Engineering Mechanics Lab Manual

CONTENTS

EXPERIMENT NO. 1

VERIFICATION OF TRIANGLE LAW & PARALLELOGRAM LAW OF FORCES

1. OBJECTIVE
To verify triangle and parallelogram law of forces with the help of Gravesand's apparatus

2. Apparatus Required
Gravesand's apparatus, paper sheet, weight, thread, pans, set square, pencil, drawing pin etc.

3. Theory
The "*triangle law of force*" states that if three coplanar forces acting on a particle can be represented in magnitude and direction by the three sides of the triangle taken in order, the force will be in **equilibrium**. *This law can also be stated as*: If two forces acting on a particle represented in magnitude and direction by the two sides of the triangle taken in order then their resultant will be given by the third side of the triangle taken in opposite direction.
"Parallelogram law of forces" states that if a particle is acted by the two forces represented in magnitude and direction by the two sides of a parallelogram drawn from a point then the **resultant** is completely represented by the diagonal passing through the same point.

4. PROCEDURE
Refer to fig. 1.1

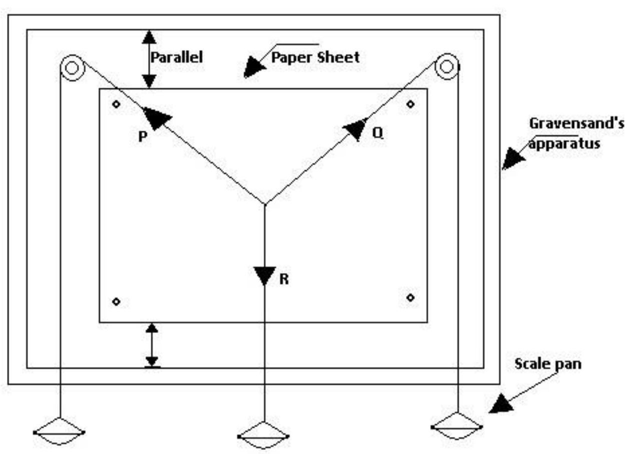


Fig. 1.1

A. Fix the paper sheet with drawing pin on the board set in a vertical plane such that it should be parallel to the edge of board.
B. Pass one thread over the pulleys carrying a pan at its each end. Take a second thread and tie its one end at the middle of the first thread and tie a pan at its other end.
C. Add weights in the pan in such a manner that the small knot comes approximately in the centre.
D. Displace slightly the pans from their position of equilibrium and note if they come to their original position of rest. This will ensure the free movement of the pulleys.

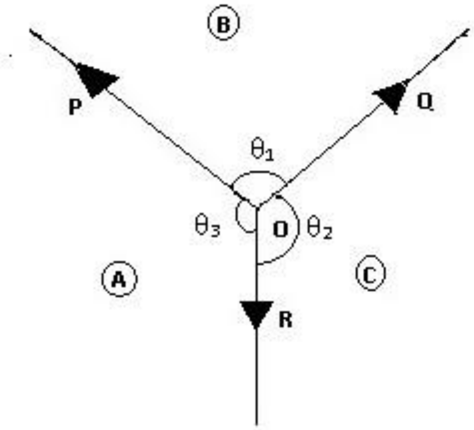
E. Mark lines of forces represented by thread without disturbing the equilibrium of the system and write the magnitude of forces i.e. **Pan Weight + Added Weight**.
F. Remove the paper from the board and produce the line to meet at O.
G. Use Bow's notation to name the force P, Q, R as AB, BC, and CA.
H. Select a suitable scale and draw the line *ab* parallel to force P and cut it equal to the magnitude of P. From *b* draw the line *bc* parallel to force Q and cut it equal to the magnitude of Q (Fig. 1.2). Calculate the magnitude of *ca* i.e., R_1 which will be equal to the third force R which proves the triangle law of forces.
If R_1 differs from original magnitude of R, the percentage error is found as follows:

$$\text{Percentage error} = \frac{R-R1}{R} * 100$$

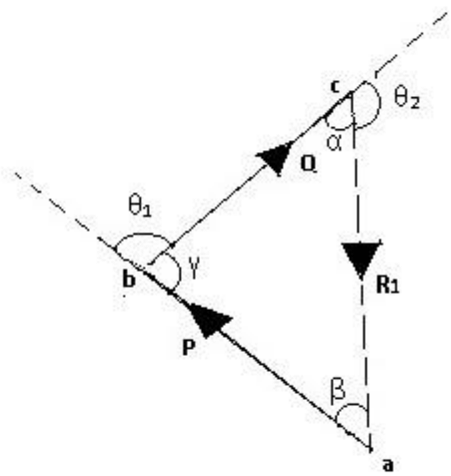
4.1 TRIANGLE LAW OF FORCES

Graphical Method

Fig. 1.2(b), draw *ab* parallel to force P in suitable scale with the use of set square and then from *b* draw *bc* parallel to force Q. The closing side of triangle represents the force R_1 which should be equal to force R. Note, the difference in R_1 and R shows the graphical error.



(a) Space diagram



(b) Vector diagram

Analytical Method

Measure angles α, β and γ and by using Lami's theorem check the following relation

$$\frac{P}{Sin\,\alpha} = \frac{Q}{Sin\,\beta} = \frac{R2}{Sin\,\gamma}$$

4.2 PARALLELOGRAM LAW OF FORCES

Graphical Method

Fig. 1.3, cut OA=P and OB=Q in suitable scale. From A draw AC' parallel to OB and BC' parallel to OA. R_1 represents the resultant of force P and Q. As the system is in equilibrium it must be equal to R.
Note that R and R_1 are in opposite direction.

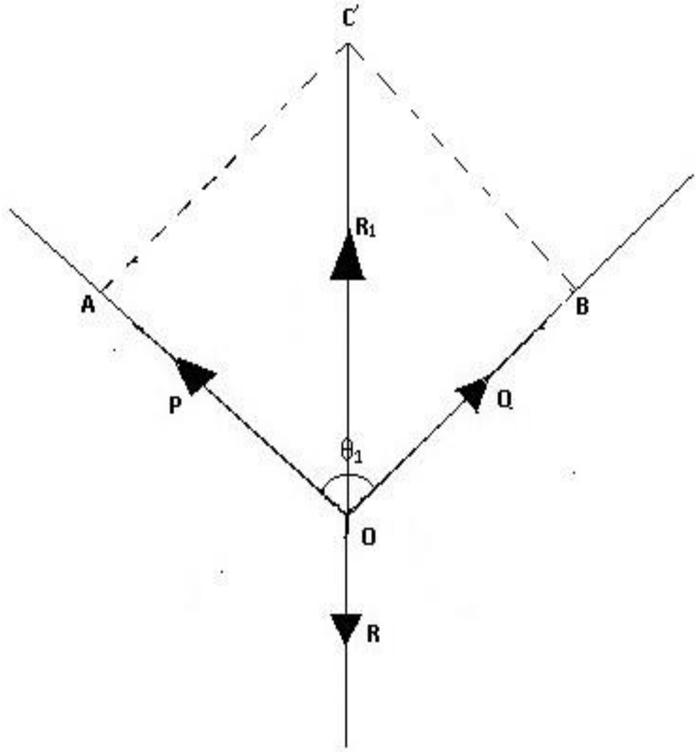


Fig. 1.3

Analytical Method

Measure angles θ_1 and by using resultant formula, calculate R_1

$$R_2=\sqrt{(P^2+Q^2+2\,PQ \text{ cosine } \theta_1)}$$

5. OBSERVATION

Scale ……….N: …….mm

Law	Total Weight of pan P	Total Weight of pan Q	Total Weight of pan R	Calculate Resultant	%age error =
Triangle Law					**Graphical** $\frac{R - R1}{R} * 100$ **Analytical** $\frac{R - R2}{R} * 100$

Parallelogram Law					$\frac{R - R1}{R} * 100$ **Graphical**
					$\frac{R - R2}{R} * 100$ **Analytical**

6. PRECAUTIONS

A. Pans/weights should not touch the vertical board
B. There should be only one central knot on the thread which should be small
C. While calculating the total force in each case the weight of the pan should be added to the weight put into the pan
D. Make sure that all the pans are at rest when the lines of action of forces are marked
E. All the pulleys should be free from friction

EXPERIMENT NO. 2

VERIFICATION OF POLYGON LAW OF FORCES

1. OBJECTIVE

To verify polygon law of forces with the help of Gravesand's apparatus

2. Apparatus Required

Gravesand's apparatus, paper sheet, weight, thread, pans, set square, pencil, drawing pin etc.

