Experiment 3: Conditions in Equilibrium

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Abstract

Cancellation of forces acting upon an object means that the object is at the state of equilibrium. This experiment is comprised of four set-ups that address several conditions in equilibrium.

Activity 1 demonstrates the concept of equilibriant force. Activity 1 yielded a percent error of 11% for magnitude and 0.69% for position. The first condition for equilibrium is carried out in Activity 2 by using a force board and a suspended cylinder with the use of two strings. Further physical elements were obtained by means of component method. The cylinder was weighed and a percent error of 38% was computed. Activity 3 deals with locating the center of gravity by means of the Plumb line and the Balancing method. The center of gravity was calculated to have the coordinates of (11.92, 4.87). The second condition for equilibrium is illustrated in the last activity by computing for the experimental weight of the metal bar. Quantifying the experimental weight of the bar against the theoretical weight of the bar yielded a percent error of 3.31%.

1. Introduction

Equilibrium is generally defined as a state of balance. In physical terms mechanical equilibrium is defined as a condition of a system wherein neither its state of motion nor its internal energy state tends to change with time. A rigid body is considered to be in equilibrium when the vector sum of all torques acting on the body equals zero which results to a constant state of rotational motion. If forces cause accelerations, then torques cause angular accelerations. There is a relationship between these two separate concepts. In general, a larger radial distance r between the applied force and the axis of rotation results in a larger acceleration. Similarly, a larger applied force will also result in a larger angular acceleration. This is the basic definition of torque regarding the special case of forces perpendicular to the position vector.

An object is said to be in mechanical equilibrium if it satisfies two conditions. First, the net external force must be zero. The first conditions is a statement of translational equilibrium which is the sum of all forces acting on the object must be zero so that the object has no translational acceleration. Second, the net external torque must be zero. The second condition talks about rotational equilibrium wherein sum of all torques on the object must be zero so the object has no angular acceleration. An object must move through space at a constant speed and rotate at a constant angular speed for it to be in equilibrium.

The following objectives are emphasized to illustrate these conditions.

1. To determine the equilibriant force using the force table and component method.
2. To determine unknown forces using the first condition and second condition for equilibrium.
3. To locate the center of gravity of a composite body.
4. To demonstrate rotational equilibrium.

2. Theory

The forces are considered to be in balance if an object is in equilibrium. This means that the forces from the leftward, rightward, upward and downward will result into zero. Objects that are in equilibrium will result into having a net force of zero and an acceleration of zero. There are two conditions. The first condition states that, the net force acting upon an object must be zero. Each axis of motion must equal to zero. The second condition states that the net torque, the force that causes angular rotation (Serway, 2015), must equal to zero.

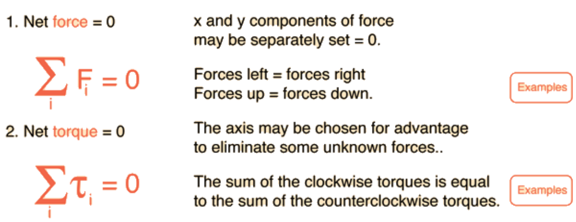

Figure 1. Two conditions of Equilibrium

In activity 1, the group computed for the equilibrant force. Equilibrant force is the force, which keeps any object motionless. A force table and three pans with weights were used to obtain the equilibriant force.

These are the formula used in activity 1 :

Ta= (Pan A +added weight) x 1Kg/1000g x 9.8 m/s2,

Tb = (Pan B + added weight) x 1Kg/1000g x 9.8m/s2

Tc= (Pan c +added weight) x 1Kg/1000g x 9.8 m/s2,

$$\sum Fx = 0$$

$$\sum Fy = 0$$

% Error = Exp. – Theoretical X 100

In activity 2, the group computed for the experimental weight of the cylinder and tension of the string using the first condition of equilibrium.

