Week 1

Introduction to Engineering Mechanics II (Dynamics)

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Contents

By the end of this lecture, you are able to:

1. Understand the scope of mechanics
2. Understand and differentiate between kinematics and kinetics
3. Define and explain fundamental concepts and principles
4. Classify different types of motion of solid bodies
5. Recognize when a Rigid body can be treated as a particle
6. Understand how the course chapters are constructed and what to expect in each chapter

1.1 Understand the scope of mechanics

- **Mechanics is defined as the science that describes and predicts the *conditions of rest or motion* of *bodies* under *the action of forces* [1].**
- **It consists of the mechanics of solid *bodies*, and mechanics of *fluids*.**

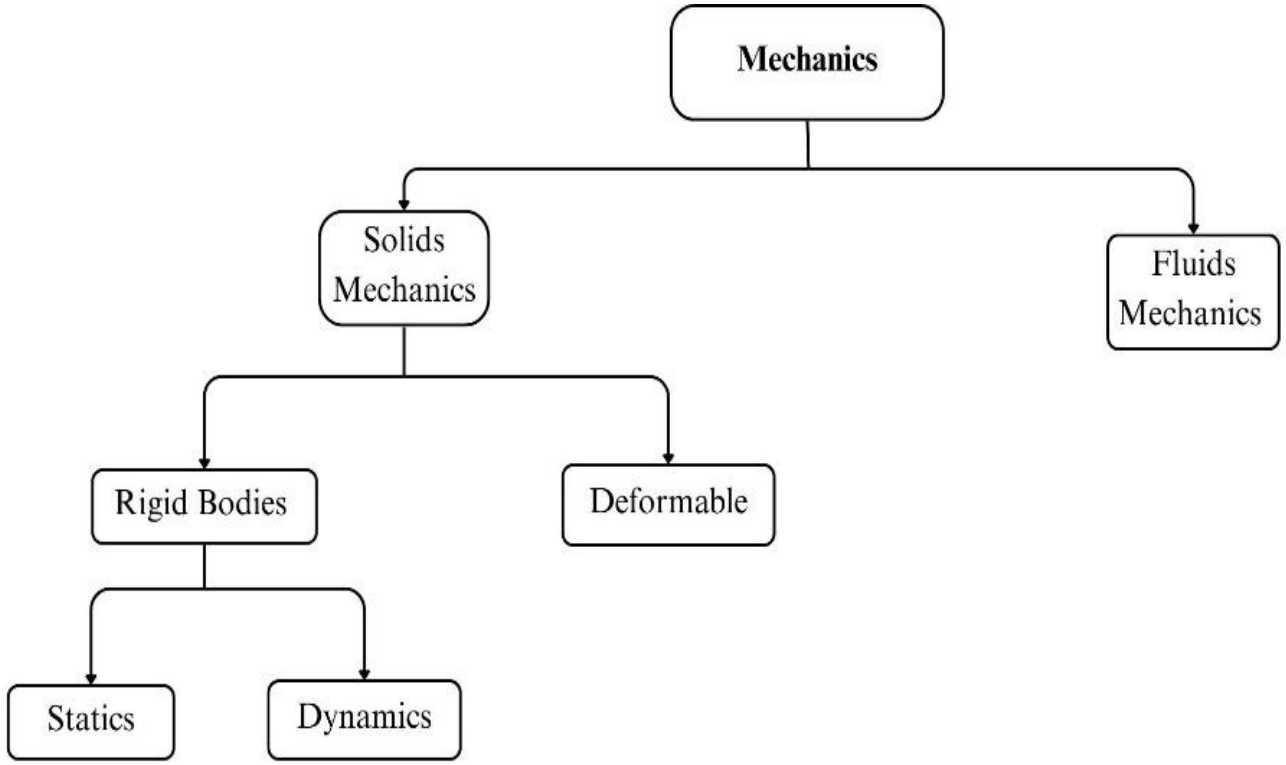


Figure 1. Classifications of engineering mechanics

Mechanics of Fluids

- **Mechanics of Fluids (often called Fluid Mechanics) studies the behavior of fluids (liquids and gases) and how they interact with forces and with their surroundings [2].**

  - Focus is on pressure, velocity, and flow behavior of fluids
  - unlike solids that only deform, fluids change shape continuously. Their behavior and math are very different from solids.
  - They are studied separately on course called fluid mechanics.
  - Examples: water flowing in a pipe, air moving over a wing, oil in a pump

Mechanics of Solids

- **Mechanics of Solids is the study of the *behavior of solid materials and structures* under external forces [3].**

Solid mechanics assumption

As Rigid bodies

- The Body does not deform under applied forces (Less deformation)
- Studies the external response of a body to external forces
- Focus are motion (velocity and acceleration), equilibrium, displacement, and reactions etc.

As Deformable body

- The body will deforms when external forces are applied
- Studies the internal response of a body to external forces
- Main parameters or Focus are Stress, strain, deformations, elasticity, and plasticity etc
- studied in a course called mechanics of materials(Strength of materials)

- NB : In this course, we assume ***solid bodies are perfectly rigid***.

Example on both assumptions

- The image shows a bar with supports in the middle and balls at the ends.
- In the first case, the bar bends a lot when loaded, so we treat it as a deformable body.
- In the second case, the bending is so small that we ignore it and assume the bar is rigid.

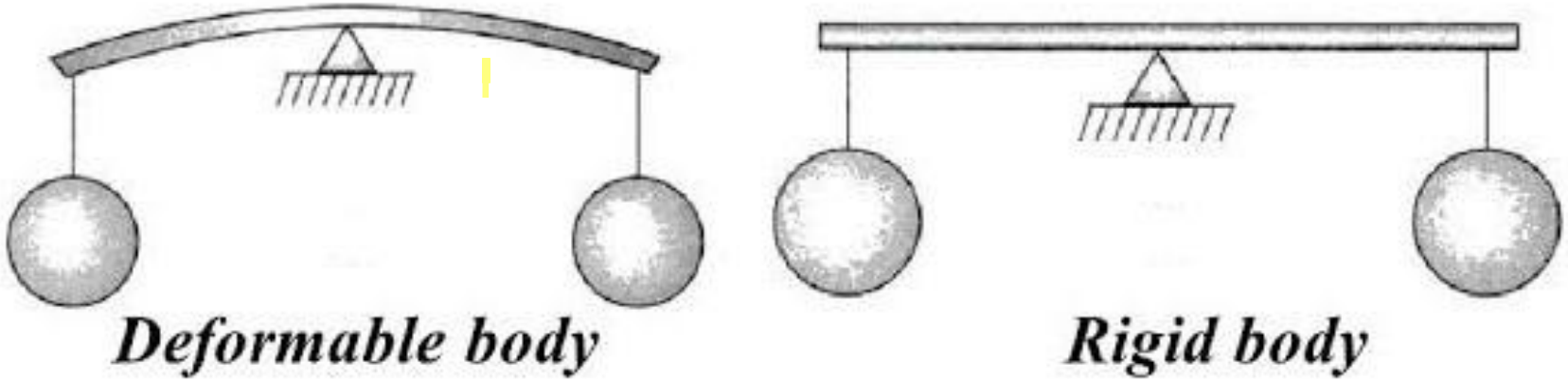


Figure 2. Rigid body Vs Deformable

Url : https://www.aakash.ac.in/important-concepts/Maths/dynamics-of-rigid-bodies-formulas

