Constant Acceleration

Objective

To determine the acceleration of objects moving along a straight line with constant acceleration.

Introduction

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

$$y - y_0 = ½\, a\, t^2 + v_0\, t$$

where *t* is time, y_0 and v_0 are the position and speed at *t* = 0, respectively. In this lab, you will find the 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.

Exercise 1 – Freely falling object

Caution: Do not touch the high-voltage wire while the spark timer is operational !
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.

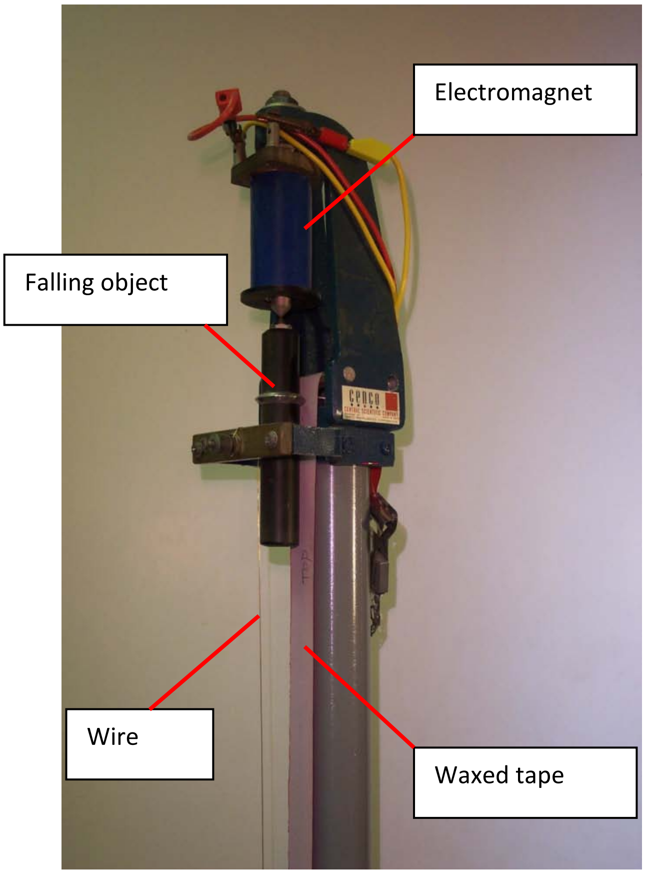


Figure 1: Free-fall Apparatus

Collecting data

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.

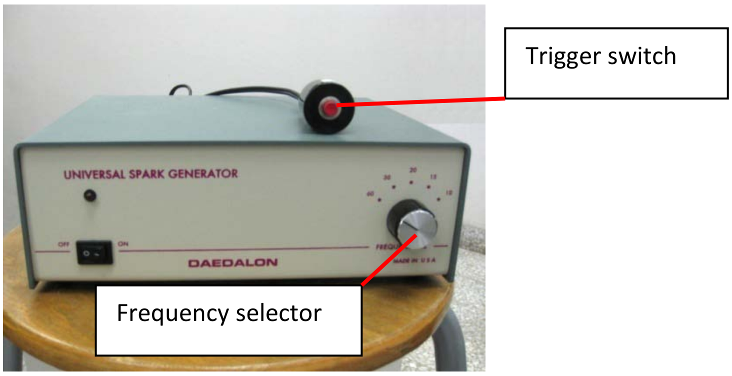
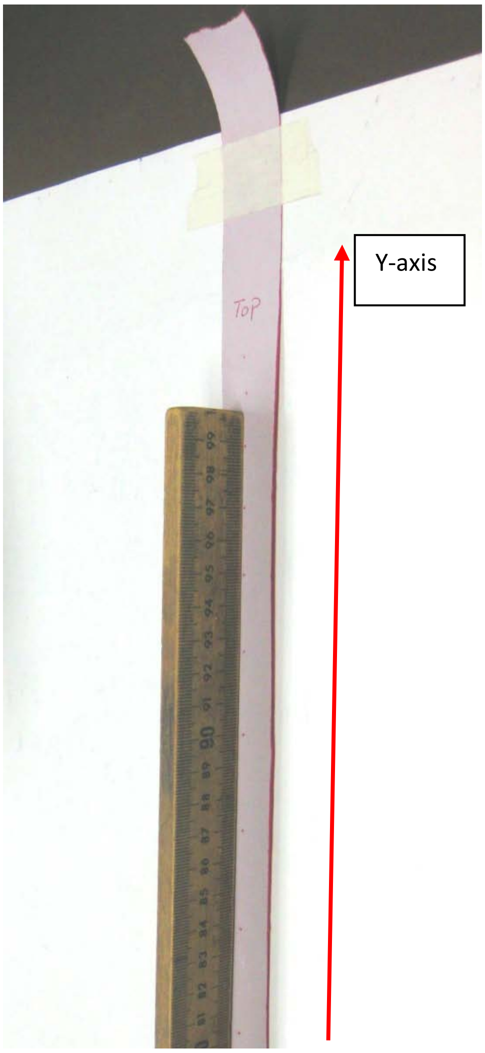


