INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

PHYSICS DEPT.

NO. 23B0940 CLASS BATCH P15/3

NAME Aditya Neeraje

EXPT. No. 8 LABORATORY

DATE 12/10/23

Centrifugal Force

Aim:

The experiment aims to determine the centrifugal force experienced by a car at rest on a track rotating with constant angular velocity. The car comes to rest (after an initial transient motion at a fixed radius from the center of the track, since the centrifugal force is balanced by the tension in the string to which the car is tied. This string is connected to a spring balance (dynamometer) on the other end, which allows us to read the tension (and therefore the centrifugal force) directly. This experiment involves determination of the centrifugal force as a function of a) mass, b) the angular velocity, c) the distance of the car from the rotation axis.

Apparatus:

1. Track
2. Car of weight 50 ± 1g (with holding pin)
3. Holding bow to keep the car from flying off.
4. Guiding roller for connecting threaded
5. Thread connecting car and dynamometer
6. Dynamometer (1N)
7. Dynameter holder
8. Holes into which the dynamometer holder can be plugged.

9. Locking pin for turning down the dynamometer holding arm
10. Dynamometer holding arm
11. Grooves for power transmission
12. Motor
13. Bearing unit for the track
14. Light barrier (with counter)

Theory:

In the reference system rotating with angular velocity ω, the equation of motion of a point mass m at position r is:

$$m\frac{dv}{dt} = -\nabla U + m r \times \frac{d\omega}{dt} + 2m\,v\times\omega + \underbrace{m\omega\times(r\times\omega)}_{F}$$

Here, F is the centrifugal force we are invested in. The external force field U (gravitational field) is compensated by the track. ω is constant.

The car is at rest in the rotating reference system

$\Rightarrow U=0,\ \vec{v}=0,\ \vec{\omega}=$ constant

$F = m\omega\times(r\times\omega) = m\omega^2 r$ since $r \perp \omega$.

Note: The centrifugal force experienced by the car is balanced by the tension in the thread connecting the car to the spring balance, which in turn is balanced by the elongation in the ~~string~~ spring balance, following Hooke's Law $F_z = -kz$, where k is the spring constant and z is the extension. Thus, measuring F_z directly from the spring balance (in N) allows us to determine the centrifugal force.

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

PHYSICS DEPT.

NO. 23B0940 CLASS BATCH

NAME Aditya Neeraje

EXPT. No. 8 LABORATORY

DATE 12/10/23

Observation:

1) Calculation of ω:

S.No:	Time Period (in s)
1	1.338
2	1.337
3	1.330

Average Time Period $(\bar{T}) = 1.335$

$r = 18cm$ $\omega = 4.706$ rad s^{-1}

S.No	Mass (m) (kg)	T (in s)	$F_{calc} = m\omega^2 r$ (in Newton)	$F_{observed}$ (in N)
1.	0.050	1.335	0.19	0.20
2.	0.080	1.335	0.32	0.32
3.	0.110	1.335	0.44	0.46
4.	0.140	1.335	0.56	0.54
5.	0.170	1.335	0.68	0.66

Least Sum of Squares Calculated values:

1) 0.208
2) 0.322
3) 0.436
4) 0.55
5) 0.664

2) $m = 100g$, $r = 18$ cm

S.No	Voltage (in V)	T_1 (in s)	T_2 (in s)	$\bar{T}$ (in s)	ω (rad/s)	ω^2 (rad^{2}s^{-2})	F_z (N)	$F_c = m\omega$ (N)
	~~40~~	2.183	2.178	2.181			0.14	0.15
1.	30	2.928	2.934	2.931	2.14	4.60	0.08	0.10
2.	40	2.183	2.178	2.181	2.88	8.30	0.14	0.15
3.	50	1.757	1.753	1.755	3.58	12.83	0.22	0.23
4.	60	1.291	1.294	1.292	4.86	23.65	0.36	0.42
5.	70	1.065	1.048	1.056	5.95	35.4	0.58	0.63

