Experimentally Determining the Rate of Free Fall Through Air

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Abstract

The following experiment examines one of the most fundamental physical constants in the natural world – that of the rate of free fall on Earth. According to the laws of gravitation, all objects from the same height will fall to the surface of the Earth at the same rate, neglecting the forces of air resistance. By measuring the fall rate of two differently shaped objects, the gravitational constant *g* was determined after taking into account the forces of air resistance.

Introduction

The value of *g*, the rate of acceleration due to gravity on Earth, has an accepted value of 9.8 m/s^2.[1] In general, the position *s* of a free falling object at time *t* from an initial position s_0 with an initial velocity v_0 can be described by the following equation:

$$s = s_0 + v_0 t + \frac{gt^2}{2} \qquad (1)$$

However, due to the effects of air resistance, which is a function of the velocity of the falling object given by $a_{air\ resistance} = -\alpha v^2$, where a is the acceleration due to air resistance and α is a constant of air resistance depending on the size and shape of the object, the equation of motion for a free falling object through air is more appropriately described by:

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

The goal of this experiment was to determine both the gravitational constant *g* and examine the effects of air resistance by determining the constant α for two different objects dropped at the same height.

Experimental Method

The laboratory equipment (figure 1) consisted of an upright aluminum track which was over 3 meters tall, with an electromagnet mounted at the top. Two photogates connected to a timer were attached along the track at specific distances to measure the time it took for the objects to fall a specific distance. The electromagnet held the objects – a small plastic ball with a metallic tip and an aerodynamic metal “bob” (see figure 2) – one at a time and released them when the power supply to the electromagnet was cut.

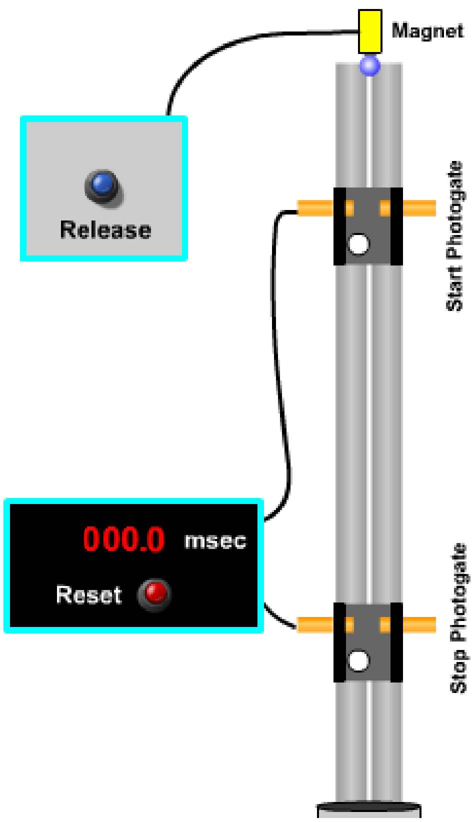

Fig 1: Schematic diagram of experimental apparatus[2]

The distance between the photogates was initially set to 35.0 cm. In each subsequent trial, the distance between the photogates was increased by 15.0 cm. The object in question was dropped through the photogates, and the time interval between the passing of the first gate and the passing of the second gate was recorded. 14 trials of free fall were conducted with the metal bob and the plastic sphere. In each trial, the times for 4 falls were recorded, and subsequently averaged for final analysis.

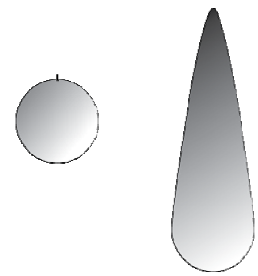

Fig 2: Objects examined in free fall - small plastic hollow ball with metal tip (left) and aerodynamic metal bob (right)

Results

The results from the 14 trials for each object was inputted into the *Faraday Fitter*, and fitted to a 3rd degree polynomial as per equation 2. The resulting graphs are displayed in figure 3. It was observed from the data that the position-time data of the aerodynamically favourable metal bob fit the 3rd degree polynomial better than the data from the plastic sphere. However, both sets of data reported a Chi-squared probability value of well over 99 – indicating a very accurate set of data.