3. Theory

"*Polygon law of force*" states that if a number of coplanar concurrent forces acting on a particle are represented in magnitude and direction by sides of a polygon taken in same order, then their resultant is represented in magnitude and direction by the closing side of the polygon taken in the ***opposite direction***.

4. PROCEDURE

Refer to fig. 2.1

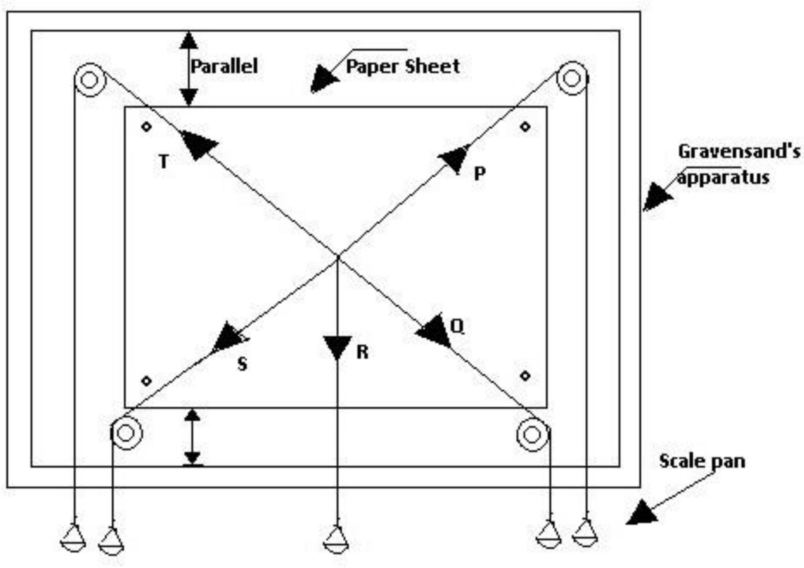


Fig. 2.1

A. Fix the paper sheet with drawing pin on the board set in a vertical plane such that it should be parallel to the edge of board.
B. Pass a thread over two pulleys. Take a second thread and tie the middle of this thread to the middle of first thread. Pass the ends of the second thread over the other set of two pulleys. C. Take a third thread and tie its one end to the point of first two threads.
D. Attach pans to the free ends of the threads as shown in Fig. 2.1.
E. Add weights in the pan in such a manner that the knot comes approximately in the centre.
F. Mark lines of forces represented by thread without disturbing the system and write the magnitude of forces i.e. **Pan Weight + Added Weight**.
G. Remove the paper from the board and produce the line to meet at O.

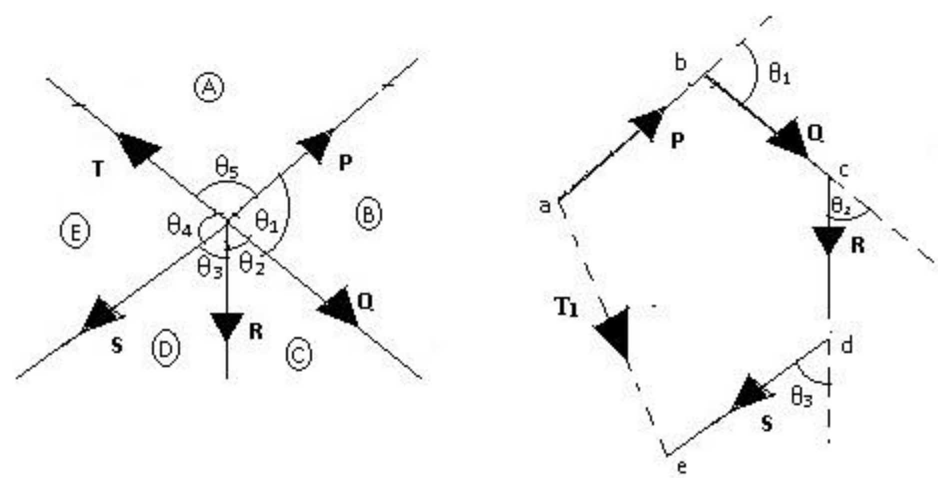
H. Select a suitable scale and draw the vector diagram (Fig. 2.2) by moving in one direction (i.e. clockwise or counter clockwise). Draw ab parallel to AB and cut it equal to force P; draw bc parallel to BC and cut it equal to Q; Draw cd parallel to CD and cut it equal to force R; draw de parallel to DE and cut it equal to S. Vector ae will be the resultant force T_1 taken in opposite direction and should be equal to force T which proves the law of polygon forces. If ae is not equal to T then percentage error is found as follows:

$$\text{Percentage error} = \frac{T-T1}{T} * 100$$

4.1 POLYGON LAW OF FORCES

Graphical Method

Fig. 2.2(b), draw *ab* parallel to force P in suitable scale with the use of set square and then from *b* draw *bc* parallel to force Q. From c draw cd parallel to R and then draw de parallel to S. The closing side of polygon represents the force T_1 which should be equal to force T. Note, the difference between T_1 and T shows the graphical error.



(a) Space diagram (b) Vector diagram

Fig. 2.2

Analytical Method

Draw a horizontal and vertical line at the point of concurrency of all the forces in Fig.2.2 (a) with the help of set square. Resolve each force in x and y axis,

$\Sigma F_x=0;$ $P_x+Q_x+R_x+S_x+T_x=0$

$T_x= -(P_x+Q_x+R_x+S_x)$

$\Sigma Fy=0;$ $Py+Qy+Ry+Sy+Ty=0$

$T_y= -(P_y+Q_y+R_y+S_y)$

$T_2= \sqrt{(T_x^2+ T_y^2)}$

Note that T is resultant from the experiment, T_1 is the resultant found from graphical method and T_2 is the resultant found from analytical method.
The difference between T_2 and T shows the experimental error.

5. OBSERVATION

Scale ……….N: …….mm

Law	Force (Pan Weight + Added Weight)					Calculated Resultant	%age error
	P	Q	R	S	T		
Polygon Law							$\frac{T - T1}{T} * 100$ Graphical
							Analytical $\frac{T - T2}{T} * 100$

6. PRECAUTIONS

A. Pans/weights should not touch the vertical board
B. There should be only one central knot on the thread which should be small
C. While calculating the total force in each case the weight of the pan should be added to the weight put into the pan
D. Make sure that all the pans are at rest when the lines of action of forces are marked E. All the pulleys should be free from friction

EXPERIMENT NO. 3

VERIFICATION OF PRINCIPLE OF MOMENT USING BELL CRANK LEVER APPARATUS

1. OBJECTIVE

To verify the law of moment by using bell crank lever

2. APPARATUS REQUIRED

Bell Crank Lever apparatus, slotted weight, spirit meter, spring balance and pointer

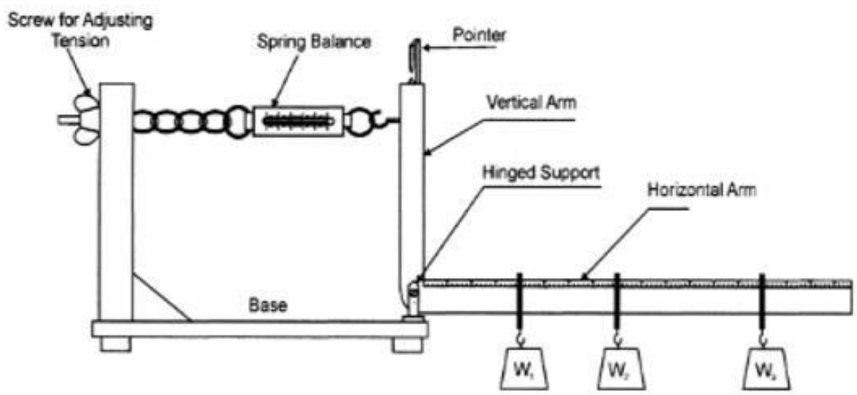


Fig. 3.1 Bell Crank Lever Apparatus

3. THEORY

The bell crank lever is an apparatus used to verify the law of moments. The bell crank is used to convert the direction of reciprocating movement. A bell crank is a type of crank that changes motion around a 90 degree angle. The name comes from its first use, changing the vertical pull on a rope to a horizontal pull on the striker of a bell, used for calling servants in upper class British households. The fixed point of the lever about which it moves is known as the fulcrum.

The bell crank consists of an "L" shaped crank pivoted where the two arms of the L meet. Moving rods (or ropes) are attached to the ends of the L arms. When one is pulled, the L rotates around the pivot point, pulling on the other arm.

Changing the length of the arms changes the mechanical advantage of the system. Many applications do not change the direction of motion, but instead to amplify a force "in line", which a bell cranks, can do in a limited space. There is a tradeoff between range of motion, linearity of motion, and size. The greater the angle traversed by the crank, the more non-linear the motion becomes (the more the motion ratio changes).