- In mechanics, we often use this **rigid body** assumption to make analysis easier

Solid Rigid bodies mechanics

- **The mechanics of solid rigid bodies is further subdivided into statics and dynamics**

Statics

- deals with bodies at rest or condition of rest
- It focusses on Equilibrium conditions, support reactions, force systems
- The Equilibrium conditions are: $\sum F=0$, $\sum M=0$
- It relies on the principle of newtons first law
- Used in Analyzing structures like bridges, buildings, cranes
- studied in a course called Engineering mechanics I (statics) which is a pre-request for dynamics

Dynamics

- deals with bodies in motion or condition of motion
- It describes the relationship between force and motion
- It relies on the principle of newtons second law $\sum F=Ma$
- Used to analyze moving systems like vehicles, projectiles, machinery parts.
- It has two Subdivisions: **Kinematics and Kinetics** which we described them in detail latter.

NB: The primary ***emphasis*** of this ***course is on dynamics***

1.2) Dynamics of solid rigid bodies

- **Focuses on analyzing the motion of bodies and the forces causing that motion. It is broadly classified into two branches: kinematics and kinetics [4].**

1.2.1 Classification of dynamics

Kinematics

- is the study of motion parameters without worrying about what causes the motion
- the parameters such us position, velocity, acceleration studied
- it is a tool or foundation for kinetics

Classification of dynamics cont'd…

kinetics

- studies how forces and mass cause an object to move or change its motion.
- it connects motion with the forces and masses that cause it.
- It uses Newton's laws, work energy, and momentum principles to relate the motion with the causing force

- NB: In dynamics the main objective is to study kinetics, The concept of kinematics is learned as a necessary tool to support this goal.

1.2.2) Fundamental Concepts and Principles

- **The basic concepts used in mechanics are space, time, mass, and force [4].**

Space

- Helps to determine the position any point at any given time. The position of a any point is defined using three distances measured from a reference point in three directions (x,y,z).

Time

- used to describe the sequence of events, and to measure the duration and rate of change of motion.

Mass

- is a measure of the amount of matter in a body and its resistance to acceleration(motion) when a force is applied.

Force

- represents the action of one body on another.

Fundamental principles

The study of elementary mechanics rests on six fundamental principles, based on experimental evidence [5].

1. Parallelogram Law

- **used to replace two forces acting on a particle by single force, called their resultant (combined effect)**

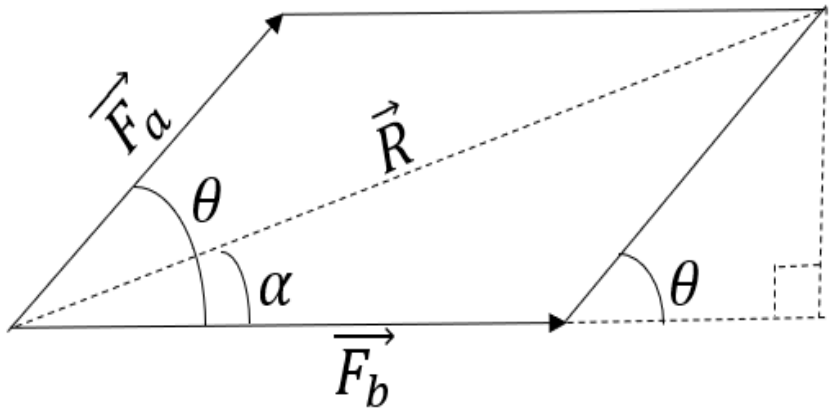


Figure 3. Parallelogram Law

Resultant, $\vec{R} = \sqrt{F_a + F_b + 2F_a F_b cos\theta}$

Direction of $\vec{R}$, $\tan \boldsymbol{\alpha} = \dfrac{F_a \, sin\theta}{F_b + F_a \, cos\theta}$

Principles Cont'd

2. Principle of Transmissibility

- **States that the condition of equilibrium or motion of a rigid body is unchanged if a force is moved along its line of action.**

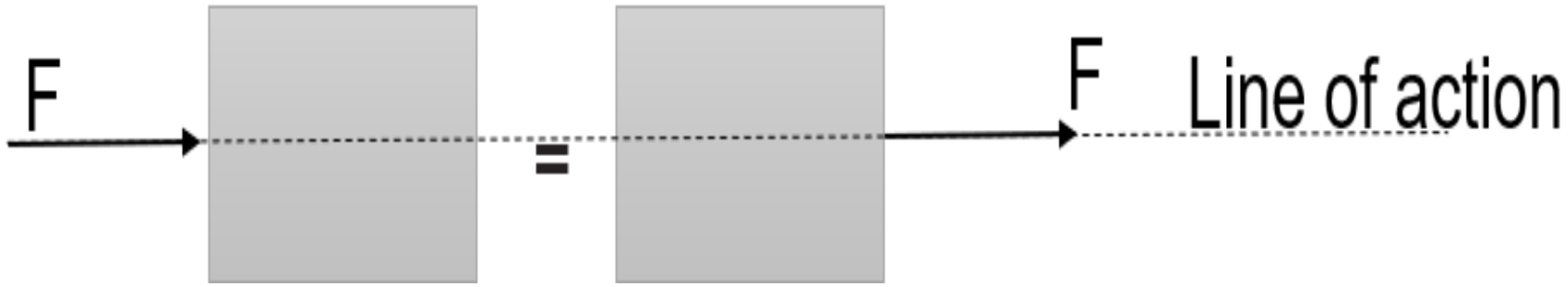


Figure 4. Principle of Transmissibility

3.Newton's Three Laws of Motion

First Laws of Motion

- A body remains at rest or in uniform motion in a straight line unless acted upon by an external force.
- meaning things don't change their motion on their own.
- It Explains the property of inertia (resistance to change in motion).

