KEMENTERIAN PENGAJIAN TINGGI

FORCE

WRITER & EDITOR

Noorul Amilin binti Saipudin
Mathematics, Science and Computer Department,
PTSB

FORCE

Most of our daily activities required the use of forces. An object's state of motion can be changed by a force.

FORCE

WRITER & EDITOR

Noorul Amilin binti Saipudin
Lecturer of Mathematics, Science and Computer Department, PTSB

REVIEWER

Shamsul Arif bin Ismail
Head of Science Unit, Mathematics, Science and Computer Department, PTSB

e-ISBN 978-967-0855-79-0

PUBLISHER

Politeknik Tuanku Sultanah Bahiyah (PTSB)
Kulim Hi-Tech Park,
09090 Kulim,
Kedah

2021 : FIRST EDITION

PREFACE

This module is written primary for all polytechnics engineering student to assist them to understand the basics of force in engineering science. This module set out force theory and illustrates as many useful example as possible. This module has seven part, which cover explanation, example, practice, question bank and answer. However, student is encourages to raise question and also urged to consult all the other possible sources of reference to obtain a full and through understanding of the subjects.
I express my gratitude to all, including colleagues, student and friends who contributed in making this module possible. I welcome suggestion from readers for improving this module in manner. May Allah forgive me for any error in this humble work and may Allah bless our effort with mercy and acceptance.

SINOPSIS

Force is part of DBS 10012 Engineering Science syllabus requirement for diploma engineering student in polytechnics. In order to graduate, student must pass this subject. This module contain the introduction and concept of force for better understanding such as Introduction of force, Newton's Law, Weight, The equation of force, Force in equilibrium and Moment of Force concept. Hopelly student will enjoy learning and understanding.

TABLE OF CONTENTS

TABLE OF CONTENTS

LEARNING OUTCOMES

UNDERSTAND THE CONCEPT OF FORCE

1. Define force and its units.
2. State the effect of force.
3. Differentiate between weight and mass.
4. Define Newton's Second Law (F=ma)
5. Define forces in equilibrium.
6. Calculate resultant force using resolution method.
7. Apply the concept of force in solving problems related to equilibrium of forces.

UNDERSTAND THE CONCEPT OF MOMENT OF FORCE

1. Define moment of force and its unit.
2. Describe principle of moment of force.
3. Apply the concept and formula of moment of force in solving the related problems.

1.0 INTRODUCTION TO FORCE IN PHYSICS

1.1 Definition of Force and Its Unit

Force is an external agent capable of changing the state of rest or motion of a particular body. It has a magnitude and a direction and be identified as vector quantity. The direction towards which the force is applied is known as the direction of the force and the application of force is the point where force is applied.

Force also can be defined as a push or a pull upon an object. Force can be measured using a spring balance and the SI unit of force is Newton(N).

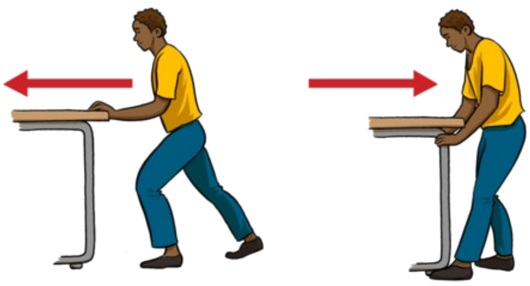
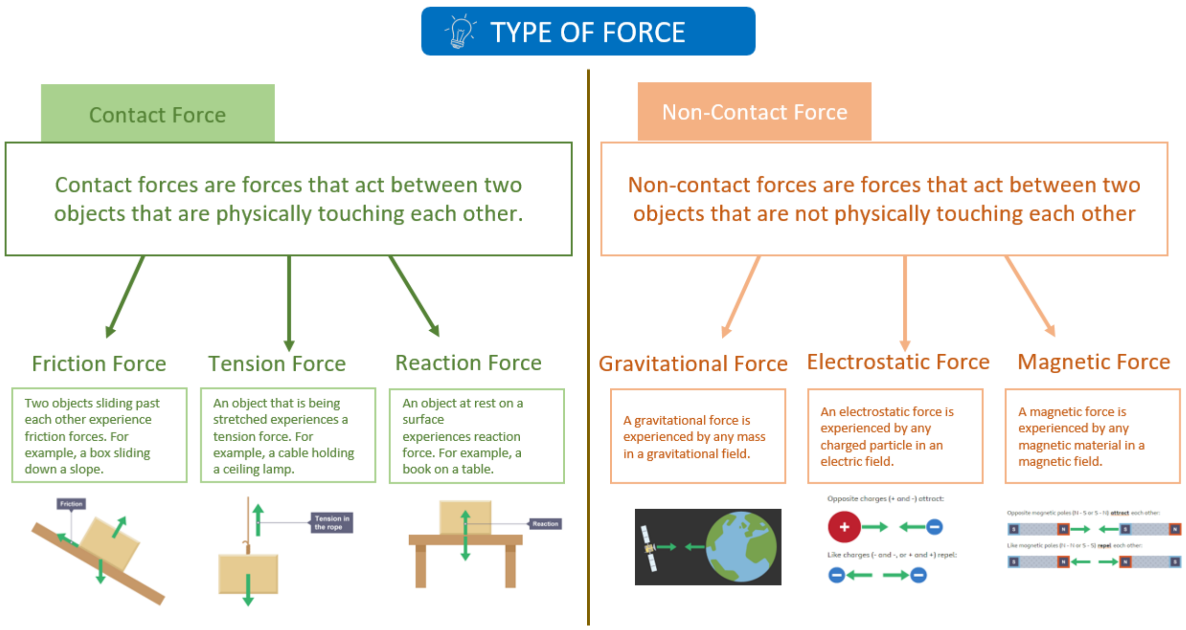


Figure 1.1: Force is push or a pull upon an object

1.2 Type of Force

Forces are responsible for all the interactions between particles and objects. There are a variety types of forces. They can be divided into two categories: contact forces and non-contact forces (at distance).



Can you give another example situation when applied force?

There are many examples of forces in our everyday lives:
-weight force
-the force of a bat on the ball
-the force of the hair brush on hair when it is being brushed
-the force of your foot pushing on the pedal when you ride your bike
-the force of a magnet on a paper clip when the magnet moves the paper clip towards it.

1.3 The Effect of Force

Force has the following effects on objects:

i. Force can make a stationary object move or make a moving object move faster

A toy car can be made to move by giving it a little push. Similarly, a stationary football can be made to move by giving it a small push (i.e., by kicking it). If we have an already moving toy car or ball, we can make it move faster by giving it a push in the direction in which it is moving. Thus, a force can make a stationary object move, and it can also make an already moving object move faster.

Figure 1.2: Move a ball by kicking (force)

ii. Force can slow down or completely stop a moving object

A moving toy car can be made to stop by applying a force. A bicycle can be stopped or slowed down by applying the brakes. In football, the force applied by the goalkeeper stops the ball hit towards the goal. In order to stop or slow down a moving body, we need to apply a force in a direction opposite to the direction of motion of the moving body.

Figure 1.3: Applying brake on bicycle

iii. Force can change the direction of a moving object

In cricket, when a batsman hits the ball that is bowled at him, the direction in which the ball is moving changes. In football, the players can change the direction of the moving ball by kicking it in a different direction. In these examples, force changes the direction of a moving object.

Figure 1.4: Batsman hits the ball

iv. Force can change the shape or size of an object

While making chapattis, we change the shape of the dough by applying force with our hands. The shape of a rubber band changes when it is pulled. You can also break things by applying a force. Materials that break easily when we apply a force are termed brittle. For example, objects made of glass and clay break easily when we apply force on them.

Figure 1.5: Changing the shape of the dough

2.0 NEWTON'S LAW

Newton's law of universal gravitation is usually stated as that every particle attracts every other particle in the universe with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers (Rohrlich, 1986). The publication of the theory has become known as the "first great unification, as it marked the unification of the previously described phenomena of gravity on Earth with known astronomical behaviors. (Mainzer, 1996)

This is a general physical law derived from empirical observations by what Isaac Newton called inductive reasoning. It is a part of classical mechanics and was formulated in Newton's work Philosophiæ Naturalis Principia Mathematica ("the Principia"), first published on 5 July 1687. When Newton presented Book 1 of the unpublished text in April 1686 to the Royal Society, Robert Hooke made a claim that Newton had obtained the inverse square law from him.

Figure 2.1: Sir Isaac Newton (1642-1727)

The three laws of motion were first compiled by Isaac Newton in his Philosophiæ Naturalis Principia Mathematica (Mathematical Principles of Natural Philosophy), first published in 1687. Newton used them to explain and investigate the motion of many physical objects and systems, which laid the foundation for Newtonian mechanics.

2.1 Newton's First Law

'An object at rest remains at rest, and an object in motion remains in motion at constant speed and in a straight line unless acted on by an unbalanced force'.

Newton's first law states that every object will remain at rest or in uniform motion in a straight line unless compelled to change its state by the action of an external force. This tendency to resist changes in a state of motion is **inertia.** There is no net force acting on an object (if all the external forces cancel each other out). Then the object will maintain a constant velocity. If that velocity is zero, then the object remains at rest. If an external force acts on an object, the velocity will change because of the force. (Glenn Research, 2021)

This means that motion cannot change or decrease without the effect of an unbalanced force. If the resultant force (the vector sum of the forces acting on the body) is zero, then the velocity of the object is constant.

As an example, wearing a seat belt in a car while driving is an example of Newton's 1st law of motion. If an accident occurs, or if brakes are applied to the car suddenly, the body will tend to continue its inertia and move forward, probably proving fatal. To prevent such accidents seat belts are used which stops your body from moving forward in inertia avoiding danger.

Figure 2.2: A different between not wearing (left) a seatbelt and wearing a seatbelt (right)

2.2 Newton's Second Law

'The acceleration of an object depends on the mass of the object and the amount of force applied'.

Newton's second law says that when a constant force acts on a massive body, it causes it to accelerate, i.e., to change its velocity, at a constant rate. In the simplest case, a force applied to an object at rest causes it to accelerate in the direction of the force. However, if the object is already in motion, or if this situation is viewed from a moving inertial reference frame, that body might appear to speed up, slow down, or change direction depending on the direction of the force and the directions that the object and reference frame are moving relative to each other. (LiveScience, 2021)

It also can be defined as a particle acted upon by an unbalanced force, **F** experiences an acceleration, **a** that has the same direction as the force and magnitude that is proportional to the force. Means that the unbalanced force acting on the particle is proportional to the time rate of change of the particle's linear momentum. (Hibbeler, 2002)

$$\boxed{\mathbf{F} = \mathbf{m}\mathbf{a}}$$

The bold letters **F** and **a** in the equation indicate that force and acceleration are vector quantities, which means they have both magnitude and direction. The force can be a single force or it can be the combination of more than one force. The large Σ (the Greek letter sigma) represents the vector sum of all the forces, or the net force, acting on a b

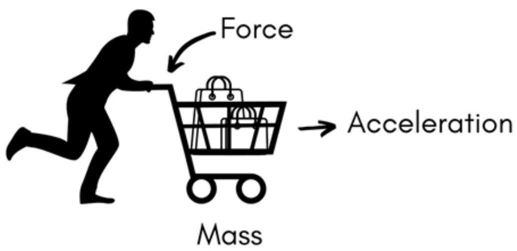


Figure 2.3: The greater the mass, the more force required to accelerated the shopping cart

2.3 Newton's Third Law

'Whenever one object exerts a force on a second object, the second object exert an equal and opposite force on the first'.

Newton's third law states that when two bodies interact, they apply forces to one another that are equal in magnitude and opposite in direction. The third law is also known as the law of action and reaction. This law is important in analysing problems of static equilibrium, where all forces are balanced, but it also applies to bodies in uniform or accelerated motion.

For example, a book resting on a table applies a downward force equal to its weight on the table. According to the third law, the table applies an equal and opposite force to the book. This force occurs because the weight of the book causes the table to deform slightly so that it pushes back on the book like a coiled spring.

