Experiment 3. Equilibrium

Addition of vectors - two forces, $F_1 = 80$ newton and $F_2 = 60$ newton can balance a force, $F_3 = 100$ newton.

Objective:

(a) To study the equilibrium of a point mass. (b) To study the equilibrium of an extended object.

Apparatus:

The apparatus consists of an vertical board having two small pulleys attached at the two top corners of the board. A thin string carrying two weights at its ends passes over the pulleys (Fig. 1). Another string which carries a third weight is tied to the first string. To study the equilibrium of an extended object, an arrangement similar to that shown in Fig, 3 is used.

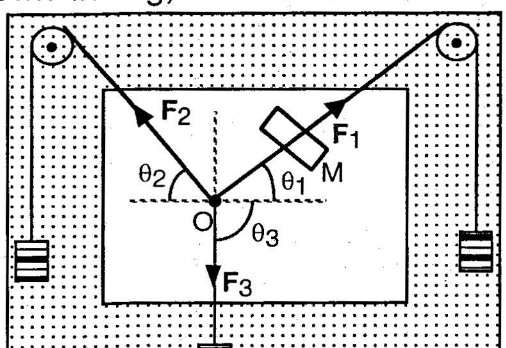

Fig. 1

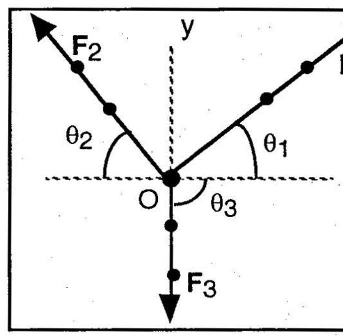

Fig. 2

Theory:

A body is said to be in equilibrium if there is no change in its translational motion or rotational motion. In other words, equilibrium entails that the body should not have translational or rotational acceleration. External forces and torques produce or tend to produce a translational and angular accelerations in a body. Thus forces and torques change or tend to change the state of equilibrium of a body. Obviously, if the resultant of external forces and the resultant of external torques are zero, the body will remain in equilibrium. Thus the conditions for equilibrium are:

I. If a number of forces, $\mathbf{F}_1$, $\mathbf{F}_2$, $\mathbf{F}_3$, etc., keep a body in equilibrium, the resultant of the forces $\Sigma\mathbf{F} = 0$. In other words,
the sum of the x-components of the forces $\mathbf{F}_1$, $\mathbf{F}_2$, $\mathbf{F}_3$, etc., $\Sigma F_x = 0$,
and
the sum of the y-components of the forces $\mathbf{F}_1$, $\mathbf{F}_2$, $\mathbf{F}_3$, etc., $\Sigma F_y = 0$.

II. The algebraic sum of the torques of $\mathbf{F}_1$, $\mathbf{F}_2$, $\mathbf{F}_3$, etc., $\Sigma\tau = 0$

Components of a force:

If a force $\mathbf{F}_1 = 80$ gm-wt makes an angle $\theta_1 = 30^o$ with the x-axis (Fig. 2),

x-component of $\mathbf{F}_1$, $Fx = F_1 \cos\theta_1 = 80 \cos 30^o$ gm-wt = 69.3 gm-wt and

y-component of $\mathbf{F}_1$, $Fy = F_1 \sin\theta_1 = 80 \sin 30^o$ gm-wt = 40 gm-wt.

Note that angles θ_1 and θ_2 are the acute angles made with the +x-axis or -x-axis. If the component points toward the +x-axis (or +y-axis), it is positive, and if it points toward the -x-axis (or -y-axis), it is negative.

Torque (moment) of a force:

Torque of a force is a measure of the capability of the force to produce angular acceleration and thereby changing the rotational motion of a body. The torque depends on the magnitude of the force and on the position of its point of application (including the direction) relative to the axis of rotation (or of intended rotation). The torque of a force can be counter-clockwise (positive) or clockwise (negative).

