2-D Motion: Projectile Motion

In this lab, we will study the motion of small plastic balls fired from a spring-powered projectile launcher. You will use two different methods to find the velocity of the balls as they leave the launcher, and use that velocity, together with the equations governing projectile motion, to predict the range of a projectile fired at an arbitrary angle. As a test of your prediction, you will be asked to use the prediction to place a target on the floor at the spot where the ball will land.

Along the way, you will also investigate some new techniques of error analysis, and the differences between systematic and random errors.

Procedure:

The apparatus for this lab consists of a spring-powered projectile launcher which will fire a small plastic ball into the air. The goal of the lab is to determine the velocity of the ball leaving the launcher, and use that velocity to predict the flight of the ball when the launcher is used to fire the ball across the room.

For the first part of the experiment, the launcher will be fired straight up into the air. Place the launcher on the floor, and make sure the protractor reads 90º, and that the screws holding the launcher to the mount are tightened down. Make sure that the launcher is not aimed at a light (launchers which are mistakenly fired on the "high" setting will fire a ball into the ceiling hard enough to shatter light bulbs and make a mess), set the launcher to the "medium" setting (the second notch down), and fire the ball by tugging sharply on the launch cord. When firing the launcher, be sure to hold it down with your free hand.

1) One method you can use to find the velocity of a ball leaving the launcher is to measure the time that the ball spends in the air. Fire the launcher straight up, and use a stopwatch to measure the time between the firing of the launcher and the highest point the ball reaches. Each member of your group should measure the flight time once. Try to estimate an uncertainty for your measurement of the time of flight.
    a) How do your measurements compare? Do the measurements of different members of your group fall within the estimated uncertainty of one another?
    b) Do you think you have overestimated or underestimated the uncertainty? Are there systematic errors which may be affecting your results?

2) Each of you should repeat the measurement nine more times (for a total of ten), and calculate an average time of flight **for your own measurements only** (you can use Microsoft Excel to calculate the average). The uncertainty in the measurement may be estimated by the standard deviation of the repeated measurements.

   a) How does this uncertainty estimate compare to the uncertainty you estimated in part 1?
   b) Was your uncertainty estimate in part 1 too high, too low, or about right?
   c) How does your average value compare with the average values obtained by your partners?
   d) How does the uncertainty in your measurement compare to those of your partner?
   e) Do the measurements of the other members of your group fall within the estimated uncertainty of one another?
   f) Do you think there were systematic errors affecting your results? If so, what were they?

3) The uncertainty of the average value you obtained is equal to the standard deviation of the measurements you made divided by the square root of the number of measurements. Calculate this uncertainty, and record your value for the average time, with uncertainty, in the appropriate format (i.e., don't write "$t_{avg} = 1.39542 \pm 0.0153$ s," but instead write "$t_{avg} = 1.40 \pm 0.02$ s"). Record the average values (with uncertainty) obtained by your lab partners.

4) Using the equations governing projectile motion (which you should have discussed in class), and the average value of the time of flight you obtained, calculate the initial velocity of the ball when it left the launcher. Remember to account for the height of the launcher in your calculation. Estimate the uncertainty in this velocity.

5) A second method of measuring the initial velocity is to measure the maximum height reached by the ball. Clamp one of the two-meter sticks provided to the edge of the lab table, and use this to measure the maximum height of the ball. You may need to stand on the table in order to read the height. Take a few practice shots to determine the best way to read the ball's height from the meter stick, then each member of your group should record ten values of the maximum height reached. Calculate the average value and the standard deviation for **your own measurements only**.
   a) How do your average height and standard deviation compare to those of your partners?
   b) Do you think there are systematic errors affecting your results?

6) Using the equations governing projectile motion, and the average value of the maximum height, calculate the initial velocity of the ball when it leaves the launcher (remember to include the height of the launcher in your calculation). Estimate the uncertainty in this velocity. How well does this velocity agree with the velocity measured in part 4? What errors (random or systematic) do you think affect these results?

For the final part of the lab, each group will be assigned a random angle between 0º and 45º. Your job is to calculate the total horizontal distance ($\pm$ the uncertainty in the distance) that the ball will travel. You will then clamp your launcher in place on one of the lab tables, set the launcher to fire at the designated angle, and place a target on the floor where you think the ball will land. The size of the target should reflect the uncertainty in the predicted distance. Then shoot the plastic ball across the room. How well do your results agree with the predicted distance, taking into account the uncertainty?