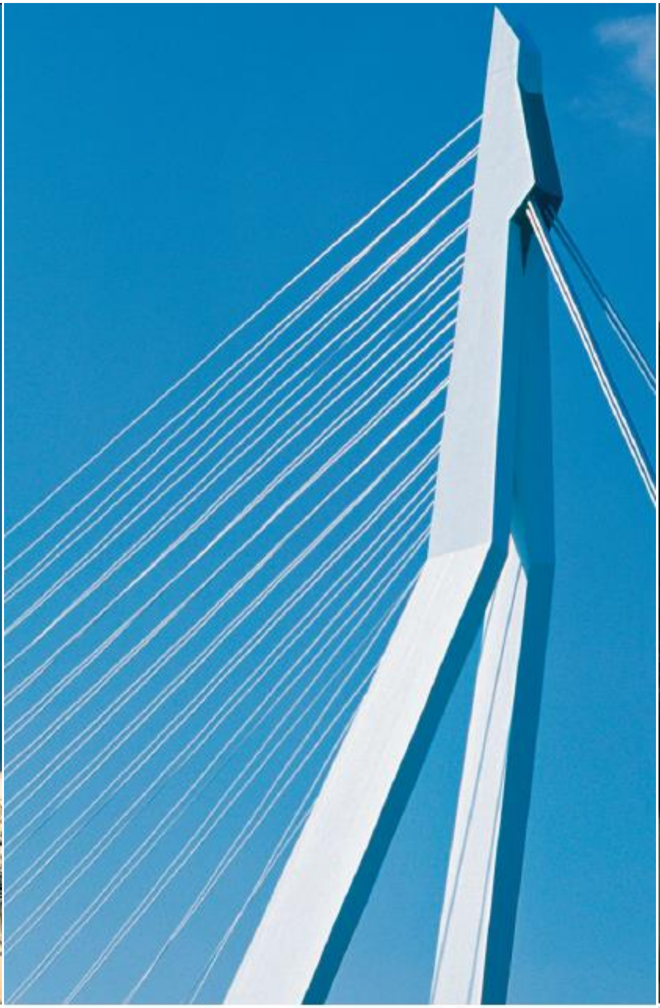
ME101: Engineering Mechanics

2019-20 (II Semester)

LECTURE 1

ME101: 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.