The torque of a force is calculated by using the formula

torque τ = force x lever arm (or moment arm),

where lever arm p = perpendicular distance of the axis of rotation from the line of action of the force.

For example (Fig. 4), if force $\mathbf{F}_1 = 100$ gm-wt, distance AT = 17 cm and $\theta_1 = 38^o$,

lever arm $AP_1 = 17 \sin 38^o$ cm = 10.5 cm,

and torque τ_1 = 100x10.5 cm-gm-wt = 1050 cm-gm-wt.

Procedure:

(a) Equilibrium of a point object:

1. Arrange the strings and weights as shown in Fig. 1. Attach a sheet of paper on the board such that the knot is nearly in the center. Hold a mirror strip M (Fig. 1) gently on the paper behind a section of the string. Mark two fine dots on the paper with a pencil such that the dots are hidden behind the string when the image of the string is hidden behind the string (see Fig. 2). Similarly, mark two pairs of dots for the other two sections of the string as well. Do not try to mark the position of the knot. The procedure using the mirror strip eliminates errors due to parallax. (What is parallax?)
2. Remove the paper from the board. check to see that the lines of action of the three forces acting on the knot meet at one point as shown in Fig. 2. If they do not meet at one point, discard the sheet of paper and repeat the procedure.

3. Extend the line of action of force $\mathbf{F}_3$ to obtain the y-axis. Then draw the x-axis as shown in Fig. 2. Record the forces including the weights of the hangers. Measure angles θ_1 and θ_2. Note that θ_3 is -90^o.
4. Repeat the procedure by using different combinations of weights.

(b) Equilibrium of an extended object:

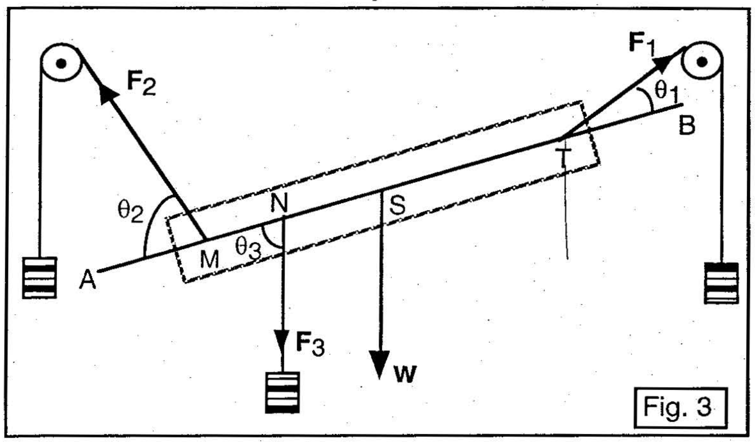

Fig. 3

5. Arrange the strings and weights as shown in Fig. 3 attaching a sheet of paper on the board. Using the mirror strip, mark the lines of action of forces $\mathbf{F}_1$, $\mathbf{F}_2$ and $\mathbf{F}_3$, and the corners of the plastic strip (for finding the central axis AB).

Calculation of torques:

Torque = force x lever arm

Lever arms:

