Habib University

PHY 101L

Mechanic and Thermodynamics Lab

Fall 2020

Lab Notebook

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Experiment 1

QUANTIFYING UNCERTAINTY : MEASUREMENT OF GRAVITATIONAL ACCELERATION

Date: 5/9/2020

1.1 Aim

In this experiment, our aim is to measure the gravitational acceleration of Earth using a pendulum and quantify various Type A and Type B uncertainties to produce a concrete uncertainty of our measurement. We observe the relationship between the Length of a pendulum and its Time Period. We use a metallic bob with a hook as our pendulum.

1.2 Background Theory

Newton's Law of Gravitation states that ‘‘ Any particle of matter in the universe attracts any other with a force varying directly as the product of the masses and inversely as the square of the distance between them. ” Mathematically, it can be expressed as

$$\vec{F} = -G\frac{m_1 \times m_2}{r^2}\hat{r}$$

where G is the gravitational constant, m_1 is the mass of body 1, m_2 is the mass of body 2 and r is the separation between the center of masses of both bodies. Newton's second of motion states “that rate of change of momentum of a body is directly proportional to the force applied” which can be expressed in the form

$$\vec{F} = m \times \vec{a}$$

where m is the mass of the body and a is the acceleration. Combining these both Laws, gives us the following equation

$$g = -G\frac{M_E}{{R_E}^2}$$

where the M_E is the mass of the Earth and R_E is the radius of the Earth.

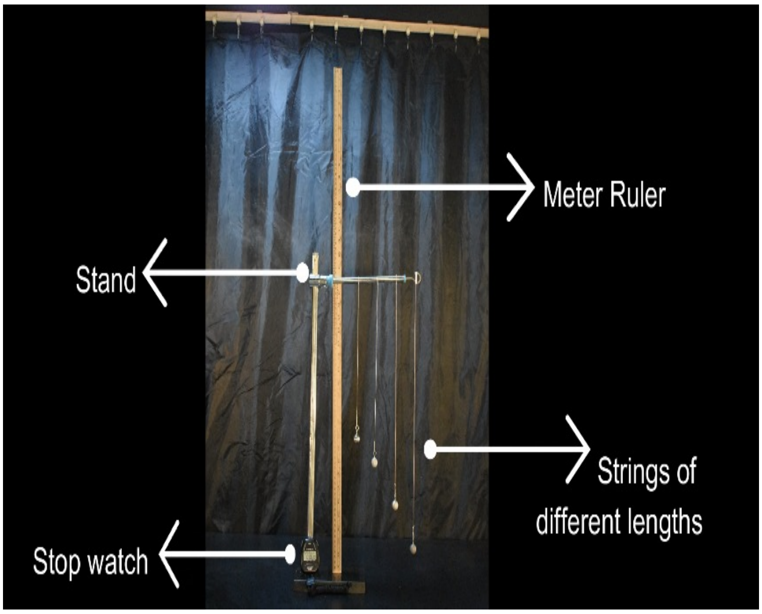
The length (L) of the pendulum is related to its time period (T) by the following equation:

$$T = 2\pi\sqrt{\frac{L}{g}}$$

This equation can be re-written by making g the subject :

$$g = 4\pi^2\frac{L}{T^2}$$

1.3 Description of Setup



Here the stand with clamp is used to provide a rigid support, metre rule is used to measure the length L of the pendulum , digital stopwatch is used to record the time period of the pendulum and the metallic bob with a hook is used as a pendulum. In this experiment, we use four different length of threads

1.4 Method / Procedure

The length of the thread is measured from the clamp to the center of the metallic bob using the metre Ruler. Digital stopwatch is used to record the time-period for ten oscillations. The same process is repeated 5 times for each thread. Length of the Pendulum is adjusted by attaching the metallic bob to a thread of different length.Threads of four different lengths are used in this Experiment.

The gravitational acceleration g_i is calculated for each different length of pendulum by using the average time period of one oscillation and theory described above. These g_i's are then combined together to calculate the final value of the gravitational acceleration g.

1.5 Data

Since the length of the pendulum was only measured it has no type A uncertainty. The type B uncertainty associated with the metre ruler and digital stopwatch are $0.0002m$ and $0.003s$

The lengths of the Pendulum measured using the metre ruler.

s.No	**Height**	**Upper (cm)**	**Lower (cm)**	**Length (cm)**	**Length (m)**
1	H1	80.7	43.0	37.7	0.377 ± 0.0002
2	H2	73.5	42.3	31.2	0.312 ± 0.0002
3	H3	68.0	42.7	25.3	0.253 ± 0.0002
4	H4	92.7	42.0	50.7	0.507 ± 0.0002

The time period for ten-oscillations recorded using digital stopwatch.

s.No	**T_H1 (s)**	**T_H2 (s)**	**T_H3 (s)**	**T_H4 (s)**
1	11.60	11.53	10.22	14.62
2	11.40	11.18	10.19	14.50
3	11.10	11.21	10.22	14.41
4	11.30	11.25	10.28	14.47
5	11.30	11.31	10.44	14.60

Type A uncertainty in the Time Period for each length was calculated using the method mentioned in the MATLAB script .

Type A uncertainty in Time Period for H1

$$\sigma_T = 0.0162s$$
$$U_T^A = 0.0081s$$

$U_T = \sqrt{{U_T^A}^2 + {U_T^B}^2}$

$U_T = \sqrt{0.0081^2 + 0.003^2}$

$U_T = 0.0086s$

Total uncertainty in Time Period (T1) for H_1 is $T = 1.134 \pm 0.009s$

Type A uncertainty in Time Period for H2

$$\sigma_T = 0.0125s$$
$$U_T^A = 0.0062s$$

$U_T = \sqrt{{U_T^A}^2 + {U_T^B}^2}$

$U_T = \sqrt{0.0062^2 + 0.003^2}$

$U_T = 0.0069s$

Total uncertainty in Time Period (T2) for H_2 is $T = 1.130 \pm 0.007s$

Type A uncertainty in Time Period for H3

$$\sigma_T = 0.090s$$
$$U_T^A = 0.0045s$$

$U_T = \sqrt{{U_T^A}^2 + {U_T^B}^2}$

$U_T = \sqrt{0.0045^2 + 0.003^2}$

$U_T = 0.0053s$

Total uncertainty in Time Period (T3) for H_3 is $T = 1.027 \pm 0.005s$

Type A uncertainty in Time Period for H4

$$\sigma_T = 0.079s$$
$$U_T^A = 0.0040s$$

$U_T = \sqrt{{U_T^A}^2 + {U_T^B}^2}$

$U_T = \sqrt{0.0040^2 + 0.003^2}$

$U_T = 0.0049s$

Total uncertainty in Time Period (T4) for H_4 is $T = 1.452 \pm 0.005s$

1.6 Data Analysis

The formula for calculating g is as follows :

$$g = 4\pi^2 \frac{L}{T^2}$$

Transferring the uncertainty in Time and Length to gravitational acceleration

$$U_g = \sqrt{\left(4\pi^2 \frac{(-2)L}{T^3}\Delta T\right)^2 + \left(4\pi^2 \frac{1}{T^2}\Delta L\right)^2}$$

$$U_g = \frac{4\pi^2}{T^2} L \sqrt{\left(\frac{-2\Delta T}{T}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}$$

$$U_g = g\sqrt{\left(\frac{-2\Delta T}{T}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}$$

Calculating g1

$$g_1 = 4\pi^2 \frac{L_1}{T1^2} = 4\pi^2 \frac{0.377}{1.134^2} = 11.5738 m/s^2$$

$$\sigma_1 = 11.5738\sqrt{\left(\frac{-2 \times 0.009}{1.134}\right)^2 + \left(\frac{0.0002}{0.377}\right)^2} = 0.1761 m/s^2$$

$$g = 11.5738 \pm 0.1761 m/s^2$$

Calculating g2

$$g_2 = 4\pi^2 \frac{L_2}{T2^2} = 4\pi^2 \frac{0.312}{1.130^2} = 9.6531 m/s^2$$

$$\sigma_2 = 9.6531\sqrt{\left(\frac{-2 \times 0.007}{1.130}\right)^2 + \left(\frac{0.0002}{0.312}\right)^2} = 0.1155 m/s^2$$

$$g = 9.6531 \pm 0.1155 m/s^2$$

Calculating g3

$$g_3 = 4\pi^2 \frac{L_1}{T1^2} = 4\pi^2 \frac{0.253}{1.027^2} = 9.4698 m/s^2$$

$$\sigma_3 = 9.4698 \sqrt{\left(\frac{-2 \times 0.005}{1.027}\right)^2 + \left(\frac{0.0002}{0.253}\right)^2} = 0.0988 m/s^2$$

$$g = 9.4698 \pm 0.0988 m/s^2$$

Calculating g4

$$g_4 = 4\pi^2 \frac{L_1}{T1^2} = 4\pi^2 \frac{0.5070}{1.452^2} = 9.4937 m/s^2$$

$$\sigma_4 = 9.4937 \sqrt{\left(\frac{-2 \times 0.005}{1.452}\right)^2 + \left(\frac{0.0002}{0.5070}\right)^2} = 0.0642 m/s^2$$

$$g = 9.4937 \pm 0.0642 m/s^2$$

Now we can combine the $g1, g2, g3$ and $g4$ and their uncertainties to obtain the final value for gravitational acceleration and its uncertainty.

$$g = \frac{\left(\frac{g_1}{\sigma_1^2} + \frac{g_2}{\sigma_2^2} + \cdots\right)}{\left(\frac{1}{\sigma_1^2} + \frac{1}{\sigma_2^2} + \cdots\right)} = \frac{\sum_i \frac{g_i}{\sigma_i^2}}{\sum_i \frac{1}{\sigma_i^2}}$$

Combining the uncertainties in $g1, g2, g3$ and $g4$

$$\sigma^2 = \frac{1}{\sum_i \frac{1}{\sigma_i^2}}$$

$$g = 9.6631 \pm 0.0472 m/s^2$$

1.7 Discussion & Conclusion

The percentage uncertainty is 0.98 %, and standard value of gravitational acceleration is not in the range $g = 9.6631 \pm 0.0472 m/s^2$. Possible factors of uncertainty and errors are external factors such as wind and human errors in recording final time. Therefore there is a chance that hypothesis is not valid since standard value is not in the range. Perhaps a more accurate set up could have given results that would agree with hypothesis. Improvement can be a more accurate mechanism for recording time such as light gate, we can also ensure that external factors such as wind are minimized by using wind blockers and we can also use a fiducial marker to mark the mean of an oscillation.

1.8 MATLAB Script

```
% Calculate Type B uncertainity in Time
time_B = (0.01 / 2)/(3^0.5);
length_B = (0.001/2)/(6^0.5);
% Calculate Type A uncertainity
th1 = T_H1./10;
th2 = T_H2./10;
th3 = T_H3./10;
th4 = T_H4./10;

H1 = 0.377;
H2 = 0.312;
H3 = 0.253;
H4 = 0.507;

% avg1

avg1 = mean(th1);
avg2 = mean(th2);
avg3 = mean(th3);
avg4 = mean(th4);
% d1
d1 = th1 - avg1;
d2 = th2 - avg2;
d3 = th3 - avg3;
d4 = th4 - avg4;
```

```
% sq d1
sqd1 = d1.^2;
sqd2 = d2.^2;
sqd3 = d3.^2;
sqd4 = d4.^2;

% std d1

std1 = sqrt(sum(sqd1)/5);
time_A_1 = std1 / (sqrt(5-1));
time_u_1 = sqrt(time_A_1^2+time_B^2);

std2 = sqrt(sum(sqd2)/5);
time_A_2 = std2 / (sqrt(5-1));
time_u_2 = sqrt(time_A_2^2+time_B^2);

std3 = sqrt(sum(sqd3)/5);
time_A_3 = std3 / (sqrt(5-1));
time_u_3 = sqrt(time_A_3^2+time_B^2);

std4 = sqrt(sum(sqd4)/5);
time_A_4 = std4/ (sqrt(5-1));
time_u_4 = sqrt(time_A_4^2+time_B^2);

g1 = (4 * pi^2) * H1/(avg1^2);
g2 = (4 * pi^2 )* H2/(avg2^2);
g3 = (4 * pi^2) * H3/(avg3^2);
g4 = (4 * pi^2) * H4/(avg4^2);
```

```
G = [g1 g2 g3 g4];

u_g1 = g1 * ((2*time_u_1/avg1)^2+(length_B/H1)^2)^0.5;
u_g2 = g2 * ((2*time_u_2/avg2)^2+(length_B/H2)^2)^0.5;
u_g3 = g3 * ((2*time_u_3/avg3)^2+(length_B/H3)^2)^0.5;
u_g4 = g4 * ((2*time_u_4/avg4)^2+(length_B/H4)^2)^0.5;

ug= [u_g1 u_g2 u_g3 u_g4];

% Square The uncertainities
ug_sq = ug.^2;
% Divide G by ug_sq
g_sq = G./ug_sq;
% Inverse of ug_sq
inv_ug_sq = 1./ug_sq;
% final value
final_g = sum(g_sq)/sum(inv_ug_sq);
% final uncertainity
final_g_u = (1 / sum(inv_ug_sq))^0.5;
```

=-

Experiment 2

EQUIVALENT SPRING CONSTANT OF COMBINATION OF SPRINGS

Date: 14/9/2020

2.1 Aim

In this experiment, our aim is to calculate the equivalent spring constant of combination of springs, in both series and parallel. We derive the relationship of spring constant by applying varying weight on springs in series and parallel.

2.2 Background Theory

Hooke's Law states force applied on a spring is proportional to its extension, given its limit of proportionality has not reached. Mathematically, it can be expressed as

$$F = k\Delta x$$

where F is force applied, k denotes spring constant and Δx is change in length of spring. When the spring reaches its elastic limit then it can not return back to its original shape and is deformed. When the springs are attached in series, the extension is equal to

$$\Delta x = \Delta x_1 + \Delta x_2$$

The force that is applied on both the strings is same, consequently :

$$F = k(\Delta x_1 + \Delta x_2)$$

$$F = k_1\Delta x_1$$

$$F = k_2\Delta x_2$$

We can then combine these equations to get an expression for k, there combined spring constant.

$$k_1 \Delta x_1 = k_2 \Delta x_2$$

$$\Delta x_2 = \frac{K_1 \Delta x_1}{k_2}$$

$$F = k(\Delta x_1 + \frac{K_1 \Delta x_1}{k_2})$$

$$F = k(1 + \frac{k1}{k2})\Delta x_1$$

$$k_1 \Delta x_1 = k(1 + \frac{k1}{k2})\Delta x_1$$

$$k = \frac{k_1 \times k_2}{k_1 + k_2}$$

When springs are attached in parallel, the total force is equal to

$$F = F_1 + F_2$$

The extension of both the springs is same, Consequently:

$$F = k\Delta x$$

$$F_1 = k_1 \Delta x$$

$$F_2 = k_2 \Delta x$$

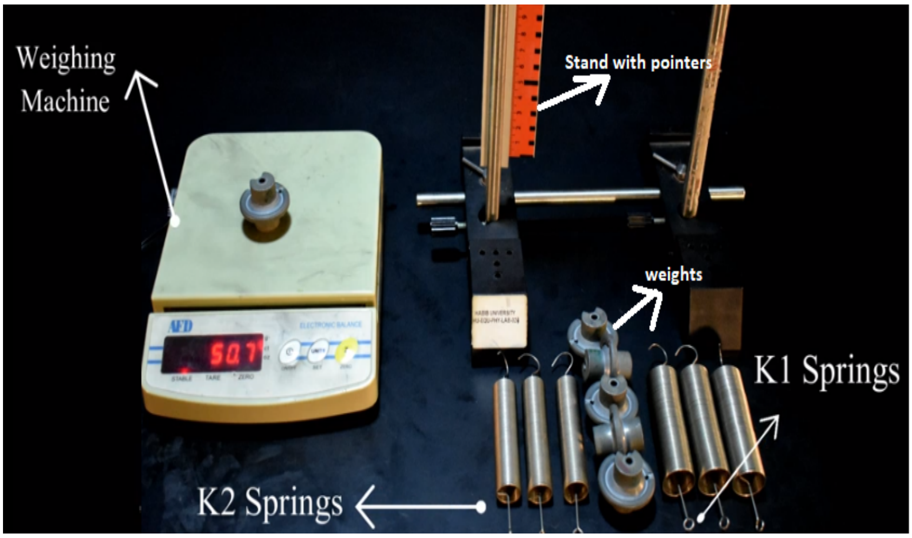
We can then combine these equations to get an expression for k, there combined spring constant.

$$k\Delta x = k_1 \Delta x + k_2 \Delta x$$

$$k\Delta x = \Delta x(k_1 + k_2)$$

$$k = k_1 + k_2$$

2.3 Description of Setup



Here the stand with pointers gives easy access to measuring the length and spring is supported on a clamp.The weights are then suspended from the spring.

2.4 Method / Procedure

The initial length of the spring is measured using the pointer stand and weights are suspended and the springs length is measured. This is repeated with adding more weights and change in the length of spring is measured. This is carried out for setting up the springs in series and parallel. The springs constant is calculated using Hooke's law by determining slope of the graph of extension against weight of masses.

2.5 Data

In this experiment, since the mass of the weights and the extension in length is measured only once they don't not have type A uncertainty. The type B certainty associated with the length and mass is respectively 0.0002m and 0.03g

Initial Measurements				
Springs	dia (cm)	single (cm)	series (cm)	parallel (cm)
K1	2.051	7.7	22.9	7.7
K2	1.524	7.7	20.3	7.7
K1+K2	-	-	21.9	7.7

K1 (single)					
s.No	Mass (grams)	Upper (cm)	Lower (cm)	Diff (cm)	Ext (cm)
1	0	94.2	86.5	7.7	0
2	50.7	94.2	81.9	12.3	4.6
3	101.4	94.2	77.2	17	9.3
4	152.1	94.2	72.7	21.5	13.8
5	202.8	94.2	68.1	26.1	18.4
6	253.5	94.2	63.6	30.6	22.9
7	304.2	94.2	58.3	35.9	28.2

K1 (series)					
s.No	Mass (grams)	Upper (cm)	Lower (cm)	Diff (cm)	Ext (cm)
1	0	94.2	71.3	22.9	0
2	50.7	94.2	62.6	31.6	8.7
3	101.4	94.2	53.1	41.1	18.2
4	152.1	94.2	43.6	50.6	27.7
5	202.8	94.2	34.2	60	37.1
6	253.5	94.2	25	69.2	46.3
7	304.2	94.2	15.7	78.5	55.6

K1 (parallel)					
s.No	Mass (grams)	Upper (cm)	Lower (cm)	Diff (cm)	Ext (cm)
1	0	94.2	86.5	7.7	0
2	50.7	94.2	84	10.2	2.5
3	101.4	94.2	81.7	12.5	4.8
4	152.1	94.2	79.2	15	7.3
5	202.8	94.2	77.2	17	9.3
6	253.5	94.2	74.7	19.5	11.8
7	304.2	94.2	72.3	21.9	14.2

K2 (single)					
s.No	Mass (grams)	l1	l2	final	Ext (cm)
1	0	94.2	86.5	7.7	0
2	50.7	94.2	84.9	9.3	1.6
3	101.4	94.2	82.8	11.4	3.7
4	152.1	94.2	81	13.2	5.5
5	202.8	94.2	79.1	15.1	7.4
6	253.5	94.2	77.4	16.8	9.1
7	304.2	94.2	75.6	18.6	10.9

K1 and K2 (series)					
s.No	Mass (grams)	Upper (cm)	Lower (cm)	Diff (cm)	Ext (cm)
1	0	94.2	72.3	21.9	0
2	50.7	94.2	65.8	28.4	6.5
3	101.4	94.2	59.4	34.8	12.9
4	152.1	94.2	52.5	41.7	19.8
5	202.8	94.2	46.2	48	26.1
6	253.5	94.2	39.5	54.7	32.8
7	304.2	94.2	33	61.2	39.3

K1 and K2 (series)					
s.No	Mass (grams)	Upper (cm)	Lower (cm)	Diff (cm)	Ext (cm)
1	0	94.2	72.3	21.9	0
2	50.7	94.2	65.8	28.4	6.5
3	101.4	94.2	59.4	34.8	12.9
4	152.1	94.2	52.5	41.7	19.8
5	202.8	94.2	46.2	48	26.1
6	253.5	94.2	39.5	54.7	32.8
7	304.2	94.2	33	61.2	39.3