Figure 2: Spark Generator

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.



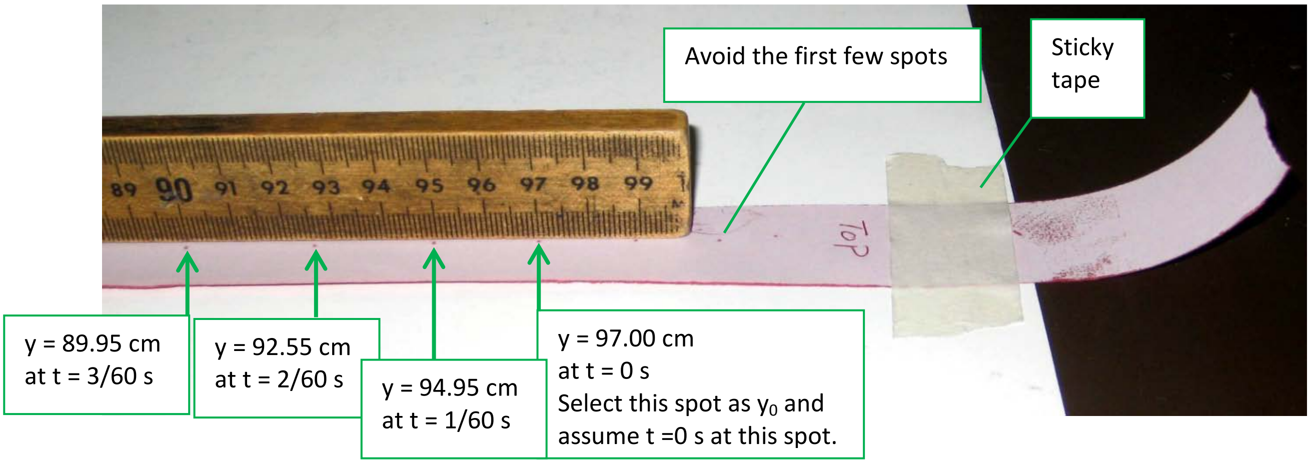


Figure 3: Data collection explained

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.