According to law of moments "the moment of a force about an axis is equal to the sum of moment of its component about the same axis."

$$\Sigma M = \Sigma (\vec{r} \times \vec{F})$$

4. PROCEDURE

A. Make the longer arm of the lever horizontal by adjusting with wing nut provided at the end of spring balance longer screw, by using a spirit meter when there is no load on longer arm. B. Adjust the initial spring balance reading as zero.

C. Hang a small weight (W) on the hook fixed in the lever. This will make the longer arm move down ward and the spring balance will show some reading on balance D. Note the final spring balance reading.

E. Change the position of load and repeat the steps B to D for different loads and calculate the moments.

F. Take at least six readings.

5. ANALYTICAL CALCULATION

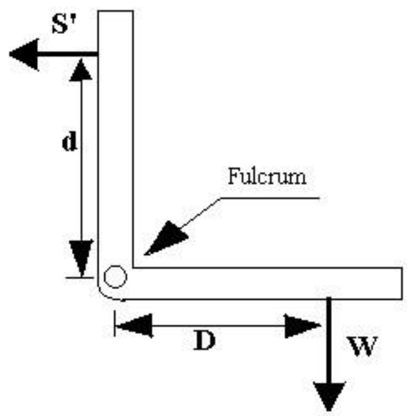


Fig. 3.2 Free Body Diagram of Apparatus

Free body diagram of bell crank lever apparatus is shown in Fig. 3.2. Here,

W →Force applied on lever

D →Varying distance on lever

S' →Theoretical spring force S

→ Experimental spring force

d → Fixed distance, measure from the fulcrum of equipment

As the system is in equilibrium,

$$\Sigma M_o=0$$

$$W*D-S'*d=0$$

6. OBSERVATIONS

S No	Weight W N	Distance (D) mm	Moment (W×D) N-m	Observed Spring force (S) N	Calculated Spring force (S')= W*D/d N	%Error= $\frac{S' - S}{S'} \times 100$
1.						
2.						
3.						
4.						
5.						
6.						

7. PRECAUTIONS

A. There should minimal disturbance as long as the pointer is concerned.
B. Only one person must take all the readings, because eye-judgment for matching the pointer with the mark on the lever will vary from individual to individual. C. Weights should not touch the table.
D. Add weights in the hanger gently.
E. The pointer should exactly coincide with the mark on the bell crank lever.
F. The optimum starching of spring should be kept in mind.
G. The apparatus should be kept on smooth and leveled surface.
H. Proper lubrication of the joints of two arms of the lever should be done so as to reduce frictional force.
I. Zero error of spring should be properly noted.

8. RESULT

From the values obtained above, it's clear that the observed and calculated values of spring force are nearly equal and within the permissible experimental error limits.

Hence the Law of Moments stating that "the moment of a force about an axis is equal to the sum of moment of its component about the same axis" has been verified.

Experiment No.4

VERIFICATION OF SUPPORT REACTION OF A SIMPLY SUPPORTED BEAM

1. OBJECTIVE

To verify the support reactions of a simply supported beam

2. APPARATUS REQUIRED

A Graduated wooden beam, two weighing machines, weights.

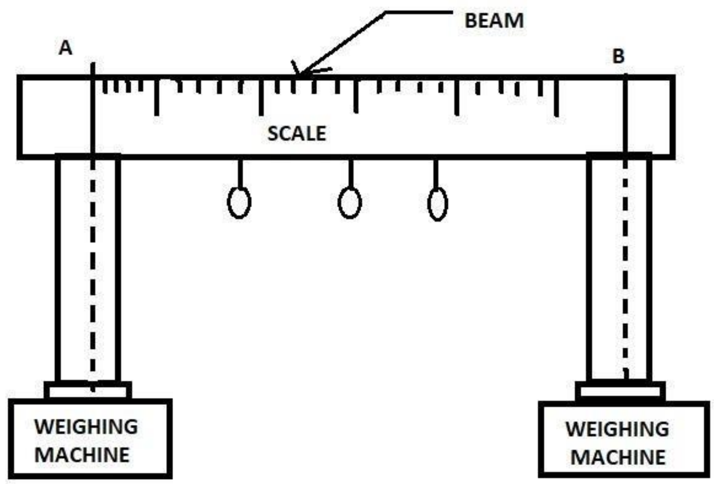


Fig. 4.1 Experimental setup for simply supported beam

3. THEORY

This experiment is based on 'Principle of moments' which states that if a body is in equilibrium under the action of a number of coplanar forces then the algebraic sum of all the forces and their moments about any point in their plane are zero.

Mathematically: The body will be in equilibrium, if

$\sum H = 0$ i.e. the algebraic sum of all horizontal forces is zero.

$\sum V = 0$ i.e. the algebraic sum of all Vertical forces is zero.

$\sum M = 0$ i.e. the algebraic sum of all moments about a point is zero.

4. PROCEDURE

A. Place the graduated beam on the weighing machine.
B. Ensure that initial reading of weighing machine is zero, if not make it equal to zero by pressing tare button.
C. Now suspend the weights at different points on the beam
D. Note down the readings of the weighing machine which represent the observed values of support reactions at A and B.
E. Measure the distance of each weight from one support.
F. Then apply the equations of equilibrium ($\sum H = 0$, $\sum V = 0$, $\sum M = 0$) to calculate the support reaction at both the ends.
G. If there is any difference between observed and calculated reactions then calculate the percentage error.

5. OBSERVATIONS

S No	Readings from the weighing Machine (N)		Weights Suspended (N)			Distances of loads from support 'A'(m)			Sum of Moments	Calculated reactions		% error	
	R_A	R_B	W_1	W_2	W_3	L_1	L_2	L_3	$W_1L_1 + W_2L_2 + W_3L_3$	R_A'	R_B'	A	B

6. ANALYTICAL CALCULATIONS

Free body diagram of the setup is shown in Fig. 4.2

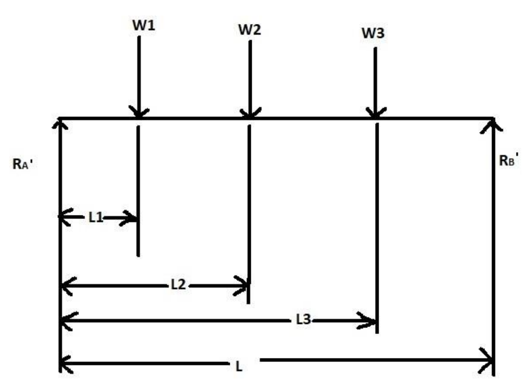


Fig. 4.2 Free body diagram

From the equation of Equilibrium , $\sum V = 0$ i.e. the algebraic sum of all Vertical forces is zero.

$\sum V = 0 \qquad R_A' + R_B' = W_1 + W_2 + W_3$

$\sum M_A = 0 \qquad R_B' * L = W_1 * L_1 + W_2 * L_2 + W_3 * L_3$

R_B' = Calculated reaction force at B
R_A' = Calculated reaction force at A R_B
= Observed reaction force at B
R_A = Observed reaction force at A

Percentage error at point A

$$= \frac{R_A - R_A'}{R_A} X\ 100$$

Percentage error at point B

$$= \frac{R_B - R_B'}{R_B} X\ 100$$

7. PRECAUTIONS

A. Measure the Distance accurately.
B. Beam should be kept at the centre of weighing pan.
C. The Weights Should suspended gently at hooks.
D. The readings should be taken carefully.
E. Before noting down the final readings, the beam should be slightly pressed downwards so as to avoid any friction at the support.

8. RESULT

Reactions at the supports of simply supported beam are verified successfully.

EXPERIMENT NO. 5

VERIFICATION OF CONDITION OF EQUILIBRIUM OF A SYSTEM OF FORCE

1. OBJECTIVE

To verify the conditions required for a system to be in equilibrium under the influence of coplanar forces, and confirm Newton's first law of motion.

2. APPARATUS REQUIRED

Force table (table, ring, string and four 50g hangers), set of slotted weights, protractor and ruler.

3. THEORY

Equilibrium - Newton's first law of motion states that an object in uniform motion will stay in uniform motion, and an object at rest will remain at rest unless it is acted upon by an external net force. In this experiment focus is kept on the object at rest. Mathematically, Newton's first law is expressed as a=0, if $\sum F = 0$.

