1 Research Question
The effect of varying distances of the pivot from the geometric center of mass of a meter rule on the period of its oscillation.

2 Introduction

2.1 Rationale
Traditionally, simple pendulums, a point-massed spherical bob extended from a thin wire of a negligible mass, were “the basis of virtually all accurate time-keeping devices” (Fitzpatrick, 2006). However, for these traditional clocks, I had observed that the use of physical pendulum that is “a rigid body with a distributed mass” (Grieve, 2001) throughout, had not been widely utilized. Just as the length of simple pendulum effects its period, I questioned whether a factor that may contribute to the period of a physical pendulum is the distance it is pivoted away from its center of mass. Therefore, this brought rise to the research question to be investigated for a common object, meter rule that is a cuboid, found in a school based laboratory: the effect of varying distances of the pivot from the geometrical center of mass of a meter rule on the period of its oscillation.

2.2 Derivation for the Effect of Distance from the Center of Mass on the Period of a Physical Pendulum
The period, \( T \), for a physical pendulum follows the relationship in [1] for small initial amplitudes. Here, \( M \) is the mass of the physical pendulum, \( g \) is the acceleration due to gravity and \( I \) is the moment of inertia of the physical pendulum pivoted a certain distance, \( D \), from its center of mass.

\[
T = 2\pi \sqrt{\frac{I}{MgD}} \quad \text{(Nave, 2012)} \tag{[1]}
\]

\[
I = \int r^2 dM \quad \text{(Kaldon, 2003)} \tag{[2]}
\]

This moment of inertia for a mass that is distributed continuously over a body is expressed in [2] as the integral or sum of every infinitesimal point mass within the object, \( dM \), multiplied by the square of its separation, \( r \), from its axis of rotation. However, \( I \) and \( D \) are both constants dependent on one another; the independent variable \( D \) could not be changed solely without \( I \) varying. Considering the expression for \( I \), if the rotational axis is changed such that its distance, separation from every point mass is increased, \( I \) should increase as well. Therefore, if the rotational axis of the meter rule were to be changed from its geometric center of mass, where the range separation of each point mass is least from the rotational axis (see Figure 2.2.1), to the end of the meter rule, where the range of separation of each point mass is greater (see Figure 2.2.2), \( I \) should increase.

This relationship in the change of \( I \) for an object, if the axis of rotation parallel to one passing through the center of mass of an object were to be shifted a distance \( D \) is expressed as such in Figure 2.2.3. Here, \( I_{\text{COM}} \) that is a constant, is the moment of inertia about the center of mass. Substituting this for \( I \) in [1] yields the equation for the period such that if \( D \) were to be changed, no other variable would vary.
Assuming the meter rule that would be used for this investigation is a rectangular plate, $I_{COM}$, could be substituted for a rectangular plate, [4], in terms of its length, $A$, and width, $B$.

$$I_{COM} = \frac{M \cdot (A^2 + B^2)}{12} \quad \text{(Richmond, 2015)}$$


Equation [5] in this form suggests that the period squared, $T^2$, for the physical pendulum is directly proportional to the sum of the distance, $D$, it’s pivoted away from its center of mass and the moment of inertia of the rectangular plate at its center of mass, divided by its mass. This is based on the assumptions that the moment of inertia of the meter rule is equivalent to that of a plate and air resistance and frictional force have a negligible impact on the period.

3 Hypothesis

Given that the assumptions aforementioned are valid, graphing the quantities that yield a direct proportionality on the Y and X axis respectively for distances above the center of mass, a straight-line graph through the origin should be drawn within each of its errors. Alternatively, since $T^2$ should be the same for similar distances pivoted below the center of mass, a reflection of the previous graph should also be obtained, producing an absolute value function (see Figure 3.1).