Second Law

- States that force = mass × acceleration (F = ma), Showing the relationship between force, mass, and acceleration.
- Shows the relationship between cause (force) and effect (acceleration).

Third Law

- For every action force, there is an equal and opposite reaction force.
- Action and reaction forces are equal in magnitude, opposite in direction, and collinear.

4. Newton's Law of Gravitation

- This force of attraction was first observed by Sir Isaac Newton and was formulated as Newton's Law of Gravitation in 1680.
- state that Every particle attracts every other with a force proportional to their masses and inversely proportional to the square of the distance between them.
- Mathematically expressed as:

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

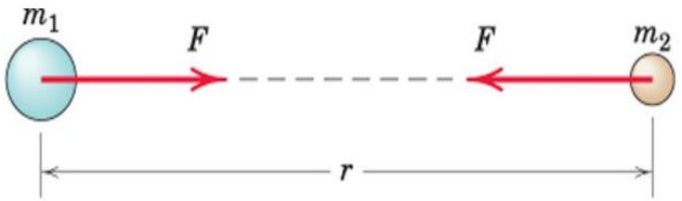


Figure 5. attraction between two bodies

Gravitation or Gravity is the force of attraction between any two bodies

NB: Near Earth's Surface Gravitational field strength is 9.8 m/s².

1.2.3) Motion of solid rigid bodies

The various types of rigid-body motion can be conveniently grouped as follows [5].

1 Translation

- any straight line inside the body maintains the same orientation during the motion.
- If the paths are straight lines, the motion is called **rectilinear translation** ; if the paths are curved lines, the motion is called **curvilinear translation**

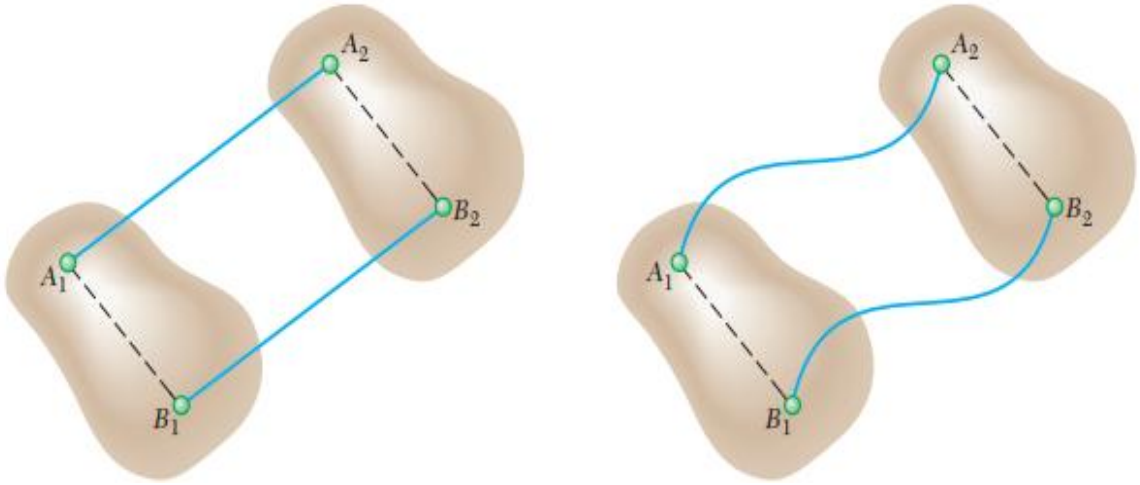


Figure 6. Translation

Source: Vector Mechanics for Engineers: Dynamics, Johnston, E. R., & Clausen, W. E., McGraw-Hill, 11th ed., 2015,page 979

2 Rotation About a Fixed Axis

- The particles forming the rigid body move in parallel planes along circles centered on the same fixed axis
- The particles located on the axis of rotation have zero velocity and zero acceleration.
- Particles or points on the body have the same angular motion and different linear motion

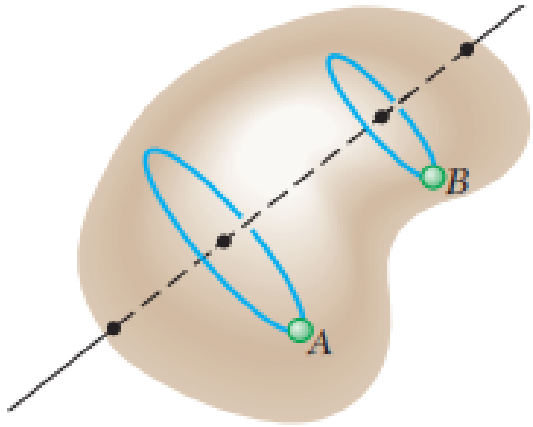


Figure 7. Fixed axis rotation

Source: Vector Mechanics for Engineers: Dynamics, Johnston, E. R., & Clausen, W. E., McGraw-Hill, 11th ed., 2015,page 979

- **Be careful not to confuse rotation with certain types of curvilinear translation [4]**

In curvilinear translation , particles move in parallel circles and any line on the body keeps the remains parallel. In rotation, particles move in concentric circles and lines on the body change orientation.

