

Engineering Mechanics

Faculty : Dr. Prashik Gaikwad
School of Mechanical Engineering

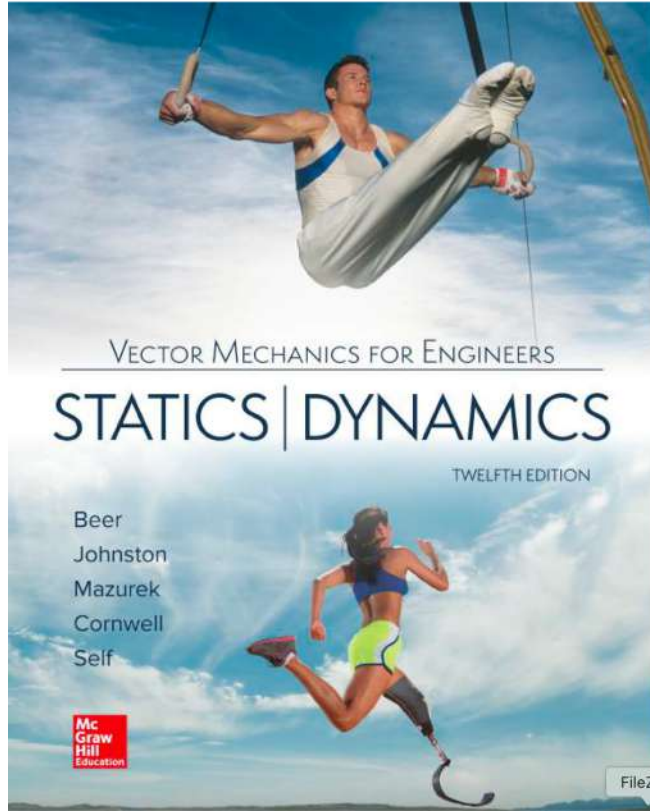
Contact details

E-mail : prashik.gaikwad@vit.ac.in

Cabin: CBMR 304-B

BMEE201L		Engineering Mechanics			L	T	P	C
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Pre-requisite	NIL	Syllabus version						
		1.0						
Course Objectives:								
1. To enable students to apply fundamental laws and basic concepts of rigid body mechanics to solve problems of bodies under rest or in motion.								
2. To enable the students to apply conditions of static equilibrium to analyse physical systems.								
3. To compute the properties of areas and bodies.								
Course Outcome:								
Upon successful completion of the course the students will be able to								
1. Compute the resultant and analyse equilibrium (without and with friction) of system of forces acting on particles and rigid bodies in plane and space.								
2. Predict the support-reactions and the internal forces of the members of trusses and frames.								
3. Apply transfer theorems to determine properties of various sections.								
4. Calculate motion parameters of particles and rigid bodies.								
Module:1 Statics of Particles					5 hours			
Fundamental concepts and principles - Resolution of a force -Resultant of forces in a plane- Equilibrium of a particle in a plane; Addition of concurrent forces in space- Equilibrium of a particle in space.								
Module:2 Statics of Rigid Bodies					7 hours			
Equivalent systems of forces- Principle of Transmissibility - Moment of a force about a point and an axis- Couples and force-couple systems- Equilibrium of rigid bodies in two and three dimensions- Types of beams, supports and reactions; Principle of virtual work – System of connected rigid bodies.								
Module:3 Analysis of Structures					5 hours			
Analysis of plane trusses - Method of joints and method of sections- Frames								
Module:4 Friction					5 hours			
The laws of dry friction – Coefficients of Friction- Angles of Friction- Types of Friction Problems - Wedges and Ladder friction- Belt friction.								
Module:5 Properties of Surfaces and Solids					7 hours			
First moments of areas and lines- Centroids of composite areas and lines- - Theorems of Pappus-Guldinus- Second moment of area- Parallel axis theorem- Rectangular and Polar Moments of inertia of composite areas- Radius of Gyration- Product of Inertia- Principal Axes and Principal Moments of Inertia- Mass moments of inertia of thin plates.								
Module:6 Dynamics of Particles					8 hours			
Kinematics of Particles: Displacement, Velocity and Acceleration – Rectilinear motion – Curvilinear motion – Tangential and Normal components – Radial and Transverse components.								
Kinetics of Particles: Newton's Second Law- Energy and Momentum Methods-Principle of Work and Energy-Principle of Impulse and Momentum- Direct Central Impact								
Module:7 Dynamics of Rigid Bodies					8 hours			
Kinematics of rigid bodies: Translation and fixed-axis rotation- General plane motion: velocity- Instantaneous centre of rotation- General plane motion: acceleration.								
Kinetics of rigid bodies:Equations of motion -Angular momentum- Plane motion of a rigid body- Principle of work and energy for rigid bodies- Principle of impulse and momentum for rigid bodies.								
Total Lecture hours:					45 hours			

Textbook for this course



Beer, Johnston, Cornwell, David Mazurek,
and Sanghi, Vector Mechanics for
Engineers: Statics and Dynamics, 12th
Edition, McGraw-Companies