If a body has a net force acting on it, it undergoes accelerated motion in accordance with the second law. If there is no net force acting on a body, either because there are no forces at all or because all forces are precisely balanced by contrary forces, the body does not accelerate and may be said to be in equilibrium. Conversely, a body that is observed not to be accelerated may be deduced to have no net force acting on it.

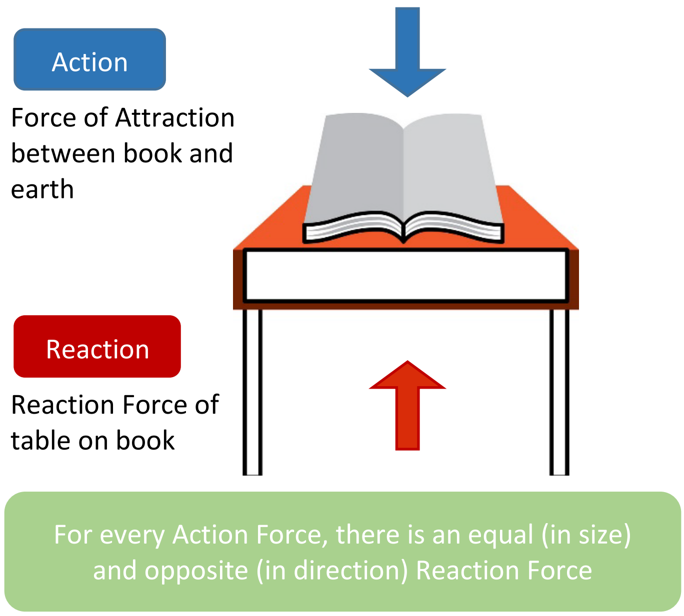


Figure 2.4: Action-Reaction force pairs

Quick Reference

Three laws published in 1687 by Isaac Newton concerning the motion of bodies:

1. A body continues in a state of uniform rest or motion unless acted upon by an external force. **(Inertia)**

2. The acceleration produced when a force acts is directly proportional to the force and takes place in the direction in which the force acts. **(Force)**

3. To every action there is an equal and opposite reaction. **(Action & Reaction)**

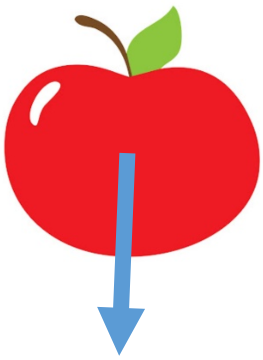
Newton's laws are applied to bodies which are idealised as single point masses, in the sense that the size and shape of the body are neglected to focus on its motion more easily. This can be done when the line of action of the resultant of all the external forces acts through the center of mass of the body. In this way, even a planet can be idealised as a particle for analysis of its orbital motion around a star.

These three laws hold to a good approximation for macroscopic objects under everyday conditions. However, Newton's laws (combined with universal gravitation and classical electrodynamics) are inappropriate for use in certain circumstances, most notably at very small scales, at very high speeds, or in very strong gravitational fields. Therefore, the laws cannot be used to explain phenomena such as conduction of electricity in a semiconductor, optical properties of substances, errors in non-relativistic ally corrected GPS systems and superconductivity. Explanation of these phenomena requires more sophisticated physical theories, including general relativity and quantum field theory.

3.0 WEIGHT (W)

Weight (W) is just another word for the force of gravity. Weight is a force that acts at all times on all objects near Earth. The Earth pulls on all objects with a force of gravity downward toward the center of the Earth. Weight can be defined as **the force of gravity that act on an object.** The SI unit of weight is Newton, N or kgm/s^2.

The magnitude of the force of gravity can be found by multiplying the mass (m) of the object by the magnitude of the acceleration due to gravity g=9.8 ms^{-2}



$$\boxed{W = mg}$$

W- Weight of object (Newton, N)
m - Mass (kg)
g - Gravitational acceleration (ms^{-2}), g = 9.81 ms^{-2}

This force of gravity is exerted on all objects by the Earth regardless of which way those objects are moving, and what other forces are exerted on the objects. In other words, there will be a gravitational force of magnitude exerted downward on all objects near the Earth whether they are falling down, flying up at an angle, sitting at rest on a table, or accelerating upward in an elevator. There may be other forces that contribute to the acceleration of the object, but the force of gravity is always present.

Any object located in the field of the earth experiences a gravitational pull. Gravitational acceleration is described as the object receiving an acceleration due to the force of gravity acting on it. It is represented by ‘g’ and its unit is m/s^2. Gravitational acceleration is a quantity of vector, that is it has both magnitude and direction.

3.1 Weight and Mass

Weight is different from mass. Weight (W) is the force of gravity exerted on an object. Mass (m) is an amount of matter in an object.

Table 3.1: Differences Between Weight and Mass

Category	Weight, W	Mass, m
Definition	The force of gravity that act on an object.	Amount of matter in an object
Value	The value changes according to gravitational field	The value is constant everywhere on the earth
Quantity of physic	Vector Quantity	Scalar Quantity
SI Unit	Measured in Newton's (N)	Measured in kilogram (kg)

The weight of an object will change if the object is brought farther away from Earth, or placed on a different planet, since the force of gravity on the object will change. However, the mass of the object will remain the same regardless of whether the object is on earth, in outer space, or on the moon.

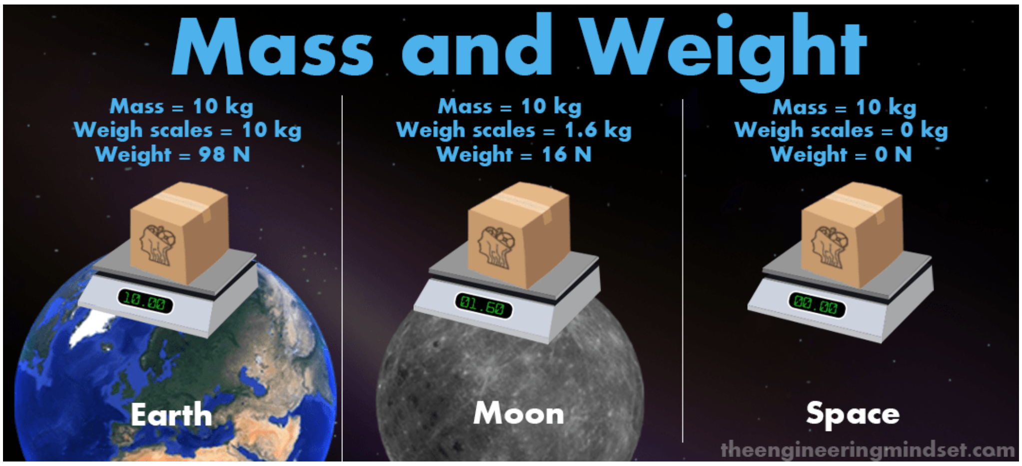


Figure 3.1: Differences Between Weight and Mass illustration

4.0 THE EQUATION OF FORCE

When more than one force acts on a particle, the resultant force is determined by a vector summation of all forces. For this more general case, the equation of force may be written as

$$\boxed{\sum F = ma}$$

W- Weight of object (Newton, N)
m - Mass (kg)
g - Gravitational acceleration (ms-2), g = 9.81 ms^{-2}

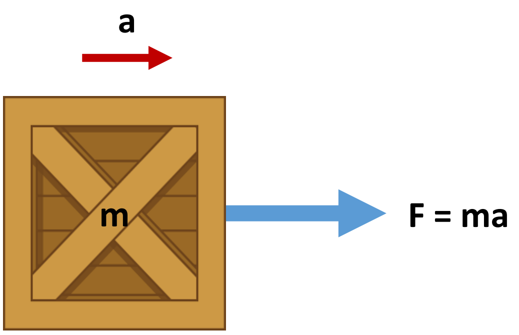


Figure 4.1: Force in one direction

However, this formula is only applied for the force in one direction. When force acting with an angle, ϴ at *x* axis, Component of force can divide into two component x-axis and component y-axis.

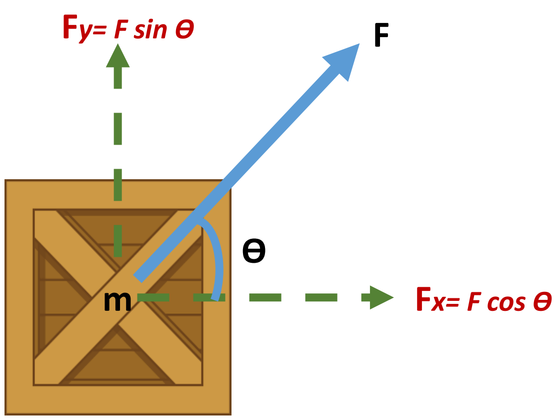
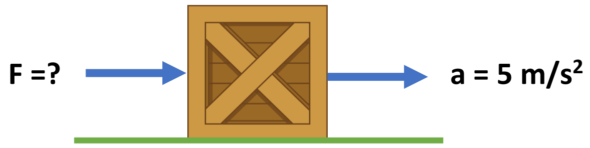


Figure 4.2: Force divided into x-axis and y-axis

Example 1

A 10 kg box moves with an acceleration of 5 m/s^2. Find the force acting on the box.



Solution:

Given: $m = 10$ kg

$a = 5\ m/s^2$

$F = ?$

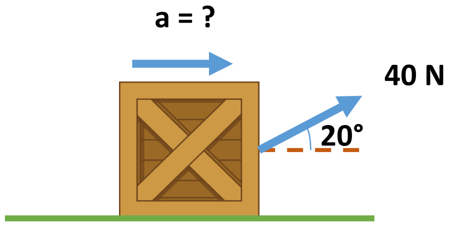
$F = m \times a$

$= 10\ kg \times 5\ m/s^2$

$\mathbf{F = 50\ N}$

Example 2

A 7 kg block is pushed with a force of 40 N. Find its acceleration.



Solution:

Given: $F_x = 40\ N \cos 20°$

$= 16.32$ N

$m = 7$ kg

$a = ?$

$F = m\,a$

$16.32\ N = 7\ kg \times a$

$a =$

$\mathbf{a = 2.33\ 5\ m/s^2}$

5.0 FORCE IN EQUILIBRIUM

When all the forces that act upon an object are balanced, the object is said to be in a state of equilibrium. The forces are considered to be balanced if the rightward forces are balanced by the leftward forces and the upward forces are balanced by the downward forces. This however does not necessarily mean that all the forces are equal to each other. Force in Equilibrium is when:

i) the resultant force that act on an object is zero

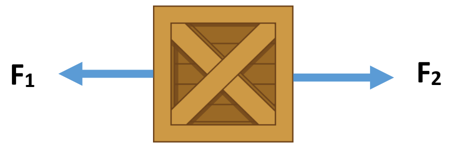
ii) the object is at rest or

iii) the object is moving with constant velocity in the straight line.

Example of forces in equilibrium

i) <u>The resultant force, F_R is Zero</u>

Example: An object moving at a constant velocity along the top of a table.



$F_1 = F_2$

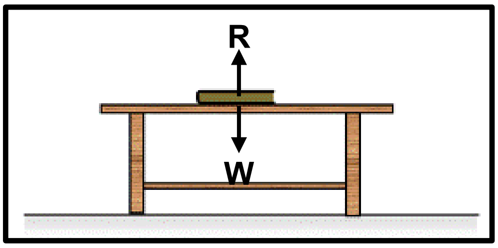
$F_R = -F_1 + F_2 = 0$

ii) <u>The object is at rest (static equilibrium)</u>

Example: A book resting on a table.

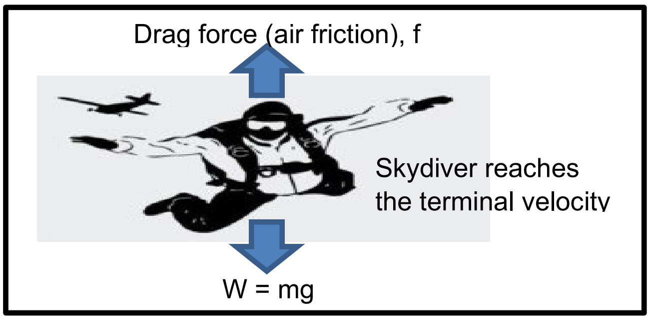
Weight of the book = Normal reaction on the book

W = R



iii) <u>The object is moving with a constant velocity (dynamic equilibrium).</u>

Ex : A skydiver falling at a constant velocity.



