Engineering Mechanics
AGE 2330

Lect 1: Introduction

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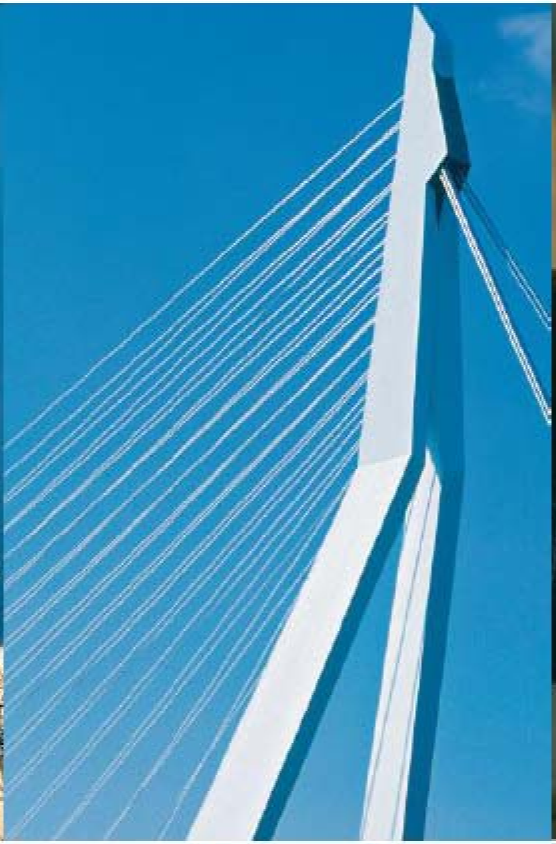
Engineering Mechanics –Why?

The design of this rocket and gantry structure requires a basic knowledge of both statics and dynamics, which form the subject matter of engineering mechanics.



This bridge tower is stabilized by cables that exert forces at the points of connection. In this chapter we will show how to express these forces as Cartesian vectors and then determine the resultant force.

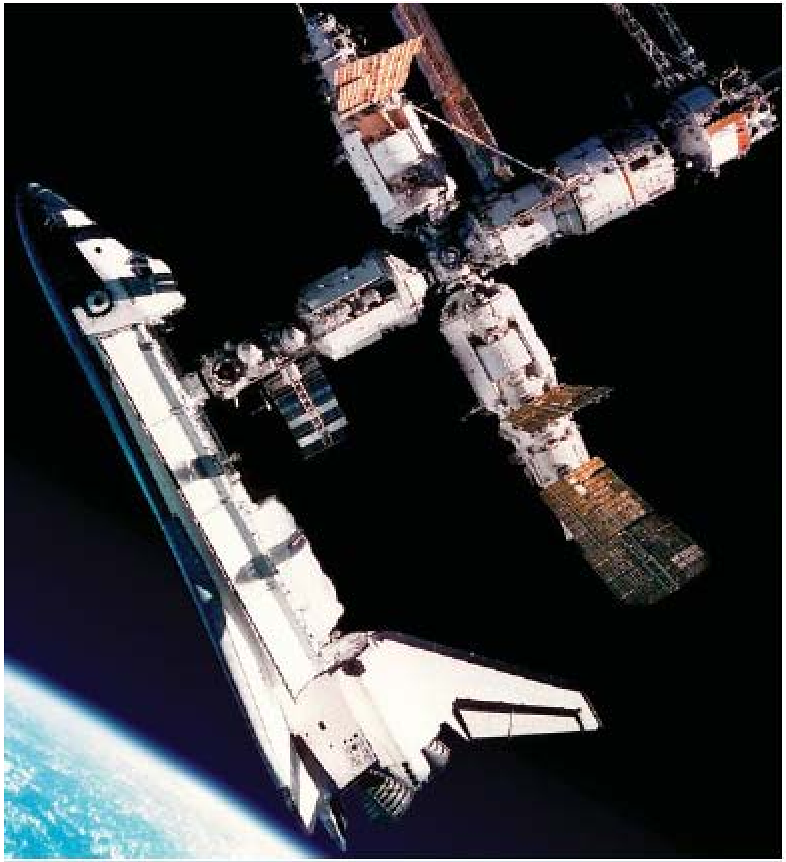
Application of forces to the handles of these wrenches will produce a tendency to rotate each wrench about its end. It is important to know how to calculate this effect and, in some cases, to be able to simplify this system to its resultants.

Engineering Mechanics –Why?

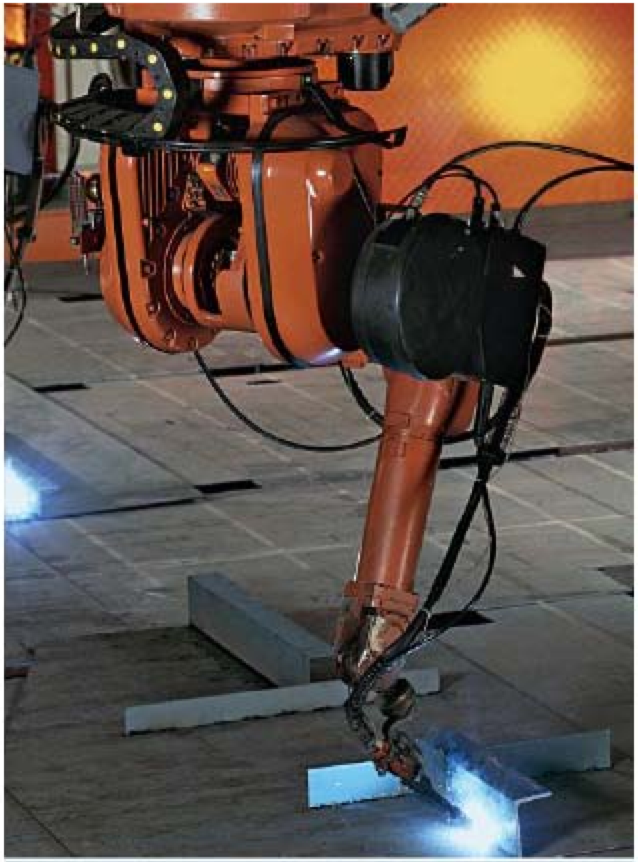
The effective design of a brake system, such as the one for this bicycle, requires an efficient capacity for the mechanism to resist frictional forces. In this chapter, we will study the nature of friction and show how these forces are considered in engineering analysis and design.

The design of conveyors for a bottling plant requires knowledge of the forces that act on them and the ability to predict the motion of the bottles they transport.

Engineering Mechanics –Why?



The docking of the space shuttle to the international space station requires application of impulse and momentum principles to accurately predict their orbital motion and proper orientation.



The three-dimensional motion of this industrial robot must be accurately specified.