These are the formula used in activity 2 :

$$\sum F=0$$

In activity 3, the location of the center of gravity was obtained using the plumb line method and balancing method. The x and y coordinates were computed.

$$x = \frac{XcWc+XsWs}{W} \qquad y = \frac{YcWc+YsWs}{W}$$

Xc and Yc are the coordinates of the center of gravity of the circle

Xs and Ys are the coordinates of the center of gravity of the square

$\bar{x}$ and $\bar{y}$ are the coordinates of the center of gravity of the composite figure.

In activity 4, the experimental weight of the bar was computed and the tension of the string using the second condition of equilibrium.

$$\sum T = 0$$

T (torque) = the force that causes rotational motion.

T = F x L = N x m

where:

F = Force (N)

L = leverarm (m)

$$\sum T = T_1 + T_2 - T_{Wc} - T_{WB}$$

T_1 (0) + T_2(l) - Wc (0.05 m) - WB (1/2) = 0

$$Wb = \frac{T_1 \times L - Wc(0.05m)}{\frac{L}{2}}$$

(Experimental Weight)

Wb = (mass in Kg) (9.8 m/s2)

(Theoretical Weight)

Where:

T_1 Is the spring scale reading

T_2 Is the tension of the string

Wc is the weight of the cylinder

WB is the weight of the bar

L is the length of the bar

3. Methodology

The materials used in this experiment were force table, force board, cylinder, spring scale, electronic gram balance, card board, aluminum bar, and protractor.

In activity one, the group estimated the location where the ring will reach equilibrium . The group weighed Pan A, Pan B and Pan C. The group then placed the each pan with their respective weights to their respective degree position. Pan A with 100g was placed on the 30° point, Pan B with 150g was placed on the 200° point and Pan C with weights was placed on the 353° point. The magnitude of each tensions and their position was then computed and recorded. Also the percent error was computed and recorded.

In activity 2, the group used a force board to suspend a cylinder by means of two strings. A spring scale was attached to one of the strings. The string was pulled horizontally until the pin on the force board was exactly at the middle of the ring. The reading on the spring scale was recorded as . The angle of the other string was

T_1

recorded as ϴ. A free body diagram was then drawn and the tension of T_2 was computed. The experimental weight of the cylinder was computed and the cylinder was weighed in an electronic gram balance for the accepted value or theoretical value. All results were then recorded.

In activity 3, the group prepared a cut out of a circle with a diameter of 10cm and a square with a side of 10cm. The circle and square was weighed and recorded as Wc and Ws respectively. The center of gravity of the composite figure was determined by using the plumbline and balancing method. The position of each center of gravity using the leftmost side of the square as the y-axis and the bottom of the square as the x-axis was specified. The results obtained was counter checked by actual computation of the center of gravity using the formulas given.

In activity 4, the center of gravity of the aluminum bar was obtained and marked by balancing it on a pencil. A cylinder was hanged 5.0 cm away from the one end of the bar. The force board was used to support the aluminum bar by using a spring scale on one end and a string on the other end until the aluminum bar obtained a horizontal position and achieved balanced. A free body diagram of the bar was drawn. The weight of the bar and the tension in the string was computed using the second condition of equilibrium. Also the theoretical weight was used in the computation. The bar was weighed using the electronic gram balance as the accepted value and the percent error was computed.

4. Results and Discussion

In this experiment, there are four activities that are connected to each other. The first activity is about finding the equal balance of different weights; the second activity is about the principle of the first condition of equilibrium by looking for the right tension for the ring while the third activity is about locating for the center of gravity of the cut out pieces from the cardboard and the last activity is all about the principle of the second condition of equilibrium.

