Date:______________

Two Dimensional Kinematics Worksheet
******* Use a pencil! *******

Name:________________________________
Lab Partner:___________________________

1) Record your initial firing angle, θ_0, and estimate its uncertainty. Record both in the table on the back side of this sheet.

2) Using Excel, make columns to record frame #, t, observed x, and observed y for each frame. Include headers. Measure the x and y coordinates of the ball for each video frame in cm.

3) Measure the horizontal distance from the lens to the grid, the horizontal distance from the ball to the grid, and both the x and y coordinates of the camera lens with respect to a known coordinate origin. Then, correct for parallax in yet two more columns.

4) Using the video, determine your observed values for the range (R), maximum height (H), and time of flight (T). Both R and T should refer to when the projectile returns to its starting height. Estimate uncertainties for all 3 quantities.

5) Make three graphs: y vs. x, y vs. t, and x vs. t

6) Determine the type of equation represented by each plot. Use “Linest” to determine the “best fit” equation for each of the graphs. Write the equations below. Include units and uncertainties.

   1. x as a function of t: ____
   2. y as a function of t: ____
   3. y as a function of x: ____

7) From the equations you wrote above, determine the following quantities. Include units.

   x_0: _______________ ± _______________

   y_0: _______________ ± _______________

   v_{0x}: _______________ ± _______________

   v_{0y}: _______________ ± _______________

   a_x: _______________ ± _______________ (a_x is **not** zero!)

   a_y: _______________ ± _______________

8) Use the results from part 7) and the *fundamental* equations of constant acceleration (i.e., NOT the ones that have already substituted $a_y = -g$ and $a_x = 0$) to determine the initial firing angle (θ_0), the magnitude of the initial velocity (v_0), the maximum height (H), the range (R), and the time of flight (T). All five may be functions of the five quantities you found in part 7). Write the *symbolic equations* in the spaces at the top of the other side of this worksheet, and then enter the values in the table on the back of this sheet.

θ_0 = ____________________ v_0 = ____________________

H = ____________________ T = ____________________

R = ____________________

9) Use the rules for propagation of uncertainties to determine the uncertainties in each of the quantities you computed in part 8). Enter the values in the table below:

10) Which rows of the table are in agreement? Why do the others disagree?____________________

____

____

11) Why is a_x not zero?____________________

____

____

12) What did you expect to obtain for a_y? How does your result compare to this value? What is the cause of any discrepancy?____________________

____

____

Quantity	**Direct observation**	**Calculated result**
θ_0	±	±
v_0		±
R	±	±
H	±	±
T	±	±

Answers:

$$\theta_0 = \tan^{-1}\left(\frac{v_{0y}}{v_{0x}}\right) \qquad \Delta\theta_0 = \sqrt{\left(\frac{v_{0y}}{v_{0x}^2+v_{0y}^2}\Delta v_{0x}\right)^2 + \left(\frac{-v_{0x}}{v_{0x}^2+v_{0y}^2}\Delta v_{0y}\right)^2}$$

$$v_0 = \sqrt{v_{0x}^2+v_{0y}^2} \qquad \Delta v_0 = \sqrt{\left(\frac{v_{0x}}{\sqrt{v_{0x}^2+v_{0y}^2}}\Delta v_{0x}\right)^2 + \left(\frac{v_{0y}}{\sqrt{v_{0x}^2+v_{0y}^2}}\Delta v_{0y}\right)^2}$$

$$H = \frac{-v_{0y}^2}{2a_y} \qquad \Delta H = \sqrt{\left(\frac{-v_{0y}}{a_y}\Delta v_{0y}\right)^2 + \left(\frac{v_{0y}^2}{2a_y^2}\Delta a_y\right)^2}$$

$$T = \frac{-2v_{0y}}{a_y} \qquad \Delta T = \sqrt{\left(-\frac{2}{a_y}\Delta v_{0y}\right)^2 + \left(\frac{2v_{0y}}{a_y^2}\Delta a_y\right)^2}$$

$$R = 2\frac{a_x v_{0y}^2}{a_y^2} - \frac{2v_{0x}v_{0y}}{a_y}$$

$$\Delta R = \sqrt{\left(\frac{-2v_{0y}}{a_y}\Delta v_{0x}\right)^2 + \left(\left(\frac{4a_x v_{0y}}{a_y^2} - \frac{2v_{0x}}{a_y}\right)\Delta v_{0y}\right)^2 + \left(\frac{2v_{0y}^2}{a_y^2}\Delta a_x\right)^2 + \left(\left(\frac{2v_{0x}v_{0y}}{a_y^2} - \frac{4a_x v_{0y}^2}{a_y^3}\right)\Delta a_y\right)^2}$$

If $a_x \rightarrow 0$, then

$$R = -\frac{2v_{0x}v_{0y}}{a_y}\text{, and} \qquad \Delta R = \sqrt{\left(\frac{-2v_{0y}}{a_y}\Delta v_{0x}\right)^2 + \left(\frac{-2v_{0x}}{a_y}\Delta v_{0y}\right)^2 + \left(\frac{2v_{0x}v_{0y}}{a_y^2}\Delta a_y\right)^2}$$