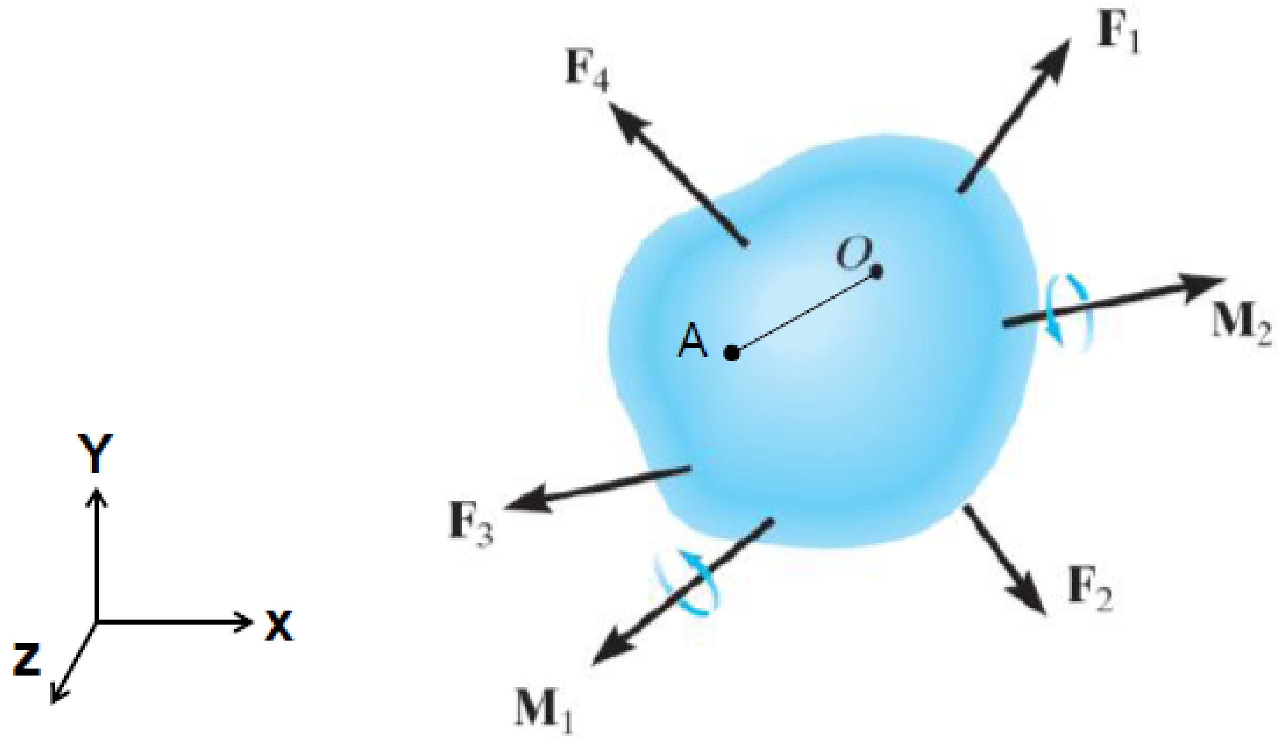
Classification

- Mechanics : *concerned with state of rest or motion of bodies subjected to the action of forces.*
  - *Rigid Body mechanics*

    To be covered in this course
  - *Deformable Body mechanics*
  - Fluid mechanics

Rigid body mechanics :: Basics

- Rigid Body: **No deformation** under any load
  - ***Change in distance*** between any two points ***negligible*** as compared to body dimensions

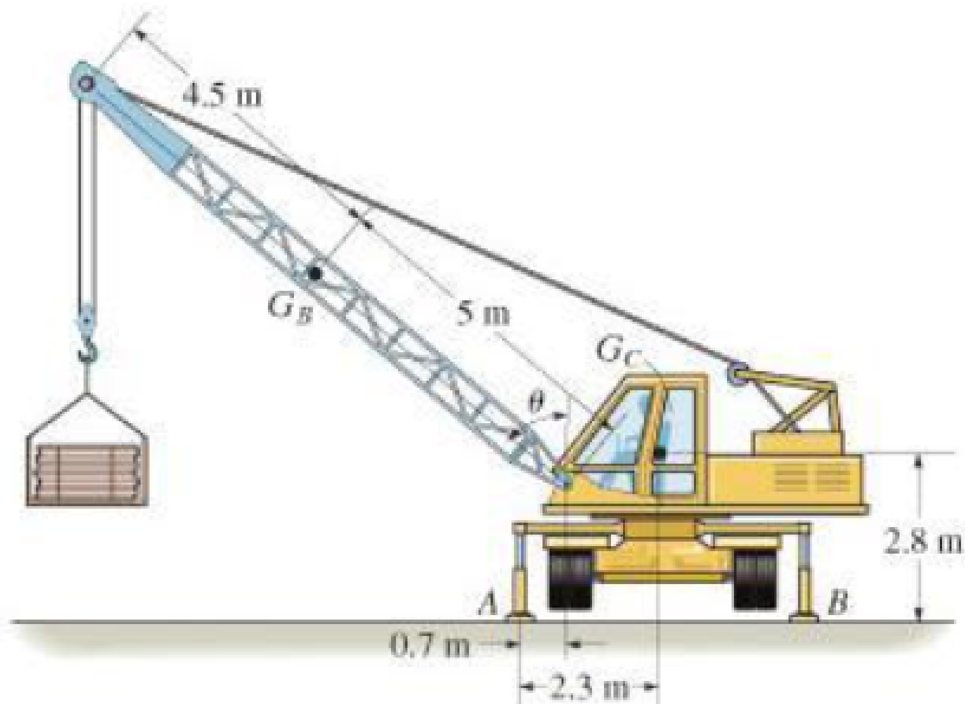


Rigid body mechanics :: Idealization

- Rigid Body
  - A **combination** of large number of **particles** in which all particles remain at a **fixed distance** (***practically***) from one another before and **after applying a load**
  - **Material properties** not required when analyzing the forces acting on the body
  - design and analysis of many types of structural members, mechanical components, electrical devices, etc., encountered in engineering.