ME101: Classification

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

  – ***Rigid Body** mechanics*

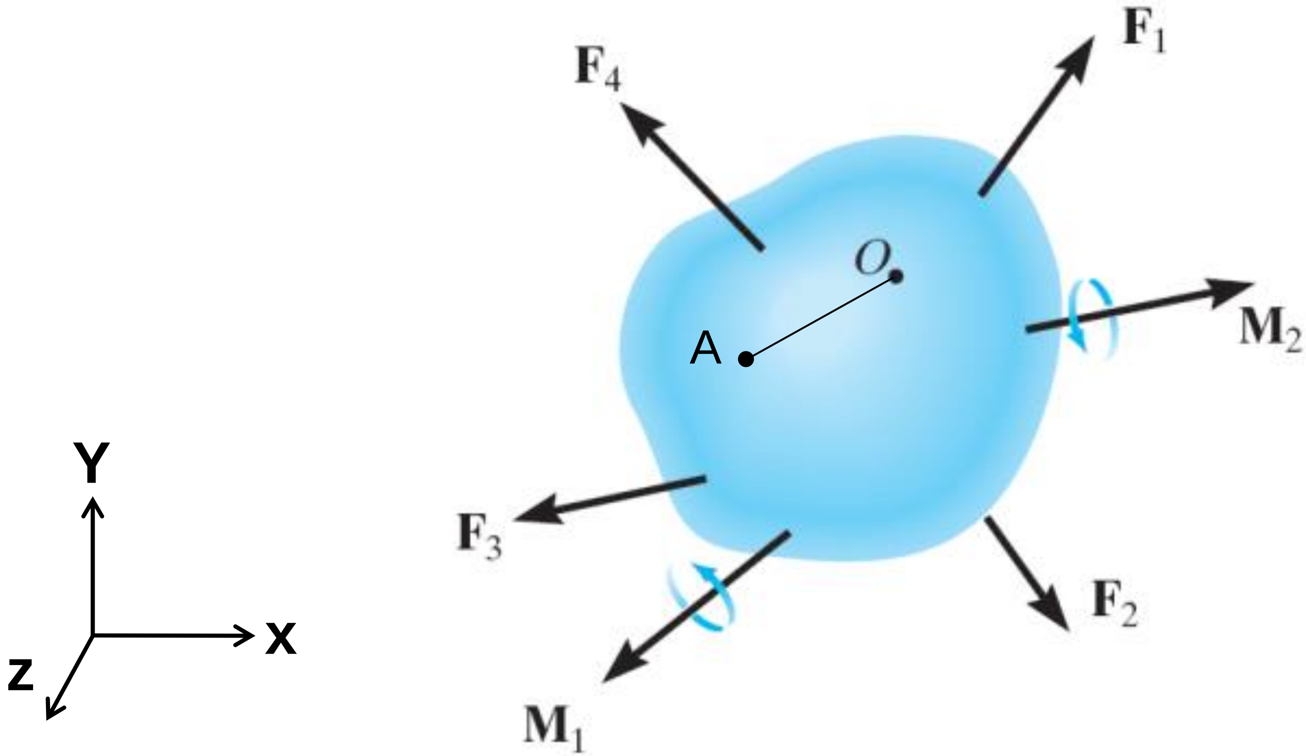
    - *To be covered in ME101 course*

  – ***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

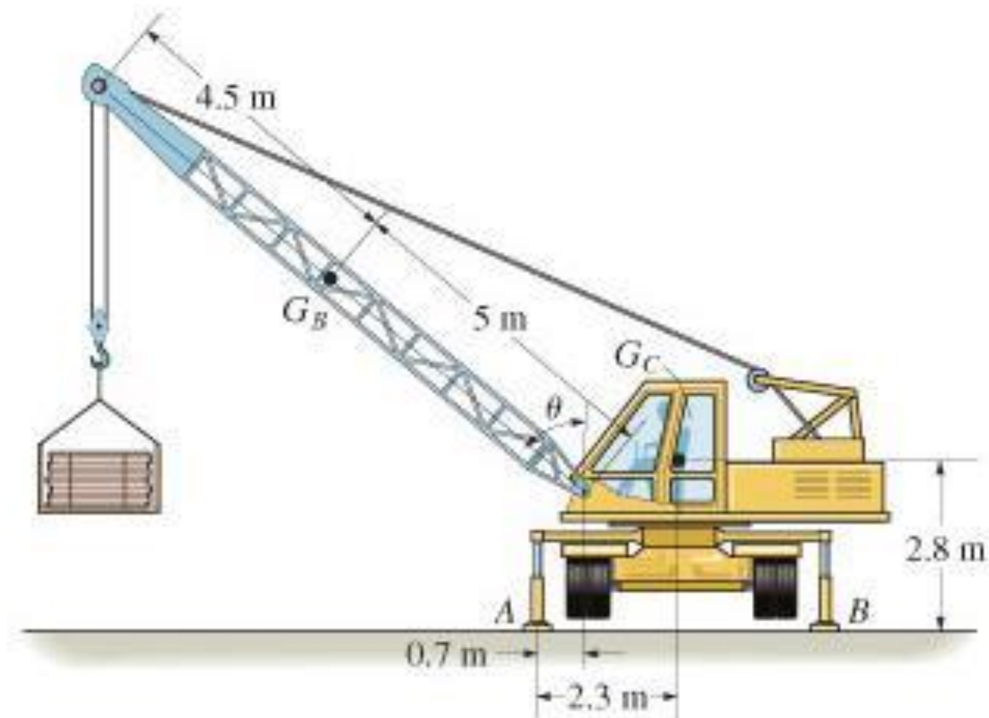


What is Rigid body?

- 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.

