Free fall

Objectives

Acceleration is the rate at which the velocity of an object changes over time. An object's acceleration is the result of the sum of all the forces acting on the object, as described by Newton's second law. Under ideal circumstances, gravity is the only force acting on a freely falling object. In this lab, you will measure the displacement of a freely falling object, calculate the average velocity of a falling object at set time intervals, and calculate the object's acceleration due to gravity. The objectives of this experiment are as follows:

1. to measure the displacement of a freely falling object,
2. to test the hypothesis that the acceleration of a freely falling object is uniform,
3. to calculate the uniform acceleration of a falling object due to gravity, g.

Theory

The instant when the ball is released is considered to be the initial time $t = 0$. The position of the ball along the ruler is described by the variable y. The position of the ball at a time t is given by

$$y(t) = y_0 + v_0 t + \frac{1}{2} g t^2. \tag{1}$$

If the ball is released from rest, the initial velocity is zero: $v_0 = 0$. Therefore,

$$y(t) = y_0 + \frac{1}{2} g t^2. \tag{2}$$

Accepted values

The acceleration due to gravity varies slightly, depending on the latitude and the height above the earths surface. In this experiment the change in height of the falling object is negligible and can be approximated as 0 km for its entire descent. The acceleration due to gravity at $40°52'21''$ N latitude (the latitude of Lehman College) and 0 km altitude is

$$g = 9.802\,\mathrm{m/s^2}. \tag{3}$$

Apparatus

The setup, depicted in Fig. 1, is composed of the following parts:

- electromagnet,
- steel ball,
- ruler,
- mobile photogate,
- timer,
- power supply,
- paper cup.

The power supply provides an output of 5 V to an electromagnet. When the switch is in the *on* position, the electromagnet can hold the steel ball under it. Once the timer is set to the *off* position, current stops circulating through the electromagnet, and the ball starts falling.

The sudden change in the current circulating through the magnet produces, following Lenz's law, a short current peak that propagates through the red wire in Fig. 1. Part of this wire is placed in parallel to the wire attaching the unused photogate to the timer (blue wire in Fig. 1). The current in the blue wire produces a magnetic field around it. The red wire, when sufficiently close to the blue one, is affected by this magnetic field, which induces a current on it. This current, in the form of a short peak, is interpreted by the timer as an interruption of the photogate, triggering the timer.

Using these principles, the setup allows to have a precise account of the initial time, since the timer starts counting when the ball is released. The second trigger of the timer happens when the ball goes through the photogate. In this moment, the timer stops counting. Therefore, the timer indicates the time (in seconds) it took the ball to go from the top position to the photogate.

Moving the photogate to different heights and measuring the time the ball takes to fall will provide the information necessary to measure the acceleration of gravity.

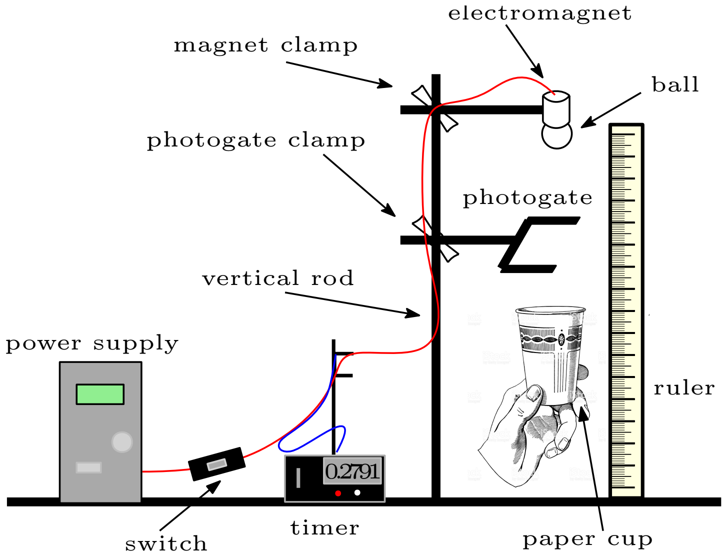

Figure 1: Experimental setup.