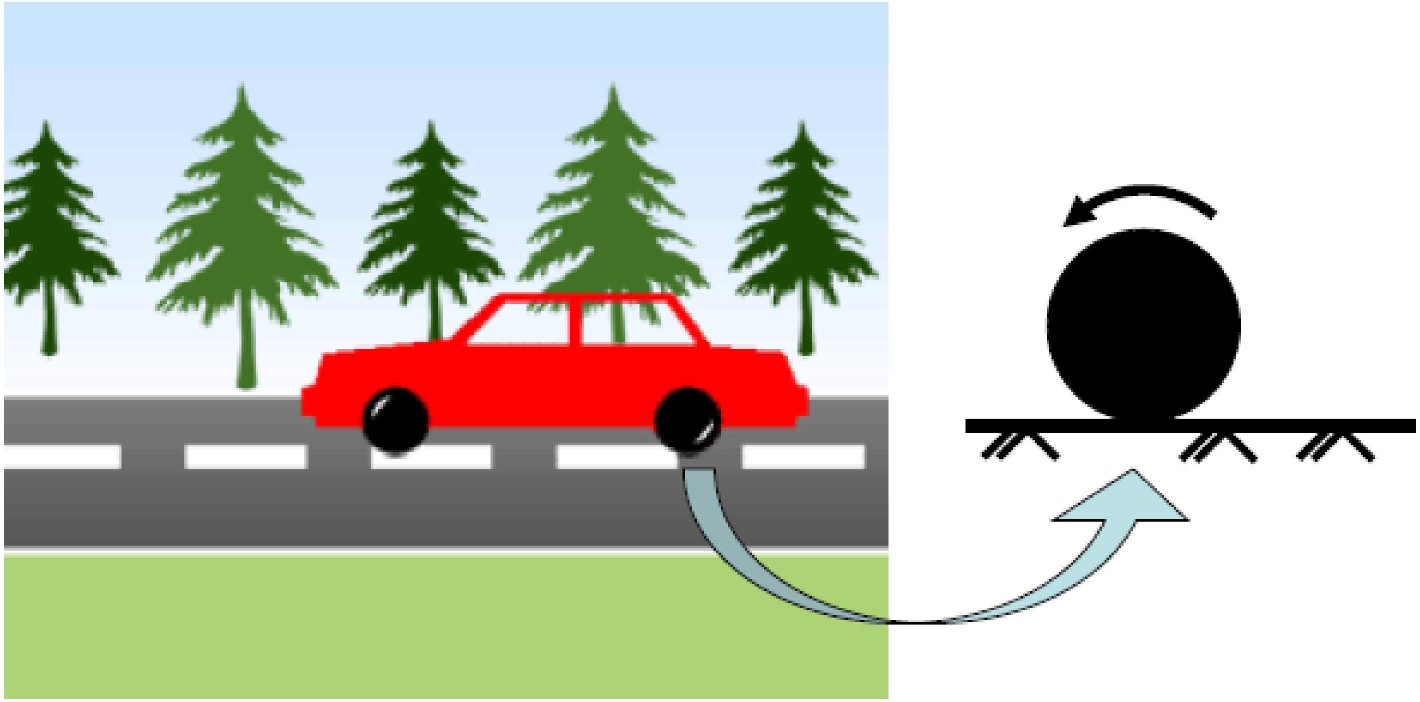
Rigid body mechanics :: Statics

- **Statics**
  - **equilibrium** of rigid body under **action of forces**



Rigid body mechanics :: Dynamics

- **Dynamics**
  - **motion** of bodies (*acceleration/deceleration*)

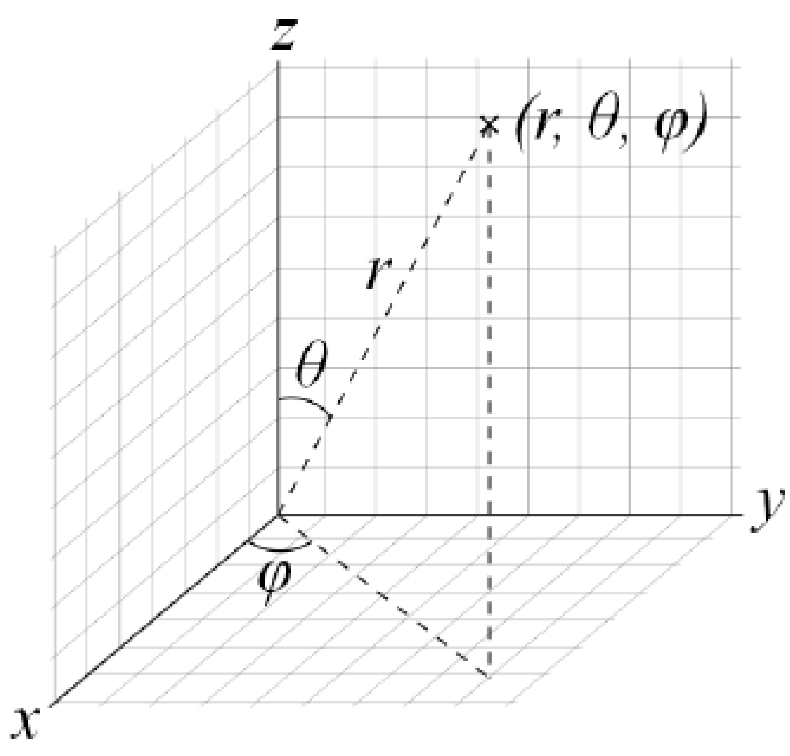


Mechanics: Fundamental Concepts

- **Length** (Space)
  - **Position** of a point in space
    - Coordinate system
      - **Cartesian** (x, y, z)
      - **Spherical** (r, θ, ϕ)
      - **Cylindrical** (ρ, ϕ, z)
  - Describe **size** of the physical **system**
    - Dimensions
  - Distance, geometric properties
  - **Basic quantity/dimension**

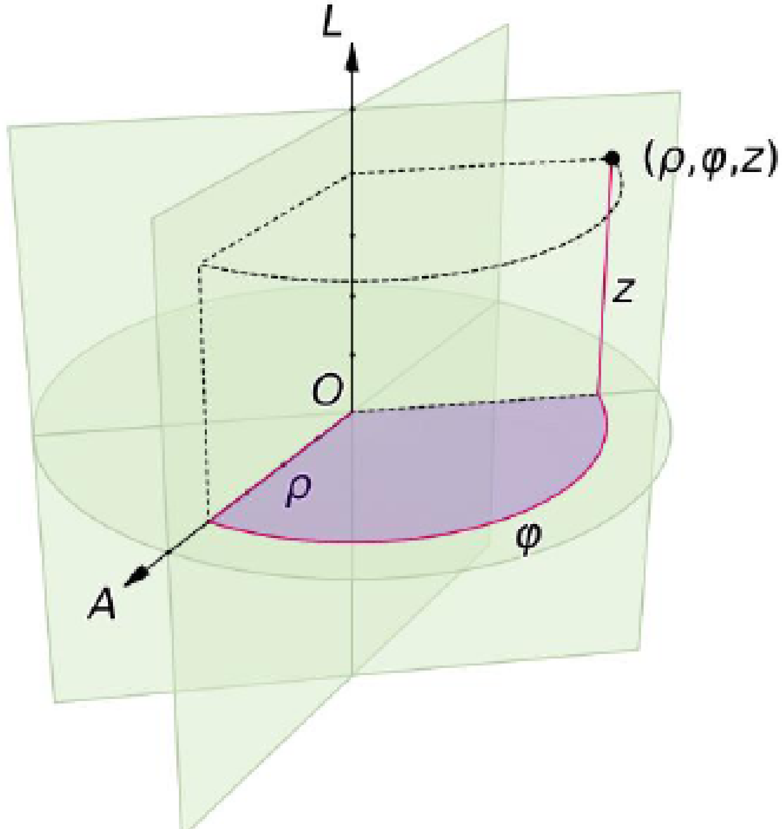
Mechanics: Spherical coordinate system

- Application
  - Separation of variables in partial differential equations, *e.g.*, Laplace eqn