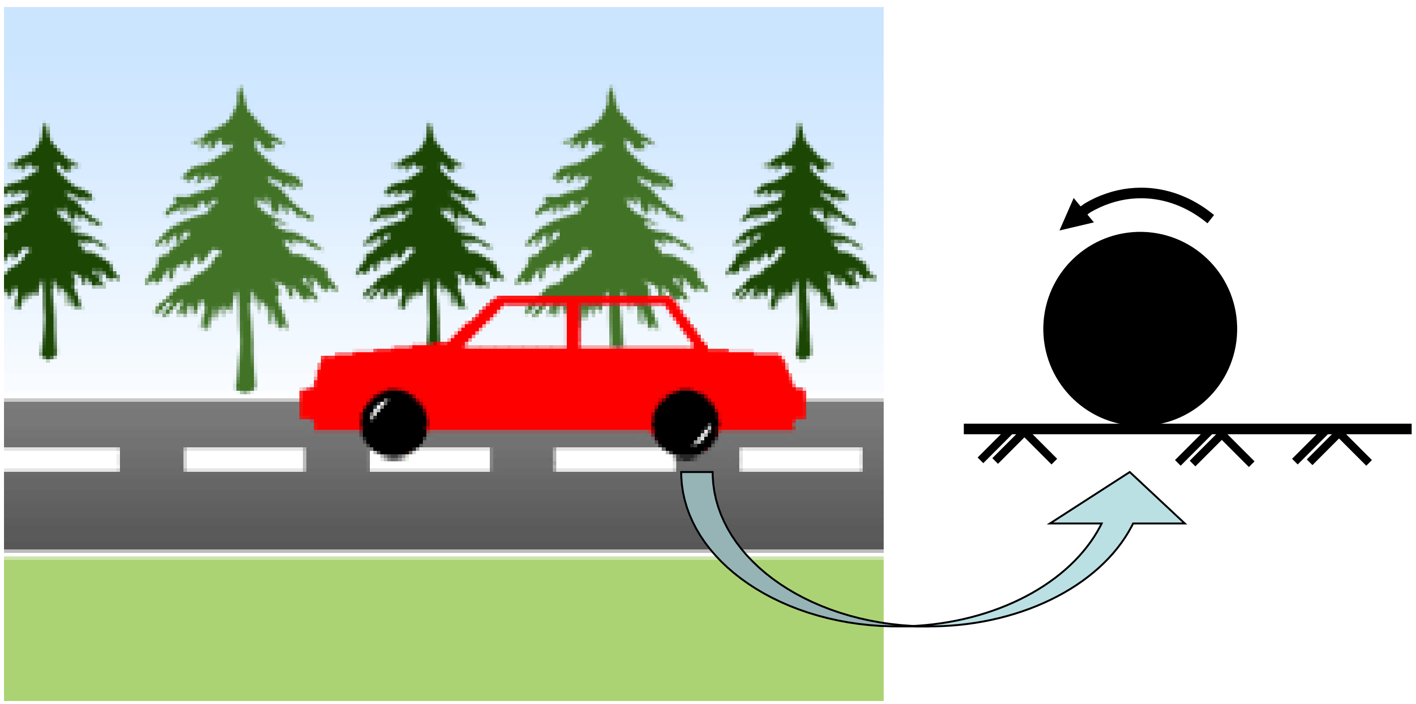
Rigid body mechanics :: Statics

- **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: 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: Units

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

$F = ma$ → 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.

$W = mg$ → N = kg.m/s^2

Mechanics: Fundamental Concepts

- **Force**
  - Tends to move a body along its direction
    - **Change in velocity**
  - Characterization
    - **Magnitude**
    - **Direction**

