# Lab 6: Projectile Motion

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For PHYS 2211L, PHYS 1111L

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(Lab outcomes: Error measurement from video data and propagation, measure angle. Produce model and overplot and experimental data with error bars.)

## Abstract

The Projectile Motion is a Tracker-based assignment. The moving body experiences the (almost) constant acceleration on the planet’s surface while the horizontal motion is independent of the vertical until the ground is impacted. Using Tracker and the theoretical model, the range of the projectile motion will be compared with theoretical prediction.

## Introduction

This experiment is from the Tracker series labs. The instructions provided will allow to measure various initial parameters of the launched projectile using the Tracker software and the video of the moving object. Hint – you can provide some background information on the science behind the projectile motion, who studied projectile motion, why it is important (any practical uses), and any other relevant information.

## Experimental Setup

For this experiment, use the high frame rate video provided. You could consider making your own video using lab equipment if you have a high-speed camera (at least 480 fps). Discuss this option with instructor if interested.

Diagram

Description automatically generated The setup schematic is outlined in Figure 1 and consists of the ruler (Figure 1a) to set the scale and the ball launcher (Figure 1b). Do not copy this schematic. Include schematic separately if you make your own video. Consider describing the screenshot instead (as in Figure 2).

b)

a)

Ruler

Figure 1: The experimental setup schematic for shooting the video. (a) ruler used to set the scale, (b) ball launcher.

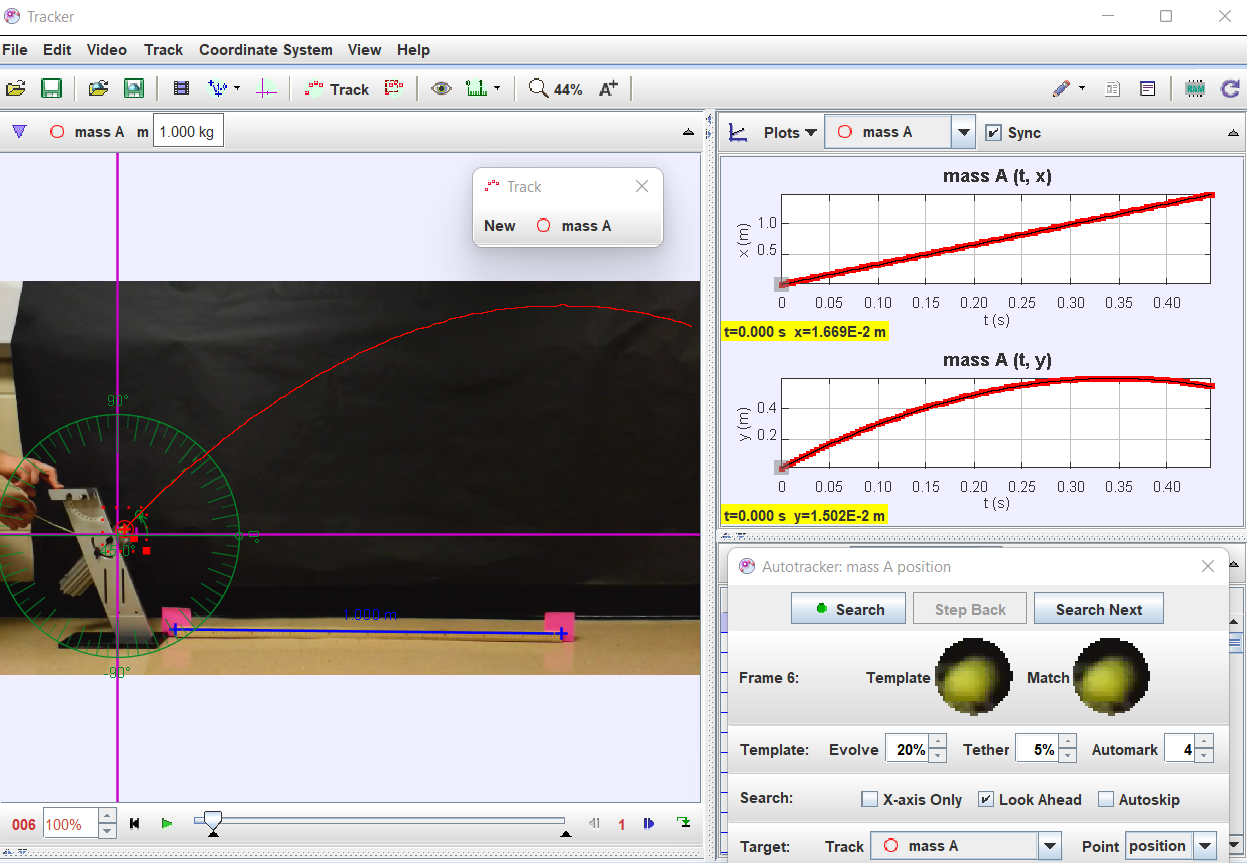


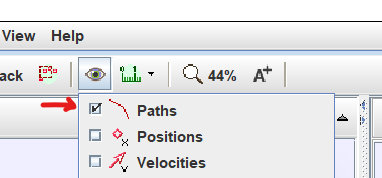
Figure 2: The Tracker screen setup. The scale, axes, protractor, and the object template are set. Ball trajectory is shown for illustrative purposes only.

### Procedure:

Download all videos provided and choose one to start with. Doesn’t matter which one. Make sure it’s not a zip archive (unzip if necessary).

Set the frame rate as indicated in the video file name (960 fps, 480 fps, etc.). The information in file properties gives you inaccurate information about the framerates due to software limitation.

