EXPERIMENT 2
ACCELERATION DUE TO GRAVITY

I. THEORY

The purpose of this experiment is to measure the acceleration of a freely falling object.

The mathematician and physicist Galileo Galilei defined the concept of acceleration, the rate of change of velocity with respect to time. He also performed experiments with spheres rolling down inclined planes. In his experiments he discovered that the acceleration of a dense rolling sphere is independent of its mass. He further deduced that all dense objects in free fall would have the same acceleration, which we now call the acceleration due to gravity. This acceleration varies from point-to-point on the earth's surface, depending mainly on the distance to the earth's center. The value at our location is close to 9.80 m/s^2.

The principal apparatus for this experiment is a vertical stand with an electromagnet at the top for holding and then releasing the falling body, called the plummet. The plummet falls between two vertical wires which are only slightly further apart than the maximum diameter of the plummet. A spark timer applies a high voltage across the two wires at uniform intervals of 1/60 s. The resulting spark jumps the gaps between the plummet and the wires, passing through a strip of heat-sensitive paper. The spark leaves a visible mark on paper.

We will measure the distances between successive marks on the paper. Knowing the time interval between sparks, we can calculate a set of average velocities for the plummet, using the definition

$$\bar{v} \equiv \frac{\Delta x}{\Delta t} \ .$$

It can be shown that the average velocity during any time interval is equal to the instantaneous velocity at the midpoint in time (not in distance) of the interval, provided that the acceleration is constant during the time interval. The set of average velocities described above may then be treated as a set of instantaneous velocities. Once velocities are known at definite times, we can find the average acceleration by using the definition

$$\bar{a} \equiv \frac{\Delta v}{\Delta t} \ .$$

When acceleration is constant, the following equations may be used:

$$v = v_0 + at$$
$$v^2 = v_0^2 + 2a(x - x_0).$$

II. LABORATORY PROCEDURE

Note: The free-fall apparatus should not be moved, as that would disturb its vertical alignment.

All of the electrical connections will be made by the instructor before you begin.

1. Hang the plummet (pointed end upward) from the electromagnet, and stop it from swinging; it should be very still before being dropped, so that it will have no horizontal velocity when released.

2. Check that an unused piece of spark-sensitive paper is in the proper position and under a slight tension. The paper should be centered on the apparatus and should not have any wrinkles or bends.

3. Make sure the spark timer is set to 60 Hz. Turn the spark timer power switch on and allow about 30 seconds for to warm-up.

4. Make sure that you are not touching a high voltage wire or terminal; then push the red button on the cable attached to the spark timer and hold it on. Turn the electromagnet off, so that the plummet falls. Release the red button only after the plummet strikes the catching device.

5. Turn the spark timer power switch off. Unclip the paper tape at the back of the apparatus and pull the paper through until you have the full portion with spark dots. Tear off the section you have used. Clip the end of the paper tape to the clip. The tape should be ready for the next group to use.

6. Examine the pattern of spark dots. The spacing should increase <u>uniformly</u> from one end to the other. Mark on the tape any missing dots, and also any false or double dots. You will not be able to use any portion of the tape with missing or false dots. Choose 12 consecutive dots near the end of the paper tape where the dots are farther apart. Circle the chosen dots. It is preferable to have large distances between the dots so that the relative uncertainty in your distance measurements is minimized.

7. Label the last of your selected dots 11. Label the remaining dots 10 through 0. Of your selected dots, 0 and 1 should be closest together, 10 and 11 should be farthest apart.

8. Use a vernier caliper to measure the distances between consecutive labeled dots to the nearest 0.01 cm. Record these measurements in a table. Add the 11 distances together and record the sum. This should be the distance between dot 0 and dot 11.

9. As a check on the preceding measurements, use a meter stick to measure directly the distance between dot 0 and dot 11. Place the stick on edge to avoid parallax error. Record the distance. If this distance is more than 0.5 cm different than the sum calculated above, repeat all of the distance measurements in step 8. Record the new measurements in a new column in your table.

III. CALCULATIONS AND ANALYSIS

1. Make a table with columns labeled: time, position, velocity, and velocity squared. We will choose time to be zero when dot 0 was made and dot 0 to be the origin for position. For the time column, record the time at which each dot was made. For the position column, calculate and record the position of the plummet when each dot was made.

2. Using the distance between dot 0 and dot 2, calculate the average velocity during the time interval between when dot 0 was made and when dot 2 was made. Record this as the velocity of the plummet when dot 1 was made. Square this value and record it in the velocity squared column.

3. Repeat step 2 to determine the velocity and velocity squared of the plummet when dots 2, 3, 4, 5, 6, 7, 8, 9, and 10 were made.

4. Calculate the average change in velocity per 1/60 s interval of time by applying the Method of Differences (as defined in the Introduction section of the lab manual) to the velocities in the table. Use this value and the definition of average acceleration to calculate the acceleration of the plummet. Find the percent error using 9.80 m/s² as the standard value for the acceleration due to gravity.

5. Plot a graph of velocity versus time, with time on the horizontal axis. Use 1/60 s as the unit for the time axis, so that the plotted points coincide with 1(1/60 s), 2(1/60 s), 3(1/60 s), … Does the data appear to fall along a straight line? Does this support our assumption that the acceleration was constant? If so, how? Use a straightedge to draw the straight line which best represents the plotted points (do not connect data points). Calculate the slope of this line to three significant figures. Find the percent error of your slope using the standard value of the acceleration due to gravity (9.80 m/s²).

6. The best fit line drawn on the velocity versus time graph should not pass through the origin. Using the best fit line, determine the velocity of the plummet when it passed dot 0. Using this velocity and the slope of your best fit line, determine the time elapsed between the release of the plummet and when dot 0 was made. Also, determine the distance the plummet fell before dot 0 was made. Does this distance seem reasonable?

7. Plot a graph of velocity squared versus position, with position on the horizontal axis. Use a straightedge to draw the straight line which best represents the plotted points. Calculate the slope of this line to three significant figures. How is this slope related to the acceleration of the plummet? Explain. From your slope calculate the acceleration of the plummet and find the percent error.

8. Plot a graph of position versus time. Draw a smooth curve which passes near or through all of the data points. Choose two points well separated on the smooth curve (not data points). For each point, draw a line tangent to the curve passing through the point. Each line should extend at least 10 cm across the paper. Calculate the slope of each tangent line to three significant figures. What is the physical interpretation of these slopes? From the slopes calculate the acceleration of the plummet and find the percent error.

9. You have used four methods for calculating the acceleration of the plummet. Which yielded a result the quickest? Which required the most work? Which is most likely to have large error? Explain what information can be gained from a graphical method that is not provided by the Method of Differences.