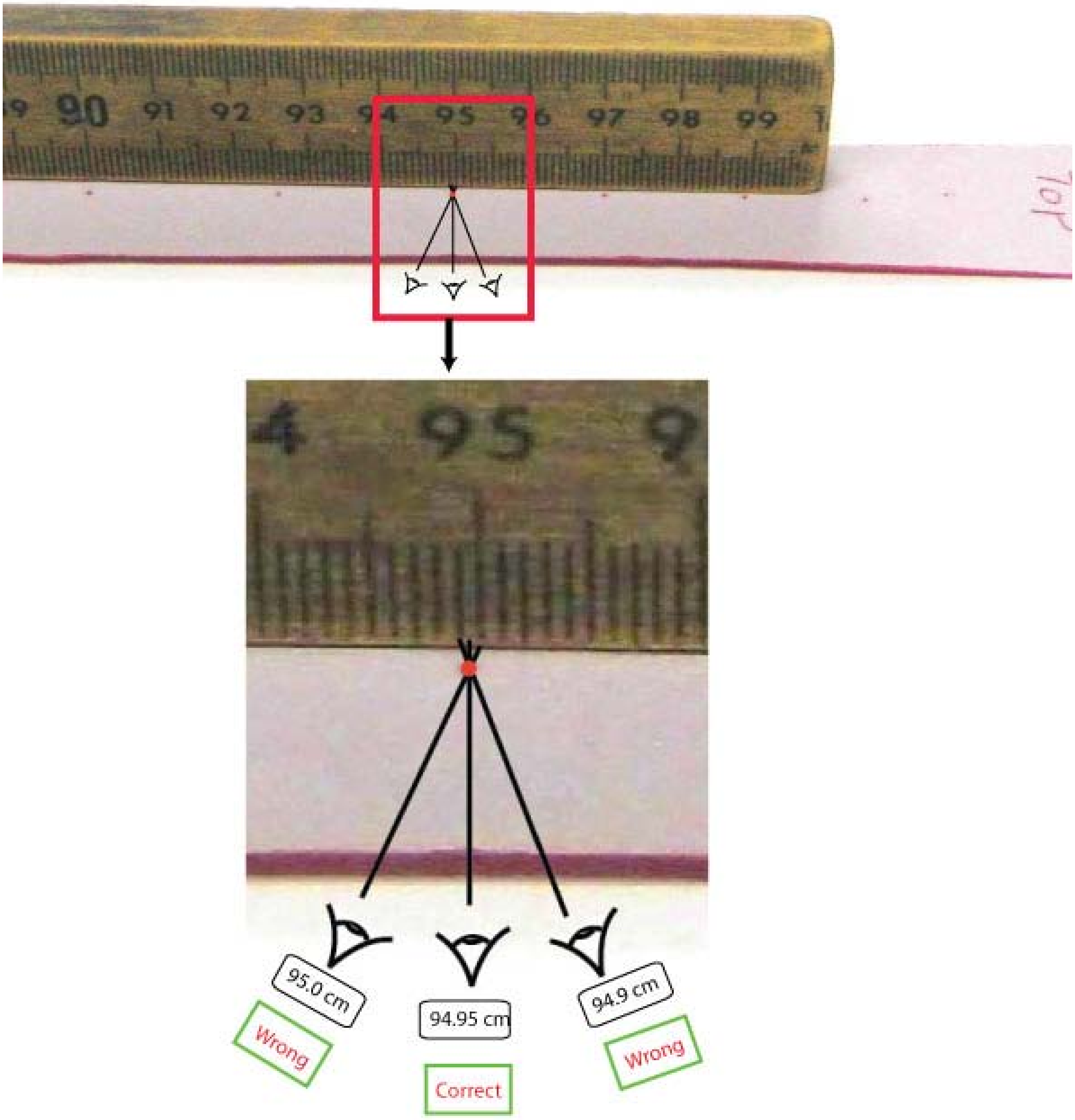


Figure 4: Parallax error explained

7. Open Microsoft EXCEL and enter 0 in cell A2 and the corresponding first y value in meters in cell B2.

8. In cell A3, write this formula: **=A2+1/60** and press the **Enter** key. Remember that you have set the time interval between any two successive spark spots to be 1/60 s. In cell B3, measure the position of the spot at t=1/60 and record it.

9. To write the other values of *t*, click on cell A3 and use the left mouse button to press on the small square at the lower right corner of the cell and drag it down to as many cells as you have data for. This will add 1/60 to the value of the previous cell. See Figure 5.

