PHY224

Kater Pendulum Lab

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Purpose:

The acceleration due to gravity on Earth varies by location around the surface, and the purpose of this experiment is to perform careful and precise measurement of the local gravitational acceleration using Kater's pendulum.

Introduction:

One of the advantages of the Kater's pendulum over other pendulum when measuring the acceleration due to gravity at a local point on earth's surface is that the effective length of the pendulum is more definitive in measurement in comparison with that of other pendulums, giving it a more accurate result when measuring the gravitational acceleration. Kater's pendulum's effective length is the distance between the two pivot points when period of oscillation of each of the two pivots points are the same, where for a simple pendulum, on a string, there is an indefinite length of where the "length" is to be measured to and from.

The gravitational acceleration could be calculated as follows:

$$g = (2\pi)^2 \cdot \left(\frac{L}{T^2}\right) \tag{1}$$

Where L is the effective length and T is the period of oscillation

Materials:

- Kater Pendulum
- Count-timer
- Cathetometer

Procedure:

First, the kater pendulum functions were observed in its protective case, so that the large and also all adjustable masses were identified. The pendulum was then hung on a wall that was in line with the eye of a lense attaches to a vertical measurement apparatus, called a cathetometer, and the lense was lined up with the tip of the lower pivot point, and it's length was recorded to the thousandths place with a millimeter divider plate. This process was repeated in measurement of one pivot point, to the bottom of the center mass, and then the other pivot point, to the top of the center mass, as the pendulum was flipped between the first two measurements and the second two. These distances were subtracted for the final determinant pendulum length. Once this length was determined, the pendulum was transferred to its point of oscillation, where both pivot points were oscillated on an oscillation count time of 16 oscillations, while the large mass shifted down the pendulum after each period was recorded for each of the two pivot points with the large mass at a set position on the pendulum. Once the large mass was in a position in which the period of both of the pivot points were close to each other, the small adjustment mass's position was moved, measuring the period of each of the pivot points at each position of the small adjustment mass, and micro-adjusting the mass, with 4-5 position per centimetre movement, recording each period of 16 oscillations. Once the data recording was complete, the data points were plotted on an overlapping linear relationship graph, where the point in which the lines cross is the position of the small adjustment mass such that the periods of both pivot points is equal, given the large adjustment mass is in the same determinant position as when the small adjustment mass changes were introduced (exact locations in "discussion").

Data:

Data for the period of oscillation was stored in 'data.txt' and the data for uncertainty measurement of count-timer was stored in 'uncertainty.txt'.

Discussion:

