Free-Fall Acceleration

Objective

To determine the acceleration due to gravity.

Introduction

The position y of a particle moving along a straight line with a constant acceleration a is given by the following equation

$$\boldsymbol{y - y_0 = \tfrac{1}{2}\, a\, t^2 + v_0\, t} \qquad (1)$$

where t is time, y_0 and v_0 are the position and speed at $t = 0$, respectively. In this experiment, you will find the free-fall acceleration by measuring the displacement of an object as a function of time.

A freely falling object is an object moving under the influence of gravitational force alone. It has a constant acceleration called free-fall acceleration. This acceleration is directed downward and its magnitude is denoted by g. The accepted value of g is 9.80 m/s^2.

If there is another constant force, such as tension force, acting on the object in addition to the gravitational force then the acceleration of the object will be different from the free-fall acceleration.

You will determine the acceleration of a freely falling object and an object moving under the influence of tension and gravitational forces.

Freely falling object experimental set-up

Caution: Do not touch the high-voltage wire while the spark timer is in operation.
If you need help ask the lab technician or your instructor to assist you in collecting data.

Figure 1 shows the apparatus that you will use for measuring acceleration. An electromagnet is used to hold and release the object. The electromagnet acts like a magnet only when there is electricity passes through it. If the electricity is switched off, the object is released. While the object is falling it passes between two vertical thin wires. A waxed tape is mounted just in front of one wire. Pulses of high voltage are applied to the other wire. The metallic part of the object makes the gap between the wires small. As a result, the pulses create sparks that jump from one wire to the other through the metallic part of the object and the waxed tape. When a spark passes through the waxed tape, it makes a spot on the tape. The time between any two successive pulses is the same. In this exercise, you will choose the time interval between any two successive spots on the tape to be 1/60 s by selecting the frequency of the spark timer at 60 Hz.

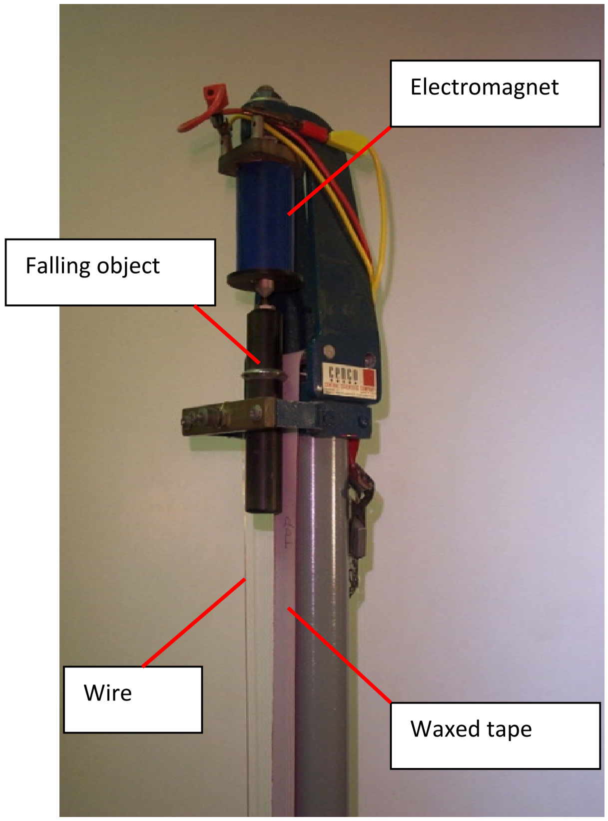


Figure 1: Free-fall Apparatus

Procedure

1. Mount a new tape in place. Later, you need to identify the top of the tape. So write on the top of the tape the word *Top*.

2. Suspend the object from the electromagnet.

3. Make sure the frequency of the spark timer is selected to be 60 Hz. See Figure 2. This means that the time interval between successive spark points is 1/60 s.

4. Switch on the spark timer and start sparking by pressing the trigger switch. Simultaneously release the object by switching off the electricity to the electromagnet. Keep pressing the trigger switch until the object reaches the ground.