Mechanics: Cylindrical coordinate system

- Application
  - Physical phenomena with spherical symmetry, e.g., water flow in a circular pipe



Mechanics: Fundamental Concepts

- **Time**
  - Measure of succession of events
  - **Basic quantity/dimension**
- **Mass**
  - Quantity of matter in a body
  - Measure of **inertia**
  - **Basic quantity/dimension**

Mechanics: Fundamental Concepts

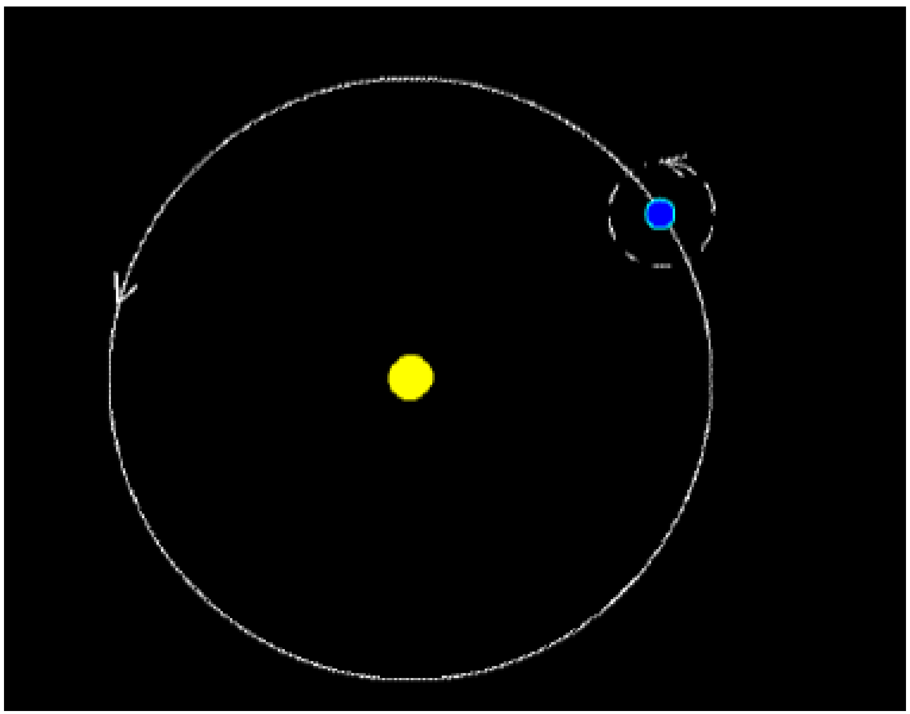
- **Force**
  - Tends to move a body along its direction
    - **Change in velocity**
  - Characterization
    - **Magnitude** } **Vector**
    - **Direction** }
    - **Point of application**
  - Derived quantity (MLT^{-2})
  - Occurrence as interaction between bodies
    - **Gravitational, electromagnetic actions**

Mechanics: Fundamental Concepts

- More about **mass** and **weight**
  - **No change** in **mass** with **change in location of body**
  - **Weight** refers to **gravitational attraction** on a body
    - **May change with location**

Mechanics: Idealization as particle

- **Particle**
  - A body with **mass** but with **negligible dimensions**



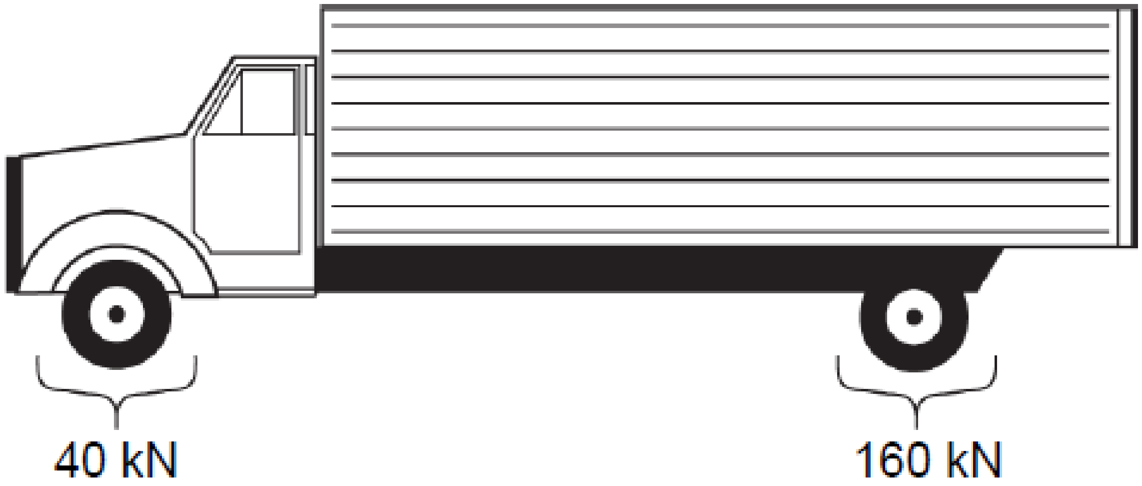
: Size of earth insignificant compared to the size of its orbit

: Earth can be modeled as a particle when studying its orbital motion

: Simplified analysis - geometry of the body is not involved in the analysis.

Mechanics: Force idealization

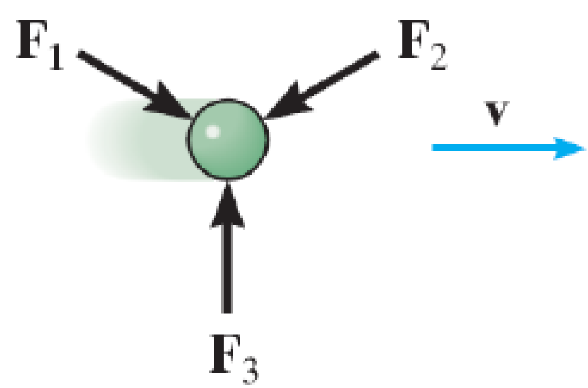
- **Concentrated Force**
  - **Line of action** of **weight** through the **centre of gravity** of the body
  - **Area** over which the **load is applied** is **very small** compared to the **overall size** of the body



Ex: Contact Force between a wheel and ground.