Module 1

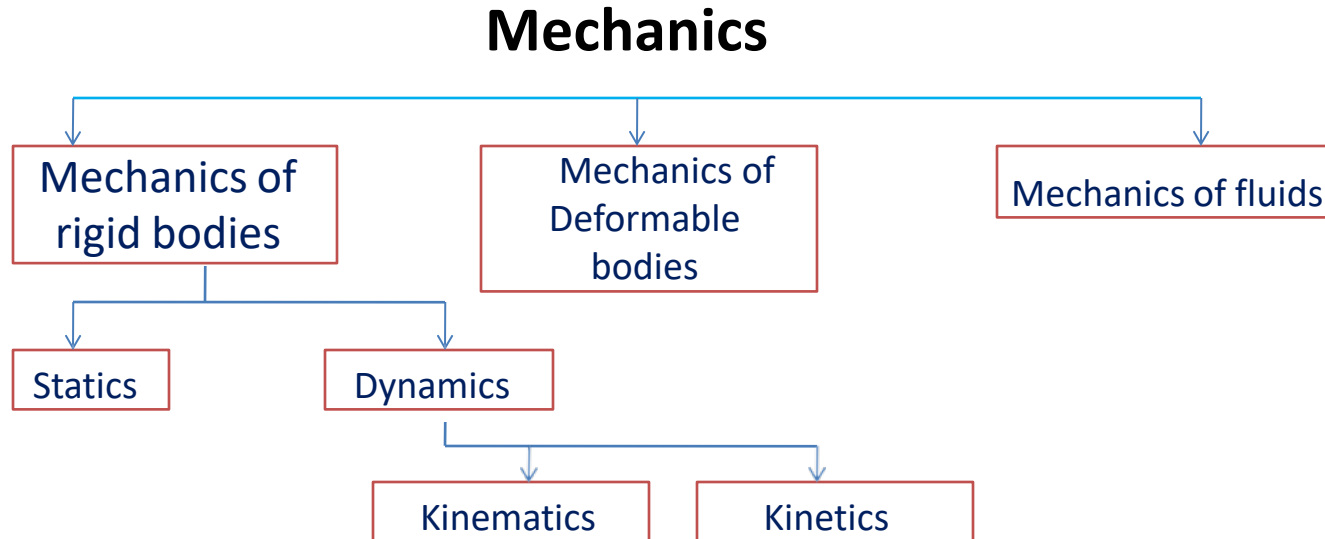
Statics of Particles

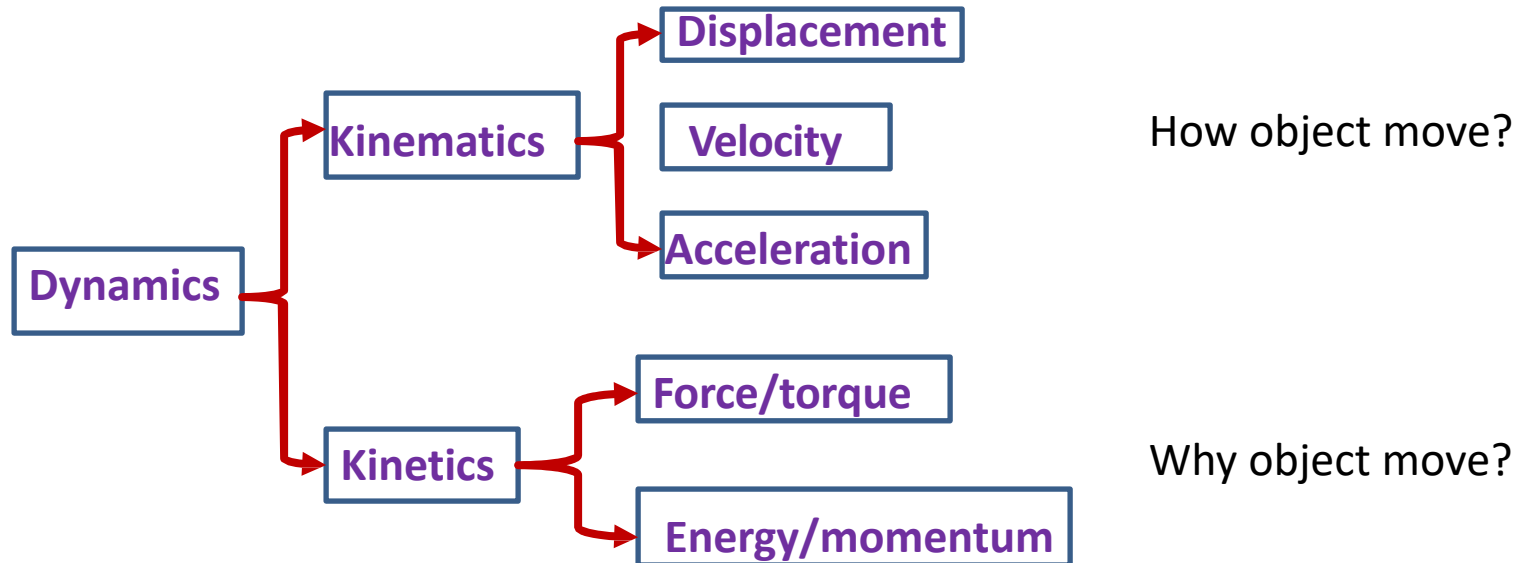
Module Overview

- Fundamental concept and principles
- Resolution of forces
- Resultant of forces in a plane
- Equilibrium of particle in a plane
- Addition of concurrent forces in a plane
- Equilibrium of particle in space

What is Mechanics?

- Science which *describes and predicts* the conditions of rest or motion of bodies under the action of forces.
- The purpose of mechanics is to explain and predict physical phenomena and thus lay the foundations for engineering applications.





Fundamental Concepts

Space

Position of a point described by 3 coordinates (x, y, z). Frame of reference is required.

Mass

A fundamental, intrinsic property representing the total amount of matter it contains

Time

Measure of succession of events. Essential in dynamics; not directly involved in statics.

Force

Action of one body on another. Characterized by: magnitude, direction (line of action), and point of application.

Newton's Laws of Motion

I

Law of Inertia

If the resultant force acting on a particle is zero, the particle will remain at rest or continue moving in a straight line with constant velocity.

