

## Freefall

**Apparatus:** 3 Tape timers operating at 40 Hz, tape, 3 right angle clamps, 3 medium rods, 3 small rods, 3 small bases, 3 foam pieces, rulers, meter sticks.

**Purpose:** To test kinematic theory as it relates to freefall, and to measure the acceleration due to gravity.

**Theory:** If the only force acting on an object is gravity, then the object is said to be in *freefall*. Since the force of gravity near the surface of the Earth is constant, the object's acceleration is also constant. We will assume the object's acceleration is constant with *magnitude* equal to  $g$ . Vertical velocity as a function of time is given by

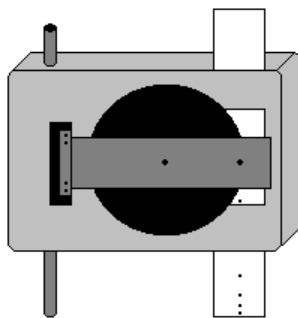
$$v_{yf}(t) = v_{yi} + a_y t$$

Vertical position as a function of time is given by

$$y_f(t) = y_i + v_{iy}t + \frac{1}{2}a_y t^2$$

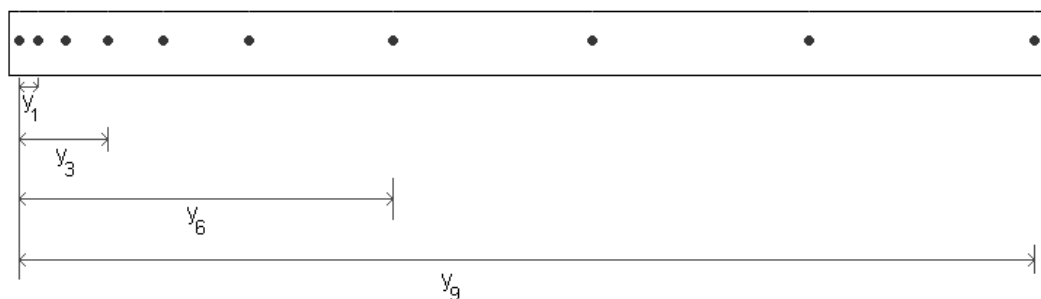
In your lab write-up you should be sure to indicate what each variable means.

**Procedure:** Place tape in the marker apparatus so that it passes under the carbon paper:



**Figure 1:** Marker apparatus. Notice the paper runs behind the carbon disk underneath the metal.

Fix a mass to the end sufficient to overcome the drag of friction and air resistance on the tape (up to 500 g). Also, detach your strip from the spool and take precautions to minimize the effects of drag and friction. Set the apparatus at 40 Hz and release the tape.



**Figure 2:** Markings on paper tape. **Note that all distances are measured from the first data point (not the distance between adjacent dots).**

The tape marker marks the position of the tape (and also the falling mass) every  $1/40^{\text{th}}$  of a second (0.025s). Fix the tape securely to a horizontal surface and identify the position marks. Choose the first clear mark and label it 0, and each successive mark 1, 2, 3, etc. These data points correspond to the tape's position at  $t = 0\text{s}$ ,  $t = 1/40\text{s}$ ,  $t = 2/40\text{s}$ , etc. You will convert these times to decimals for your table.

**Data:** Using Excel, make a table of the data indicating units, labels, and errors.

[This video playlist](#) on you tube may help if you are new to Excel.



Remember: You can change the sig figs of a cell by clicking these buttons.

Notice that each  $y$  value in the table below is negative because the tape was moving downward.

**Double check that each  $y$  value is measured from the starting point (not distance between adjacent dots).**

Note: errors indicated in the picture below are nonsense numbers; ensure you figure out the %errors yourselves!