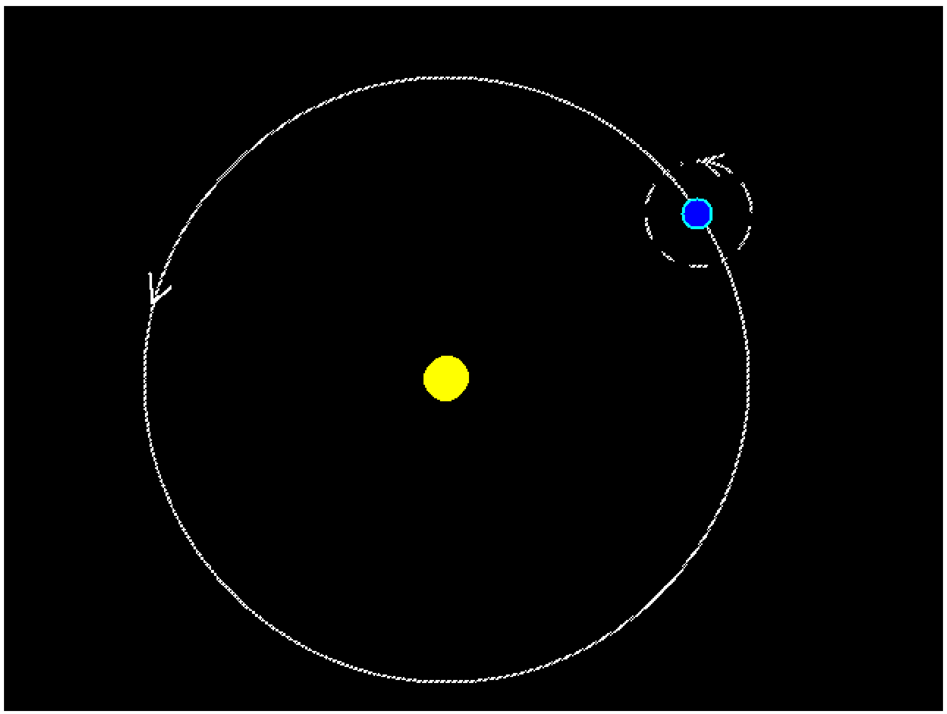
      Vector
    - **Point of application**
  - Derived quantity (MLT^{-2})
  - Occurrence as interaction between bodies
    - **Gravitational, electromagnetic actions**

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**



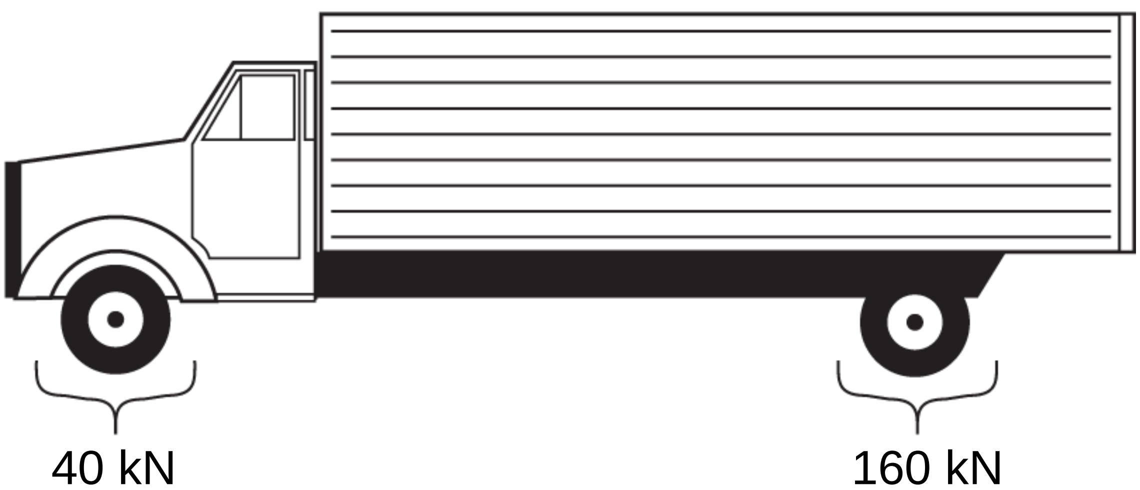
: Size of earth insignificant compared to the size of its orbit

: 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

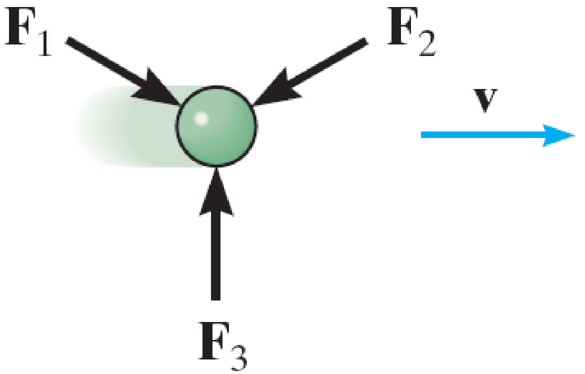
- **Concentrated Force**
  - **Line of action** of **weight** through the **centre of gravity** of the body
  - **Area** over which the **load is applied** is **very small** compared to the **overall size** of the body