Length AP_1

$= AT \sin\theta_1 = d_1 \sin\theta_1$

Length AP_2

$= AM \sin\theta_2 = d_2 \sin\theta_2$

Length AP_3

$= AN \sin\theta_3 = d_3 \sin\theta_3$

Length AP_4

$= AS \sin\theta_3 = d_4 \sin\theta_3$

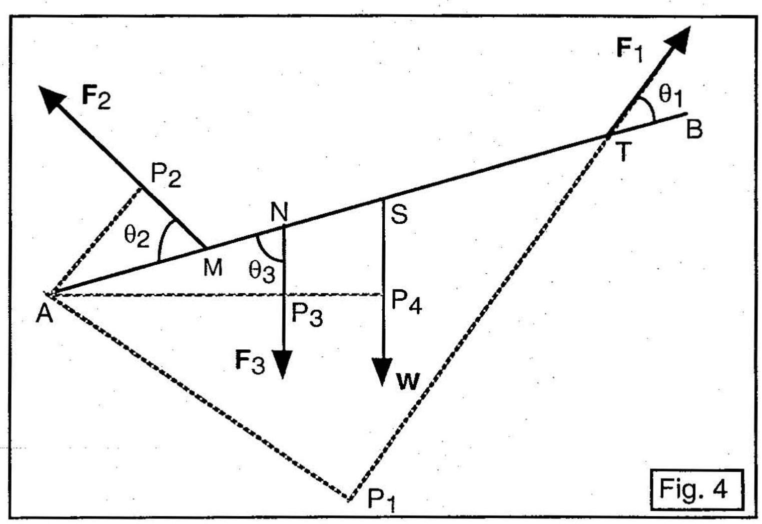

Fig. 4

6. Remove the sheet of paper, draw the lines of action of the forces $\mathbf{F}_1$, $\mathbf{F}_2$ and $\mathbf{F}_3$, and draw the line AB. Record the weights and the weight of the plastic strip. Note that the weight of the strip acts through S, the geometric center of the strip and makes an angle equal to θ_3. Here point A is chosen arbitrarily and AB is taken to be the x-axis for convenience.
7. Measure the angles and the distances d_1 = AT, d_2 = AM, d_3 = AN, d_4 = AS.
8. Take one more set of data, if time permits.

Use gm-wt as the unit of weight and cm as the unit of length in this experiment.

York College of The City University of New York

Physics I Name:

Experiment No. 3: Pre-Lab Questionnaire

1. In Fig. 1, let $\mathbf{F}_1$ = 120 gm-wt, $\mathbf{F}_2$ = 195 gm-wt, $\theta_1 = 35^\circ$ and $\theta_2 = 60^\circ$.
   (a) Determine $\mathbf{F}_3$. (b) Calculate ΣFx.

2. In Figs. 3 and 4, let length AM = 6.5 cm, $\mathbf{F}_2$ = 120 gm-wt, angle $\theta_2 = 60^\circ$. Calculate the torque of $\mathbf{F}_2$ about A.

3. In Figs. 3 and 4, let length AN = 16.5 cm, $\mathbf{F}_3$ = 85 gm-wt, angle $\theta_3 = 80^\circ$. Calculate the torque of $\mathbf{F}_3$ about A.

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Experiment No. 3

Name:

Marks:

Partner:

Remarks:

Section:

Date Submitted:

Title:

Objective:

Theory/Formulas:

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Data Sheet

a. Equilibrium of a point object:

No.	Force	Angle	x-component	y-component
1.	$\mathbf{F}_1$	θ_1		
	$\mathbf{F}_2$	θ_2		
	$\mathbf{F}_3$	θ_3		
			$\Sigma F_x =$	$\Sigma F_y =$
2.	$\mathbf{F}_1$	θ_1		
	$\mathbf{F}_2$	θ_2		
	$\mathbf{F}_3$	θ_3		
			$\Sigma F_x =$	$\Sigma F_y =$

b. Equilibrium of an extended object:

Weight of the plastic strip =

No.	Force	Angle	x-component	y-component
1.	$\mathbf{F}_1$	θ_1		
2.	$\mathbf{F}_2$	θ_2		
3.	$\mathbf{F}_3$	θ_3		
4.	w	θ_3		
			$\Sigma F_x =$	$\Sigma F_y =$

No.	Distance of point of application	Lever arm	Torque
1.	$AT = d_1 =$		
2.	$AM = d_2 =$		
3.	$AN = d_3 =$		
4.	$AS = d_4 =$		
			$\Sigma\tau =$

Make similar tables if you have more observations.

Conclusions

Experiment No. 3: Questions

1. Define force and torque. Does the torque depend on the point of application of the force? Explain.

2. What are the conditions of equilibrium?

3. A rain drop falling toward the ground was observed to have a constant velocity. Was the rain drop in equilibrium? Explain.