II

Law of Acceleration

If the resultant force on a particle is not zero, the particle will have an acceleration proportional to the magnitude of the resultant and in the same direction.

$$F = m a$$

III

Law of Action-Reaction

The forces of action and reaction between bodies in contact are equal in magnitude, opposite in direction, and collinear.

Newton's Laws of Gravitation

This states that two particles of mass M and m are mutually attracted with equal and opposite forces $\mathbf{F}$ and $-\mathbf{F}$ of magnitude F given by the formula.

$$F = G \frac{Mm}{r^2}$$

Where r = distance between the two particles, G = universal constant called the constant of gravitation

Application: The force $\mathbf{F}$ exerted by the earth on the particle located on its surface, is defined as the *weight* $\mathbf{W}$ of the particle.

$$g = \frac{GM}{R^2} \qquad W = mg$$

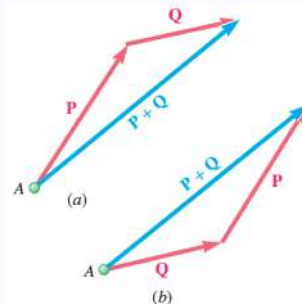
Systems of Units

Quantity	SI Unit	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Force	Newton	N
Weight	Newton	N

Vector Addition: Laws & Properties

- **Triangle Rule (Tip-to-Tail)**

- Draw first vector, then place tail of next at tip of previous
- Resultant = from tail of first to tip of last

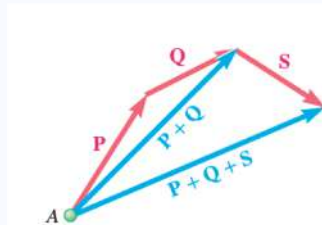


- **Commutative Law**

- $P + Q = Q + P$
- Order of addition does not matter

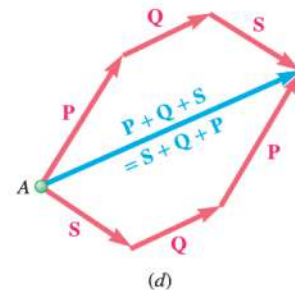
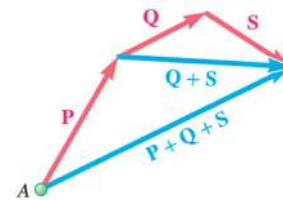
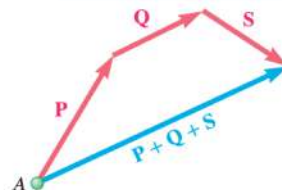
- **Associative Law**

- $(P + Q) + S = P + (Q + S)$
- Grouping does not affect the resultant



- **Polygon Rule (Multiple Forces)**

- Extends triangle rule to any number of forces
- Draw each force tip-to-tail; close the polygon with the resultant



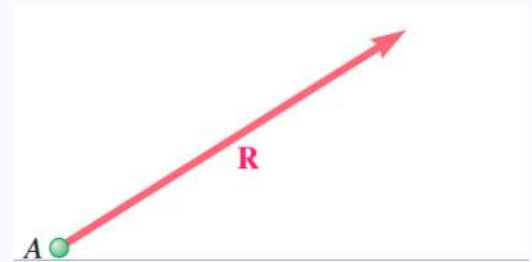
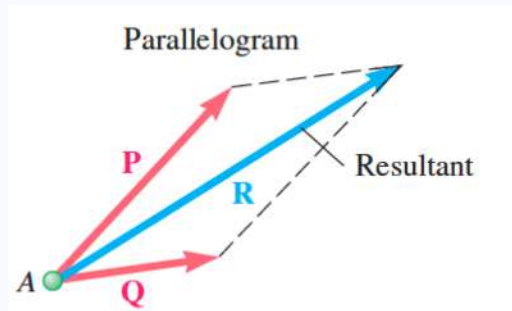
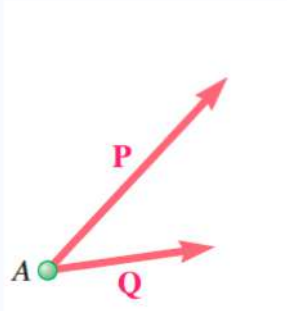
$$P + Q + S = (P + Q) + S = S + (P + Q) = S + (Q + P) = S + Q + P$$

Order of vector addition does not matter

Resultant of Two Forces

Parallelogram Law

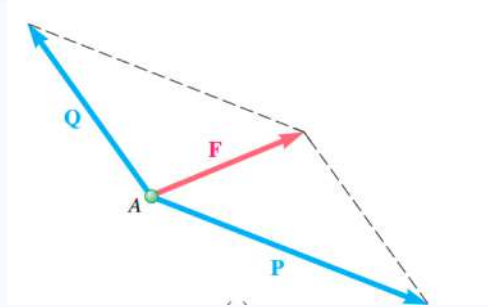
When two forces P and Q act on a particle, their resultant R is the diagonal of the parallelogram formed with P and Q as sides.



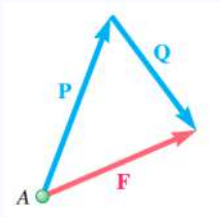
Resolution of a Force into Components

Key Idea

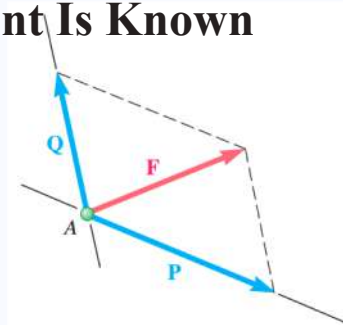
A single force F can be replaced by two (or more) component forces that have the same effect on a particle.