Activity 1: Equilibrant Force

Tension	Magnitude (N)	Position
T_A	1.4 N	30°
T_B	1.9 N	200°
Experiment Equilibrant	0.5 N	353°
Theoretical Equilibrant	0.56 N	352.66°
% Error	11%	0.09%

Activity 1 is about determining the equilibrant force that will balance and center the ring on a force table. Each pan had different weights therefore resulting in different tensions. The given positions were 30° and 200° each with varying weights. The equilibrant force is the force which brings equilibrium state. This means that the ring is centered in the middle of the force table and its sides are not touching the middle portion of the force table. To determine the experimental equilibrant is pure trial and error using the force board but it can also be computed so get the exact position and magnitude. After performing various trails, the group was able to generate a result of 0.5 N and a position of 353°. These results were able to balance the ring and prevent is from touching the middle portion of the force table. This indicates that the setup is in equilibrium. The given magnitudes and positions were used for computation to check for the validity of the experimental equilibrant. This resulted in 11% error in magnitude and 0.09% error in position therefore the experimental equilibrant is very close to the theoretical equilibrants. The group was successful in using the trial and error method based on the low % errors.

Activity 2: First Condition for Equilibrium

T_1 (N)	1.0 N
ɵ (°)	35°
T_2 (N)	1.2 N
Experimental Weight	0.69 N
Theoretical Weight	0.5 N
% error	38%

Activity 2 is about the First condition for Equilibrium. The group was tasked with using the force board to suspend an unknown weight and to find its equilibrium. This means that the ring must be centered and its sides must not touch the pin. The first condition of equilibrium states that the net acting force must be equal to zero. This is shown when the pin is in the middle of the ring. There were various sources of error when the group performed the activity. First, a possible source of error could be the misreading of the spring scale therefore resulting in a much higher result for T1. Also, the group may have not properly followed the procedure given for the experiment. Instead of using the nail on the force board to hold the spring scale in place, the group used a group member's fingers to hold it in place therefore creating more tension. Finally, the tensions T1 and T2 should be equal because they both have different angles therefore should result in different tensions. The group committed 38% error.

Activity 3: Locating the Center of Gravity

Weight of Square: 0.097 N

Weight of Circle: 0.076N

Method	Center of Gravity	
	x-coordinate	**y-coordinate**
Plumb line Method	9.5 cm	5.4 cm
Balancing Method	9.4 cm	4.8 cm

Computation	11.92 cm	4.87 cm

Activity 3 is about locating the center of gravity of a circle and square together. The group was tasked with tracing the lines made when the sample was hung at different positions. The center of gravity is where all the lines intersect. The postion was measured by using the x and y axis of the square. Based on the results taken, both the plumb-line method and balancing method have the same measurements for the center of gravity. This is because the center of gravity does not change for an object. The center of gravity can also be computed using the taken measurements and weights of the circle and square. This will result in the exact position of the center gravity while the previous methods would only give a very good estimate but not the exact location.

Activity 4: Second Condition for Equilibrium

Reading of Spring Scale (N)	0.50 N
Weight of Cylinder (N)	0.5 N
Tension in the String	1.06 N
Experimental Weight of bar (N)	0.87 N
Theoretical Weight of Bar (N)	0.90 N
% Error	3.3 %

The fourth activity is about the application of the principle of the second condition for equilibrium by the use of a cylinder, and a bar. The tension of the string depended on gravity and the pressure of hold by one of the member of the group. The position of the cylinder was determined by ruler and by following the instructed distance. Afterwards, the group computed for the tension applied eliciting a 3.3% error from this activity.

5. Conclusion

The experiment done by the group which consists of four activities aims to determine the different conditions for equilibrium. The first activity was performed by the group with the use of the force table to determine the equilibrant force with the application of component method, the second activity was with the use of the force board and a suspended cylinder to determine unknown forces using the first condition for equilibrium, the third was about locating the center of gravity which was done by the group with the use of a circle and square cardboard by balancing and the use of plumb-line method. The fourth activity is about determining the tension of the bar and the suspended cylinder.

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6. Applications

7. References

[1] Serway, R. & Vuille, C. (2015). College Physics (10th ed.). Singapore: Cengage Learning Asia Pte Ltd