2.6 Data Analysis

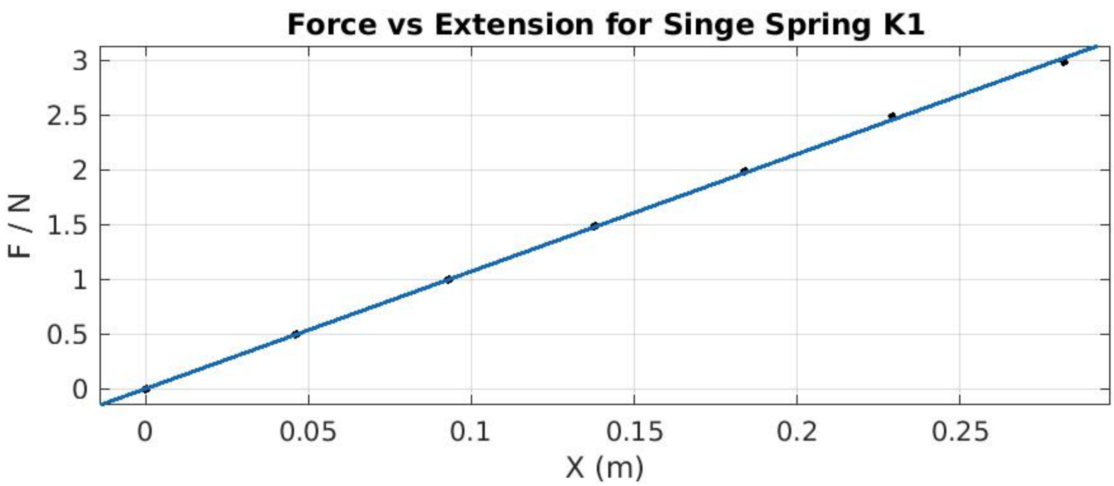


Figure 2.1: Graph of Force vs Extension for spring K1

$$K1_{single} = 10.72N/m$$

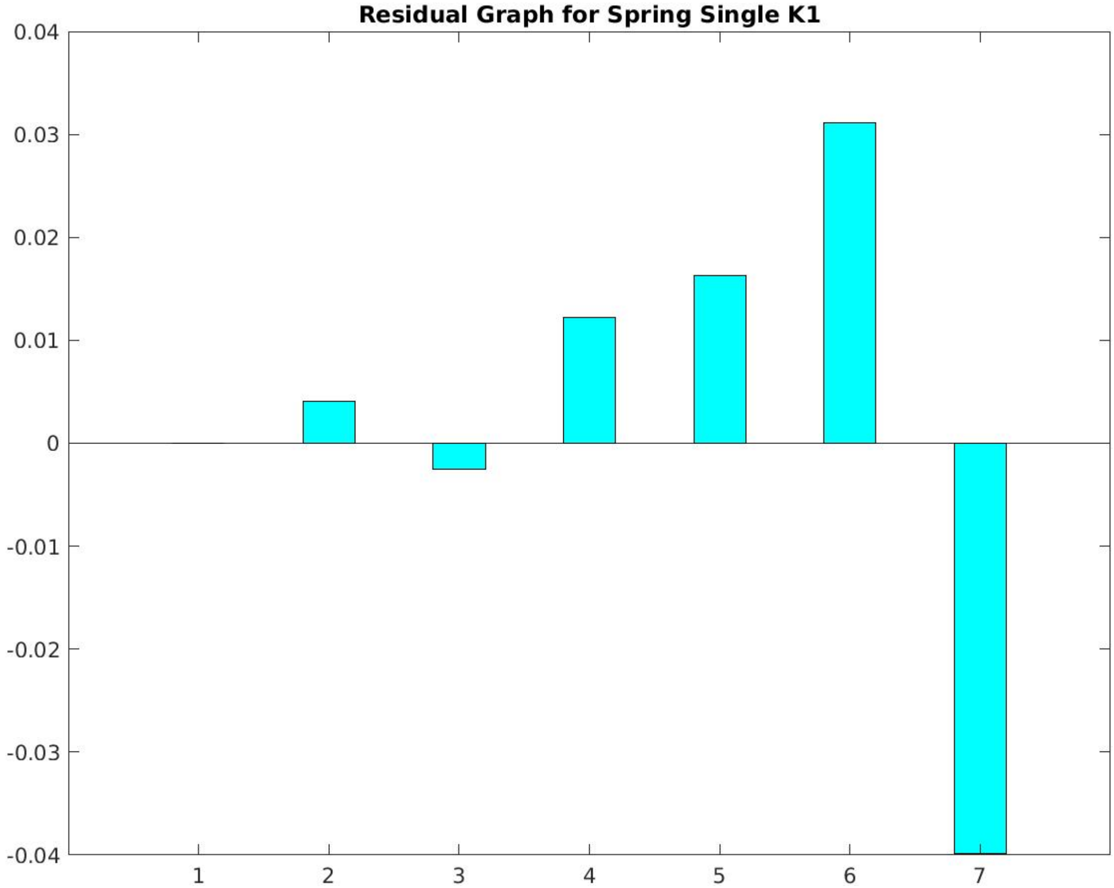


Figure 2.2: Residual Plot for Single Spring K1

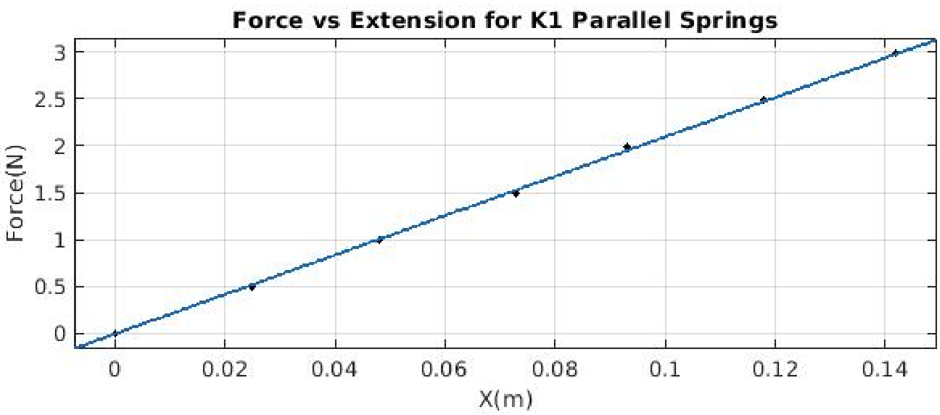


Figure 2.3: Graph of Force vs Extension for K1 Parallel Springs

$$K1_{Parallel} = 21N/m$$

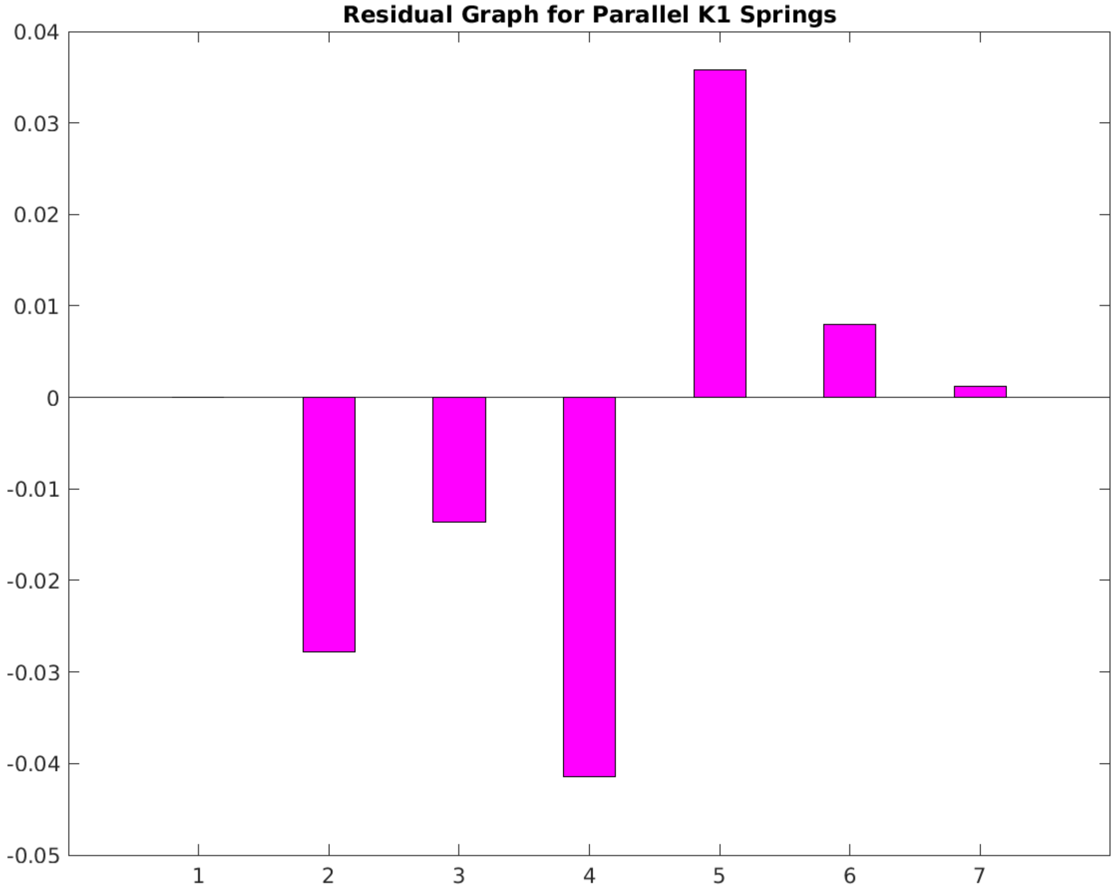


Figure 2.4: Residual Plot for Single K1 Parallel Springs

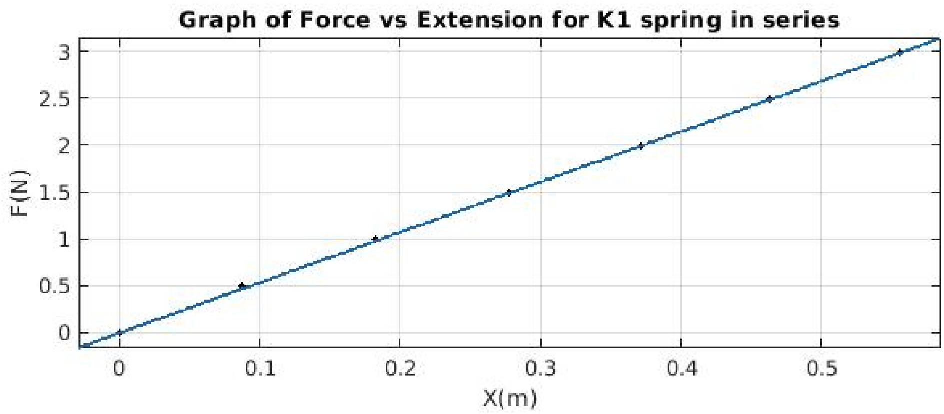


Figure 2.5: Graph of Force vs Extension for K1 Springs in Series

$$K1_{Parallel} = 5.375N/m$$

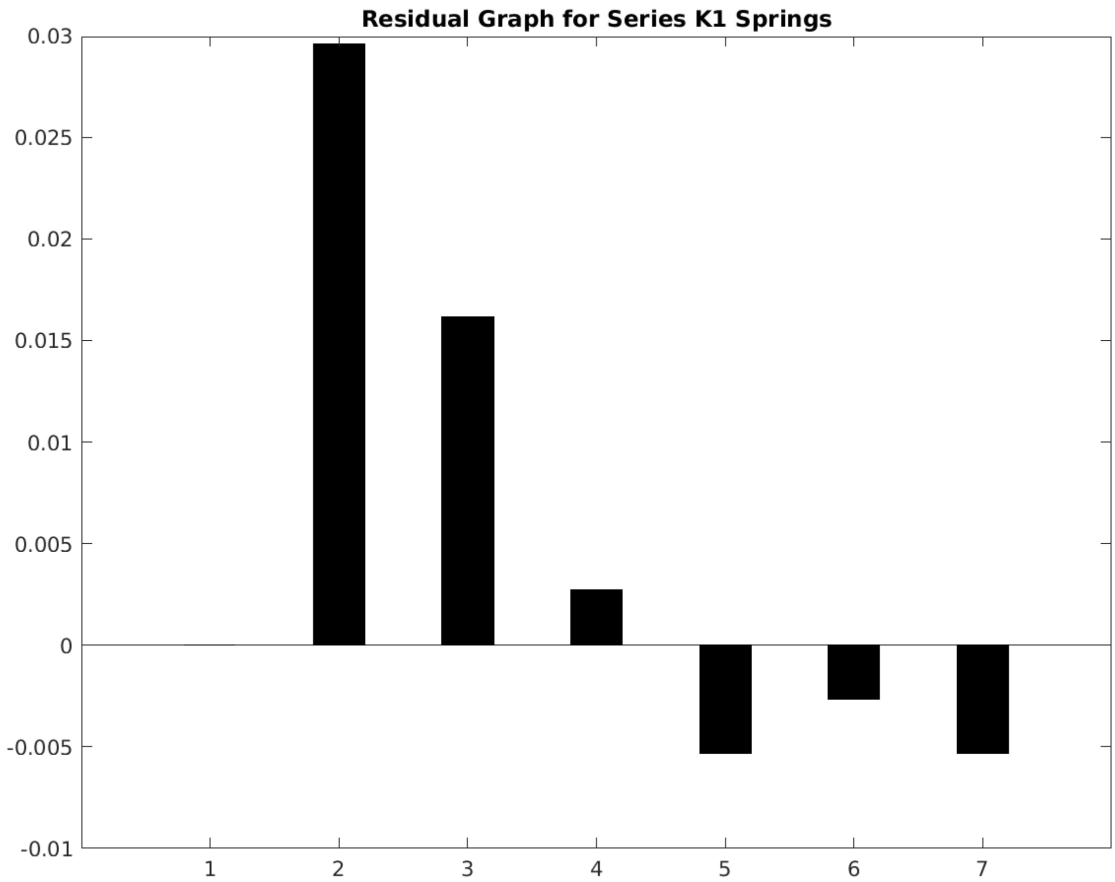


Figure 2.6: Residual Plot for K1 Springs in Series

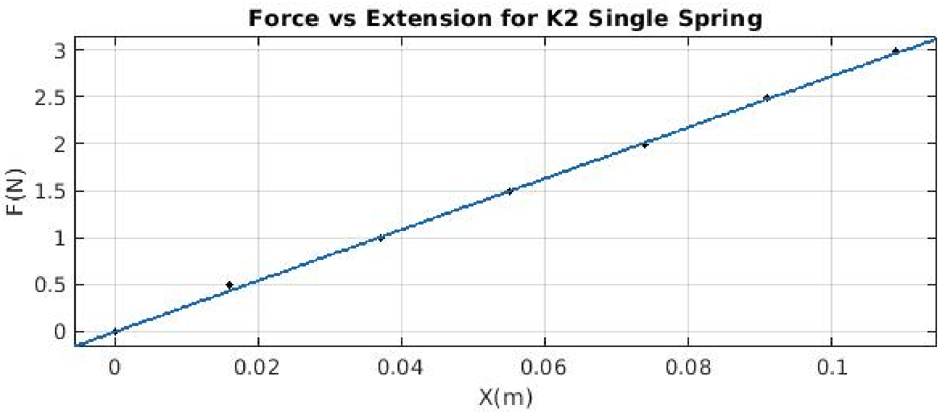


Figure 2.7: Graph of Force vs Extension for Single Spring K2

$$K2_{single} = 27.25N/m$$

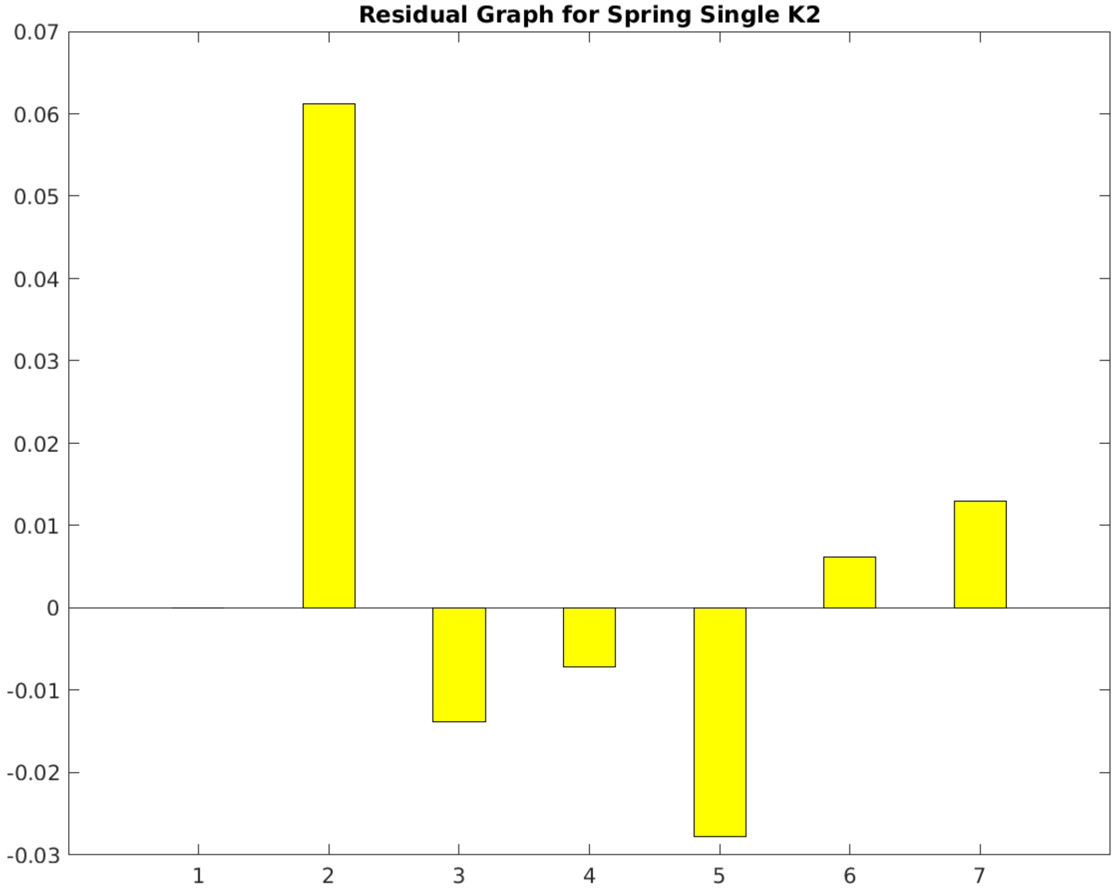


Figure 2.8: Residual Plot for Single K2 Spring

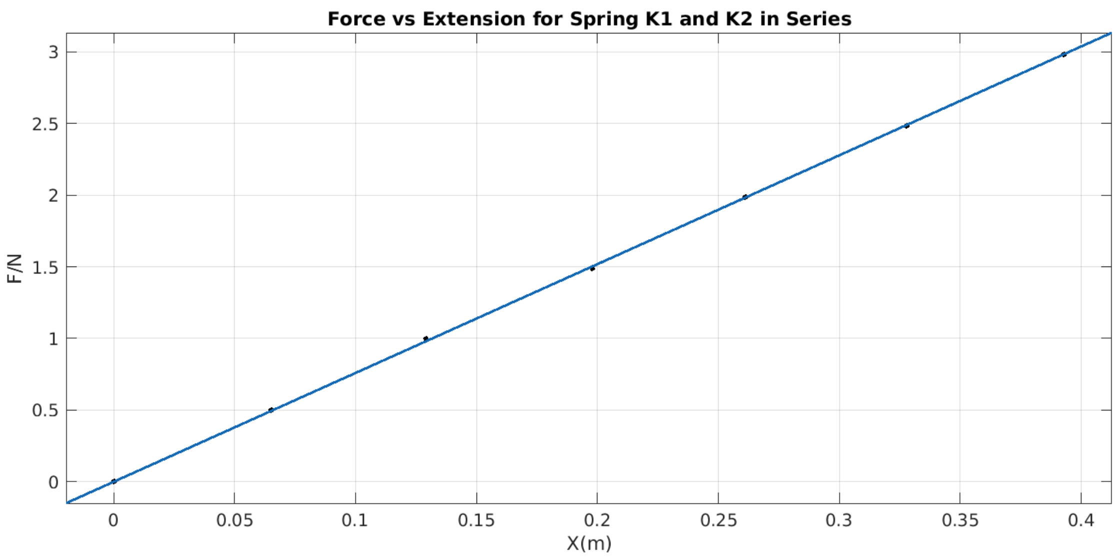


Figure 2.9: Graph of Force vs Extension for Spring K1 and K2 in series

$$K1andK2_{series} = 7.593N/m$$

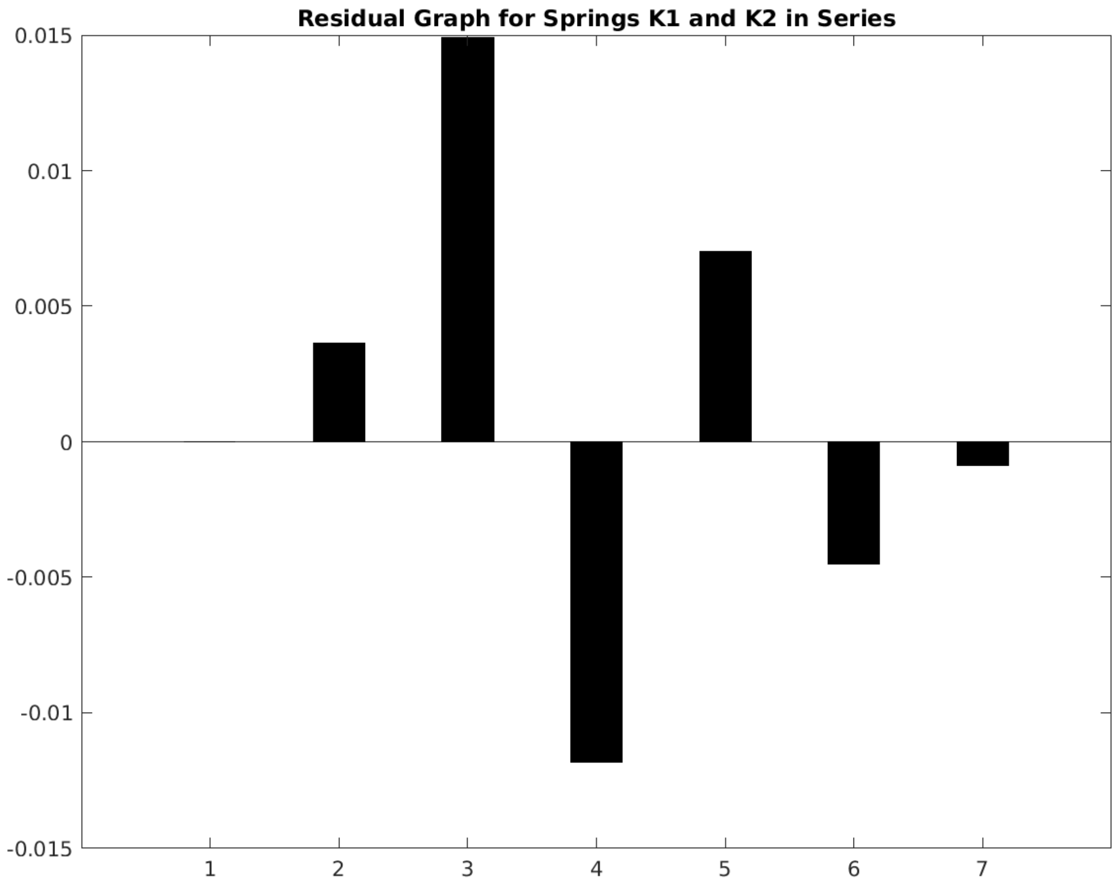


Figure 2.10: Residual Plot for Parallel Springs K1 and K2 in Series

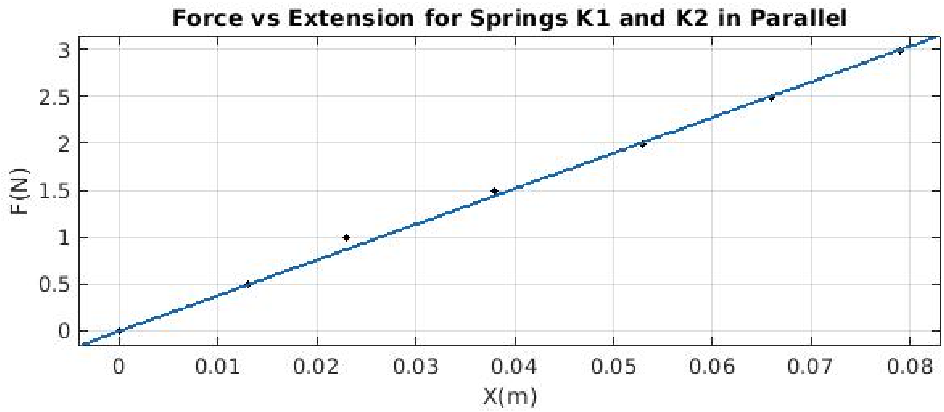


Figure 2.11: Graph of Force vs Extension for Springs K1 and K2 in Parallel

$$K1andK2_{Parallel} = 38.02N/m$$

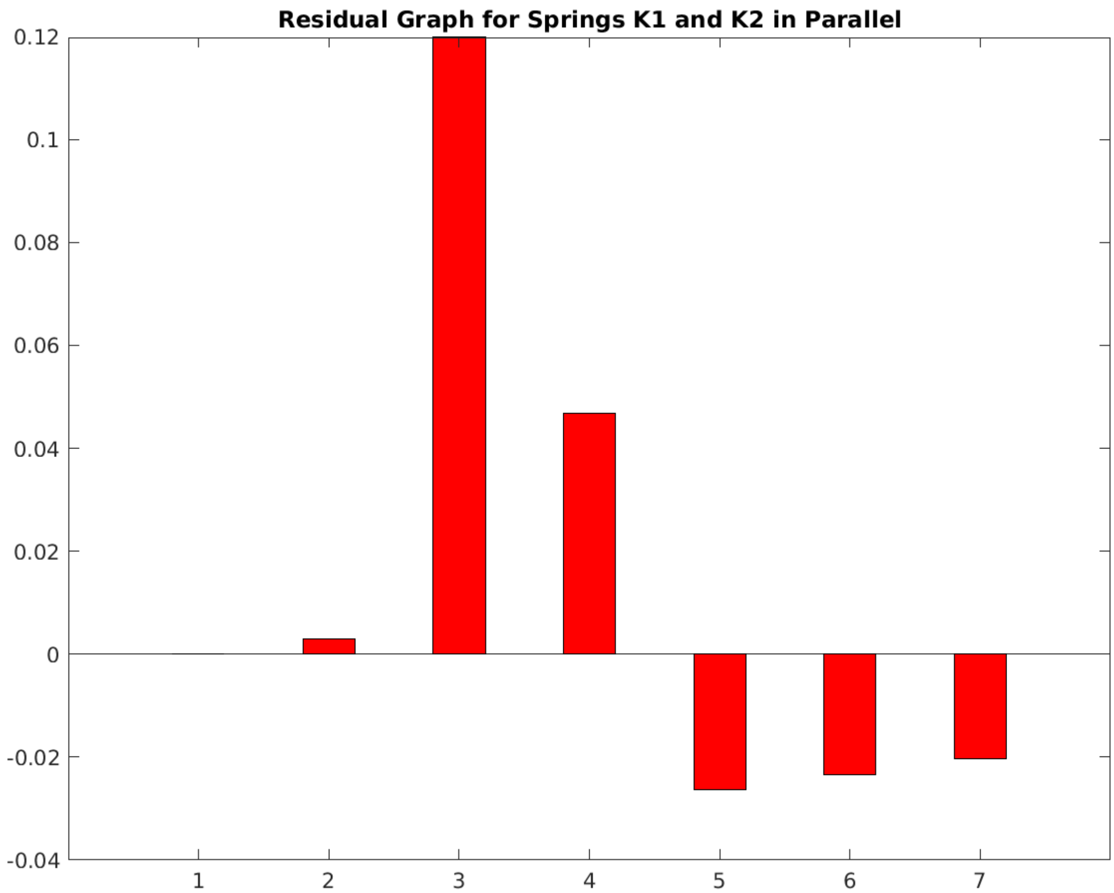


Figure 2.12: Residual Plot for Parallel Springs K1 and K2 in Parallel

Theoretical value of K1 and K2 in series = $7.695 N/m$

Theoretical value of K1 and K2 in Parallel = $37.97 N/m$

2.7 Discussion & Conclusion

The theoretical and experimental values are the following: 7.593 experimental and 7.695 is experimental values of spring constant for series, they have an error of 0.1 which is quite small. For parallel experimental value is 38.02 and theoretical is 37.97, with error of 0.05. We can also see the random pattern in the residual plots that indicate random errors. Our experimental values are closely matching with theoretical values so our hypothesis is supported by this experiment.

Possible factors of uncertainty and errors can be varying shape of spring, if we attach weights that exceed the springs the springs elastic limit then the spring can deform.

2.8 MATLAB Script

```
Mass_kg = Mass_g./1000;
Weight_N = Mass_kg * 9.80665;

% K1 - single
K1_single_m = K1_single_cm./100;
Residual_1 = Weight_N - K1_single_m.*10.72;
figure;
bar(Residual_1,0.4,"cyan")
title("Residual Graph for Spring Single K1")

% y = 10.72 x

% K1 - parallel
K1_parallel_m = K1_parallel_cm./100;
```

```
Residual_2 = Weight_N - K1_parallel_m.*21;
figure;
bar(Residual_2,0.4,"m")
title("Residual Graph for Parallel K1 Springs")

% y = 21 x

% K1 - series
K1_series_m = K1_series_cm./100;
Residual_3 = Weight_N - K1_series_m.*5.375;
figure;
bar(Residual_3,0.4,"black")
title("Residual Graph for Series K1 Springs")
% y = 5.375 x

% K2 - Single
K2_single_m = K2_single_cm./100;
Residual_4 = Weight_N - K2_single_m.*27.25;
figure;
bar(Residual_4,0.4,"y")



% y = 27.25 x

% K1 + K2 - Series
K1_K2_series_m = K1_K2_series_cm./100;
Residual_5 = Weight_N - K1_K2_series_m.*7.593;
figure;
bar(Residual_5,0.4,"k")
```

```
% y = 7.593 x

% K1 + K2 - Parallel
K1_K2_parrallel_m = K1_K2_parallel_cm./100;
Residual_6 = Weight_N - K1_K2_parrallel_m.*38.02;
figure;
bar(Residual_6,0.4,"red")

% y = 38.02 x
```

Experiment 3

DAMPING CONSTANT OF A DAMPED HARMONIC OSCILLATOR

Date: 21/9/2020

3.1 Aim

In the experiment we aim to measure the damping constant by examining the amplitude of an under damped harmonic oscillator in air using different length pendulums. We observe the change in frequency and model it against curve fitting using data from CASSY software.

3.2 Background Theory

Acceleration in Simple Harmonic Motion is proportional to the displacement from the start position with a negative sign. When an object that is oscillating moves towards its extreme the negative sign slows it and speeds it up when it is near the mean position. Mathematically, position of pendulum is

$$x(t) = x_0 \cos(\omega t + \phi)$$

with x_0 as distance of pendulum from center that is maximum, ω is a constant and ϕ is phase angle. These characteristics are without damping where amplitude remains constant. For a damped harmonic oscillator, damping force is

$$F_{damping} = -bv(t)$$

where it is linearly scaled and dependent on speed. Damping constant gives an equation of

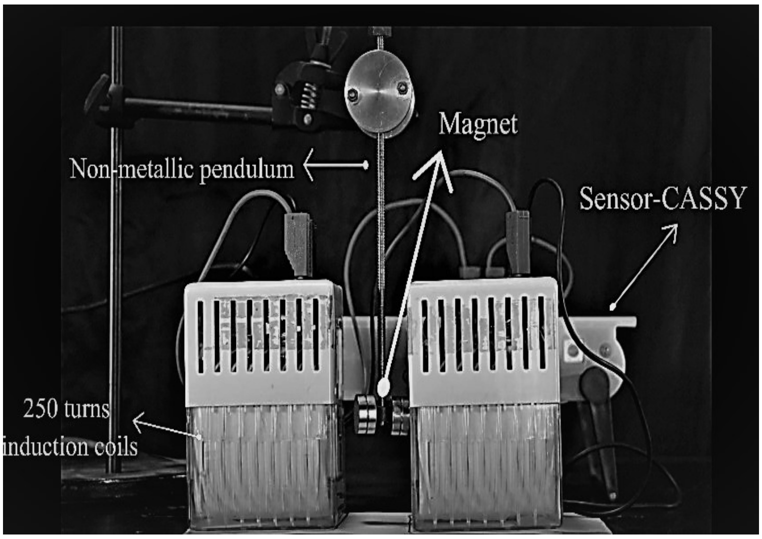
$$m\frac{d^2x(t)}{dt^2} + b\frac{dx(t)}{dt} + \omega^2 x(t) = 0$$

To check whether oscillator is under damped the condition $b^2 - 4m\omega^2 < 0$ should be satisfied and $b^2 - 4m\omega^2 > 0$ and $b^2 - 4m\omega^2 = 0$ holds for over damped and critically damped oscillator. Equation of motion for a damped oscillator is

$$x(t) = Aexp(-\gamma t)\cos(\Omega t + \phi)$$

where γ is damping constant and Ω is frequency of damped oscillator. They are given by the following equations: $\gamma = b/2m$ and $\Omega = \sqrt{b^2 - 4m\omega^2}$

3.3 Description of Setup



A Non-metallic pendulum is suspended with two magnets, two 250 turns induction coils and a CASSY Sensor is attatched as above to record the motion and amplitude of the oscillator that is damped in air.A rule was used to take the measurement of the length of the pendulum.