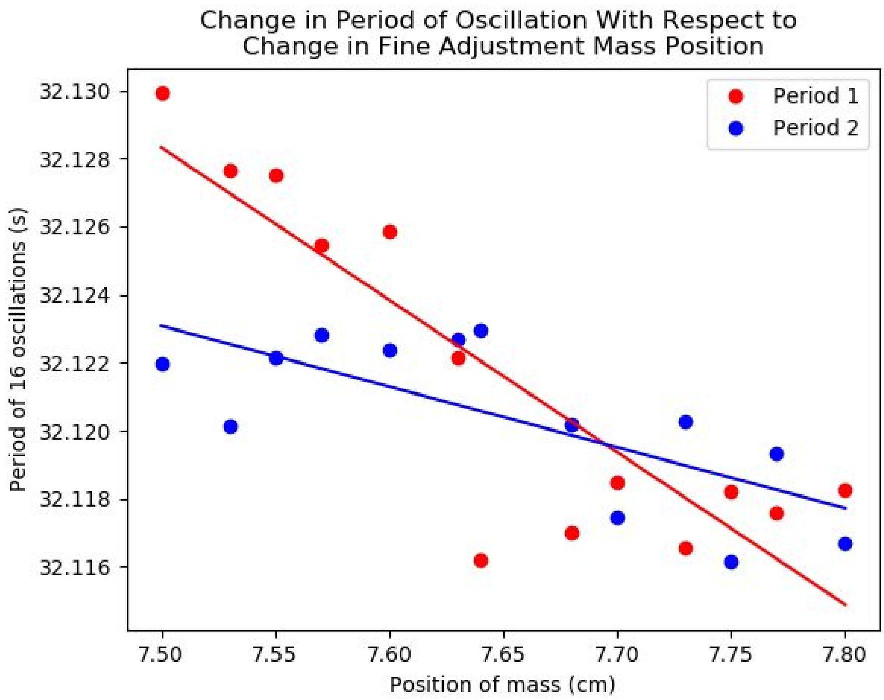

Figure 1: 'Change in period of oscillation with respect to change in fine adjustment mass position'. Period 1 is period with the fixed main mass on the bottom of the pendulum, opposite the pivot point being measured, and period 2 is period with fixed main mass on top, next to the measured pivot point.

On a small scale, the relation between the period of oscillation and position of fine adjustment mass could be approximated as a linear relation. Chi-squared values are 82.02, and 37.50 for period 1 and period 2. These high chi-square values suggest that the linear model is not a good approximation model for this relation, most likely due to the period relation between the different pivot points not being linear, and a higher order polynomial may be a better model. However, error will be small when mass for small mass displacement, so linear model is used.

The line of best fit for period 1 and period 2 are:

$$y_1 = -(0.0448086 \pm 0.0000007)x + (32.46439 \pm 0.00004)$$

$$y_2 = -(0.0178671 \pm 0.0000007)x + (32.25708 \pm 0.00004)$$

The intersection of these two trend-lines means these two periods are the same when the fine-adjustment mass was at the position where the lines crossed, as the fine adjustment mass was the one that was used to scan a region of the kater pendulum where when the large adjustment mass was moved, the period approached equality. The period of intersection is: 32.119±0.002s, therefore, period of one oscillation is 2.0074±0.0001s, as the oscillation count was 16.

Using equation 1, the gravitational constant was calculated as: $9.81 \pm 0.02\ m/s^2$. The literature gravitational value at Toronto is: $9.822\ m/s^2$, fell within experimental result.

(https://www.wolframalpha.com/widgets/view.jsp?id=e856809e0d522d3153e2e7e8ec263bf2)

Length between pivot points and period of oscillation are major contributor to uncertainty. When measuring the length, the length of pendulum exceeds the maximum reading of cathetometer, therefore 3 measurements was taken, one measuring the position of one pivot point, and the other two measuring the position of the adjustment mass with pendulum being hung upright and up-side-down. A magnifying glass was used to minimize uncertainty, and considering human error, error was taken to be 0.05 cm per measurement, therefore 0.15 cm was the error in length measurement.

To measure the error in count-timer, 8 measurements were taken with masses in the same position, and take the standard deviation, it was 0.000116s.

Uncertainty for this experiment can also come from other factors, such as human error in the measurement of length between pivot points, as it was a manual line up of the points of pivot, period of oscillation, air drag, buoyancy of air, and friction at pivot points.

To minimize the effect caused by other factors such as air drag, the pendulum was made to oscillate in one plane, no wobbling.

Using equation 1, the gravitational constant was calculated as: $9.81 \pm 0.02\ m/s^2$. The literature gravitational value at Toronto is: $9.822\ m/s^2$, fell within experimental result.

<u>Conclusion:</u>

The local gravitational acceleration measured with Kater pendulum was $9.81 \pm 0.02\ m/s^2$, and this result confirmed the literature gravitational value at Toronto; $9.822\ m/s^2$. With a slight variation as the acceleration due to gravity on earth is not constant in all local positions on earth's surface, and can be slightly higher or lower relative to altitude, air pressure, and other local position factors. With this, the kater pendulums resulting acceleration due to gravity is more consistent with that of the relative position of earth's suface's gravitational acceleration than that of a simple, single mass pendulum could provide, making the kater pendulum and its adjustable masses and dual pivot points an effective and purposeful means of calculating local acceleration due to gravity, as with the purpose of this experiment.