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

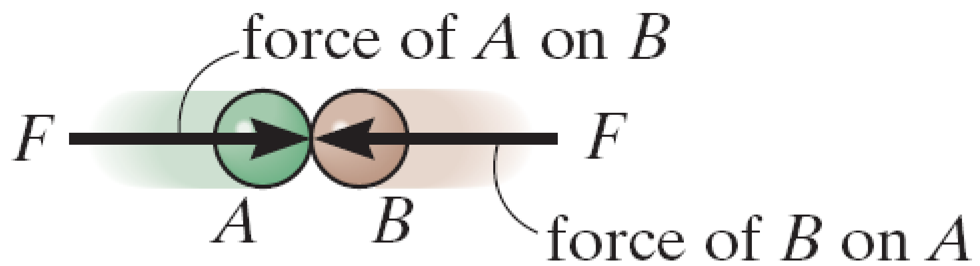
Mechanics: Newton’s Three Laws of Motion

- **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



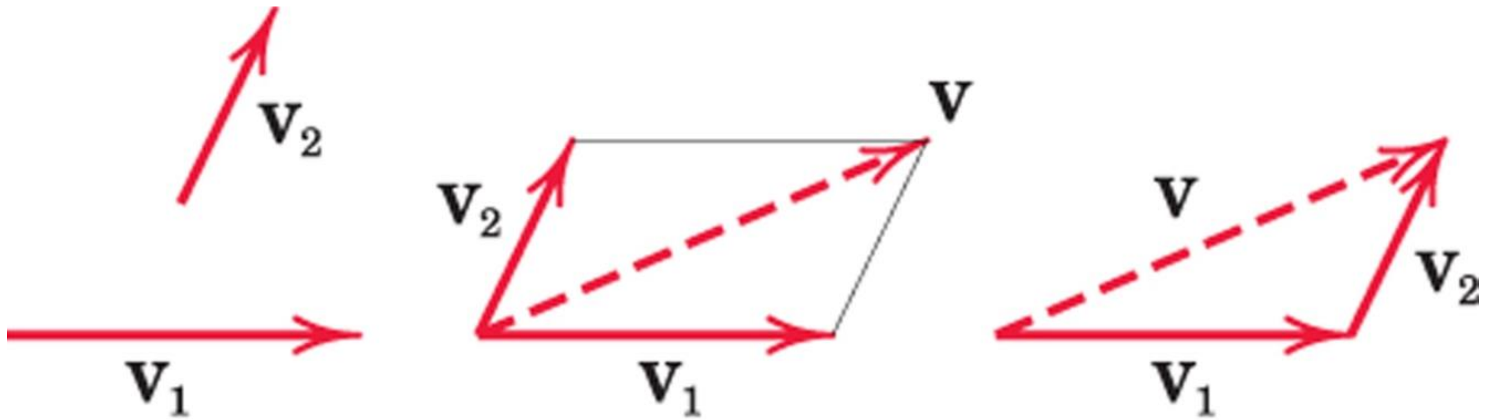
Action – reaction

Mechanics: Scalars and Vectors

- Scalar
  - Only **magnitude** is associated with it
    - *e.g.*, time, volume, density, <u>speed</u>, 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$\times$3 components)

Mechanics: Scalars and Vectors

- Laws of vector addition
  - Equivalent vector **V** = **V$_1$** + **V$_2$** **(Vector Sum)**



Mechanics: Scalars and Vectors

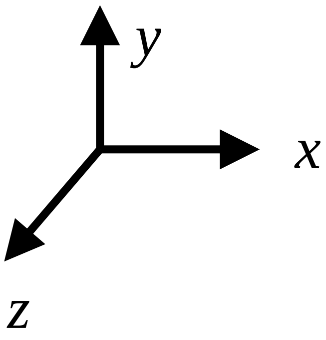
- A Vector **V** can be written as: $\mathbf{V} = V\mathbf{n}$

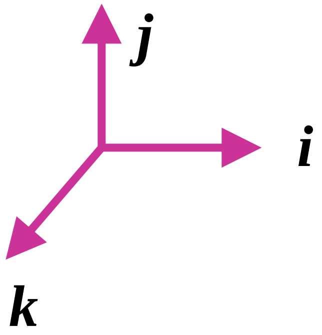
V = magnitude of **V**

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*)