1. One of the Two Components, P , Is Known.

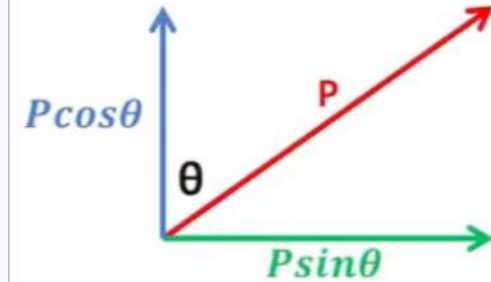
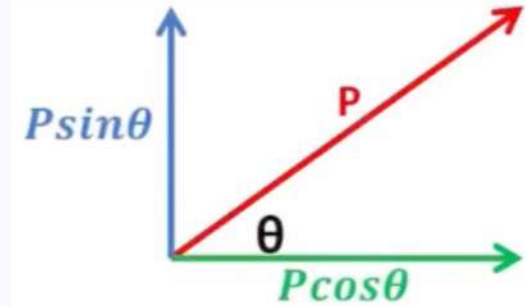


2. The Line of Action of Each Component Is Known

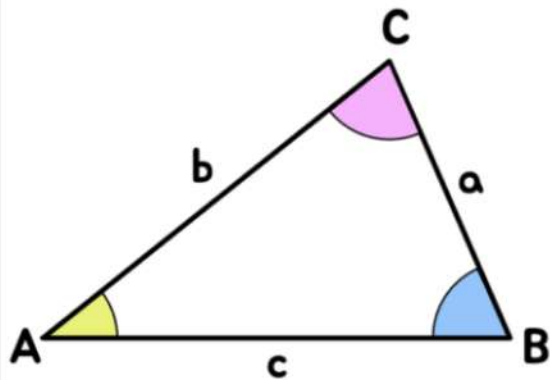


Rectangular Components of a Force

	Angle from horizontal axis	Angle from vertical axis
x-component:	$P_x = P \cos \theta$	$P_x = P \sin \theta$
y-component:	$P_y = P \sin \theta$	$P_y = P \cos \theta$
Magnitude:	$P = \sqrt{P_x^2 + P_y^2}$	$P = \sqrt{P_x^2 + P_y^2}$
Direction:	$\theta = \tan^{-1}(P_y / P_x)$	$\theta = \tan^{-1}(P_y / P_x)$



Law of sine

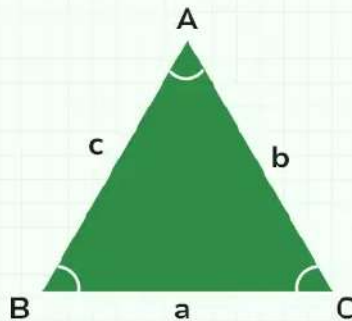


$$\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}$$

OR

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

LAW OF COSINES



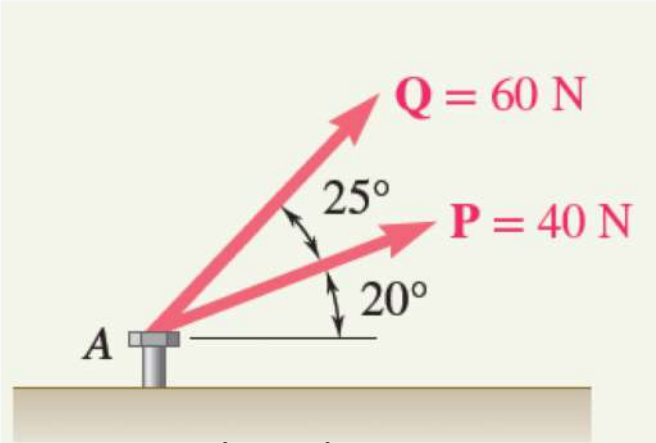
Formula:

1. $a^2 = b^2 + c^2 - 2bc \cos A$

2. $b^2 = c^2 + a^2 - 2ca \cos B$

3. $c^2 = a^2 + b^2 - 2ab \cos C$

Numerical example



Using trigonometry

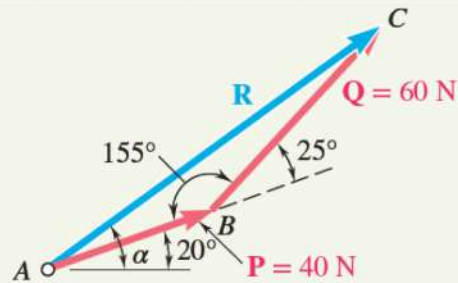
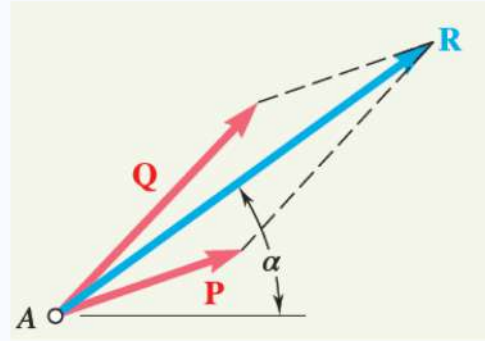


Fig. 3 Geometry of triangle rule applied to add forces P and Q .