Set the axes such as y-axis is vertical. You can choose to have the coordinate system origin at any location that is convenient, like the initial or final position of the ball… The exit point of the ball from the launcher muzzle is recommended – make sure that ball is visible on the first frame you use. You should **align** the vertical axis along the string with a bob if its present in the video (see the example on the left).

Set the scale by using the calibration stick tool.

Set the start point to the first frame where the ball is fully visible above the muzzle.

Enable the path visibility (see the image on the right. **Never** use images this way in the report!)

Create a new point mass, set the footprints to circle, and choose a good size that will encompass most of the moving object. If you don’t get it right, you can resize it after you click on the object holding the right control keys (refer to Tracker manual video if unsure).

Choose to track every 1st frame. Do the tracking.

Set the display to show two plots similar to Figure 2.

Fit the plot with a parabola and write down the with its error from the fit. This is the statistical error that also includes the tracking uncertainty from point to point.

Fit the plot with a line and write down the from the fit and its error. Don’t close the fit window yet. These errors are the statistical ones (separately for x and y velocity components!!!)

(IMPORTANT: In the theory section, give the equations of motion for x and y positions vs time. Later in the analysis section, identify the initial velocities needed by comparing these equations and corresponding fit results).

A screenshot of a computer

Description automatically generated with medium confidenceCreate a new protractor. Move the protractor so that the center of the protractor matches the center of the axes you set before in Tracker. Align the horizontal part of the protractor with the x-axis. Next, move the protractor and place it at the projectile launcher and measure the angle that it makes with the horizontal. You may want to zoom in a bit (using your mouse wheel). Write down this value and delete the protractor. Repeat 4 more times measuring at different parts of the projectile launcher such as its top, bottom or a sideline – do your best to avoid getting previously measured value only because you already know it. Maybe you can ask your lab partner to do this, or a friend, etc. Get all 5 values, find the average and stdev. This is a mix of statistical + systematic errors[[1]](#footnote-1) for the angle. (Alternative – you can use the velocity angle instead, do the average of the first four points or so, and stdev is the statistical error)

From the plots and data table, find the moment when the ball returns to the **same height as leaving the muzzle** in the first frame that you use – not shown in Figure 1. The value of at that time will be the total range of the projectile. Record this value. You will notice that you can’t exactly judge when the ball actually passes the same heigh as it has exited from the muzzle. Do four more assessments of that moment and record the x-values. Use average as range R and stdev as the statistical error. (Hint – you can take couple of x values before and couple after the best point that you think is the ball returning to the same height).

For systematic error on the velocities, 4 more times delete and add the calibration stick tool. This should recalculate the fit values as well. Record new values - the statistical error is provided by the Tracker software (error for the fit parameter ). The stdev of the five values that you have is the systematic (separately for x and y, for a single video!!). Combine it in quadrature! While doing this, record the new x values for the range (one for each new calibration stick, for the total of four, or five including the original measurement) – use the stdev of these five values that you have as the systematic error for the measured range.

You are given more than one video (most likely), process all remaining videos in this matter. *You can skip finding the and angle/range errors and use the same ones from the first video if you’d like to*. You should end up with the values of R and angle for each video. After you calculate the for each video, the stdev of the multiple values that you have is the additional error that shows the spread of the initial velocities. Add all velocity errors together (add in quadrature!). Use this error and propagate this for R equation into theoretical values. Show error bars for the theoretical values as well.

Now find the . You have a choice on how to find it – you can use the angle and one of the components to find it, or the square root of the sum of two velocity components squared – your choice. Remember to include this equation in theory or analysis section, and to do the error propagation for it. **PHYS2211L** – you must do the partial derivative in either choice as simplified equations don’t work for sine, cosine or square root functions! **PHYS1111L** – break the process into two parts: and ; for each step you can find the error using the simplified equations.

In theory section, derive the equation for the range. Use the fact that the at the top of the object’s path. You should get equation for range .

You may assume that is the same for all videos provided (if more than one). If you processed several videos, comment if that is so and how much error this assumption may be adding to the results! And how does that affect the alignment of the measured and theoretical values for R.

In excel, make a plot using the equation for the range of **R vs**  for a range of angles (say from about 5 degrees to 85 degrees, with a step of at least 0.5 or less. Hint – in Excel, SIN and COS functions take argument in radians. You can use something like SIN(RADIANS(angle)) to use the angles in degrees. Note that the values of angle for this predicted plot are ‘perfect’ but the value of that we use has an associated error. Propagate it to error in R using simplified equations and use it as the y-error bar value.

The resulting plot is the predicted values of the range for the different angles – a type of the physics simulation. On the same plot, show the values from all the videos that you analyzed, include the y and x error bars (that is, for the measured range and the measured angle!)

## Theory

Consider the equation 1 that described the dependence of position y on time for the body moving under the constant force.

where y0 is the initial position and so on (list the other parameters descriptions!).

Remember to include all other relevant formulas and derivations.

## Analysis

Highlight the process of fitting and getting fit parameters, and the average and stdev from multiple trials. Provide the results. Show a sample calculation for a predicted range. Show calculations of the errors (once for each variable).

## Conclusion

Comment on the measured points and the predicted values. DO they match well? Are some above and some below the predicted values or all are above/below? What could be the reasons for that? Any comments and improvements?

## Appendix

A sample of the resulting plot may look something like this:

This plot is given as a sample ONLY. Don’t copy it, all values are made-up.

1. You can also get the statistical and systematic separately: delete and create protractor, measure the angle in the same spot 5 times – stdev of values is the statistical error. Delete and create protractor, measure the angle in the DIFFERENT spots 5 times – stdev of values is the systematic error. [↑](#footnote-ref-1)