4 Experimental Design

4.1 Variables
Independent Variable: The independent variable would be the varying distances the meter ruler would be pivoted away from its geometric center. The pivot points were made by drilling holes along a drawn line that goes through the center of the ruler (see Figure 4.1.1), at distances 46cm, 42cm, 38cm, 44cm, 30cm and 26cm both above and below from the center of the ruler’s 50cm mark that should be the geometric position of its center of mass (see Figure 4.1.1), assuming the meter rule's mass is uniformly distributed (Hall, 2015). These distances were measured, verified again using another meter ruler, extended from the center of the 50cm mark to the center of the drilled hole. Furthermore, the drill bit used to drill the holes was used as the pivot to ensure the distance from the center of mass the pendulum oscillates is not increased slightly as a consequence of a smaller, loose fit.

![Figure 4.1.1: Pivot points are to be made along the drawn line along the center of the ruler. The center of the 50cm mark should be its geometric center of mass.](image)

![Figure 4.1.2: Meter rule pivoted at an arbitrary distance such that the line through the center of the ruler rests at the 90° mark of the protractor.](image)

Dependent Variable: The dependent variable would be the period of one oscillation by the meter ruler that is pivoted a distance away from its center. This would be obtained by placing a photogate below the meter ruler and measuring the time it takes for it to complete oscillation or when the photogate switches state from being blocked to unblocked twice till its first blocked again (Vernier.com, n.d.). To ensure the reliability of the results, 10 such repeats would be taken.

Controlled Variables:

Initial Angle of the Swing The initial angle of the swing would be controlled ensuring the center of the meter ruler is displaced and released from the same small angle of 5 degrees each time. This would be ensured by attaching a protractor to the point of suspension of the meter rule on the retort stand, and aligning it such that the drawn line that goes through the center of the pivoted meter ruler, rests at the 90-degree mark on the protractor (see Figure 4.1.2). The line drawn through the center of the rule would then be displaced 5° which would be measured using the protractor attached.

Position of Center of Mass on the Meter Rule Assuming the mass of the meter rule is uniformly distributed, its geometric center of mass should be conserved and not shifted by drilling holes symmetrically along the drawn line that goes through the center of the meter ruler. Therefore, holes were drilled at distances 46cm, 42cm, 38cm, 44cm, 30cm and 26cm both above and below the center of the ruler's 50cm marks to ensure symmetry.

Length and Width of the Ruler The same meter ruler was used throughout the experiment whose length and width was verified by measuring it utilizing another meter rule and Vernier caliper respectively, at 5 random positions along it. Their average width and length were taken to ensure the validity of the assumption regarding the uniform length and width of the meter rule. This should ensure the moment of inertia of the meter rule, that is assumed to be equivalent to a rectangular plate, remains constant.

4.2 Apparatus
4.3 Procedure
1. First, Using the Vernier caliper and other meter rule, take 5 measurements of the meter rule's depth, at random positions along the ruler, and length respectively.
2. Using a 15cm ruler, measure the width of a meter ruler and mark its center at both ends. Then using another meter ruler, draw a line along the center of the meter ruler that joins both marks (see Figure 4.1.1).
3. At distances, 46cm, 42cm, 38cm, 44cm, 30cm, 26cm and 0cm both above and below the ruler’s 50cm mark, draw a line across the ruler’s width.
4. Then, at each intersection of the drawn lines, excluding the one at the meter rule’s 50cm mark, drill holes utilizing a drill bit.
5. Measure and verify that the distances from the central, undrilled intersection point to the center of the drilled holes are 46cm, 42cm, 38cm, 44cm, 30cm and 26cm above and below it respectively.
6. Clamp the drill bit to the retort stand and place either hole that is 46cm away from the meter rule’s center through the clamped drill bit.
7. Then, attach the protractor on the drill bit, and align it such that such that the drawn line that goes through the center of the pivoted meter ruler, rests at the 90-degree mark on the protractor (see Figure 4.1.2).
8. Place, a photogate that is connected to the data logger below the pivoted meter ruler. Ensure that the meter ruler is low enough such that is the state of the photogate is blocked and the data logger is in a mode, ‘Pendulum’.
9. Displace the meter ruler by an angle of 5 degrees with reference to the drawn line along its center. Then, start data collection on the data logger and let the meter rule to oscillate freely.
10. Record the period for the first 10 oscillations of the meter rule. A single oscillation would have occurred when the photogate switches state from being blocked to unblocked twice till it’s first blocked again.
11. Repeat steps 5 to 10 for the 11 other drilled holes.