Newton's first law is complimented by his second law of motion (this law will be examined in detail in a later experiment), which is often simplified to the expression F=ma. or net force ¡s equal to mass times

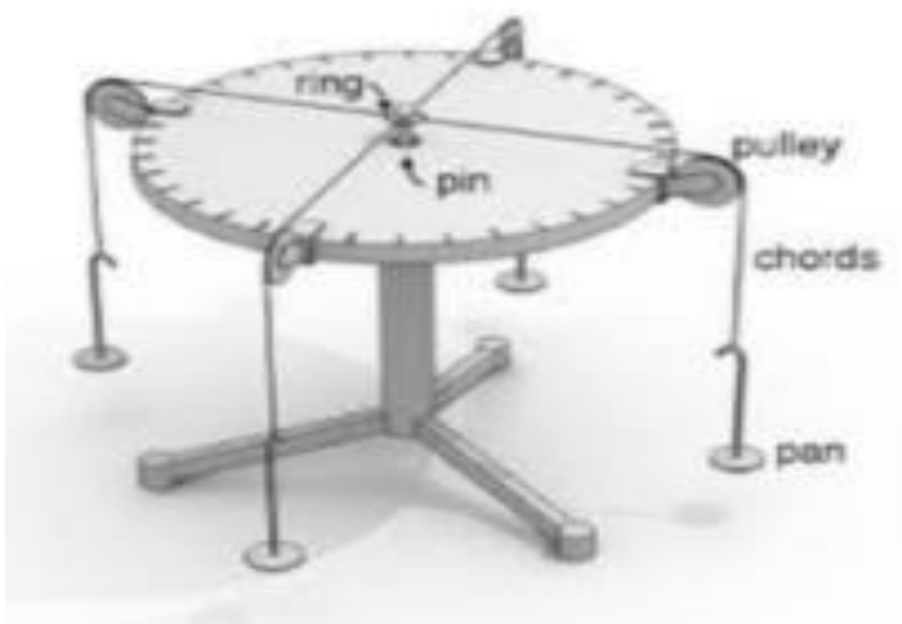


Fig. 5.1 Force Table Apparatus

acceleration. Notice that force and acceleration are both vectors, but mass is a scalar; t simply scales the magnitude of acceleration, hence the term scalar, Force and acceleration always point in the same direction. Net force means the sum of all forces acting on the object. Using these two laws, we can say that if the net force on an object is equal to zero, the object will not experience an acceleration. This is the condition required for equilibrium of concurrent forces. So, if an object is set at rest in an equilibrium condition, it will not accelerate, and thus it will remain at rest and this is how it can be tested for equilibrium.

In this experiment, we are concerned with balancing coplanar forces. If the forces are balanced, the sum of the vectors or the net force is zero, and equilibrium is reached.

4. PROCEDURE

You will be hanging masses on the force table via the pulleys to create forces on the center ring. The edge of the table is marked with angle graduations to measure the direction of the force vector. Because mass is a scalar, it needs to be multiplied by the acceleration of gravity, $g=9.81\ m/s^2$, to find the magnitude of the force it is exerting on the ring. Be sure to use SI units in your calculations; mass has the units Kg, which multiplied by m/s^2 from acceleration gives Kgm/s^2 = N (Newtons), the unit for force.

By balancing three and four forces around the table, you will find a configuration for equilibrium of the forces. To verify equilibrium has been achieved, ensure the strings come of the ring radially and run true over the pulleys, and then pull the ring to the side so that it is touching the center pin. When you let go of the ring, it will readjust itself to be centered. Ideally , the ring should be centered on the table to be in equilibrium, but for the purpose of this experiment, it Is sufficient as long as the ring is not touching or resting against the pin (the closer to center you can get the ring, the better your results will be).

Part 1 - DFE

1. **Place a hanger on the end of each of three strings. Leave the fourth string coiled on top of the table.**
2. **Set each pulley at 0°, 120° and 240°, respectively, and add 50g to each hanger.**
3. **Verify that the strings come off the ring radially and run true over the pulleys.**
4. **At this point, the ring should be perfectly centered on the table. Add small masses to one of the hangers to determine the smallest amount of mass that must be added to make the ring touch the center pin.**
5. **Multiply the small added mass by the g to find the magnitude of the force required to take the system out of equilibrium. This magnitude is your DFE.**

Part 2 – Three forces

6. **Remove all added mass from the hangers.**
7. **Move the pulleys to "crazy" angles (i.e. avoid multiples of 30° and 45°... the crazier the angle, the more interesting your results). Note: you may leave one pulley at 0°, which will save you some work later on.**
8. **Add mass to the hangers to move the ring so that it is as close to center as you can get it.**

9. Verify that equilibrium has been reached by pulling the ring to the pin and releasing it as described at the beginning of the procedure section.
10. Multiply each total mass (hanger mass + added mass) by g to find the magnitude of force.
11. Label your force vectors **A**, **B**, and **C** (it doesn't matter which one is which) and record the directions and magnitudes in table 1.

Part 3 – Four forces

12. Add the fourth pulley to the table and attach a hanger to the fourth string.
13. Repeat steps 6-11, recording the four vectors (labeled **A**, **B**, **C**, and **D**) in table 2.

Data analysis

14. Use the triangle or parallelogram method to find $\mathbf{R}_1$ by adding vectors **A** and **B** from part 2. This diagram must be to scale (be sure to denote the scale in the diagram) and be a full page in size.
15. Compare the resultant vector, $\mathbf{R}_1$, to vector **C**, compare the magnitudes and find the difference in the angles (should ideally be 180°). Record this in table 3.
16. Resolve the three vectors in table 1 into their x and y components.
17. Add the components in table 1 to find the net force $\mathbf{R}_2$ and convert it into a magnitude and angle.
18. Use a vector polygon to find $\mathbf{R}_3$ by adding vectors **A**, **B**, **C** and **D** from part 3. This diagram must also be to scale (denote the scale in the diagram) and be a full page in size.
19. Record the resultant, $\mathbf{R}_3$, in table 3.
20. Resolve the four vectors in table 2 into their x and y components.
21. Add the components in table 2 to find the net force $\mathbf{R}_4$ and convert it into a magnitude and angle.

<u>Report:</u>

Table 1 – part 2

Force	Magnitude	Angle	X component	Y component
A				
B				
C				
$\mathbf{R}_2$ (Net force)				

Table 2 – part 3

Force	Magnitude	Angle	X component	Y component
A				
B				
C				
D				
$\mathbf{R}_4$ (Net force)				

Table 3 – Results

Force	Magnitude	Angle	Discrepancy (magnitude)	Angle difference
$\mathbf{R}_1$				
$\mathbf{R}_3$				

EXPERIMENT NO. 6

VERIFICATION OF AXIAL FORCES IN THE MEMBERS OF A TRUSS

1. OBJECTIVE

To find the axial forces in all the bars of the triangular truss and find out the type of force

2. APPARATUS REQUIRED

Triangular truss, weights hangers, weights, measuring rape and divider for measuring angles

3. THEORY

A truss is defined as a structure that is made of straight rigid bars joined together at their ends by pin or welding or reverting and subjected loads only at joints or nodal points. The assumptions made are

A. The truss is statically determinate
B. The loads are applied only at joints
C. Members are two force member
D. The weights of the members are negligibly small compared to the loads carried by the whole truss

4. PROCEDURE

Using Method of Joints:

1. Measure the length of all members and make a scale drawing.
2. Calculate all the required angles based on the dimensions.
3. Name all the joints.
4. Number all the members.
5. Check redundancy of the truss
6. Assume tension in all the members.
7. Determination of all reaction forces.
8. Now start with a joint where there is at least one known force and not more than two unknown forces.
9. Write down the **ROUTE satisfying the condition no.7.**
10. Proceed as per **ROUTE** to determine the axial forces in all the members.

Using 2D Truss Software:

The use of the program is broken into three steps:
Step 1: Designing the truss.
Step 2: Naming the joints and the forces in the truss members and supports
Step 3: Viewing the various reports such as the report on the system of equations for the truss or the report on the solutions of the equations.

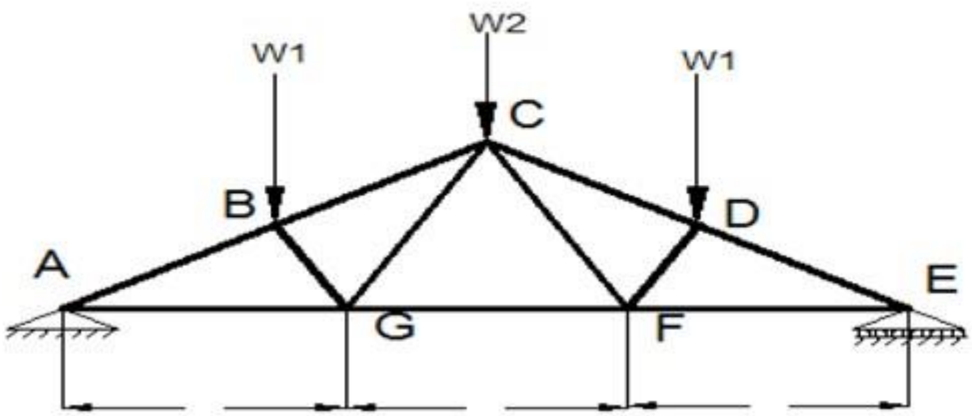


Fig. 6.1 Triangular Truss

5. OBSERVATION

S No	Magnitude of force (N)		Nature of force	Error value I(1)-(2) I
	Using Method of joints (1)	Using 2D Truss software (2)		

6. PRECAUTION

A. Length of bar must be measures carefully

B. Angle of bar must be measured carefully

7. RESULT

The analysis of truss is done and type of force in each bar is stated in the tabular form and both the methods are compared.

