Name: ———————————   Partner's Name: ———————————
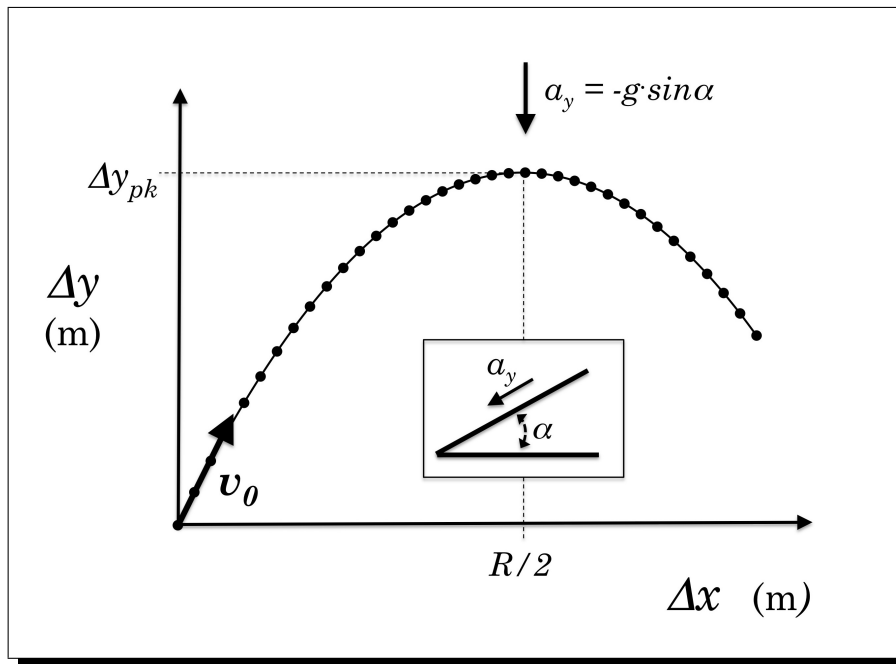
Projectile Motion

In this experiment, you will study projectile motion on a tilted air table.

1. Apparatus:

- Air table with puck and spark timer
- puck launcher
- recording paper
- ruler, protractor
- drawing triangle

2. Introduction:

An air table will be used in this experiment to provide a record of the motion of an object in two dimensions. The puck floats on a cushion of air supplied by a compressor through a light, very flexible tube. This air cushion almost entirely eliminates friction. Inside the flexible tube is a light chain connecting a spark generator to a sharp point inside a depression in the base of the puck. The puck floats over a sheet of newsprint laid over a carbonized piece of paper so that each time the spark generator fires, a spark jumps between that point and the metal table top to mark the puck position at that instant. The spark interval is known, so measurements may be made of the puck positions to make a quantitative study of the motion of the puck.

If the air table is carefully leveled to begin with and then tilted in one direction, there results a two dimensional framework with any desired amount of acceleration (up to g) along one dimension. The acceleration is given by

$$a_y = -g \sin \alpha , \tag{1}$$

where α is the angle of tilt of the table above the horizontal (see cover figure). As would be expected, this formula shows that the value of a depends direclty on the tilt angle. For a flat table with no tilt, $\alpha = 0$, so $a = 0$ and as expected the puck wouldn't move. For a table tilted completely upright $\alpha = 90^0$, so $a = -g$, and as expected the puck would feel the full force of gravity. For any angle in between 0^0 and 90^0, however, only a fraction of gravity is acting along the page.

3. Procedure

1. First check the air table is level by checking that a puck placed on it doesn't drift only in one direction. (This was already done by your instructer).
2. Only one puck will be used so place the other puck somewhere on the table where it will be out of the way. (Both pucks need to be on the table in order to have a complete circuit for the spark.) Turn **ON** the puck launcher.
3. First make a dry run. Use the rubber band positioned at the lower right corner of the table to launch the puck. Do **NOT** activate the spark generator during these preliminary test. Try different **ENERGY** settings by stretching the rubber band by different amounts and different launcher angles until a good trajectory is achieved. A good flight path should go over the peak of "flight" for a reasonable distance, say a few centimeters, before terminating. It need not involve a return to the launcher level.
4. Make sure the edge of the recording paper is parallel to the front edge of the air table. Reset the launcher and puck. Set the spark interval to 60 Hz. Activate the spark generator and fire the launcher. Release the foot switch when the "flight" terminates.

