ACCELERATION DUE TO GRAVITY

OBJECTIVE: To study uniformly accelerated linear motion and to determine the acceleration due to gravity, *g*.

THEORY: Velocity is defined as the rate of change of position, and acceleration is defined as the rate of change of velocity. For linear motion, then

$$V = \Delta s / \Delta t \qquad a = \Delta v / \Delta t \tag{1,2}$$

If *a* is CONSTANT, we can begin with these equations and derive equations for the velocity and displacement of an object after the elapse of any length of time *t*:

$$v = v_o + at \tag{3}$$

$$s = s_o + v_o t + (1/2)at^2 . \tag{4}$$

The best example of constant acceleration is that provided by gravity in the absence of air resistance. We can ignore the resistance of air if the body is small and travels only a short distance. (Actually, for large distances, this resisting force is significant and eventually results in motion with a constant velocity instead of constant acceleration. Also, the value of *g* varies somewhat according to height and geographical location.)

Experimentally we are not able to get values of instantaneous velocity. Instead we use very small intervals of time, and calculate the values of AVERAGE velocities. As an interval gets smaller, the average value approaches the instantaneous value at the midpoint of the interval:

$$v_{avg} = \Delta s / \Delta t = (s_2 - s_1) / (t_2 - t_1) \approx v_{1.5} . \tag{5}$$

And the average acceleration is given by:

$$a_{avg} = \Delta v / \Delta t = (v_{2.5} - v_{1.5}) / (t_{2.5} - t_{1.5}) \approx a_2 . \tag{6}$$

PROCEDURE:

1. Connect the synchronous timer to the two posts on the board attached to the desk. Turn on the timer (left switch) to allow it to warm up. The high voltage is not on until the other switch (right side) is also turned on. Do not touch the wires or terminals when this switch is on.
2. Cut off a piece of tape about one meter long. Attach the weighted clip and feed the tape up between the two wires.

3. One partner should stand on a stool to hold the tape while the other turns on the high voltage. As soon as the high voltage is turned on, the person on the stool should drop the tape. This will leave a trace of the falling object by means of dots on the tape. There are two set-ups. Groups will take turns. If you are the last group, turn off the timer.
4. While the dots are spaced at intervals of 1/60 second, calculations will be made on the basis of 1/30 second. Starting with a dot that is several centimeters from the first dot, mark every other dot by circling it. Label these dots 1, 2, 3, etc. You can use the table on the last page to record your measurements.
5. Lay the tape out flat and place the meter stick edgewise on the tape. Why? Do not place the end of the meter stick on the first dot, but use some position such as the 10 cm mark. Why? Record the positions and times in the table on the last page under the Raw Data heading.
6. Determine Δs, the distance between each pair of dots. Note that Δt, the time between dots, is always 1/30 sec. Record these values in the table under the Calculated Data for Velocity heading between every two consecutive dots.
7. Calculate the average velocity during each interval according to Eq. (5). Note that the average velocity is equal to the instantaneous velocity at the MIDPOINT in time for that interval if the acceleration is constant. Indicate this by recording this velocity between dot numbers just as you did for Δs and Δt above. Also, calculate the midpoints of the time intervals and record these in the time column next to the average velocity values. You will plot the average velocities versus these times in Graph 1.
8. Find the changes in velocity, Δv, from one velocity to the next and record these between the v values under the Calculated Data for Acceleration heading. Note that Δt, the time between two consecutive average velocity times, is again always 1/30 sec. Record the Δt values in the column to the right of the Δv values.
9. From the Δv and Δt values, calculate the values of the acceleration using Eq.(6) and record them.
10. Take the average of all the accelerations.
11. Using 980 cm/(sec^2) as the correct value for g, determine the percent error.
12. Look over your experimental procedure and determine the major sources of uncertainty that might explain your error.

GRAPH #1: *v* versus *t*

1. Graph v vs t using your data from the sixth and seventh column of the Data Table. Be sure to label your axes and include units. (**Be careful**. The v's you have calculated are for the times *between* dots, not the times at the dots! Your data and graph should reflect this fact.)
2. Now draw the best straight line through these points. For constant acceleration we know that: $v = v_o + at$. Thus, the slope of the v vs t line should be the acceleration. Find the slope of this line. To do this find the coordinates of a point on the line near the upper end of the line, and of another near the lower end of the line. Both points should be on the line even if they are not actual data points. Divide the rise (Δv) by the run (Δt). Remember, the slope has UNITS, and those units should be those of acceleration! Record this on the graph along with the percent difference between this slope and the accepted value of g.
3. Also determine v_o from your graph (v_o is the v-intercept).
4. Finally, determine the time at which the motion actually started, that is, determine t_o, the time when $v = 0$. This should be a negative time.

GRAPH #2: *s* versus *t*

1. Graph *s* vs. *t* using your raw data. According to Eq. (4), *s* is a function of *t*, but not a linear one. Thus, this graph should not be a straight line. In analysis, it is difficult to determine the precise function unless we have a straight line. (In the next part we will try to get a linear function of some power of *t*.) According to Eq. (4), this second graph should be a parabola. Does it look like it might be?
2. The slope of this curve at any point is *ds*/*dt*, which we recognize as the velocity at that time. Choose one of the recorded points and draw a tangent to the curve. Determine the slope of this tangent line (which is also the slope of the curve at that point) and compare with the calculated velocity at that point (from the table). Again, be careful - your calculated velocities are between points. Record this comparison on the graph.

GRAPH #3: *s* versus T^2

1. Since theory (Eq. (4)) predicts $s = s_o + v_o t + \frac{1}{2}at^2$, we should get a straight line if we plot *s* vs t^2 only if v_o is zero. Recall that it is not zero! However, by uniformly shifting our time values by the amount of t_o determined in Graph #1, we can make the velocity of zero correspond to the time of zero. We symbolize the shifted times with upper case *T* where

$$T = t - t_o \tag{7}$$

Calculate *T* and then T^2, and record these values on your data sheet.
2. On a third sheet of graph paper, <u>graph *s* versus T^2</u>. Since v_o is now zero ($v = 0$ for $T = 0$), you should get a straight line, confirming Eq. (4).
3. Find the slope of this line. What should the slope equal? (HINT: consider Eq. (4) with $v_o = 0$.) Compare your slope to this expected value.

<u>REPORT:</u>

In your report, include the data table and your graphs. Comment on what your graphs say (answer the questions in each of the parts above). Do they agree with the theory? Finally, include an analysis of experimental uncertainty and the resulting error. In particular, consider how your graphs both show and compensate for the uncertainties.

DATA TABLES

RAW DATA			CALCULATED DATA FOR VELOCITY				CALCULATED DATA FOR ACCELERATION		
Dot #	***t*** ( )	***s*** ( )	**Δ*s*** ( )	**Δ*t*** ( )	***v*** ( )	***t*** ( )	**Δ*v*** ( )	**Δ*t*** ( )	***a*** ( )
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									

Average *a* ____________

For Graph #3

Dot #	*t* ( )	*s* ( )	*T* ( )	T^2 ( )
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				