Summary of the Free Fall Experiment

This is a summary of the web-based document on the Free Fall experiment at:

http://faraday.physics.utoronto.ca/IYearLab/Intros/FreeFall/FreeFall.html.

See that document for the complete discussion. Here we summarise that document in a form suitable for printing.

Equations of Motion

In the absence of air resistance:

$$s = s_0 + v_0 t + \frac{g t^2}{2}$$

where:

s = the position at time t
s_0 = the position at time $t = 0$
v_0 = the speed at time $t = 0$
g = the acceleration due to gravity.

When there is air resistance, it is characterised by a constant α :

$$a_{air\ resistance} = -\alpha v^2$$

Then the equation of motion is approximately:

$$s = s_0 + v_0 t + \frac{(g - \alpha v_0^2) t^2}{2} - \frac{\alpha v_0 (g - \alpha v_0^2) t^3}{3}$$

The Apparatus

- The precision of the metal scale is one part in 4000.
- The accuracy of the timer is within its reading error of 0.05 msec.
- The minimum distance between the suspended object and the *Start Gate* should be about 10 cm.
- The minimum distance between the *Start Gate* and the *Stop Gate* should be about 10 cm.
- The maximum distance between the *Start Gate* and the *Stop Gate* should be the maximum provided by the apparatus.
- You should take 10 or so datapoints for both the streamlined bob and the plastic sphere.

- Make sure that when the streamlined bob is suspended from the magnet that its oscillations have stopped before releasing it.
- Do not tighten the knob that holds the photogates in place too tightly.

Data Analysis

- Putting the data for both the streamlined bob and the plastic sphere into a single dataset is a good idea.
- A good fit has:
  - The *chi-squared* statistic approximately equal to the number of degrees of freedom.
  - Residuals that are randomly distributed about zero.
- A poor fit has:
  - A *chi-squared* much greater than or much less than the number of degrees of freedom.
  - Residuals that show a systematic deviation from zero.
  - One or more fitted parameters that are zero within errors.

Preparatory Questions

1. Call the positions of the two photogates s_1 and s_2.What are the reading errors in these quantities? The distance s is the difference between these two values.
2. What, then, is the error in s in terms of these errors? Now add in the error in the metal scale, 1 part in 4000, in quadrature to give an expression for the total error in s.
3. The accuracy of the timer is within its reading error of 0.05 msec. How can you determine whether the error of precision of your measurements of the time of fall is greater than 0.05 msec? *Hint*: the answer can only be determined by using the apparatus.
4. How can you estimate the speed of the object when it enters the first photogate *before* actually taking any data?
5. When an object is falling through the air, the *terminal speed* is the maximum speed it will reach.The terminal speed of a person is about 50 meters / second, depending on the individual and especially their orientation. What is their value for α as defined in second equation on page 1?
6. If air resistance is not negligible, the third equation on page 1 relates the distance to the time and the coefficient of air resistance α. Meanwhile, if you fit distance versus time to a third-order polynomial, the fit is to:

   $$s = a_0 + a_1 t + a_2 t^2 + a_3 t^3$$

   and the fitter will give values and errors for the coefficients a_1, a_2 and a_3. Write the equations that will allow you to determine v_0 , g and α in terms of a_1, a_2 and a_3.