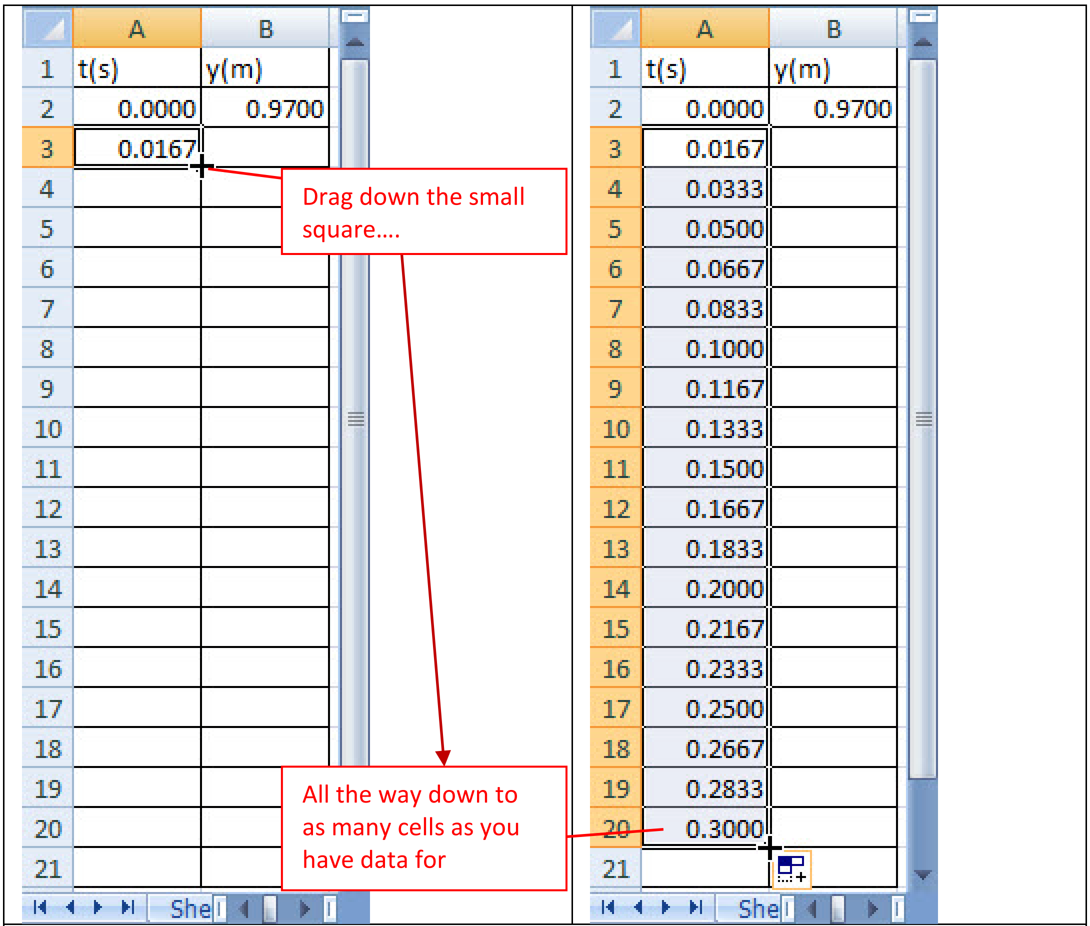


Figure 5

10. Continue entering the position values for t=2/60, t =3/60 and so on. 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 15 points. Write the values of y, in units of meters, that you recorded from the tape in column B. Note the values should be decreasing.

11. Copy the entire table and paste it in your report as a Microsoft Excel Worksheet Object. To do this: click **Paste** in the Home Tab → **Paste Special..** → Choose **Paste** As **Microsoft Excel Worksheet Object** and click **OK**.

Analyzing Data

You will determine the acceleration by plotting *y* versus *t*, and fitting the curve to a parabola. Plotting *y* versus *t* means that you need to plot *y* on the vertical axis and *t* on the horizontal axis.

1. To plot, select the data with the heading, click on ***Insert*** tab, then in the ***Chart*** group click on ***Scatter*** button and choose the first option as you did in Lab 2-Graphing. Then in the ***Chart Layouts*** group choose Layout 1. Change the chart title to *Exercise 1*, x-

axis title to *t (s)* and y-axis title to *y (m)*. Add gridlines to the x-axis by right clicking on the x-axis numbers and choose ***Add Major Gridlines***.

2. To fit your data to a parabola, right click on the data points in your plot and choose ***Add Trendline***. Select ***Polynomial*** with order 2, tick ***Display Equation on chart*** and close the ***Format Trendline*** window. Your graph will look like Figure 6 (the numbers of your trendline equation may be different).