Parallelogram law



$$R^2 = P^2 + Q^2 - 2PQ \cos B$$

$$R^2 = (40\text{ N})^2 + (60\text{ N})^2 - 2(40\text{ N})(60\text{ N}) \cos 155^\circ$$

$$R = 97.73\text{ N}$$

Now apply the law of sines:

$$\frac{\sin A}{Q} = \frac{\sin B}{R} \quad \frac{\sin A}{60\text{ N}} = \frac{\sin 155^\circ}{97.73\text{ N}}$$

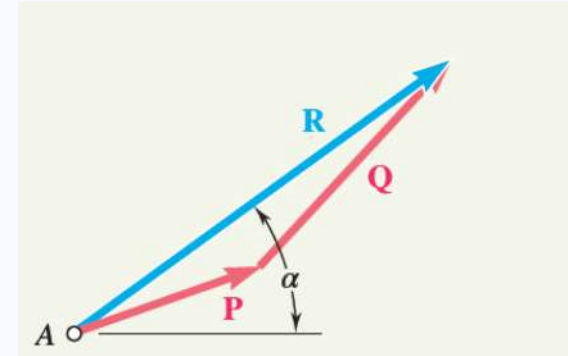
Solving Eq. (1) for $\sin A$, you obtain

$$\sin A = \frac{(60\text{ N}) \sin 155^\circ}{97.73\text{ N}}$$

Using a calculator, compute this quotient, and then obtain its arc sine:

$$A = 15.04^\circ \quad \alpha = 20^\circ + A = 35.04^\circ$$

Triangle rule

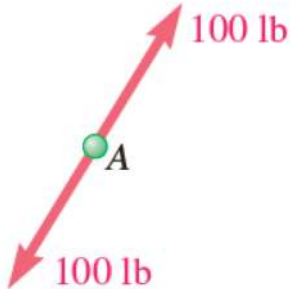


$$R = 98\text{ N}$$

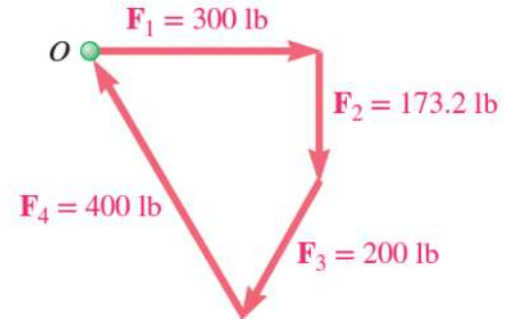
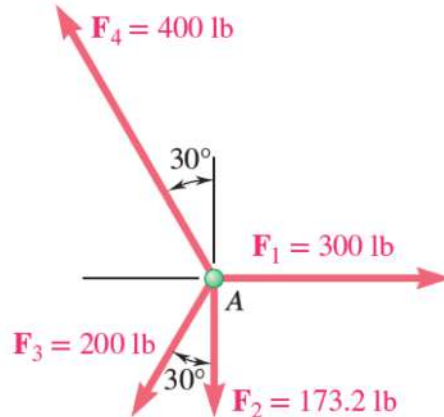
$$\alpha = 35\text{ deg}$$

Equilibrium of particle in plane

- When the resultant of all the forces acting on a particle is zero, the particle is in equilibrium.



A particle acted upon by two forces is in equilibrium if the two forces have the same magnitude and the same line of action but opposite sense.

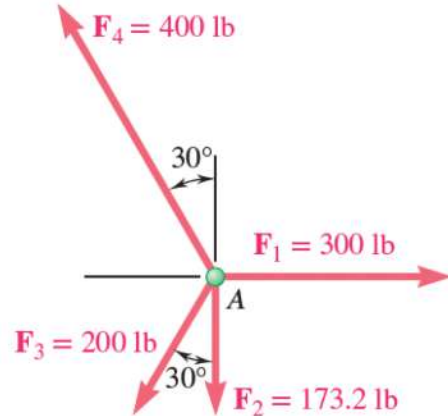


Equilibrium of particle in plane

- When the resultant of all the forces acting on a particle is zero, the particle is in equilibrium.
- $R = \Sigma F = 0$
- Resolving each force F into rectangular components, we have
 $\Sigma (F_x \mathbf{i} + F_y \mathbf{j}) = 0$ or $(\Sigma F_x) \mathbf{i} + (\Sigma F_y) \mathbf{j} = 0$
- Equilibrium of a particle (scalar equations): $\Sigma F_x = 0$ $\Sigma F_y = 0$

$$\begin{aligned}\Sigma F_x &= 300 \text{ lb} - (200 \text{ lb}) \sin 30^\circ - (400 \text{ lb}) \sin 30^\circ \\ &= 300 \text{ lb} - 100 \text{ lb} - 200 \text{ lb} = 0\end{aligned}$$

$$\begin{aligned}\Sigma F_y &= -173.2 \text{ lb} - (200 \text{ lb}) \cos 30^\circ + (400 \text{ lb}) \cos 30^\circ \\ &= -173.2 \text{ lb} - 173.2 \text{ lb} + 346.4 \text{ lb} = 0\end{aligned}$$



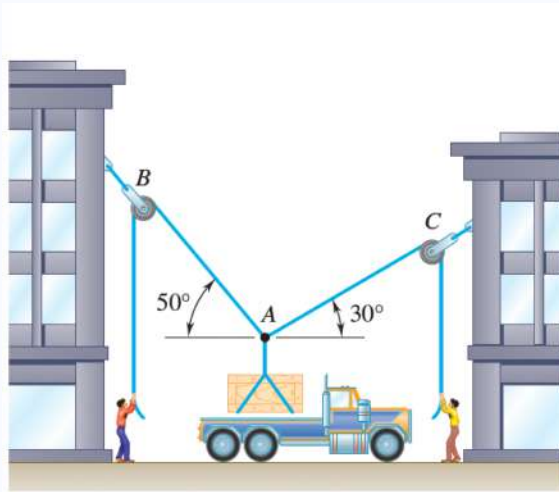
Free-Body Diagrams (FBD)

Definition

A Free-Body Diagram is a sketch showing the particle (isolated from its surroundings) with ALL forces acting on it drawn as vectors.