3.4 Method / Procedure

The length of the pendulum is measured using the metre Rule. The two coils were placed close to the magnets and the pendulum was oscillated. CASSY was used to record the data for 50 seconds to view damping. The same process is repeated 3 times for different pendulum lengths.

Data of the length of pendulum and its amplitude with time was collected to analyse damping.

3.5 Data

Since the length of the pendulum was only measured once , it does not have type A uncertainty. The type B uncertainty associated is 0.0002m.

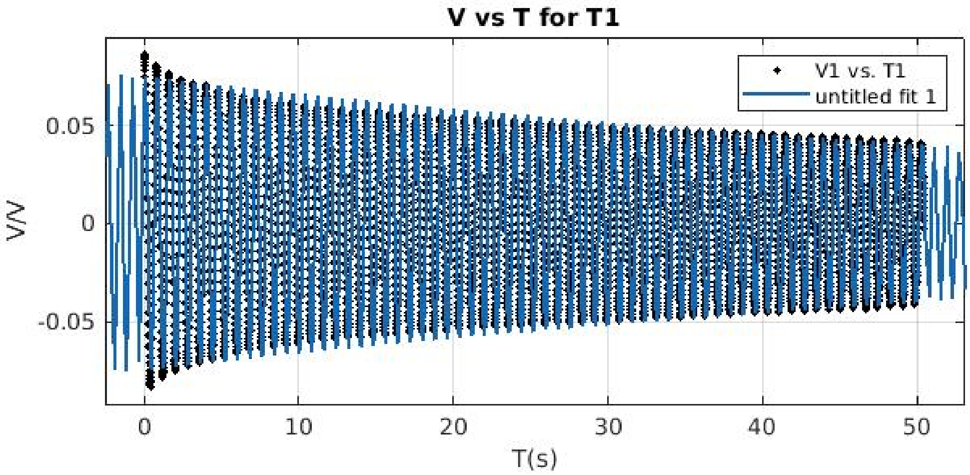


Figure 3.1: Graph of V vs T

$$x(t) = 0.07449^{-0.01244t} \times cos(7.873t - 0.08103)$$

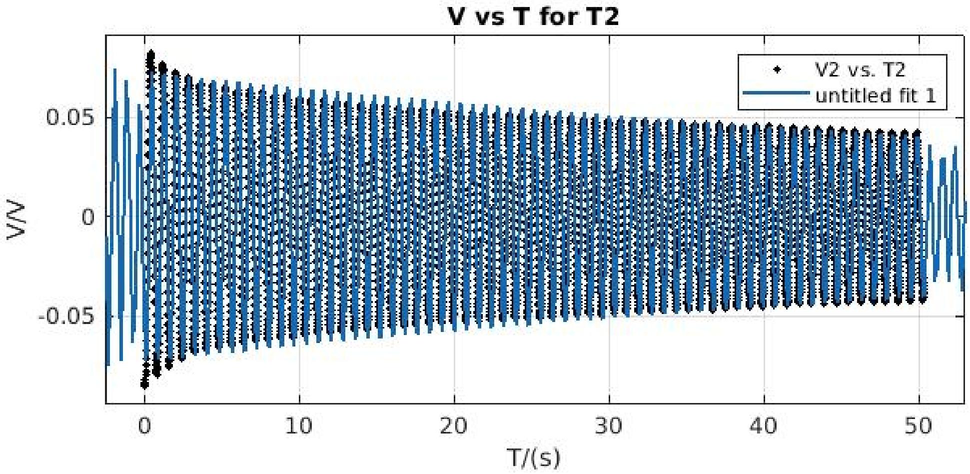


Figure 3.2: Graph of V vs T

$$x(t) = -0.07236^{-0.01184t} \times cos(7.882t - 0.42)$$

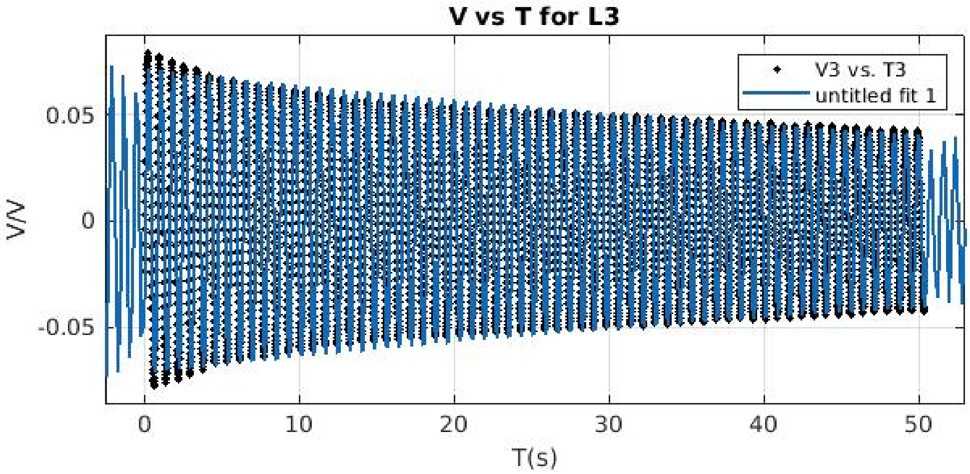


Figure 3.3: Graph of V vs T

$$x(t) = 0.07135^{-0.01141t} \times cos(7.965t - 1.922)$$

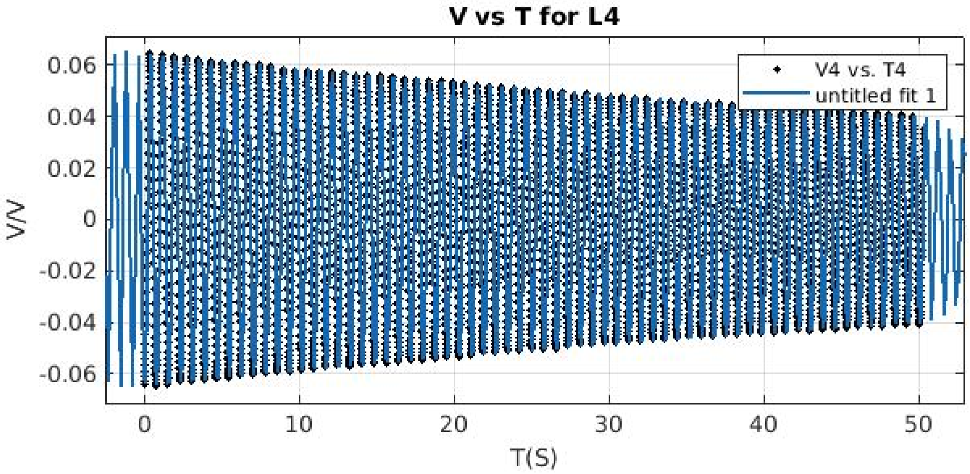


Figure 3.4: Graph of V vs T

$$x(t) = -0.06439^{-0.009528t} \times cos(8.031t - 0.1526)$$

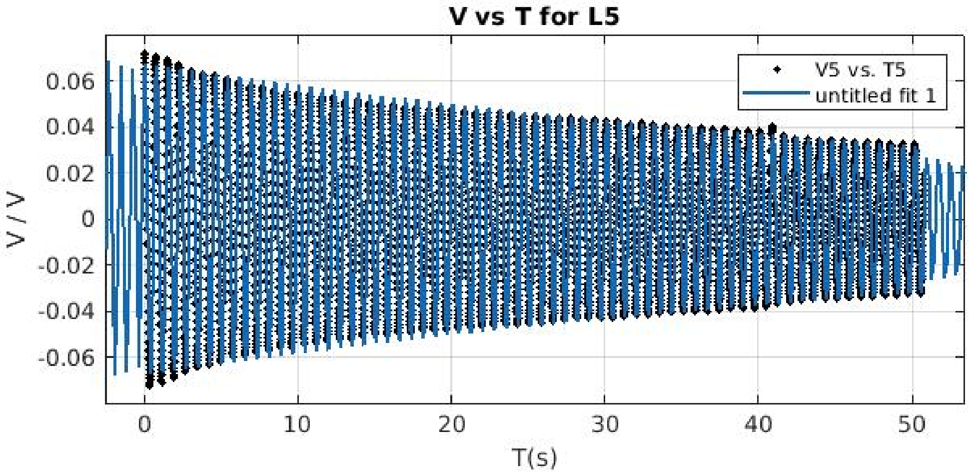


Figure 3.5: Graph of V vs T

$$x(t) = 0.0673^{-0.01495t} \times cos(8.142t - 0.07685)$$

3.6 Data Analysis

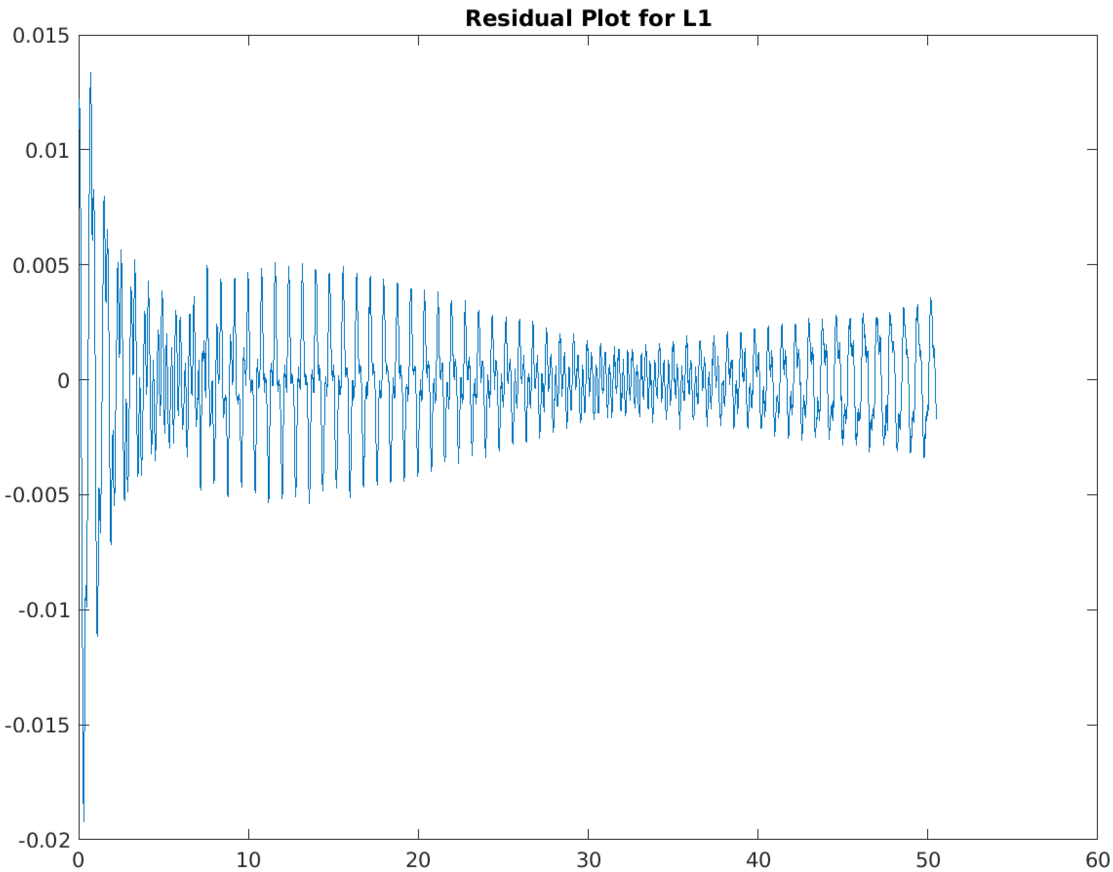


Figure 3.6: Residual Plot for L1

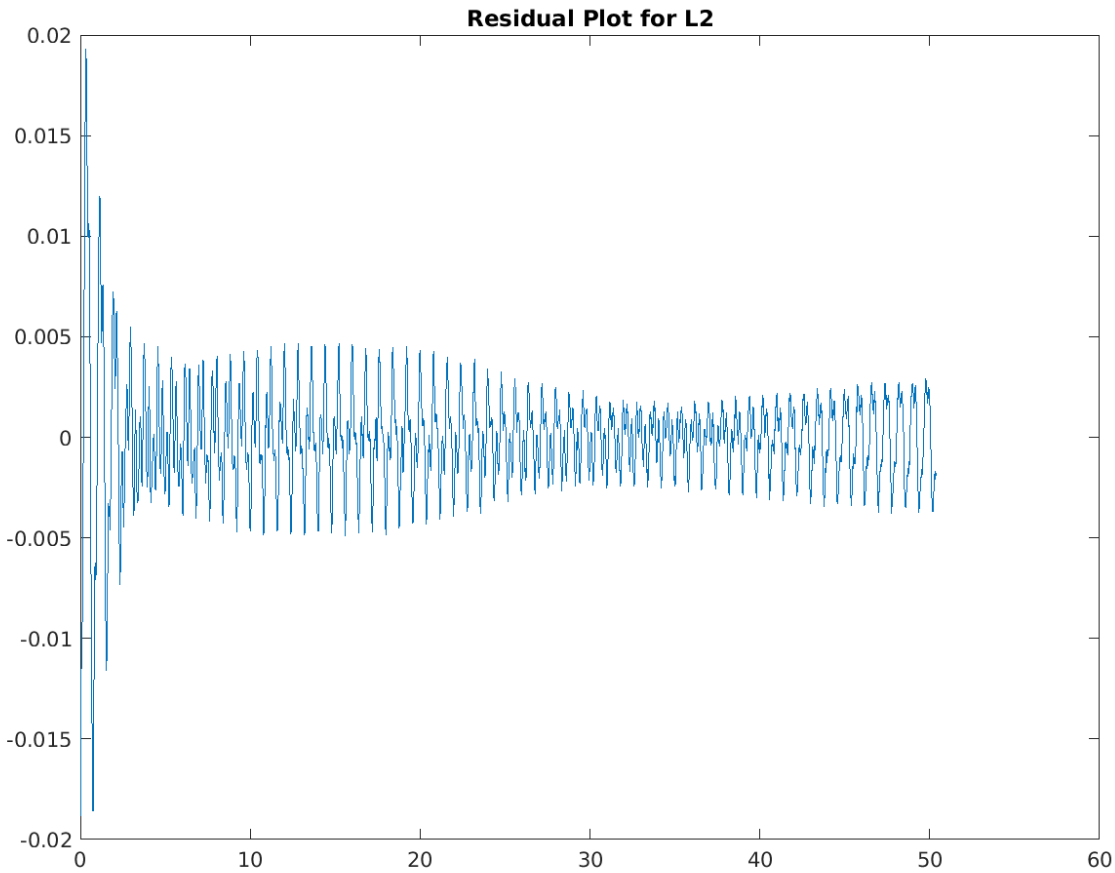


Figure 3.7: Residual Plot for L2

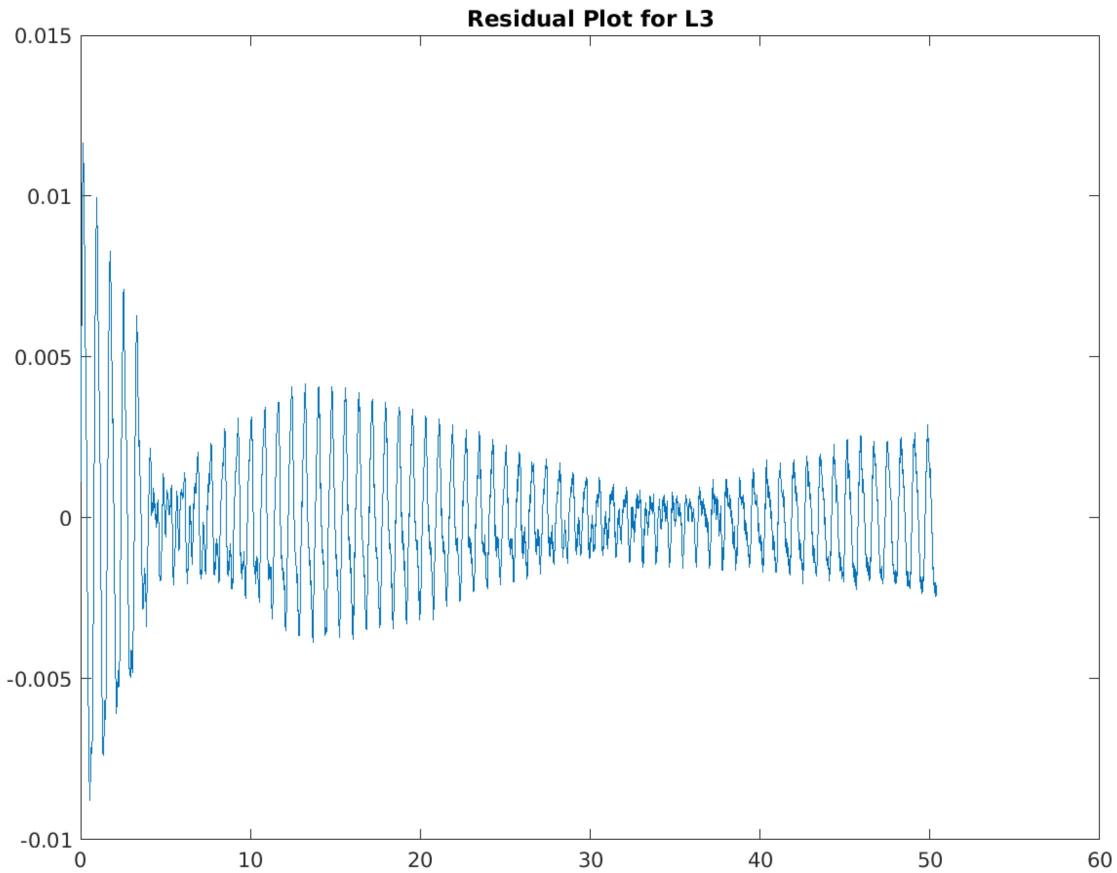


Figure 3.8: Residual Plot for L3

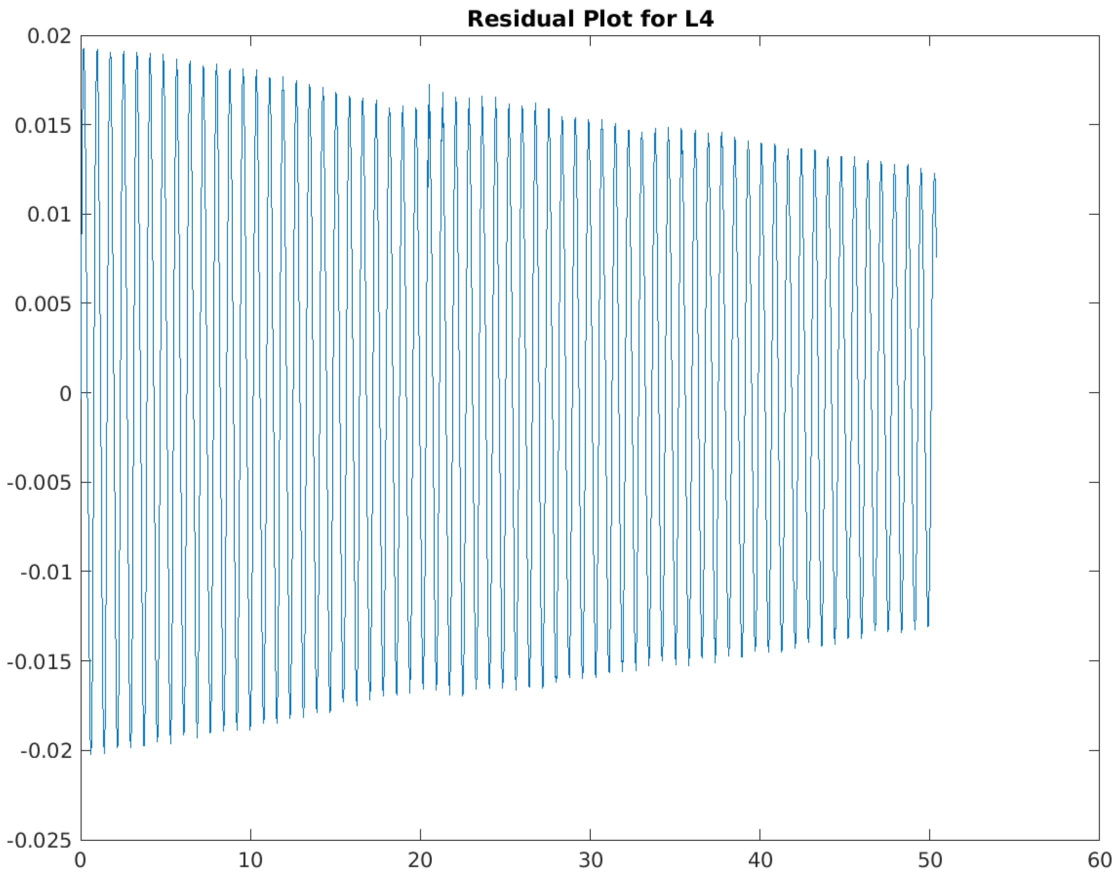


Figure 3.9: Residual Plot for L4

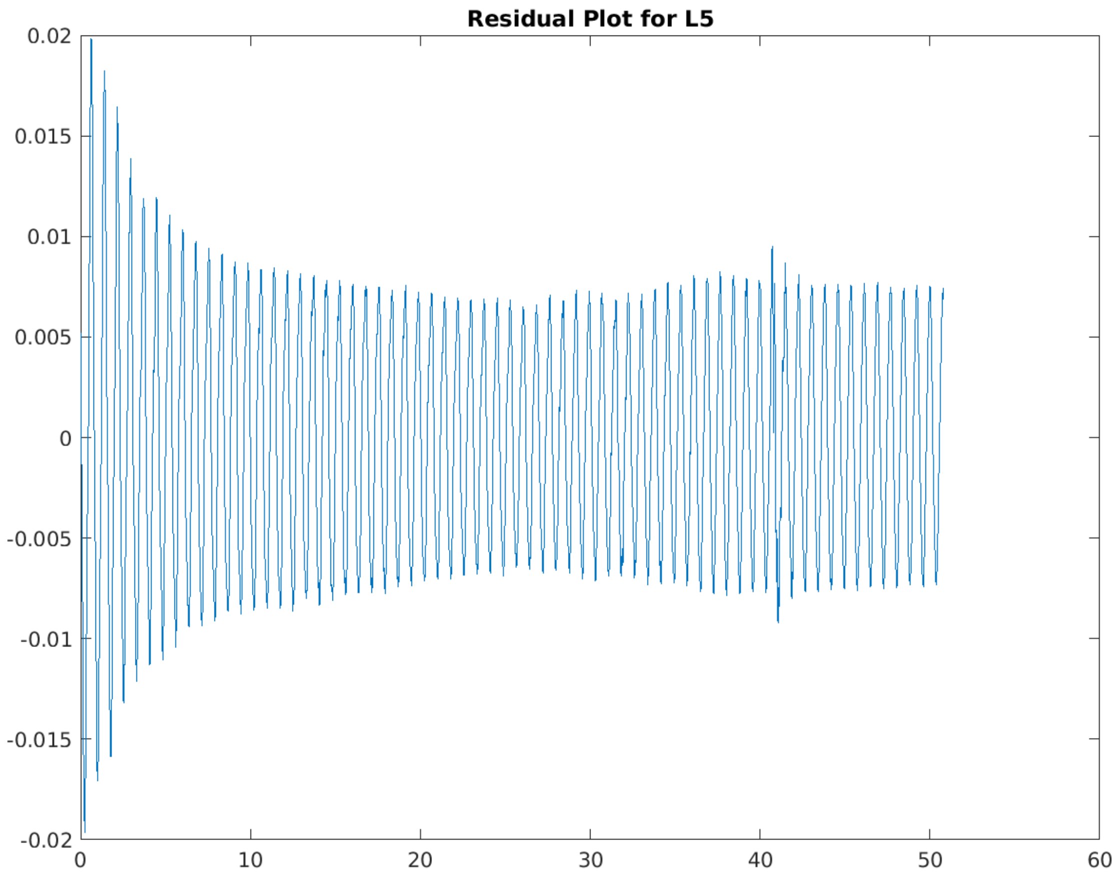


Figure 3.10: Residual Plot for L5

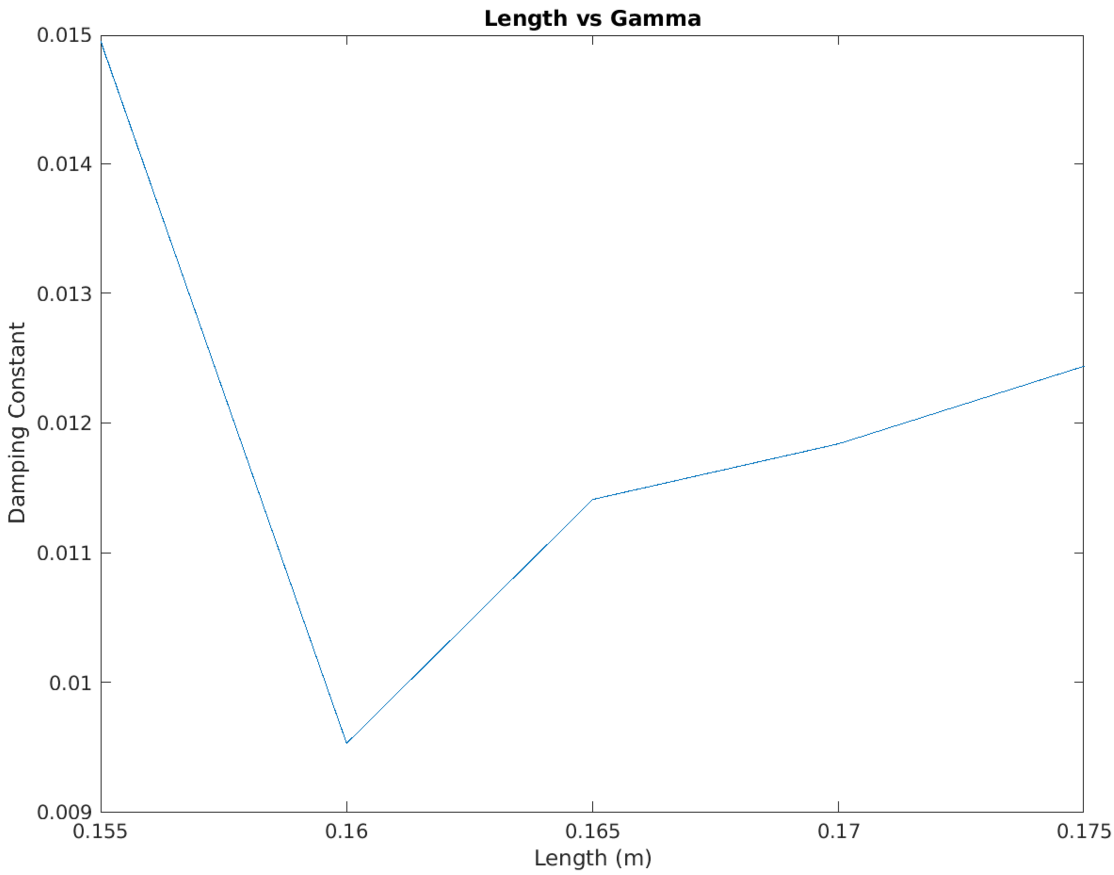


Figure 3.11: Graph of Length vs Damping Constant

3.7 Discussion & Conclusion

The graph of the the damping constants vs length and the residual plots show have random pattern which indicate the presence of random errors. The experiment could have been improved by ensuring that there was no wind in the room while doing the experiment.