4.4 Safety Considerations
The use of the drill invites several concerns regarding safety. Therefore, whilst drilling holes into the meter rule, the use of safety goggles and thick gloves was considered. This ensured any wooden material does not fall into the eye and that an injury as a result wooden splinters or hot temperatures was avoided. Prior to drilling, the meter rule was secured firmly with clamps to mitigate any accident as a result of its slipping and long clothing such as ties that may get entangled with the drill was taken off. Furthermore, the drill was unplugged whilst not in use and the drilling was conducted a distance away from surrounding people.

5 Raw Data
5.1 Quantitative Observations
5.1.1 Raw Data Table to Determine the Average Values of A and B

<table>
<thead>
<tr>
<th>Trial</th>
<th>A (m) ±0.000025</th>
<th>B (m) ±0.0005</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.02670</td>
<td>0.999</td>
</tr>
<tr>
<td>2</td>
<td>0.02675</td>
<td>0.999</td>
</tr>
<tr>
<td>3</td>
<td>0.02700</td>
<td>1.000</td>
</tr>
<tr>
<td>4</td>
<td>0.02685</td>
<td>0.998</td>
</tr>
<tr>
<td>5</td>
<td>0.02685</td>
<td>1.000</td>
</tr>
</tbody>
</table>

5.1.2 Raw Data Table Displaying the Period for a Distance Away from the Ruler’s Center of Mass
Period (T) of the Meter Ruler Pivoted a Distance Away From its Centre of Mass (D)

<table>
<thead>
<tr>
<th>D (m)</th>
<th>±0.0005</th>
<th>T (s)</th>
<th>±0.000001</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.460</td>
<td>1.612229</td>
<td>1.612449</td>
<td>1.613166</td>
</tr>
<tr>
<td>0.420</td>
<td>1.577239</td>
<td>1.577044</td>
<td>1.576322</td>
</tr>
<tr>
<td>0.380</td>
<td>1.559229</td>
<td>1.560052</td>
<td>1.560163</td>
</tr>
<tr>
<td>0.340</td>
<td>1.534268</td>
<td>1.534636</td>
<td>1.532641</td>
</tr>
<tr>
<td>0.300</td>
<td>1.521629</td>
<td>1.522739</td>
<td>1.517375</td>
</tr>
<tr>
<td>-0.260</td>
<td>1.526027</td>
<td>1.528336</td>
<td>1.528365</td>
</tr>
<tr>
<td>-0.280</td>
<td>1.497846</td>
<td>1.513420</td>
<td>1.508436</td>
</tr>
<tr>
<td>-0.300</td>
<td>1.526418</td>
<td>1.523375</td>
<td>1.523676</td>
</tr>
<tr>
<td>-0.340</td>
<td>1.531071</td>
<td>1.527468</td>
<td>1.526313</td>
</tr>
<tr>
<td>-0.380</td>
<td>1.551624</td>
<td>1.550589</td>
<td>1.549361</td>
</tr>
<tr>
<td>-0.420</td>
<td>1.567861</td>
<td>1.567163</td>
<td>1.567255</td>
</tr>
<tr>
<td>-0.460</td>
<td>1.607977</td>
<td>1.607191</td>
<td>1.605903</td>
</tr>
</tbody>
</table>

5.2 Qualitative Observations

1. For distances 34cm, 30cm and 26cm both above and below the meter rule’s center of mass, the initial amplitude of 5° decreased significantly, within 5 oscillations such that the photogate continually remained in a blocked state, preventing a period measurement to be taken. Therefore, for these distances the first 3 oscillations were taken and repeated such that 10 periods were obtained.

