Experiment # 1

Static Equilibrium of Forces

Laboratory Objectives:

This experiment has the following objectives:

- To study the concepts of force and torque.
- To study the conditions for translational and rotational equilibrium.
- To learn analytical and graphical methods for the addition of vector quant

Apparatus:

A drawing board and a torque disk in addition to a set of masses (10-1000 gm), weight holders, pulleys, spring balances, etc.

Theory:

A **rigid body** is an object whose parts move together under the influence of external forces and torques. This body is said to be under static equilibrium when the following two conditions are satisfied:

1) The sum of all external forces acting on the body is equal to zero.

$$\Sigma \vec{F}_i = \vec{0} \quad (1)$$

2) The sum of all external torques acting on the body is equal to zero.

$$\Sigma \vec{\tau}_i = \vec{0} \quad (2)$$

If, in the case of equation (1), the number of forces ,n, equals 3, then one can write:

$$\vec{F}_1 + \vec{F}_2 = -\vec{F}_3 \quad (3)$$

The force $\mathbf{F_3}$ is called the *equilibrant* force. This force is opposite in direction to the *resultant* force obtained from adding F_1 and F_2.

Figure 1 shows the experimental set-up for this experiment.

- Make Sure the pulleys are in ONE vertical plane.
- Make the pulleys run with as little friction as possible.
- Make sure you look vertically on the ropes. Use a plane mirror to draw proper lines of force by placing it behind the rope and drawing a line.

EXPERIMENTAL:

The actual steps for performing the experiment are:

1. Place appropriate weights on pans R and Q (see fig.1). (Include the weight of the pan).

2. While holding the string (with your hand)at point x, place enough weights on pan E until equilibrium is reached (pans stop moving).

3. Draw lines tracing the pieces of string and record the weights in each pan.

Calculations:

The equilibrant force **E** is given by $\vec{E} = -(\vec{R} + \vec{Q})$. Figure 2 is a *free body diagram* for the point mass x. The forces **R**, **Q**, and **E** can be decomposed into x-, and y-components as follows:

$$E = R\cos(\theta_1) + Q\cos(\theta_2)$$

$$0 = R\sin(\theta_1) - Q\sin(\theta_2)$$

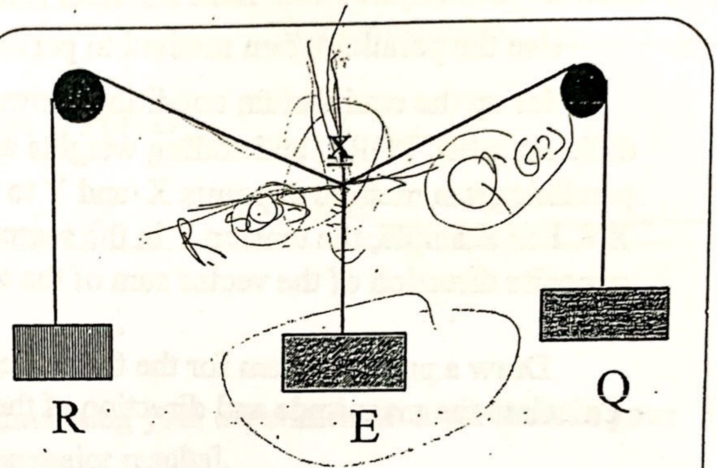


Fig. 1: Force board with 3 forces.

Your results should be summarized in a table. The table entries should be the measured values of **R**, **E**, and **Q**, and the computed components. You should also compute the following values:

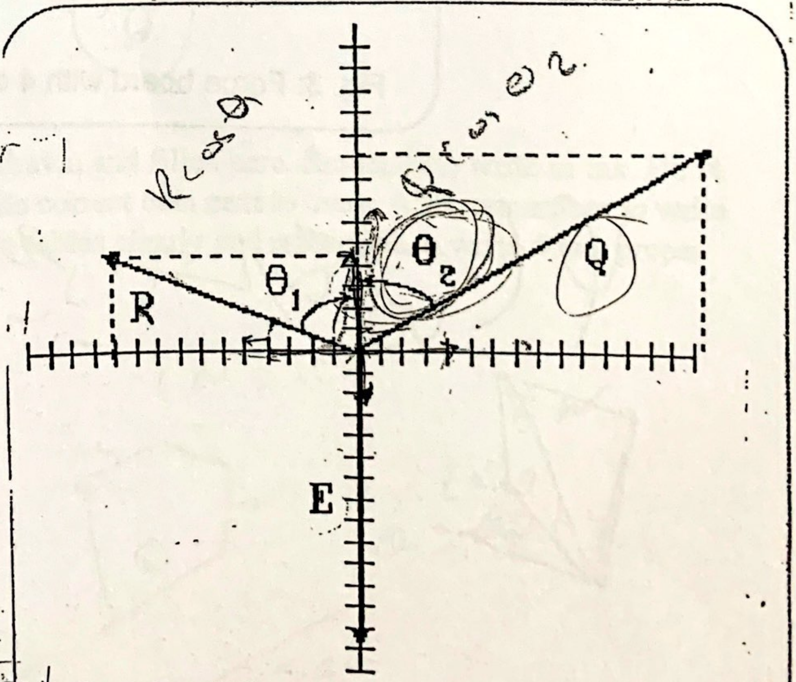
$$U_1 = R\sin(\theta_1) - Q\sin(\theta_2)$$

$$U_2 = E_{meas} - [R\cos(\theta_1) + Q\cos(\theta_2)]$$

These values should be near zero.

$U_1 = R\sin\theta_1 -$

$U_2 = E_{meas} - (R\cos\theta_1 +$



$R\sin(\theta_1) - Q\sin(\theta_2)$

Fig. 2: Resolution of vectors into components.

The parallelogram Method:

Vectors can be added graphically using the parallelogram method. To represent a vector, an arrow is used. The length of the arrow represents the magnitude of the vector. The direction of the arrow is chosen to represent the vector direction relative to a common reference axis, usually the positive x-axis. The two vectors to be added represent two sides of a parallelogram with their sum being the diagonal. (You can go back to your Physics 131 book for more information.)

Use the parallelogram method to perform the following exercise:

Set up the equilibrium condition shown in figure 3. This is done by hanging four different pans, PQRS, and adding weights until equilibrium is achieved. Use the parallelogram method at points X and Y to find the tension **T** in the string segment XY. For example, the tension T in the segment XY has the same magnitude, and the opposite direction of the vector sum of the tension due to P, and due to Q.

Draw a parallelogram for the forces defined by the weights **P, Q, R,** and **S.** Calculate the magnitude and direction of the vector **T.**

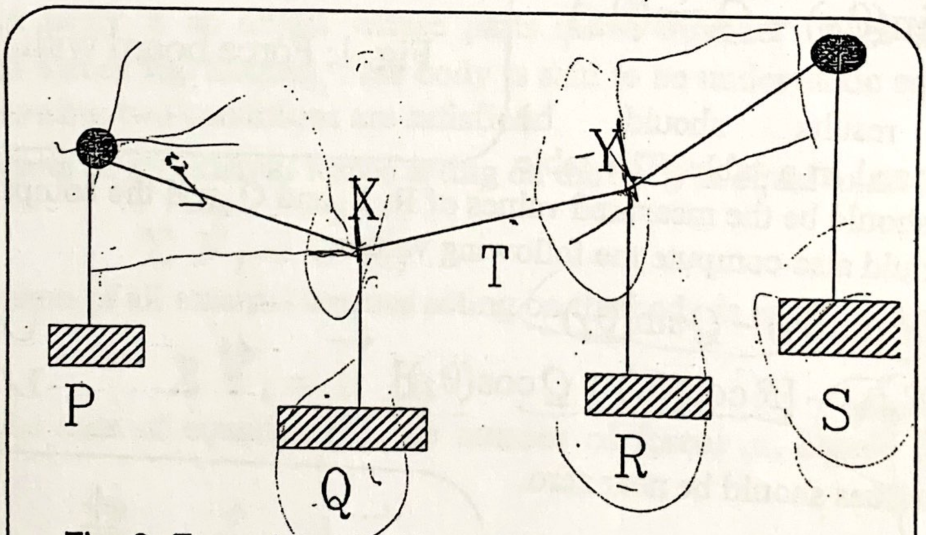
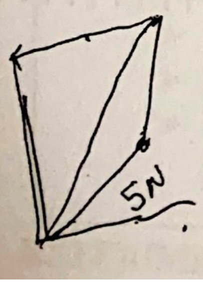


Fig. 3: Force board with 4 different forces.