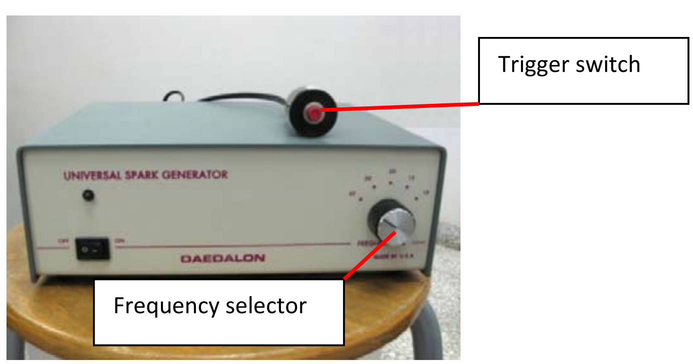
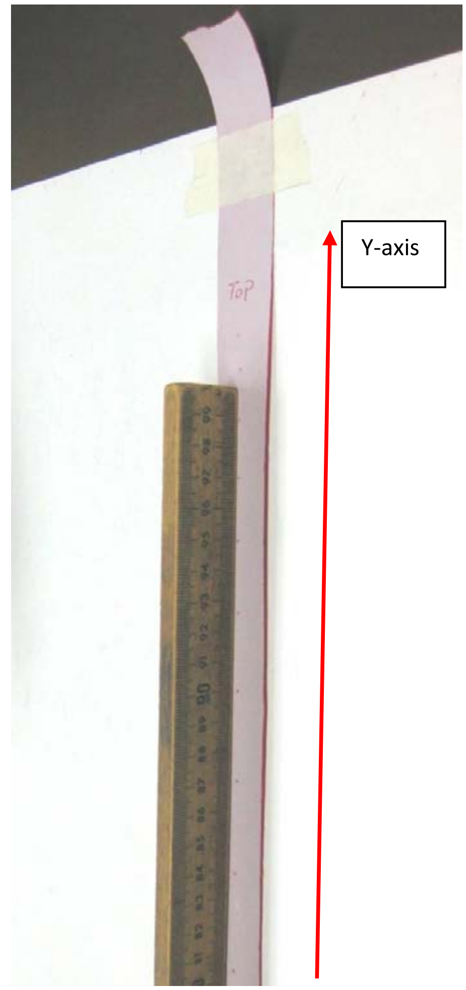


Figure 2: Spark Generator

5. After you have performed the experiment, remove the tape from the apparatus and place it on a table with a ruler as shown in Figure 3. Fasten the tape to the table using sticky tape. Note that the ruler is placed such that the numbers are decreasing towards the bottom of the tape. This is because the positive y-axis is taken along the upward direction.

   It is possible that the object remained with the magnet for a very brief moment before falling, after the first spot is made on the tape. In that case the distance between the first and the second spots would be shorter than what it should be. Therefore, it is advisable to avoid the first few spots especially if you see any irregularities in them.

   Note that the position y_0 for the spot where you choose t = 0 does not have to be at 97.00 cm.