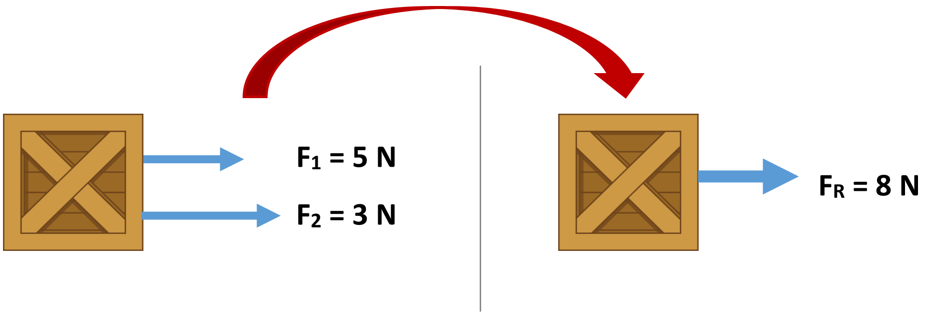
Weight of the skydiver = air friction

$W = f$

5.1 Resultant Force, F_R

The resultant force (F_R) is described as the total amount of force acting on the object or body along with the direction of the body. The resultant force is zero when the object is at rest or it is traveling with the same velocity as the object. The resultant force should be equal for all the force since all the force is acting in the same direction. It also can be defined as a single force that represents the combined effect of two or more forces acting on a rigid body.

i) <u>Forces act at a same direction (x-axis)</u>

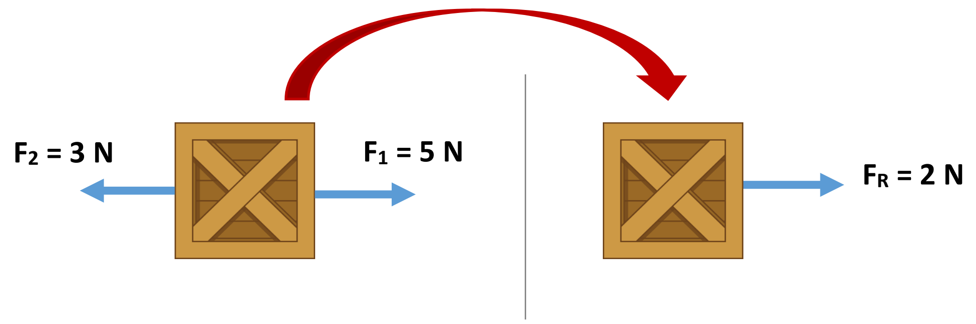


Resultant force, F_R $= F_1 + F_2$

$= 5 + 3$

$= 8$ N

ii) Forces act in opposite direction

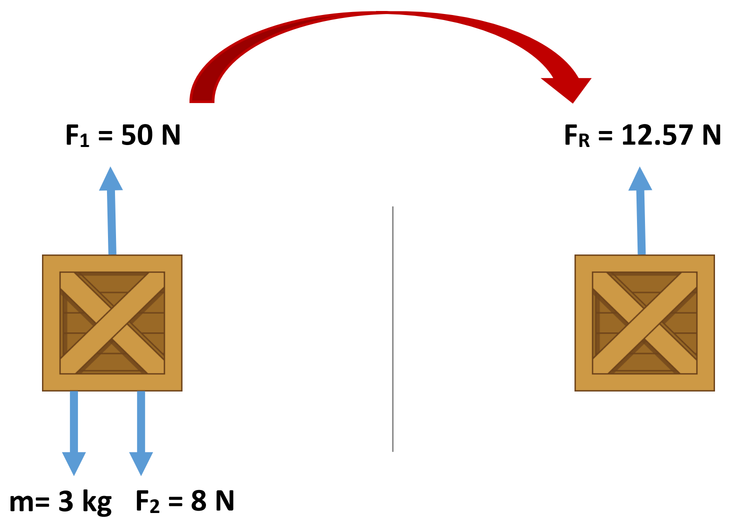


Resultant force, $F_R = F_1 - F_2$

$= 5 - 3$

$= 2$ N

iii) Forces act at a same direction (y-axis)



Weight, w = mg

= 3 kg x 9.81

= 29.43 N

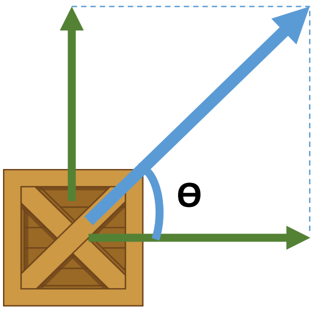
Resultant force, F_R = F1 - (Weight + F_2)

= 50 - (29.43 + 8)

= 12.57 N

iv) Two Perpendicular Forces

For two perpendiculars forces acting on an object, the resultant force is obtained using **Pythagoras Theorem.**



Resultant force, F_R $= \sqrt{F_1{}^2 + F_2{}^2}$

$= \sqrt{4^2 + 3^2}$

$= \sqrt{25}$

= 5 N

5.2 Resolution Force

When two forces combined together will form a single resultant force. On the other hand, a single force can be divided into two components. The reversal of this process is called the resolution of forces. Resolution of forces is a single force with an angle, θ that can be resolved into two components. There is horizontal component, F_x and vertical component, F_y.

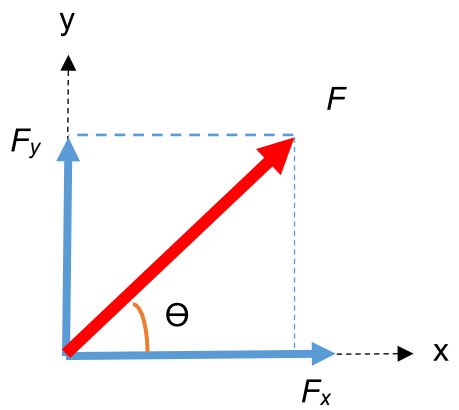


Figure 5.1: Force divided into x-axis and y-axis

A force is usually resolved into two components that are perpendicular to each other. A force can be resolved into two component forces graphically or by using trigonometry.

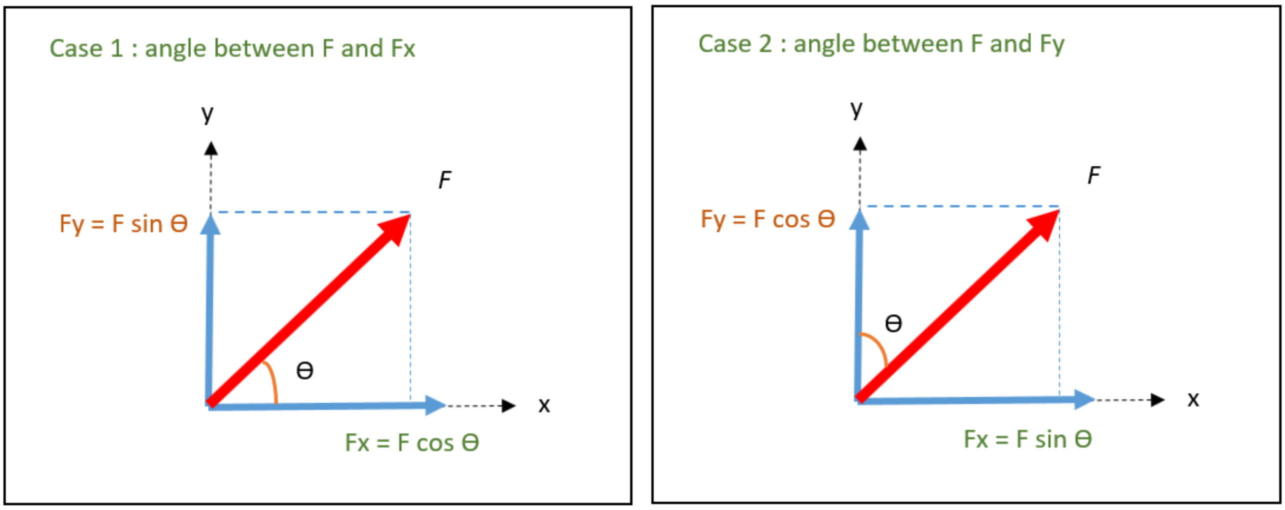
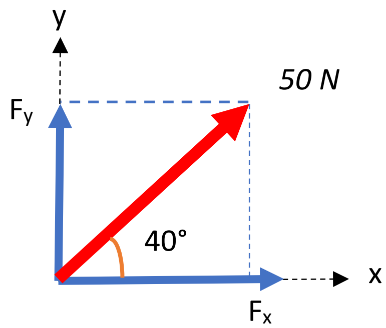


Figure 5.2: Different cases due to ϴ location

Example 3

Find the horizontal and vertical components for each of the following forces given.

a)



The horizontal component: Fx = **F cos Ө**

= 50 N cos 40°

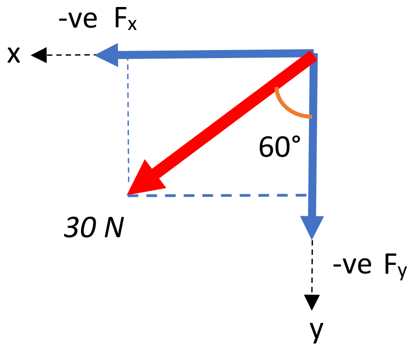
= 38.30 N

The vertical component: Fy = **F sin Ө**

= 50 N sin 40°

= 32.14 N

b)



The horizontal component: Fx = **F sin Ө**

= 30 N sin 60°

= -25.98 N

The vertical component: Fy = **F cos Ө**

= 30 N cos 60°

= - 15.00 N

5.3 Concept of Force

To apply the concept of force in solving problem related to equilibrium we need to understand a very basic concept when dealing with it. In general, an object can be acted on by several forces at the same time. A force is a vector quantity which means that it has both a magnitude (size) and a direction. If the size and direction of the forces acting on an object are exactly balanced, then there is no net force acting on the object and the object is said to be in equilibrium.

Example 4

The diagram below shows forces acting on an object. Calculate the resultant force of object in Newton.

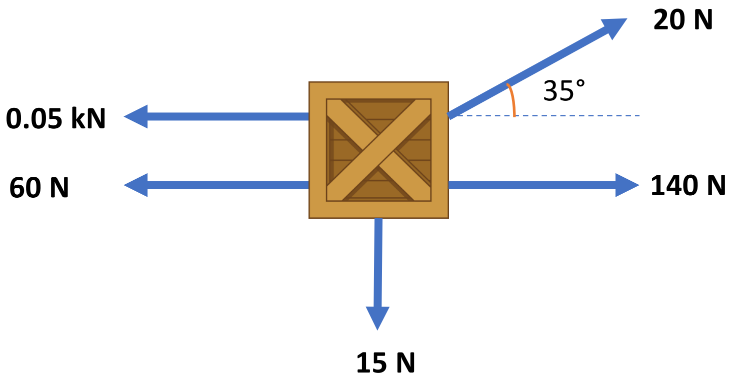


Figure 5.3: Resultant Force of Object

Solution:

x-axis: $F_x = (140 + 20\cos 35°) - (0.05 \times 10^3 + 60)$

$= 156.38 - 110$

$= 46.38\ \text{N}$

y-axis: $F_y = 20\sin 35° - 15$

$= -3.53\ \text{N}$

Resultant Force, $F_R = \sqrt{F_x^{\,2} + F_y^{\,2}}$

$= \sqrt{46.38^2 + (-3.53^2)}$

$= 46.51\ \text{N}$

5.4 Calculation of Resultant Force Using Resolution Method

Several forces can act on a body or point, each force having different direction and magnitude. In engineering the focus is on the resultant force acting on the body. When two or more forces are acting on a body, then the total of all the forces which causes the resulting effect is the resultant force or net force.