(Plot Best fit line above)

3) $V = 60$ V, $m = 100g$

S.No	Time (in s)
1	1.288
2	1.307
3	1.306
4	1.307
5	1.307

Average Time $(\bar{T}) = 1.303$ s, $\bar{\omega} = \frac{2\pi}{\bar{T}} = 4.822$ rad s^{-1}, $m = 100g$

S.No.	r (cm)	T (in s)	F_z (in N)	F_c $(= m\omega^2 r)$ (in N)	δF_c (in N)
1.	17	1.303	0.40	0.39	0.02
2.	15	1.303	0.34	0.35	0.02
3.	20	1.303	0.46	0.465	0.022
4.	22	1.303	0.50	0.5115	0.02[illegible]2
5.	13	1.303	0.3	0.302	0.0281

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

PHYSICS DEPT.

NO. 23B0940 CLASS

NAME Aditya N

EXPT. No. 8

DATE 12/10/23

BATCH 15/3

LABORATORY

Calculation:

1) Sum of times (ΣT) = 4.005 s

Average time ($\bar{T}$) = 1.335 s

Average $\bar{\omega} = \frac{2\pi}{\bar{T}} = \frac{2 \times \pi}{1.335} = 4.706$ rad s^{-1}

$\Sigma F \cancel{\Sigma} \Sigma \omega^2$

$y = mx + c$, $y = F, x = m$

$$m = \frac{N \Sigma x_i y_i - (\Sigma x_i)(\Sigma y_i)}{N \Sigma x_i^2 - (\Sigma x_i)^2}$$

$$c = \frac{\Sigma y}{N} - \frac{m \Sigma x}{N}$$

$$m = \frac{N \Sigma m_i F_i - (\Sigma m_i)(\Sigma F_i)}{N \Sigma x_i^2 - (\Sigma x_i)^2}$$

$= 5\times$

~~2) $F_c = m\omega^2 r =$~~

$\Sigma m_i = 0.550$ kg

$\Sigma F_i = 2.18$ N

$\Sigma m_i^2 = 10^{-4} \times (695)$ kg^2

$\Sigma m_i b_i = 27.4 \times 10^{-2}$

$= 0.274$ kg N

$$m = \frac{5 \times 0.274 - 0.55 \times 2.18}{5 \times 695 \times 10^{-4} - (0.55)^2} = 3.8 \text{ N/kg}$$

$$c = \frac{\Sigma F_i - m \Sigma x_i}{N} = \frac{2.18 - 3.8 \times 0.55}{N} = \frac{0.09}{5} \text{ N} = 0.018 \text{ N}$$

12

3) Average Time $\bar{T} = \frac{\text{Sum of } T}{N}$

$$\bar{\omega} = \frac{2\pi}{\bar{T}} = \frac{2\times 3.14}{1.303} = 4.822 \text{ rad s}^{-1}$$

$$\bar{\omega}^2 = 4.822^2 = 23.25 \text{ rad}^2 \text{s}^{-2}$$

$$\delta T = \sqrt{\frac{1}{5}\sum_{i=1}^{5}(T_i - \bar{T})^2}$$

$$= \sqrt{\frac{1}{5}\left[(0.015)^2 + (0.004)^2 + (0.003)^2 + (0.004)^2 + (0.004)^2\right]}$$

$$= 10^{-3}\sqrt{\frac{1}{5}(225 + 16 + 9 + 16 + 16)}$$

$$= 7.509 \times 10^{-3} \text{ s}$$

$$\frac{\delta T}{T} = 0.57\%$$

$$\frac{2\delta T}{T} = 1.151\%$$

$$\frac{\delta m}{m} = \frac{1}{100} = 1\%$$

$\frac{\delta F}{F} =$

1) $2.151 + \frac{100}{34} = 5.09\% \Rightarrow \delta F = 1.98 \times 10^{-2} N$