2. Due to a loss of equipment, during experimentation the meter rule had to be pivoted on a smoother, but slightly larger thin metal rod than the drill bit used to drill the holes for distances, 46cm, 42cm, 38cm, 34cm, 30cm and 26cm below the meter rule’s center of mass.

3. For certain trials, the meter rule rocked sideways after which in some occasions did not oscillate perpendicular to the pivot and the placed photogate.

6 Processed Data

6.1 Data Processing

6.1.1 Avg. Value of A (A<sub>Avg</sub>)

$$A_{Avg} = \frac{1}{5} \sum_{n=1}^{5} A_n$$

$$\Delta A_{Avg} = \frac{A_{Max} - A_{Min}}{2} + 2.5 \times 10^{-5} m$$

Sample Calculations:

$$A_{Avg} = \frac{0.02670 + 0.02675 + 0.02700 + 0.02685 + 0.02685}{5} = 0.02683 m$$

$$\Delta A_{Avg} = \frac{0.02700 - 0.02670}{2} m = 1.500 \times 10^{-4} m$$

Here, the precision of the Vernier Caliper, 2.5×10<sup>-5</sup> m, was not added as its insignificant in comparison to A<sub>Avg</sub> by a degree of 10<sup>-3</sup>.

6.1.2 Avg. Value of B (B<sub>Avg</sub>)

$$B_{Avg} = \frac{1}{5} \sum_{n=1}^{5} B_n$$

$$\Delta B_{Avg} = \frac{B_{Max} - B_{Min}}{2}$$

Sample Calculations:

$$B_{Avg} = \frac{0.999 + 0.999 + 1.00 + 0.998 + 1.00}{5} m$$

5
\[ T_{Avg.} = \left( \frac{1}{10} \sum_{n=1}^{10} T_n \right)^2 \]

\[ \Delta T_{Avg.}^2 = 2 \cdot \left[ \frac{T_{Max.} - T_{Min.}}{2 \cdot T_{Avg.}} \right] \cdot T_{Avg.}^2 \]

Sample Calculations of \( T_{Avg.}^2 \) for a Distance of 0.460m Away from the Center of Mass:

\[ T_{Avg.}^2 = \left[ \frac{1.612229s + 1.612449s + 1.613166s + 1.613845s + 1.613410s + 1.611128s + 1.613252s + 1.613709s + 1.613597s + 1.613744s}{10} \right] \]

\[ = 2.601940s^2 \]

\[ \Delta T_{Avg.}^2 = 2 \cdot \left[ \frac{1.613854s - 1.611128s}{2 \cdot 1.613053s} \right] \cdot 2.601940s^2 \]

\[ = 4.397183 \times 10^{-3}s^2 \]

### 6.1.4 Determining \( \frac{A^2 + B^2}{12D} + D \)

\[ \left[ \frac{A^2 + B^2}{12D} + D \right] = \frac{A_{Avg.}^2 + B_{Avg.}^2}{12D} + D \]

\[ \Delta \left[ \frac{A^2 + B^2}{12D} + D \right] = 2 \cdot \frac{\Delta A_{Avg.}}{A_{Avg.}} + 2 \cdot \frac{\Delta B_{Avg.}}{B_{Avg.}} + \frac{0.0005m \cdot 12}{12 \cdot D} \cdot \left[ \frac{A_{Avg.}^2 + B_{Avg.}^2}{12D} \right] + 5 \times 10^{-4}m \]

