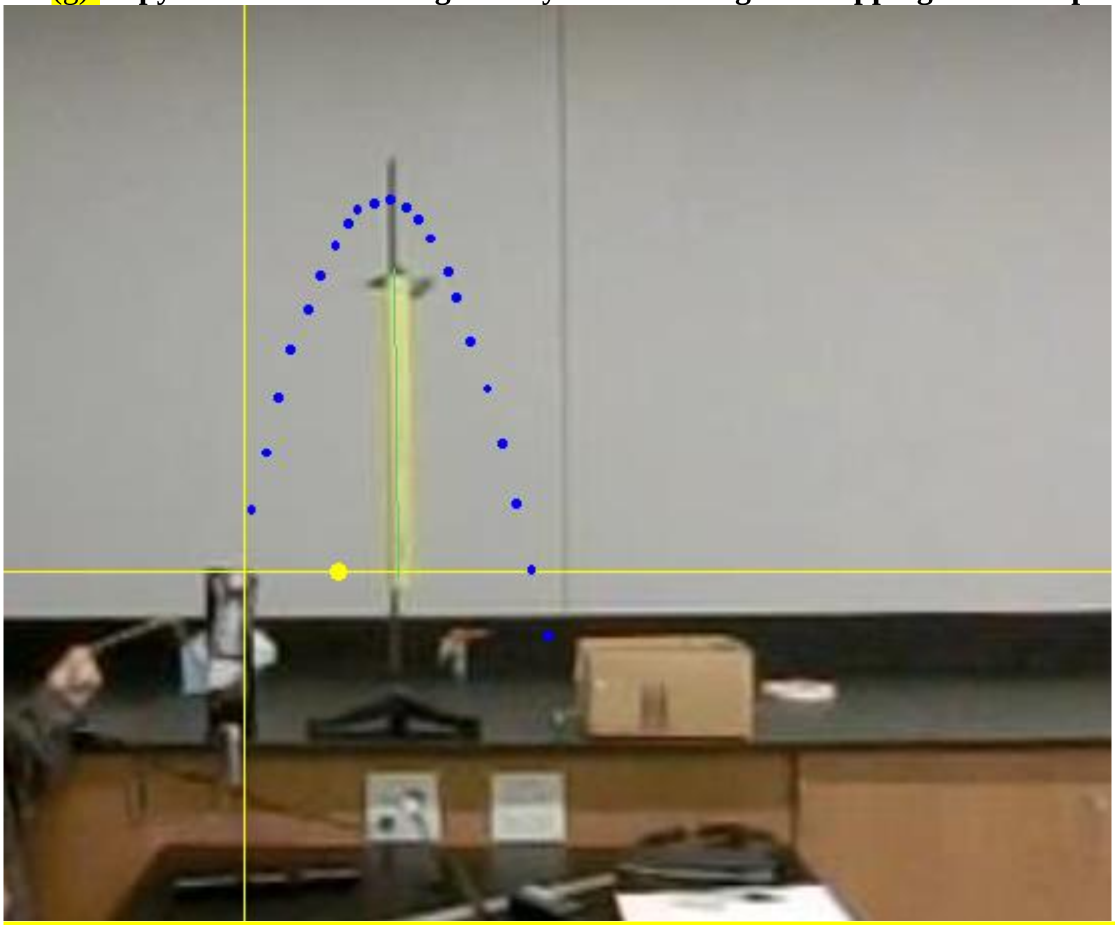

Figure 2. Projectile Motion of ball. This image shows the motion in Trial 2, the trial that produced an acceleration closest to the accepted value of -9.8028m/s^2. The y-axis is in line with the yard stick and starts from the exit of the projectile launcher. The x-axis is in line with the table and also starts from the exit of the projectile launcher.

4. Data Analysis
   (a) Select the graph that shows the plot of both the *x* and *y* coordinates of the projectile as functions of time.
   (b) If there is no acceleration in the horizontal direction, then the *x* coordinate as a function of time should be a straight line. Use the curve fit option under the analyze menu to fit the *x* coordinates of the projectile's motion to a straight line. Compare the functional form of the fit to the kinematic equation for zero acceleration. **Use kinematic equations to explain the physical meaning of the fit parameter *m* here.**

y = b + mt

$x = x_0 + v_{0x}t + (1/2)a_xt^2$

x = horizontal position(m) x_0 = original position (0m). This is equivalent to b.

v_{0x} = initial velocity of the ball moving horizontally (m/s). This is equivalent to m.

a_x = acceleration of the ball moving horizontally (m/s^2). This is 0 because the velocity is constant.

t = time (s)