2) $2.151 + \frac{100}{30} = 5.48\% \Rightarrow \delta F = 0.019 N$

3) $2.151 + \frac{100}{40} = 4.651 \Rightarrow \delta F = 0.0216 N$

4) $2.151 + \frac{100}{44} = 4.423 \Rightarrow \delta F = 0.0226 N$

5) $2.151 + \frac{100}{26} = 5.99\% \Rightarrow \delta F = 0.0181 N$

5

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY	NO. 23B0940 CLASS	BATCH 15/3
	NAME Aditya Neeraje	
	EXPT. No. 8	LABORATORY
PHYSICS DEPT.	DATE 12/10/23	

~~Set Up and Procedure:~~

~~I~~ I Plot Fitting and Error Analysis:

1) For all the experiments, F_c and F_z should be plotted using best fit, except the analysis of F_z v m, which should be performed using least square fit.
To be able the fit a straight line,

$$y = mx + c,$$

Average value of y and x:

$$\bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i \quad , \quad \bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

and

$$m = \frac{N\sum_{i=1}^{N} x_i y_i - \sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i}{N\sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2}$$

$$c = \bar{y} - m\bar{x}$$

The values of m and c should then be used to fit the straight line to the data.

2) For the third measurement (dependence ~~of~~ on r), a plot of $F_c = m\omega^2 r$ as a function of r has to be plotted on the same plot as F_z v. r. For this plot, first ω has to be determined. ω is calculated from the average time period of 5 values of T.

$$\overline{T} = \frac{1}{5}\sum_{i=1}^{5} T_i$$

Then calculate the standard deviation as:

$$\delta T = \sqrt{\frac{1}{5}\sum_{i=1}^{5}(T_i - \overline{T})^2}$$

$$\overline{\omega} = \frac{2\pi}{\overline{T}} \; ; \quad \frac{\delta\omega}{\omega} = \frac{\delta T}{T}$$

mass $= \overline{m} + \delta m = 50 \pm 1g$ (Mass of the car)

Uncertainty in $r = \pm 0.5cm$.

$$\frac{\delta F_c}{F_c} = \frac{\delta m}{m} + 2\frac{\delta\omega}{\omega} + \frac{\delta r}{r} \quad (\text{from } F_c = m\overline{\omega}^2 r)$$

In the plot of F_c v r, show the error bars.

Precautions:

1) The current and voltage knobs should be at zero before switching power on.
2) Take care not to hit anyone with the track
3) The track must turn perfectly horizontally to avoid gravity causing the dynamometer redding to fluctuate. Use cardboard to correct the footing ~~the~~ of the bench clamp if need be.
4) When motor is on, track should pass smoothly between the arms of the light barrier.
5) For keeping Ω constant in first and third part, use toggle switch. Do not change the knob position

INDIAN INSTITUTE OF TECHNOLOGY

PHYSICS DEPT.

NO. CLASS BATCH

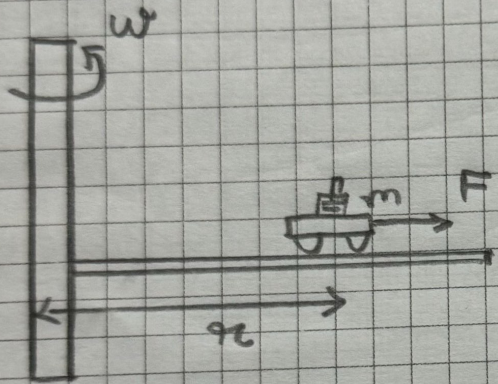
NAME

EXPT. No. LABORATORY

DATE

Diagram

Fig 2: Schematic showing the car of mass m at rest in the reference frame of the rotating track.