PQR

Experiment #2
Freely Falling Objects

Laboratory Objectives:

This experiment has the following objectives:

1. To familiarize the student with the use of logarithmic graph paper.
2. To serve as an exercise in experimental data analysis using spreadsheets.
3. To determine the acceleration due to gravity at Birzeit.

Apparatus:

Falling sphere apparatus consisting of a support rod, meter scale, connecting wires, electronic timer, and power supply.

Software:

$mg = ma$ $\quad g = a \quad g = \frac{d^2h}{dt}$

LOTUS spreadsheet program or compatible software. Review the skills of creating columnar data, regression analysis, x-y plotting of data.

Theory:

An object falling near the earth's surface will have a nearly constant acceleration given by Newton's second law as follows:

$$m\vec{g} = m\frac{d^2\vec{h}}{dt^2} \text{.............................(1)}$$

$h = h_0 + v_0 t + \frac{1}{2} g$

or

$$\frac{d^2\vec{h}}{dt^2} = \vec{g} \text{.......................................(2)}$$

$\vec{h}(t) = \boxed{\frac{1}{2}gt^2}$

The solution of the above differential equation is given by:

$$\vec{h}(t) = \vec{h}_0(t) + \vec{v}_0 t + \frac{1}{2}\vec{g}t^2 \text{...............................(3)}$$

If the object is dropped from rest, and **h** is measured so that $\mathbf{h_0}$ is set equal to zero, the relationship between **h** and **t** that we are left with is simply the quadratic relationship:

$$h = \frac{1}{2}gt^2 \text{..(4)}$$

$h = \log \frac{1}{2}g + 2\log t$

Experimental:

The experimental setup for the experiment is schematically shown in figure 1.

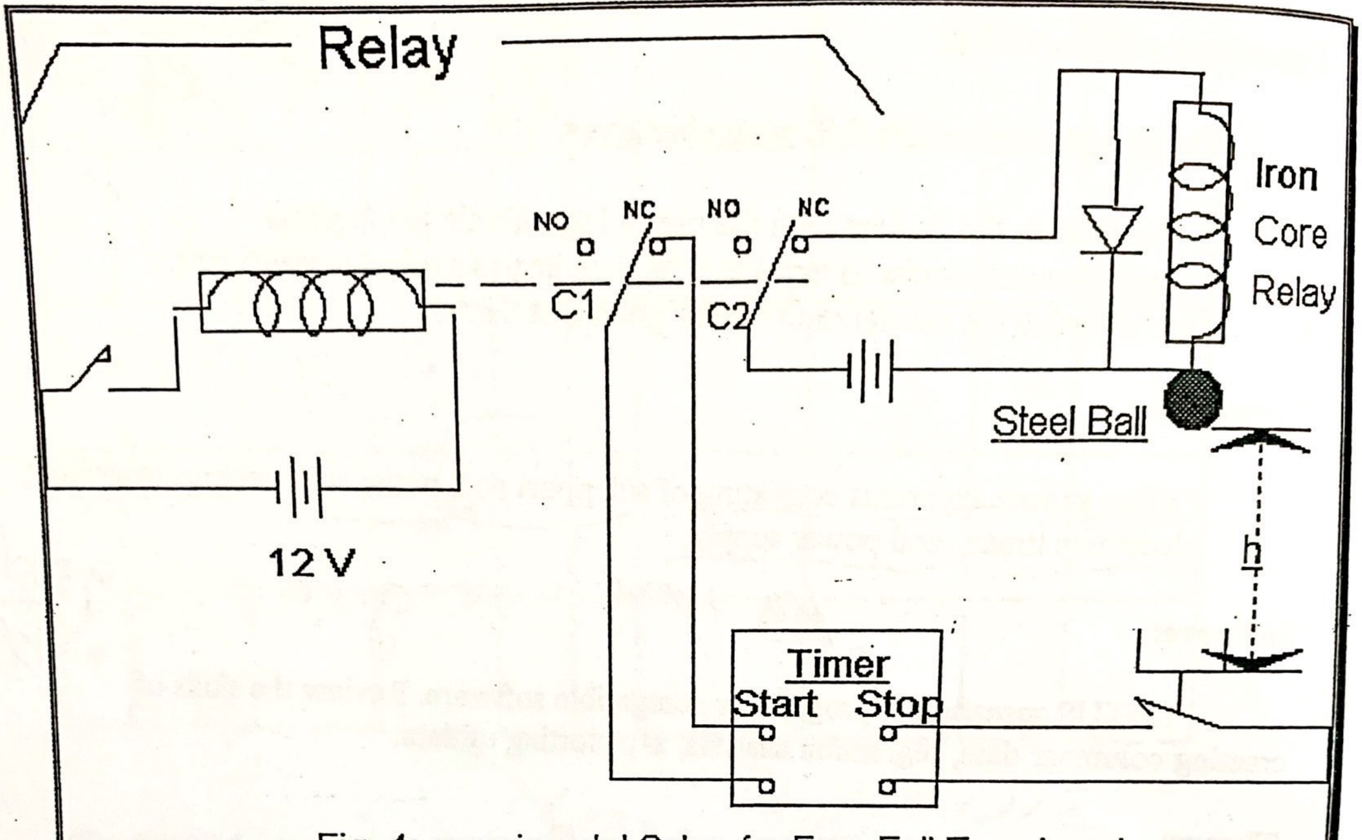


Fig. 1: experimental Setup for Free Fall Experiment.

When the current through the solenoid is interrupted the ball falls a distance h. At this very instant the timer starts. When the ball hits the pan below, the stop switch for the timer is closed stopping the time measurement. Repeat the time measurement three times for each height h.

Calculations:

1. Record your data in the table shown below.

Time t (sec)					
Height h(cm)	t_1	t_2	t_3	$\bar{t}$	t^{α}
10 cm	0.176	0.176	0.173		0.0164
20 cm	~~0.234~~ ~~0.115~~	0.233	0.232		0.0306
30 cm	0.280	0.279	0.280		0.0535
40 cm	0.313	0.315	0.315		0.07[illegible]
50	0.345	0.345	0.346		0.0620
60 cm	~~0.355~~	~~0.357~~			0.0949

0.362

0.709

$0.35 = h$

2. Use the spreadsheet program (LOTUS) available with the computer in your lab to analyze your results:
    a. Create columns for h, t_1, t_2, t_3 and t **(average time)**.
    b. Graph log(h) vs log(t) using LOTUS.
    c. Use the Data/Regression feature of LOTUS (D/R) to determine the slope of your plot, and calculate α.
    d. Create a separate plot of h vs t^2. Perform the D/R operation on the h-t data. Calculate g from this latter calculation.

Print your worksheet and graphs and submit with your report.
Also answer the questions for this experiment in the manual.

Log h vs log t

Log t vs Log t

0.001

$h = \frac{1}{2} g t^2$

Log h vs log t

Log h = $\frac{1}{2}$g log t

$\frac{\log 0.7 - \log 0.10}{\log 0.4 - \log 0.2}$

Log h = g log t

$g = \frac{2h}{t^2}$

$x = 2\frac{\Delta y}{\Delta x}$

$h = \frac{1}{2} g t^2$

Log h = Log g + log t

$\boxed{2}$ 1.98

x. uncertainty

EXPERIMENT #3

Newton's Laws of Motion

Preparation for the Experiment:

- Read the introductory instrumentation article, in this manual , on the air track.
- Read about Newton's Laws of Motion in your 131 book.