Sample Calculations for a Distance of 0.460m Away from the Center of Mass:

\[ \left[ \frac{A^2 + B^2}{12D} + D \right] = \frac{(0.02683m)^2 + (0.999m)^2}{12 \cdot 0.460m} + 0.460m \]

\[ = 0.641m \]

\[ \Delta \left[ \frac{A^2 + B^2}{12D} + D \right] = 2 \cdot \frac{1.500 \times 10^{-4}m}{0.02683m} + 2 \cdot \frac{1.00 \times 10^{-3}m}{0.999m} + \frac{0.0005m \cdot 12}{12 \cdot 0.460m} \cdot \left[ \frac{(0.02683m)^2 + (0.999m)^2}{12 \cdot 0.460m} \right] + 5 \times 10^{-4}m \]

\[ = 0.003m \]

### 6.2 Processed Quantitative Observations

<table>
<thead>
<tr>
<th>( \left[ \frac{A^2 + B^2}{12D} + D \right] ) (m)</th>
<th>( T_{Avg.}^2 ) (s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.641 ±0.003</td>
<td>2.601940 ±4.397183 \times 10^{-3}</td>
</tr>
<tr>
<td>0.618 ±0.003</td>
<td>2.482435 ±9.291163 \times 10^{-3}</td>
</tr>
<tr>
<td>0.599 ±0.004</td>
<td>2.435499 ±4.257340 \times 10^{-3}</td>
</tr>
<tr>
<td>0.585 ±0.004</td>
<td>2.335564 ±2.582751 \times 10^{-2}</td>
</tr>
<tr>
<td>0.578 ±0.005</td>
<td>2.289657 ±3.566521 \times 10^{-2}</td>
</tr>
<tr>
<td>0.580 ±0.005</td>
<td>2.321456 ±1.669292 \times 10^{-2}</td>
</tr>
<tr>
<td>-0.580 ±0.005</td>
<td>2.260981 ±2.516775 \times 10^{-2}</td>
</tr>
<tr>
<td>-0.578 ±0.005</td>
<td>2.324433 ±1.399286 \times 10^{-2}</td>
</tr>
<tr>
<td>-0.585 ±0.004</td>
<td>2.345923 ±1.579121 \times 10^{-2}</td>
</tr>
<tr>
<td>-0.599 ±0.004</td>
<td>2.407166 ±9.035962 \times 10^{-3}</td>
</tr>
<tr>
<td>-0.618 ±0.003</td>
<td>2.455090 ±1.113708 \times 10^{-2}</td>
</tr>
<tr>
<td>-0.641 ±0.003</td>
<td>2.575365 ±1.372260 \times 10^{-2}</td>
</tr>
</tbody>
</table>
7 Data Analysis

7.1 Graphical Presentation and Justification of Anomaly

The processed data table was graphed; however, for clarity $T_{\text{Avg}}^2$ for distances above and below the meter rule’s center of mass were graphed onto separate graphs respectively. This enables a clear trend to be seen within $T_{\text{Avg}}^2$ that varies little, by a maximum of 0.314384, that is less than 1.

![Graph Displaying the Linearized Relationship Between the Centre of Mass and the Period of a Physical Pendulum]

**Figure 7.1.1:** Period of the physical pendulum for distances above the center of mass of the meter rule.

![Graph Displaying the Linearized Relationship Between the Centre of Mass and the Period of a Physical Pendulum]

**Figure 7.1.2:** Period of the physical pendulum for distances below the center of mass of the meter ruler. Here, a line of best fit through the origin cannot be drawn through the error bars of the anomaly.
For distance above the center of mass of the meter rule, a line of best fit through the origin could be drawn within the $X$ and $Y$ error bars of the collected data, suggesting a direct proportionality with a regression of 0.96. However, this was not possible for distances below the meter rule’s center of mass; a line of best fit through the origin cannot be drawn through the error bars of $T_{\text{Avg.}}^2$ for 26cm below the center of mass that deviates from the trend. Furthermore, its $T_{\text{Avg.}}^2$ value is lower than for a distance of 26cm by $6.6485 \times 10^{-2} s^2$. Although apparently small, this difference is significant given the number of trials obtained for it, 10, and the precision of the period measurement, $\pm 1 \times 10^{-6} s$. Furthermore, its high $Y$ error bars that is the second highest from the collected data, $\pm 2.516775 \times 10^{-2} s^2$, is typical of an anomalous result. 