EXPERIMENT NO. 7

VERIFICATION OF EQUILIBRIUM OF THREE DIMENSIONAL FORCES

1. OBJECTIVE

To understand the vector quantities and find out axial forces in a non-coplanar force system.

2. APPARATUS REQUIRED

Vertical Stand, Cotton thread, Rings, Metal body

3. THEORY

The resultant **R** of two or more forces in space is determined by summing their rectangular components. Graphical or trigonometric methods are generally not practical in the case of forces in space. The method followed here is similar to that used in with coplanar forces. The strings attached to the vertical stand are three dimensionally oriented. The metal plate having weight 'W' is in equilibrium by the three noncoplanar tensions S_1, S_2 & S_3 in the three strings. These tensions are directly measurable by respective spring balance attached to it.

Addition of Concurrent Force in Space

$$\boldsymbol{R} = \Sigma \boldsymbol{F}$$

$$R_x \boldsymbol{i} + R_y \boldsymbol{j} + R_z \boldsymbol{k} = \Sigma (F_x \boldsymbol{i} + F_y \boldsymbol{j} + F_z \boldsymbol{k})$$

$$= \Sigma F_x \boldsymbol{i} + \Sigma F_y \boldsymbol{j} + \Sigma F_z \boldsymbol{k}$$

$$\therefore \quad R_x = \Sigma F_x \qquad R_y = \Sigma F_y \qquad R_z = \Sigma F_z$$

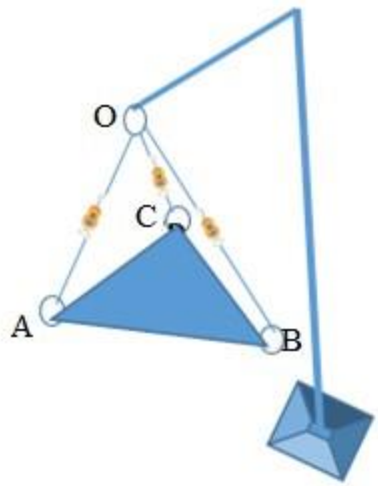
and $$R = (R_x^2 + R_y^2 + R_z^2)^{1/2}$$

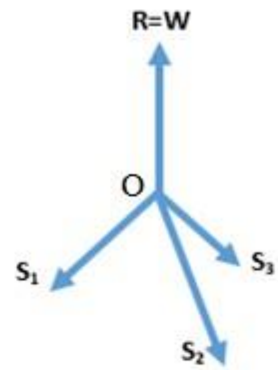
$$\cos\theta_x = \frac{R_x}{R} \qquad \cos\theta_y = \frac{R_y}{R} \qquad \cos\theta_z = \frac{R_z}{R}$$

Equilibrium of a Particle in Space

a particle A is in equilibrium if the resultant of all the forces acting on A is zero, i.e.

$$\boldsymbol{R} = \Sigma \boldsymbol{F} = 0 \quad \Rightarrow \quad \Sigma F_x = 0 \quad \Sigma F_y = 0 \quad \Sigma F_z = 0$$





Space diagram **Free Body Diagram**

4. Procedure

A. Attach one end of three cotton threads to the free end of the vertical stand.
B. Attach the spring balance somewhere between two ends of each thread.
C. Attach the other end of each thread to the three holes of the given lamina having a measurable weight 'W'.
D. Measure the weight 'W' of the lamina using a weighing machine.
E. Consider origin at the centroid of the plate and then measure the coordinate at point O, A, B, C. F. Find out the three unknown tensions in the threads S_1', S_2' & S_3' directly from the spring balance.
G. Calculate the same three unknown tensions in the threads S_1, S_2 & S_3 from three equilibrium equations

$$\Sigma F_x = 0 \quad \Sigma F_y = 0 \quad \Sigma F_z = 0$$

H. Find out the percentage error in the values of S_1, S_2 & S_3.

Calculations :

$$\overrightarrow{OA} = (x_2 - x_1)\vec{i} + (y_2 - y_1)\vec{j} + (z_2 - z_1)\vec{k}$$

$$|\overrightarrow{OA}| = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

$$\lambda = \frac{\overrightarrow{OA}}{|\overrightarrow{OA}|}$$

$$\overrightarrow{S_1} = \vec{F}_{OA} = F_{OA}\,(\lambda) = \boldsymbol{F_{OA}}\left[\frac{(x_2-x_1)\vec{i}+(y_2-y_1)\vec{j}+(z_2-z_1)\vec{k}}{\sqrt{(x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2}}\right] \text{ ----------------------------1}$$

Similarly Calculate $\vec{F}_{OB}$ & $\vec{F}_{OC}$

Then apply the conditions of equilibrium

$\sum F_X = 0 \qquad \sum F_Y = 0 \qquad \sum F_Z = 0$

After calculating

$$Error\,\% = \frac{s_1 - s'_1}{s_1}\, X\, 100$$

5. OBSERVATION TABLE

Force	Theoretical tension"S"	Spring balance reading "S'"	%age error $\left(\frac{S-S'}{S} \times 100\right)$
$S_1(F_{OA})$			
$S_2(F_{OB})$			
$S_3(F_{OC})$			

6. PRECAUTION

1. Keep the weighing plate horizontal and measure the coordinate O,A,B and C carefully.
2. Check the initial spring balance reading and make sure it is at zero.

7. RESULT

From the experiment, the vector representation of force in three dimension is understood. The magnitudes of S_1, S_2, & S_3 found from spring balance are compared with that of theoretical values and %age error in magnitudes of S_1, S_2, & S_3 are found out.

EXPERIMENT NO. 8

DETERMINATION OF COEFFICIENT OF FRICTION BETWEEN TWO SURFACES

Object. To find co-efficient of friction between two surfaces, angle of response, mechanical advantage and efficiency of an inclined plane.

Apparatus. Inclined plane apparatus (Fig. 5.1), slider, weight box, pan, thread etc.

Fig. 5.1. Inclined plane apparatus

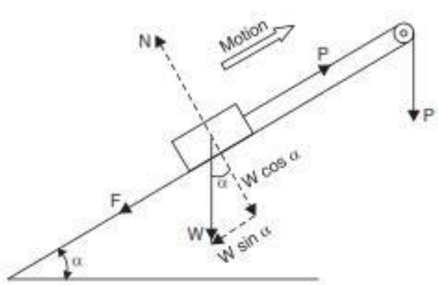
Theory. When a body slides upon another body, the property by virtue of which the motion on one relative to the other is retarded is called *friction*. The frictional force is directly proportional to the normal reaction 'N' *i.e.*,

$$F \propto N$$

or $$F = \mu N \text{ or } \mu = \frac{F}{N}$$

Suppose a body of weight W is to be lifted by an inclined plane and this requires effort P. When this load just moves upwards a frictional force F acts downwards which opposes its motion.

Refer to Fig. 5.2



Component of load W parallel to the plane = $W \sin \alpha$

Component of load W perpendicular to the plane = $W \cos \alpha$

or, $$F = P - W \sin \alpha \quad ...(i)$$

Considering equilibrium perpendicular to the plane

$$N = W \cos \alpha \quad ...(ii)$$

From (*i*) and (*ii*),

Co-efficient of friction,

$$\mu = \frac{F}{N} = \frac{P - W \sin \alpha}{W \cos \alpha}$$

Mechanical advantage $\quad (\text{M.A}) = \dfrac{W}{P}$

Velocity ratio $\quad (\text{V.R}) = \dfrac{\text{distance moved by effort}}{\text{distance moved by load}}$

Let effort P comes down through one centimetre, movement of the load along the plane = 1 cm

Vertical uplift of load $= 1 \times \sin \alpha$

$$\text{V.R.} = \frac{1}{1 \times \sin \alpha} = \text{cosec } \alpha$$

$$\% \text{ efficiency} = \frac{\text{M.A}}{\text{V.R.}} \times 100$$

Procedure :

1. Take the inclined plane apparatus and keep it first horizontal and put the slider on it.
2. Increase the inclination of the inclined board gradually till the slider just begins to slide downwards on it.