Objectives:

The experiment is meant to satisfy the following objectives:

- ☐ To familiarize the student with the utility of the air track.
- ☐ To verify the Newton's first and second laws of motion.

Apparatus:

Figure 1 is a schematic(drawing) of the apparatus. Objects traveling on the track are levitated (lifted) via the action of the air blower. Motion is caused by objects (M') pulled down by gravitational attraction. The figure does not show the timer circuits used to measure t and Δt.

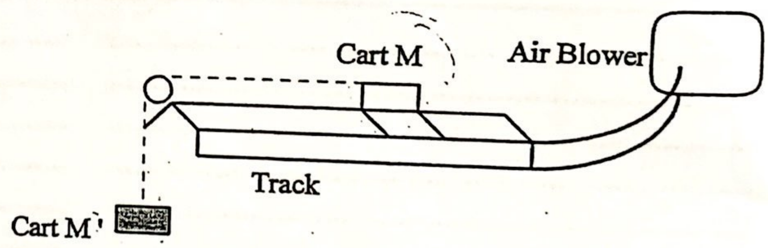


Figure 1: Air Track Assembly

Theory:

Every student attending this laboratory should be familiar with the statements of Newton's Laws. If you are not sure of them, then go back to your general physics text! This experiment is made of three parts. One related to the First law while the other two are related to the Second.

- ☐ Part I: According to the first law, objects moving at constant velocity stay moving unless diverted by an external force. In this part, you will be asked to move a cart with a constant speed along the track, measuring its speed at two different locations separated by about 50 cm. The registered speeds should be the same within experimental error.

F = M'g = (M + M') a

☐ Part II: The Second law can be mathematically represented by the following relationship: $\vec{F} = m\vec{a}$. where **F** is the total external force on the object and **a** is its total linear acceleration.

For the arrangement shown in figure 1, the objects will experience a constant force and hence a constant acceleration.

$$|\vec{F}| = M'|\vec{g}| = (M + M')|\vec{a}|$$

the speed of the cart is therefore

$$v(t) = \frac{M'g}{(M+M')} t$$

and the distance travelled by the objects is given by:

$$d(t) = \frac{1}{2}\frac{M'g}{(M+M')} t^2$$

$\frac{1}{2} g t^2$

where the last couple of equations are derived by integrating the first equation , once and twice respectively.

Experimental:

0.02

WARNING

Never move any object on the track before starting the air blower, because this will immediately scratch the track!

Part I:

1. Start the air track.
2. Set up the both timers to measure Δt.
3. Launch one cart along the track and record the times on both photocells.
4. Calculate the velocity of the cart near each photocell and compare.

Part II-A: <u>Fixed M, fixed M', variable d</u>:

1. Start the air track.
2. Set up timer 1 for measurement of t, timer 2 for measurement of Δt.
3. Start the system M, M' into motion by triggering the release mechanism(magnet).
4. Change the position of the first photocell (in effect changing d). Record **d, t, and Δt.**
5. Repeat the process for 5 different values of d.

Part II-B: <u>Fixed M + M', variable M and M'</u>:

1. Keep the set up in part II-A (steps 1,2 above).
2. Load cart M with additional weights.

Photo
46-2.4-18

3. Keep d constant. Repeat step 3 in part II-A. Record **d, t, and Δt**
4. Transfer some weight from M to M', changing M' but keeping the total mass M+M' constant, and repeat step 3 different values of M'.

2.4×10^{-2}

Data, Calculations, and Analysis:

Part I:

Create a table similar to the following, fill in values of Δt, v.

Attempt	Δt_1	Δt_2	V_1	V_2
	0.107 ~~0.095~~	0.095		
	0.103	0.093		
	0.104	0.094		
	0.019	0.017		
	0.034	0.032		

Table I: First Law.

Use lotus to analyze your results. Create columns for v_1-v_2 and $2(v_1-v_2)/(v_1+v_2)$. The second value represents the deviation from the First law.

MS 20 mg

Part II-A: $\Delta E = 1.8$ cm

M = 50g + 20
m' = 40g

Create a table to contain t, Δt, v, d.

d 39.6   t 1.151   Δt 0.02

Δt	t	v	d
0.28	0.788		25.6
0.024	0.788		49.6
0.020	1.156		59.6
0.018	1.253		69.6
0.017	1.321		79.6

1. Fill in table.
2. Plot v vs t on a log-log plot, calculate slope. What does it mean?(Use equations in theory section).
3. Repeat 2 for d vs t.

N = a

Part II-B:

$\frac{m'g}{M+m'}$

Create a table to contain M, M', t.

Δt	t	M	M'	a
0.038	1.126	60	20	0.467
0.025	0.727	50	30	1.120
0.022	0.620	40	40	1.540
0.019	0.571	30	50	1.816
0.018	0.480	20	60	2.51

1. Use t, d to calculate a.($d = (1/2)at^2$)
2. Plot M'g vs a.
3. Calculate slope. What is its meaning?(Use equations in theory section).

0.592

196

$\frac{\Delta x}{\Delta t}$

Moment of Inertia of a Flywheel

Preparation for the Experiment:

- Read chapters 11 and 12 of **Serway**, ***PHYSICS***, *for scientists and engineers with modern Physics.*
- The flywheel is very heavy. Beware of the possibility of injury if it falls on feet or

Objectives:

Cons

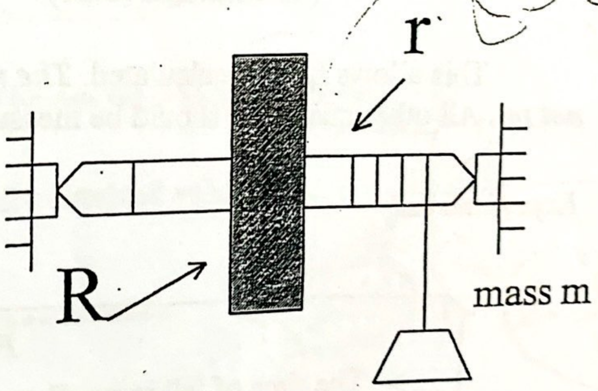
- ☐ Application of the concepts of energy conservation to cases where both rotational and translational motion are effective.
- ☐ Calculation of the moment of inertia of a flywheel.

Apparatus:

Flywheel mounted on a horizontal axis, weights, meter scale, caliper, and a stop watch.

Theory:

As shown in the figure the flywheel is a heavy object that is pivoted so as to rotate on a horizontal axis. The way this experiment is done is to let the object **m** fall from rest and to count the number of rotations of the wheel before and after the object hits ground.



Flywheel and axle

Let **I** be the moment of inertia of the flywheel defined as:

$$I = \int r^2 dm$$

where **r** is the distance of mass element **dm** from the axis of rotation. Let **r=d/2** be the radius of the axle, **R** be the radius of the wheel itself. Let v be the linear velocity of the falling object and ω be the angular velocity of the flywheel when the weight reaches the floor. Let **n** be the number of rotations of the wheel before the object reaches ground, and N be the number of subsequent rotations until the wheel stops. If **W** is the amount of work done against friction per one rotation (assumed to be constant), then:

$$mgh = \frac{1}{2}mv^2 + \frac{1}{2}Iw^2 + nW$$

kg.m²

To determine W, we use the fact that the flywheel's energy is dissipated against the friction incurred in N rotations, then :

$$NW = \frac{1}{2} Iw^2$$

$$W = \frac{Iw^2}{2N}, \text{ where } w = \frac{v}{r}$$

the result of which is as follows:

$$mgh = \frac{v^2}{2} m + \frac{Iv^2}{2r^2}(1 + \frac{n}{N})$$

on another note, one can show that :

$$v = 2\frac{h}{t} \quad = \quad 2 \times (average \quad velocity \quad of \quad fall)$$

hence,

$$mgh = 2\frac{h^2}{t^2} m + \frac{2Ih}{r^2}(1 + \frac{n}{N})\frac{2h^2}{t^2}$$

this will give finally for the moment of inertia:

$$\boxed{I = mr^2 \frac{N}{n+N}(\frac{gt^2}{2h} - 1) = \frac{1}{4} md^2 \frac{N}{n+N}(\frac{gt^2}{2h} - 1)}$$

(m=attached mass)

This allows I, to be calculated. ***The mass of the wheel used is (7.12+/- 0.01) Kg(This is not m).*** All other quantities should be measured as shown in the procedure below.

d869

Experimental:

Precautions

- The time of fall is small, so one should be careful about accuracy.
- If the bearings are not well oiled, friction will prevent any reasonable motion of the system.
- The thread must be well packed to avoid slipping.