Resultant Force, $F_R = \sqrt{F_x{}^2 + F_y{}^2}$

Direction of force, $\emptyset = \tan^{-1}\left[\frac{\sum F_y}{\sum F_x}\right]$

Example 5

Figure shows three forces F_1, F_2 and F_3 acting on A. Calculate the magnitude of the resultant force acting on point A.

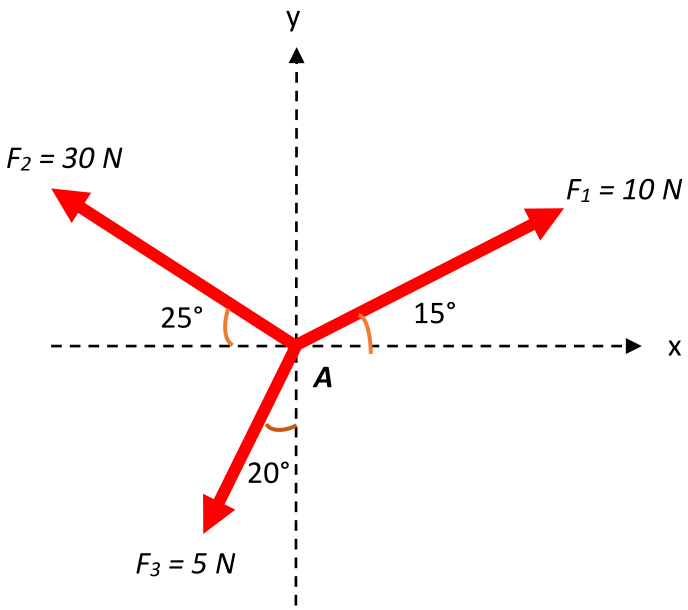


Figure 5.4: Force act on point A

Solution:

Step 1: Table of Resolution method

Force	Fx (assume $\xrightarrow{+}$)	Fy (assume $\uparrow +$)
10N	10 cos 15° = 9.66	10 sin 15° = 2.59
30N	30 cos 155° = -27.19	30 sin155° = 12.68
5N	5 cos 250° = -1.71	5 sin 250° = -4.70
Total	**∑ Fx = - 19.24 N** ←	**∑ Fy = 10.57 N** ↑

Step 2: Resultant Force

$$R = \sqrt{\sum Fx^2 + \sum Fy^2}$$

$$= \sqrt{(-19.24)^2 + (10.57)^2}$$

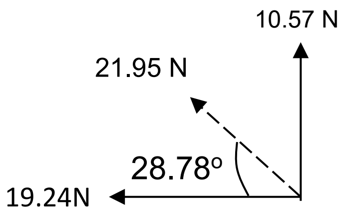
$$= 21.95\,N$$

Step 3: Direction of force

$$Ø = \tan^{-1}\left(\frac{10.57}{19.24}\right)$$

$$= 28.78°$$

Step 4: Force Diagram



Example 6

Figure shows three forces F_1, F_2 and F_3 acting on Z. Calculate the magnitude of the resultant force acting on point Z.

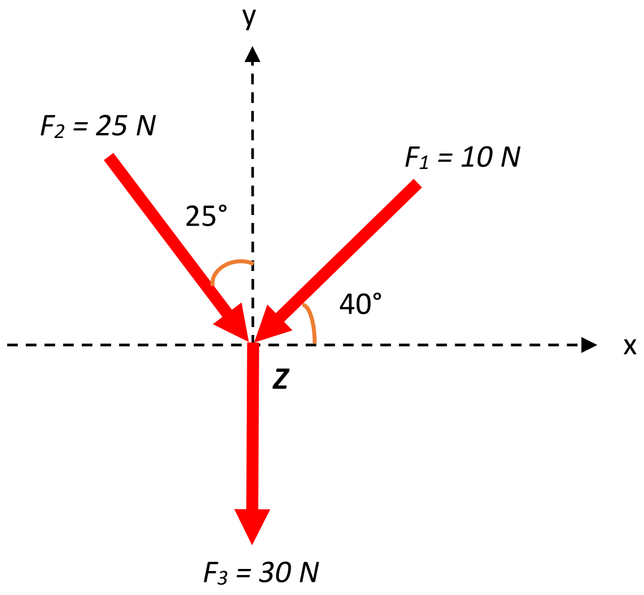
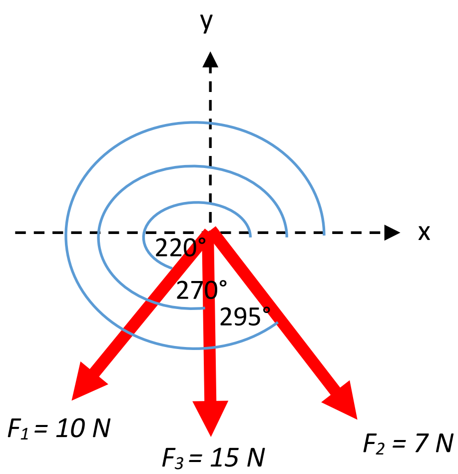


Figure 5.5: Force act on point Z

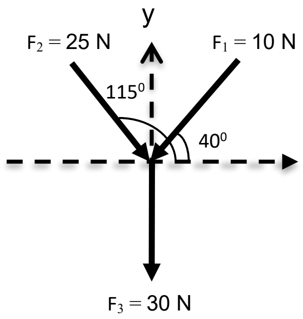
Solution:



Step 1: Table of Resolution method using 360 degree

Force	Fx (assume $\xrightarrow{+}$)	Fy (assume ↑ +)
10N	10 cos 220° = -7.66 N	10 sin 220° = -6.43 N
25N	25 cos 295° =+10.57 N	25 sin 295° = -22.66 N
30N	30 cos 270° = 0 N	30 sin 270 ° = -30 N
Total	**∑ Fx = 2.91 N** →	**∑ Fy = - 59.09 N** ↓

OR another method



Force	Fx (assume $\xrightarrow{+}$)	Fy (assume) ↑
-10N	-10 cos 40° = -7.66 N	- 10 sin 40° = -6.43 N
-25N	- 25 cos 115° = +10.57 N	- 25 sin 115° = -22.66 N
30N	30 cos 270° = 0 N	30 sin 270 ° = -30 N
Total	**∑ Fx = 2.91N** →	**∑ Fy = - 59.09 N** ↓

Step 2: Resultant Force

$$F_R = \sqrt{\sum Fx^2 + \sum Fy^2}$$
$$= \sqrt{(2.91)^2 + (-59.09)^2}$$
$$= 59.16\ \text{N}$$

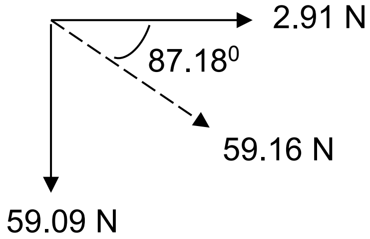
Step 3: Direction of force

$$\theta = \tan^{-1}\left(\frac{\sum fy}{\sum fx}\right)$$

$$\theta = \tan^{-1}\left(\frac{59.09}{2.91}\right)$$

θ = 87.18°

Step 4: Force Diagram



6.0 MOMENT OF FORCE CONCEPT

6.1 Introduction to Moment of Force

The Moment of a force is a measure of its tendency to cause a body to rotate about a specific point or axis. (Shaeffer, 2007). SI Unit of Moment is Newton metre (Nm).

In order for a moment to develop, the force must act upon the body in such a manner that the body would begin to twist. This occurs every time a force is applied so that it does not pass through the centroid of the body.

The magnitude of the moment of force acting about a point is directly proportional to the magnitude of the acting force and to the distance of this point from the vector line of the force that produces the moment. The distance between the vector line of the force and a selected point is called moment arm.

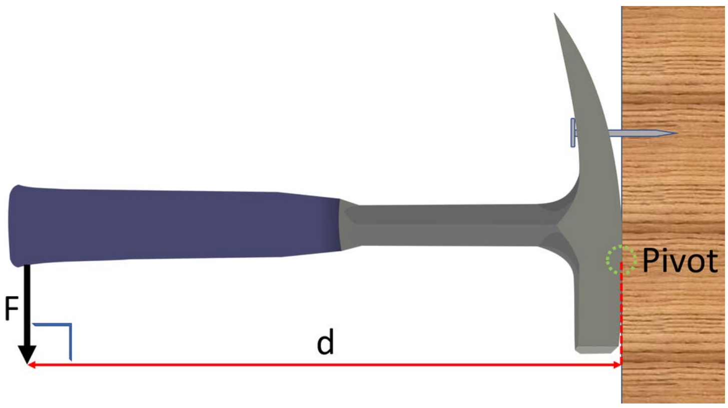


Figure 6.1: A hammer is used to pull out a nail from a wall

Base on Figure 6.1, a hammer is used to pull out a nail from a wall. A ***F*** of force is applied at a perpendicular distance of ***d*** from the pivot. To calculate moment caused by the force use this formula:

Moment,M = Force, F x Distance,d or M = (F)(d)

The ability of a force to make an object turn depends on TWO factors:

a. The size of the force that acts at right-angles to a line through the turning point of the object you wish to turn.

b. The perpendicular distance the force is applied from the turning point.

Example 7

a) Find the moment of force at A experienced by the beam of length 3 m as shown in Figure 6.2 .

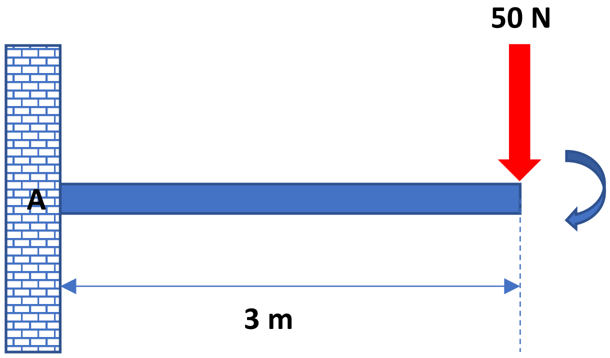


Figure 6.2: A point load acting on beam

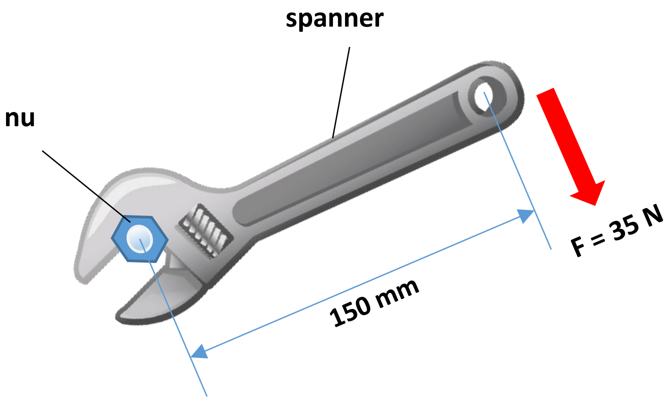
Solution:

Moment = Force x distance

= 50 N x 3.0 m

= 150 Nm (Rotate Clockwise)

b) Calculate the spanner's turning effect in newton meters if the effort is 35 N.