3.8 MATLAB Script

```
m_v1 = 0.07449*exp(-0.01244.*T1).*cos(7.873.*T1 -0.08103)
    ;
r1 = V1 - m_v1;
% Residual Plot
figure
```

```
plot(T1,r1);
title("Residual Plot for L1")


m_v2 = -0.07236*exp(-0.01184.*T2).*cos(7.882.*T2-0.42);
figure
r2 = V2 - m_v2;

plot(T2,r2);
title("Residual Plot for L2")

m_v3 = 0.07135*exp(-0.01141.*T3).*cos(7.965.*T3-1.922);
figure
r3 = V3 - m_v3;
plot(T3,r3);
title("Residual Plot for L3")

m_v4 = -0.06439*exp(-0.009528.*T4).*cos(8.031*T4-0.1526);
figure
r4 = V4 - m_v4;
plot(T4,r4);
title("Residual Plot for L4")

m_v5 = 0.0673*exp(-0.01495.*T5).*cos(8.142.*T5 - 0.07685)
    ;
figure
r5 = V5 - m_v5;
plot(T5,r5)
title("Residual Plot for L5")
```

```
L = [0.175 0.170 0.165 0.160 0.155];

gamma = [0.01244 0.01184 0.01141 0.009528 0.01495];

figure
plot(L,gamma)
title('Length vs Gamma')
xlabel ('Length (m)')
ylabel ('Damping Constant')
```

Date: 15/08/2020

=-

Experiment 4

ENERGY CONSERVATION BETWEEN 2D MOTIONS

4.1 Aim

In this experiment, our aim is to understand how energy is transferred when objects collide by varying the angle at which an object is released to collide with another.

4.2 Background Theory

According to principle of physics energy is always conserved in a close system. Therefore, energy can be in different firms but the total energy remains the same. Energy for a moving object is kinetic energy and can be calculated using

$$E = \frac{1}{2}mv^2$$

and gravitational potential energy is when an object is stationary at a height and is has the ability to move. It is given by the equation

$$E = mgh$$

For an object in projectile motion the position of body in x and y position are as following:

$$x(t) = x_0 + v_{0,x}t$$

$$y(t) = y_0 + v_{0,y}t - \frac{1}{2}gt^2$$

There is no acceleration in the horizontal direction, just a constant velocity but in the vertical direction there is constant acceleration. When two objects collide, the distance that the ball will reach the ground is

$$d = 2\sqrt{hL(1 - \cos(\theta)}$$

where h denotes height pf collision, L is length of pendulum, θ is angle from which the swinging pendulum is placed.

4.3 Description of Setup

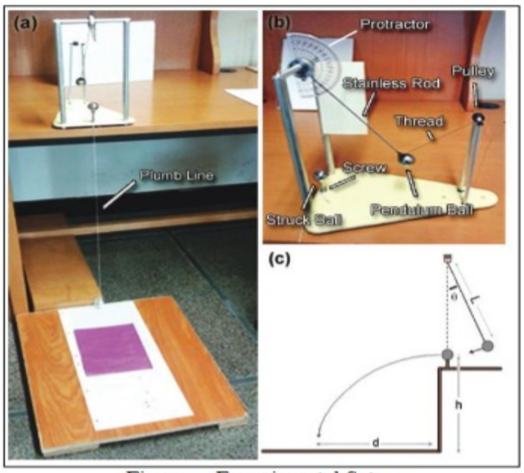


Figure 1: Experimental Setup

Here a pendulum is strung over a pulley with a fixed protractor and a metal ball is placed as shown in the figure. White sheets are placed below with a carbon paper on top to locate the position of the ball when released. A meter rule is also required.

4.4 Method / Procedure

The vertical height from the center of the ball to the ground is measured and marked. White papers are fixed to the ground with carbon paper on top. The pendulum is held at a high position at an angle of 30 measured through the fixed protractor on the pendulum and swung. It strikes the ball which follows a parabolic path and strikes the carbon sheet placed on the white papers on the floor. Repeat this process four times at the same angle. The same steps should be repeated at an angle of 40, 50 and 60 degrees and 5 readings should be taken at each angle. The length, d, of all the points of impact from initial position is measured and compared with theoretical predictions. .

4.5 Data

In this experiment, the constants h and L were only measured once and therefore don't have any Type A uncertainty. The type B uncertainty associated with both h and L is respectively 0.0002m. Consequently, $h = 0.935 \pm 0.0002$m and $L = 0.25 \pm 0.0002m$. The angle θ was also only measured only it doesn't have type A uncertainty. The type B associated with the angle θ is 0.04 degrees. The distance d was measured multiple and therefore it has both type B and type A uncertainty. The recorded values for the angle θ

s.No	**Angle**	**angle (°)**
1	A1	30
2	A2	40
3	A3	50
4	A4	60

The values measured for the distance d (cm).

s.No	**d_A1 (cm)**	**d_A2 (cm)**	**d_A3 (cm)**	**d_A4 (cm)**
1	30.5	42.7	55	64.7
2	31.5	43.3	55.7	63.8
3	31.8	43	57.7	65.4
4	32.7	44.6	54	65.3
5	31.4	43.5	54.8	64.7

Type A uncertainty in distance d when Angle($\theta = 30$)

$$\sigma_d = 0.0071m$$
$$U_d^A = 0.0035m$$

Type A uncertainty in distance d when Angle($\theta = 40$)

$$\sigma_d = 0.0065m$$
$$U_d^A = 0.0032m$$

Type A uncertainty in distance d when Angle($\theta = 50$)

$$\sigma_d = 0.0125m$$
$$U_d^A = 0.0063m$$

Type A uncertainty in distance d when Angle($\theta = 60$)

$$\sigma_d = 0.0057m$$
$$U_d^A = 0.0029m$$

4.6 Data Analysis

We will calculate the expected value for d using the following formula

$$d = 2\sqrt{hL(1 - cos(\theta))}$$

where h and L are constants with the values $h = 0.935m$ and $L = 0.25m$

s.No	Angle(°)	Expected value of d(m)
1	30	0.3539
2	40	0.4677
3	50	0.5779
4	60	0.6837

Average Value of the distance d for each value of the Angle(θ)

s.No	Angle(°)	Avg_d (cm)	Avg_d(m)
1	30	31.58	0.316
2	40	43.42	0.434
3	50	55.44	0.554
4	60	64.78	0.648

The graph of average distance d vs Angle (θ)

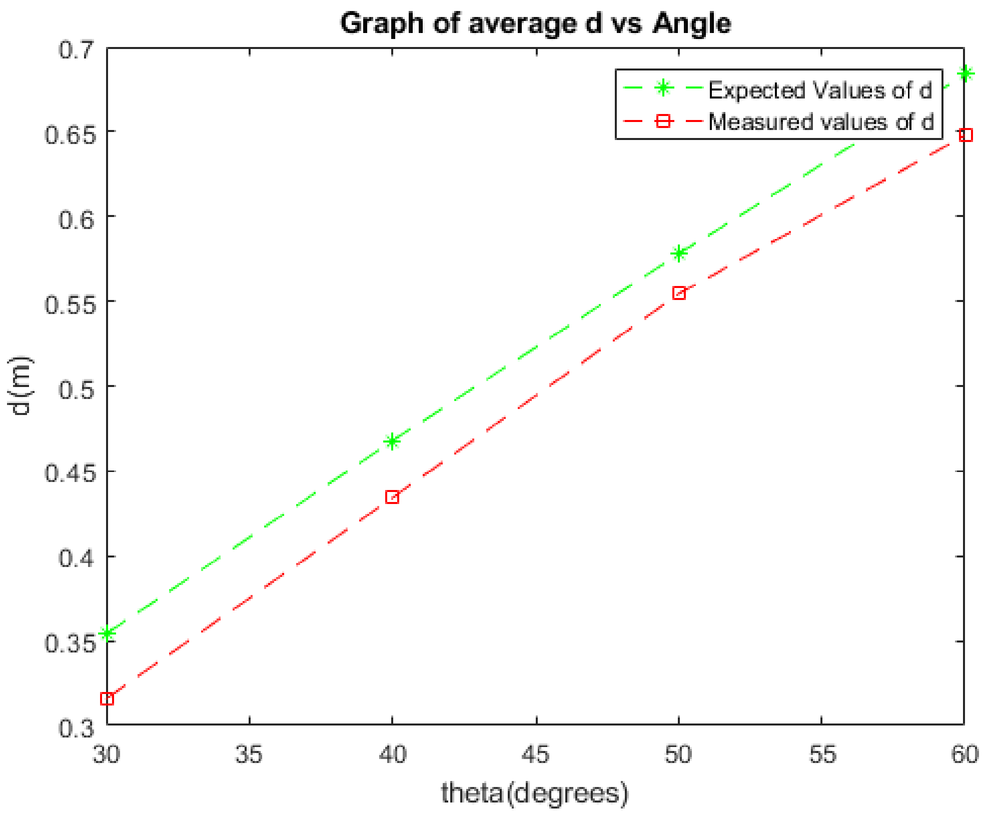


Figure 4.1: Graph of Average d vs Angle (θ)

Residual plot for d as when $\theta = 30$

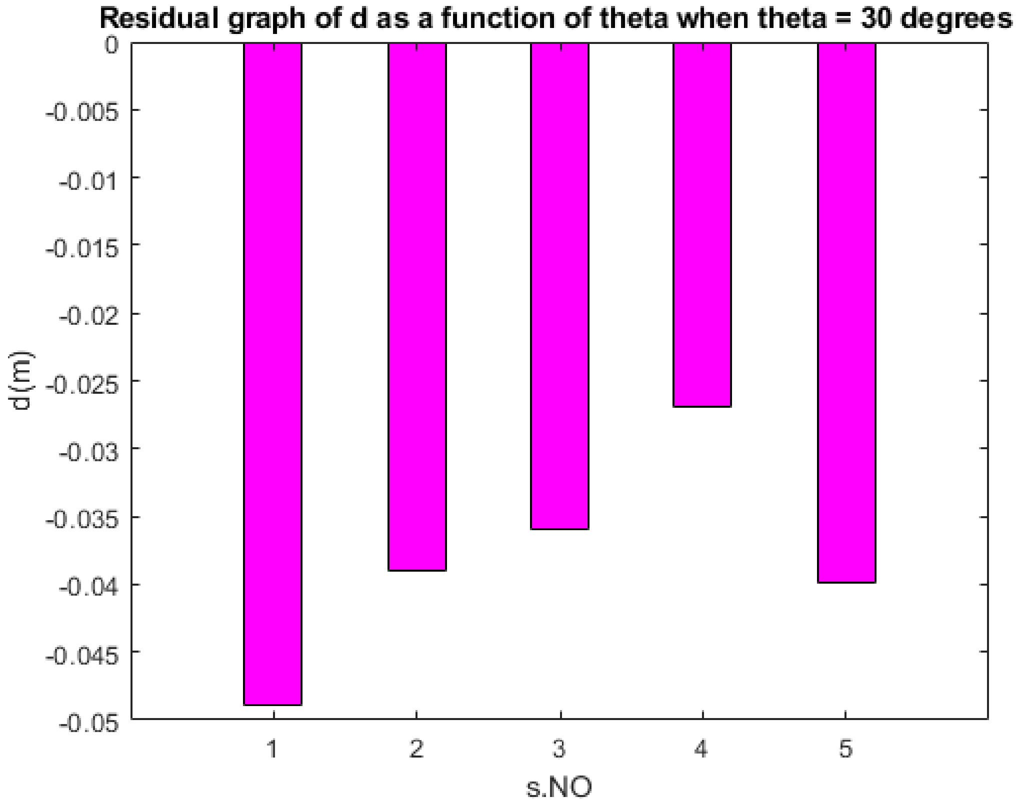


Figure 4.2: Residual Plot for d when Angle (θ = 30)

Residual plot for d as when $\theta = 40$

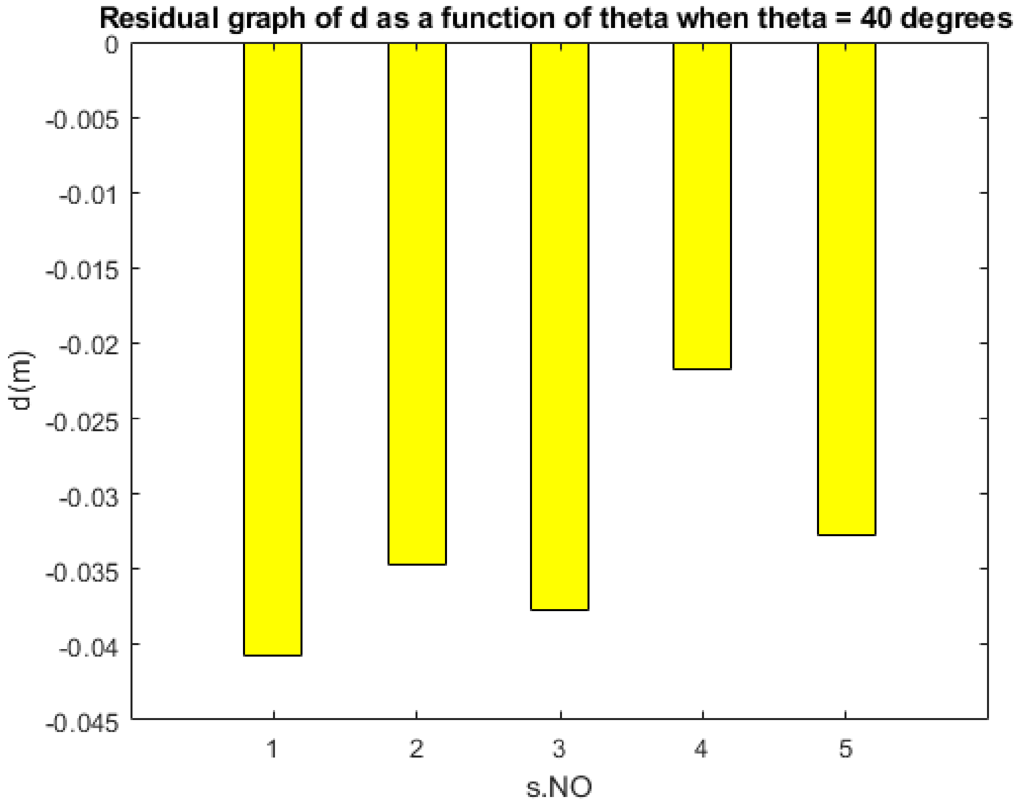


Figure 4.3: Residual Plot for d when Angle(θ = 40)

Residual plot for d as when $\theta = 50$

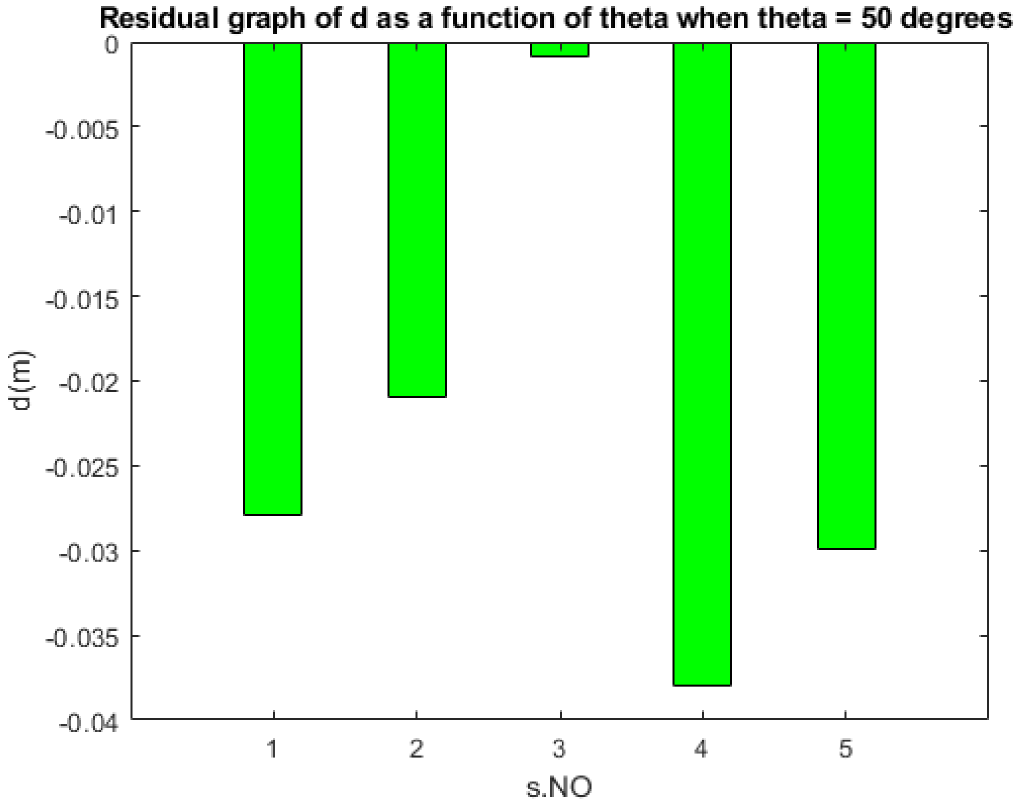


Figure 4.4: Residual Plot for d when Angle (θ = 50)

Residual plot for d as when $\theta = 60$ We can transfer uncertainty from Angle(θ) to

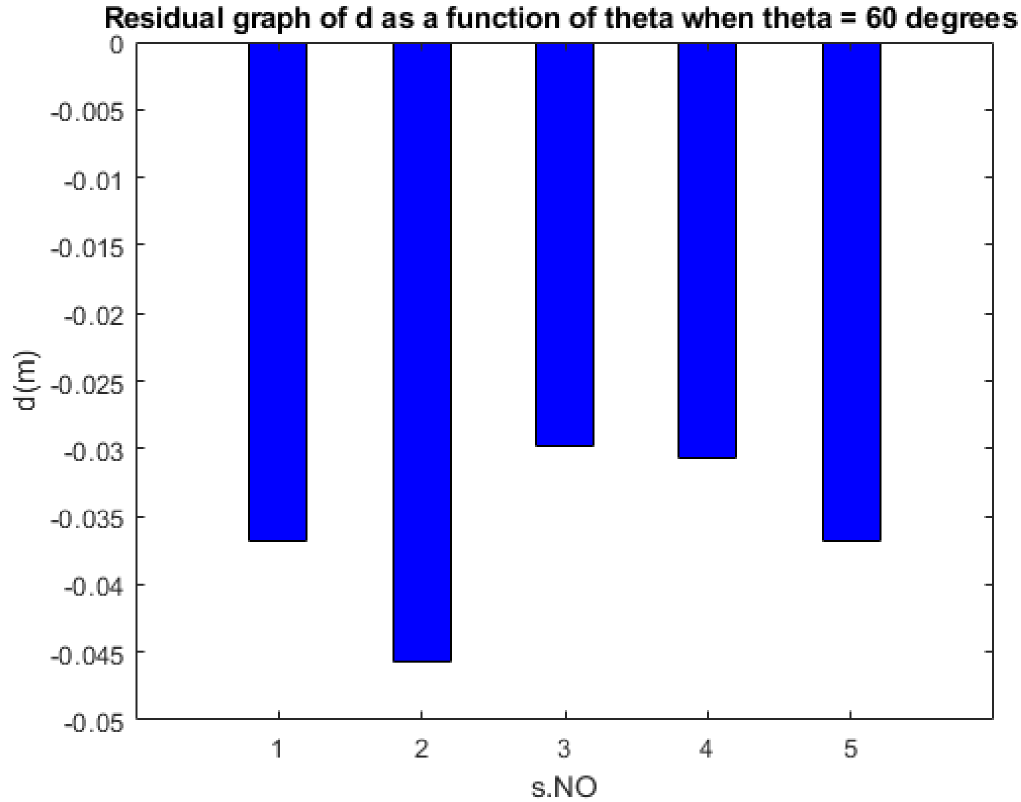


Figure 4.5: Residual Plot for d when Angle ($\theta = 60$)

distance (d) using the following formula:

$$U_d = \sqrt{{U_T^A}^2 + {U_T^B}^2 + \left(\frac{\sqrt{hL}sin(\theta)\Delta\theta}{\sqrt{1 - cos(\theta)}}\right)^2}$$

Expected value of d(m)	Total Uncertainty in d(m)	Final Value(m)
0.316	0.0272	0.316 ± 0.027
0.434	0.0264	0.434 ± 0.026
0.554	0.0261	0.554 ± 0.061
0.648	0.0243	0.648 ± 0.024

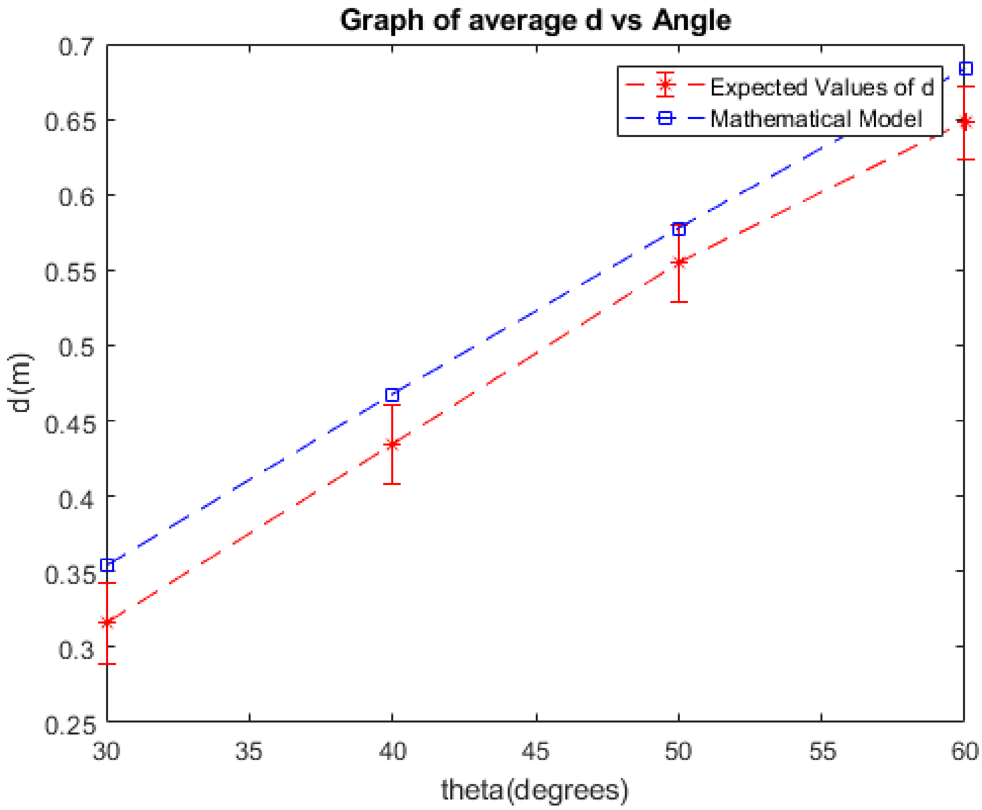


Figure 4.6: Graph of d vs Angle(θ)

4.7 Discussion & Conclusion

For our experiment and data, we can evaluate that at angle 30, theoretical value of d should be 0.3539 and our experimental value is 0.316 with error of 0.027. The theoretical value does not lie in the range 0.316 ± 0.027. Whereas for angle of 40, and 50 it does but not 60. We can also see that all our measured values are below expected values of d from figure 4.1. This implies that it is difficult to conclude if hypothesis is valid because half values agree with theoretical values. Possible factors of uncertainty could be wind and parallax errors in measuring the distances using metre rule. Air resistance could also cause experimental values to be less than the theoretical values since it acts as an opposing force. Furthermore, it may be difficult to locate exact location of where the ball may have struck first as it may touch several points on the carbon paper. A more accurate set up could have given results with the hypothesis that could include wind blockers, a camera or motion detector to ensure exact location of contact can be recorded. To deduce a better conclusion, the experiment should be carried out on multiple angles or in a setup to minimize air resistance so that a conclusion may be reached.