To perform the actual experiment, step through the following short procedure:

1. Wind several turns of the string around the axle raising the weight up a few tens of centimeters from the ground.
2. Allow the weight to fall from rest, while measuring the following quantities:
   a) The time of fall (until the mass hits the ground) .

b) The number of turns the wheel makes until weight hits the ground.
c) The number of turns, after the wheel hits the ground, until it stops.

Calculations, discussion and Conclusions:

Create a spreadsheet to perform your calculations.
In the sheet, start by recording your data for the various attempts:

Attempt	t	n	N	I
	0.05	5	12	
	.05	5	13	
	.05	5	13	
	.05	5	12	

0.05 5 12

$M=(7.12\pm0.01)kg,\quad r=(\ \pm\ )\ ,\quad R=(\ \pm\ )$ 286g
$h=(\ \pm\ ).$ d = 2.5 m

$r = \frac{d}{2} = 1.25$ cm

➢ Calculate the average value of **I+/-ΔI.**
In the derivation of ΔI, the following quantities are to be used:

0.0356

ΔN	Use sample standard deviation of N.
Δn	Use sample standard deviation. σ_m
Δh	Use instrumental error.
Δd	Use instrumental error.
Δt	Use sample standard deviation.

50cm

➢ Assume the wheel consists of one cylinder whose mass is given above.
1. Calculate **I** using $I=\frac{1}{2}Mr^2$.
2. Compare this value with the experimentally obtained value for **I.**

$\left(\frac{\Delta M}{m}\right)^2 + \left(2\frac{\Delta r}{r}\right)^2$

****

$I = mr^2 \frac{N}{n+N}\left(\frac{gt^2}{2h} - 1\right)$

$I = mr^2 \frac{N}{N+n}\left(\frac{gt^2}{2h} - 1\right)$

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EXPERIMENT #5

The Helical Spring

Preparation for the Experiment:

➢ Read Chapter 13 of **SERWAY,** ***Physics For Scientists and Engineers with Modern Physics,*** Third Edition, on the subject of small oscillations.

Objectives:

This laboratory session has the following objective:

- ☐ To determine the force constant for a soft spring.
- ☐ To study vertical oscillations of a long spring.

Apparatus:

A long helical spring, meter stick, and a stop watch.

Theory:

When a weight m is suspended from the end of a soft spring, it will stay in equilibrium under the influence of its weight and the elastic force in the spring.

$$\vec{F} = -k\vec{y} = m\vec{g}$$

If the spring is stretched an additional length y', and then released, it will oscillate with its equation of motion being:

$$m\frac{d^2\vec{y}'}{dt^2} = -k\vec{y}'$$

The solution to this equation is simple harmonic motion with angular frequency $\omega = (\kappa/m)^{1/2}$ which gives the following useful equation for the period of oscillations:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

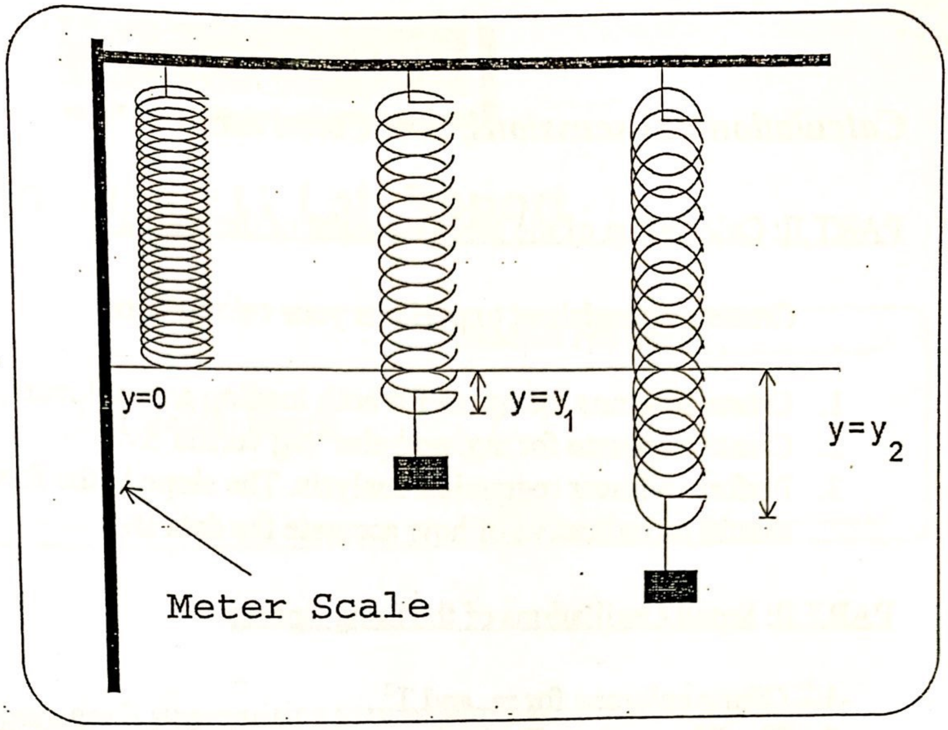
But one has to include an "effective mass" for the spring in the above equation, so the period for small oscillations would look something like the following:

$$T = 2\pi\sqrt{\frac{(m+m_{eff})}{k}}$$

(The spring mass is usually neglected. To compensate for the error, the term m_{eff} is introduced into the equation).

Experimental:

The figure shows a schematic of the experimental set-up for both parts of the this experiment.



Part I:

The purpose of this part is to determine the force constant of the long spring.

m(kg)	Δy(m)
50	26.5
100	25
150	23.4
200	21.8
250	19.5
300	18.2

1. Place the spring in a vertical position and suspend the pan holder for weights.
2. Mark clearly the lower end of the pan and use it as your zero point for the y-axis.
3. Start adding loads and record the extension $\Delta \mathbf{y}$ vs the added mass $\mathbf{m}$.

Part II:

This part is used to study oscillations of the spring.

m(kg)	T(sec)
50	0.95
100	0.64
150	
200	
250	
300	

1. Load the spring with a given mass m.
2. Stretch it slightly and let it oscillate in small oscillations.
3. Using the stop watch, measure the time for 10 oscillations then use it to compute the period T.

$\frac{k}{m}$

mg = ky

Calculations, Discussions, and Conclusions:

PART II: Calculation of the force constant of the spring **k**

Create a spreadsheet to perform your calculations.

1. Create columns for Δy, m for both loading and unloading cases. Fill in your data.
2. Create a column for mg, and plot mg versus Δy.
3. Perform a linear regression analysis. The slope is the force constant k and the y-intercept should be indicative of how accurate the data is.

PART II: Small Oscillations of the Long Spring

1. Create columns for m, and T^2 .
2. Plot T^2 versus m. Perform a regression analysis and compute the slope and y-intercept.
3. Compute k again.
4. The *effective mass* of the spring can be obtained from the ~~y~~-intercept.
5. For all computed quantities, calculate the uncertainties.

******

mg

Δy

T^2

m

f = mg

mg

Torsional Torques and the Torsional Modulus

Laboratory Objectives:

The torsional pendulum is used to study the elastic properties of Aluminum and Steel rods. The torsional constant is determined, its dependence on rod geometry is analysed, and the shear modulus for these materials is determined!