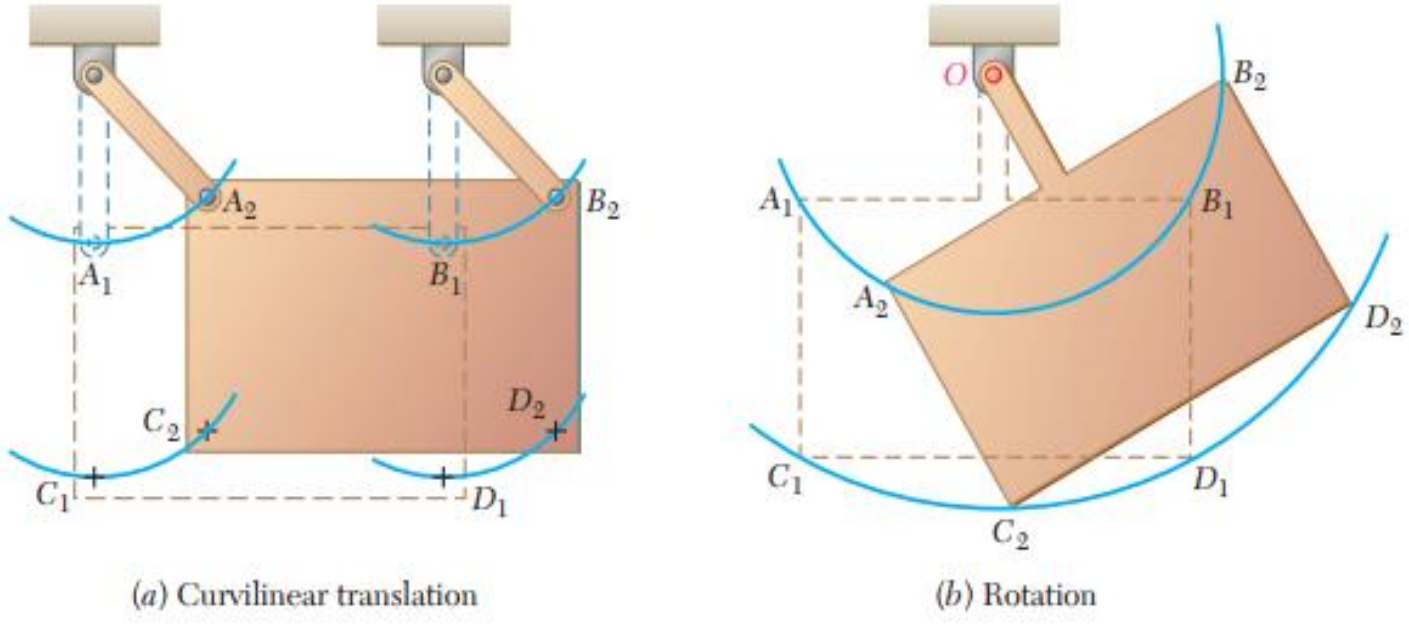


Figure 8. Curvilinear translation Vs rotation

Source: Vector Mechanics for Engineers: Dynamics, Johnston, E. R., & Clausen, W. E., McGraw-Hill, 11th ed., 2015,page 979

3 General Plane Motion

- Motions in which all the particles of the body move in a single plane
- Any plane motion that is neither a rotation nor a translation is referred to as general plane motion.
- It combined translational and rotational motion

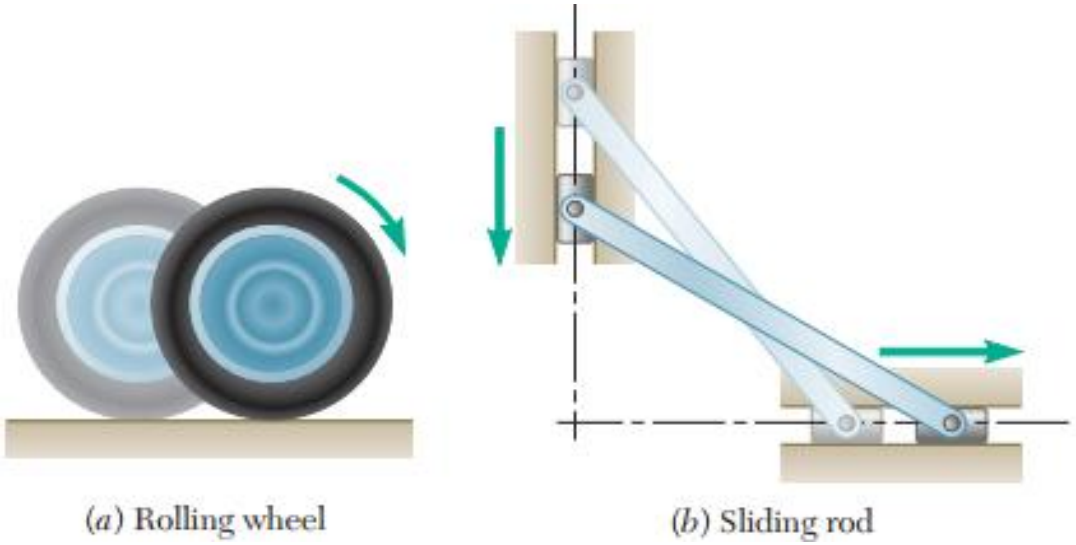
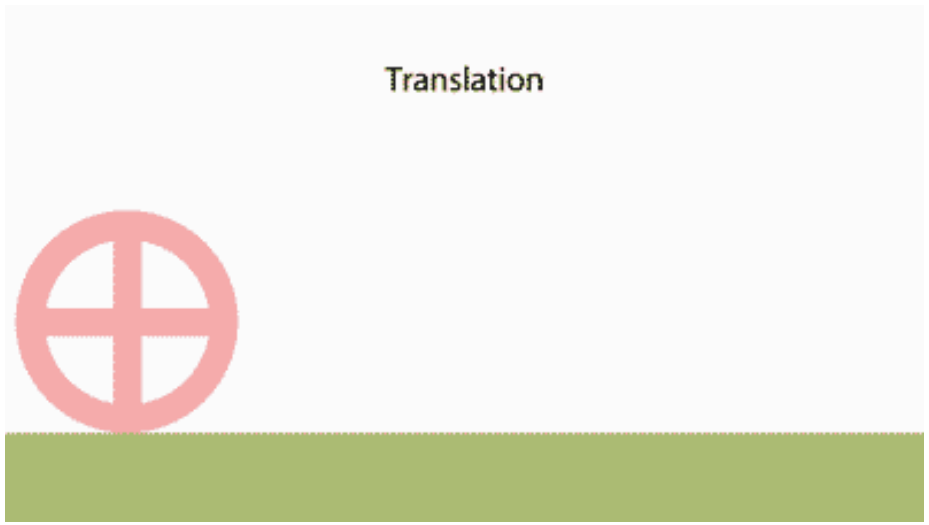
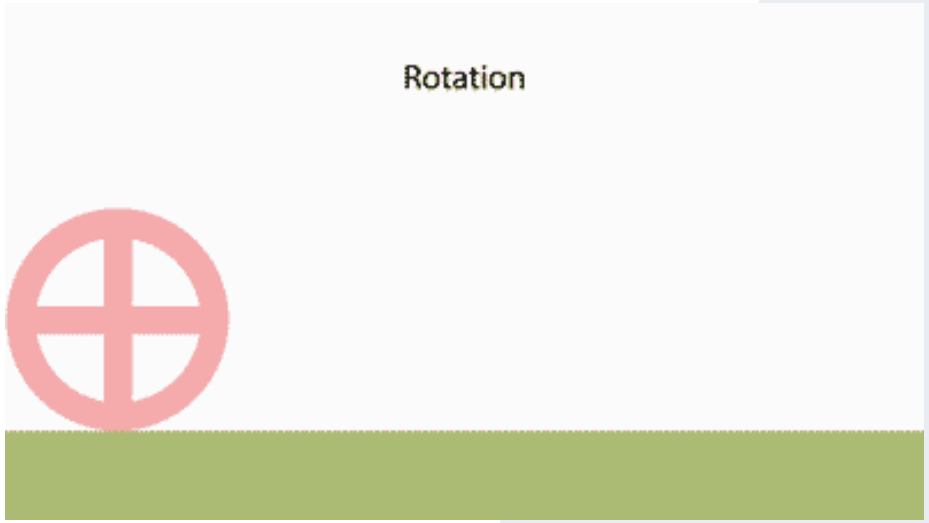