Solution:

d = 150 mm = 0.15 m

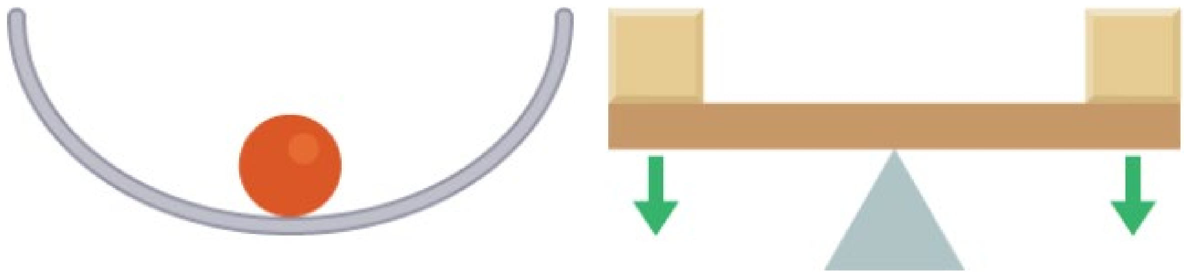
Moment = Force x distance

= 35 N x 0.15 m

= 5.25 Nm (Rotate Clockwise)

6.2 Principle of Moment of Force

The Principle of Moments states that when a body is balanced, the total clockwise moment about a point is equals to the total anticlockwise moment about the same point. (Bitesize, 2021) . When a force is applied to a body it will produce a tendency for the body to rotate about a point that is not on the line of action of the force. This tendency to rotate is sometimes called a torque, but most often it is called the moment of a. Below is the example of balanced objects where there is no rotation.



(a) a ball at the bottom of a trough (b) a balanced see-saw

Figure 6.3: The diagrams show two examples of balanced objects where there is no rotation.

An object in equilibrium will not turn or accelerate. For a balanced object, we can calculate:

a. the size of a force, or
b. the perpendicular distance of a force from the pivot

Quick Reference

Object is balanced:

Total of anticlockwise moment =Total of clockwise moment

6.3 Application of Moment of Force Concept

The center of gravity of an object is sometimes described as its balance point or that point about which an object would balance without a tendency to rotate. For this reason, the center of gravity is often identified as the point where all the weight of the object is concentrated. More accurately, it is the point where the weight of the object may be said to act.

The ability to locate the center of gravity of an object is based on the knowledge of what it takes for a system to be balanced, or in equilibrium. Two conditions must be met:

- ✓ All the linear forces acting on the body must be balanced.
- ✓ All the rotary forces (torques) must be balanced.

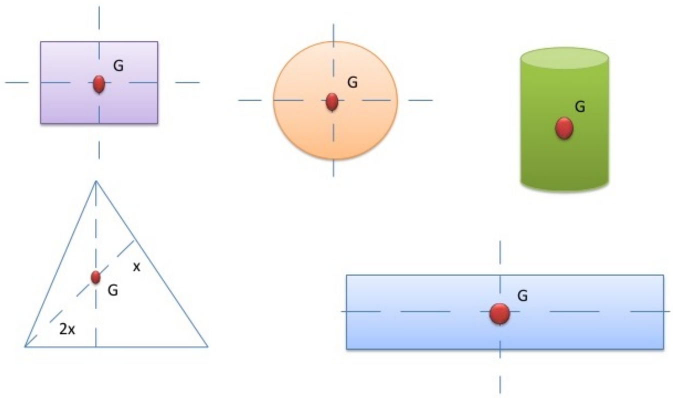


Figure 6.4: Centre of gravity of common shapes

Another way of expressing these necessary conditions for equilibrium is to say that the sum of all the forces acting on the body must equal zero. If there is a downward-directed linear force, there must be an equal upward force so that the vector sum of these forces equals zero. If there is a negative clockwise torque, it must be canceled out by a positive counterclockwise torque of equal magnitude.

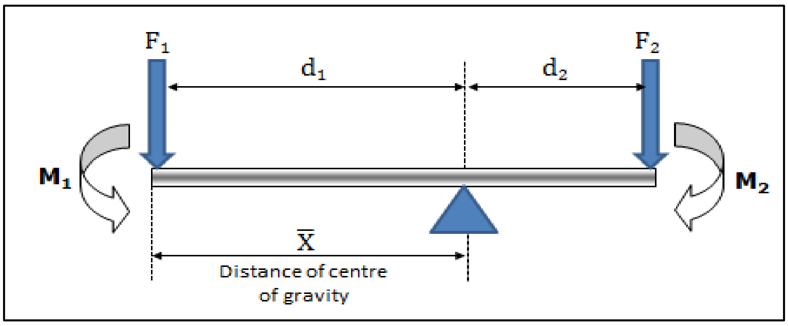
Based on these concept, There are two methods to find center of gravity, $\bar{X}$ for forces to ensure bar on the horizontal balance or in equilibrium.

i) Force Moment Method

ii) Resultant Moment Method

6.4 Force Moment Method

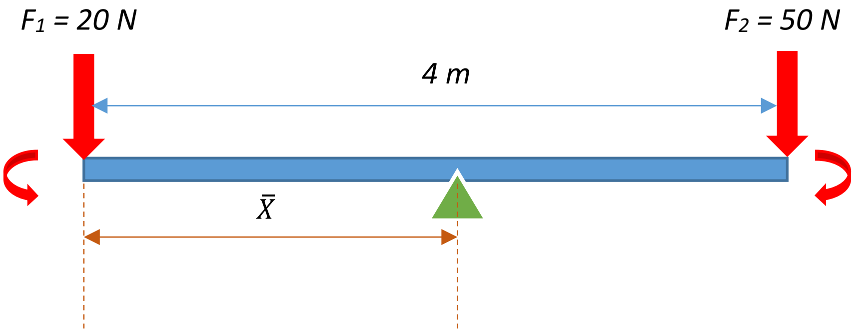
Force Moment Method are using the total moment in anticlockwise is equal to the total moment of clockwise as concept in the calculation. **[$\sum M_1 = \sum M_2$]**



Notes:
F = force
d=distance
$\bar{X}$ =centre of gravity
M= Fd

Example 8

Determine the center of gravity, $\bar{X}$ for two forces to ensure bar on the horizontal balance with using Force Moment Method.



Solution:

$$\sum M1 = \sum M2$$

$$F_1 d_1 = F_2 d_2$$

$$20 (\bar{X}) = 50 (4 - \bar{X})$$

$$20 (\bar{X}) = 200 - 50 \bar{X}$$

$$20\bar{X} + 50\bar{X} = 200$$

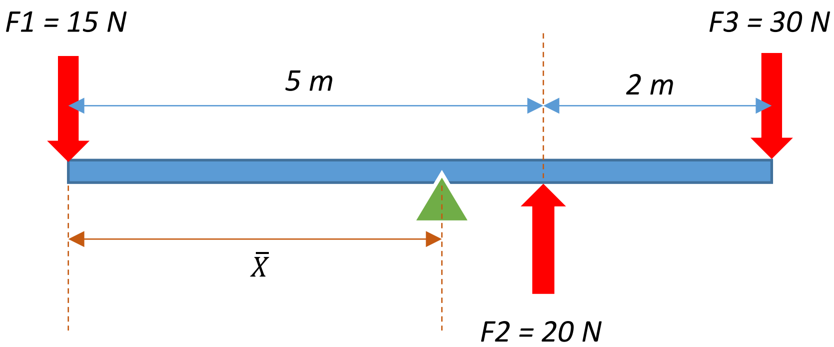
$$70\bar{X} = 200$$

$$\bar{X} = 2.86 \text{ m}$$

The distance of center of gravity from A is **2.86** m

Example 9

Determine the center of gravity, $\bar{X}$ for three forces to ensure bar on the horizontal balance with using Force Moment Method.



Solution:

$$\sum M1 = \sum M2$$

$$15\ (\bar{X}) = -20\ (5 - \bar{X}) + 30\ (7 - \bar{X})$$

$$15\ \bar{X} = -100 + 20\ \bar{X} + 210 - 30\ \bar{X}$$

$$15\ \bar{X} = 110 - 10\ \bar{X}$$

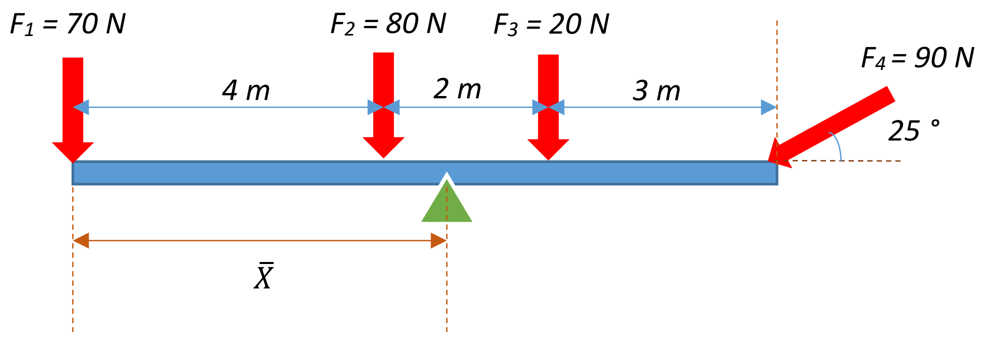
$$25\ \bar{X} = 110$$

$$\bar{X} = 4.40 \text{ m}$$

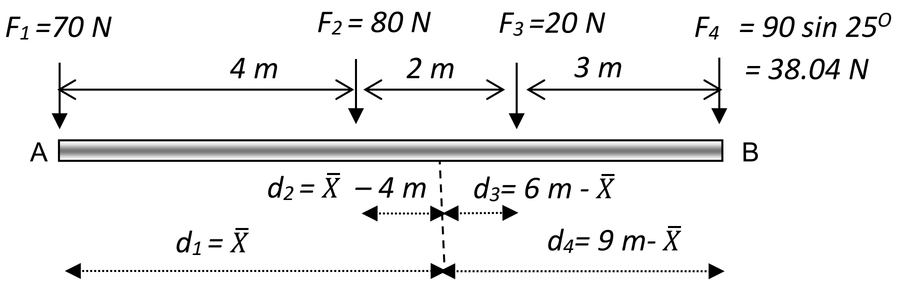
The distance of center of gravity from A is **4.40** m

Example 10

Determine the center of gravity,X for four forces to ensure bar on the horizontal balance with using Force Moment Method.



Solution:



$$M_1 = M_2$$

$$F_1d_1 + F_2d_2 = F_3d_3 + F_4d_4$$

$$70\,(\bar{X}) + 80\,(\bar{X}\text{-}4) = 20\,(6\text{-}\bar{X}) + 38.04\,(9\text{-}\bar{X})$$

$$70\,\bar{X} + 80\,\bar{X} - 320 = 120 - 20\,\bar{X} + 342.36 - 38.04\,\bar{X}$$

$$70\,\bar{X} + 80\,\bar{X} + 20\,\bar{X} + 38.04\,\bar{X} = 120 + 342.36 + 320$$

$$208.04\,\bar{X} = 782.36$$

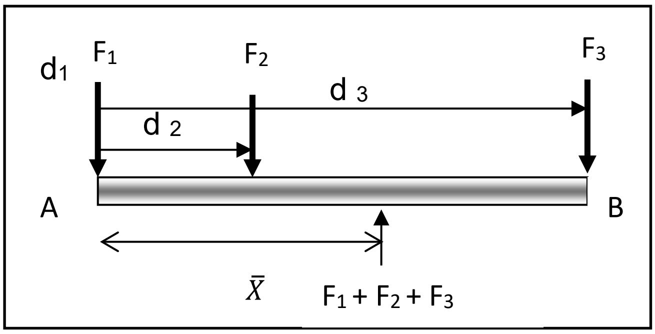
$$\bar{X} = 782.36/\,208.04$$

$$\bar{X} = 3.76 \text{ m}$$

The distance of center of gravity from A is **3.76** m

6.5 Resultant Moment Method

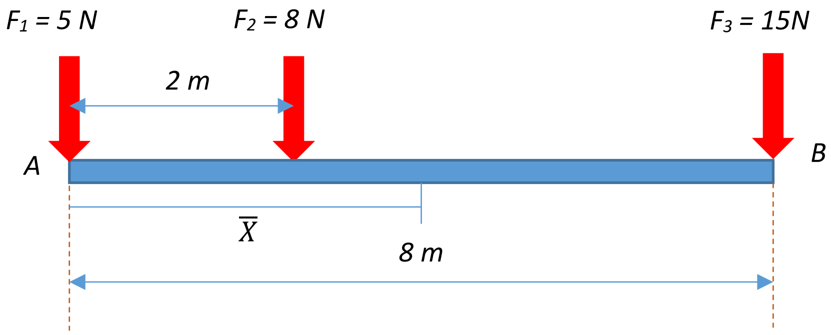
Resultant Moment Method are using total moment of force divided to total of force.