Apparatus and Method:

The apparatus is shown in Fig.1. A massive dumbbell shaped object is fixed to a thin metallic rod (aluminum or Steel). The system is twisted and set in vibration. The period for small vibrations is measured and is related to the torsional constant.

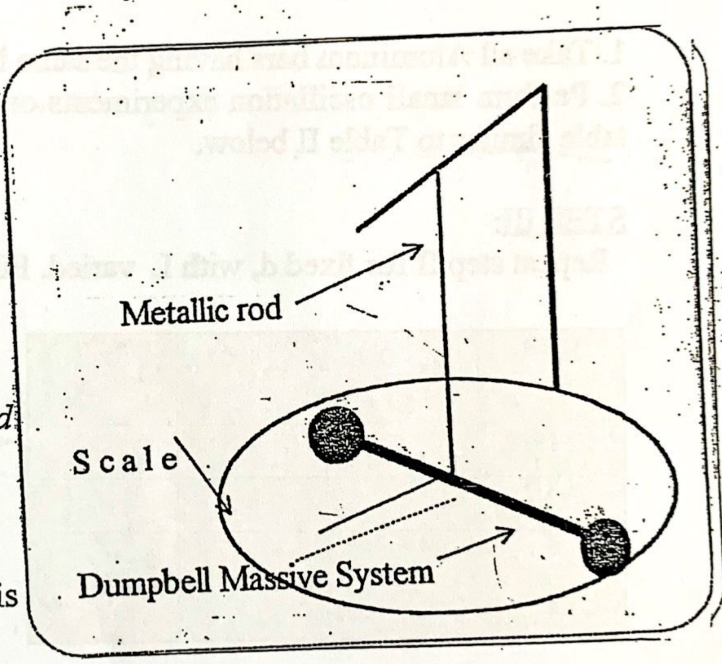
Theory:

The period for small oscillations is given by:

$T^2 = 4\pi^2 \frac{I}{\kappa}$

$$T = 2\pi\sqrt{\frac{I}{\kappa}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where **T** is the period, **I** is the moment of inertia of the system, and **k** is the torsional constant. *Note that the mass of the rod is small compared with that of the dumbbell, and **I** is therefore constant for the whole experiment and is determined once.* (**I_{rod}** *is negligible*)



For elastic twisting of the rod, the torque τ is related to the twist angle θ by :

$$\tau = -\kappa\theta \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

N.m/rad

where κ itself is related to the dimensions of the rod by the following relation:

$$\kappa = G\frac{\pi d^4}{32 L} \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

In this last formula, **G** is the shear modulus, **d** is the rod's diameter, and **L** is its length.

Experimental:

STEP I: Determine the **moment of inertia** of the apparatus as follows:
1. Using one rod (picked at random), twist the system through six different angles θ calculating τ each time. Plot τ vs θ, and use the graph to determine κ.(To calculate the torque, the applied force should be read from the spring used to pull the dumbbell object).

$\tau = -k\theta$

2. Set the dumbbell object into oscillation by pulling it with the spring and releasing it. Measure the period of oscillations for the system and determine **I** by using equation 1. This value for **I** is going to be constant throughout the experiment.

θ(deg)	θ(rad)	τ(N)
10		
20		
30		
40		
50		

$\boxed{1.6}$

$\tau = F \times L$

$= 3.15$

STEP II: κ versus **d** (the rod's diameter).

1. Take all Aluminum bars having the same length.
2. Perform small oscillation experiments on each determining the period for each rod. Create a table similar to Table II below.

STEP III:

Repeat step II for fixed d, with L varied. Fill in table III.

Rod	L(cm)	T(sec)	κ
1			
2			
3			
4			

Table III: κ vs L.

Rod	d(cm)	T(sec)	κ
1	4		
2	3		
3	2		
4			

5 **Table II: κ vs d.**

Calculations:

1. From tables II and III, plot κ vs **d**, and κ versus **L** on log-log paper. Use this to determine **m** and **n** in equation 3. Use the same plots to determine **G**. Find the average value for **G** and record it down.
2. Report the error in the value of **G** from a proper "propagation of errors" calculation. (Refer to the error analysis section at the beginning of this manual).

$$k = \frac{G \pi d^n L^m}{32}$$

Summarize your results in the following sheet:

Torsional Vibrations Result Summary
System Moment of Inerita(**I**):____________________.
n = (±) , **m** = (±).
G = (±).

2.5

-1

4

$7.10 \left(\frac{I}{...}\right)$

Sound Waves

$v_s = 2f(L_2 - L_1)$ $v_s = 2fL_2 - 2fL_1$

Preparation for the Experiment:

- Read the introductory article on the use of the oscilloscope and the signal generator.
- Review chapter 17 in **Serway, PHYSICS for scientists and engineers, with modern physics.**

Objectives:

$(L_2 - L_1) = \frac{\lambda}{2}$

This experiment aims at the generation of sound waves in air and the calculation of their speed.

$v_s = \lambda f$ $v_s = 2f(L_2 - L_1)$

Apparatus:

Resonance tube, signal generator, oscilloscope, microphones, and an amplifier.

Theory:

$v = \lambda f \rightarrow \frac{v}{f}$

For a tube closed at one end, the condition for resonance is resulting from the formation of a *node* at the closed end and an *antinode* at the open end. This leads to the following conditions for the first and second resonances as shown schematically in figure 1:

$$L_1 + e = \frac{\lambda}{4}$$

$$L_2 + e = \frac{3\lambda}{4}$$

where **e** is called the end correction (The antinode occurs outside the tube). By subtracting the two equations from one another one gets:

$v_s = \lambda f$

$$(L_2 - L_1) = \frac{\lambda}{2}$$

which using, $\lambda f = v_s$, where **f** is the frequency and $\mathbf{v_s}$ is speed of sound in air, gives for $\mathbf{v_s}$

$$v_s = 2f(L_2 - L_1)$$

$f = \frac{v}{\lambda}$

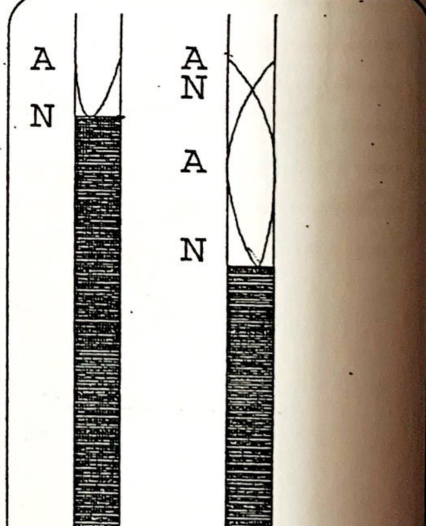


Fig. 1: Conditions for resonance in a tube closed at one end.

Experimental:

A schematic drawing of the experimental set-up is shown in figure 2.

The signal generator is connected to one microphone to produce the audio signal. The second microphone picks up a weak signal which is *amplified* and then sent to the oscilloscope for display together with the original signal.