Result:

1) In the F_z vs m graph, for the least sum of squares line,

$m = 3.8$ N/kg

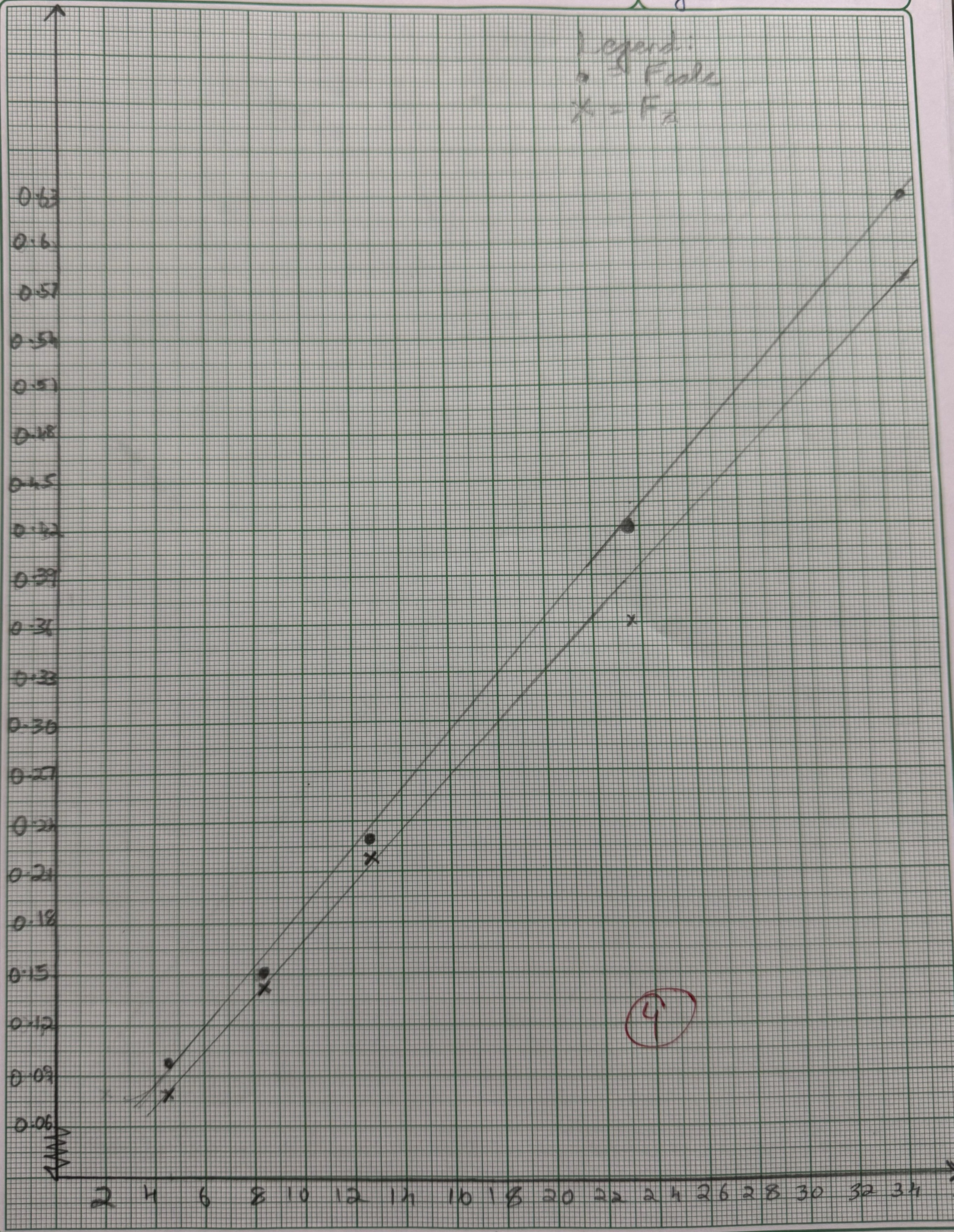
$c = 0.018$ N

2) $\dfrac{\delta T}{T} = 1.151\%$