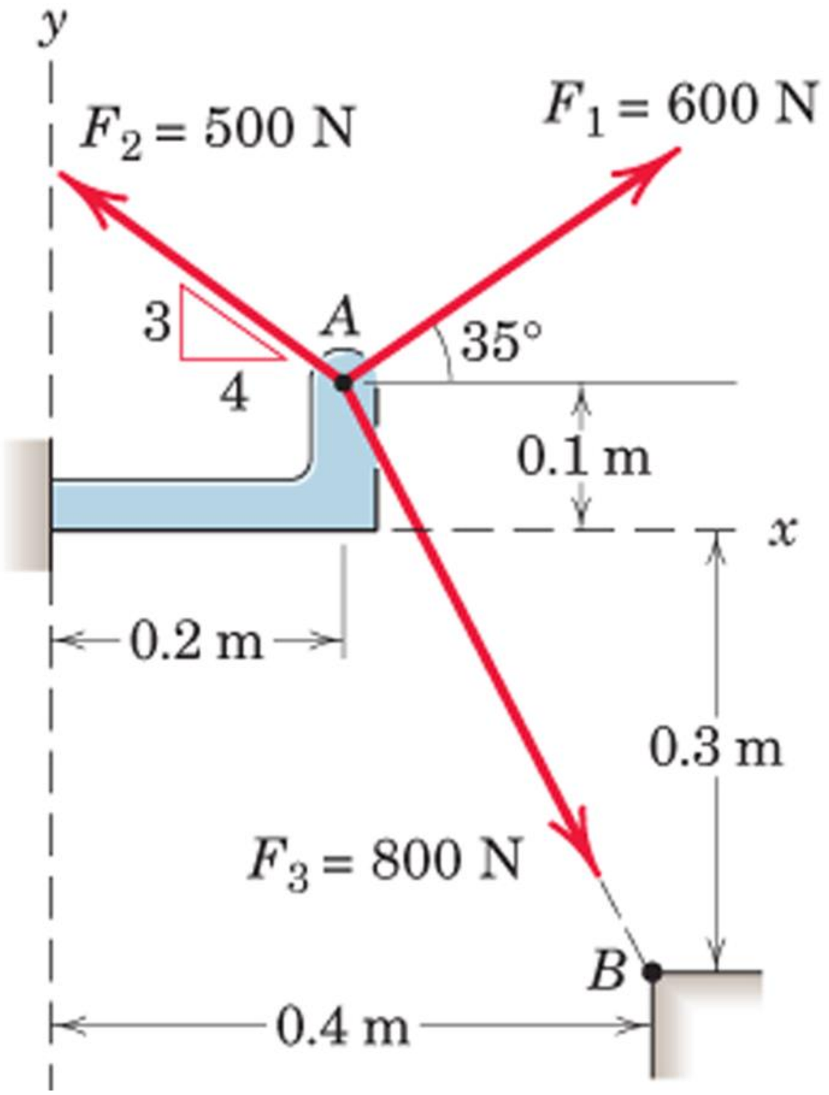




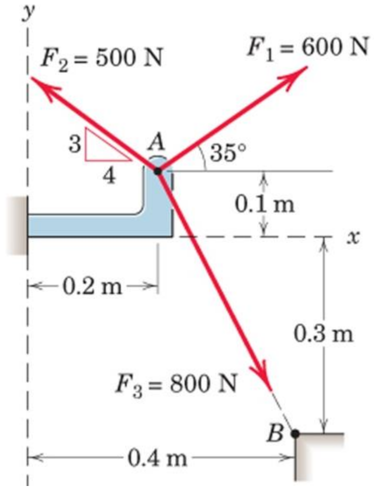
Components of a Force

Example 1:

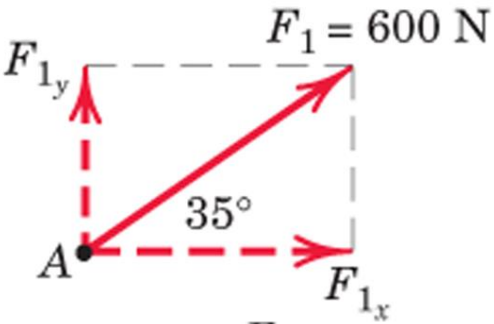
Determine the x and y scalar components of $\mathbf{F}_1$, $\mathbf{F}_2$, and $\mathbf{F}_3$ acting at point A of the bracket