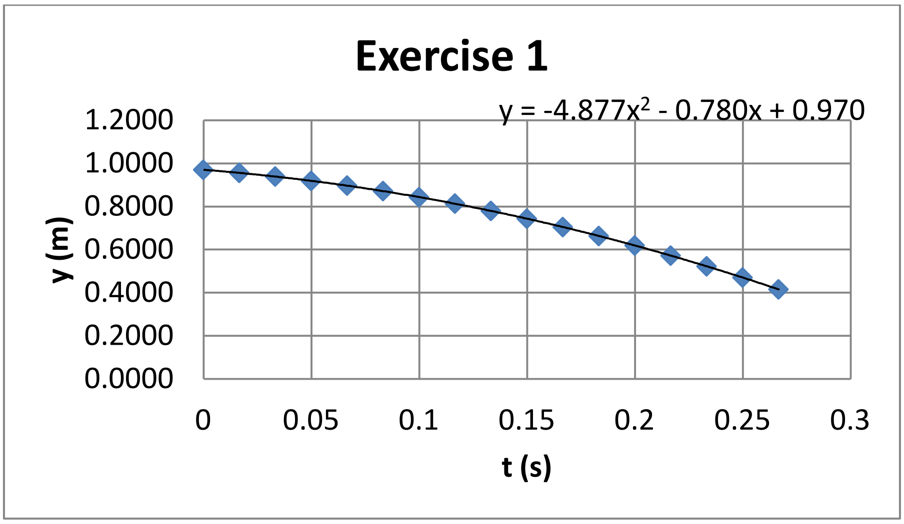


Figure 6: An example of polynomial fit

3. You can determine the acceleration *a* by comparing

$$y = \tfrac{1}{2} a t^2 + v_0 t + y_0$$

with the Trendline equation

$$y = -4.877\,x^2 - 0.780\,x + 0.970$$

Therefore, ½ a = –4.877 or your measured value of a = –9.75 m/s^2.
The negative sign indicates that the free fall acceleration is downwards.

4. The accepted value of free fall acceleration in Dhahran area is -9.80 m/s^2. How well does your measured value (–9.75 m/s^2 in the example) agree with the accepted value? Calculate the percent difference between your measured value and the accepted value using

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

5. <u>Copy your graph and paste it in your report. Also record your values of *a* and the percent difference in your report.</u>

Exercise 2 – Another way of analyzing the data

Another way of getting the acceleration *a* is plotting the data such 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

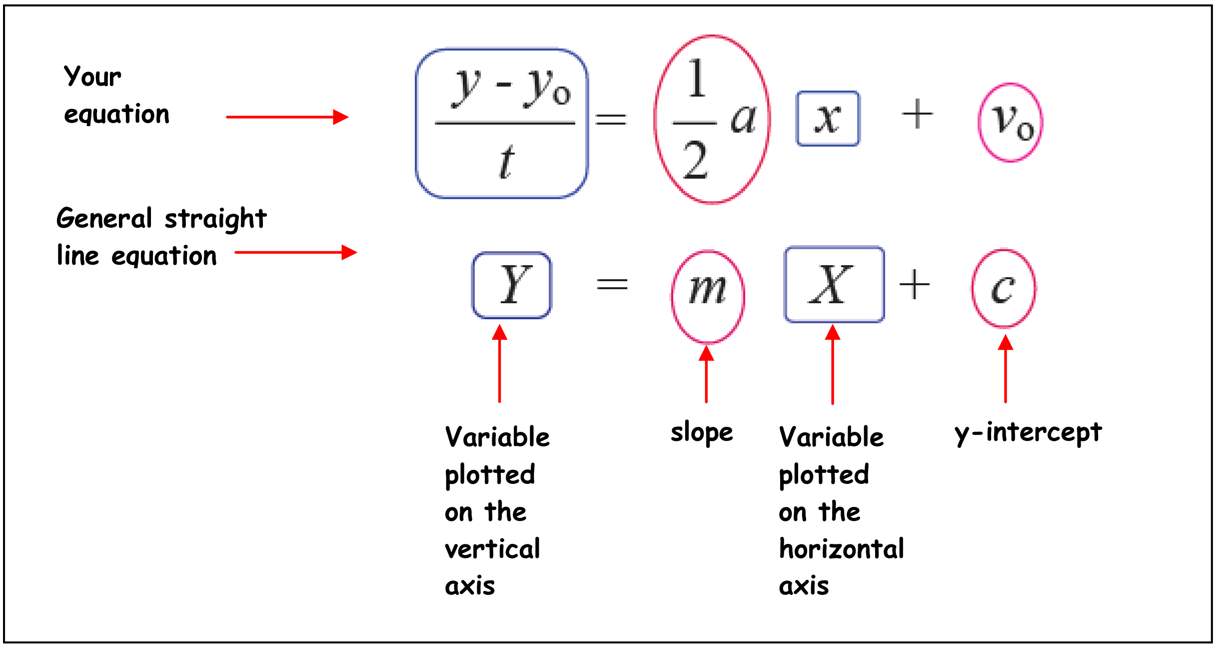
$$Y = m\,X + b.$$

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

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

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



1. In column C of your Excel worksheet of Exercise 1 analysis, calculate $\frac{y-y_0}{t}$. Remember y_0 is the position at time t = 0. That is the value in cell B2. To calculate $\frac{y-y_0}{t}$, type *=(B2-B$2)/A2* in cell C2 and press ***Enter*** on the keyboard. Since y_0 is a fixed value, it needs to be kept as a constant in calculating column C values. This is done by typing *B$2*.