- 1 Decide which particle to isolate
- 2 Draw ALL external forces: applied loads, cable tensions, weight, reactions
- 3 Label each force with its known magnitude or assign an unknown variable
- 4 Add coordinate axes and a sense of positive direction

Example to solve a problem using FBD



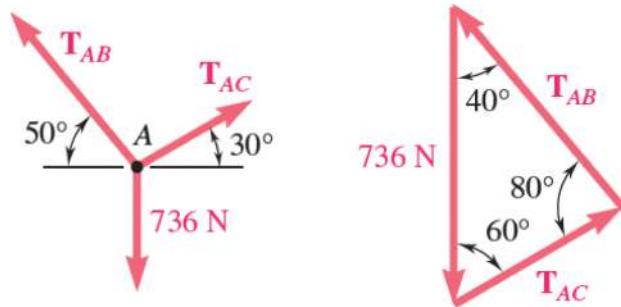
Consider the 75-kg crate shown in the space diagram of Fig.. This crate was lying between two buildings, and is now being lifted onto a truck, which will remove it. The crate is supported by a vertical cable that is joined at A to two ropes, which pass over pulleys attached to the buildings at B and C. We want to determine the tension in each of the ropes AB and AC.

Solution

Step 1 : $W = mg = (75 \text{ kg})(9.81 \text{ m/s}^2) = 736 \text{ N}$

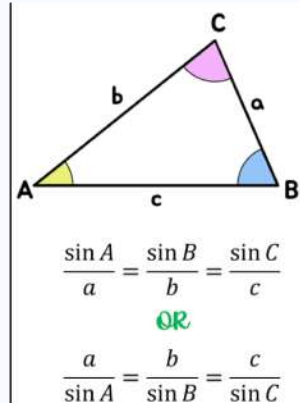
Step 2: Using sine law, we can find T_{AB} and T_{AC} .

Law of sine

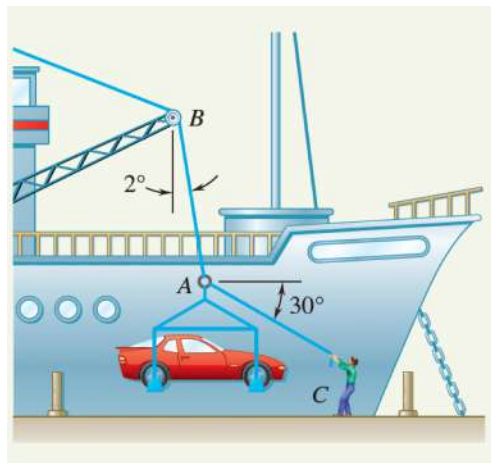


$$\frac{T_{AB}}{\sin 60^\circ} = \frac{T_{AC}}{\sin 40^\circ} = \frac{736}{\sin 80^\circ}$$

$$\begin{aligned} T_{AB} &= 647 \text{ N} \\ T_{AC} &= 480 \text{ N} \end{aligned}$$



Numerical 1



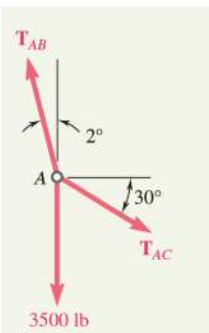
In a ship-unloading operation, a 3500-lb automobile is supported by a cable. A worker ties a rope to the cable at A and pulls on it in order to center the automobile over its intended position on the dock. At the moment illustrated, the automobile is stationary, the angle between the cable and the vertical is 2° , and the angle between the rope and the horizontal is 30° . What are the tensions in the rope and cable?

Because only three forces act on point A, draw a force triangle to express that it is in equilibrium, use law of sine:

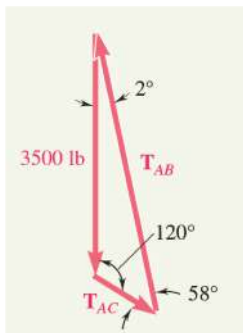
$$\frac{T_{AB}}{\sin 120^\circ} = \frac{T_{AC}}{\sin 2^\circ} = \frac{3500}{\sin 58^\circ}$$

$$T_{AB} = 3570 \text{ lb}$$

$$T_{AC} = 144 \text{ lb}$$



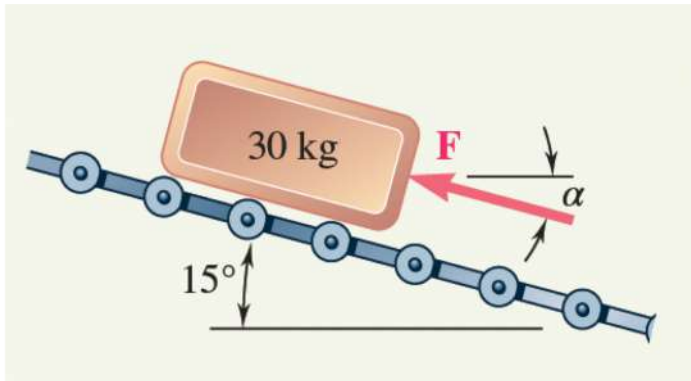
Step 1: Free body diagram



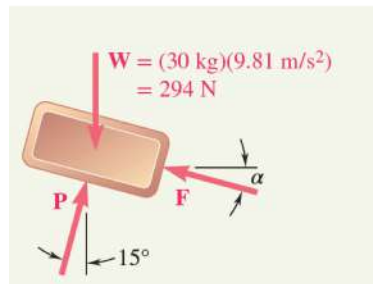
Step 2: Apply triangle law (tip-toe)

Step 3: Solve using Law of sine

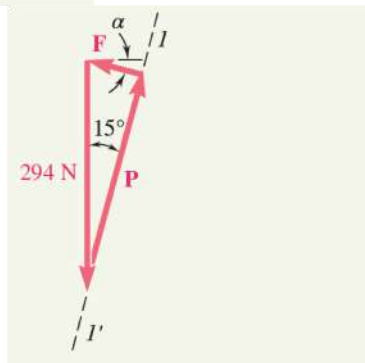
Numerical 2



Determine the magnitude and direction of the smallest force $\mathbf{F}$ that maintains the 30-kg package shown in equilibrium. Note that the force exerted by the rollers on the package is perpendicular to the incline.