With the omitted anomaly, a line of best fit can then be drawn through the origin and within all the error bars that is consistent with the hypothesized direct proportionality. A higher regression of 0.98 than previously 0.92 was obtained which could be further corroborating evidence for the identified result being an anomaly, qualifying its omission. 

Hence, the anomalous result was omitted. Since the absolute values of both gradients ($G_1$ for distance above and $G_2$ for distances below with the omitted anomaly) should be the same, their absolute average was obtained, $G_{\text{Avg.}}$, with its error propagated with the maximum and minimum possible gradients formed. This average gradient would be used as a reference point for the percentage error of the experiment; the deviation from the experimental gradient from the hypothesized gradient. This would enable a conclusion to be made as to whether the hypothesis should be accepted.

### 7.2 Experimental Error Calculations

#### 7.2.1 Determining $G_{\text{Avg.}}$

$$G_{\text{Avg.}} = \frac{G_1 + |G_2|}{2}$$

$$\Delta G_{\text{Avg.}} = \left[ \frac{G_{1,\text{Max}} - G_{1,\text{Min}}}{2} + \frac{G_{2,\text{Max}} - G_{2,\text{Min}}}{2} \right] \cdot \frac{1}{2}$$

Calculations:

$$G_{\text{Avg.}} = \frac{4.03 \text{ ms}^{-2} + |-4.01 \text{ ms}^{-2}|}{2}$$

$$= 4.02 \text{ ms}^{-2}$$

$$\Delta G_{\text{Avg.}} = \left[ \frac{5.17 \text{ ms}^{-2} - 3.57 \text{ ms}^{-2}}{2} + \frac{(-3.01 \text{ ms}^{-2}) - (-5.29 \text{ ms}^{-2})}{2} \right] \cdot \frac{1}{2}$$
\[ T^2 \cdot D = \frac{4\pi^2}{g} \cdot \frac{I_{\text{COM}}}{M} + \frac{4\pi^2}{g} \cdot D^2 \]
its mass the assumption could be argued as valid and accurate. For distances, above the meter rule's center of mass the experimental value of $I_{COM}$ divided by its mass was 4.5% away from the assumed value that was calculated using $A_{Avg}$ and $B_{Avg}$. (see Table 9.1.3). Alternatively, for distance below the discrepancy was 0.89% (see Table 9.1.3). Both these percentage deviations being less than 5% away from the experimental value, renders the assumption to be valid for this investigation.

![Graph](image_url)

**Figure 9.1.1:** The maximum and minimum gradients were not drawn since only the Y intercept for the line of best fit is necessary to evaluate the assumption.

![Graph](image_url)

**Figure 9.1.2:** The anomaly for a distance 26cm below the meter rule’s center of mass was omitted. Here, the error bars are too small to visualize the anomalous result.

<table>
<thead>
<tr>
<th>Percentage Variation ($\delta_{I_{COMA}}$) in Experimental $\frac{I_{COM}}{m}$ Values from Assumed Values for Distances Above the Meter Rule's Center of Mass:</th>
<th>Percentage Variation ($\delta_{I_{COMB}}$) in Experimental $\frac{I_{COM}}{m}$ Values from Assumed Values for Distances Below the Meter Rule's Center of Mass:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
\[
\delta_{\text{ICOMA}} = \left| \frac{g}{4\pi^2} \cdot \text{Intercept} - \frac{(A^2 + B^2)}{12} \right| \cdot \frac{12}{(A^2 + B^2)} \times 100
\]