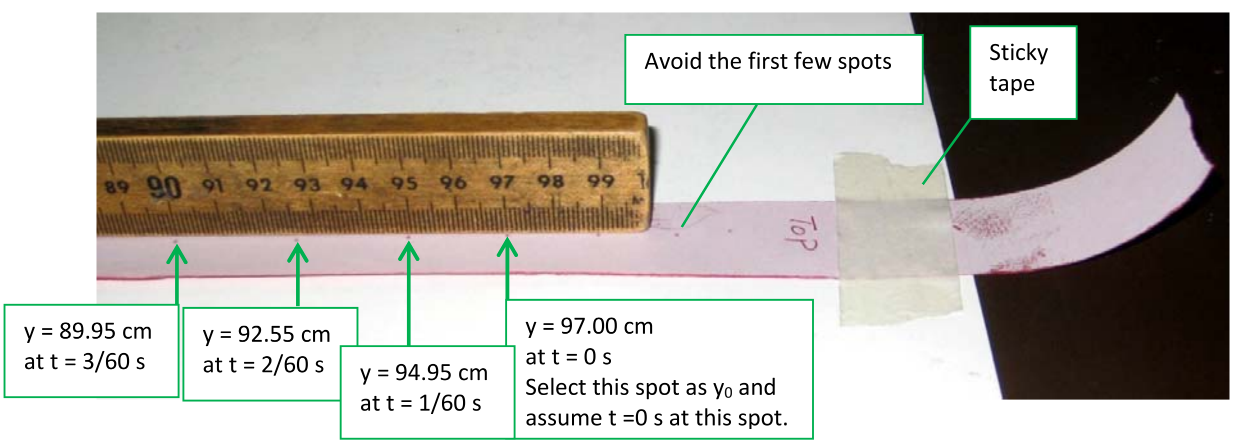


Figure 3: Data collection explained

6. When you take the readings, look at the reading straight on to avoid any parallax error (see Figure 4). This is also the reason why the meter scale is kept standing on its edge than lying flat; to minimize parallax error.