2. To write other values of $\frac{y-y_0}{t}$, click on cell C2 and use the left mouse button to press on the small square at the lower right corner of the cell and drag it down. Note for the first data point you are dividing 0 by 0, and you will get **#DIV/0!**. Remove this and leave the cell empty for this data point.

3. Select only the columns A and C with the help of ***Ctrl*** key on the keyboard and plot $\frac{y-y_0}{t}$ versus *t*, and add linear trendline.

4. From the slope calculate *a*.

5. <u>Copy your graph and paste it in your report. Also record your value of *a* in your report.</u>

Exercise 3 –An object with small net force

In this exercise, you will determine the acceleration of an object moving under the influence of tension and gravitational forces. You do not need to use the electromagnet here. The falling object is connected to a pulley system as shown in shown in Figure 7. The object is no more freely falling as the tension is acting on it in addition to the gravity.

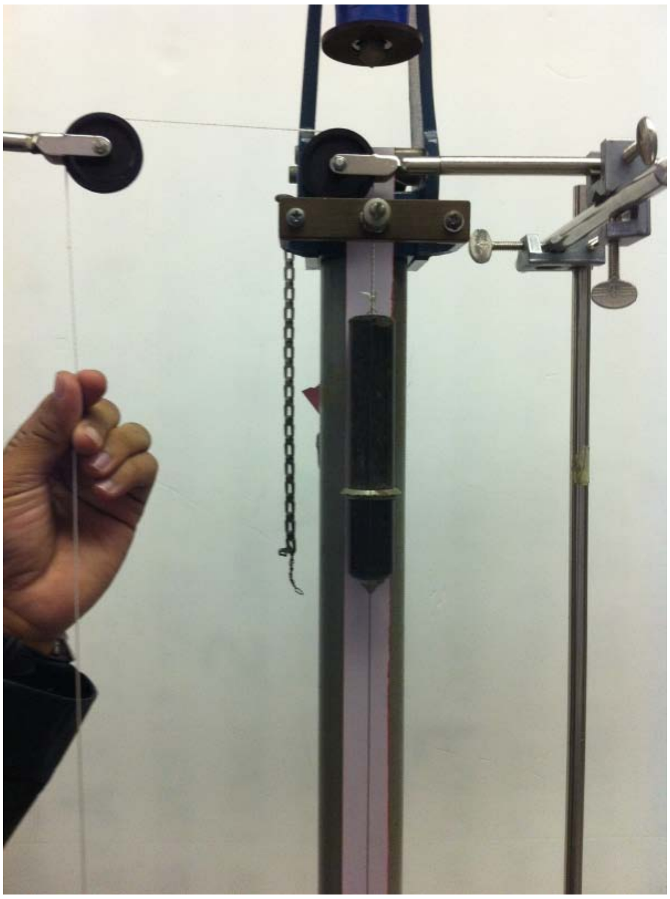


Figure 7: An experimental set up for measuring smaller acceleration

1. Mount a new tape in place and mark its top located near the electromagnet.

2. The masses in the mass holder are already selected for you to be slightly (about 10 g) less than the object so when the string is released it will go down with a smaller acceleration (much less than 9.80 m/s^2).

3. Bring the object to the top (near the electromagnet) and hold the object at the top with your hand.

4. Set the frequency of the spark timer to 10 Hz. This means that the time interval between any two successive spark spots is now 1/10 s. This is because the speed of

the object will be small, and thus the distance between two successive spots will be very small for 1/60 s time interval.

5. Start the spark timer by pressing the trigger switch and immediately release the object from the top. You should NOT release the spark timer trigger switch until the object reaches the bottom.

6. Analyze your data, plot y versus t and determine the acceleration of the object as you did in Exercise 1.

7. Find the ratio of this acceleration with the free-fall acceleration: $|a/g|$.

8. Copy your graph and paste it in your report. Also record your values of a and the ratio $|a/g|$ in your report.

Department of Physics
Dhahran 31261