$\lambda = \frac{4L}{n}$ $L_1 + e = \frac{\lambda}{4}$

The experiment consists of raising and lowering the funnel so as to produce different heights of the water column. *Resonance will occur when the height of the air column is an integer multiple of a quarter wave length on the first order and three quarters of a wavelength on the second order. These lengths are recorded against frequency.*

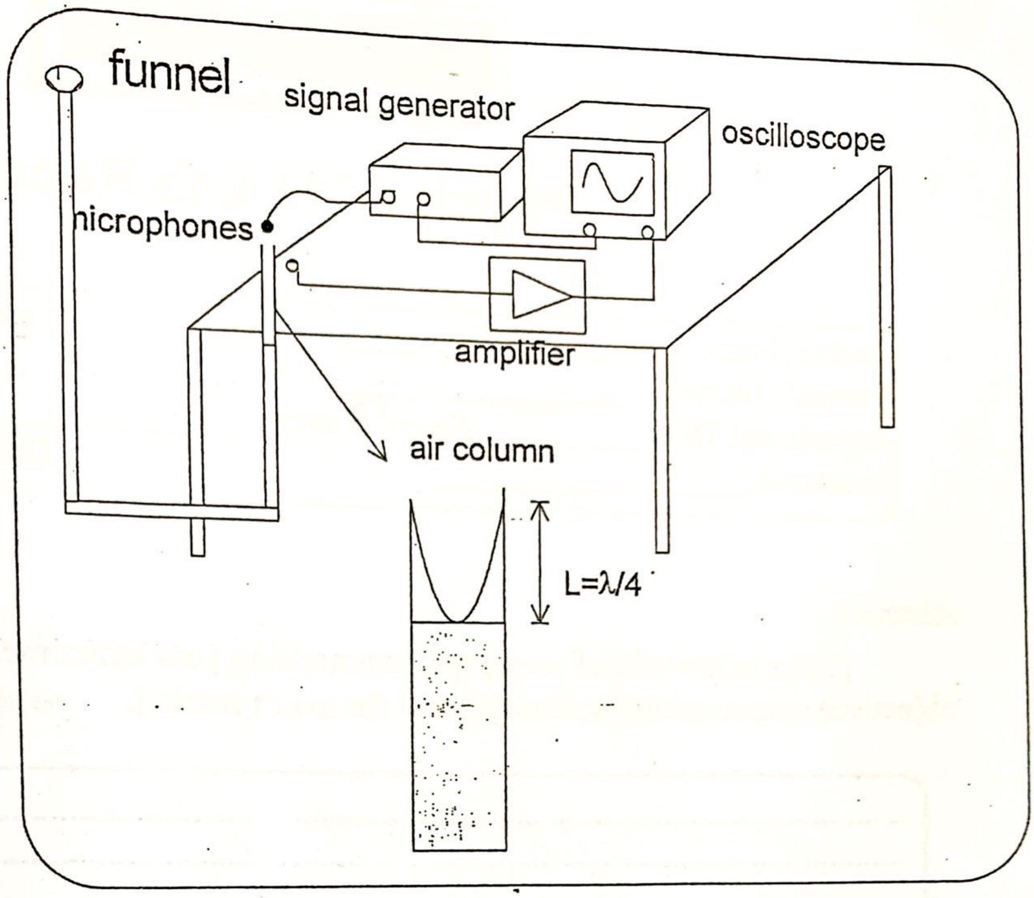


Fig. 2: Experimental Set-up for the sound waves

Important Note:

Frequency should be computed from a measurement of the period of the original signal using the oscilloscope. Reading the dial on the frequency meter is not accurate enough!

Calculations, Results, and Conclusions:

- Create a spreadsheet with a main column containing the frequencies at which resonance is to be looked for. Begin around a frequency of 350 Hz, and then increase it by steps of about 50 Hz. **(The frequency does not have to be exactly 350, 400, etc.)**

  For each frequency record L_1 , L_2 and compute 1/f.

Frequency	350	400	450	500	550	600	650	700
frequency[1]								
1/f(sec)								
L_1(cm)	22	20						
L_2(cm)	71	61						

[1] Computed from 1/T as measured from the oscilloscope. (T is the oscillation period).

- Plot L_1 and L_2 versus 1/f on linear graph paper. Use the values obtained for the slope and the y-intercept to compute the speed of sound and the end correction (**e**).
- Compute the error in both experimental quantities computed above.

EXPERIMENT # 8

The Thermal Expansion Coefficient of Brass

Preparation for the Experiment:

- Review chapter 20 in **Serway, PHYSICS for scientists and engineers, with modern physics.**
- Note the table in appendix C which lists the linear expansion coefficients of several materials.

Objectives:

The objectives of this experiment are:

- ☐ To determine the coefficient of linear expansion of a brass rod.
- ☐ To learn how to calibrate an instrument (in this case for the indirect determination of very small distances).

Apparatus:

A brass rod, mirror/scale assembly, 12 V power supply (to heat the rod, and light the lamp), meter stick, micrometer, and a thermometer.

Theory:

Most metals expand when heated. Their expansion is linear over wide ranges of temperatures. The length of a metallic rod whose length at temperature $T = T_0$ (room temperature) is L_0 can be found at temperature $T > T_0$ °C by the following relationship:

$$L(T) = L_0(1 + \alpha(T - T_0))$$

$\Delta L \quad \alpha L_0 \quad \Delta T$

where α is called the linear coefficient of thermal expansion.

$L(T) = L_0(T)(1 + \alpha(T - T_0))\ \alpha$ $\quad L = L_0(1 + \alpha(T - T_0$

$L(T) = L_0 + L_0\alpha T - \alpha T_0$

$(9 \ T)$ $\quad (1 + \alpha\Delta T)$

Experimental:

The brass rod is fixed at one end as shown in the figure. The other end is allowed to expand and pushed against the back of a mirror. The mirror is held with a rubber band. A light is reflected from the mirror onto a meter scale and the position of the light on the scale changes upon expansion of the brass rod. Two main steps in the experimental procedure are required so as to build the length versus temperature data:

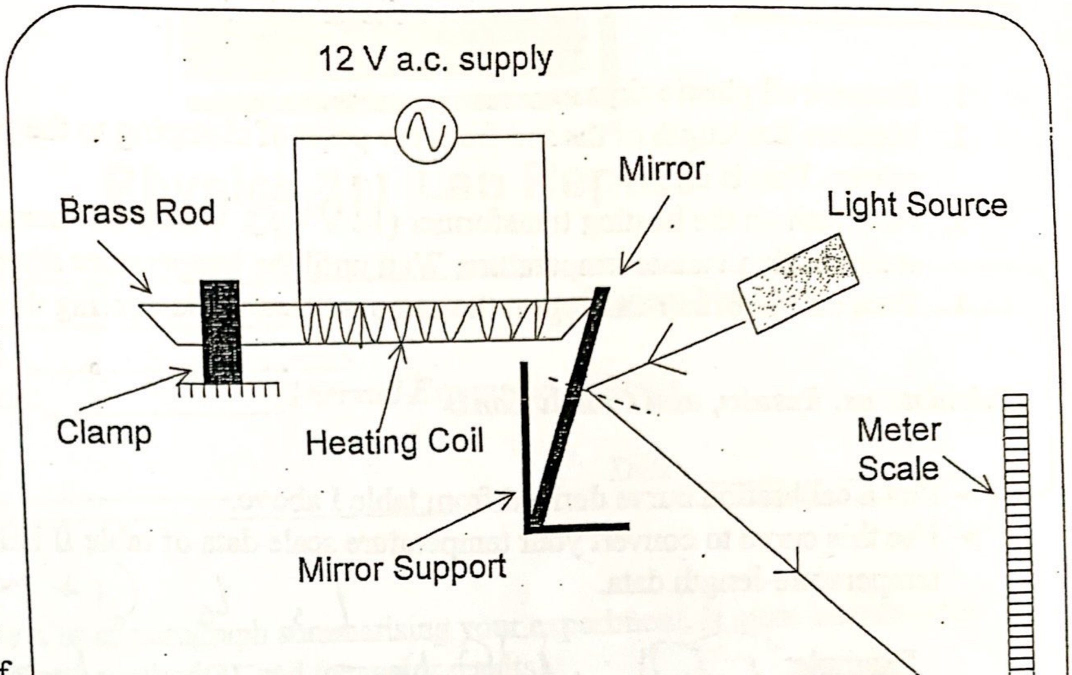


Fig.1: Experimental Set-up for the determination of tthe thermal expansion of brass.

1. A calibration curve is to be created between rod length and scale reading.
2. The scale reading is to be recorded against temperature increase and then decrease.

From these two steps, one can build the temperature versus length data required to compute the coefficient of thermal expansion.

STEP I: Calibration Curve

1. Measure the thickness of 10 identical pieces of plastic.
2. Start inserting the pieces one-by-one between the brass rod and the mirror and record the total thickness of the inserted papers versus the scale reading.
3. Plot on a linear graph the scale reading versus thickness inserted. This is your calibration curve!