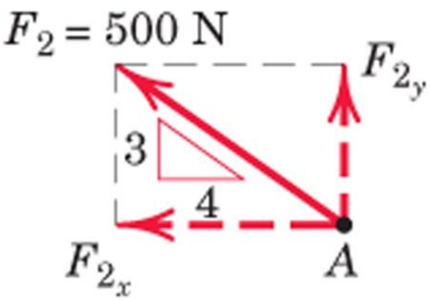


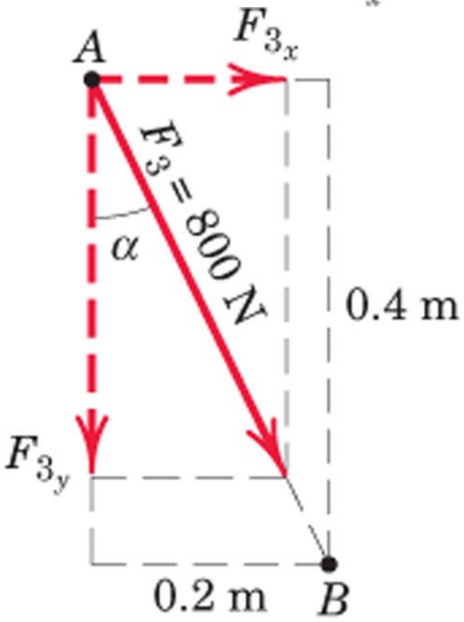
Components of Force



Solution:







$$F_{1_x} = 600 \cos 35^\circ = 491 \text{ N}$$

$$F_{1_y} = 600 \sin 35^\circ = 344 \text{ N}$$

$$F_{2_x} = -500(\tfrac{4}{5}) = -400 \text{ N}$$

$$F_{2_y} = 500(\tfrac{3}{5}) = 300 \text{ N}$$

$$\alpha = \tan^{-1}\left[\frac{0.2}{0.4}\right] = 26.6^\circ$$

$$F_{3_x} = F_3 \sin \alpha = 800 \sin 26.6^\circ = 358 \text{ N}$$

$$F_{3_y} = -F_3 \cos \alpha = -800 \cos 26.6^\circ = -716 \text{ N}$$

Components of Force

Vector approach: Scalar components of $\mathbf{F_3}$ can be obtained by writing $\mathbf{F_3}$ as a magnitude times a unit vector $\mathbf{n}_{AB}$ in the direction of the line segment AB.

$$\mathbf{F}_3 = F_3\mathbf{n}_{AB} = F_3\frac{\overrightarrow{AB}}{\overline{AB}} = 800\left[\frac{0.2\mathbf{i} - 0.4\mathbf{j}}{\sqrt{(0.2)^2 + (-0.4)^2}}\right]$$