4.8 MATLAB Script

```
% Value of H and uncertanity in H
h_cm = 93.5;
h_m = 0.935;
U_h = (0.0005)/(6^0.5);

% Value of L and uncertainty in L
L_cm = 25;
L_m = 0.25;
U_L = (0.0005)/(6^0.5);

% Type B Uncertainity in Angle
U_b_Angle = (0.1)/(6^0.5);

% Type B uncertainity in d
U_B_d = (0.0005)/(6^0.5);

d_A1_m = d_A1/100;
d_A2_m = d_A2/100;
d_A3_m = d_A3/100;
d_A4_m = d_A4/100;
avg_d_m = [mean(d_A1_m) mean(d_A2_m) mean(d_A3_m) mean(
    d_A4_m)];

% Type A uncertainty in d
```

```
U_A_d_A1 = std(d_A1_m,1)/sqrt(5-1);
U_A_d_A2 = std(d_A2_m,1)/sqrt(5-1);
U_A_d_A3 = std(d_A3_m,1)/sqrt(5-1);
U_A_d_A4 = std(d_A4_m,1)/sqrt(5-1);


% Theorotical Model
% d = 2*(hL(1-cos(theta)))^0.5


% Angle(theta) = 30

%1. Expected Value
exp_d_A1 = 2*(h_m*L_m*(1-cosd(30))).^0.5;
%2. Residual Plot
d_A1_r = d_A1_m - exp_d_A1 ;
figure;
bar(d_A1_r,0.4,"m")
title("Residual graph of d as a function of theta when
   theta = 30 degrees ")
ylabel("d(m)")
xlabel("s.NO")



% Angle(theta) = 40
%1. Expected Value
exp_d_A2 = 2*(h_m*L_m*(1-cosd(40))).^0.5;
%2. Residual Plot
```

```
d_A2_r = d_A2_m - exp_d_A2 ;
figure;
bar(d_A2_r,0.4,"y")
title("Residual graph of d as a function of theta when
    theta = 40 degrees ")
ylabel("d(m)")
xlabel("s.NO")

% Angle(theta) = 50
%1. Expected Value
exp_d_A3 = 2*(h_m*L_m*(1-cosd(50))).^0.5;
%2. Residual Plot
d_A3_r = d_A3_m - exp_d_A3 ;
figure;
bar(d_A3_r,0.4,"g")
title("Residual graph of d as a function of theta when
    theta = 50 degrees ")
ylabel("d(m)")
xlabel("s.NO")

% Angle(theta) = 60
%1. Expected Value
exp_d_A4 = 2*((h_m*L_m*(1-cosd(60)))^0.5);
%2. Residual Plot
d_A4_r = d_A4_m - exp_d_A4 ;
figure;
bar(d_A4_r,0.4,"b")
title("Residual graph of d as a function of theta when
    theta = 60 degrees ")
```

```
ylabel("d(m)")
xlabel("s.NO")


%Transfer the uncertainity in angle to d
U_d_1 = (( ((h_m*L_m)^0.5*(sind(30))*U_b_Angle)/(1-cosd
    (30))^0.5   )^2+(U_B_d)^2+(U_A_d_A1)^2)^0.5;
U_d_2 = (( ((h_m*L_m)^0.5*(sind(40))*U_b_Angle)/(1-cosd
    (40))^0.5   )^2+(U_B_d)^2+(U_A_d_A2)^2)^0.5;
U_d_3 = (( ((h_m*L_m)^0.5*(sind(50))*U_b_Angle)/(1-cosd
    (50))^0.5   )^2+(U_B_d)^2+(U_A_d_A3)^2)^0.5;
U_d_4 = (( ((h_m*L_m)^0.5*(sind(60))*U_b_Angle)/(1-cosd
    (60))^0.5   )^2+(U_B_d)^2+(U_A_d_A4)^2)^0.5;
U_d = [U_d_1 U_d_2 U_d_3 U_d_4];
Expected = [exp_d_A1 exp_d_A2 exp_d_A3 exp_d_A4];
figure;
errorbar(Angle,avg_d_m,U_d,'--r*');
hold on
plot(Angle,Expected,'--bs');
legend('Expected Values of d','Mathematical Model');
title('Graph of average d vs Angle');
xlabel('theta(degrees)')
ylabel('d(m)')

figure;
plot(Angle,Expected,'--g*');
hold on
plot(Angle,avg_d_m,'--rs')
legend('Expected Values of d','Measured values of d');
```

```
title('Graph of average d vs Angle');
xlabel('theta(degrees)')
ylabel('d(m)')
```

Experiment 5

CONSERVATION OF LINEAR MOMENTUM

Date: 29/10/2020

5.1 Aim

In this experiment we aim to observe the final velocities of two trolleys, on a track using light gates, that are colliding elastically and in-elastically by varying their masses. We observe their initial velocity and make inferences using data from CASSY software.

5.2 Background Theory

We define Linear momentum for a object of mass m kg and velocity $\vec{v}$ to be

$$\vec{p} = m \times \vec{v}$$

The principle of conservation of momentum states that "If no net force acts upon a system, then there is no change in the total momentum of the system.". This can be expressed mathematically as

$$\vec{p_{initial}} = \vec{p_{final}}$$

In case of an elastic collision, the total momentum and the kinetic energy before and after the collision is conserved. This can be expressed as

$$m_1 \times \vec{v_{i^1}} + m_2 \times \vec{v_{i^2}} = m_1 \times \vec{v_{f^1}} + m_2 \times \vec{v_{i^2}}$$

$$\frac{1}{2} \times (m_1 \times (\vec{v_{i^1}})^2 + m_2 \times (\vec{v_{i^2}})^2) = \frac{1}{2} \times (m_1 \times (\vec{v_{f^1}})^2 + m_2 \times (\vec{v_{i^2}})^2)$$

In case of an in-elastic collision, only the total momentum is conserved. This can be expressed as

$$m_1 \times \vec{v_{i1}} + m_2 \times \vec{v_{i2}} = (m_1 + m_2) \times \vec{v_f}$$

Elastic Collision and $m1 = m2$.

- $\vec{v_{f1}} = \vec{v_{i2}}$
- $\vec{v_{f2}} = \vec{v_{ii}}$

Elastic Collision and $m1 \neq m2$.

- $\vec{v_{f1}} = \frac{m_1 - m_2}{m_1 + m_2} \times \vec{v_{ii}} + \frac{2 \times m_2 \vec{v_{i2}}}{m1 + m2}$
- $\vec{v_{f2}} = \frac{m_2 - m_1}{m_1 + m_2} \times \vec{v_{i1}} + \frac{2 \times m_1 \vec{v_{i1}}}{m1 + m2}$

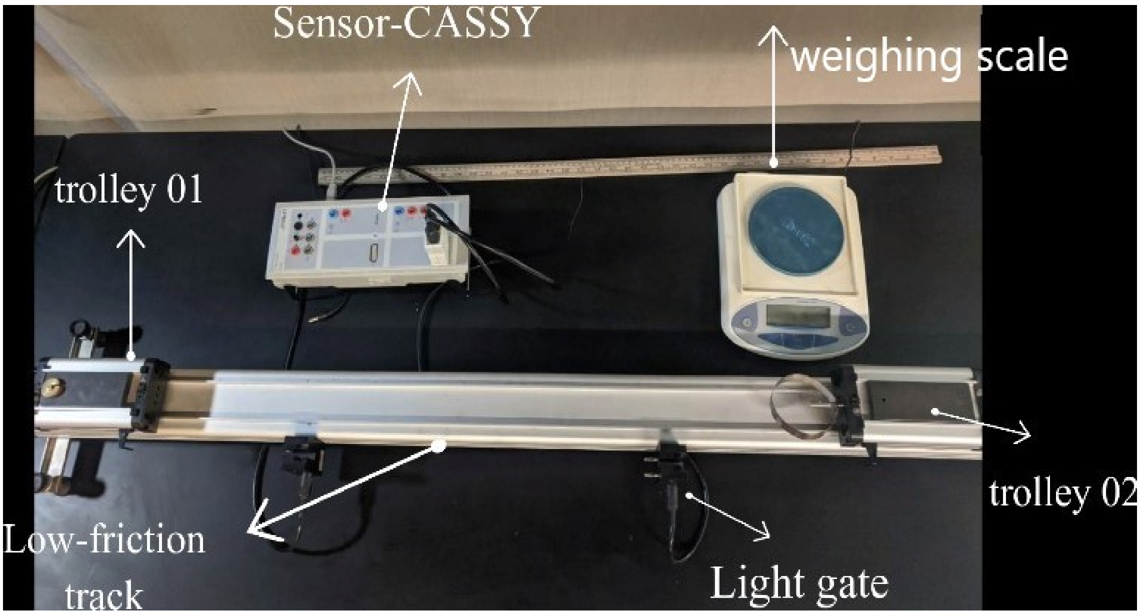
In-Elastic Collision and $m1 = m2$.

- $\vec{v_f} = 0.5 \times \vec{v_{i2}}$

In-Elastic Collision and $m1 \neq m2$.

- $\vec{v_f} = \frac{(m_1 \times \vec{v_{i1}} + m_2 \times \vec{v_{i2}})}{m_1 + m_2}$

5.3 Description of Setup



In the setup above two trolleys with additional weights are placed on a track with light gates. Cassy Software is attached to record data and an electronic balance is used to measure the mass of trolleys.

5.4 Method / Procedure

The CASSY software settings were set up for the conservation of momentum. The masses of trolleys were measured using the balance alongside the spring for elastic collision and the two trolleys were pushed to collide elastically with equal masses. This was repeated five times. Elastic collision was also performed using unbalanced masses and velocities data was seen through CASSY. The same procedure was repeated for inelastic collision with equal masses and unequal masses five times respectively. CASSY was used to collect the data of masses of trolleys and initial and final velocities of trolleys before and after collisions with the help of light gates.

5.5 Data

Elastic Collision (Case a: m1 = m2)						
Serial No	V1-initial - m/s	V2-initial - m/s	V1-final (experiment) - m/s	V1-final (theoretical) - m/s	V2-final (experiment) - m/s	V2-final (theoretical) - m/s
1	0.687	-0.511	-0.453	-0.511	0.679	0.687
2	0.762	-0.83	-0.762	-0.83	0.704	0.762
3	0.55	-0.572	-0.523	-0.572	0.553	0.55
4	0.637	-0.702	-0.634	-0.702	0.63	0.637
5	0.547	-0.611	-0.558	-0.611	0.543	0.547

Elastic Collision (Case b: m1 != m2)						
Serial No	V1-initial - m/s	V2-initial - m/s	V1-final (experiment) - m/s	V1-final (theoretical) - m/s	V2-final (experiment) - m/s	V2-final (theoretical) - m/s
1	0.573	-0.616	-0.178	-0.210155718	0.936	0.978844282
2	0.594	-0.538	-0.154	-0.151611667	0.848	0.980388333
3	0.411	-0.477	-0.156	-0.173896785	0.691	0.714103215
4	0.393	-0.694	-0.299	-0.322971627	0.731	0.764028373
5	0.491	-0.566	-0.18	-0.205211601	0.827	0.851788399

In-Elastic Collision (Case a: m1 = m2)						
Serial No	V1-initial - m/s	V2-initial - m/s	V1-final (experiment) - m/s	V1-final (theoretical) - m/s	V2-final (experiment) - m/s	V2-final (theoretical) - m/s
1	0.535	0	0.26	0.2675	0.262	0.2675
2	0.677	0	0.331	0.3385	0.332	0.3385
3	0.693	0	0.337	0.3465	0.345	0.3465
4	0.584	0	0.258	0.292	0.263	0.292
5	0.616	0	0.298	0.308	0.301	0.308

In-Elastic Collision (Case b: m1 != m2)						
Serial No	V1-initial - m/s	V2-initial - m/s	V1-final (experiment) - m/s	V1-final (theoretical) - m/s	V2-final (experiment) - m/s	V2-final (theoretical) - m/s
1	0.559	-0.521	0.196	0.199193133	0.196	0.199193133
2	0.441	-0.424	0.151	0.152821352	0.152	0.152821352
3	0.512	-0.511	0.172	0.17118294	0.173	0.17118294
4	0.454	-0.539	0.117	0.123177575	0.12	0.123177575
5	0.51	-0.328	0.23	0.230816524	0.232	0.230816524

5.6 Data Analysis

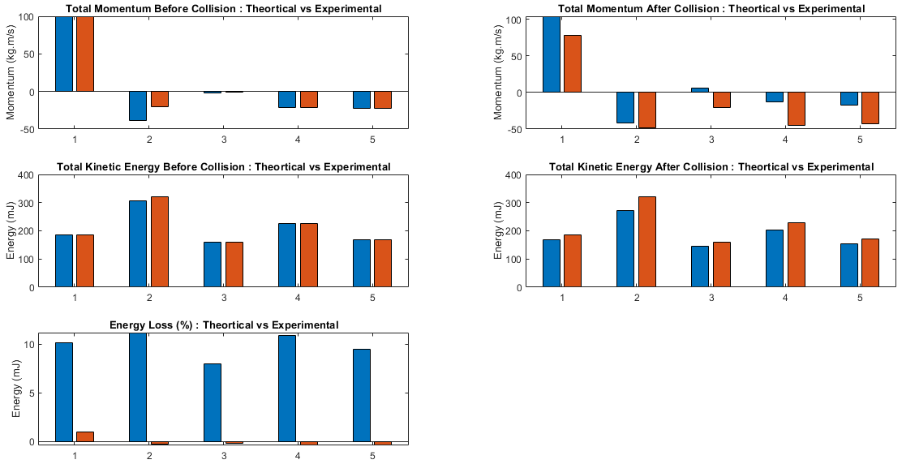


Figure 5.1: Elastic Collision with $m_1 = m_2$

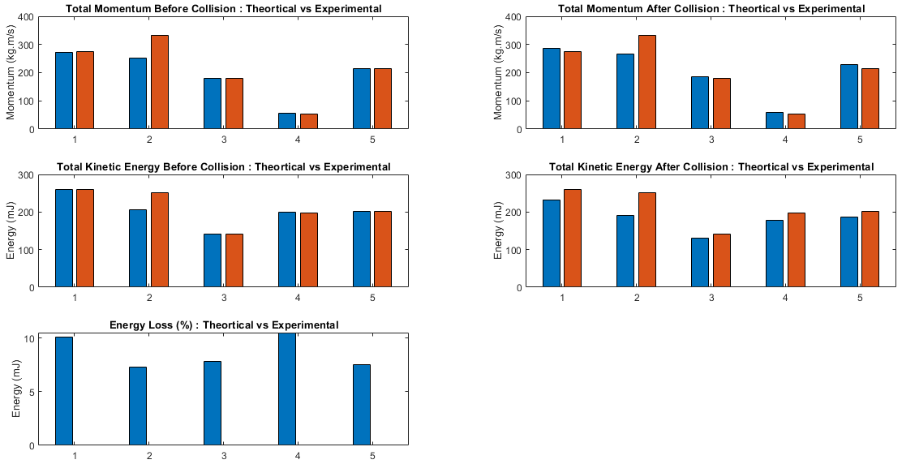


Figure 5.2: Elastic Collision with $m_1 \neq m_2$

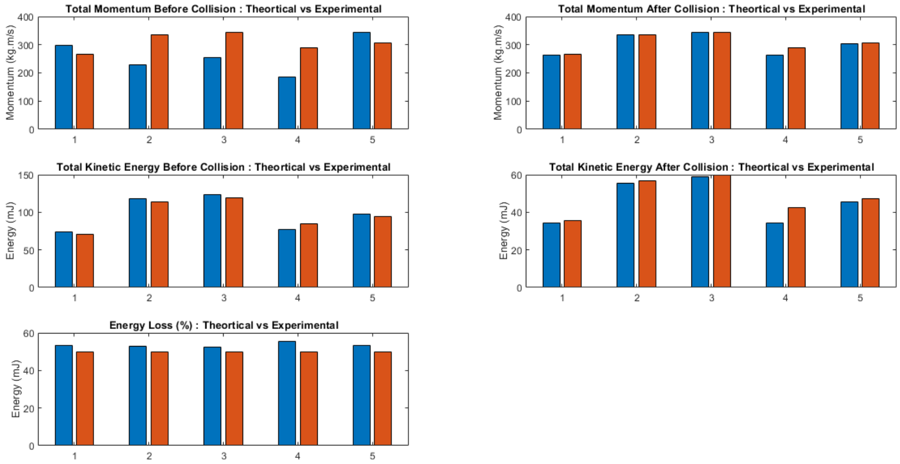


Figure 5.3: In-Elastic Collision with $m_1 = m_2$

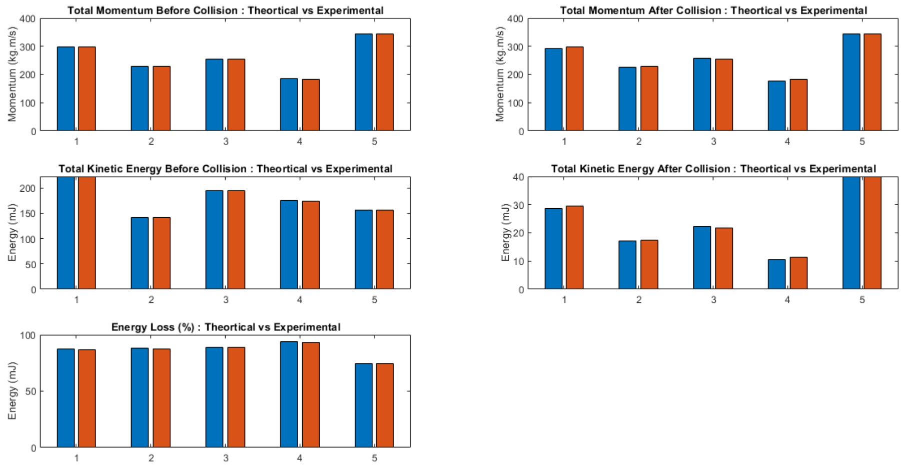


Figure 5.4: In-Elastic Collision with $m_1 \neq m_2$

5.7 Discussion & Conclusion

In both elastic and in-elastic, the experiment values agreed with the theoretical values up to a great extent when $m1 \neq m2$. This is because in reality we didn't use equal masses. Moreover, elastic collisions don't occur in nature unless they are atomic in nature.

5.8 MATLAB Script

```
figure;
subplot(3,2,1)
bar(horzcat(T_P_B_E_1,T_P_B_T_1))
title('Total Momentum Before Collision : Theortical vs
    Experimental')
ylabel('Momentum (kg.m/s)')

subplot(3,2,2)
bar(horzcat(T_P_A_E_1,T_P_A_T_1))
title('Total Momentum After Collision : Theortical vs
    Experimental')
```

```
ylabel('Momentum (kg.m/s)')


subplot(3,2,3)
bar(horzcat(T_K_B_E_1,T_K_B_T_1))
title('Total Kinetic Energy Before Collision : Theortical
    vs Experimental')
ylabel('Energy (mJ)')


subplot(3,2,4)
bar(horzcat(T_K_A_E_1,T_K_A_T_1))
title('Total Kinetic Energy After Collision : Theortical
   vs Experimental')
ylabel('Energy (mJ)')

subplot(3,2,5);
bar(horzcat(EL_E_1,EL_T_1))
title('Energy Loss (%) : Theortical vs Experimental')
ylabel('Energy (mJ)')


figure;
subplot(3,2,1)
bar(horzcat(T_P_B_E_2,T_P_B_T_2))
title('Total Momentum Before Collision : Theortical vs
   Experimental')
ylabel('Momentum (kg.m/s)')
```

```
subplot(3,2,2)
bar(horzcat(T_P_A_E_2,T_P_A_T_2))
title('Total Momentum After Collision : Theortical vs
   Experimental')
ylabel('Momentum (kg.m/s)')


subplot(3,2,3)
bar(horzcat(T_K_B_E_2,T_K_B_T_2))
title('Total Kinetic Energy Before Collision : Theortical
    vs Experimental')
ylabel('Energy (mJ)')


subplot(3,2,4)
bar(horzcat(T_K_A_E_2,T_K_A_T_2))
title('Total Kinetic Energy After Collision : Theortical
   vs Experimental')
ylabel('Energy (mJ)')

subplot(3,2,5);
bar(horzcat(EL_E_2,EL_T_2))
title('Energy Loss (%) : Theortical vs Experimental')
ylabel('Energy (mJ)')


figure;
subplot(3,2,1)
bar(horzcat(T_P_B_E_3,T_P_B_T_3))
```

```
title('Total Momentum Before Collision : Theortical vs
   Experimental')
ylabel('Momentum (kg.m/s)')

subplot(3,2,2)
bar(horzcat(T_P_A_E_3,T_P_A_T_3))
title('Total Momentum After Collision : Theortical vs
   Experimental')
ylabel('Momentum (kg.m/s)')



subplot(3,2,3)
bar(horzcat(T_K_B_E_3,T_K_B_T_3))
title('Total Kinetic Energy Before Collision : Theortical
    vs Experimental')
ylabel('Energy (mJ)')



subplot(3,2,4)
bar(horzcat(T_K_A_E_3,T_K_A_T_3))
title('Total Kinetic Energy After Collision : Theortical
   vs Experimental')
ylabel('Energy (mJ)')

subplot(3,2,5);
bar(horzcat(EL_E_3,EL_T_3))
title('Energy Loss (%) : Theortical vs Experimental')
ylabel('Energy (mJ)')
```

```
figure;
subplot(3,2,1)
bar(horzcat(T_P_B_E_4,T_P_B_T_4))
title('Total Momentum Before Collision : Theortical vs
   Experimental')
ylabel('Momentum (kg.m/s)')

subplot(3,2,2)
bar(horzcat(T_P_A_E_4,T_P_A_T_4))
title('Total Momentum After Collision : Theortical vs
   Experimental')
ylabel('Momentum (kg.m/s)')



subplot(3,2,3)
bar(horzcat(T_K_B_E_4,T_K_B_T_4))
title('Total Kinetic Energy Before Collision : Theortical
    vs Experimental')
ylabel('Energy (mJ)')



subplot(3,2,4)
bar(horzcat(T_K_A_E_4,T_K_A_T_4))
title('Total Kinetic Energy After Collision : Theortical
   vs Experimental')
ylabel('Energy (mJ)')

subplot(3,2,5);
bar(horzcat(EL_E_4,EL_T_4))
```

```
title('Energy Loss (%) : Theortical vs Experimental')
ylabel('Energy (mJ)')
```

Experiment 6

EQUATION OF MOTION FOR ANGULAR MOTION

Date: 29/10/2020

6.1 Aim

The aim of this experiment is to determine the angular acceleration and angular displacement for rotational motion using curve fitting in MATLAB. We also aim to derive equations of motion for rotational motion.

6.2 Background Theory

Rotational motion has similar characteristics to linear motion that is known as transnational motion. Rotational bodies have a moment of inertia similar to mass. The kinematics of rotational motion describes the relationships among rotation angle, angular velocity, angular displacement, angular acceleration, and time. Similar to linear motion equations, rotational motion equations can be written from the table provided in the manual. For linear equation

$$v = v_0 + at$$

Rotational can be written as following. In rotational $a = \alpha$ and $a = r\alpha$ as angular acceleration is constant. $v = r\omega$ for rotational. Therefore

$$r\omega = r\omega_0 + r\alpha t$$

$$\omega = \omega_0 + \alpha t$$

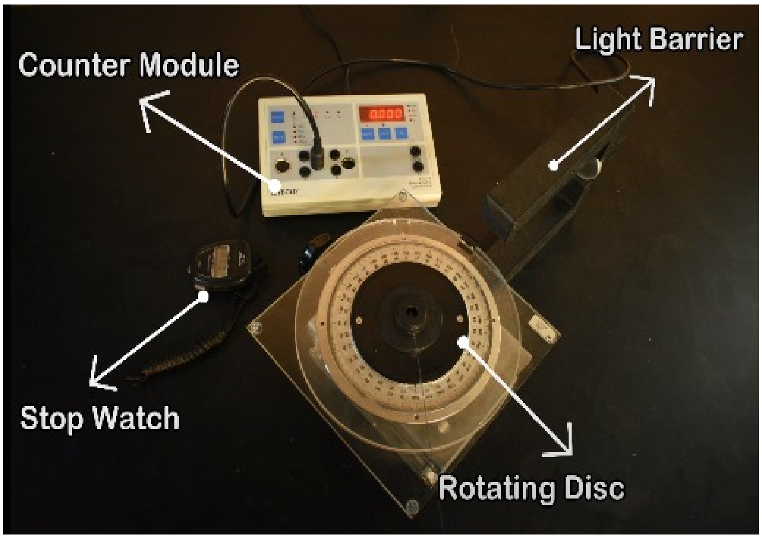
For linear equation

$$S = S_0 + v_i t + \frac{1}{2}at^2$$

. In rotational motion $S = \theta$, $v = \omega$, $a = \alpha$. Therefore

$$\theta = \theta_0 + \omega_i t + \frac{1}{2}\alpha t^2$$

6.3 Description of Setup



Using the setup above, a light barrier is attached to the lab bench using a table clamp to place a rotating disk. The counter module and light barrier record the time when the flag interrupts the barrier. The stopwatch is used to record the time from rotation to when the main platter is detected. A pulley and thread help rotate the disk at constant acceleration.

6.4 Method / Procedure

The experiment was set up and the disk was rotated at an angle of 90' and stopwatch was started when disk was released. The stop watch was stopped when the flag was detected by motion detector. The time measured by stopwatch and light gate at that angle was noted and repeated four times. The process was repeated five times by rotating disk at an angle of 120, 150, 180, 210, 240, 270 and 300'. The respected data was recorded.