Step 1: Free body diagram



Step 2: Apply triangle law (tip-toe)

- Because only three forces act on the free body, draw a force triangle to express that it is in equilibrium
- In order to obtain the minimum value of the force $\mathbf{F}$, choose the direction of $\mathbf{F}$ to be perpendicular to that of $\mathbf{P}$, therefore from the geometry of triangle we get:

$$\mathbf{F} = (294 \text{ N}) \sin 15^\circ = 76.1 \text{ N}$$

Step 3

Points to remember for equilibrium of particles in plane

- When a particle is in equilibrium under three forces, you can solve the problem by drawing a force triangle.
- When a particle is in equilibrium under more than three forces, you can solve the problem graphically by drawing a force polygon. If you need an analytic solution, you should solve the equations of equilibrium:

$$\Sigma F_x = 0 \text{ and } \Sigma F_y = 0$$

- These equations can be solved for no more than two unknowns.
- Similarly, the force triangle used in the case of equilibrium under three forces can be solved for only two unknowns.

Equilibrium of a Particle in space

Three Equilibrium Equations for space:

$$\Sigma F_x = 0$$

$$\Sigma F_y = 0$$

$$\Sigma F_z = 0$$

- Three equations allow solution for up to 3 unknowns
- Same procedure as 2D: draw FBD → resolve forces into x, y, z components → apply equilibrium equations
- Typical 3D problems: ball-and-socket joints, three-cable systems, space trusses
- Direction cosines are essential when cables are defined by geometry (coordinates of endpoints)

Problem Solving Strategy – Summary

Step	Action	Tip
1. Identify the particle	Choose the point/body in equilibrium	<i>Pick the point where most unknowns meet</i>
2. Draw FBD	Show all forces with arrows and labels	<i>Include weight, cable tensions, reactions</i>
3. Set up axes	Choose convenient x-y (or x-y-z) system	<i>Align an axis with an unknown when possible</i>
4. Write equations	Apply $\Sigma F_x=0$, $\Sigma F_y=0$ (and $\Sigma F_z=0$ in space)	<i>Count equations vs. unknowns first</i>
5. Solve & check	Solve algebraically, then substitute	<i>Verify units and sign of answers</i>

Key Equations – Quick Reference

Force Components (2D)

$$F_x = F \cos \theta$$

$$F_y = F \sin \theta$$

$$F = \sqrt{F_x^2 + F_y^2}$$

$$\theta = \tan^{-1}(F_y/F_x)$$

Force Components (3D)

$$\mathbf{F} = F_x \mathbf{i} + F_y \mathbf{j} + F_z \mathbf{k}$$

$$F = \sqrt{F_x^2 + F_y^2 + F_z^2}$$

$$\cos^2 \theta_x + \cos^2 \theta_y + \cos^2 \theta_z = 1$$

Resultant

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

$$R_x = \Sigma F_x$$

$$R_y = \Sigma F_y$$

$$R_z = \Sigma F_z \text{ (3D)}$$

Equilibrium

$$\Sigma F_x = 0$$

$$\Sigma F_y = 0$$

$$\Sigma F_z = 0 \text{ (3D)}$$

$$\text{Newton's 2nd: } \mathbf{F} = m\mathbf{a}$$

Common Mistakes to Avoid

X

X Forgetting to include all forces in the FBD

Always include weight, normal forces, cable tensions, and applied loads

X

X Using degrees in radians mode (or vice versa)

Always check your calculator mode before computing trig functions

X

X Sign errors in component resolution

Establish a clear positive direction before writing equations

X

X Mixing up angle reference (from x-axis vs. from vertical)

State the reference angle clearly; draw a sketch to confirm

X

X Solving numerically before eliminating unknowns

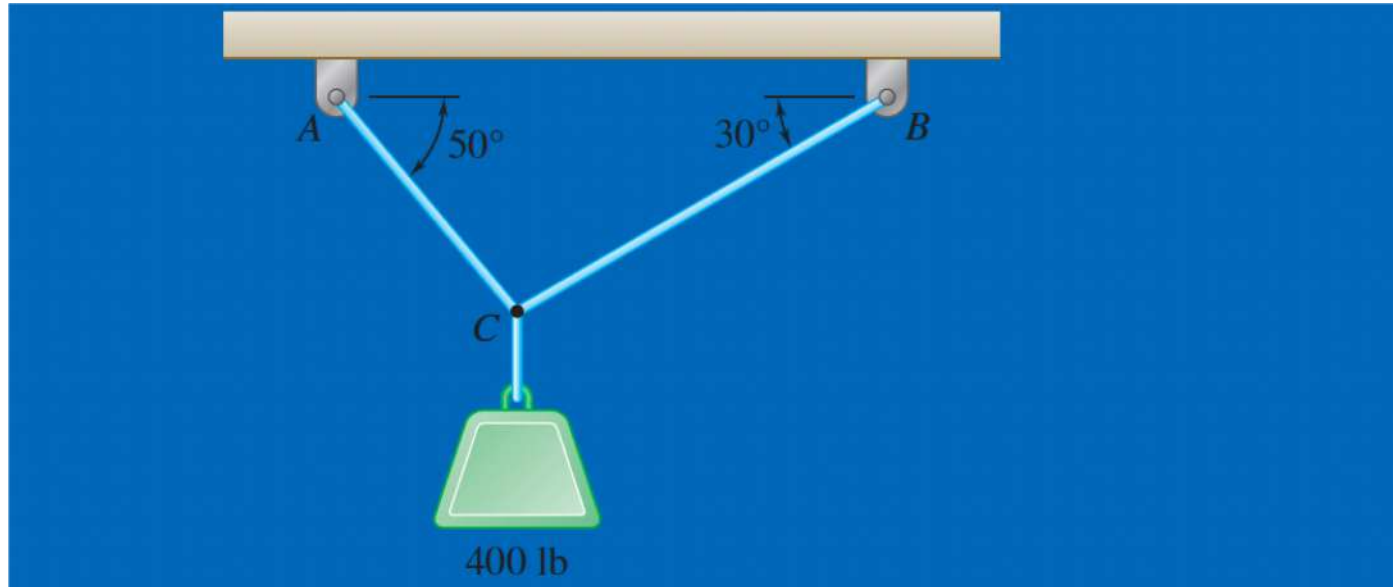
Solve algebraically first — eliminate unknowns, then substitute numbers