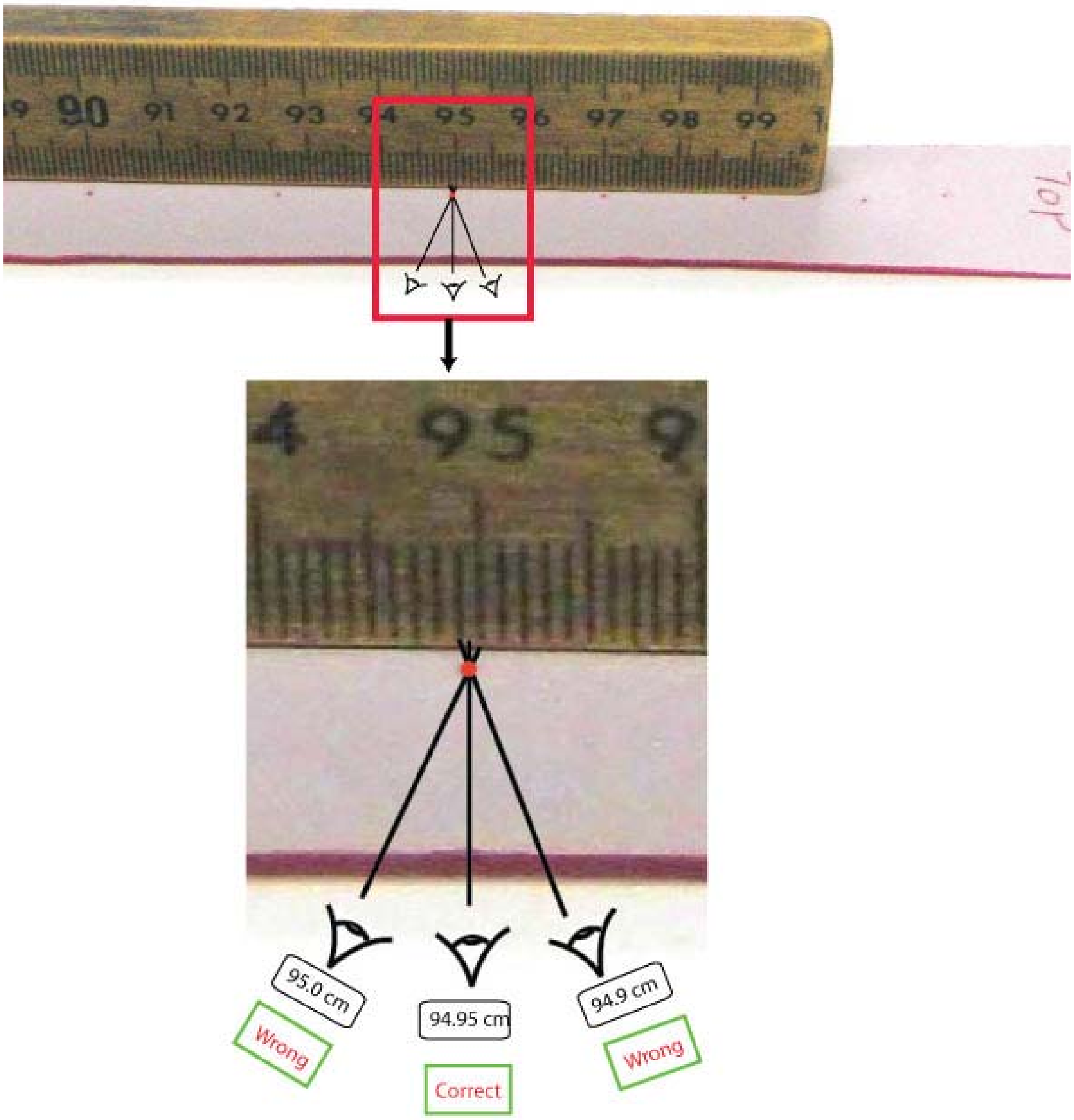


Figure 4: Parallax error explained

7. Record the chosen value of y_0 at t = 0 in your notebook (see Figure 3).
8. Measure the position of the spot at t=1/60 and record it. Remember that you have set the time interval between any two successive spark spots to be 1/60 s.
9. Continue entering the position values for t=3/60, t =5/60 and so on (odd multiples of 1/60 **ONLY**). Make sure to use cm-scale of the ruler, not inch-scale. For the example in the figure, at t = 0, y = 0.9700 m; t = 1/60 s, y = 0.9495 m; t = 2/60 s, y = 0.9255 m; t = 3/60 s, y = 0.8995 m and so on. Take at least **10** points. Write the values of y, in units of meters. Note the values of y should be decreasing.

10. A table for your data will look like the following:

t (s)	y (m)
0	$y_0 = ?$
1/60	
3/60	
5/60	
7/60	

Data Analysis

In order to get the acceleration $\boldsymbol{a}$, you need to plot the data so that you get a straight line. You can do this by redefining your variables. The redefined variables should make the original equation looks like that of a straight line

$$Y = m\,X + b.$$

Here, Y is the variable plotted on the vertical axis and X is the variable plotted on the horizontal axis. The constant *m* is the slope and the constant b is the y-intercept (recall Lab 1-Graphing).

If you divide the original equation, $\boldsymbol{y - y_0 = ½\, a\, t^2 + v_0\, t}$, by $\boldsymbol{t}$ you will get

$$\boldsymbol{\frac{y - y_0}{t} = ½\, a\, t + v_0}$$

So you need to plot $\boldsymbol{\frac{y-y_0}{t}}$ on the vertical axis and *t* on the horizontal axis. Then the slope will be ½ $\boldsymbol{a}$ and the y-intercept will be $\boldsymbol{v_0}$. This equation forms the basis for the data analysis for this exercise.

1. Now, your table of data will be as follows:

t (s)	y (m)	$(y-y_0)/t$
0	$y_0 = ?$	Empty
1/60		
3/60		
5/60		
7/60		

2. Calculate $\boldsymbol{\frac{y-y_0}{t}}$ and plug it in the 3rd column**.** Remember that y_0 is the position at time $t = 0$. Note, for the 1st data point you are dividing 0 by 0. Leave the cell empty for this data point.
3. Plot $\boldsymbol{\frac{y-y_0}{t}}$ versus *t* in your notebook. (*Hint*: you may take 1/60 as a common factor for the time axis. This will make your life much simpler). The best straight line is the one that passes through most of your points.
4. Find the slope of the straight line, and then calculate *a*.
5. From the y-intercept, find v_0.

6. To get a good estimate of the accepted value for the acceleration due gravity in Dhahran, you may use the formula (discussed in Chapter 13 of your Physics textbook)

$$a_g = \frac{GM_e}{r^2}$$

Where,

G	is the gravitational constant = 6.67 x 10^{-11} Nm^2/kg^2
M_e	is the mass of Earth = 5.98 x 10^{24} kg
r	is the distance from your location to the center of Earth ≈ 6370 km = (6.37 x 10^6 m)

7. Calculate the percent difference between your measured value and the accepted value using:

$$\textbf{Percent difference} = \left|\frac{\textbf{Measured value} - \textbf{Accepted value}}{\textbf{Accepted value}}\right| \times \mathbf{100}$$

8. How well does your measured value agree with the accepted value?
9. Calculate the final speed of the object just before it hits the ground?
10. Calculate the total time of flight (from beginning to hitting the ground)?
11. Describe the speed of the object during its motion (is it constant, increasing or decreasing?).
12. Describe the acceleration of the object during its motion (is it constant, increasing or decreasing?).
13. Describe the distance travelled by the object during every second of its motion (is it the same, increasing or decreasing?).
14. List few sources of error in your experiment.
15. Write a conclusion.