6.5 Data

The type B uncertainty associated with the angle θ is 0.04 degrees. The type B associated uncertainty with the time T is 0.003s

s.No	Angle	angle (°)
1	A1	90
2	A2	120
3	A3	150
4	A4	180
5	A5	210
6	A6	240
7	A7	270
8	A8	300

Time period from Start to Cut								
s.No	**T_A1 (s)**	**T_A2 (s)**	**T_A3 (s)**	**T_A4 (s)**	**T_A5 (s)**	**T_A6 (s)**	**T_A7 (s)**	**T_A8 (s)**
1	1.94	2.31	2.59	2.66	2.88	3.25	3.35	3.47
2	1.93	2.31	2.65	3	3.03	2.84	3.35	3.35
3	1.81	2.41	2.75	2.62	2.9	2.65	3.22	3.46
4	2.03	2.34	2.84	2.69	2.75	3.19	3.34	3.42
5	2.09	2.63	2.63	2.59	2.87	3.04	3.28	3.41

Time period from Start to Cut								
s.No	**T_A1 (s)**	**T_A2 (s)**	**T_A3 (s)**	**T_A4 (s)**	**T_A5 (s)**	**T_A6 (s)**	**T_A7 (s)**	**T_A8 (s)**
1	1.94	2.31	2.59	2.66	2.88	3.25	3.35	3.47
2	1.93	2.31	2.65	3	3.03	2.84	3.35	3.35
3	1.81	2.41	2.75	2.62	2.9	2.65	3.22	3.46
4	2.03	2.34	2.84	2.69	2.75	3.19	3.34	3.42
5	2.09	2.63	2.63	2.59	2.87	3.04	3.28	3.41

Angle(rad)	Light Flag(s)	Stopwatch(s)
1.5707963	0.100081	1.96
2.0943951	0.087436	2.4
2.6179939	0.078868	2.692
3.1415927	0.072822	2.712
3.6651914	0.067409	2.886
4.1887902	0.060538	2.994
4.712389	0.060429	3.307
5.2359878	0.056155	3.42167

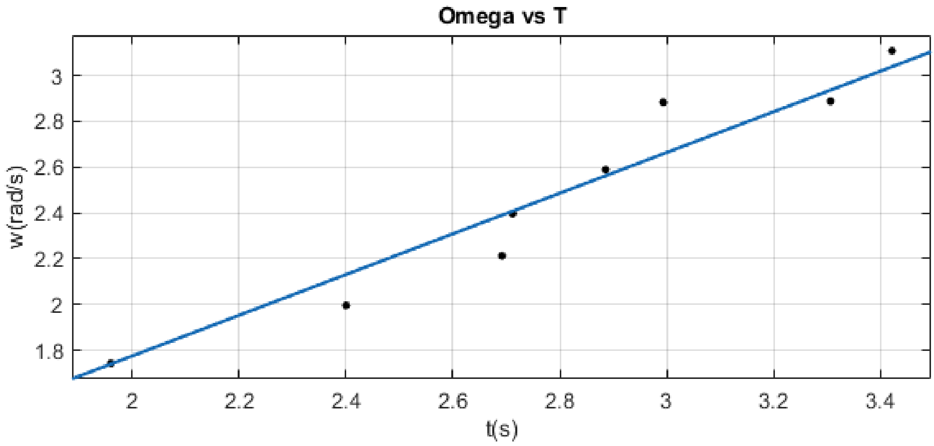


Figure 6.1: Graph of ω vs t

$$\omega_f = \alpha t$$

$$\alpha = 0.888 rad/s^2$$

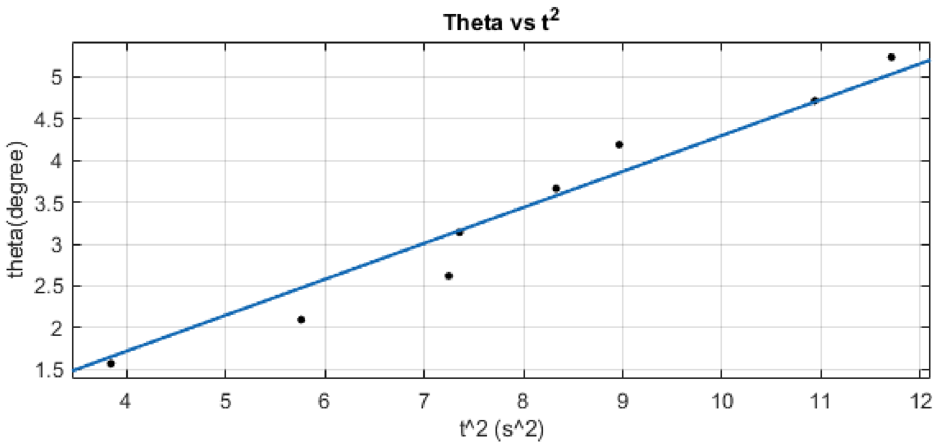


Figure 6.2: Graph of θ vs t^2

$$\theta = \alpha t^2$$

$$\alpha = 0.430 rad/s^2$$

6.6 Data Analysis

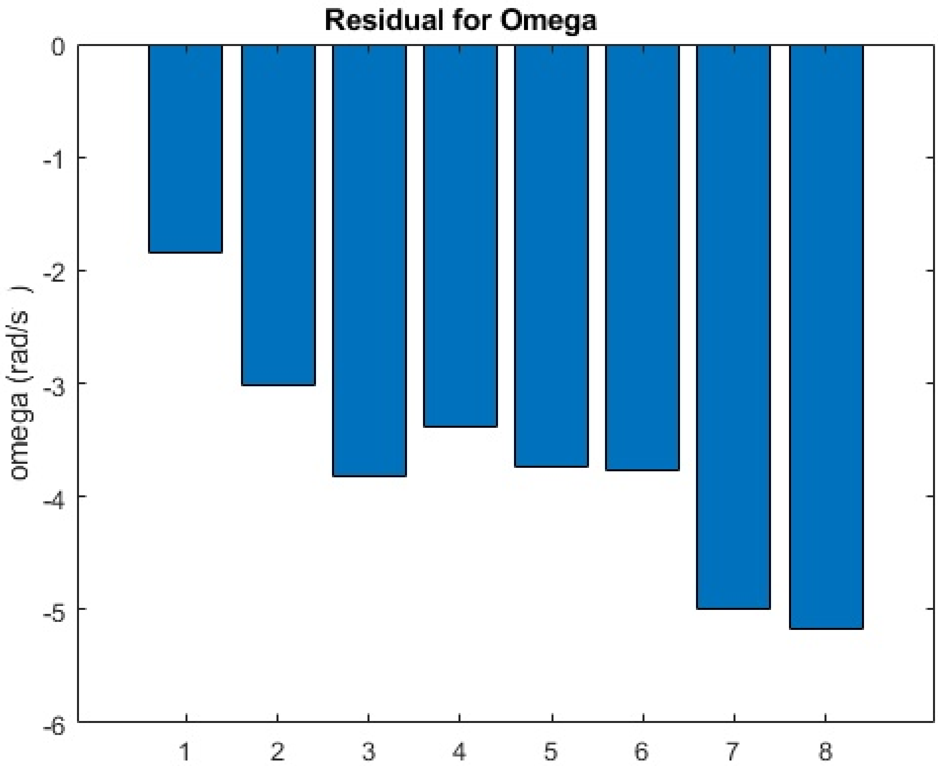


Figure 6.3: Residual plot for omega

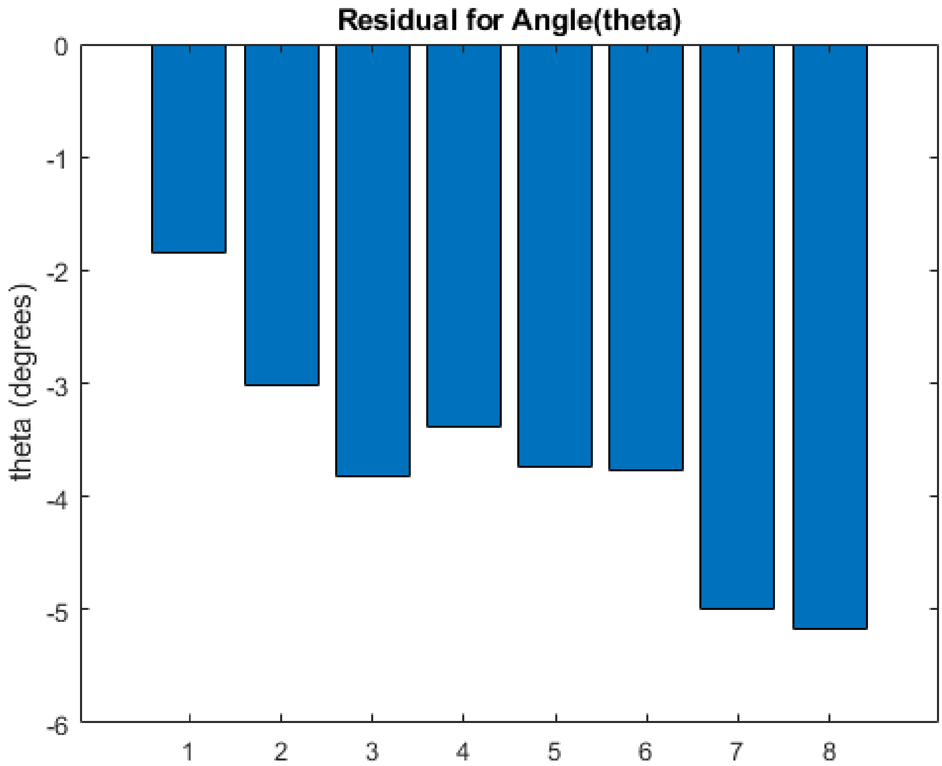


Figure 6.4: Residual plot for theta

6.7 Discussion & Conclusion

The graphs of ω vs t and θ vs t^2 are linear with an equal distribution of points on line as predicted by our hypothesis which verifies the equations of angular motion. There is a degree of uncertainty and error in the instruments while measuring time and angle, 0.04 for angle and 0.003 for time respectively. Reasons for points varying from the exact position on line include human error while measuring the time from stopwatch. Friction in the pulley, air resistance can also affect our experimental values. The degree of errors is increasing with increasing omega as seen in figure 6.3.

6.8 MATLAB Script

```
f = 10 * (pi/180);
wf = f./Light_t_s_;
st2 = Stop_t_s.^2;
```

```
% wf = 0.888 t %
% a = 0.888 rad/s^2
% theta  = 0.4298 t^2

figure;
residual_angle = Angle_rad_ - 0.888.*st2;
bar(residual_angle)
title("Residual for Angle(theta)")
ylabel("theta (degrees)")

figure;
residual_omega = Angle_rad_ - 0.4298.*st2;
bar(residual_angle)
title("Residual for Omega(theta)")
ylabel("omega (rad/s^2)")
```

Experiment 7

ENERGY CONSERVATION IN MAXWELL'S WHEEL

Date: 8/11/2020

7.1 Aim

The aim of this experiment is to understand the principle of conservation of energy and how it is distributed among the translational and rotational motion. We study the combination of rotational and transalational motion in a Maxwell's wheel

7.2 Background Theory

In transalational motion of an object, the entire object can be considered as a single point. All points of the object move in similar fashion and hence can be described from the same equation of motion. However, rotational objects cannot be replaced by a single point as it is done in transalational motion. Different points on the object are moving with different speeds, depending on the distance from the axis of rotation.
The potential energy of the Maxwell's wheel is given by the expression,

$$U = mgh \tag{7.1}$$

where m is the mass of the object and h is the maximum height .
The transalational kinetic energy of the Maxwell's wheel is given by the expression,

$$KE = \frac{1}{2}mv^2 \tag{7.2}$$

where m is the mass of the object and v is the linear speed.

The rotational kinetic energy of the Maxwell's wheel is given by the expression,

$$RE = \frac{1}{2}I\omega^2 \tag{7.3}$$

where I is the moment of the Inertia and ω is the angular speed.

As the wheel rotates, the change in the potential is equal to the sum of the transalational kinetic and rotational kinetic energy.

$$\Delta U = KE + RE \tag{7.4}$$

$$mg\Delta h = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 \tag{7.5}$$

where Δh is the height of the Maxwell's wheel from the surface of the table.

We can write $v = \omega r$, giving us the equation.

$$mg\Delta h = \frac{1}{2}mv^2 + \frac{1}{2r^2}Iv^2 \tag{7.6}$$

Re-arranging equation 7.6 and making v^2 as the subject gives us the following equation.

$$v^2 = \frac{2mgr^2}{mr^2 + I}\Delta h \tag{7.7}$$

7.3 Description of Setup

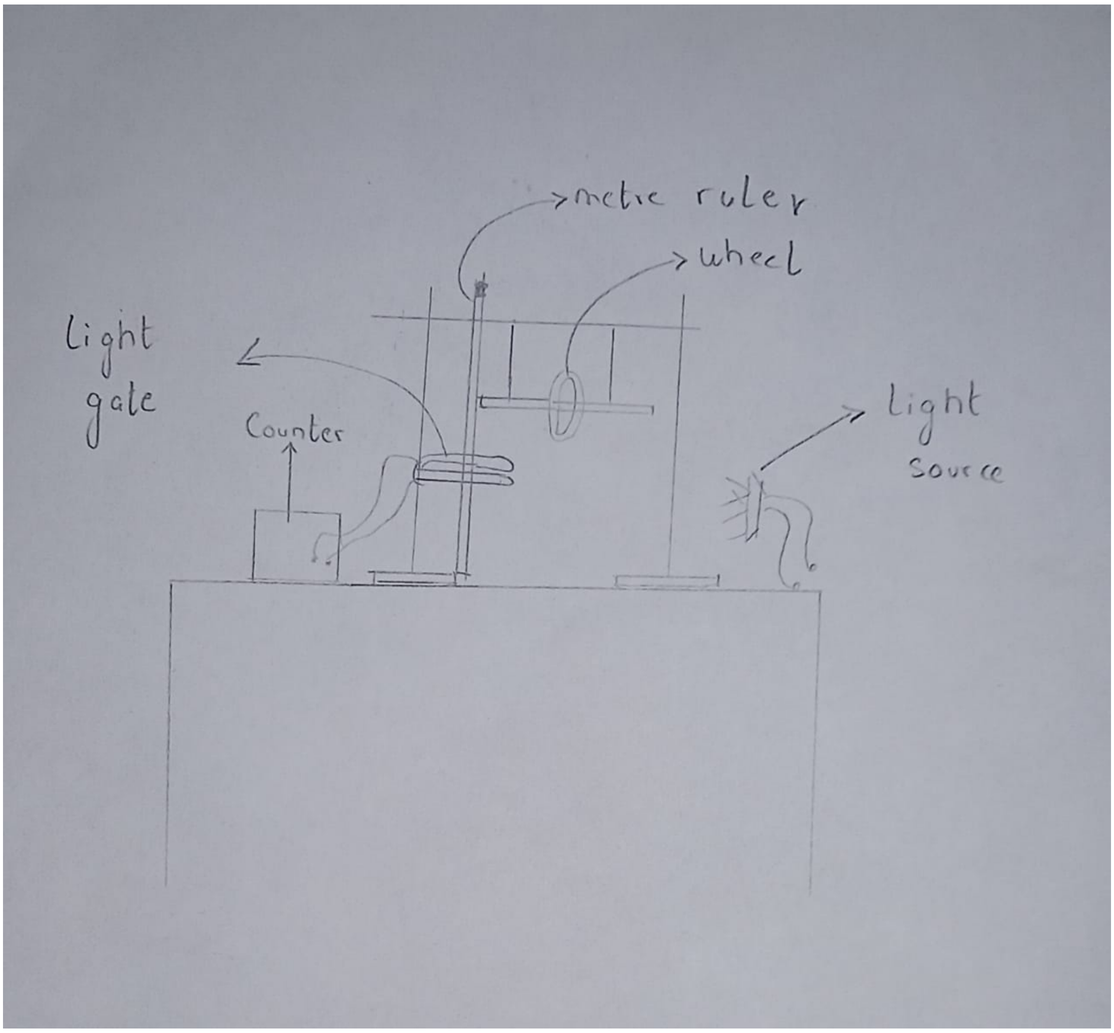


Figure 7.1: Sketch of the experiment setup.

Here the Light Gate and counter is used to measure translation speed v at given heights, the metre scale is used to measure the height of the Maxwell wheel Δh with respect from the surface of the table.

7.4 Method / Procedure

The Maxwell's wheel is rotated up about its spindle such that the cord uniformly wounds about the spindle. When the wheel is released, it then falls as the chord unwinds. The speed of the translational of the wheel is calculated using the formula $v = \frac{d}{t}$ where d is the diameter of the spindle and t is the time recorded by the counter. The height Δh

is adjusted by changing the position of the light gate. The above process is repeated 5 times for each Δh and we chose 5 different values of the Δh. The graph of v^2 vs Δh and then slope of best fit is determined. The value of the best slope and the equation 7.7 is used to calculate the value of the moment of Inertia, I

7.5 Data

The type B uncertainty associated with the height h is $0.002m$ and the time is $0.0000003s$. The mass of the object is $m = 0.450kg$, the diameter of the wheel is $0.13m$ and the diameter of the spindle is $0.003m$

s.No	$\Delta h(m)$	Avg t(s)	v (m/s)	$v^2(m^2/s^2)$
1	0.44	0.0321104	0.186855	0.034914921
2	0.37	0.03222875	0.186169	0.034658964
3	0.3	0.032023333	0.187363	0.035105036
4	0.23	0.031566	0.190078	0.03612962
5	0.16	0.031749	0.188982	0.035714321

7.6 Data Analysis

s.NO	TypeTimeA	TypeBTime	TimeUncertainity	TimeVelocity	HeightB	TimeHeight	Combined
1	0.000324683	0.0000003	0.000325	0.0000001360356	0.000204124	0.0000156804345	0.0000156810245
2	0.0000350323	0.0000003	0.000035	0.0000000128247	0.000204124	0.0000156804345	0.0000156804397
3	0.0001901485	0.0000003	0.000190	0.0000000555547	0.000204124	0.0000156804345	0.0000156805329
4	0.0001874448	0.0000003	0.000187	0.0000000417399	0.000204124	0.0000156804345	0.0000156804900
5	0.0001901485	0.0000003	0.000190	0.0000000252239	0.000204124	0.0000156804345	0.0000156804548

$$v^2 = 0.0814\Delta h \tag{7.8}$$

The gradient $a = 0.0814$

$$gradient = \frac{2mgr^2}{mr^2 + I}\Delta h \tag{7.9}$$

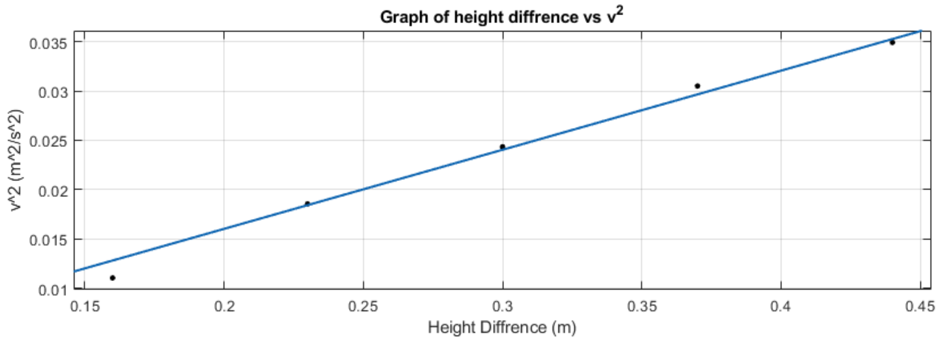


Figure 7.2: Graph of y vs x

Making the I,moment of inertia as a subject gives us the equation

$$I = \frac{2mgr^2 - amr^2}{a} \tag{7.10}$$

where a is the gradient, m is the mass of object, g is the gravitational acceleration and r is the radius of the spindle.

- $m = 0.450kg$
- $g = 9.80665m/s^2$
- $r = 0.003m$

Using the equation 7.8 and the above values we can calculate the value of I, the moment of Inertia

$$I = \frac{2 \times 0.450 \times 9.80664 \times 0.003^2 - 0.0814 \times 0.450 \times 0.003^2}{0.0814} = 0.97178 \times 10^{-3} kgm^2$$

7.7 Discussion & Conclusion

The graph of v^2 vs Δh is a linear which suggests a linear trend. Furthermore, the actual value of the Moment of Inertia I, $1.03 \times 10^-3 kgm^2$ is very close to the measured value of the Moment of Inertia, $0.9718 \times 10^-3 kgm^2$. The residual plot of the actual data as the function of Δh shows a certain pattern which indicates the pattern of a systematic error. One of the possible sources of these systematic errors energy losses due to friction

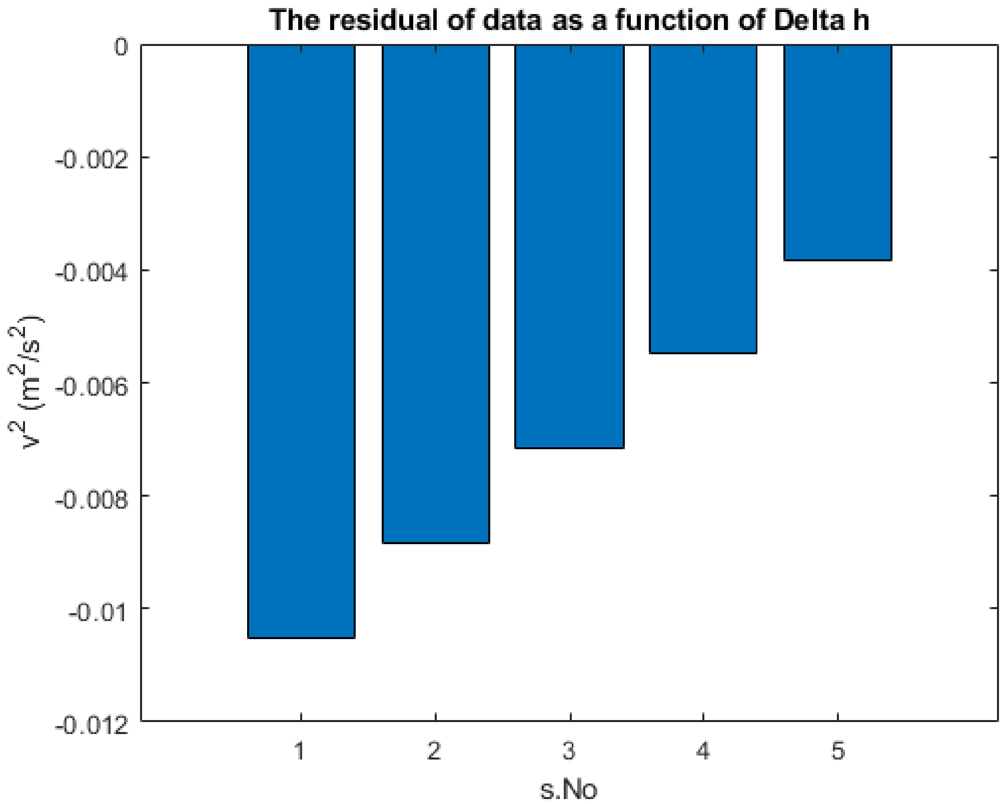


Figure 7.3: Residual of actual as a function of delta H

7.8 MATLAB Script

```
% Type B uncertainity in Height
Length_B = (0.001/2)/(6^0.5);
% Type B uncertainity in Time
Time_B = (0.001/2)/(3^0.5);

theoretical_value = ((2*0.450*0.03^2)
    /(0.450*0.03^2+1.03*10^-3)).*Height;
measured_value = ((2*0.450*0.03^2)/(0.450*0.03^2+
    0.97178*10^-3)).*Height;
residual = flipud(theoretical_value - measured_value);

figure
```

```
bar(residual)
title("The residual of data as a function of Delta h")
xlabel("s.No")
ylabel("v^2 (m^2/s^2)")
```

Experiment 8

LATENT HEAT OF VAPORIZATION OF LIQUID NITROGEN

Date: 5/11/2020

8.1 Aim

The aim of this experiment is to understand latent heat of vaporization through liquid nitrogen and safe use of cryogens through a setup of circuits for heating and measurement of current and voltage through liquid nitrogen.

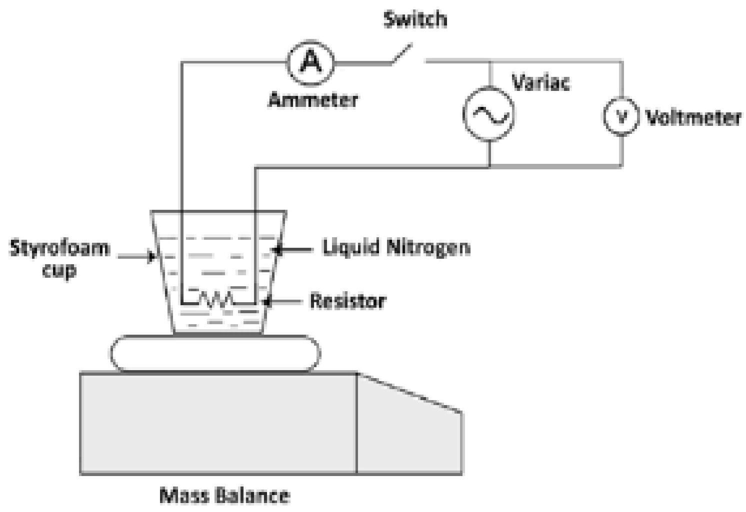
8.2 Background Theory

Latent heat is defined as energy released or absorbed when a substance changes state. Latent heat absorbed when a solid changes to liquid is latent heat of fusion. Latent heat absorbed when a liquid changes to vapour, to break inter-molecular forces, is known as latent heat of vaporisation. It can be calculated using

$$L_v = \frac{\triangle Q}{\triangle m}$$

where Q is amount of energy and m is mass. Liquid Nitrogen is an odourless and a colourless fluid that starts to evaporate at room temperature

8.3 Description of Setup



Using the setup above, a resistor is attached to variac through an ammeter in series. Liquid Nitrogen is used in a Styrofoam cup to isolate it thermally to calculate latent heat. An electronic balance is used to measure the change in mass of nitrogen as it is heated.

8.4 Method / Procedure

The apparatus was set up and liquid nitrogen was poured from a cryogenic container into the Styrofoam cup using gloves and safety goggles. The mass of the cup with resistor inside was measured and the mass lost is measured. Start the stopwatch timer and wait for 20 seconds. Note mass for every second for 30 seconds. Start the variac and heater which increases the rate of mass loss. The mass was recorded for every second for 30 seconds. The heating was then turned off for 30 seconds and mass recorded. The previous two steps are repeated one more time. At the end, the cup is removed and leftover liquid nitrogen is poured back.