	A	B	C	D	E	F	G	H
1	$t$ (s)	$y$ (m)	$v$ (m/s)					
2	0.000	0.000	NA		errors	$\delta t$ (s)	$\delta y$ (m)	
3	0.025	-0.004	-0.24			0.001	0.001	
4	0.050	-0.012	-0.44					
5	0.075	-0.026	-0.68		% errors	for $t$	for $y$	for $v$
6	0.100	-0.046	-0.88			about 3%	about 6%	about 9%
7	0.125	-0.070	-1.05					
8	0.150	-0.099	-1.34					
9	0.175	-0.137	-1.65					
10	0.200	-0.181	NA					

**Figure 3:** Data table made using Microsoft Excel. You should make your own, more realistic estimates for the %error on your measurements.

Recall that  $v_{avg} = \Delta y / \Delta t$  so on your table  $v_1 = (y_2 - y_0) / (t_2 - t_0)$  and  $a_3 = (v_4 - v_2) / (t_4 - t_2)$ . Notice that to get the velocity at point 1 you use the data from points 0 and 2. **THINK:** Why? Why are you unable to get  $v_0$ ? Will you be able to determine the acceleration and velocity of your final point(s)? **SPEED HINT!** You can use excel to speed up your calculations by entering a formula. See Figure 4 below and follow the examples given by your instructor in class.

	A	B	C
1	$t$ (s)	$y$ (m)	$v$ (m/s)
2	0.000	0.000	NA
3	0.025		$= (B4 - B2) / 0.05$
4	0.050	-0.012	
5	0.075	-0.026	

	C
3	$v$ (m/s)
4	NA
5	-0.24

	C
1	$v$ (m/s)
2	NA
3	-0.24
4	-0.44
5	-0.68
6	-0.88
7	-1.05
8	-1.34
9	-1.65

**Figure 4:** These figures show the steps when using excel to “fill down” a formula. In cell C3 type the formula shown. Then put the mouse over the bottom right corner of the cell. Click on the mouse and drag it down to the bottom of the column.

### Now graph $y$ vs. $t$ and $v$ vs. $t$ .

[This video playlist](#) on you tube may help if you are new to Excel.

Look back at your graph and check the following things:

- remove the gridlines
- graph has title using variables (in italics) but no units are necessary
- axis labels have **variables in italics** with **units not italicized**
- the graph fills the entire field (graph size should be about 1/3 to 1/2 a page)
- no legend for single set of data (a legend is only used if more than one thing is on a single graph)
- if a trendline is shown there is an equation with  $R^2$  value on the chart
- show the data as points only (no connecting smooth line)
- for graphs with both theoretical & experimental data: theory is a smooth line (no points) while experiment is a only points (no line)
- the graph and data table are sized such that it fits on a single sheet of paper (not always possible)
- everything except the legend has appropriate subscripts and superscripts
- title is y-axis label versus x-axis label

A graph of  $v$  vs.  $t$  will produce a line, the slope of which is the acceleration.

The magnitude of this acceleration is  $g_{exp}$ , the experimental value of  $g$ .

A graph of  $y$  vs.  $t$  should make a parabola.

Use the LINEST command to determine the error in the slope ( $\delta slope$ ) for your  $v$  vs.  $t$  graph (instructions are in the error appendix somewhere).

The percent precision in today's lab will be estimated from the error in the slope calculation. The %precision is given by  $(\delta g_{exp}/g_{exp}) \times 100\% = (\delta slope/slope) \times 100\%$ .

**Check print preview prior to printing to avoid wasting paper.**

### Conclusions:

1. According to the  $y$ - $t$  trendline, what is the experimental value of  $g$ ?
2. According to the  $v$ - $t$  trendline, what is the experimental value of  $g$ ?
3. According to the  $y$ - $t$  trendline, what is the experimental value of the initial velocity in the  $y$ -direction?
4. According to the  $v$ - $t$  trendline, what is the experimental value of the initial velocity in the  $y$ -direction?
5. Compare the %difference to the %precision. Was the  $g_{exp}$  in good agreement with the accepted value?  
Draw a target diagram representing your measurement.
6. Air resistance and the friction between the paper and the spark timer were neglected. Should this cause your %difference to be more positive or more negative? Explain for credit.