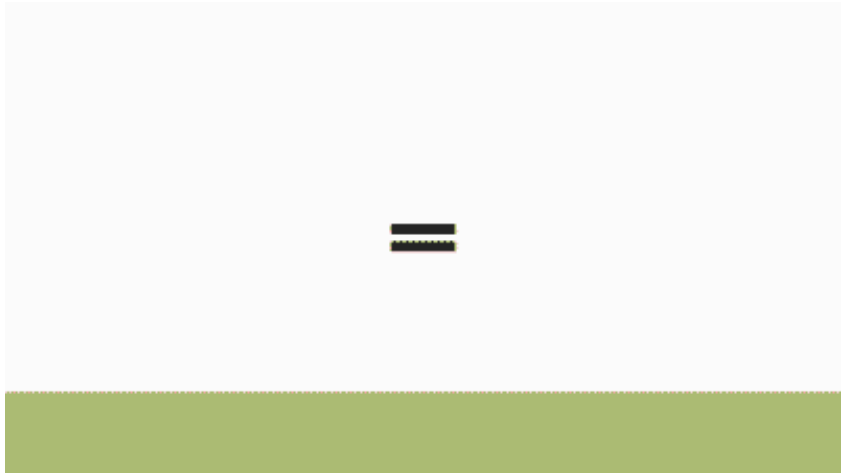
Figure 9 . General plane motion

Source : Vector Mechanics for Engineers: Dynamics, Johnston, E. R., & Clausen, W. E., McGraw-Hill, 11th ed., 2015,page 979

Motion cont'd…







Url:https://commons.wikimedia.org/wiki/File:Rolling_animation.gif

Figure 10. Motion types separately

Example Motion of motion types on Mechanisms

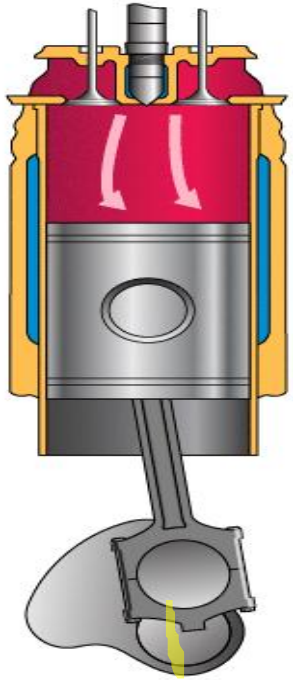


Figure 11: Piston-cylinder

Source: The moving GIF. (2014, July 23). Frame animation of a piston's 4-stroke cycle. *https://themoving-gif.tumblr.com/post/92678111225/frame-animation-of-a-pistons-4-stroke-cycle*

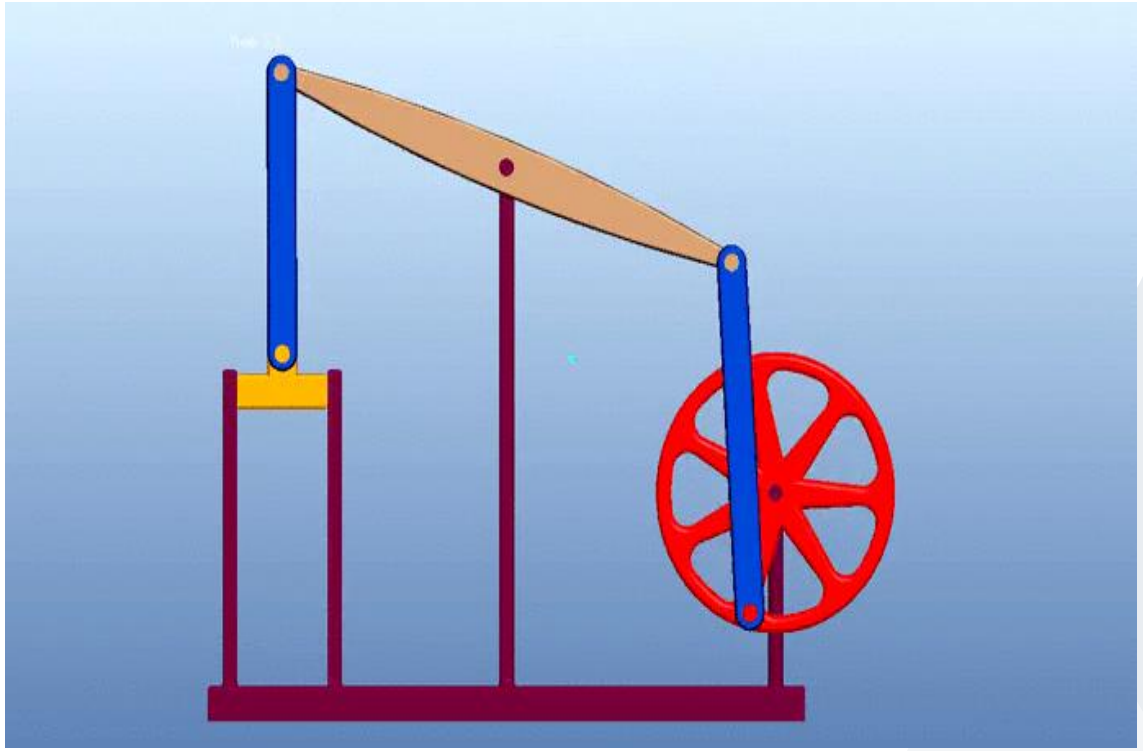


Figure 12 : Beam engine

Source: GrabCAD. (n.d.). *Simple Beam engine*. GrabCAD. https://grabcad.com/library/simple-beam-engine-1

1.2.4) **Rigid Bodies and Particles**

- **In dynamics , solid rigid bodies sometimes are treated as a particle and the difference between them is as follows [1] :**

Rigid Bodies Vs Particles

Particles	Rigid Bodies
• is a body of negligible size, having only mass but no shape or dimensions •It is Considered as a point mass having translational motion • Its rotation and internal structure are ignored	• By definition it is body in which the distance between any two points remains constant, even when external forces are applied • Compared to particle, It Has size and shape With Both translational and rotational motion. • it is the main objective of study

- So why we sometimes treat solid rigid bodies as a particle?

