Projectile

Goals: Use analog measuring devices to acquire data. Convert numeric data from a table into a graph. Propagate errors and report the accuracy.

APPARATUS

This experiment uses two tubes to launch a ball horizontally. Both tubes use gravity to get the ball rolling, and a straight section to launch the ball. A long tube will be used in part A to find the range of a ball. A short tube will be used in part B to plot the trajectory of the ball.

In part A, the end of the long tube is situated at a height (h) above the ground. The ball comes out of the tube with an initial horizontal velocity (v_0). As the ball flies through the air it will curve downward due to gravity and strike the floor some distance (d) away from the end of tube.

In part B the ball curves downward and its path can be measured with a vertical board sided with carbon paper. The board can be place at various distances (x) away from the end of the tube. The impact of the ball on carbon paper leaves a mark that can be measured at the end of the experiment. The sequence of carbon paper marks represents the vertical position (y) of the ball at different points in flight.

THEORY

The ball comes out of either tube in the direction of the last section of the tube. This direction is purely in the horizontal direction at some initial velocity v_0. This velocity can be measured by finding the time T that it takes to go between two points in the horizontal tube separated by a distance (D). The velocity is then the

$$v_0 = D/T \qquad \text{(EQ 1)}$$

A projectile in the air is subject to an acceleration (a) downward due to Earth's gravity. The acceleration only acts downward and has no effect on the horizontal motion. Since there is no initial vertical motion for the ball, the distance downward is given by

$$y = y_0 + \frac{1}{2}at^2 = h - \frac{1}{2}gt^2 \qquad \text{(EQ 2)}$$

where h is the initial height and g is the acceleration due to gravity, $g = 9.8$ m/s^2.

The time it takes to hit the ground is found by setting y equal to 0 (the ground) and solving EQ 2 for t.

$$t = \sqrt{\frac{2h}{g}} \qquad \text{(EQ 3)}$$

There is no acceleration in the horizontal direction so the forward distance covered when the ball hits the ground, called the range (R), is found by substituting the time from EQ 3 into an expression for distance: $d = v_0 t$, or

$$R = v_0\sqrt{\frac{2h}{g}} \qquad \text{(EQ 4)}$$

A similar set of equations applies to the motion of a projectile before it reaches the ground. The vertical distance down from the starting point is $y = gt^2$ and the horizontal distance is $x = v_0 t$. If these two equations are combined to eliminate t, then we get
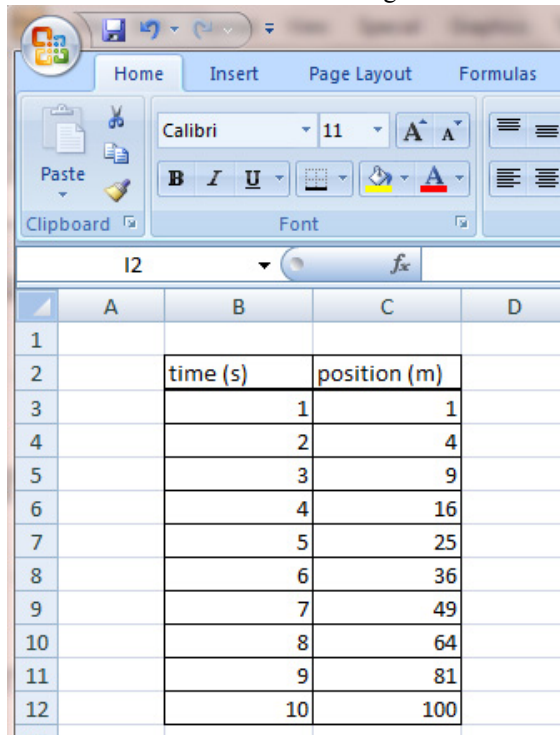
$$y = g\left(\frac{x}{v_0}\right)^2 = h - \frac{g}{2}\frac{x^2}{v_0^2} \qquad \text{(EQ 5)}$$

This equation that relates two distances describes the trajectory of the projectile.