Step:
1) Assume the location of $\bar{X}$ from A
2) Use the formula to find $\bar{X}$

Example 11

Determine the center of gravity, $\bar{X}$ for three forces to ensure bar on the horizontal in balance by using Resultant Moment Method.



Solution:

Take **A** as a point for all distance of the force.

F_1 = 5N, d_1 = 0 m F_2 = 8N, d_2 = 2 m F_3 = 15N, d_3 = 8 m

$$\mathbf{x} = \frac{\mathbf{F_1 d_1 + F_2 d_2 + F_3 d_3}}{\mathbf{F_1 + F_2 + F_3}}$$

$$= \frac{5\text{ N }(0) + 8\text{ N }(2\text{m}) + 15\text{ N }(8\text{m})}{5\text{ N} + 8\text{ N} + 15\text{N}}$$

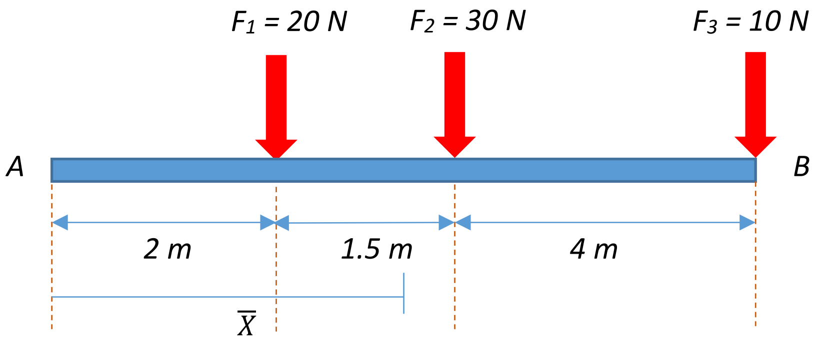
$$= \frac{136}{28}$$

$$\bar{X} = 4.86\text{ m}$$

The distance of center of gravity from A is 4.86 m

Example 12

Based on figure below, calculate the center of gravity, $\bar{X}$ by using Resultant Moment of Force Method.



Solution:

Take **A** as a point for all distance of the force.

F_1 = 20N $\quad$ d_1 = 2 m

F_2 = 35N $\quad$ d_2 = 3.5 m

F_3 = 10N $\quad$ d_3 = 7.5 m

$$\bar{x} = \frac{F_1 d_1 + F_2 d_2 + F_3 d_3}{F_1 + F_2 + F_3}$$

$$= \frac{20\text{ N }(2) + 35\text{ N }(3.5\text{m}) + 10\text{ N }(7.5\text{m})}{20\text{ N} + 35\text{ N} + 10\text{ N}}$$

$$= \frac{237.5\text{ Nm}}{65\text{ N}}$$

$\bar{X}$ = 3.65 m

The distance of center of gravity from A is 3.65 m

7.0 PRACTICE

ANSWER ALL QUESTION

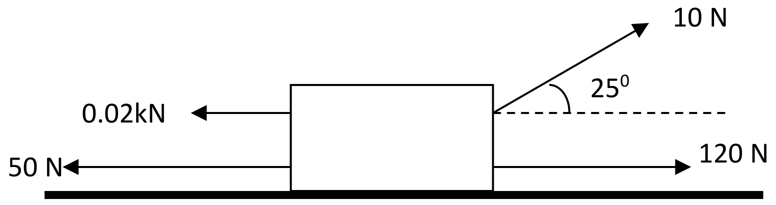
1. Give **definition** and **SI unit** of force.

2. Give the **TWO (2**) examples situation when applied a force.

3. Give **THREE (3**) effects of force.

4. State **THREE (3)** differences between weight and mass.

5. The diagram below shows forces acting on an object. Calculate the resultant force of object and give direction of object either to the right or to the left.

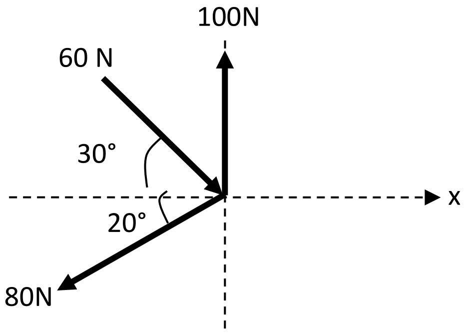


ANSWER: F_R = 59.06 N

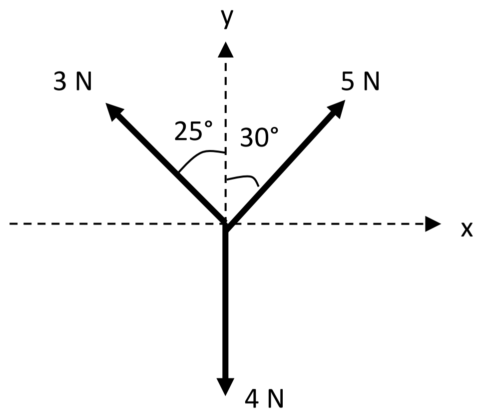
Direction: move to the right →

6. Calculate the magnitude and direction of resultant force.

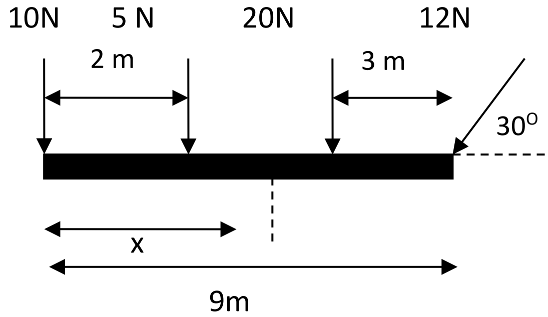
a)



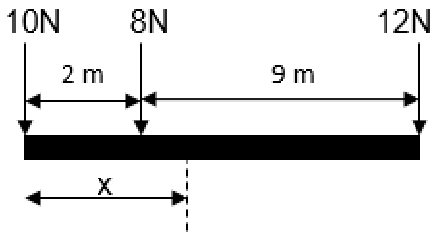
b)



7. Find the center of the figure below so that it is in equilibrium.

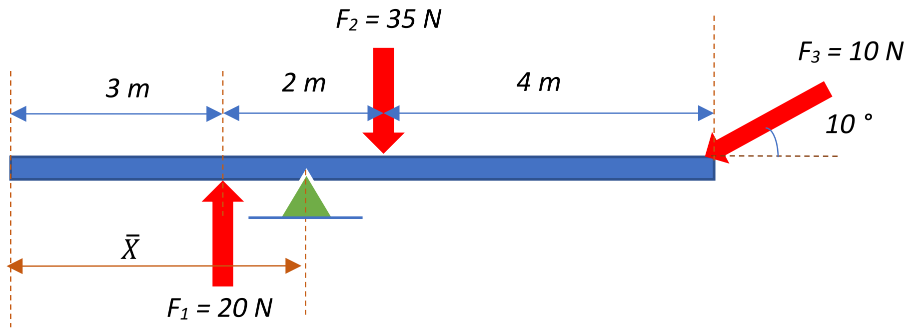
a) 

ANSWER: x = 4.49 m

b) 

ANSWER: x = 4.93 m

8. Find the center of the figure below so that it is in equilibrium by using Force Moment Method and Resultant Moment Method.



Solution:

Force Moment Method

Resultant Moment Method

ANSWER : x = 7.81 m

QUESTION BANK

Answer All The Question

1.

a. Based on Figure 1 (a), determine the magnitude and direction of resultant force from the system below by using the resolution of method.

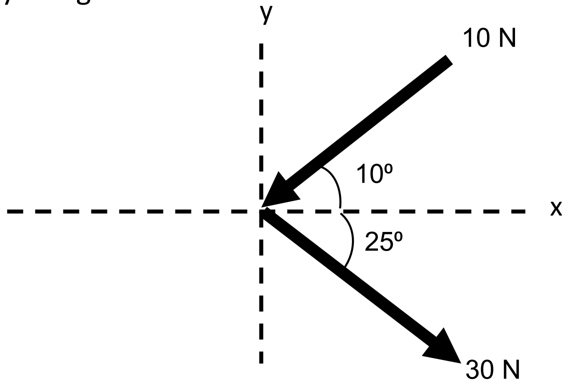


Figure 1 (a)

b. Figure 1 (b) below shows three forces acting on a beam. By assuming the beam is in equilibrium, find the center of gravity $\bar{x}$ by using resultant moment method.

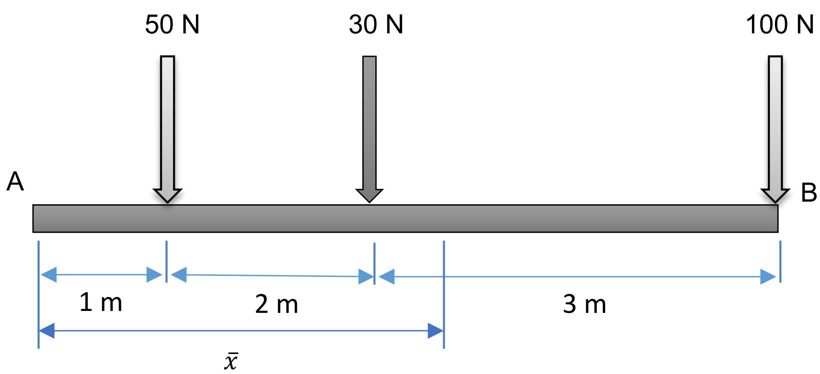


Figure 1 (b)

2. Figure 2 below shows three forces acting on a car. Calculate the resultant force acting on the car.

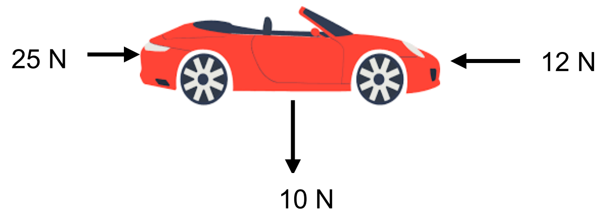


Figure 2

3. Determine the center of gravity, $\bar{x}$ for the forces given by using Force Moment method. Assume the beam is in equilibrium as shown in Figure 3.

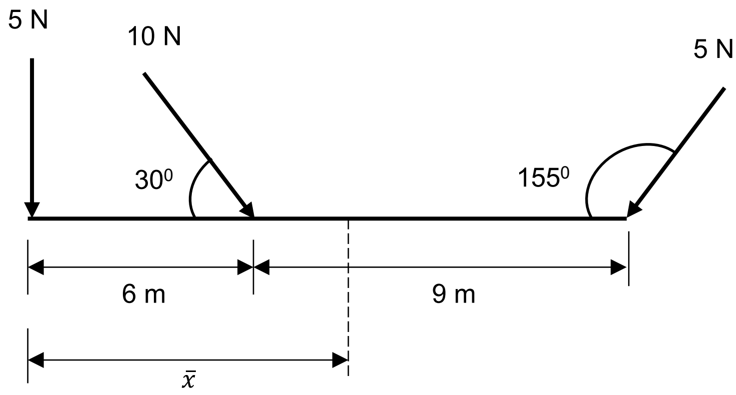


Figure 3

4. Figure 4 shows three forces F_1, F_2 and F_3 acting on an object. Calculate the magnitude and direction of the resultant force by using the resolution of method.

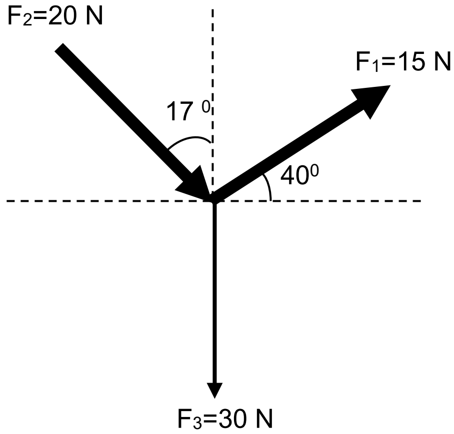


Figure 4

5. Calculate the centre of gravity, $\bar{x}$ from A to B for the beam in Figure 5 so that the beam remains in equilibrium by using force moment method.