$\dfrac{\delta m}{m} = 1\%$

2. Fz vs ω^2

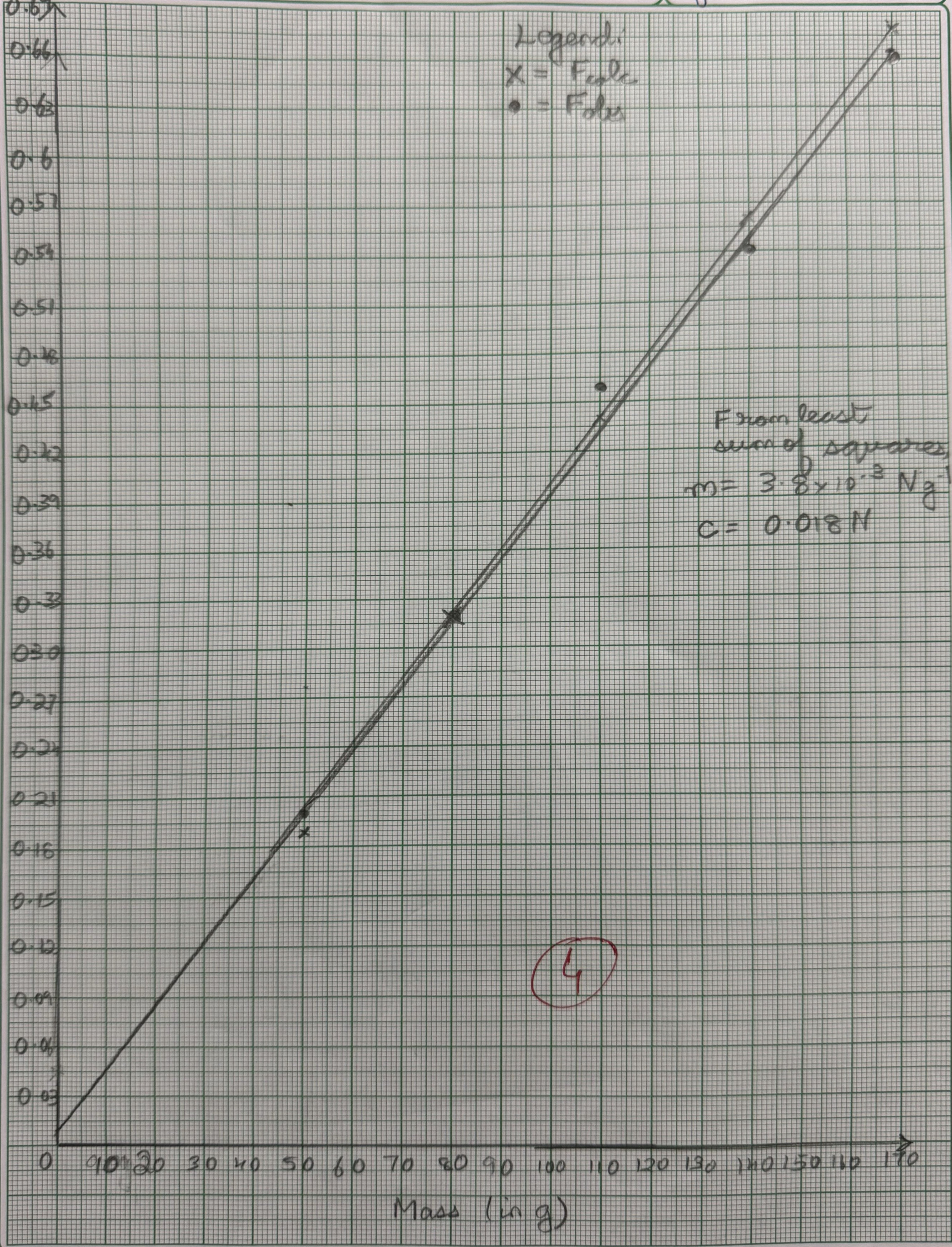
SCALE :-
x axis: 1cm = 2 rad^{2}s^{-2}
y axis: 1cm = 0.03N