$$= 800[0.447\mathbf{i} - 0.894\mathbf{j}]$$

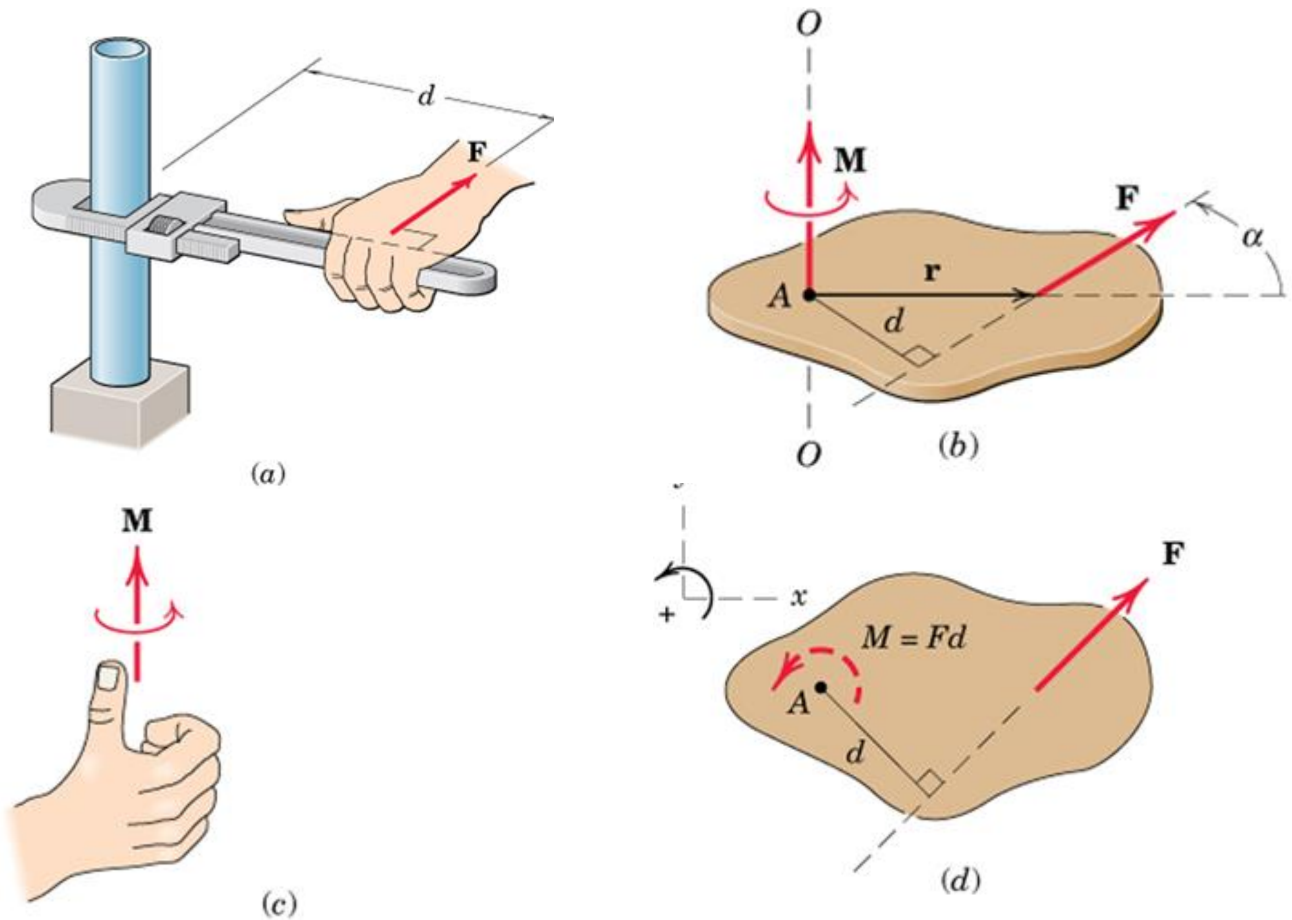
$$= 358\mathbf{i} - 716\mathbf{j}\ \text{N}$$

$$F_{3_x} = 358\ \text{N}$$

$$F_{3_y} = -716\ \text{N}$$

Moment of a Force (Torque)

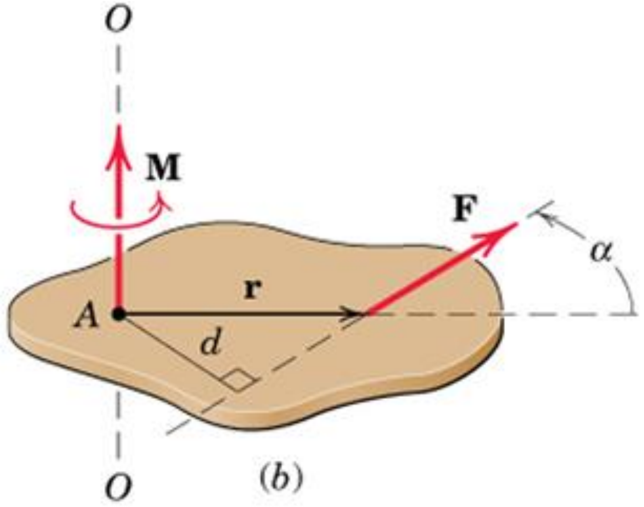
- **Moment** of a **Force ($\mathbf{F}$) @ point A**
  - $\mathbf{M_o} = \mathbf{r} \times \mathbf{F}$



$\mathbf{r}$ = position vector directed from O to any point on the line of action of $\mathbf{F}$

Moment of a Force

- **F** tends to rotate the body about an axis along $\mathbf{M_O}$



$$M_O = rF\sin\alpha = F(r\sin\alpha) = Fd$$

- Moment arm – $d = r\, sin\alpha$