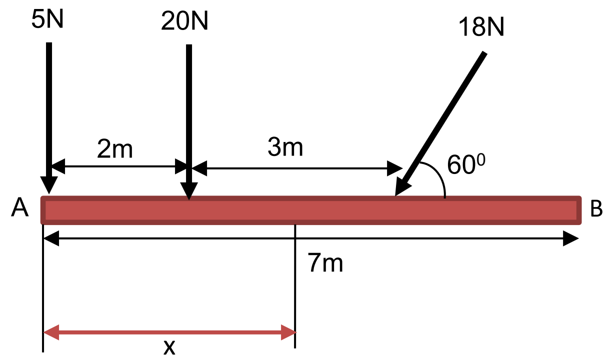


Figure 5

6. Determine the magnitude and direction of resultant force produced from the system of forces below by using the resolution method in Figure 6.

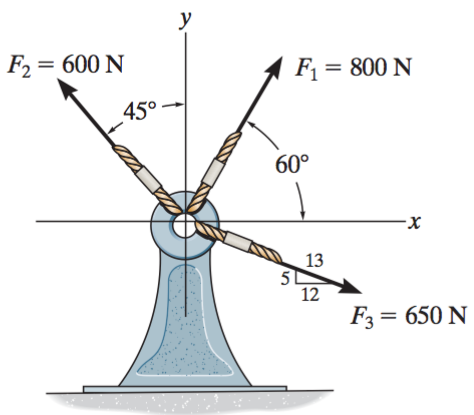


Figure 6

7. Based on Figure 7 below, determine the centre gravity the beam must be supported from A so it will remain in equilibrium.

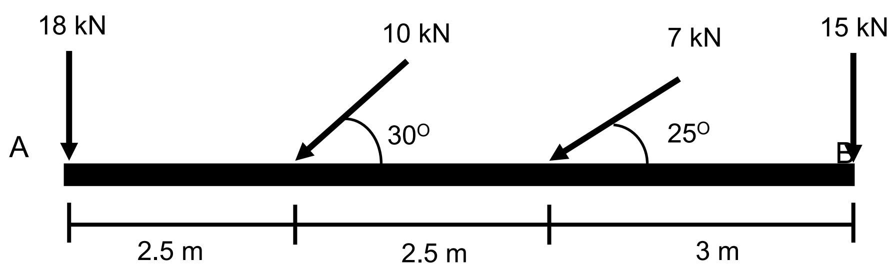


Figure 7

8. Determine the magnitude and direction of resultant force produced from the system of forces by using resolution method in Figure 8.

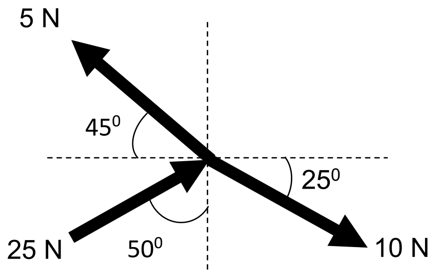


Figure 8

9. Determine the magnitude and direction of resultant force from the system of force below by using the resolution of method in Figure 9.

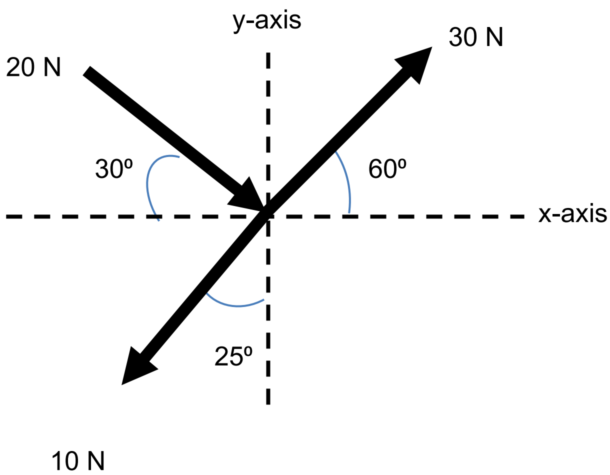


Figure 9

10. Determine the magnitude and direction of resultant force from the system of forces below by using the resolution of method in figure below:

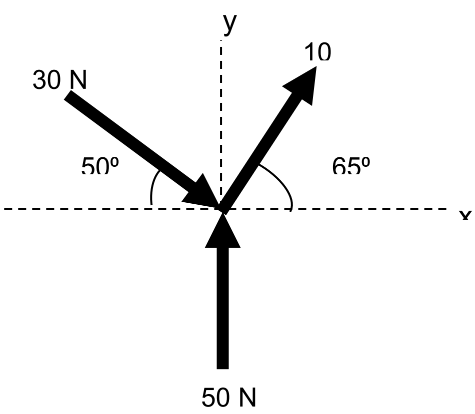


Figure 10

11. Figure 5.0 shows the beam in equilibrium. If the length of beam is 5 m. Find the center of gravity, ***x*** by using 'Force Moment Method'.

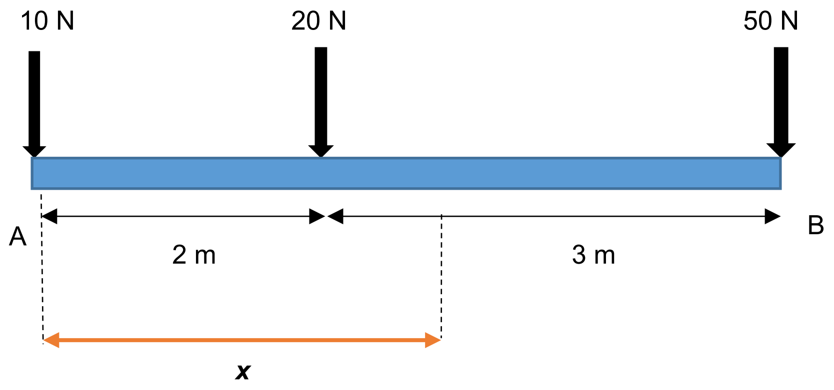


Figure 11

12. Calculate the reaction force at point A and B in Figure 12 (a) below.

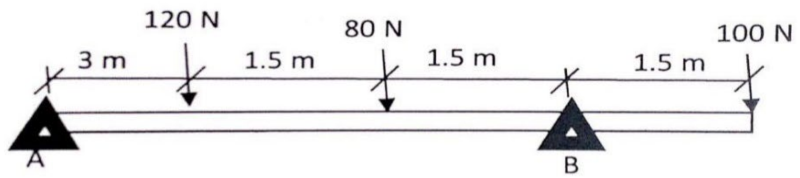


Figure 12

13 A force of 100 N is applied to an object of 15kg mass on a flat surface. Find its acceleration.

14. Calculate the net force on the x –axis and y –axis of an object in Figure 14.

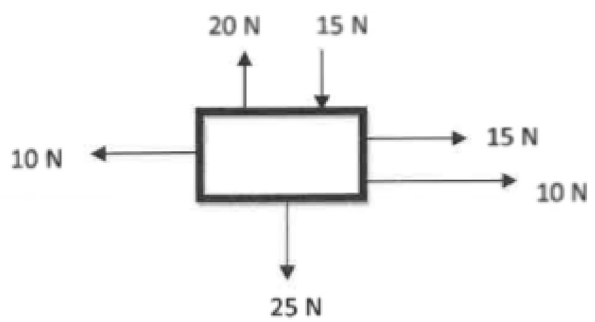


Figure 14

15. Calculate the resultant force and determine its direction for Figure 15.

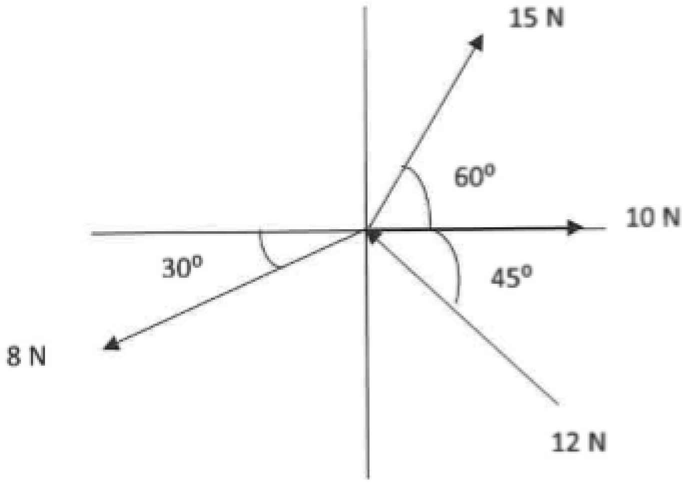


Figure 15

16. Figure 16 shows a loaded. Find the distance of x from point A to keep beam in equilibrium.

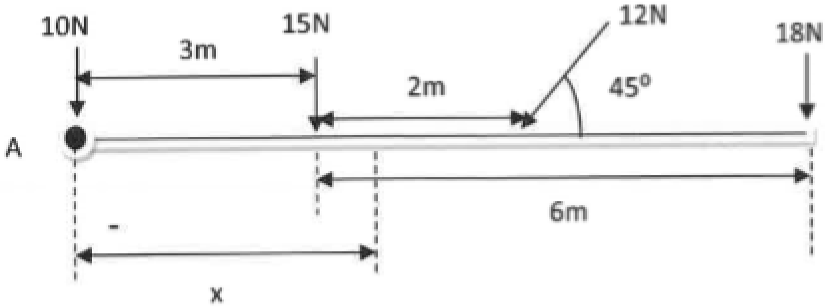


Figure 16

17. Describe Newton's Second Law.

18. Based on Figure 18, determine the value of F_1 so that the object is in equilibrium.

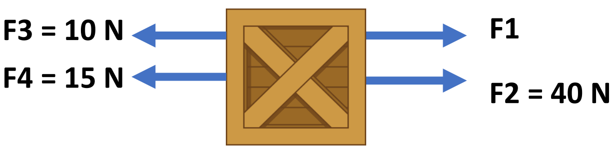


Figure 18

19. Figure 19 below shows forces acting on a block. Calculate the magnitude of resultant force acting on the block.

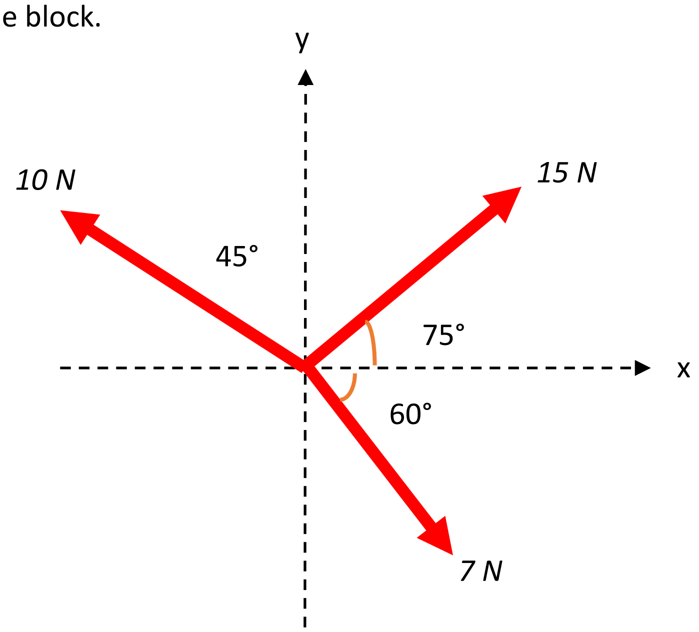


Figure 19

20. From Figure 20 below, calculate the center of gravity for the system assuming the objects is in equilibrium by using:

    a. Moment of Force Method
    b. Resultant Moment of Force Method.