Mechanics: Newton's Three Laws of Motion

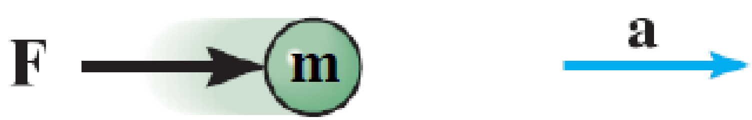
- **Basis** of rigid body **statics**
  - First Law: A particle originally at rest, or moving in a straight line with constant velocity, tends to remain in this state provided the particle is not subjected to an unbalanced force
  - **Principle** of **force equilibrium**
    - *Statics*



Equilibrium

Mechanics: Newton's Three Laws of Motion

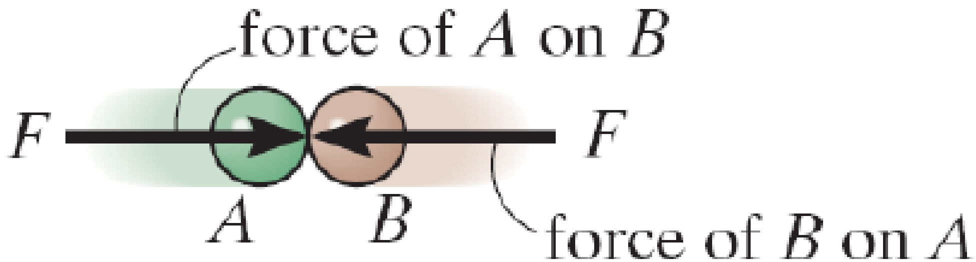
- **Basis** of rigid body **dynamics**
  - Second Law: A particle of mass "m" acted upon by an unbalanced force "F" experiences an acceleration "a" that has the same direction as the force and a magnitude that is directly proportional to the force



Accelerated motion

Mechanics: Newton's Three Laws of Motion

- Application in both statics and dynamics
  - Third Law: The mutual forces of action and reaction between two particles are equal, opposite and collinear



Action – reaction

Mechanics: Newton's Law of Gravitational Attraction

- Gravitational attraction between any two particles

$$F = G\frac{m_1 m_2}{r^2}$$

F = mutual force of attraction between two particles

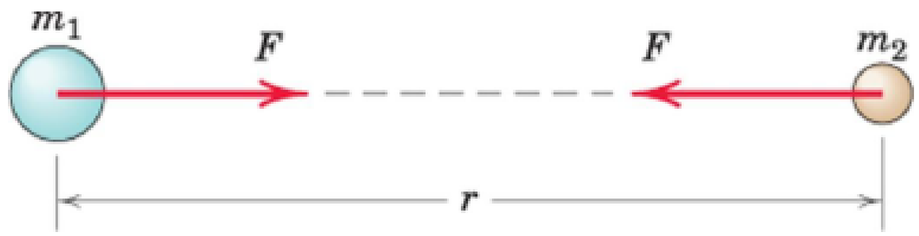
G = universal constant of gravitation

Experiments → G = 6.673x10-11 m3/(kg.s2)

: **Rotation of Earth is not taken into account**

m_1, m_2 = masses of two particles

r = distance between two particles



Mechanics: Gravitational Attraction of Earth

- Weight of a particle/body
  - **Location** of a particle/body **near or at the surface** of the earth
    - Only **significant gravitational force** is that between the earth and the particle/body
      - Weight of particle/body

$$W = G\frac{mM_e}{r^2}$$

: Assuming earth to be a non-rotating sphere of constant density and having mass $m_2 = M_e$

: r = distance between the earth's center and the particle

$$W = mg$$

: Let $g = GM_e/r^2$ = accln. due to gravity (9.81 m/s^2)

: **In g, earth's rotation is taken into account**

Mechanics: Units

QUANTITY	DIMENSIONAL SYMBOL	SI UNITS: UNIT	SI UNITS: SYMBOL
Mass	M	Base units: kilogram	kg
Length	L	Base units: meter	m
Time	T	Base units: second	s
Force	F	newton	N

$$F = ma \rightarrow N = kg.m/s^2$$

1 Newton is the force required to give a mass of 1 kg an accln of 1 m/s^2.

$$W = mg \rightarrow N = kg.m/s^2$$

Mechanics: Prefixes of units

- **Very large** or **very small** numerical quantity

	Exponential Form	Prefix	SI Symbol
Multiple			
1 000 000 000	10^9	giga	G
1 000 000	10^6	mega	M
1 000	10^3	kilo	k
Submultiple			
0.001	10^{-3}	milli	m
0.000 001	10^{-6}	micro	μ
0.000 000 001	10^{-9}	nano	n

  – Mil: $1/1000^{th}$ of an inch
    - Machining/foils

Mechanics: Accuracy

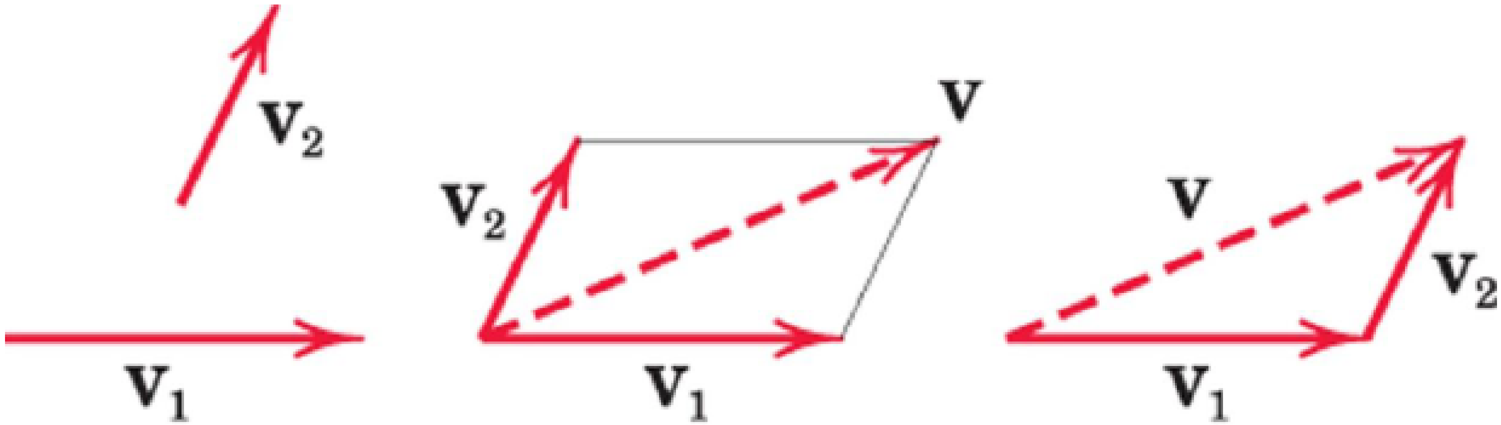
- **Significant Digits**
  - Number of significant digits in an answer should depend on the accuracy of measurement involved
    - Length of the side of a square: 24 mm
    - Area of square : 580 mm^2
      - Not 576 mm^2
  - Accuracy in industries
    - Millimeters (10^{-3}) in Civil Engineering construction
    - Nanometer (10^{-9}) in Integrated Circuits