8.5 Data

The type B uncertainty associated with time is 0.003s. The type B uncertainty associated with Mass is 0.03 g.

	heating off 1		heating on 1		heating off 2		heating on 2	
s.No	time (s)	Mass (grams)	time (s)	Mass (grams)	time (s)	Mass (grams)	time (s)	Mass (grams)
1	20	90.2	50	88.8	80	83.6	110	82.6
2	21	90.0	51	88.7	81	83.6	111	82.6
3	22	89.9	52	88.7	82	83.6	112	82.6
4	23	89.9	53	88.5	83	83.4	113	82.4
5	24	89.8	54	88.3	84	83.4	114	82.2
6	25	89.8	55	88.1	85	83.4	115	82.1
7	26	89.8	56	88.0	86	83.4	116	81.9
8	27	89.7	57	87.7	87	83.4	117	81.8
9	28	89.6	58	87.7	88	83.4	118	81.6
10	29	89.6	59	87.3	89	83.4	119	81.5
11	30	89.5	60	87.2	90	83.3	120	81.2
12	31	89.5	61	87.0	91	83.3	121	81.1
13	32	89.5	62	86.8	92	83.2	122	81.0
14	33	89.4	63	86.7	93	83.2	123	80.8
15	34	89.4	64	86.5	94	83.2	124	80.6
16	35	89.3	65	86.2	95	83.1	125	80.4
17	36	89.3	66	86.2	96	83.1	126	80.2
18	37	89.3	67	85.9	97	83.0	127	80.0
19	38	89.2	68	85.8	98	83.0	128	80.0
20	39	89.2	69	85.6	99	83.0	129	79.8
21	40	89.2	70	85.4	100	83.0	130	79.6
22	41	89.0	71	85.2	101	82.9	131	79.6
23	42	89.0	72	85.2	102	82.9	132	79.4
24	43	89.0	73	84.9	103	82.9	133	79.2
25	44	89.0	74	84.8	104	82.8	134	79.0
26	45	89.0	75	84.6	105	82.8	135	78.8
27	46	88.9	76	84.5	106	82.8	136	78.8
28	47	88.9	77	84.2	107	82.8	137	78.7
29	48	88.8	78	84.1	108	82.8	138	78.5
30	49	88.8	79	83.9	109	82.6	139	78.3

8.6 Data Analysis

Rate of Change Mass at different times

Time	Rate of Change of Mass (g/s)
Heating Off 1	-0.04349
Heating On 1	-0.1744
Heating Off 2	-0.03418
Heating On 2	-0.1562

The average rate of change in mass when heating is off is $-0.3884g/s$ and the average of change in mass when heating is on is $-0.1653g/s$

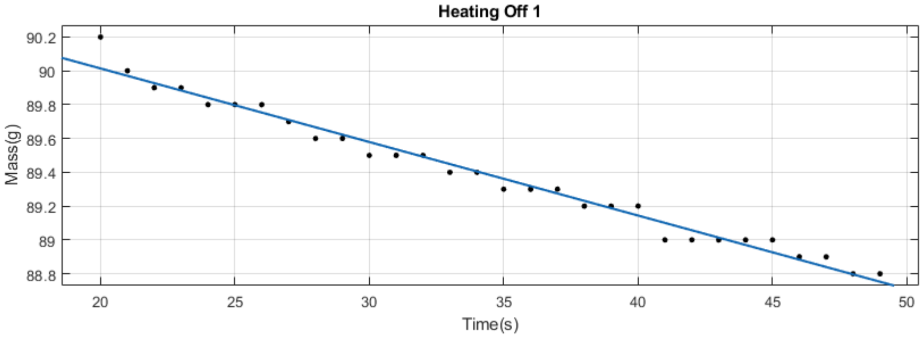


Figure 8.1: Heating Time Off 1

The line of best fit : $y = -0.04389x + 90.88$

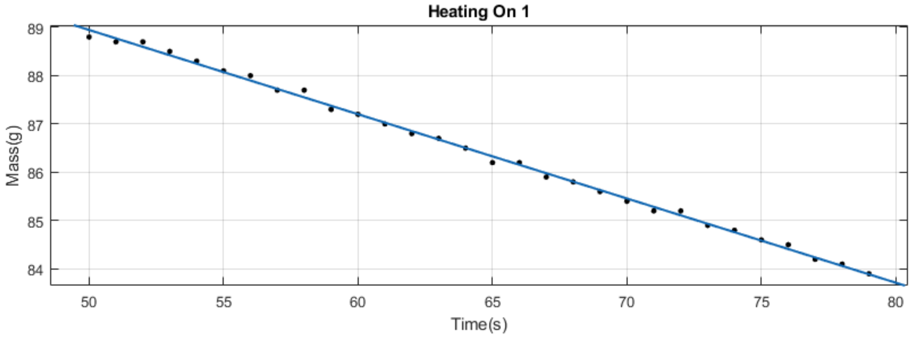


Figure 8.2: Heating Time On 1

The line of best fit : $y = -0.01744x + 97.67$

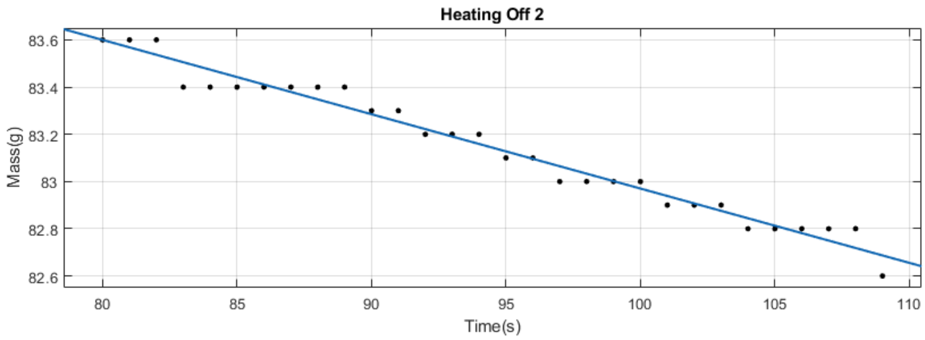


Figure 8.3: Heating Time Off 2

The line of best fit : $y = -0.03418x + 86.12$

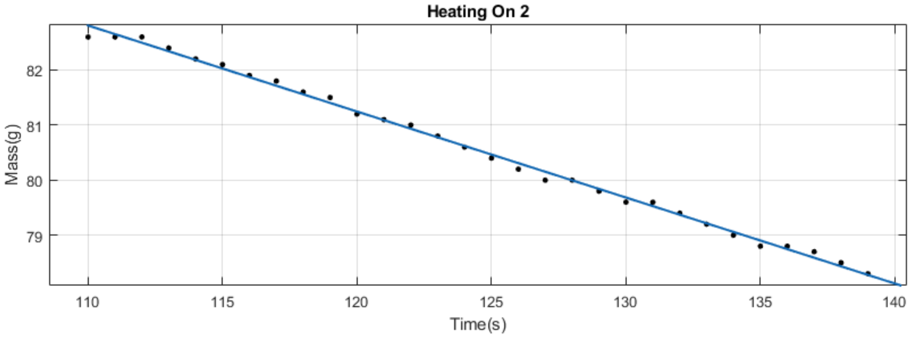


Figure 8.4: Heating Time On 2

The line of best fit : $y = -0.1562x + 99.99$

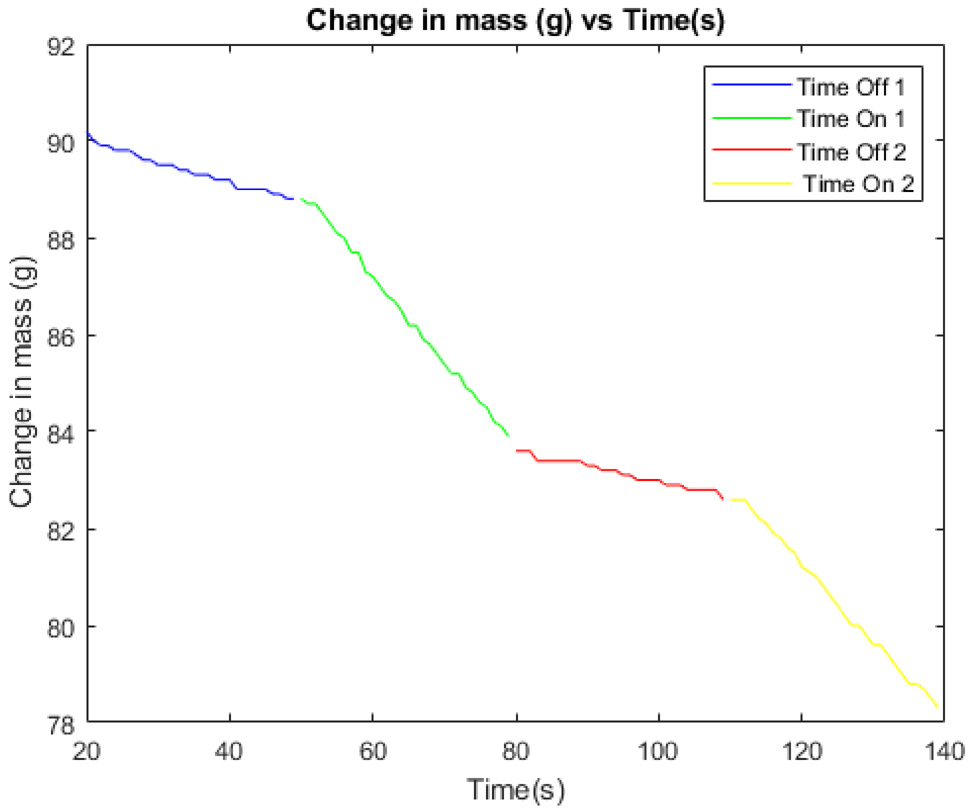


Figure 8.5: The graph of change in mass vs Time

Rate of mass lost for electrical heating is calculated using

$$\frac{\triangle m}{\triangle t}_{Electric-heating} = \frac{\triangle m}{\triangle t}_{Electric-heating+Ambient-heat} - \frac{\triangle m}{\triangle t}_{Ambient-heat} \tag{8.1}$$

Therefore, rate of change in mass is $-0.1265g/s$.

Average Power dissipated is $29.323W$.

Using the equation we calculate Latent heat of vaporization.

$$L_v = \frac{VI}{\frac{\triangle m}{\triangle t}_{Electric-heating}} \tag{8.2}$$

Thus, our experimental value of L_v is

$$L_v = \frac{29.323}{0.1265} = 231.8J/g \tag{8.3}$$

8.7 Discussion & Conclusion

The experimental value and theoretical value for Latent heat of vaporization have a huge difference. Thus, our hypothesis is not valid since experimental value for L_v does not agree with theoretical. This is due to heat losses to the environment from liquid nitrogen as its boiling point is below room temperature which is why our values do not match. Heat losses could be minimized using high resolution apparatus that ensures the experiment is conducted in a controlled environment. The mass was also measured in grams using the electronic balance which has a higher uncertainty, but using an apparatus that could give smaller values of mass would give more accurate results.

8.8 MATLAB Script

```
figure;
plot(TimeOff1,MassOff1,'b');
xlabel('Time(s)');
ylabel('Change in mass (g)');
title('Time Off 1');
% y = mx + c
% m = -0.04349
% c = 90.88

figure;
plot(TimeOn1,MassOn1,'g');
xlabel('Time(s)');
ylabel('Change in mass (g)');
title('Time On 1');
% y = mx + c
% m = -0.1744
```

```
% c = 97.67


figure;
plot(TimeOff2,MassOff2,'r');
xlabel('Time(s)');
ylabel('Change in mass (g)');
title('Time Off 2');
% y = mx + c
% m = -0.03418
% c = 86.12


figure;
plot(TimeOn2,MassOn2,'y');
xlabel('Time(s)');
ylabel('Change in mass (g)');
title('Time On 2');
% y = mx + c
% m = -0.1562
% c = 99.99



figure;
plot(TimeOff1,MassOff1,'b'); hold on
plot(TimeOn1,MassOn1,'g');
plot(TimeOff2,MassOff2,'r');
plot(TimeOn2,MassOn2,'y'); hold off
```

```
legend("Time Off 1", "Time On 1", "Time Off 2"," Time On
    2");
xlabel('Time(s)');
ylabel('Change in mass (g)');
title('Change in mass (g) vs Time(s)');
```

Experiment 9

DETERMINING THE CURIE TEMPERATURE OF KANTHAL-D WIRE

Date: 15/11/2020

9.1 Aim

The magnetic properties of materials depend upon the atomic and molecular arrangements within the material. These alignments also depend upon the temperature of the material. The aim of this experiment is to understand how temperature affects the magnetic properties of the Kanthal-D wire.

9.2 Background Theory

Both naturally-occurring and human-made materials have a range of magnetic properties. *Ferromagnetic* materials posses an intrinsic magnetic field. Materials which acquire a magnetic field in the presence of external magnetic fields are called *paramagnetic* materials. *Diamagnetic* materials are those which are not affected by external magnetic fields.

The origin of magnetism in materials lies in the motion and configuration of electrons within an atom. These electrons constitute a current and hence produce a tiny magnetic for each atom. Each atom is called to make a magnetic dipole. The arrangement and orientation of these elementary dipoles determine the overall magnetic properties. If these magnetic dipoles are naturally aligned and kept in that configuration by the inter molecular forces, then the magnetic fields enforce each other and, as a result, the material gets an overall intrinsic magnetic field. These materials are called ferromagnetic materials.

Combinations of atoms are called *magnetic domains*. Atoms within these magnetic domains are aligned in a certain direction on average. If these domains are randomly distributed it cancels the overall magnetic field of the material. In some materials, atoms in the domains, and thus the domain itself,can be made to align if an external magnetic field is applied.

In ferromagnets atoms in domains are aligned in a certain preferred direction and held in that place with the inter-molecular forces . In figure 1, boundaries between randomly aligned domains is shown in the absence and presence of a external magnetic fields.

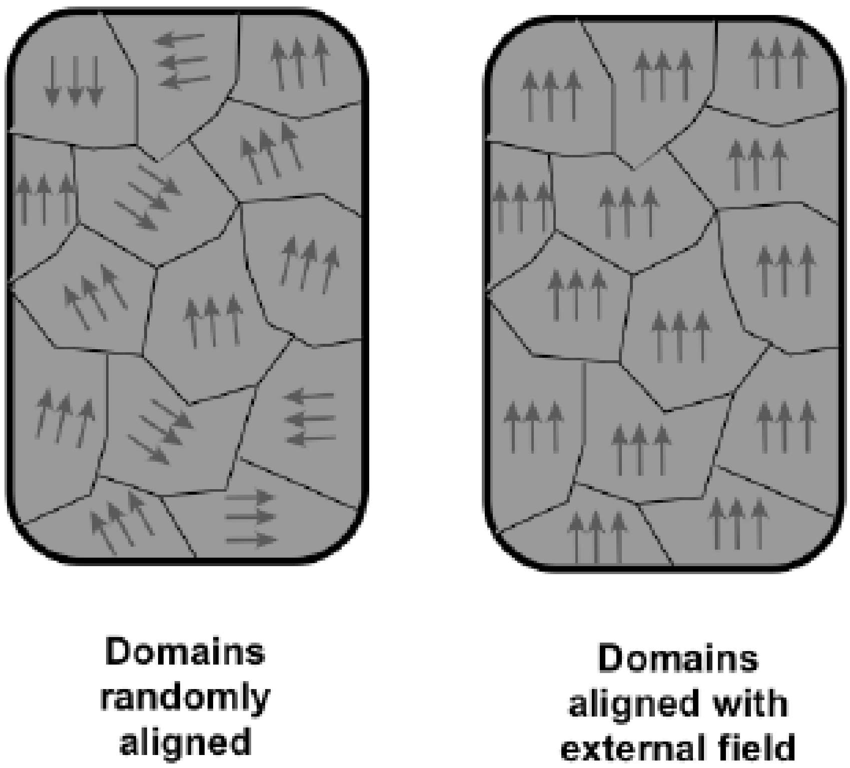


Figure 9.1: Graph of y vs x

The thermal energy of atoms and molecules tends to the disturb the alignment of elementary magnets. As the temperature increases, the alignment is disturbed, and above a critical temperature, the *Curie temperature* T_C, a ferromagnetic turns into a paramagnet.

The electrical energy supplied in Δt time supplied by voltage V and current I can be calculated by the following equation

$$E_E = VI\Delta t \tag{9.1}$$

The energy E_a, absorbed in raising the temperature of the Kanthal wire is given in terms of specific heat of Kanthal wire and change in temperature,

$$E_a = mc(T_C - T_0) \tag{9.2}$$

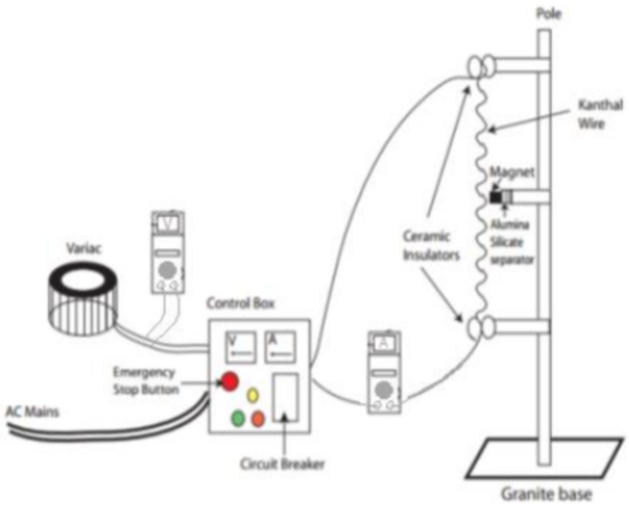
The energy radiated E_r ratiated from the wire is,

$$E_r = \epsilon\sigma S({T_c}^4 - {T_0}^4)\Delta t \tag{9.3}$$

Combining equation 1 and 2, and re-arranging the terms gives us the following equation.

$$-(mcT_o + \epsilon\sigma S{T_0}^4\Delta t + VI\Delta t) + mcT_C + \epsilon\sigma S{T_C}^4\Delta t = 0 \tag{9.4}$$

9.3 Description of Setup



The experiment is set up as above where the variac is attached to an ammeter, voltmeter and a control box. The kanthal-D wire is attached to a magnet with minimum area contact on a pole. A stopwatch is used to record the time taken to reach curie temperature. A digital ammeter and voltmeter is used to get accurate readings since the control box isn't precise.

9.4 Method / Procedure

The kanthal-D wire is attached to the magnet in such a way that there is minimum area in contact. The control box is set up and green button is pressed to turn it on. The output voltage is set on 25.3 V on a variac and the current is measured using a digital ammeter. To turn off the control box the toggle switch is pressed. After the wire is cooled, we turn on the toggle switch and start the stopwatch. When the wire snaps away from the magnet, the stopwatch is stopped and we turn off the toggle switch. The time is recorded and the heating element is cooled. Four more readings at the same voltage are taken. The same procedure is repeated for nine different voltages on variac with 5 readings at every voltage.

9.5 Data

The mass m of the Kanthal wire is 2.35 ± 0.01 gm,diameter is 0.723 ± 0.002 mm , length is 100 ± 0.1cm, c specific heat capacity (c) is $460 JKg^{-1}K^{-1}$ and the Emissivity (ϵ) is 0.7 . T_0 the room temperature is taken as $25°$ C.

The following data was recorded

s.No	Voltage (V)	Current (A)	Avg_t(s)
1	25.3	5.63	14.29
2	26.3	5.87	9.09
3	27.2	6.04	8.76
4	28.8	6.39	6.84
5	29.3	6.57	5.74
6	31.5	6.95	4.98
7	33.2	7.31	4.20

9.6 Data Analysis

Solving the the degree 4 polynomial equation gives us the value of the Curie Temperature T_C for value of Voltage and Current.

s.No	Curie Temperature (Tc) / K
1	999.595
2	959.303
3	974.734
4	967.115
5	943.795
6	958.587
7	953.408

The average value of the Curie Temperature T_C is $692.220°C$. The type A uncertainty in the value of the Curie Temperature is $6.820°C$. The final value is $692.220 \pm 6.820°C$

9.7 Discussion & Conclusion

The expected value of the Curie Temperature for the Kanthal-D wire is $600°$ C whereas the calculated value is $692.220°C$. One of the reasons for this huge difference is the environmental losses. The long wire radiates more heat since the room is open and room temperature is not maintained. Furthermore, the time that is being recorded is very small and since its being recorded by a stopwatch there is human reaction time. Instead of using a stopwatch, record the motion by a video camera and then playback frame by frame to know the exact moment the wire becomes detached. The experiment should be carried out in a close environment.

9.8 MATLAB Script

```
b = 5.675E-8; % Boltzman constant
e = 0.7 ;% Emissivity

To = 25 + 273; % Room Temperature in Kelvin
m = 2.35/1000; % Mass in Kg
c = 460; % Specific Heat Capacity
```

```
r = 0.723/2000; % Radius
L = 100/100; % Length
S = 2*pi*r*L; % Surface Area


tc4 = e * b * S.*t;
tc1 = m * c;
tc0 = -(e*b*S*(To^4).*t+ V.*A.*t+m*c*To);
for i = 1:7
    p = [tc4(i) 0 0 tc1 tc0(i)];
    roots(p)
end
```

Experiment 10

DETERMINING THE COEFFICIENT OF CONVECTIVE HEAT TRANSFER

Date: 20/10/2020

10.1 Aim

The aim of this experiment is to measure the change of temperature of a body as heat flows from it to the surrounding through convective losses where the concept of heat is the flow of thermal energy through conduction, convection, radiation.

10.2 Background Theory

Heat is transferred through conduction, convection and radiation. Conduction is the process whereby heat energy is transferred across a medium. There are materials which are good or poor conductors of heat just like there are materials which are good or bad conductors of electricity. Thus, thermal conduction is the transfer of energy by microscopic collisions of particles and movement of electrons within a body. The equation under thermal equilibrium is as following:

$$P = \frac{dQ}{dt} = -kA\frac{T_2 - T_1}{L}$$

where P represents power transmitted, A represents area and $T_2 - T_1$ is temperature difference and L represents length. Specific heat capacity is defined as amount of energy required per unit mass to raise temperature by one unit. It is given by

$$Q = mc\triangle T$$

. When heat is lost by object with time then it can be calculated by differentiating the above formula:

$$\frac{dQ}{dt} = -mc\frac{dT(t)}{dt}$$

.

Thermal convection occurs when a liquid comes in contact with an object whose temperature is higher than that of it. When the less energetic molecules of the air encounter the fast vibrating molecules of the hotter object, they pick up some energy off the molecules of the hot surface. At the interface of the object and the air the process is exactly similar to conduction. But the temperature of the air soon rises at the surface causing them to be less dense. The molecules have more energy and the hot air rises. These molecules then transfer the thermal energy to neighboring molecules through collisions conduction as well as through the bulk flow of air convection. In practice, both of these modes of heat transfer go on, hands in hand. When the molecules cool down they become dense and sink and when are hot they become less dense and rise.

For small temperature difference between a body and its surrounding, the rate of cooling of the body is directly proportional to the temperature difference and the surface area exposed.

$$\frac{dQ}{dt}(q{-}q_s)$$

where q and q_s are temperature corresponding to object and surroundings.

Newton's law of cooling concerns the process of thermal conduction through convection is mathematically stated as

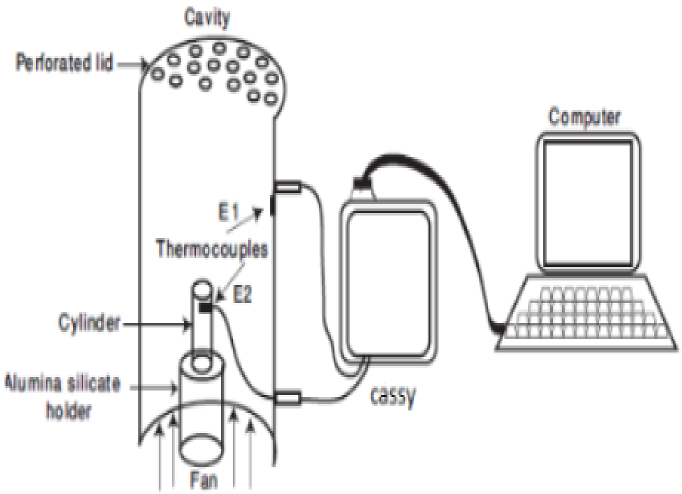
$$\frac{dQ_{conv}}{dt} = hA(T_2 - T_1)$$

When an amount Q heat is provided to cylindrical rod of a certain material to raise its temperature by an amount $\triangle T$. When the rod cools down through convection in air currents the same amount of energy is lost with time to convection. This heat loss is :

$$hA(T(t) - T_0) = \frac{dQ}{dt} = -mc\frac{dT(t)}{dt}$$

where T is temperature of rod. T_0 is temperature of surrounding, m is mass, A is area of convection and h is coefficient of heat transfer.

10.3 Description of Setup



The experiment is set up as above where the cylinder is placed inside the cavity to provide a closed environment and a thermocouple is used to measure voltage against the temperature and is inputted into the CASSY software to record readings.Other equipment includes heating machine, graphite powder, weighing machine, temperature gun, and Vernier calipers.

10.4 Method / Procedure

First the mass is measured using weighing machine, the length and diameter of the cylinders are measured using vernier calipers. Then the cylinder is placed inside the steel box on the hot plate. Then it is covered with graphite powder and heated up to 350 $^{\circ}C$ for 45 minutes. After heating we attach a thermocouple to the heated cylinder and transfer the cylinder into the cavity with the fan off.One thermocouple is attached to the cylindrical cavity to measure the temperature of the air in the cylinder. Second thermocouple is attached to the heated cylinder through a clip. Then CASSY software is opened and readings are recorded. The cylinder is removed from the cavity and the thermocouple is attached to another cylinder. Then we transfer the cylinder into the cavity with the fan on. The data is recorded on CASSY software.

10.5 Data

The type B uncertainty in the mass of the rod 1 and rod 2 is $0.000003grams$, in the diameter of the rod 1 and rod 2 is $0.000002m$ and in the length of rod 1 and rod 2 is $0.00002m$.