(c) If the acceleration in the vertical direction is constant, then the *y* coordinate as a function of time should be quadratic. Use the curve fit option to fit the *y* coordinates of the projectile motion to a quadratic function. Compare this quadratic fitting function to the equation of motion for the vertical position of the projectile. **Use kinematic equations to explain the physical meaning of the fit parameter *A* here.**

$y = C + Bt + At^2$
$y = y_0 + v_{0y}t + (1/2)a_yt^2$
y = vertical position (m). This is equivalent to C.
v_{0y} = initial velocity of the ball moving vertically(m/s). This is equivalent to B.
a_y = acceleration of the velocity moving vertically (m/s^2). This is equivalent to 2A.
t = time (s)

(d) Copy the *A* fit parameter into the trial 1 row of your Excel sheet. Use this to calculate the *y* component of the acceleration.

(e) Format your graph to make it easier to read. Add a title. Label the axes with variables and units. Increase the font size of the fitting parameter boxes, and make sure that they do not block the data points. Change the data point symbols to filled circles. **Paste your graph here.**

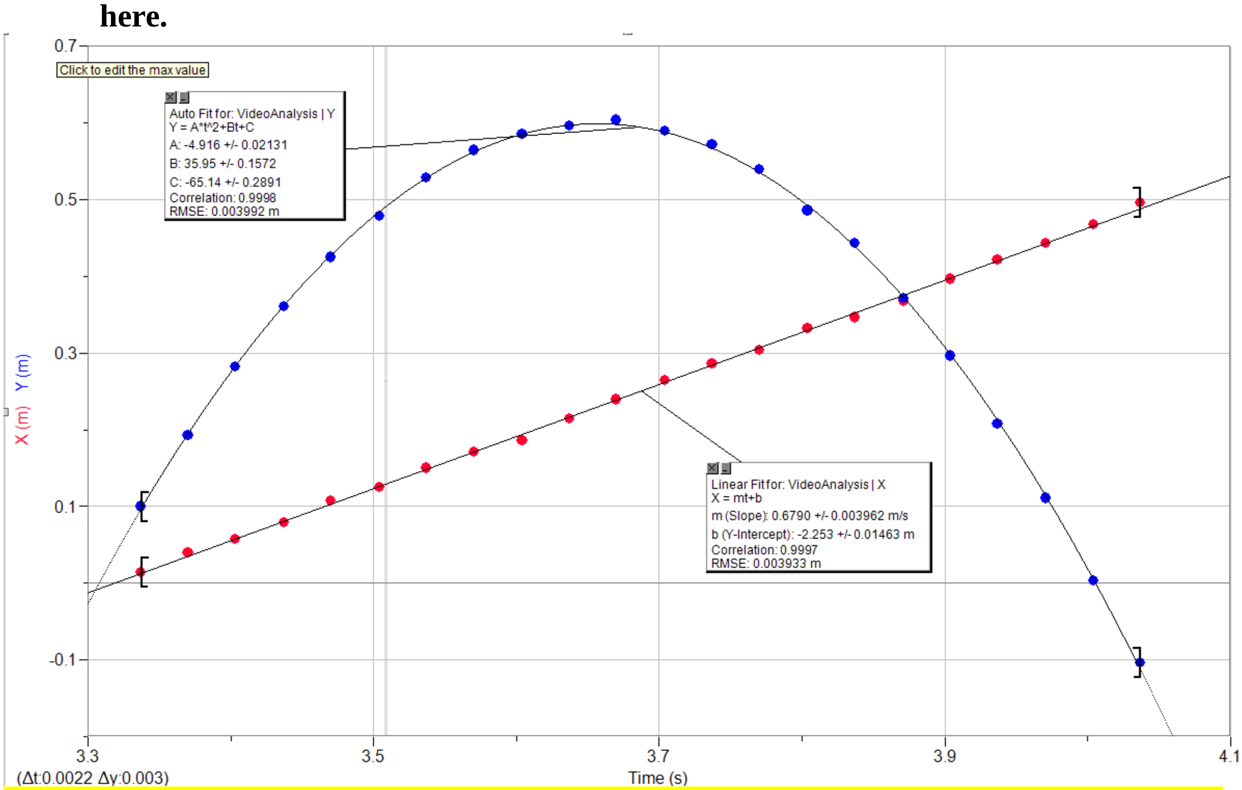

Figure 3. Graph projectile motion of x and y over time. This graph shows the results from Trial 2, the trial that produced an acceleration closest to the accepted value of $-9.8028 m/s^2$. X, graphed in red, represents horizontal motion. Y, graphed in blue, represents vertical motion.