Motion cont'd…

- we sometimes treat a solid rigid body as a particle when we are only interested in its overall movement from one place to another, known as translational motion.
- In pure translation, every point on the rigid body has the same velocity and acceleration, so its motion is identical to that of a particle.
- **For example,** Imagine a **car moving straight down a road at constant speed**. Every poi nt on the car (roof, wheels, doors, etc.) moves forward at the same speed and in the same direction**.**

- Since all parts of the car move the same way, we can simplify by treating the whole car as a particle at its center of mass (i.e, the translational motion of the entire car is equivalent to the translational mo tion of a ball) [5].

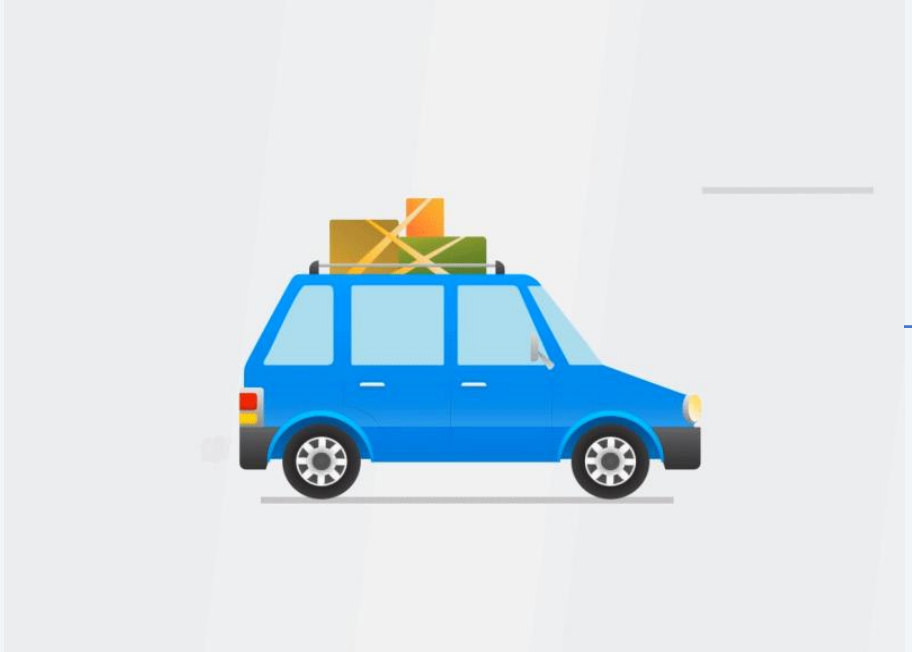


Figure 13. Pure translation of car

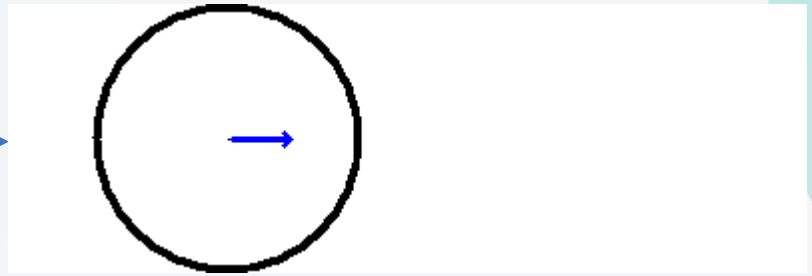


Figure 14 .Particle approximation of the car

Source: *car Animation free* [Animation template]. Dribbble .Zourob, M. (2016, November 22). https://dribbble.com/shots/3111670-car-Animation-free

- On another hand , If the car were also **rotating** (like skidding and spinning), then we couldn't t reat it as a particle anymore, we would have to study it as a rigid body in rotation + translation, see spinning car the example below

Figure 15. Pure Rotation of car

Source: "car Animation free." Dribbble . Zourob, Mohammed., 22 Nov. 2016, https://dribbble.com/shots/3111670-car-Animation-free. Accessed 7 Sept. 2025

1.3 Understand the course chapters

- **Based on the above concepts and definitions, This course is divided into five chapters (including this chapter or introduction).**

We begin study by

- treating rigid bodies as particles to study translational motion only (**kinematics of particles**).

Then,

- we connect this translational motion to the forces that cause it (**kinetics of particles).**

After that,

- we remove the particle assumption and study rigid bodies in rotational motion as well as combined translational and rotational motion (general plane motion), which is covered under **kinematics of rigid bodies.**

Finally,

- we relate these rigid body motions to the forces that produce them (**kinetics of rigid bodies**).

Examples

To understand the chapters and their applications more, see at a classic slider-crank or four-bar linkage type mechanism, which is composed of: Slider/Piston ,Connecting Rod, Crank ,Rocker Arm