Mechanics: Scalars and Vectors

- Scalar
  - Only **magnitude** is associated with it
    - *e.g.*, time, volume, density, speed, energy, mass etc.
- Vector
  - Possess **direction** as well as **magnitude**
  - Parallelogram law of addition (and the triangle law)
  - *e.g.*, displacement, velocity, acceleration etc.
- Tensor
  - *e.g.*, stress (3×3 components)

Mechanics: Scalars and Vectors

- Laws of vector addition
  - Equivalent vector $\mathbf{V} = \mathbf{V}_1 + \mathbf{V}_2$ (Vector Sum)



Mechanics: Scalars and Vectors

A Vector **V** can be written as: $\mathbf{V} = V\mathbf{n}$

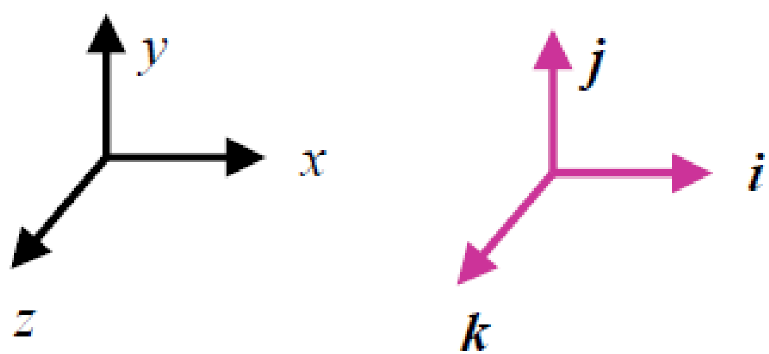
V = magnitude of **V**

n = unit vector whose magnitude is one and whose direction coincides with that of **V**

Unit vector can be formed by dividing any vector, such as the geometric position vector, by its length or magnitude

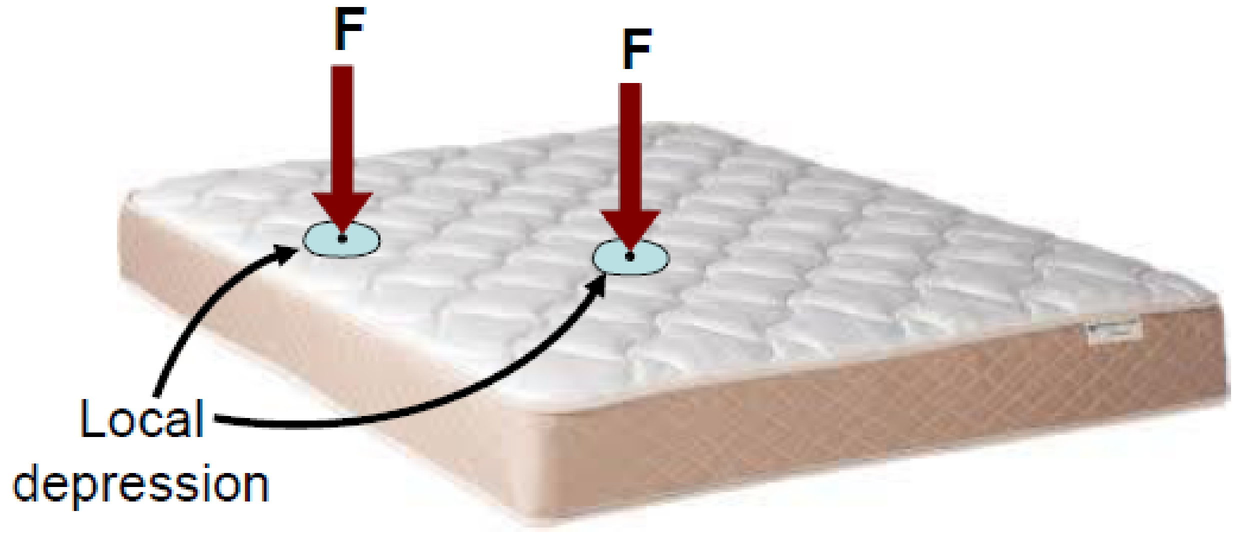
Vectors represented by Bold and Non-Italic letters (**V**)

Magnitude of vectors represented by Non-Bold, Italic letters (V)



Types of Vectors: Fixed Vector

- **Fixed Vector**
  - Constant magnitude and direction
    - **Unique point of application**
  - *e.g.*, force on a deformable body

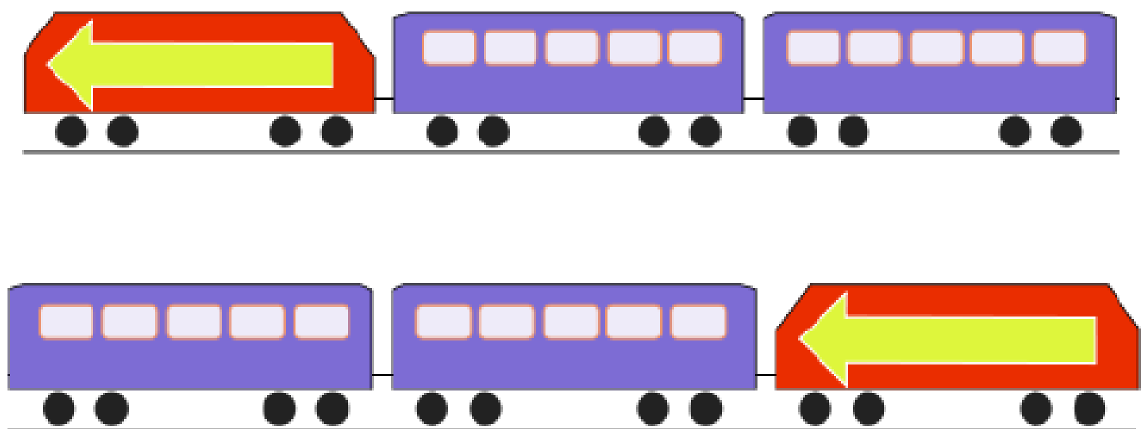


  - *e.g.*, force on a given particle

Types of Vectors: Sliding Vector

- **Sliding Vector**
  - Constant magnitude and direction
    - **Unique line of action**
      - “**Slide**” along the line of action
    - **No unique point of application**