Calculation:

\[
\delta_{\text{ICOMA}} = \frac{g}{4\pi^2} \cdot 0.319 m^2 - \frac{1.500 \times 10^{-4} + 0.999^2}{12} \cdot m^2
\]
\[
= 4.5\%
\]

\[
\delta_{\text{ICOMB}} = \left| \frac{g}{4\pi^2} \cdot \text{Intercept} - \frac{(A^2 + B^2)}{12} \right| \cdot \frac{12}{(A^2 + B^2)} \times 100
\]

Calculation:

\[
\delta_{\text{ICOMB}} = \frac{g}{4\pi^2} \cdot 0.319 m^2 - \frac{1.500 \times 10^{-4} + 0.999^2}{12} \cdot m^2
\]
\[
= 0.89\%
\]

Table 9.1.3: Calculations displaying the difference between the experimental value of \( I_{\text{COM}} \) divided by the meter rule’s mass and the assumed value.

9.2 Limitations and Improvements

The deviating result obtained for distances below the center of mass of the ruler, was justified as an anomaly on the basis of a limited range of the independent variable, \( L \). Therefore, to justify and omit this result on a strong basis so as to reliably reflect the random or percentage error of the experiment on which a strong, conclusion could be made, there should have been a greater range for the distances on the meter rule where the period measurement should be taken. A possible range is 46cm, 43cm, 40cm, 37cm, 34cm, 31cm, 28cm and 25cm both above and below the center of mass.

Figure 9.1.1: If the approach of the meter rule were perpendicular to the photogate, the angular it would have to travel to block it would be least.

Figure 9.2.2: If the angle of approach were to vary, the angular distance the meter rule would have to travel to block the photogate would be greater and vary. Thus, period measurements would vary.

The meter rule was observed to wobbled sideways after being released which may have contributed to the random error of the experiment. This sideways wobbling motion varies the angle at which the meter rule approaches the photogate. Hence, the photogate would reach the final blocked stage that determines the end of one oscillation later, by varying amounts, as the meter rule would have to travel a greater distance to block the photogate if it were approaching it angled (see Figure 9.1.2) than perpendicular (see Figure 9.1.1). The discrepancy between these period measurements when perpendicular or angled during its wobbling motion should contribute to the random error and is significant given the high precision of the photogate, \( \pm 1 \times 10^{-6} \) s. Therefore, to mitigate this behavior the meter rule could have been pivoted between two large, secured washers that are sufficiently close to each other. This ensures oscillations are perpendicular to the pivot.

It is still unclear as to how the low anomaly, for a distance of 26cm below the meter rule’s center of mass, may have been brought about. Typically, the factor explored above could systematically increase period measurements rather than reduce period measurements to bring about the anomaly. Furthermore, its random error, \( \pm 2.516775 \times 10^{-2} \) s\(^2\), not being the highest and looking back at the raw data, suggests that there wasn’t any data that may have significantly reduced the average. Since how the anomaly may have been brought about is inconclusive, it would be best to repeat the measurements taken for this distance of 26cm below the meter rule’s center of mass.

The amplitude was qualitatively observed to have deteriorated significantly that is likely to be the consequence of frictional force opposing its motion, invalidating this assumption. This could be attributed to the slightly larger metal rod used as the pivot after a loss of equipment whose tight fit may have accentuated the role of frictional force. Though the period is independent of the amplitude (Burley et al., 1997), this significant reduction of the meter rule’s amplitude to within a few oscillations disallowed its period to be measured due to the continual blocking of the photogate. Therefore, to mitigate this behavior and the role of friction, the drilled holes and the pivot could have been greased.
10 Extensions

The investigation established effect of varying distances of the pivot from the center of mass of rectangular plate on the period of its oscillation. Upon further research, it was found that there exists a minimum period for a certain distance the rectangular plate is pivoted from its center of mass. Therefore, factors such as the rectangular plate's length, width and depth on the effect of this minimum period could be investigated given more time. This could possibly aid in determining or shortlisting the length of pendulum required for a certain measurement of time. Alternatively, the investigation could have possible extended by comparing the periods obtained for different regularly shaped objects or on different axis of rotations.

11 Bibliography