COMPUTER SKILLS

In this exercise you will make a graph using Excel.

1. Open Excel and make a table like the one in the figure below.

2. To plot this data go to the **Insert** tab, select **Scatter** in the *Charts* section, and then click on the **Scatter with only Markers** icon. You will get an empty chart box on the spreadsheet.

3. You should be on the **Design** tab under **Chart Tools**. Select **Select Data** in the *Data* section. You should get the following dialog box.
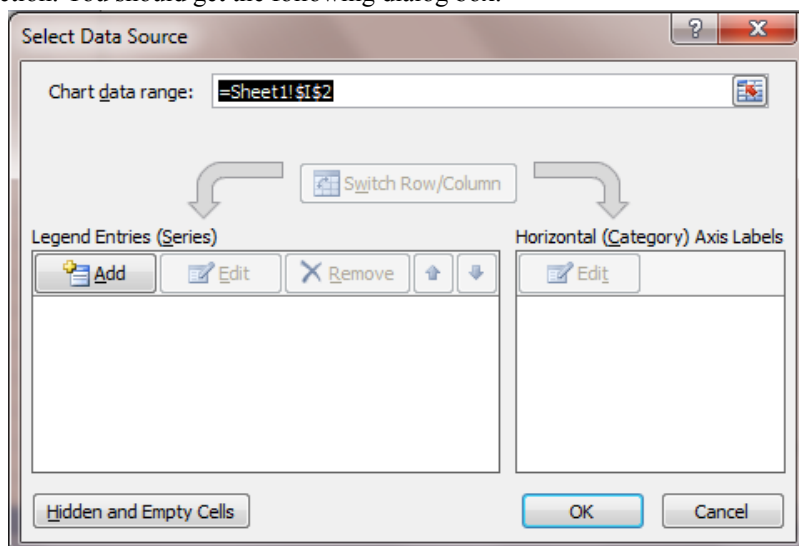
4. Click on the **Add** button in that box, which will give another dialog box.
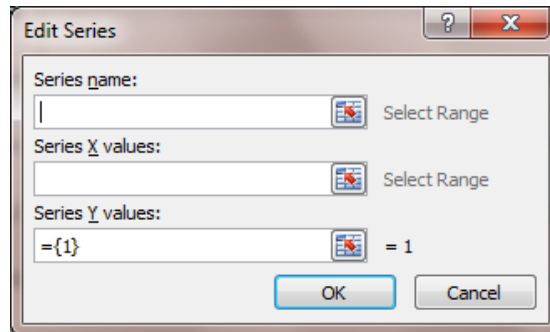
5. In that **Edit Series** box type "Position vs Time" under *Series name*.

6. Click on the *Series X values* selection tool (the far right icon which has the red diagonal arrow). You will get another dialog shown below.
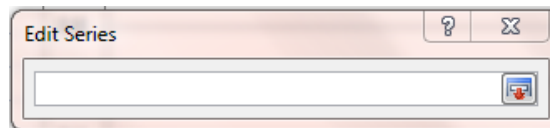

7. Use the mouse to highlight the data in the time column, then press enter which will take you back to the previous dialog box. This will be the data for the horizontal axis.

8. Click on the *Series Y values* selection tool, and in the dialog box highlight the data in the position column, then press enter which will take you back to the previous dialog box. This will be the data for the vertical axis.