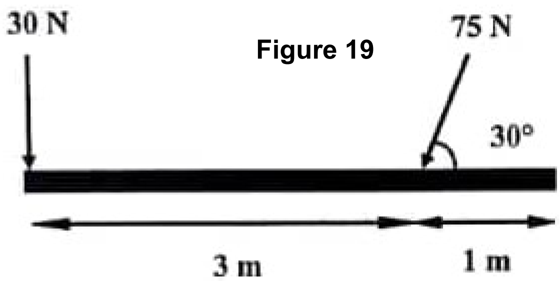


Figure 20

21. Define force and state THREE (3) effects of force to an object.

22. What is the weight of an object on earth if the weight of the object is 115 N on the moon? Given that the gravity of the earth is 9.81 ms^{-2} and the gravity of the moon is 1.6 ms^{-2}.

23. Figure 3 (a) below shows three forces acting on a block. Calculate the magnitude of resultant force acting on the block.

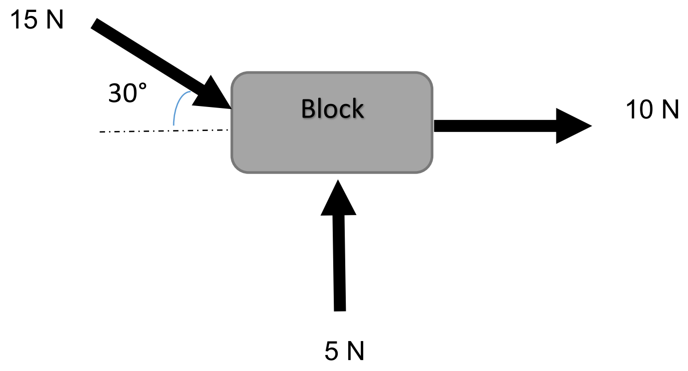


Figure 23

24. Figure 24 below shows three forces acting on a beam. Find the center of gravity from A, by assuming the beam is in equilibrium state.

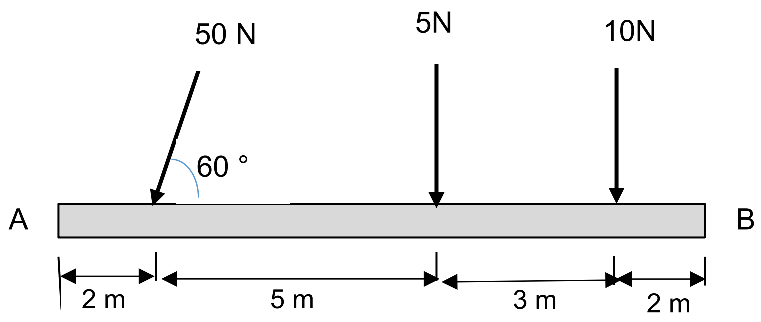


Figure 24

25. List **FOUR (4)** example of forces.

26. State **THREE (3)** differences between weight and mass.

27. The solar panel are fitted to a frame supported by a beam, as shown in the Figure 27 (a) and the forces are acted on the beam as shown in the Figure 27 (b) below. Calculate the size of reaction force, R_2 by considering the moments at R_1.

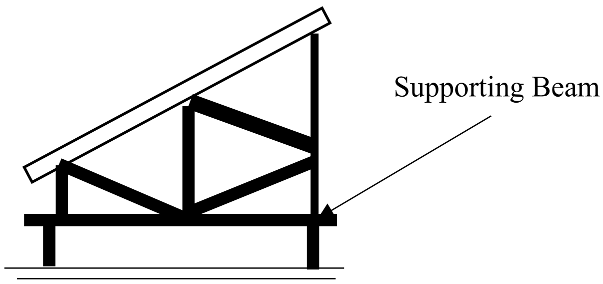


Figure 27 (a)

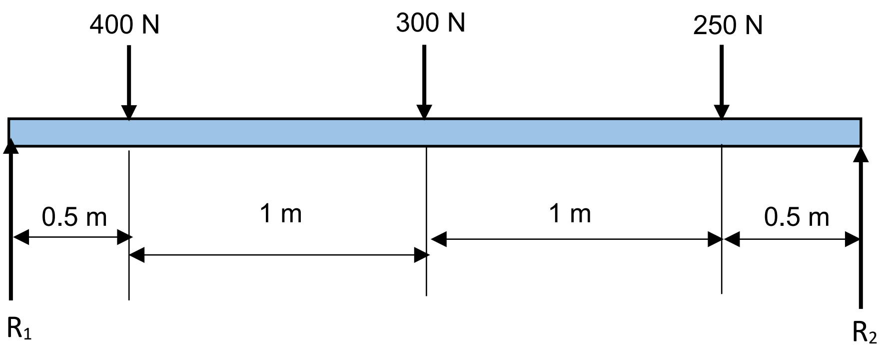


Figure 27 (b)

28. Calculate the magnitude and angle of the resultant force for Figure 28.

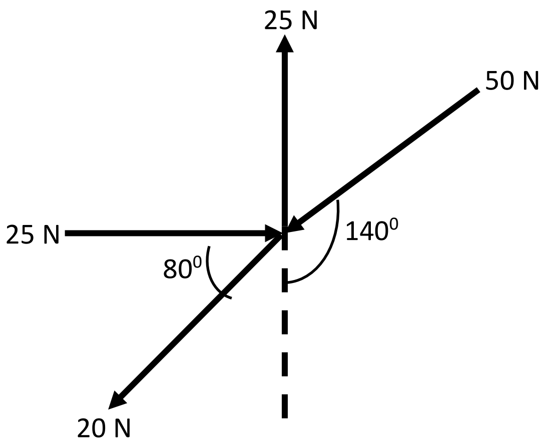


Figure 28

ANSWER BANK

1. a) Fr= 22.55 N

   $\theta = 39.74^0$

   b) x = 4.11 m

2. Fr = 16.40 N

3. x = 5.05 m

4. Fr = 43.13 N

   $\theta = 66.29^0$

5. x = 2.91 m

6. Fr = 1040.82 N

   $\Theta = 56.42^0$

7. 3.596 m

8. Fr = 29.08 N
   $\theta = 31.93°$

9. Fr = 28.93 N
   $\theta = 13.83^0$

10. Fr = 43.07 N
    $\theta = 56.91^0$

11. x = 3.625 m

12. RB = 245 N, RA = 55 N

13. 6.67 m/s^2

14. F_x net = 15 N
    F_y net= -20 N

15. FR= 17.6 N, θ = 83.210

16. 4.84 m

17. It states that when the net external force acts on an object, the acceleration of the objects is directly proportional to the net force and inversely proportional to its mass.
    F=ma

18. 35 N

19. 15.403 N

20. (a) 1.67 m
    (b) 1.67 m

21. Force can be defined as a push or a pull action.

    Effects of force to an object are

    - Change of shape
    - Change of speed
    - Change of direction

22. m = 71.875kg
    W = 705.09 N

23. Fr = 23.13 N

24. x = 3.80 m

25. - Playing football
    - Lifting Luggage
    - Pressing a switch button
    - Stretching a spring

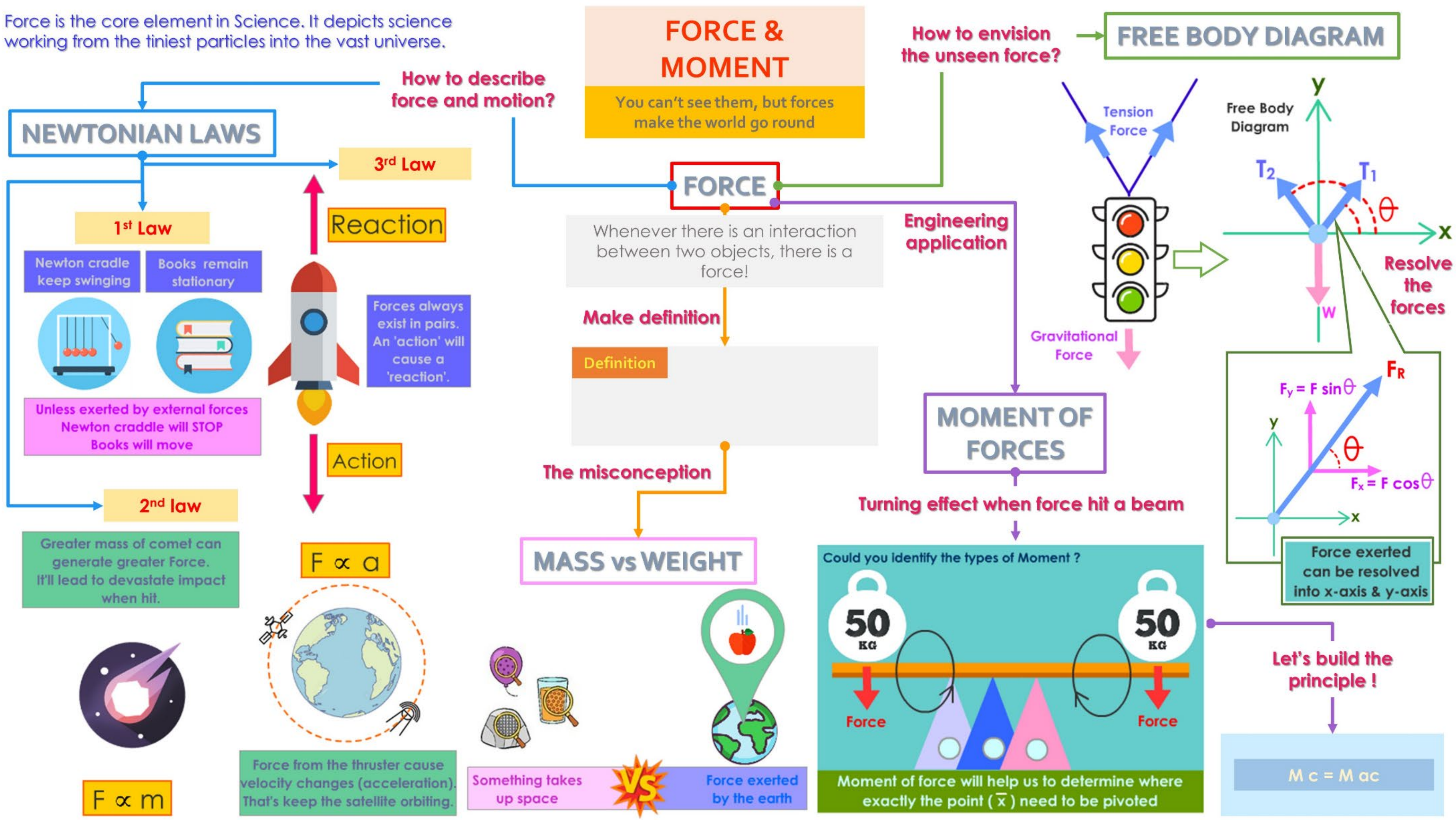
26.

Category	Weight	Mass
Definition	Mass multiply by gravity	Amount of matter in an object
SI Unit	Newton	Kilogram
Quantity	Vector Q	Scalar Q

27. FR_2 = 425 N

28. F_R = 34.66 N
    $\theta = 72.17^0$

REVIEW AND SUMMARY



References

Glenn Research, C. (8 August, 2021). *NASA's Glenn Research Center*. Retrieved from https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/newtons-laws-of-motion/

Hibbeler, R. (2002). *Engineering Mechanics Dynamics 2nd Edition.* Prentice Hall.

LiveScience. (12 August, 2021). *FORCE, MASS & ACCELERATION: NEWTON'S SECOND LAW OF MOTION*. Retrieved from https://www.livescience.com/46560-newton-second-law.html

Mainzer, K. (1996). *Symmetries of Nature: A Handbook for Philosophy of Nature and Science.* Berlin: Walter de Gruter.

Rohrlich, F. (1986). From Paradox to Reality: Our Basic Concepts of the Physical World. *Cambridge University Press*, p. 28.

PUBLISHER

Politeknik Tuanku Sultanah Bahiyah (PTSB)
Kulim Hi-Tech Park,
09090 Kulim,
Kedah

e ISBN 978-967-0855-79-0

9 7 8 9 6 7 0 8 5 5 7 9 0