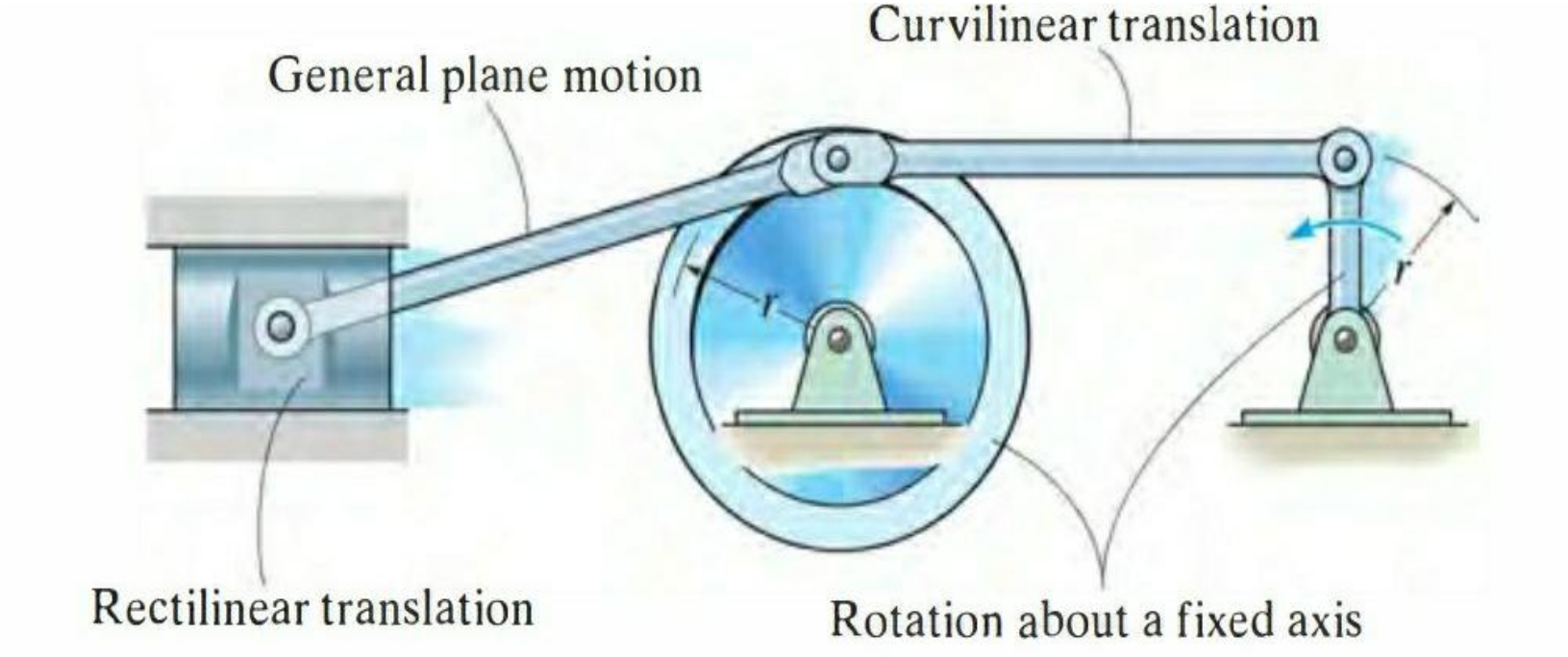
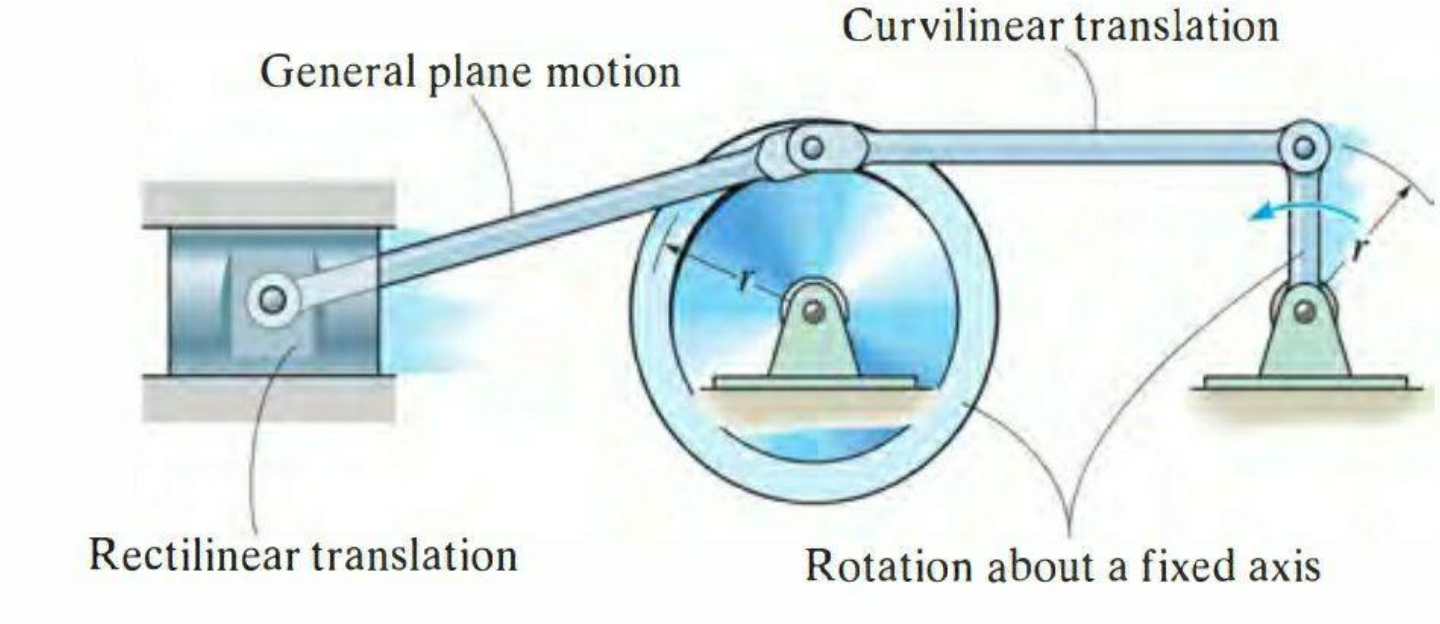


Figure 16. slider-crank

Source: Engineering Mechanics: Dynamics, Hibbeler, Rusel M.,Prentice Hall,10th ed., 2003,page 328

DYNAMICS COURSE CHAPTER MAPPING

- **Now, let's place each link into the right chapter of a Dynamics course**



Link	Type of Motion	Relevant Chapter
1. Piston (Slider)	Rectilinear Translation	Kinematics and Kinetics of Particles
2. Rocker Arm	Curvilinear Translation	
3. Cranks	Rotation about Fixed Axis	Plane Kinematics and Kinetics of Rigid
4. Connecting Rod	General Plane Motion)	

Activity 1

Classify Motions of Power Hacksaw parts shown below. Identify the motion of each link in the mechanism when the flywheel or crank rotates ?