5. Repeat this video capture and analysis process for a total of 5 trials. Realign the spring gun and the scale before each trial. Lab partners should take turns analyzing the video footage. Save each video and graph with the fitted curves to your folder, but you do not need to paste every one into this report. Record the *A* fit parameter from each trial into the Excel spreadsheet.

6. Calculate the vertical component of acceleration for each trial.

7. Calculate the average and standard deviation of your measured accelerations. The standard deviation is the absolute uncertainty. Also calculate the relative uncertainty in percent.

8. Compare your measured acceleration to the standard value of $-9.8029 \pm 0.0001\frac{\text{m}}{\text{s}^2}$ using our ratio test.

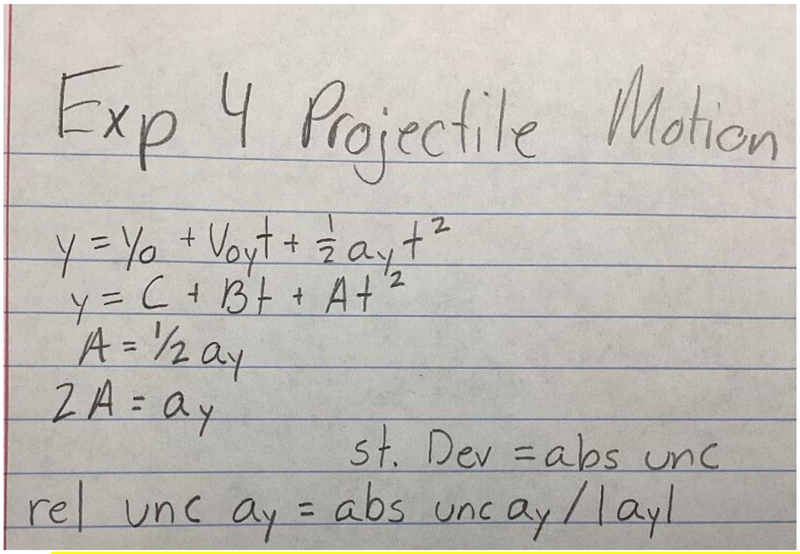

Figure 4. Equations used in calculating acceleration in projectile motion. Y represents position (m), v represents velocity (m/s), a represents acceleration (m/s^2) and t represents time (s). The first equation comes from known constant acceleration equations and the second equation comes from the quadratic motion of y over time.

9. **Format your Excel file to make it easy to read and paste it here**.

Exp 4 - Projectile Motion

trials	A fit parameter (m/s^2)	a_y (m/s^2)		
1	-4.919	-9.838		
2	-4.916	-9.832		
3	-4.977	-9.954		
4	-4.942	-9.884		
5	-5.022	-10.044		
	average a_y (m/s^2)	-9.9104	accepted value of a_y (m/s^2)	-9.8029
	st. Dev. a_y (m/s^2)	0.089	abs unc of accepted a_y (m/s^2)	0.0001
	rel unc (no units)	0.009	ratio test comparing measured a_y to accepted value	0.989152809

Table 1. Projectile Motions Data.

10. **Write a brief analysis here**. What possible systematic effects could influence your results? How might they affect your value of *g*?

The video was rather low quality which effected how accurate the motion of the ball points were and how accurate the scale was (Figure 2). Systematic errors seem to have increased the calculated acceleration as all the trails produced results above the accepted value. Trials 3 and 5 resulted in accelerations there were more than 0.1 m/s^2 higher than the accepted value. Both are still considered close by ratio test but are still decently high. More trials may have further skewed the average or provided a more accurate result that accounts for more extreme values like the results from trials 3 and 5.

11. **Write a brief conclusion here**. State your results. Does your measured acceleration agree with the accepted value?

After 5 trials, the calculated value of acceleration is -9.9104 ± 0.089 m/s^2. Since the results of the ratio test are less than 2, the measured data agrees with the accepted value of -9.8029 m/s^2. Even if the range of the projectile is different the acceleration should stay the same. Doing another set of trails with a different launch angle should prove this.

12. Adjust the formatting (pagination, margins, size of figures, etc.) of this report to make it easy to read. Save this report as a PDF document. Upload it to the course Moodle page.

13. Delete all the video files from the camera. To do so, press the play button (green arrow) and then the down button (there is a little trash can on the back of the camera). Select “Delete All” and do so. Turn off the camera.

14. Clean up your lab station. Put your equipment back where you found it. Remove any temporary files from the computer desktop. Make sure that you logout of Moodle and your email, then shut down the computers. Ensure that the laptop is plugged in.

15. Check with the lab instructor to make sure that they received your submission before you leave.