The small difference in accuracy between the two sets of data is likely caused by the relative masses of the two objects. The metal bob was significantly heavier than the hollow plastic sphere. As a result, the sphere is more susceptible to force of air resistance – both from the object going through the air downward and by local crosswinds.

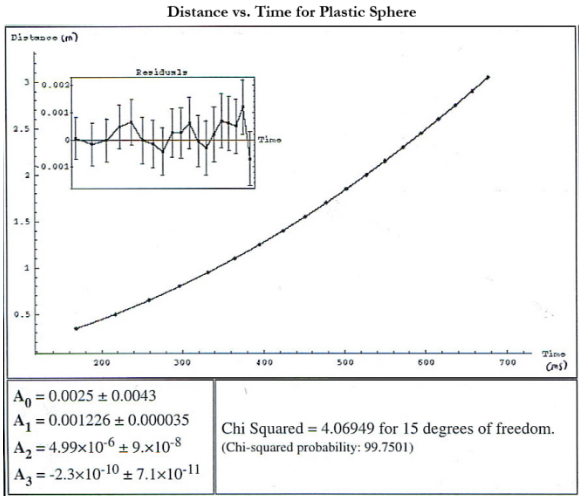

Figure 3a: Distance vs Time graph for plastic sphere

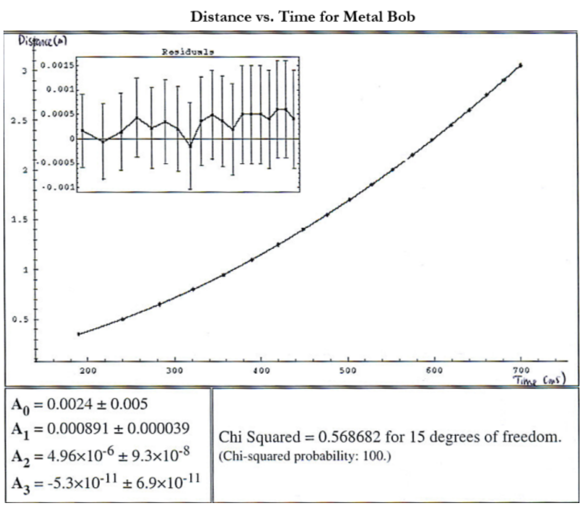

Figure 3b: Distance vs Time graph for metal bob

Using the metal bob, the value of *g* was calculated to be 9.9 ± 0.3 m/s^2. The plastic sphere yielded a result of *g* = 9.9 ± 0.2 m/s^2. The consistent overestimate of *g* may be due to a systematic error in the timing equipment, but is not significant as both values were within range of the theoretical value of *g* = 9.8 m/s^2 after taking into account the calculated experimental error. The air resistance coefficient, α, was found to be -0.02 ± 0.02 m^{-1} for the metal bob – statistically insignificant – and -0.06 ± 0.02 m^{-1} for the plastic sphere. Thus, air resistance had a greater effect on the plastic sphere than the metal bob.

Conclusion

The experiment determined the acceleration due to gravity, using precise photogate timers to measure the time an object took to fall through a specified distance. Results from the experiment concluded that the value of *g*, the gravitational constant for Earth, was 9.9 m/s^2. Taking into account experimental errors, the data from this experiment confirmed the accepted value of 9.8 m/s^2. In addition, the effect of air resistance was measured on two different objects – an aerodynamic metal bob and a small plastic sphere – and it was found that air resistance had a greater effect on the lighter plastic sphere than on the heavier metal bob.

Sources

1. Serway, Raymond A. and John W. Jewett, Jr. *Physics for Scientists and Engineers*. Toronto: Nelson Thomson Learning, 2004.

2. Harrison, David M. "The Free Fall Experiment." University of Toronto Physics. April 2003. <http://faraday.physics.utoronto.ca/IYearLab/Intros/FreeFall/FreeFall.html>.