KEEP HANDS OFF AIR TABLE WHILE SPARK GENERATOR IS ACTIVATED.

5. Lift the recording paper and check that a good record of the flight has been obtained on the reverse side. If so, record the spark interval on the spark record.

.

4. Data Analysis

1. Draw a straight line across the spark record through the first good point near the start of the path, making the line parallel to the bottom edge of the spark record. (It is important that the line be parallel to the edge; this line is the $x-$axis) Do NOT use the first couple of points because when those were recorded the puck was still being launched by the rubber band. Circle the first good point and label it 0, this is the origin.

2. **Circle every sixth point** along the path and label them $0, 1, 2 \ldots$ There should be at least 10 points circled.

3. With a ruler held firmly parallel to the $x-$axis, slide a triangle along the ruler until the vertical edge of the triangle goes through the point labelled 0. Make a short thin pencil line vertically through the $x-$axis at this position. Mark it with the number 0.

4. Continue the procedure of step 3 for each circled spark point. **You should have at least 10 data points circled**. You may need to establish a new horizontal line higher up on your record sheet, if you exceed the limit of your triangle length, in order to record the horizontal position of each circled spark point. The purpose of these marks is to make possible a measurement of the horizontal component of the puck displacement for each time interval. We shall call these the $x-$components. Measure and record in Data Table 1 the values of Δx for each time interval. Calculate and record the corresponding values for v_x. Should v_x be constant? Explain.

5. Now establish (using the triangle) a vertical axis ($y-$axis) and make short marks on the $y-$axis of the vertical component of displacement for each circled spark point. Measure and record in Data Table 1 the values of Δy for each time interval. We shall call these the $y-$components. Calculate the corresponding values of v_y and record them in Data Table 1. Should v_y be constant? Explain.

6. **<u>Initial Velocity</u> $\vec{v}$**: To find the initial direction of $\vec{v}_0$, draw a straight line from data point 1 to data point 2. This line is tangent to the initial flight path. Using a protractor, measure the angle θ_0 of this line above the horizontal. You can also find the magnitude of $\vec{v}_0$ by measuring the distance along the tangent line and dividing this distance by the time interval. This is a reasonably good value, but of course is not exact.

$$\theta_0 = \underline{\hspace{2cm}} \qquad\qquad v_0 = \underline{\hspace{2cm}}$$

7. **Horizontal Velocity** v_x: We first examine in detail how uniform the velocity component in the horizontal direction is. From your values of v_0 and θ_0, calculate the initial velocity in the $x-$direction,

$$\textit{Initial x-velocity:}\ \ v_{x,0} = v_0 \cos\theta_0 = \underline{\hspace{3cm}}\ .$$

Now average the values of v_x in Table I to find the overall average value $\bar{v}_x$.

$$\textit{Average x-velocity:}\ \bar{v}_x = \underline{\hspace{3cm}}\ .$$

Find the percent difference between the initial and average values $v_{x,0}$ and $\bar{v}_x$.

$$\text{The \% difference} = \underline{\hspace{2.5cm}}\ .$$

Which value is larger? What might cause that? Explain.

8. **Peak Position:** We next examine the $x-$position of peak of the curve. If the distance R represents the full distance (the range) along the $x-$axis when the puck is back at $y = 0$, then $R/2$ should be the distance to the peak of the curve (see cover figure). Begin by directly measuring on the chart the $x-$distance to the curve peak,

$$\textit{Measured: } R/2 = \underline{\hspace{3cm}}\ .$$

We can compare this to the value of $R/2$ calculated from the equation for projectile motion, $\Delta x = v_{0,x}t$. To do this, first count the points from 0 to the peak and multiply by the spark interval to find the time $t_{R/2}$. Using this time, and the value of $v_{0,x}$ above, calculate $R/2$

$$\textit{Calculated: } R/2 = v_{0,x}t_{R/2} = \underline{\hspace{3cm}}\ .$$

Finally compute the percent differences between these values,

$$\text{The \% difference} = \underline{\hspace{3cm}}\ .$$

Which value is larger? What might cause that? Explain.