	Rod 1	**Rod 2**
Mass (grams)	114.47	114.45
Length (mm)	24.95	25.23
Diameter (mm)	78.53	78.42
Specific Heat Capacity of Aluminium (J/(kg*K))	887	887

10.6 Data Analysis

$$hA(T(t) - T_0) = -mc\frac{dT(t)}{dt} \tag{10.1}$$

$$hA = \frac{-mc}{T(t) - T_0}\frac{dT(t)}{dt} \tag{10.2}$$

$$c + hAt = -mc \times ln(T(t) - T_0) \tag{10.3}$$

$$c = -mcln(X_0) \tag{10.4}$$

$$-mcln(X_0) + hAt = -mc \times ln(X(t)) \tag{10.5}$$

$$-mcln(X_0) + hAt = -mcln(X(t)) \tag{10.6}$$

$$-hAt = mcln(X(t)) - mcln(X_0) \tag{10.7}$$

$$X(t) = X_0 e^{(}\frac{-hAt}{mc}) \tag{10.8}$$

Units of h $=\frac{W}{m^2K}$

	Rod 1	**Rod 2**
Mass (grams)	114.4700	114.4500
Mass (kg)	0.1145	0.1145
Length (mm)	24.9500	25.2300
Length (m)	0.0250	0.0252
Diameter (mm)	78.5300	78.4200
Diameter (m)	0.0785	0.0784
Surface Area	0.0062	0.0062

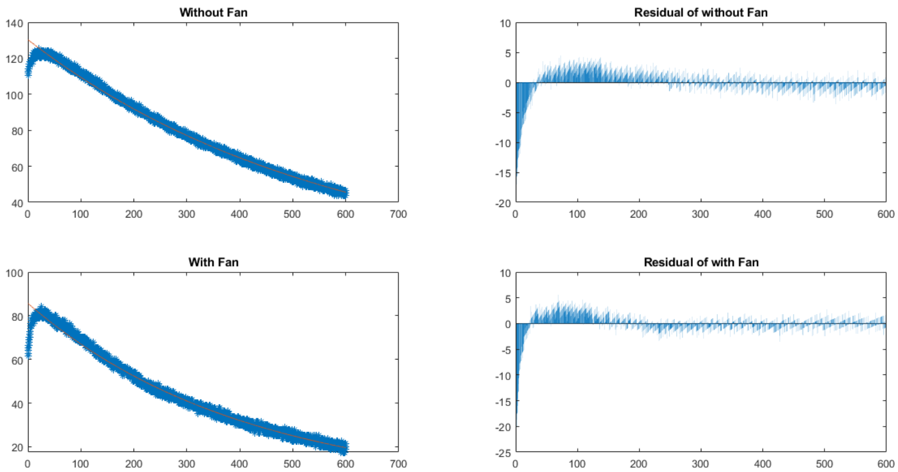


Figure 10.1: Graph of Temperature vs Time

Value of h without fan = $28.667\frac{W}{m^2K}$

Value of h with fan = $40.1610\frac{W}{m^2K}$

10.7 Discussion & Conclusion

As expected as value of h with fan $40.1610\frac{W}{m^2K}$ is greater than h without fan $28.667\frac{W}{m^2K}$. In the residual graph, there is an irregular pattern which indicates the presence of random error. The major source of this error is the heat loss to the environment. The Newton's Law of cooling is limited because the difference in temperature between the body and surroundings must be small. Another major limitation of Newton's law of cooling is that the temperature of surroundings must remain constant during the cooling of the body.

10.8 MATLAB Script

```
m1 = m1(1:3);
m2 = m2(1:3);

%%
mass1 = m1(1);
```

```
mass2 = m2(1);
c = 887;

s1 = pi * m1(2)*m1(3);
s2 = pi * m2(2) * m2(3);
%%
x0_1 = 130.3;
b1 = -0.00175;

x0_2 = 85.69;
b2 = -0.002459;

%%
h1 = -(b1*mass1*c)/s1;
h2 = -(b2*mass2*c)/s2;
%%
xm1 = x0_1*exp(b1.*t1);
xm2 = x0_2*exp(b2.*t2);
%%
res1 = x1 -xm1;
res2 = x2 -xm2;
%%
figure;
subplot 221
plot (t1,x1,'*');hold on
plot (t1,xm1);hold off
title('Without Fan')

subplot 222
```

```
bar (t1,res1);hold on
title('Residual of without Fan')


subplot 223
plot (t2,x2,'*');hold on
plot (t2,xm2);hold off
title('With Fan')

subplot 224
bar(t2,res2);
title('Residual of with Fan')
```

Experiment 11

ROTATIONAL MOTION AND FRICTIONAL LOSSES

Date: 29/11/2020

11.1 Aim

The aim of this experiment is to understand energy losses due to frictional. We will study the relationship between frictional losses in a pulley and mass of the object.

11.2 Background Theory

Consider the provided circular disks (rigid bodies) to be made up of small infinitesimal particles of masses $m_1, m_2, m_3, \cdots, m_n$. Their placement may be defined with the position vectors $\vec{r_1}, \vec{r_2}, \cdots .\vec{r_n}$ and when rotating, their instantaneous velocities may be defined as $\vec{v_1}, \vec{v_2}, \vec{v_3}, \cdot, \vec{v_n}$. The angular momentum of a particle given is by

$$\vec{J_i} = m\vec{v_i} \times \vec{r_i} \tag{11.1}$$

For a particle rotating with angular velocity ω about z axis, we can say that

$$v_i = r_i\omega_i \tag{11.2}$$

We can then combine 11.1 and 11.2 to obtain the following equation

$$\vec{J_i} = m\vec{r_i}\vec{\omega_i} \tag{11.3}$$

Then the total angular momentum of the disk is simply the sum of the angular momentum of the individual particles making the disk.

$$\vec{J} = \sum_{i}^{n} m\vec{r_i}^2 \vec{\omega_i} \tag{11.4}$$

The quantity $\sum_i^n m\vec{r_i}^2$ is known as moment of Inertia I. In this form , the angular momentum of the disc becomes

$$J_z = \omega I \tag{11.5}$$

We can write I in the similar form as transalational moment,

$$I = \frac{1}{2} M R^2 \tag{11.6}$$

Rotational Kinetic energy is defined as

$$K = \frac{1}{2} I \omega^2 \tag{11.7}$$

Moment of inertia of a particular body is defined with respect to a particular rotation axis and is different for a body when it is rotating about x, y or z axes.

11.3 Description of Setup

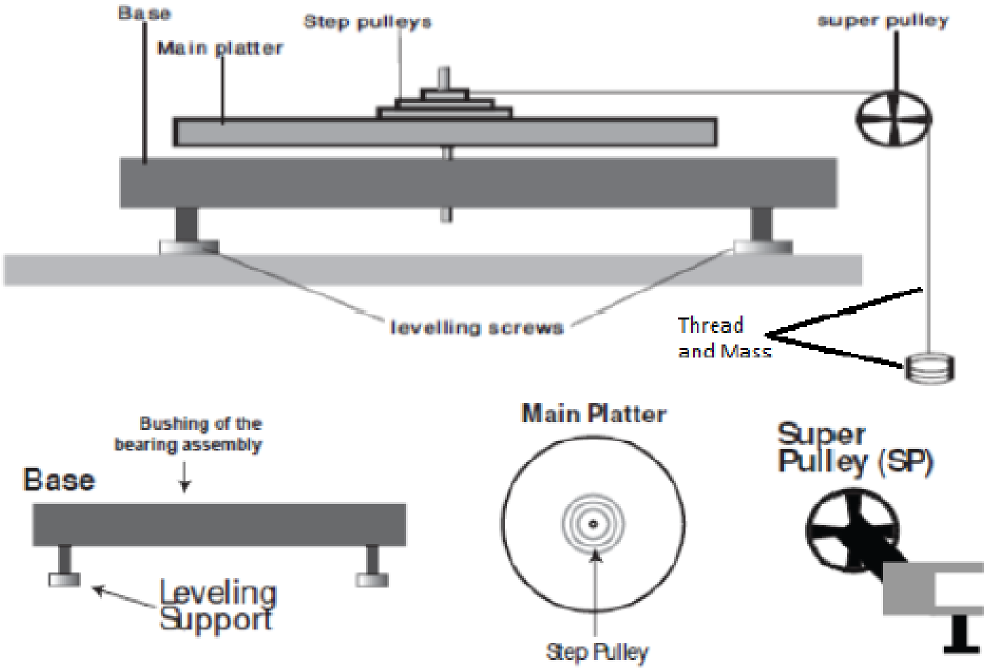


Figure 11.1: Apparatus and the arrangement of the experimental setup.

Here the base is used to hold the platters and pulleys, main platter is the object which is performing the Rotational motion, camera and metre are used in conjunction to measure the height of the hanging mass, step pulley is used to adjust the torque , super pulley is used to provide a smooth transition from Translation to Rotational Motion and the Thread ans Mass are used to execute Translation Motion and rotate the main platter.

11.4 Method / Procedure

In the given experimental setup, the thread is wrapped about the spindle as the wheel is spun. This lifts the mass tied to the other end of the thread by some distance, thereby storing potential energy in it. The disk is released, and the mass is let to oscillate for about five cycles, recording the height of the mass as a function of time.The same experiment using is for three other masses four masses. Then a graph of potential energy vs time is plotted in MATLAB for each particular value of Mass.

11.5 Data

The type B uncertainty in the height h is $0.001m$, in the time t is $0.003s$ and in the mass is $0.00003kg$.

Mass (grams) = 23.3					
s.No	**Time (s)**	**Max_h (cm)**	**Min_h (cm)**	**Diff_h (cm)**	**P.E(J)**
0	0	68	12	56	0.1280009
1	17.37	60	12	48	0.109715
2	33.41	52	12	40	0.0914292
3	48.09	45.5	12	33.5	0.076572
4	62.37	40	12	28	0.0640004
5	73.81	35.5	12	23.5	0.0537147

Mass (grams) = 43.0					
s.No	**Time (s)**	**Max_h (cm)**	**Min_h (cm)**	**Diff_h (cm)**	**P.E(J)**
0	0	68	12	56	0.236225
1	12.21	62.5	12	50.5	0.219352
2	24.12	56.5	12	44.5	0.202478
3	35.71	51.5	12	39.5	0.183496
4	46.89	46.5	12	34.5	0.166623
5	57.16	43	12	31	0.153968

Mass (grams) = 62.6					
s.No	**Time (s)**	**Max_h (cm)**	**Min_h (cm)**	**Diff_h (cm)**	**P.E(J)**
0	0	68	12	56	0.3438994
1	10.02	63.5	12	51.5	0.3162646
2	20.27	58.5	12	46.5	0.2855593
3	30.31	54	12	42	0.2579245
4	39.43	50	12	38	0.2333603
5	48.86	46.5	12	34.5	0.2118666

Mass (grams) = 82.2					
s.No	**Time (s)**	**Max_h (cm)**	**Min_h (cm)**	**Diff_h (cm)**	**P.E(J)**
0	0	68	12	56	0.451574
1	9.2	64	12	52	0.419319
2	18.45	60	12	48	0.387063
3	27.09	55.5	12	43.5	0.350776
4	35.54	51.5	12	39.5	0.318521
5	43.62	48.5	12	36.5	0.294329

11.6 Data Analysis

Values obtained by curve Fitting of Potential Energy vs Time using the equation $a \times e^{bt}$ are summarised in the following table.

Curve Fitting Results			
s.No	Mass(gram)	a	b (Frictional Loss Coefficient)
1	23.3	0.1305	-0.01131
2	43	0.2389	-0.01034
3	62.6	0.3467	-0.00992
4	82	0.4645	-0.00986

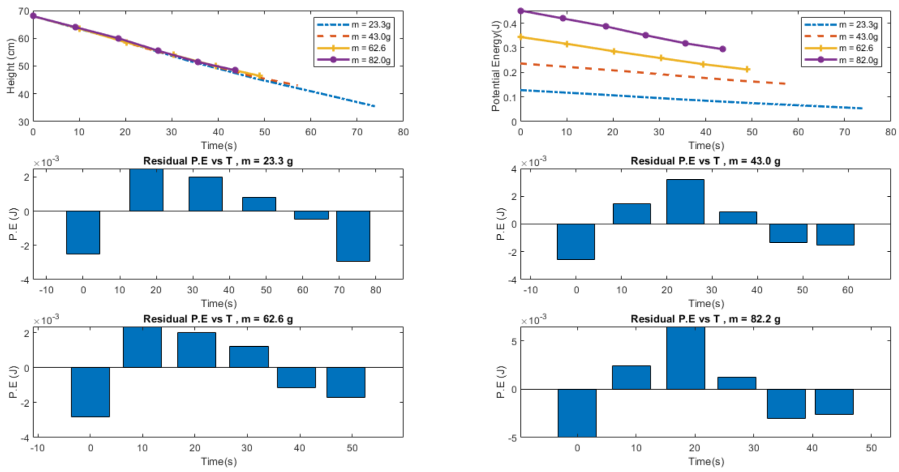


Figure 11.2: Graph of Height, Potential Energy vs Time and Residual Plots

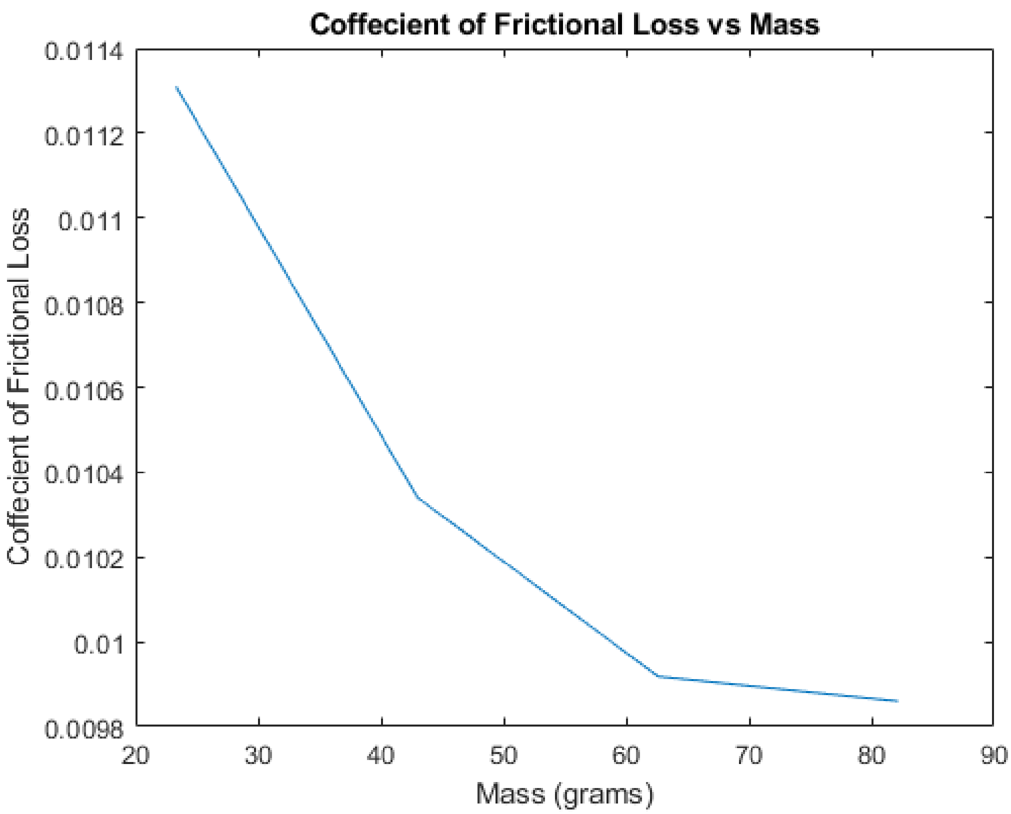


Figure 11.3: Graph of coefficient of Frictional Loss vs Mass

11.7 Discussion & Conclusion

The fit plot of Potential Energy vs Time is decreasing exponentially which is what we expected . Due to energy loss to friction, the maximum height decreased in each cycle and this turn meant that the potential energy decreased and we observed this in the plot. The graph of coefficient of frictional loss vs mass has an increasing trend which means that more larger the mass , greater the energy loss. Sinusoidal pattern in the residual indicates the presence of random error. One way to improve these errors is to take more readings which can be done by taking more values of masses and recording maximum height for more cycles.

11.8 MATLAB Script

```
a1 = 0.1305;
b1 = -0.01131;
a2 = 0.2389;
b2 = -0.01034;
a3 = 0.3467  ;
b3 = -0.009918;
a4 =  0.4565;
b4 = -0.00986;

b  = -[b1 b2 b3 b4];
m  = [23.3 43.0 62.6 82.2];
pm1 = a1*exp(b1.*t1);
pm2 = a2*exp(b2.*t2);
pm3 = a3*exp(b3.*t3);
pm4 = a4*exp(b4.*t4);

r1 = p1 - pm1;
r2 = p2 - pm2;
r3 = p3 - pm3;
r4 = p4 - pm4;
```

```
figure;
subplot 321;
plot(t1,h1,'-.','LineWidth',2); hold on
plot(t2,h2,'--','LineWidth',2);
plot(t3,h3,'-+','LineWidth',2);
plot(t4,h4,'-*','LineWidth',2);hold off
legend( 'm = 23.3g','m = 43.0g','m = 62.6', 'm = 82.0g')
xlabel('Time(s)')
ylabel('Height (cm)')

subplot 322;
plot(t1,p1,'-.','LineWidth',2); hold on
plot(t2,p2,'--','LineWidth',2);
plot(t3,p3,'-+','LineWidth',2);
plot(t4,p4,'-*','LineWidth',2);hold off
legend( 'm = 23.3g','m = 43.0g','m = 62.6', 'm = 82.0g')
xlabel('Time(s)')
ylabel('Potential Energy(J)')

subplot 323;
bar(t1,r1);xlabel('Time(s)'); ylabel('P.E (J)'); title('
   Residual P.E vs T , m = 23.3 g');


subplot 324;
bar(t2,r2);xlabel('Time(s)'); ylabel('P.E (J)'); title('
   Residual P.E vs T , m = 43.0 g');
```

```
subplot 325;
bar(t3,r3);xlabel('Time(s)'); ylabel('P.E (J)'); title('
   Residual P.E vs T , m = 62.6 g');


subplot 326;
bar(t4,r4);xlabel('Time(s)'); ylabel('P.E (J)'); title('
   Residual P.E vs T , m = 82.2 g');

figure;
plot(m,b);
xlabel('Mass (grams)')
ylabel('Coffecient of Frictional Loss')
title('Coffecient of Frictional Loss vs Mass')
```

Experiment 12

VIBRATIONS ON STRINGS AND RESONANCE

Date: 12/04/2020

12.1 Aim

The aim of this experiment is to induce and observe standing waves on a string, identify where resonance occurs, to distinguishing linear from non-linear behaviour and compare experimental plots with mathematical relationships.

12.2 Background Theory

Wave is a disturbance or variation that transfers energy in a medium which provides the means for waves to propagate. Speed of a wave is given by

$$v = \sqrt{\frac{T}{\mu}} \tag{12.1}$$

A travelling wave oscillates in time and space. It is given by $Asin(kx - \omega t$. Where k is wave number related to wavelength of the wave and is given by

$$k = \frac{2\pi}{\lambda} \tag{12.2}$$

and ω is angular frequency given by

$$\omega = 2\pi f = \frac{2\pi}{T} \tag{12.3}$$

Where f i frequency, T is time period of the wave. Therefore, speed of wave is given as

$$v = f\lambda = (\frac{\omega}{2\pi})(\frac{2\pi}{k}) = \frac{\omega}{k} \tag{12.4}$$

Interference is a phenomena that occurs when two waves meet travelling along same medium. There are two types, constructive and destructive. Constructive interference occurs when the crest meets crest or likewise for trough. A destructive interference happens when crest meets trough or the other way and leads to reduction of amplitude. Standing waves are formed by the interference of two traveling waves in opposite direction of same frequency and amplitude. Nodes are point where the total wave is zero at all times and anti-nodes are points that have maximum amplitudes. Distance between these two points is half wavelength. Harmonic is frequency where string vibrates with single antinode, called first harmonic. For higher harmonics frequency is given by

$$f_n = \frac{nv}{\lambda} = \frac{n}{\lambda}\sqrt{\frac{T}{\mu}} \tag{12.5}$$

and the frequency of nth harmonic is

$$f_n = \frac{n}{2L}\sqrt{\frac{T}{\mu}} \tag{12.6}$$

When the string is loaded with beads, wave number is given as

$$k_n = \frac{2\pi}{\lambda_n} = \frac{n\pi}{(N+1)m} \tag{12.7}$$

U sing previous equations we have

$$\frac{\omega_n}{v} = \frac{n\pi}{(N+1}m \tag{12.8}$$

$$\omega_n = 2\pi f_n = \frac{n\pi}{(N+1)m}\sqrt{\frac{T}{\mu}} \tag{12.9}$$

$$f_n = \frac{n}{2(N+1)m}\sqrt{\frac{T}{\mu}} \tag{12.10}$$

12.3 Description of Setup

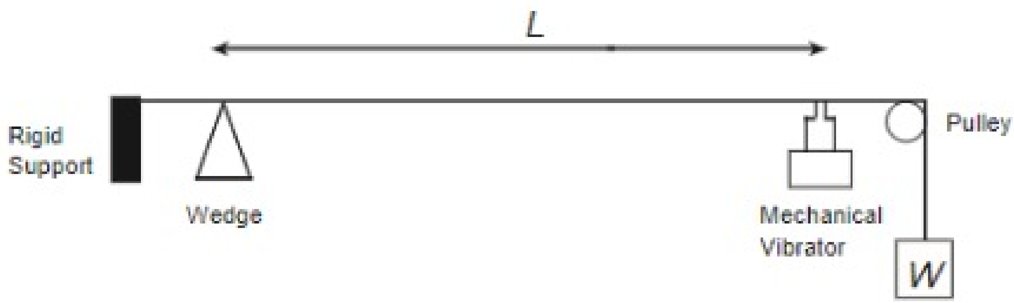


Figure 12.1: Apparatus and the arrangement of the experimental setup.

The experiment is set up as above with the string with and without beads, a signal generator, a speaker that produces waves and weight to create tension in string.

12.4 Method / Procedure

We first measure the diameter of the string using a micrometer, measure the length of the string using the meter rule. We also find the theoretical values to have a close frequency range for sweep frequency. We find the value of μ . Output leads of the signal generated to woofer is connected at 10V. Then we sweep the frequency of the signal generator and find the frequency at which standing waves appear. We do it for the first harmonic, second harmonic, third harmonic, fourth harmonic. We then repeat the same process for the loaded string, with beads, and measure the inter-bead distance first. We find the four harmonic frequencies in the same manner. We note down all harmonics and plot graph between frequency and number of the harmonics for both.

12.5 Data

Type B uncertainty of diameter is 0.00002m and 0.002m for length and 0.002 for frequency.

un-loaded Steel String				
	h1	h2	h3	h4
S.no	f1 (Hz)	f2 (Hz)	f3 (Hz)	f4 (Hz)
1	23.5	46.3	70.2	95.6
2	24.14	50	73	93
3	23.5	46	70.8	96

un-loaded Steel String	
No. of Anti Nodes	Average Frequency(Hz)
h1	23.71333333
h2	47.43333333
h3	71.33333333
h4	94.86666667

Loaded Steel String				
	h1	h2	h3	h4
S.no	f1 (Hz)	f2 (Hz)	f3 (Hz)	f4 (Hz)
1	13	26	35	44
2	14	25	35	44
3	12.7	24.5	35.6	44.5

Loaded Steel String	
No. of Anti Nodes	Average Frequency(Hz)
h1	13.23333333
h2	25.16666667
h3	35.2
h4	44.16666667

12.6 Data Analysis

We have two equations for density and μ

$$\rho = \frac{mass}{volume}$$

$$\mu = \frac{mass}{l}$$

We equate the two equations according to mass

$$\rho * v = l * \mu$$

where v denotes volume and l denotes length. It is further divided into

$$\rho * 2\pi r^2 * l = l * \mu$$

We get our final equation as

$$\mu = \rho * 2\pi r^2$$

Our values of tension T and μ are 11.9878 and 0.00314. Our theoretical values for harmonics are calculated using

$$f_n = \frac{n}{2L}\sqrt{\frac{T}{\mu}} \tag{12.11}$$

are as following:

un-loaded Steel String	
No. of Anti Nodes	Frequency(Hz)
h1	16.96705
h2	33.9341
h3	50.90116
h4	67.86821

For loaded string we calculated harmonics using

$$f_n = \frac{n}{2(N+1)m}\sqrt{\frac{T}{\mu}} \tag{12.12}$$

Loaded Steel String	
No. of Anti Nodes	Frequency(Hz)
h1	22.0571682
h2	44.11433639
h3	66.17150459
h4	88.22867278

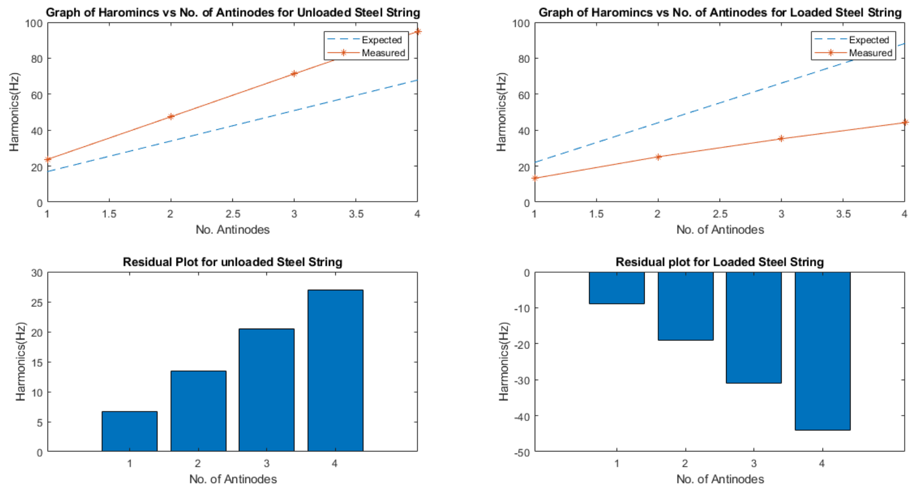


Figure 12.2: Apparatus and the arrangement of the experimental setup.

12.7 Discussion & Conclusion

We can see in the graph of Harmonics vs antinodes that there is a linear trend although, the value of harmonics does not double when the number of antinodes increase. Furthermore, we can see from both the residual plots that as the number of antinodes the error in the values of the harmonics also increase. This was expected because as the number of antinodes increase, the maximum amplitude decreases which in turn makes it difficult to observe. We can reduce the random errors in this experiment by recording more values of harmonics for each antinodes. We can also vary the tension in string using different weights and then repeating the experiment for each value of Tension.

12.8 MATLAB Script

```
values = (1:4);
figure;
subplot 221
plot(values,m1,”--”); hold on
plot(values,e1,”-*”);hold off
legend(”Expected”,”Measured”);
```

```
ylabel("Harmonics(Hz)");
xlabel("No. Antinodes");
title("Graph of Harornincs vs No. of Antinodes for
  Unloaded Steel String");


subplot 222
plot(values,m2,"--"); hold on
plot(values,e2,"-*");hold off
legend("Expected","Measured");
ylabel("Harmonics(Hz)");
xlabel("No. of Antinodes");
title("Graph of Harornincs vs No. of Antinodes for Loaded
  Steel String");

r1 = e1 - m1;
subplot 223
bar(values,r1);
ylabel("Harmonics(Hz)");
xlabel("No. of Antinodes");
title("Residual Plot for unloaded Steel String");

r2 = e2 - m2;

subplot 224
bar(values,r2);
ylabel("Harmonics(Hz)");
xlabel("No. of Antinodes");
title("Residual plot for Loaded Steel String");
```