Note the angle in this position. This is called *angle of repose*.

3. Place the slider on the plane with the desired angle α.
4. Tie the slider to the pan with the help of a thread passing over the pulley.
5. Put the weights in the pan till the slider just starts moving. Note down the weights.
6. Measure the angle of inclination from the scale provided and find the value of μ.
7. Calculate M.A., V.R. and % efficiency.

Observations :

S.No.	*Total weight of the slider W*	*Weight of Pan + weights in the pan P*	$\mu = \dfrac{P - W \sin \alpha}{W \cos \alpha}$	$M.A. = \dfrac{W}{P}$	$V.R. = \text{cosec } \alpha$	$\% \eta = \dfrac{M.A.}{V.R.} \times 100$

Precautions :

1. The plane should be clean and smooth.
2. The guide pulley should move freely. It should be lubricated to make it frictionless.
3. Weight should be added gently in the pan.
4. The slider should just begin to move slowly, it should not move abruptly.
5. The direction of thread should be parallel to the inclined plane.

EXPERIMENT NO. 9

VERIFICATION OF CENTROID OF DIFFERENT LAMINAE

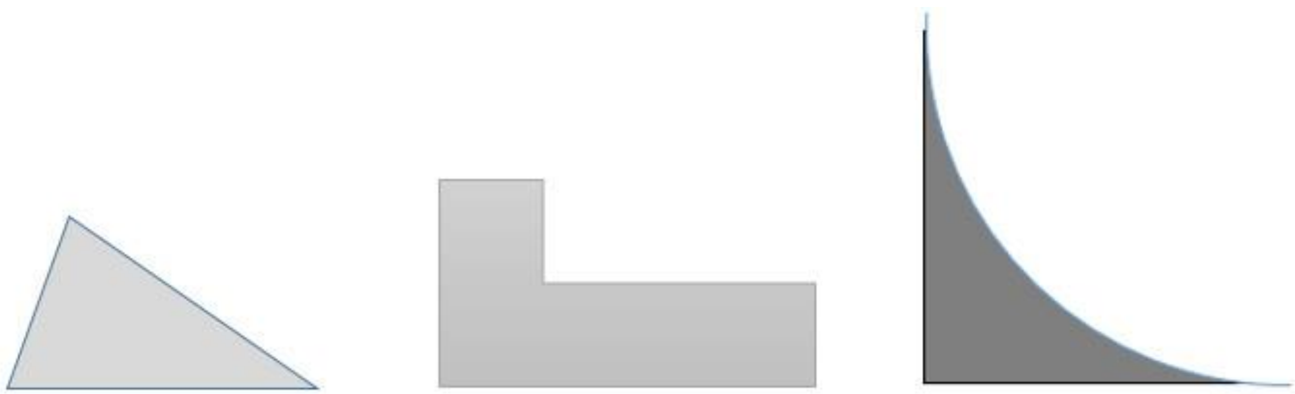
1. OBJECTIVE

To verify the coordinates of the centroid of given lamina determined from the experiment with theoretical result.

2. APPARATUS REQUIRED

Vertical stand, laminae (Triangular, L section, Parabolic) and Measuring tape

3. THEORY



TRIANGULAR LAMINA L SECTION LAMINA PARABOLIC LAMINA

Resultant of all gravity forces) is considered to be concentrated. But in case of areas (since area is a two dimensional figure) do not have weights, gravity forces are not to be considered. However, the point at which the whole area is considered to be concentrated is named as centroid. What **centre of gravity** for masses, is **centroid** for areas.

For regular bodies and areas, the centroid is at the geometric centre. However, for irregular areas, the centroid is to be determined experimentally or analytically. If an area has a line of symmetry, the centroid lies on the line of symmetry. But if an area has more than one line of symmetry, then the centroid lies on the point of intersection of those lines of symmetry.

The centroid of a uniform plane lamina, such as (a) below, may be determined, experimentally, by using a plumb and a pin to find the centroid. It is assumed that the thin body is of uniform density through out. The plate (lamina) is held by the pin inserted at a point near the body's perimeter as shown in the figure. The plate hangs in such a way that it can freely rotate around the pin; and the plumb line is dropped from the pin (b). The position of the plumbline is traced on the body. The experiment is repeated by hanging the plate from different points as shown in the figure and tracing the plumb line. The intersection of at least two plumb lines is the centroid of the figure (c).

Verify the experimental results with theoretical and find out the % error in X_c $\left(\frac{X_c - X'_c}{X_c} \times 100\right)$

And Y_c $\left(\frac{Y_c - Y'_c}{Y_c} \times 100\right)$.

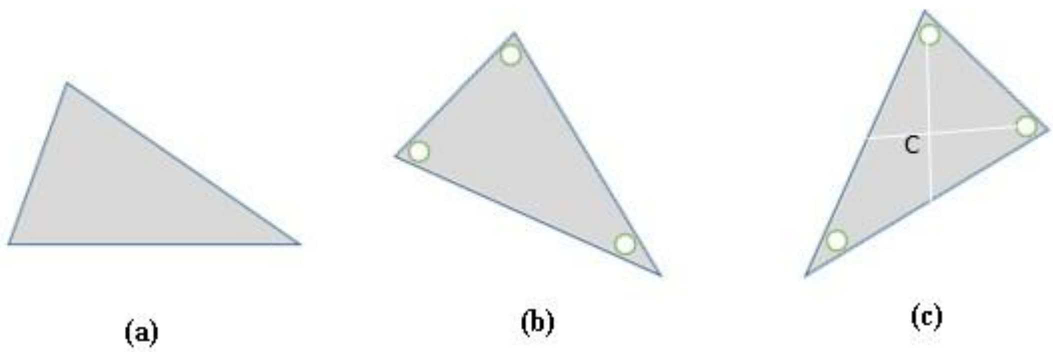


Fig. 9.1 Lamina

4. OBERVATION

S.No	Shape of the Plane Lamina	Experimental		Theoritical		% error in	
		X_C	Y_C	X'_C	Y'_C	X_C	Y_C
1	Triangle						
2	L section						
3	Parabolic						

5. PRECAUTION

Length of bar must be measured carefully

6. **RESULT**

The centroid of regular and irregular plane lamina has been found out for various reference points

Experiment No. 10

Determination of moment of inertia of a flywheel

OBJECT: Determination of Polar Mass Moment of Inertia of the flywheel (rotating mass) using the relationship between angular velocity and kinetic energy.

SYSTEM: Flywheel keyed to a shaft, mounted with the help of bearings (one at each end of the shaft) with the shaft axis horizontal and free to rotate. The system (Flywheel keyed to shaft, mounted with bearings) rests on a bracket fixed to the wall. The Flywheel can be imparted angular velocity with the help of string wound over the shaft with the help of a peg (i.e. one end of the string is hooked to the peg and then wound over the shaft) and then weight can be hooked at other end.

PRIMARY VARIABLE: The angular velocity of the flywheel is the dependent variable. Different angular velocities may be imparted by allowing different weights (here, weight, W = 0.5 kgf, 1.0 kgf, 1.5 kgf, 2.0 kgf, 2.5 kgf) attached to the free end of the wound string to fall through. The difference in the height of the fall should be measured between the C.G. of weight in the starting position and the C.G. when it just touches the ground. The techniques not only allow imparting different velocities but also enable to measure the value of angular velocity imparted and also to measure the kinetic energy given to flywheel. Let the time of the fall be 't_1' in second (s) , the height of fall be 'h' in meter (m) and falling to be equal to 'mg' in Newton (N) , assuming that the bearing friction of the shaft remaining constant as weight falls. Hence the weight will fall with uniform acceleration. Thus the final linear velocity of falling weight will be given by,

$$v = 2h/t_1, \qquad \text{Where,} \quad h = 1.54 \text{ m}$$

angular velocity given to shaft on which the string is wound will be given by, 2v/d,
where, 'd' is the diameter of the shaft in meter (m) , d=0.029m
also using principle of conservation of energy,

$$m\,g\,h = (1/2)\,mv^2 + \theta_1 E_f + (1/2)I\omega^2$$

Where, θ_1 = angle turned in the time 't_1' seconds,
E_f = energy dissipated in the bearing per radian of the flywheel

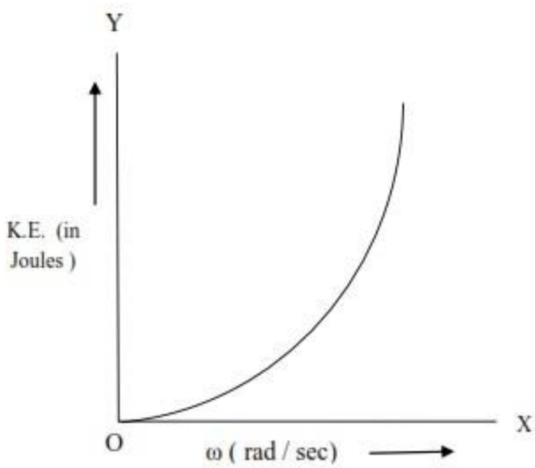
If E_f assumed independent of angular velocity , the value can be determined in terms of the K. E. given to the total angle turned by the flywheel (from rest to rest in radians in the time 't_2' seconds).