9. Click on the OK button and you should return to the **Select Data Source** dialog box. Click OK and you should get the following plot. Note, if you are seeing a curve plotted through the data points, use the **Change Chart Type** in the *Type* section to select the **Scatter with only Markers** icon in the *XY (Scatter)* section.
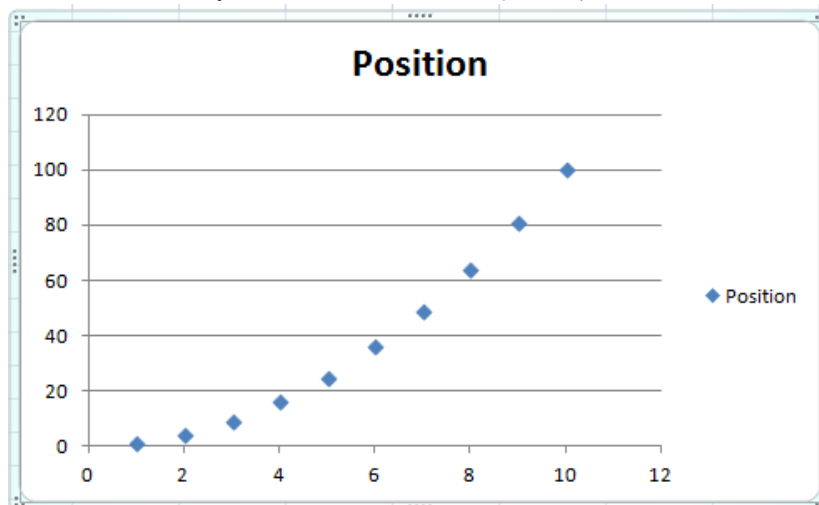
10. Click on the **Layout** tab under **Chart Tools** and find the **Axis Titles** in the *Labels* section. Where it says **Primary Horizontal Axis Title** select **Title Below Axis** and type "time (s)" followed by *Enter*. Where it says **Primary Vertical Axis Title** select

Rotated Title and type "position (m)" followed by *Enter*. The units are an essential part of the axis labels.

11. Click on **Chart Title** in the *Labels* section and select **Above Chart** from that menu. Type "Position versus Time" followed by *Enter*.

12. Click on **Error Bars** in the *Analysis* section and select **More Error Bars Options** from the menu. In the **Vertical Error Bars** dialog box click by **Percentage**, type 15 then click **Close**. Note that this is a large amount, but the error bars become easily observable. If you get horizontal error bars, click on one of the longest horizontal error bar line segments which will select all horizontal error bars (make certain not to select the vertical error bar line segment), and press backspace (or delete).

13. Click on **Trendline** in the *Analysis* section and select **More Trendline Options**. In the **Format Trendline** dialog box click by **Polynomial** and set the Order to 2 (a parabola). In the *Trendline Name* area in the dialog box click by Custom and type "Parabolic Fit". Check the **Display Equation on chart** box, then click **Close**.

14. Use the mouse to left click and drag the equation below the legend at the right to get the following graph.
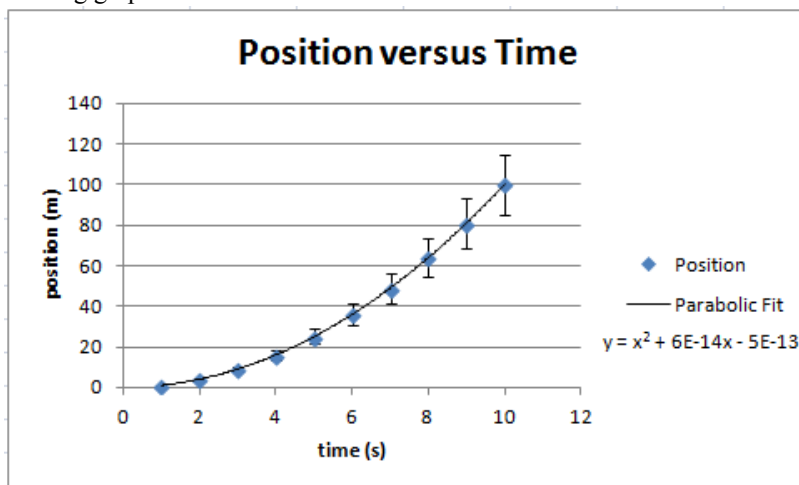
15. Let the TA check you on your work (each member must do this separately).

16. Copy and paste the Excel table and graph with appropriate captions into your Word report. The report should start with the title information (name, date, group members) and then a section with a heading for the computer exercise.

DATA COLLECTION

Part A - Long tube

1. Start a new Word document for your report with the heading *Data Collection*. This only needs to be done once for each group. Briefly describe the apparatus and draw a simple diagram in your report. You do not need to copy or repeat all the information from the handout, but you should cite the handout in this description as a reference. A group may work on the joint text parts of the report outside of lab.