- Crank OB (radius 100 mm) , Coupler/Link AB (length 450 mm) and Saw slider (moves along the horizo ntal guide)

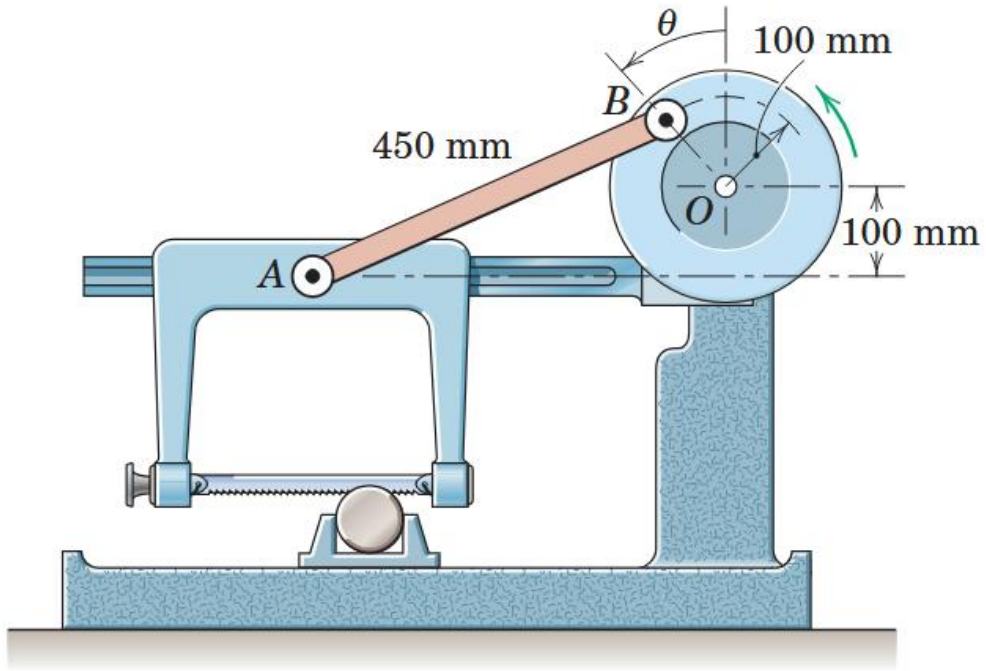


Figure 17. Power Hacksaw

Source: Engineering Mechanics - Dynamics, Meriam J.L.,John Wiley & Sons , 9th ed., 2020., page 383

Activity 2

- Based on what we have learned Identify the type of motion for each link of beam engine when crank O A rotates . Then, think about how to treat them(particle or rigid body) when analyzing and also identify which chapter of the Dynamics course will cover the analysis of these motions**?**

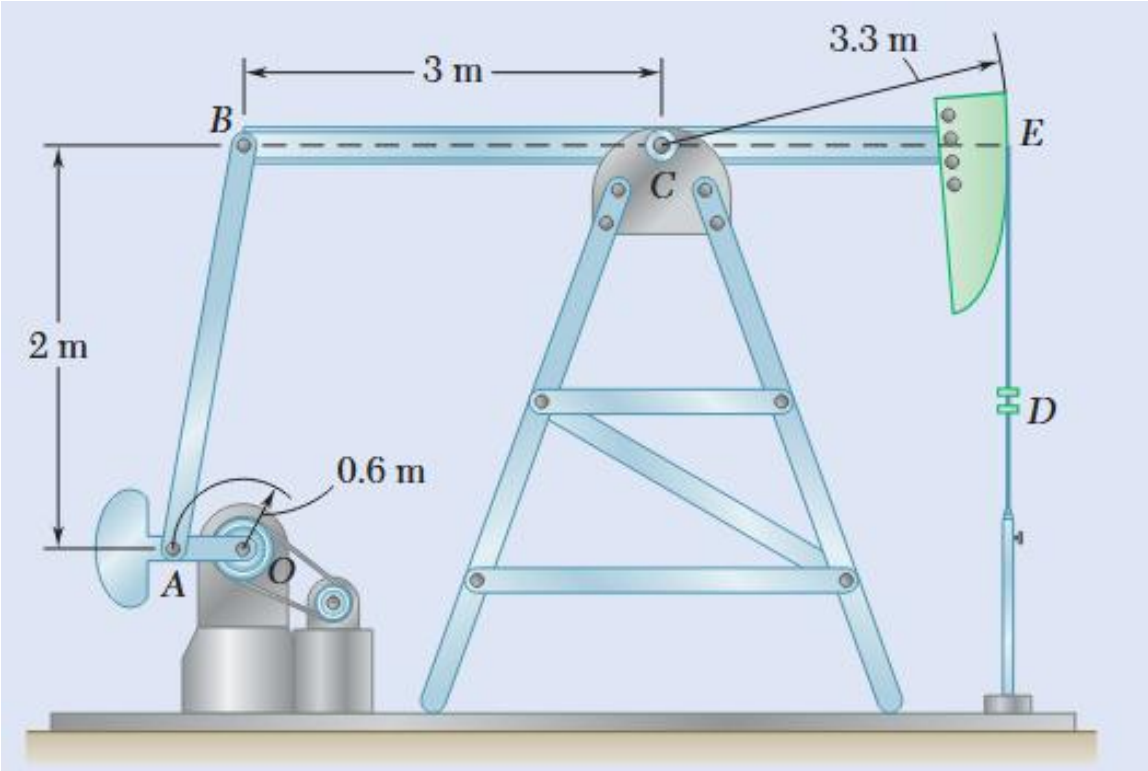


Figure 16. beam engine

Source : (Vector Mechanics for Engineers: Dynamics, Johnston, E. R., & Clausen, W. E., McGraw-Hill, 11th ed., 2015,page 1045.

Summary

In This Lecture We Covered:

1. Mechanics and its branches → Statics (rest) & Dynamics (motion)
2. Dynamics and Differentiate between kinematics and kinetics
3. Key concepts → Space, Time, Mass, Force, Newton's Laws, and principles
4. Solid Rigid Body Motion → Translation, Rotation, General Plane Motion
5. Rigid body vs particles → description
6. Course Roadmap → from particles → rigid bodies

References

[1] Dynamics, Hibbeler, Rusel M.,Prentice Hall,10th ed., 2003

[2] Cengel, Yunus, and John Cimbala. *Ebook: Fluid mechanics fundamentals and applications (si u nits)*. McGraw Hill, 2013.

[3] Car Animation free [Animation template] Zourob, M. (2016, November 22). Dribbble. https://dribbble.com/shots/3111670-car-Animation-free

[4] Engineering Mechanics - Dynamics, Meriam J.L.,John Wiley & Sons, 9th ed., 2020.,

[5] Vector Mechanics for Engineers: Dynamics, Johnston, E. R., & Clausen, W. E., McGraw-Hill, 11th ed., 2015