Then, $$K.E. = (1/2)I\omega^2 = [mgh - mv^2/2]\,(1 - t_1/t_2)$$

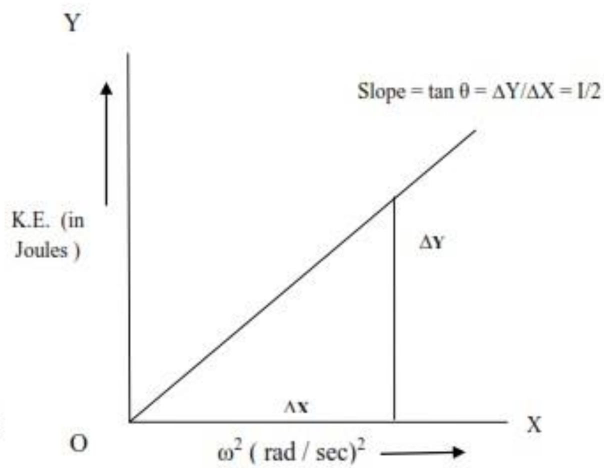
GRAPH:

a. K.E. vs. ω
b. K.E. vs. ω^2

Flywheel Apparatus



GRAPH FOR K.E. Vs. ω



GRAPH FOR K.E.Vs. ω^2

TABLE:

Sl. No.	Load in Kg (W)	Time in Second (t_1)	Time in Second (t_2)	$v = 2h/t_1$	$\omega = 2v/d$ rad/sec.	ω^2	K.E. (Joule)	I Kg-m^2

Note:- Write about,

1. **Conclusions & comments.**
2. **Its place of application.**

Experiment No. 11

Verification of Newton's laws of motion

1. OBJECTIVE

To verify Newton's laws of motion and hence establish relation among motion parameters

2. APPARATUS

Modified Atwood device, Cart, Stop watch, Cotton thread, Pulley and weighing hangers and mass

3. THEORY

Newton's laws of motion describe the effects of forces on an object's or system's motion. In brief, if the vector sum of all forces acting on a system is unbalanced, then the system will accelerate in a manner governed by the net force and the mass of the system.

First Law – Newton's first law states that, in the absence of a net force, a system will have no acceleration. For example, an object falling at terminal velocity is subject to two main forces; gravity exerts a force toward the earth's surface, and air resistance exerts a force in the opposite direction. At terminal velocity, the force from air resistance is equal in magnitude to the gravitational force and opposite in direction. Thus there is no net force on the falling object, and its velocity is constant.

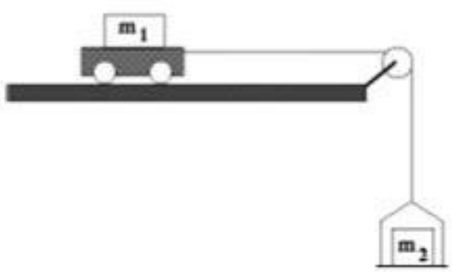
Second Law – When a system is subject to a nonzero net force, it accelerates. Newton's second law describes this acceleration in terms of the mass of the system and the net force:

$$F_{net} = m_{system} \cdot a_{system} \qquad \text{Eq. 1}$$

Thus, for a given mass, a larger force will produce a greater acceleration. Likewise, for a given force, a larger mass will experience a smaller acceleration.

Third Law – Forces do not materialize out of thin air; Newton's third law addresses this. The weight of a chair is a force acting on the floor beneath it. If the floor did not exert a force equal in magnitude and opposite in direction on the chair, the chair would accelerate in some direction, according to Newton's first law. Two objects that share a force in this manner may be called an action-reaction force pair.

This experiment used a modified Atwood device to examine Newton's laws of motion, as described below.



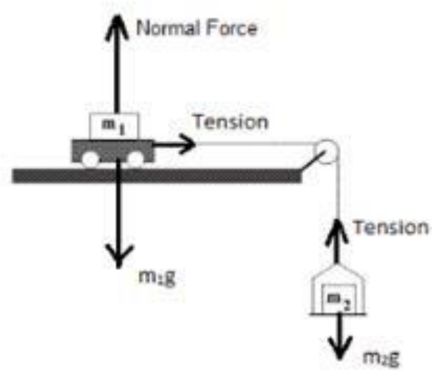


Figure 1a: Modified Atwood device

Figure 1b: Forces considered in this experiment

The modified Atwood device used consisted of a low-friction cart on a level track, connected to a hanging mass by a string. The string had a paper clip on either end, and was fed over a low-friction pulley, as shown in Figure 1a. The forces considered to be acting on the system are shown in Figure 1b above. Air resistance and friction were neglected.

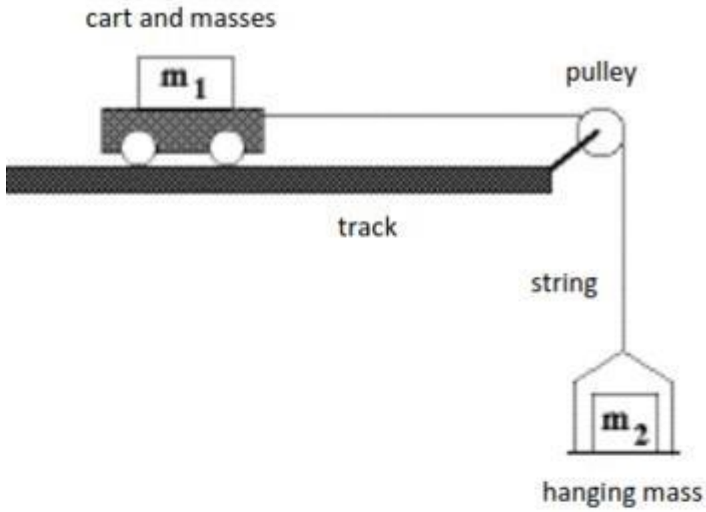
Several action-reaction force pairs are apparent from Figure 1b. First, the cart is pulled toward the earth via gravitation. Likewise, the earth is pulled toward the cart, but with a much smaller acceleration. Opposing the weight of the cart (although not its force pair) is the normal force exerted on the cart by the track. It is paired with an equal and opposite contact force exerted by the cart. The two tension forces are also a third law pair, although they constitute an internal force, and are in effect equal and opposite.

Without the tension force acting horizontally on the cart, it remains stationary on the track. Thus the normal force and the weight (m_1g) of the cart must cancel. Both tension forces are internal, and cancel as well. Therefore the net force on the system is produced exclusively by the weight (m_2g) of the hanging mass. Substituting into Eq. 1:

$$m_2g = (m_1 + m_2) \cdot a \qquad \text{Eq. 2}$$

The purpose of this experiment is to examine and verify Newton's laws of motion empirically. Eq. 2 above is in linear form $y = mx + b$, where dependent variable (y) is the net force (m_2g), slope (m) is the system mass ($m_1 + m_2$), independent variable (x) is the acceleration (a) of the system, and intercept (b) is zero. Force and acceleration are the independent and dependent variables, respectively, and would normally be graphed a vs. F. However, for this experiment they were graphed F vs. a, in order to have a slope equal to the system mass.

We hypothesize that we will be able to determine the system mass graphically in this manner, to within reasonable error, having measured the hanging mass and the acceleration of the system. We expect the vertical intercept to be zero; in the context of Newton's first law, zero net force will produce zero acceleration. We expect our calculated system mass to be slightly larger than the value obtained using a double pan balance, due mainly to air resistance and internal friction. These are neglected in Eq. 2 and will cause measured acceleration to be slightly less than expected, making the slope of the graph steeper.



4. PROCEDURE :

Activity 1: Newton's First and Third Laws

The cart is placed on the track, and the four small masses and paper clips and string are placed atop it. The forces acting on the system were the gravitational force on the cart and objects atop it, and the normal force from the track opposing the cart's weight. The net force on the system is zero. Thus there is no imbalance of forces, and no acceleration. One end of the string is attached to the cart with a paper clip, while the other end of the string is fed over the pulley. While keeping three masses atop the cart, one 0.020 kg mass was hung from the vertical end of the string with the second paper clip. It is observed that when released, the system accelerates (hanging mass toward the floor, cart toward the pulley). The forces acting on the system are those shown in Figure 1(b) above. The net force acting on the system is the weight of the hanging mass, given by $m_2g = (0.020\text{ kg})*(9.81\text{ m/s}^2) = 0.20\text{ N}$.
The system is now accelerating because there is an imbalance of force, as described by Newton's first law.

