Measuring the Acceleration Due to Gravity with Free Fall

The acceleration due to gravity depends, in general, on the distance from the gravitational source. If the distance over which an object moves is very small compared to the distance from the source, then that acceleration is approximately constant, and given the symbol $g$. $g$ is not a fundamental constant of nature. It is not even a constant. You will learn later in PHYS 160, that the gravitational force due to the earth on an object with mass number $m$ is

$$F_G = G\frac{mm_{\text{earth}}}{r^2}$$

where $G$ is the universal gravitational constant (a truly fundamental constant) and $r$ is the distance of the object from the center of the earth. You know, or will soon know, that Newton’s Second Law states that $F = ma$. Therefore, the acceleration due to the earth’s gravity is

$$a \equiv g = G\frac{m_{\text{earth}}}{r^2}.$$  

Thus the value of $g$ depends on $r$, and will, for example, be significantly different (approximately 1%) at the top of Mount McKinley from that at the lowest spot in Death Valley, and, because the earth is not a perfect sphere, even more different at the poles as compared to the equator. So, for this and other reasons, it depends very much where you are when you measure this number. Note, $g$, which is not "gravity" but the acceleration due to gravity, does not equal $9.8 \text{ m/s}^2$, which, is fairly close to the value one gets by plugging into Equation 2 the average radius of the earth

$$\bar{r}_{\text{earth}} = 6371 \text{ km}$$

(If you plug in the numbers, you get something around $9.82 \text{ m/s}^2$).

The change in the value of $g$ when rising or falling over a displacement $\Delta r$ near the surface of the earth is

$$\Delta g \approx \frac{\Delta r}{r_{\text{earth}}^3}$$

Over the distance $\Delta r = 1 \text{ m}$, the change in the acceleration due to gravity $\Delta g \approx 4 \times 10^{-21} \text{ m/s}^2$, a change so small as to be insignificant to any measurement you can make. We can therefore safely consider $g$ constant in the region you are performing an experiment.

You know from kinematics, that, when the acceleration is constant,

$$v[t] = v[t_i] + g(t - t_i),$$

where $t_i$ is an initial time, $v[t]$ means velocity at time $t > t_i$, and $v[t_i]$ means the velocity at the initial time.

You will employ equation Equation 3 to determine $g = (\text{average value} \pm \text{standard error of the mean}) \text{ m/s}^2$.

1. Check that the Motion Sensor is set to the correct distance range: look at the top of the sensor and make sure the switch is set to the short-range designation.

2. Make sure that the yellow and black wires are plugged into the (1) and (2) digital channels, respectively, of the interface box.

3. Double click on the Data Studio icon on your computer desktop. Choose Create Experiment. (Note: If the software cannot find the interface box, check that the interface box is powered. If not, turn it on, and restart Data Studio. If it is on, reboot the computer. This will allow the box to be seen by the computer. Do not turn off the interface box at any time, even at the end of the experiment!)

4. Double click on Motion Sensor from the Sensors menu. An icon will appear connected to the interface box image in the experimental setup area. Check that the yellow and black wires of the motion sensor are connected to the interface box as shown in the icon.
5. Double click on the icon. This will bring up a window with a GUI of settings and options. Set the trigger rate to 50 Hz.

6. Notice that the variables Position, Velocity, and Acceleration have appeared in the Data section to the left of the Experiment Setup. Data Studio will calculate all of these for you. Hold a ball about 20 cm below the motion sensor. Click on the Start button on the top of the Data studio screen. When the timer begins, release the ball. Let the ball bounce underneath the position sensor. Press the Stop button when bounces have stopped or the ball is no longer in the range of the sensor. You will want a total of 9 bounces but these may be collected from a number of different trials.

7. To view the data graphically, drag the variable icons and place them on the graph image in the Displays section below the Data section. You should understand each of these graphs. In the velocity vs time graph, for example, you should notice that for each section where the ball is in the air, this graph is a straight line as predicted by Equation 3.

8. Use the mouse to draw a rectangle around the section of your velocity plot where the ball is (certainly) in the air. The selected data will be highlighted in yellow.

9. Use the Fit menu button in the Statistics area of the graph. Select Linear Fit from the Curve Fit menu to display the slope of the selected region of your velocity vs. time plot. The slope of this part of the velocity vs time plot is the acceleration due to gravity during the selected region of motion. Record and repeat for each of your nine bounces.

10. Enter all "g" values in an Excel spreadsheet.

11. Find the average value of g. To do this, select an empty cell and type ‘=AVERAGE(A1:A9)’ assuming that your g values are in cells A1 through A9. If not, simply type in the appropriate range to calculate the average.

12. Calculate the standard deviation for g by selecting an empty cell and typing ‘=STDEV(A1:A9)’. Again, if your data are in a different column and different row range, type the appropriate range values.

13. Calculate the standard error of the mean.

14. What is your result for g?