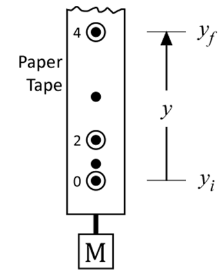
The Motion of Free Fall

Fall 2023

Introduction



In this experiment, you will measure the displacement as a function of time for a mass, M in free fall, and determine its acceleration and initial velocity from the kinematic expression $y = y_o + v_o t + \frac{1}{2} a_o t^2$. A mass in free fall will accelerate at a constant rate, g.

Experiment

1. Prepare a strip of paper tape to hold the 200-*g* mass: Tear off a length of paper tape that is a little shorter than the height of the timer attached to your lab bench; make a loop at the 'bottom' end of the tape and secure with tape.
2. Feed the 'top' end of the paper tape through the timer, between the carbon disc and metal striker plate, and attach the 200-*g* mass. While holding the paper tape near the 'top', your partner will turn the timer on (move the switch *left* to **40** Hz); you will release the tape when you hear the timer start. *Be sure not to let the tape drag through your hand!* At this setting, the timer will create small dots on the tape at $1/40$ -second intervals.
3. Choose the first clear dot you can see near the beginning of the tape and number this dot *zero*. Circle and number each *even* numbered dot to make it more visible, as shown in the sketch above.
4. Create the following data table in your journal. *Before measuring your tape*, also create a table in Excel to hold your values of t (*dots*) and y (*cm*); recall that in Excel, the quantity plotted along the x-axis is entered in the first column. Notes about the data table follow the table:

Elapsed time, t (*dots*)	Initial position, y_i (*cm*)	Final position, y_f (*cm*)	Displacement, $y = y_f - y_i$ (*cm*)
0	10.0	10.0	0.0
18		—	—
2		—	—
4		—	—
⋮		—	—

- The elapsed time is in units of *dots* (the even numbers you labeled), where each dot occurs $1/40$ -seconds apart (i.e., 40 dots are created during every second of time). This will make it easier to graph your data; you will wait until you calculate your final result to convert time units into seconds.
    - Note the order of the entries in the "Elapsed Time" column. We will first take measurements of minimum and maximum values, and then immediately begin creating a graph. Subsequent measurements are then plotted on the graph as they are collected. Your tables (in your journal and Excel) will appear in the order in which you collected your data. This allows you to see that your experiment is behaving as expected. See the *"Graphs"* section in the *Introduction to Laboratory Practices (ILP)* for more details.
- The initial position, y_i, is held constant at 10.0 *cm*. You will introduce measurement error if you use the end of the meter stick, since the end may be worn due to its age, or obscured by a protective metal cap. Using this position for y_i gives you a position that allows easy calculation of the displacement. Affix the paper tape to the bench and lay the meter stick next to it with the 10.0 *cm* mark aligned with the zeroth dot.

5. Measure the position of the shortest and longest distance fallen (the even numbered dots) and record your measurements in the journal data table. Calculate the displacement, y of the mass and record it in the data table. *Carefully note that you are* ***not*** *measuring the distance between each dot!*
6. Record the values of t (*dots*) and y (*cm*) from your two measurements in the Excel table. Measure, calculate and record t and y for a third even-numbered dot (Excel requires *at least three points* to properly create an x-y scatter plot.)
7. Create a graph of y vs. t in Excel with the three data points measured. Continue to measure the displacement for your remaining even-numbered dots, *remembering to plot each point as it is measured* (your instructor can show you how to easily add new data points to your existing graph.)

   Important observation: As you collect your data, carefully note the changing separation between each dot on the tape. Since the time interval between each dot is the same, the velocity of the mass must be increasing with time so that more tape is pulled through the timer between dots. Velocity changing with time? Ahh ... *acceleration*!!

Analysis - Calculating the initial position, initial velocity, and acceleration of the falling mass

1. After all your data are plotted, add a best-fit curve (a 2nd order polynomial: $y = Ax^2 + Bx + C$); remember to include the equation for the line on the graph. Print a copy of the graph for each member of your group, remembering to include your name (and your partners) in the header.
2. Use the procedure introduced in last week's Excel exercise (pg. 3 "Analyzing the Graph" – matching the best-fit function to the theory) to determine the initial position (y_o), initial velocity (v_o), and acceleration (a_o) of the falling mass. *Keep in mind that your graph uses 'dots' for time units, not seconds!*
3. Convert your values of v_o and a_o to units of *cm/sec* and to *cm/sec*^{2}, respectively (recall that 40 dots = 1 sec).
4. Record your acceleration results on the blackboard; keep the units in *cm/sec*^{2}.
5. Compare your final calculated results to their expected values (*i.e., calculate the percent difference – see ILP, pg. 3!*) The *expected* value for a_o should be $\boldsymbol{g}$, which is approximately 980 *cm/sec*^{2}. What were you expecting v_o and y_o to be?
   - *Note*: You cannot calculate the percent difference between two numbers if one of those numbers is zero; if you try this calculation, you will always get a 200% difference! If your expected value is zero, then you should expect that your measured value is very small and close to zero – **if** the experiment and theory agree! Be sure to comment on this agreement between your values.

Discussion

- Begin your discussion by restating your numerical results (a summary table is a nice way to display these results). In this experiment, you will journal your *calculated* values for each of the three coefficients (a_o, v_o and y_o) as well as their *expected* values.
- In the Analysis section above, you compared calculated and expected values. Do you notice a *significant* discrepancy in one (or more) of these values? Explain the cause of this discrepancy.
- Look at the graph of displacement vs. time you created with Excel. How well does the best-fit line drawn by Excel (the line represents *the theory*) fit your data points (*the experiment*). What does the graph tell you about the acceleration of the falling mass?
- Examine the results of your classmates written on the blackboard. Are the results consistent with each other? Do you notice a trend in these results? If so, what might be the cause of this trend?
  - *A summary table of the class results will better support your conclusion!*
- Finally, *carefully* fold the paper tape and staple it to the back of the journal of one group member – never throw away data!