T(mm)	Scale (arb.)	T(mm)	Scale (arb.)	T(mm)	Scale (arb.)	T(mm)	Scale (arb.)	T(mm)	Scale (arb.)	T(mm)	Scale (arb.)

STEP II: L vs T data

1. Remove all plastic slips.
2. Measure the length of the rod from the point of clamping to the point where it touches the mirror. This is L_0.
3. Now turn on the heating transformer (12 V a.c.). Watch the thermometer and record the scale reading versus temperature. Wait until the temperature stops rising.
4. Turn off the heater and repeat the same process while cooling down.

Calculations, Results, and Conclusions:

- Plot a calibration curve derived from table I above.
- Use this curve to convert your temperature scale data of table II below into temperature-length data.

$L = L_0 (1 + \alpha (T - T_0))$

Example: $L(T) = L_0 + L_0\alpha T - L_0\alpha T_0 \; ; T_0 + L_0\alpha (T - T_0)$

  - Take the point (53, 35.7) from table II below, where T=53, and s=35.7.
  - From the calibration curve find the thickness of slips corresponding to s=35.7.
  - Add this thickness to L_0 and record this as L(53) in table II.
- Plot L(T) versus ~~T.~~ The slope of this line is αL_0 and its Y-intercept is $L_0 - \alpha L_0 T_0$
- Perform the regular regression analysis and calculate $\Delta\alpha$ also.

T(°C)	Scale (heating)	Scale (cooling)	T(°C)	Scale (heating)	Scale (cooling)

Table II: Thermal Expansion of Brass

Remember

Perform all your calculations on a spreadsheet! This will let you do regression analysis and graphing in the same environment!

EXPERIMENT #9

Thermal Conductivity

Preparation for the Experiment:

- Review chapter 20 in Serway, **PHYSICS for scientists and engineers, with modern physics.**

Objectives:

The objectives of this experiment can be summarized as:

- To familiarize oneself with some of the thermal properties of insulating materials.
- To determine the thermal conductivity of ebonite and glass using **Lee's Disk** method.

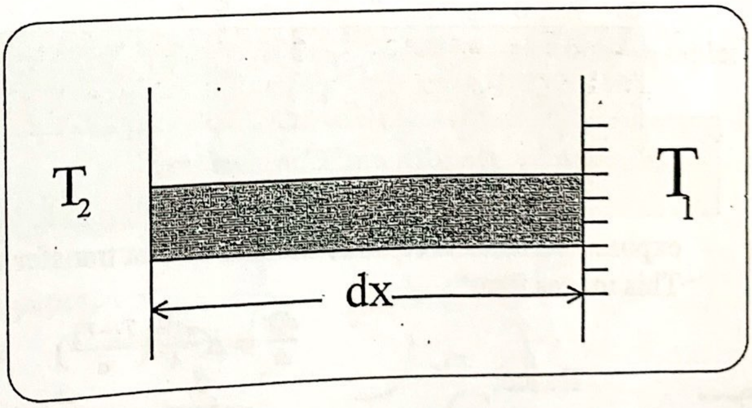
Apparatus:

Lee's Disk apparatus (from *Griffin and George*), stop watch, holders and clamps, mercury thermometers, rubber tubing, and a steam heater.

Theory:

If a medium having conductivity **K**, is placed between two heat reservoirs with one at a temperature (T_2) that is higher than that of the other (T_1), then heat is transferred according to the following equation:

$$\frac{dQ}{dt} = -KA\frac{dT}{dx} \text{..........(1)}$$



where **A** is the cross-sectional area of the thermal conductor, **dx** is its thickness, and **dT** is the temperature difference across its ends. ~~The rate of~~ heat transfer also depends on the mass of the object. If heat is transferred into (out of) an object of mass M then this rate is given by:

$$\frac{dQ}{dt} = -MC\frac{dT}{dt} \text{............(2)}$$

C is called the specific heat and dT/dt is the rate of change of the object's temperature. In this experiment, we equate (1) and (2) when a block of copper of known **C** is held in contact with an ebonite disk whose **K** is unknown. This yields the value of **K**.

Experimental:

The apparatus, shown in figure 2, is made from a heavy copper disk **C**[1], suspended from a firm stand. The ebonite disk is placed on top of the disk and is heated by passing steam through a hollow cylinder which is placed on top of the ebonite.

1 The only reason that the disk is white is that it is nickel plated.

The temperature is measured in two places: in a hole near the bottom of cylinder **A** and in the disk **C**. The following procedure is to be followed to calculate the thermal conductivity of ebonite:

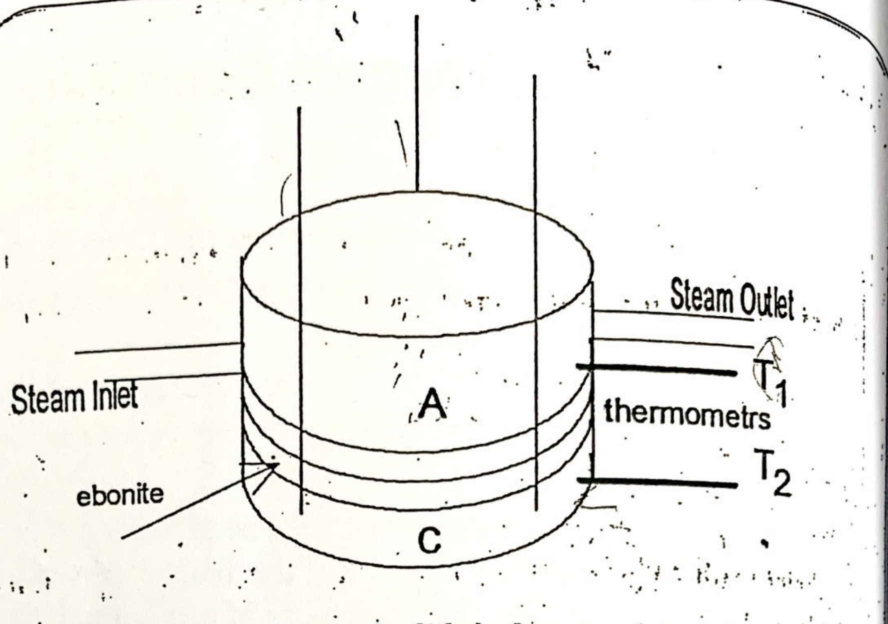


Fig. 2: Lee's Disk Apparatus

1. Suspend the Lee's disk apparatus horizontally.
2. Start heating the water container and observe the temperatures T_1 abd T_2 rise as the steam passes through cylinder **A**.
3. When the temperatures stop changing (the steady state) record the two temperatures.
4. Remove **A** and heat slab **C** directly by the burner to 10 °C higher than its steady state temperature(T_2+10).
5. Stop heating and allow **C** to cool down while recording T as a function of time creating the table below.
6. Measure the diameter of the ebonite disk, its thickness, and the mass of slab **C**.

7. 8. 9. 10. 11. 12. 13, 14. 15, 16.

Time (min)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Temp (°C)																

Calculations, Results, and Conclusions:

In the steady state, the rate at which slab **C** loses heat to the surroundings through its exposed surfaces is equal to the rate of heat transfer through the ebonite disk. This means that:

$$\frac{dQ}{dt} = K\frac{\pi D^2}{4}\left(\frac{T_1-T_2}{d}\right) = MC\left(\frac{dT}{dt}\right)_{T_2}$$

Hence:

$$\boxed{K = \frac{4MCd\left(\frac{dT}{dt}\right)_{T_2}}{\pi D^2(T_1-T_2)}}$$

To obtain dT/dt at temperature T_2 we plot a cooling curve compiled from the table above and find its slope at T_2.

One can now compute **K**. Note that C for copper = 0.092 cal/gm C. Compute ΔK also. Compare your result with that obtained from the handbook of chemistry and physics.

EXPERIMENT # 10

Torque and Angular Momentum

Torque and angular momentum

Preparation for the Experiment:

- Review chapter 11 in Serway, **PHYSICS for scientists and engineers, with modern physics.**
- Review the introductory article on the use of the timer counter at the beginning of this manual.