Summary: Statics of Particles

- **Forces as Vectors**
 - Characterized by magnitude, direction, and point of application
- **Resultant of Forces**
 - Use Parallelogram Law or Triangle Rule for two forces; Polygon Rule for multiple forces
- **Rectangular Components**
 - $F_x = F \cos \theta$, $F_y = F \sin \theta$ — most systematic method for multiple forces
- **Adding Forces by Components**
 - $R = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}$; direction $\theta = \tan^{-1}(|R_y|/|R_x|)$
- **Equilibrium Condition**
 - $\Sigma \mathbf{F} = 0 \rightarrow \Sigma F_x = 0$ and $\Sigma F_y = 0$ (2D); extend to z for 3D
- **Free-Body Diagrams**
 - Isolate the particle; show all external forces — the key to equilibrium problems
- **Equilibrium Condition in space**
 - $\Sigma \mathbf{F} = 0 \rightarrow \Sigma F_x = 0$ and $\Sigma F_y = 0$ and $\Sigma F_z = 0$

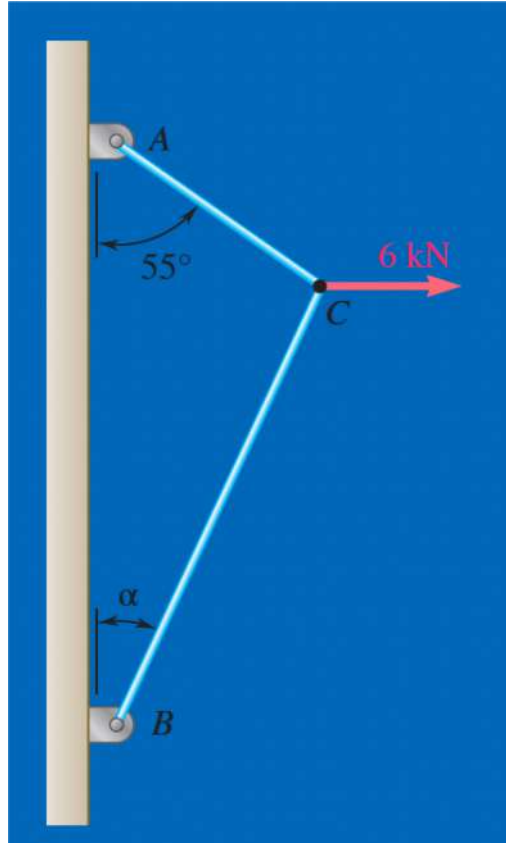
Problem 1

Two cables are tied together at C and are loaded as shown. Determine the tension (a) in cable AC , (b) in cable BC .



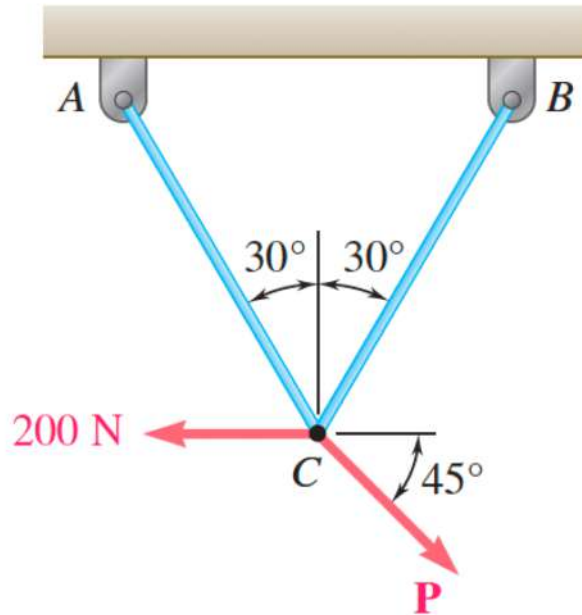
Problem 2

Two cables are tied together at C and are loaded as shown. Knowing that $\alpha = 30^\circ$, determine the tension (a) in cable AC , (b) in cable BC .



Problem 3

Two cables are tied together at C and are loaded as shown. Knowing that $P = 300\text{ N}$, determine the tension in cables AC and BC .



As.No.	Assessment Title	Question Upload	Answer Upload	Due Date	Activity Date	Max. Mark	Weightage %
1	Digital Assignment - Digital Assignment - I	Mandatory	Mandatory	29-May-2026	-	10	10
2	Digital Assignment - Digital Assignment - II	Mandatory	Mandatory	19-Jun-2026	-	10	10
3	QUIZ - Quiz - I	Not Applicable	Not Applicable	-	-	10	10
4	Mid Term	Not Applicable	Not Applicable	-	-	50	30
5	FAT - Final Assessment Test	Currently info not available	Currently info not available	-	-	100	40
Total Weightage Mark							100