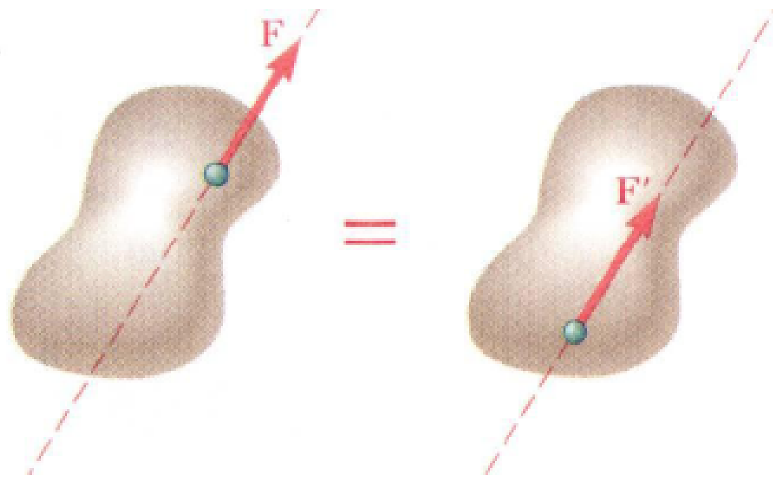
Force on coach **F**

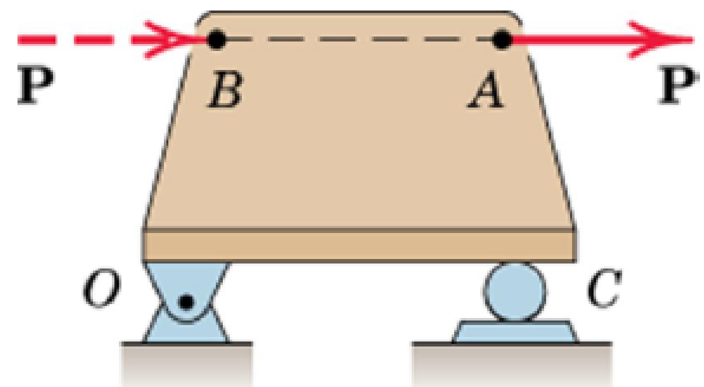


Force on coach **F**

Types of Vectors: Sliding Vector

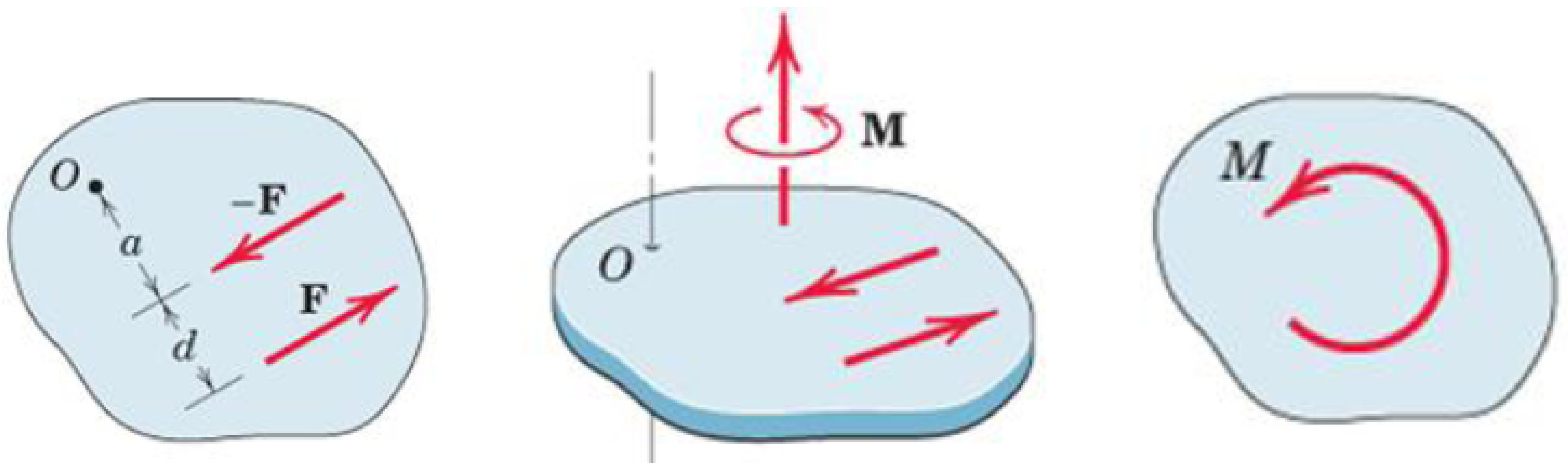
- **Sliding Vector**
  - Principle of Transmissibility
    - **Application of force** at **any point** along a **particular line of action**
      - **No change in resultant external effects** of the force





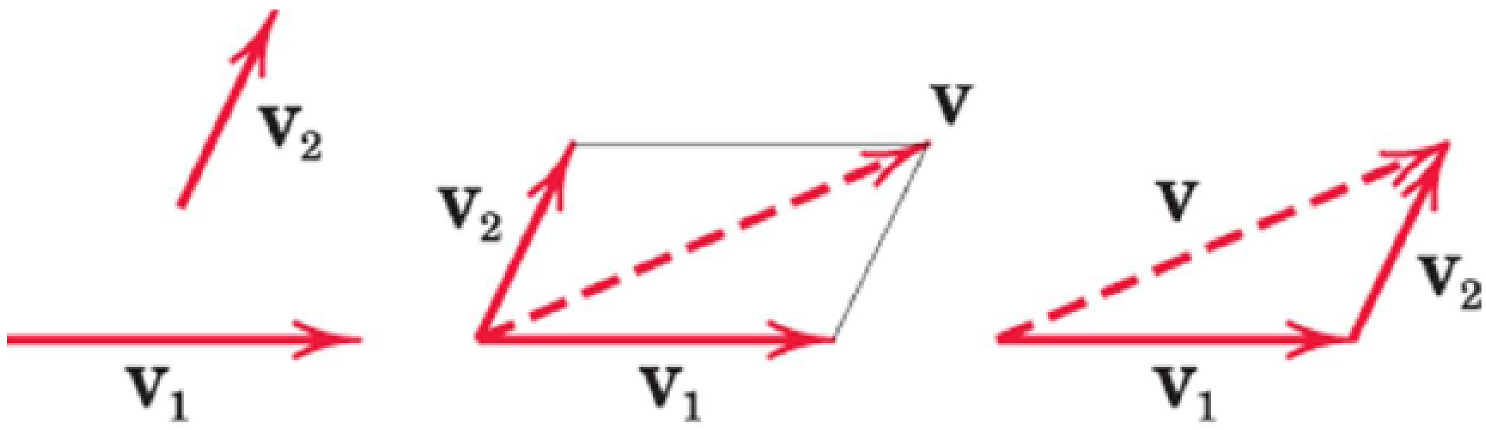
Types of Vectors: Free Vector

- **Free Vector**
  - Freely movable in space
    - **No unique line of action**
      - **No unique point of application**
  - *e.g.*, moment of a couple