Objectives:

The aim of this experiment is to study rotational motion of a rigid body with constant acceleration by studying:

- ☐ the variation of the angle of rotation with time.
- ☐ the variation of angular velocity with time.
- ☐ the dependence of the angular acceleration on the applied torque.

$\frac{dL}{dt}$ $= I\omega$

Apparatus:

Rotary plate assembly including angle scale, retaining device with release, weight holder, and weights. Light barrier and timer.

$L = I\omega$ rotational of inertia

Theory:

A rigid body rotating about a fixed axis is subject to the rotational version of Newton's 2nd Law:

$$\vec{L} = I\vec{\omega} \quad \text{.......................(1)}$$

where I is the moment of inertia of the rigid body, $\vec{L}$ is the total angular momentum of the system, and $\vec{\omega}$ is the angular velocity of the body. A net force causes a body to accelerate linearly. A net torque causes an object to accelerate in an angular direction (rotate). The derivative of (1) will put this relationship in the familiar form:

$$\vec{\tau} = \frac{d\vec{L}}{dt} = I\frac{d\vec{\omega}}{dt} = I\vec{\alpha} \quad \text{......(2)}$$

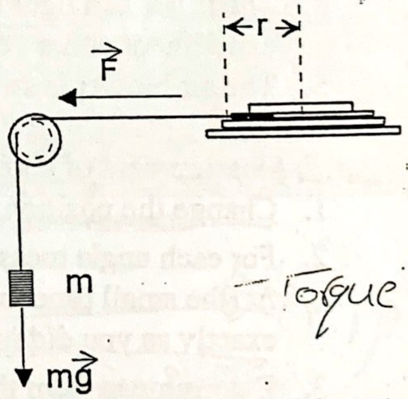


Fig. 1: The weight-disk system.

Torque

where α is the angular acceleration of the rigid body and τ is the torque acting on it given by:

$$\vec{\tau} = \vec{r} \times \vec{\ } \quad \text{....................(3)}$$

Torque

In this experiment, for the disk being pulled down by the hanging weight the total external torque is given by:

$$\tau = rmg \text{.........:...............(4)}$$

$I\alpha = rmg$ $\tau = rmg$

0.262 $\omega = \alpha t$
$\theta = \frac{1}{2}\alpha t^2$

and this in turn is equal to $\tau = I\alpha$. Starting with the following initial conditions (at t=0), for the angular position and velocity:

$$\theta(0) = 0;\ \omega(0) = \qquad$$, one gets the following solutions for the time dependence of the angular displacement and angular velocity:

$\omega \to \alpha t$

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

$$\omega(t) = \frac{mgr}{I}t = \alpha t \text{ ....(6)}$$

and

$$\theta(t) = \frac{1}{2}\frac{mgr}{I}t^2 = \frac{1}{2}\alpha t^2 \text{ ....(7)}$$

The moment of inertia is fixed, but the torque acting on the disk can be varied by either varying the driving weight or the radius around which the string holding the weight passes (three different radii are available).

$\omega = \alpha t$

$\theta(t) = \frac{1}{2}\alpha t^2$

Experimental Procedure:

Preparation for the experiment:

154.6625 0.10875

Before doing any experimental parts, you need to set the apparatus up properly. This involves the following steps:

1. The experiment is set up as in figure 2.
2. The rotary disk is adjusted to be in a horizontal position.
3. The air blower is connected and made ready. It used to eliminate friction between the disk and its support rod.

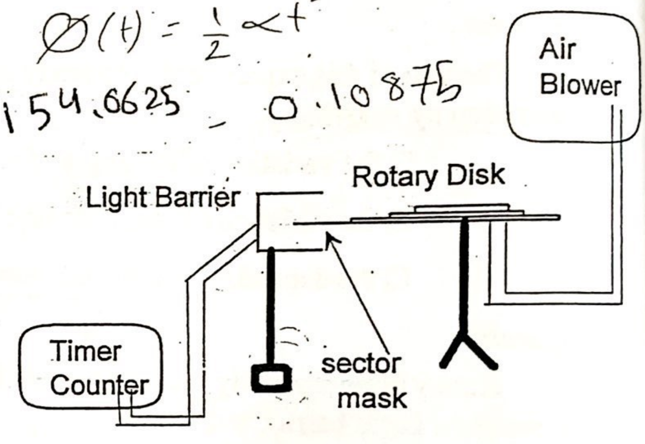


Fig.2: Schematics of Experimental Assembly.

4. The timer and light barrier are connected to measure the proper quantity (in this experiment either t or Δt).
5. The air blower is switched on.

0.2616 $I\alpha = \frac{mgr}{I}$

Part I: Measurement of θ and ω as a function of time:

1. Change the position of the light barrier to choose about 7 angles from 0 to 360°.
2. For each angle measure t (the time it takes the disc to travel the angular distance θ) and Δt (the small time interval it takes the disc to cross the light barrier) by setting the timer exactly as you did in the experiment for the linear case (Newton's laws of motion).
3. Determine ω from the relationship $\omega = \Delta\theta/\Delta t$ and record your data in a table like table 1 below. (Δθ is the width of the mask (see figure) in radians)

r = 3 cm and m = 20 gm. 240 270 5.314

θ(rad)	π/3	π/2	2π/3	π	4π/3	3π/2	2π
t(sec)	1.785	2.153	2.484	2.913	3.585	3.886	~~4.480~~
Δt(sec)	0.293	0.230	0.203	0.157	0.134	0.127	0.111
$\omega = \frac{\Delta\theta}{\Delta t}$	0.394	1.139	1.291	1.659	1.955	2.063	2.360

Table 1: Measurement of θ and ω as a function of t.

$\omega = \frac{\Delta\theta}{\Delta t}$ $\omega = \frac{\Delta\theta}{\Delta t}$

Scanned with CamScanner

$\omega = \alpha t \qquad \frac{mgr}{I}$

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

Part II: Dependence of the Angular Acceleration on the Applied Torque.

A. Varying the hanging weight mg.

1. Fix the angle at $\theta = 2\pi$.
2. Vary the weight, and for each weight measure t and Δt.
3. Find ω for each weight (use $\omega = \Delta\theta/\Delta t$) and also find α, the angular acceleration. ($\alpha = \frac{2\theta}{t^2}$)
4. Arrange your data in a table like table 2 below.

r = 3 cm and $\theta = \pi$ rad.

mass (gm)	~~10~~ 20	~~15~~ 25	~~20~~ 30	~~25~~ 35	40
t (sec)	3.118	2.415	2.331	2.070	2.015
Δt (sec)	0.157	0.126	0.119	0.104	0.1
ω(rad/sec)	1.669	2.079	2.202	2.514	2.576
α(rad/sec^2)	0.646	1.077	1.156	1.4666	1.547

Table 2: Angular Acceleration as a function of Force (mg).

B. Varying the lever arm.

1. Keep the force constant (m= 15 gm) and also the angle constant $\theta = \pi$.
2. Repeat part II.A for different radii filling table 3 below.

$\theta = \pi$ and m = 15 gm.

Radius (cm)	1.5	3	4.5
t (sec)	5.066	3.608	~~3.83~~
Δt (sec)	0.289	0.187	0.151
ω(rad/sec)	0.906	1.401	1.736
α(rad/sec^2)	0.245	0.482	0.880

Table 3: Angular Acceleration Dependence on the lever arm.

Calculations, Results, and Conclusions:

Part I:

1. Plot θ and ω versus **t** on log-log graph paper.
2. Determine the slope in each case and comment on the meaning of these results.
3. From the graphs find the moment of inertia of the disk ($I \pm \Delta I$).

Part II:

1. From tables 2 and 3, plot the acceleration α versus the force F and versus r respectively, on linear graph paper.
2. What do these graphs mean?
3. Again find ($I \pm \Delta I$) and compare it with the results of part I.

$\log\theta = 2\log t + \log\frac{\alpha}{2}$

Radius