Procedure

1. Adjust the top clamp (the one holding the magnet) in such a way that, with the ruler standing on the table, the center of the ball is at about the same height as the zero of the ruler (see Fig. 2);

2. turn on the timer by moving the switch to the *pulse* mode;

3. adjust the height of the bottom clamp (the one holding the photogate) to around 10 cm below the magnet;

4. align the photogate with the electromagnet so that the ball will pass through the photogate while falling. To do so, you can rotate the clamp around the vertical rod, and adjust the photogate along the horizontal rod. To check that the alignment is correct, hold the top of the ruler right below the magnet so that it doesn't touch the table, and make sure that the ruler goes through the photogate (see Fig. 3);

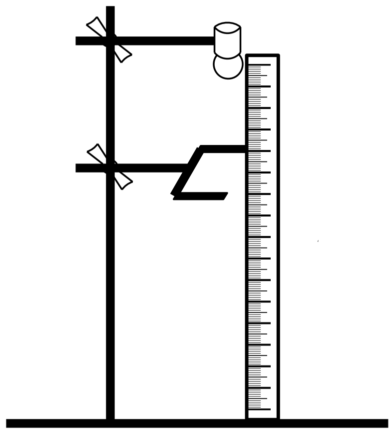

Figure 2: Setup for the magnet holder.

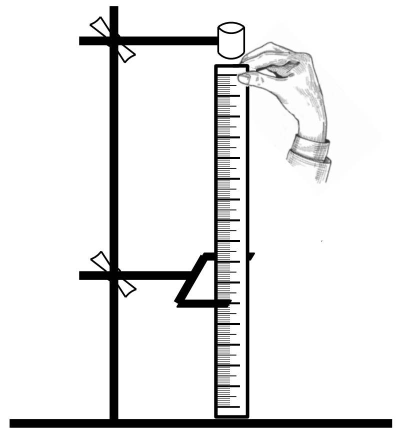

Figure 3: Alignment of the photogate.

5. measure the position of the photogate, and record it on the table as a value for y;

6. switch on the magnet, and place the ball under it, making sure that it remains there;

7. hold a paper cup right below the photogate to catch the ball when it falls;

8. while paying attention to the timer, switch the magnet off. The ball will fall. Three outcomes are possible:

   (a) the timer starts and stops immediately, showing a really small value (like 0.0001). In this case, disregard this value and measure again,

   (b) the timer doesn't start when the magnet is switched off, but it starts later when the ball goes through the photogate. Therefore, the timer keeps running after the ball has fallen. In this case, press reset and measure again,

   (c) the timer starts when the magnet is switched off, and stops when the ball goes through the photogate. In this case, record the time on the table as a value for t;

9. move the photogate to a position around 10 cm below the previous position;

10. measure again: repeat steps 4 to 9 until there is no more space to keep the paper cup under the photogate (around 80 cm).

Troubleshooting

If the timer never starts when the switch is changed to the *off* position, it could be due to several reasons. First, check that when it is in the *on* position, the electromagnet is able to hold the ball. If this is not the case, it is possible that there is a short in the circuit. Turn the power supply off and ask your instructor for help. If the magnet is able to hold the ball, but the timer doesn't start when switched off, a possible solution is to connect the red and black power cables to the front of the power supply, rather than to the back, and selecting a bit higher voltage (around 6 V).

Data

y ( )	t ( )	t^2 ( )

Calculations and analysis

1. Fill in the right column of the data table calculating the square of each time value. For simplicity, you can do this on a spreadsheet computer software;

2. using a spreadsheet software (preferable), or using plotting paper according to the methods described on page 6 of the lab manual, make a distance-time squared plot of the points in the second and third columns of the table. Assign distance (y) to the vertical axis, and time squared (t^2) to the horizontal axis;

3. make a fit of the plotted data to a straight line using either the spreadsheet software or a straight edge (as described on page 6 of the lab manual);

4. find the slope and the intercept of the best fit straight line. A general straight line is given by
$$y = ax + b,$$
where a is the slope and b the intercept. Comparing this equation to (2) find y_0 and g from the slope and the intercept of the fit;

5. calculate the percent difference between the value you obtained for g and the accepted value (3);

6. describe the meaning of y_0 and whether or not the value you obtained matches your expectations.