ω^2 (rad^2 s^{-2}) →

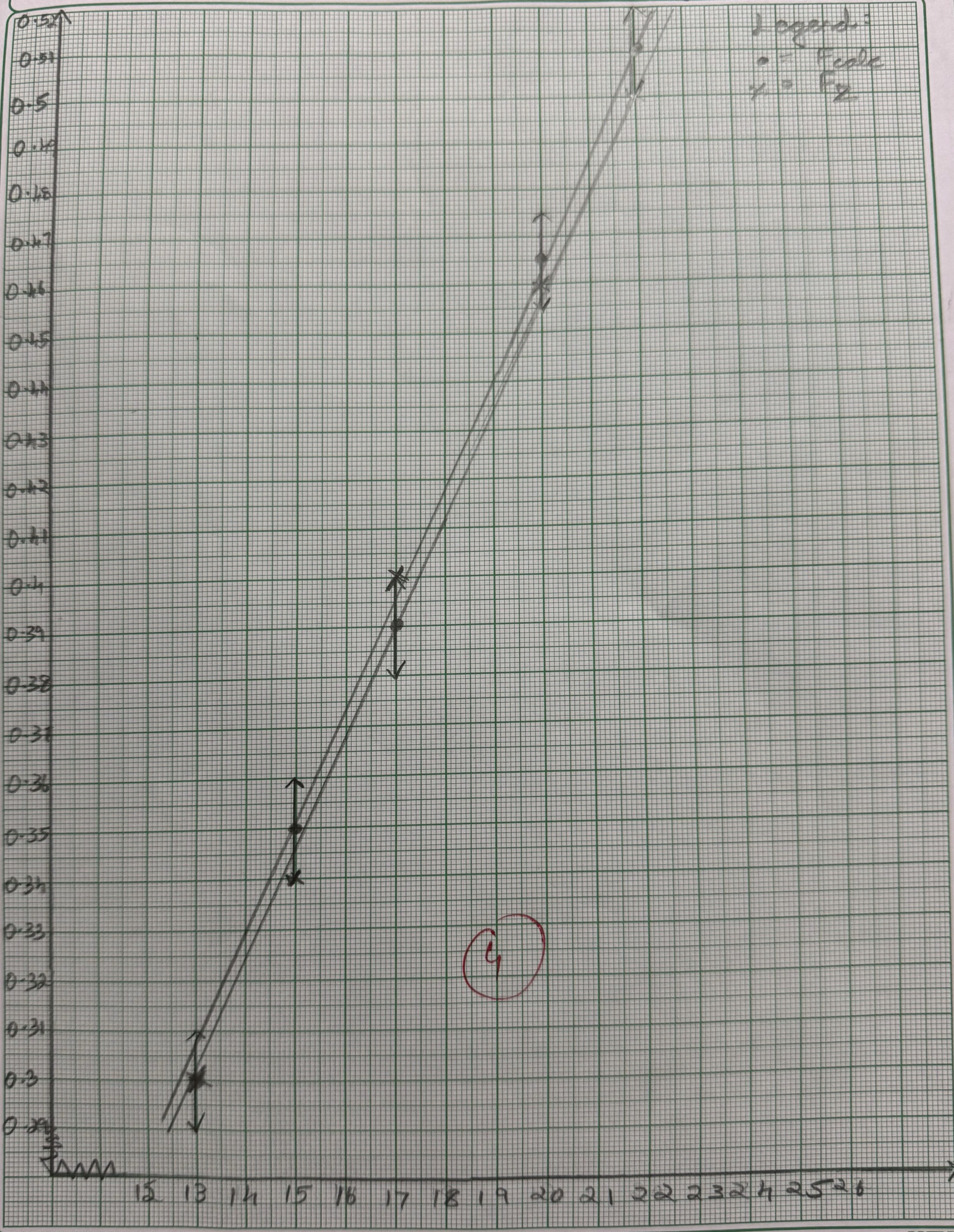
1. F_2 vs m

SCALE :- x axis: 1cm = 10 g
y axis: 1 cm = 3N



3. F_z vs r

SCALE :-
x axis : 1cm = 1cm
y axis : 1cm = 0.01N



r(in cm) →