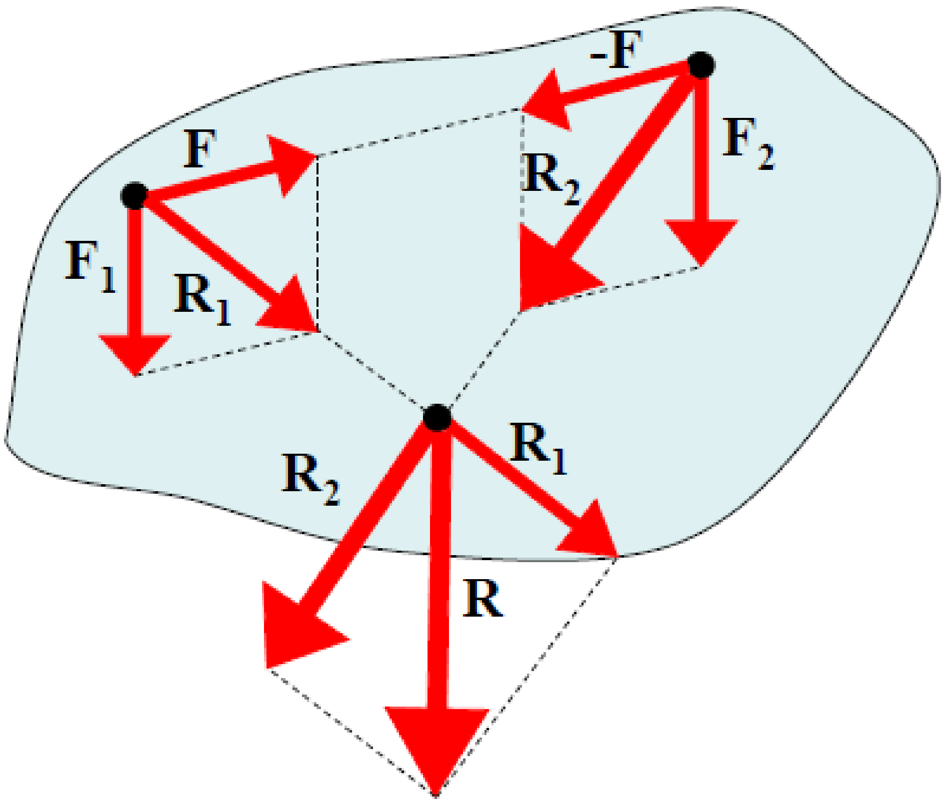
Vectors: Rules of addition

- **Parallelogram Law**
  - Equivalent vector represented by the diagonal of a parallelogram
    - $\mathbf{V} = \mathbf{V}_1 + \mathbf{V}_2$ *(Vector Sum)*
    - $V \neq V_1 + V_2$ (Scalar sum)



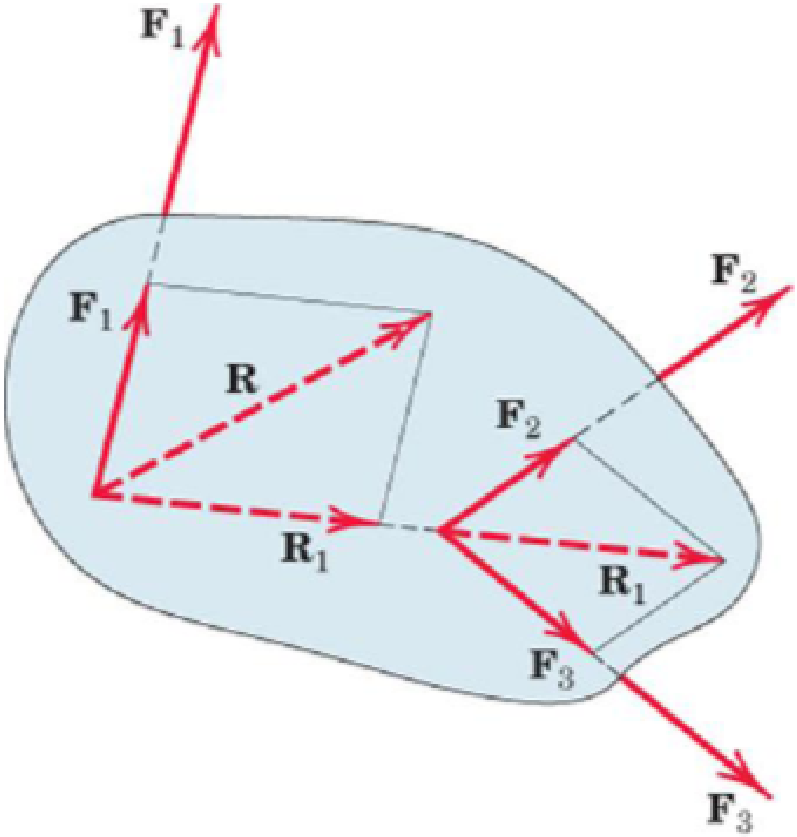
Vectors: Parallelogram law of addition

- Addition of two parallel vectors
  - $\mathbf{F_1} + \mathbf{F_2} = \mathbf{R}$



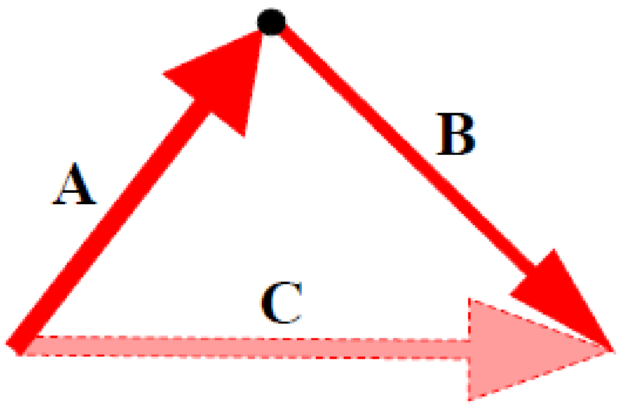
Vectors: Parallelogram law of addition

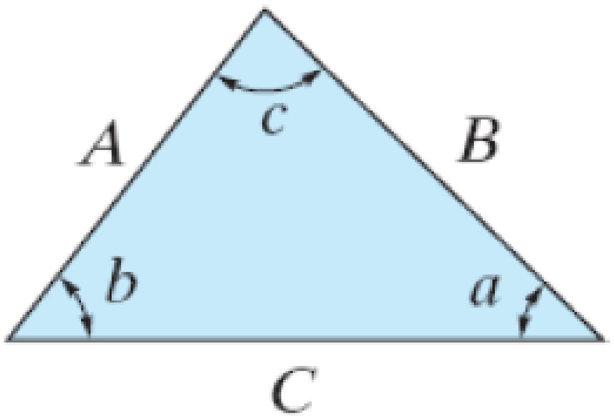
- Addition of 3 vectors
  - $\mathbf{F}_1 + \mathbf{F}_2 + \mathbf{F}_3 = \mathbf{R}$



Vectors: Rules of addition

- **Trigonometric Rule**
  - Law of Sines
  - Law of Cosine





Sine law:

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

Cosine law:

$$C = \sqrt{A^2 + B^2 - 2AB\cos c}$$