Activity 2: Graphical Representation of Newton's Second Law

Net Force vs. Acceleration to examine the relationship between net force, system mass, and acceleration, one variable must be held constant. In this experiment, system mass was held constant by keeping all masses either hanging on the end of the string over the pulley, or else sitting atop the cart. When taking data, net force was the independent variable, since it could be controlled by adjusting the hanging mass. Acceleration was the dependent variable. Velocity of the cart is determined by measuring the displacement(s) of the cart and the time (t). For the different masses velocity is determined from the graphs acceleration and net force is determined as follows:

GRAPHS OF VELOCITY VS. TIME AND FORCE VS. ACCLERATION :

The graph should suggest that acceleration is roughly constant as the cart moved along the track toward the pulley, as expected. The acceleration is determined experimentally, from a linear fit to the velocity vs.

time data using Microsoft excel.

i. To construct a force vs. acceleration graph, the previous procedure is repeated for various different hanging masses. In each case, an experimental acceleration is obtained from a linear fit to the velocity vs. time graph produced. The net force acting on the accelerating system is calculated by multiplying the hanging mass m_2 by the acceleration of gravity g =9.81 m/s2

ii. To construct a force vs. acceleration graph, the previous procedure repeated for different hanging masses. In each case, an experimental acceleration was obtained from a linear fit to the velocity vs. time graph produced. The net force acting on the acceleration system was calculated by multiplying the hanging mass m_2 by the acceleration due to gravity $g=9.81 m/s^2$. These data are tabulated. A graph of net force vs. acceleration created with the data from table.

The linear fit to the Force vs Acceleration data can be rewritten as:

$$F_{net}\,(N) = \mathbf{m_2}\,(kg) \cdot a\,(m/s^2) + \mathbf{C}\,(N) \qquad \text{Eq. 3}$$

This gave a graphical value for the system mass of m_2 The measured system mass obtained using the double pan balance was m_2 These values were compared using percent difference:

$$\%difference = \frac{|experimental1 - experimental2|}{average} \cdot 100\% \qquad \text{Eq. 4}$$

$$= \frac{|0.7082\,kg - 0.6592\,kg|}{(0.7082\,kg + 0.6592\,kg)/2} \cdot 100\% = 7.2\%$$

5. OBSERVATION

S.No.	Hanging Mass m_2(kg)	Displacement *s* (m)	Time *t* (sec)	Velocity *v* (m/s^2)	Net Force F_{net}(N)	Acceleration ***a*** (m/s^2)	% of difference of mass
1							
2							
3							
4							

6. RESULT

Newton`s laws are verified by plotting graph to obtain acceleration and system mass using the modified Atwood device.

EXPERIMENT NO. 12

VERIFICATION OF ANGULAR ACCELERATION OF A ROLLING DISC ON AN INCLINED PLANE

1. OBJECTIVE:

To understand the relationships among mass moment of inertia and angular acceleration of disk rolling down on an inclined plane

2. APPARATUS

Two rolling discs of different radius, Inclined plane, stop watch

3. THEORY:

The pure rolling motion of a wheel can be considered in two ways:-

A. Rotation of the wheel about an axis through its centre of gravity
B. Rotation of the wheel about an instantaneous axis through the point of contact between the wheel and the ground

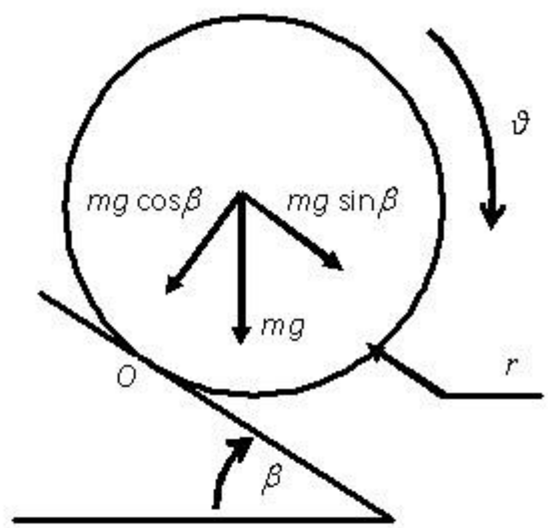


Fig. 1 Dynamic Modelling of Rolling Disc

A point in the body which is on the instantaneous axis is momentarily at rest. During pure rolling, the body moves along the instantaneous axis which remains parallel to the centre of gravity. The angular velocity of the wheel about the instantaneous axis is the same as axis through center of gravity.
The general motion of a rigid body may be considered in two ways:

A. Translation about centre of gravity.
B. Rotation of the body about an axis through centre of gravity.

The angular velocity and angular acceleration can be calculated by taking the torques and the moment of inertia about an axis through the center of gravity and the linear velocity and the linear acceleration can be calculated by assuming all the forces through centre of gravity.

In Fig. 1, a disk of radius *r* and mass *m* rolls down without slipping on an inclined plane of angle β. The normal component of weight *mg* is *mg* cos β, perpendicular to the plane and passing through the center of the disk, and tangential component of weight *mg* sinβ acting parallel to the plane at the point of contact *O* and responsible for opposing the frictional force. The instantaneous axis of rotation passes through point *O* and is perpendicular to the plane of the disk.

4. PROCEDURE:

1. Set the apparatus in horizontal position and then adjust the first angle (1°) with the help of height adjuster.
2. Release the bigger disk and note the time taken to hit the end point with the help of stop watch. Repeat the same, three times to obtain an average time.
3. Repeat the Step 2 for the small disk to obtain an average time.
4. Repeat Steps 2 & 3 for four different angles (3°, 5°,7° and 9°)

A. Analytical Method:

The analytical angular acceleration can be found by summing the moment acting on the objects at about contact point, O,

$$\Sigma M_o = I_o\ddot{\theta}$$

$$(mg\ \sin\beta)r = I_o\ddot{\theta}$$

$$\boldsymbol{\ddot{\theta}} = \frac{\boldsymbol{mgr\ \sin\beta}}{\boldsymbol{I_o}} \text{ (Analytical Angular Acceleration)}$$

B. Experimental Method:

Experimental angular acceleration can be determined by the Newton's equation of motion for rotating body:

$$\theta^{\,2} = \theta_o{}^2 + 2\theta(\theta - \theta_o)$$

$$\theta = \theta_o + \theta t$$

$$\theta = \theta_o + \dot{\theta}_o t + \frac{1}{2}\ddot{\theta}t^2$$

as, disk starts to roll from rest, $\theta_o = 0$

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

$$\boldsymbol{\ddot{\theta}} = \frac{\boldsymbol{2\theta}}{\boldsymbol{t^2}} \text{ (Experimental Angular Acceleration)}$$

Where, M_o - Moment about point O

I_o - Mass moment of inertia (Need to apply parallel axis theorem at O)

$\ddot{\theta}$ - Angular Acceleration

θ - Angular Velocity

θ - Angular Displacement

m - Mass of disk

g - Gravitational Acceleration ($9.81 m/s^2$)

β - Inclination angle r-

Radius of the disk

t - Time taken for disk to roll from a point to another point

5. OBSERVATION:

Table-1: Time taken for disk to roll down in 1m distance, t(s)

Inclination Angle, β (°)	Time taken for disk to roll down in 1m distance, t(s)							
	Big Disk				Small Disk			
	t_1	t_2	t_3	t_{avg}	t_1	t_2	t_3	t_{avg}
1								
3								
5								
7								
9								

Table-2: Percentage error of the angular acceleration of the disks

Inclination Angle, β (°)	Theoretical Angular Acceleration, θ (rad/s^2)		Experimental Angular Acceleration, θ (rad/s^2)		Percentage of Error (%)	
	Big Disk	Small Disk	Big Disk	Small Disk	Big Disk	Small Disk
1						
3						
5						
7						
9						

A. GRAPH

For comparing the performance of bigger disc and the smaller disk plot the graph between the angle of inclination (on x-axis) and percentage error (on y- axis) by taking both the disks readings on the same graph.

6. RESULT

The mass moment of inertia is calculated for two differently sized disks and angular acceleration is found through analytical and experimental method. Graph is drawn to find the comparison between angle of inclination and percentage error for better understanding of mass moment of inertia on angular acceleration.