2. Measure the height of the long tube opening above the floor. This is the vertical distance (h) that the ball will fall. Record both the height and the accuracy of the measurement.

3. Use a timer to determine how long it takes the ball to travel the distance between two marks separated by one meter while in the tube. Repeat your timing five times,

recording each time, and take an average to use as time (T). Record both the time and the standard error of the time measurement.

4. Calculate the horizontal speed of the ball (v_0) in the long level portion of the tube with $D = 1$ m using EQ 1.

5. Use the height (h) and horizontal speed (v_0) to predict how far out from the spot on the floor directly beneath the opening of the tube the ball will land using EQ 4. This is the predicted range (R).

6. Calculate the error on your speed by using the error on predicted range using the accuracy of the distance and the standard error on the time (like the method used in the Coin Toss lab for the area of the table). Use the same method with to get the error on the predicted range, but multiply the accuracy of the height by 0.5 to account for the fact that EQ 4 uses the square root of h.

7. Test your prediction by taping some carbon paper to the floor where you expect the ball to hit. Send the ball through the tube ten times letting it hit the paper each time to make a mark on the carbon paper.

8. Measure the horizontal distance from the spot on the floor directly beneath the opening to the edge of the paper.

9. Measure and record the distance of each mark on the paper from the edge of the paper and find an average and standard error.

10. Add the average distance on the paper to the distance of the paper from the tube along the floor to get the measured range.

11. Include sentences in your report to describe your recorded values, calculations, and experimental error. Include observations in the report about the marks and effects that would cause them to vary.

Part B - Short tube

1. Continue the *Data Collection* part of the report by briefly describing the apparatus for Part B with a simple figure.

2. Measure and record the height of the short tube opening above the table. This is the starting value of the vertical distance (h).

3. Drop a small metal ball in the tube and watch its path after it leaves the tube; see how it curves downward. Do this a few times.

4. Tape a strip of carbon paper with the white side out to the backstop. The top of the paper should be just above the point where the ball leaves the tube. Place the backstop upright against the lower opening of the tube. Drop the ball five times, allowing it to hit the board.

5. Move the backstop back 2 cm from the end of the tube. Drop the ball five times again. Try to hold the backstop vertical and as steady as possible during the five trials.

6. Repeat step 4, moving the backstop back in 2 cm steps, until the backstop is so far away that the ball no longer hits it.

7. Take the paper off of the backstop. Each set of five dots should be clearly separated from the others. Estimate by sight an average position from each group of dots, and mark it.

8. Next to each mark on the paper record the horizontal distance from the tube. This should begin at $x = 0$ and increase in steps of 2 cm.

9. Determine the vertical position in cm of each average position marked on the paper. Use 0 cm for the mark at $x = 0$. Copy the numbers from the tape into a data table in Excel with columns for x and y for your report.

10. Write in the report any observations about how the trials went from this part of the experiment.

DATA ANALYSIS

11. Start a new section in the report with the heading *Data Analysis*.

12. Estimate the accuracy of the horizontal distance measurement and record that as a single number for all of the measurement.

13. Estimate the error on the vertical measurement by looking at the spread of the dots for each measurement. The error will typically be less than the dot most separated from the average value, but about two thirds of the dots at each point should be within the error of the value in your table from step 9.

14. Use Excel to make a graph of the horizontal and vertical positions. Notice that the graph has no time axis; only distance units (cm) are used. Your graph marks the trajectory of the ball.

15. Add both horizontal and vertical error bars. Instead of setting a percentage, used the **Fixed value** option and enter the estimated errors from steps 12 and 13.

16. Add a parabolic curve to the graph and place the completed and labeled graph in your report with a caption. Include some text to help the reader understand what they are looking at.

17. Your TA will assign an addition question or two to answer in the report. This work should be done by each group member individually.

18. Each student should assemble a single report from the computer exercise, the group data report and the additional individual question. This report will be turned in for grading.