9. **Vertical Acceleration** a_y: We next examine the values of the downward acceleration a_y that acts on the puck. As explained in the introduction, by tilting the table up by a slight angle α, there is an effective acceleration, $a_y = -g\sin\alpha$, pointing in the negative $y-$direction on your chart (see cover figure). From the definition $a_y = \Delta v_y/\Delta t$, you can determine the acceleration acting on the puck by studying the change in the puck's $y-$velocity in time. You will find the average acceleration $\bar{a}_y$ from the slope of the v_y vs. t graph:

   - **Graphical Method:** Make a graph of your data for both v_x and v_y vs. time t. The average acceleration in the $y-$direction, $\bar{a}_y$, is equal to the average slope of the v_y vs. t graph. Do a trendline fit of v_y and record the slope value.

$$\textit{Average Acceleration from Trendline Fit : } \bar{a}_y = \underline{\hspace{3cm}}$$

10. **Peak Height:** We next examine the $y-$position of the peak of the curve, Δy_{pk} (see cover figure). Begin by directly measuring on the chart the $y-$distance to the curve peak.

Measured Peak Height: $\Delta y_{pk} = $ ⎯⎯⎯⎯⎯⎯⎯⎯ .

We can compare this to the value calculated from the equation for projectile motion, $\Delta y_{pk} = -v_{0,y}^2/2a_y$. Use your measured values for v_0, θ_0, and $\bar{a}_y$ above to calculate the peak height Δy_{pk}.

Calculated Peak Height: $\Delta y_{pk} = -\frac{(v_0 \sin \theta_0)^2}{2a_y} = $ ⎯⎯⎯⎯⎯⎯⎯⎯ .

Compute the percent differences between the measured and calculated values.

The % difference = ⎯⎯⎯⎯⎯⎯ .

Which value is larger? What might cause that? Explain. In addition, derive the equation $\Delta y_{pk} = -(v_0 \sin \theta_0)^2/2a_y$ used in your calculation.

11. **Tilt Angle α:** Finally, we examine the tilt angle α of the table. Use a protractor to directly measure α.

Measured Tilt Angle: $\alpha = $ ⎯⎯⎯⎯⎯⎯⎯ .

We can compare this to the value calculated using Equation (1) and your value for the average $y-$acceleration $\bar{a}_y$ above.

Calculated Tilt Angle: $\alpha = \arcsin(-\bar{a}_y/g) = $ ⎯⎯⎯⎯⎯⎯⎯ .

Compute the percent differences between the measured and calculated values.

The % difference = ⎯⎯⎯⎯⎯⎯ .

12. Label your spark record completely, including the names of everyone who used it, and turn it in with your report.

⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯
⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯⎯

Table 1: Data and Analysis of Motions in the $X-$ and $Y-$ Directions.

Δx	$v_x = \frac{\Delta x}{\Delta t}$	$\leftarrow$(units)$\rightarrow$ Interval	Δy	$v_y = \frac{\Delta y}{\Delta t}$
		0 - 1		
		1 - 2		
		2 - 3		
		3 - 4		
		4 - 5		
		5 - 6		
		6 - 7		
		7 - 8		
		8 - 9		
		9 - 10		
		10 - 11		
		11 - 12		
		12 - 13		
		13 - 14		

.

DUE NEXT WEEK...

1. The spark record (one for each group. Write your names on the record).
2. This lab handout with all data. Show your work for all calculations on a separate sheet of paper.
3. The Data Tables 1 and 2 with all data values.
4. Graphs of v_x vs. t and v_y vs. t. Both graphs should show linear trendline fits and their slopes.

.