Warm welcome to every body

ENGINEERING MECHANICS

STATICS & DYNAMICS

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Disclaimer

These lecture slides were prepared and used by me to conduct lectures for first-year B. Tech. Students as part of the course 'Engineering Mechanics' (XEC 01) at the National Institute of Technology Durgapur. Theories, problems, figures, and concepts used in the slides to fulfil the course requirements are primarily taken from the following textbooks and PowerPoint slides available on the internet. The material is used purely for educational purposes. Students are instructed to use it for their reading. Don't distribute as the presentation slides contain copyright materials. Despite my best efforts, some of the content may contain errors. Students are requested to rectify when using the same, and I invite them to write to me about the mistakes to ranajnkumar.mitra@me.nitdgp.ac.in. I thank the following authors for making their books and lecture notes available for reference.

- **Vector Mechanics for Engineer: Statics, 9th edition, Ferdinard P. Beer and E. Russell Johnston, Jr., McGraw-Hill**
- **Vector Mechanics for Engineer: Statics, 10th edition, Ferdinard P. Beer and E. Russell Johnston, Jr., McGraw-Hill**
- **Lecture notes on Engineering Mechanics: Statics, J. Walt Oler, Taxas Tech University, 9th edition, McGraw-Hill Companies, Inc.**
- **Lecture notes on Engineering Mechanics: Statics, John Chen, California Polytechnic State University, McGraw-Hill Companies, Inc.**

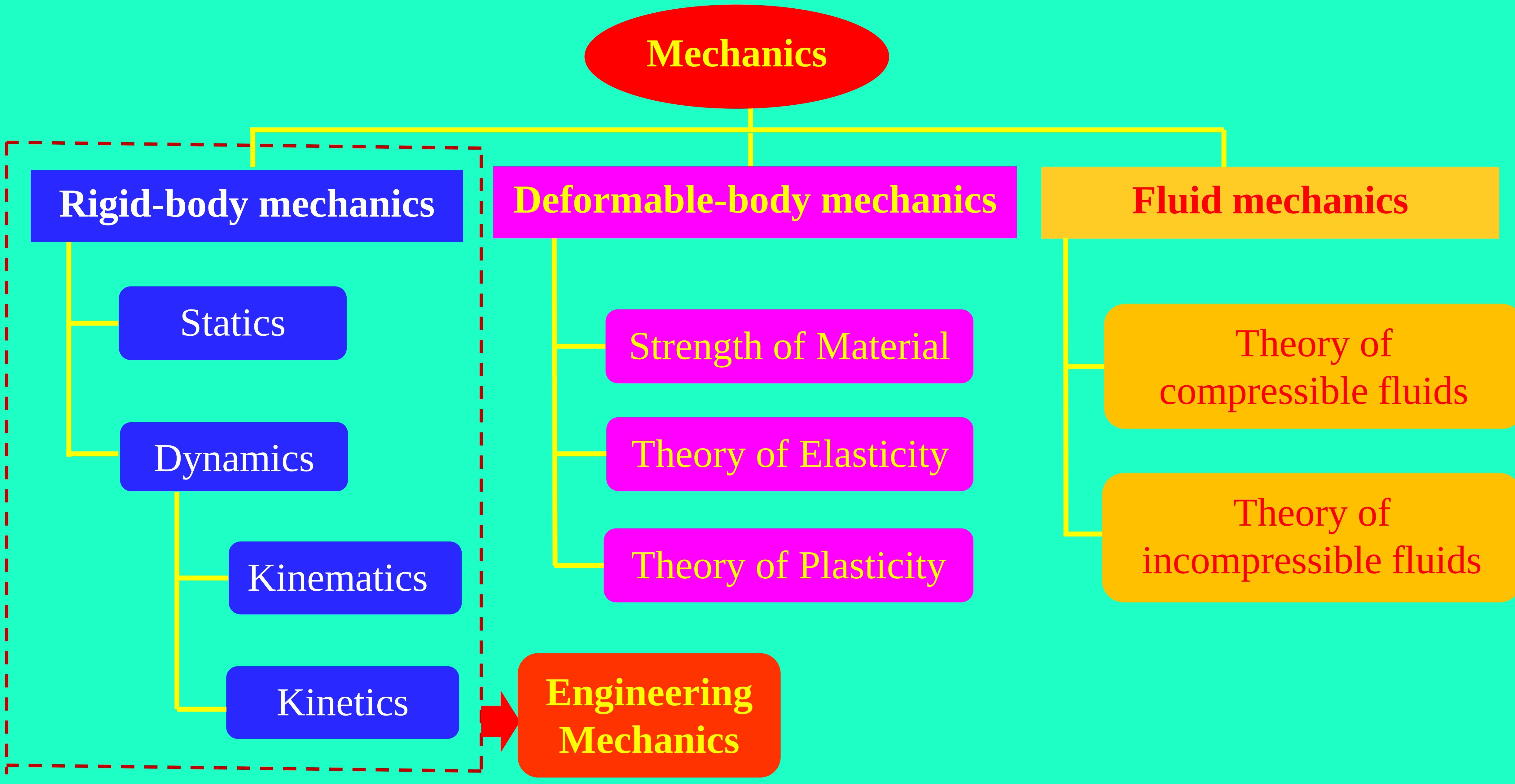
Dr. Ranjan Kumar Mitra

Chapter 1
Introduction

Brief outline of the lecture

- What is Mechanics?
- What is Engineering Mechanics?
- What can you do with statics knowledge?
- System of Units
- Method of Problem Solution
- Idealizations in Mechanics
- Laws of Mechanics
- Force and force systems
- Principle of transmissibility of a force

Introduction



Introduction

What is Mechanics?

- Mechanics is the study of bodies under the action of forces.
- Categories of Mechanics:
  - *rigid-body mechanics*
  - *deformable-body mechanics and*
  - *fluid (gas or liquid) mechanics*

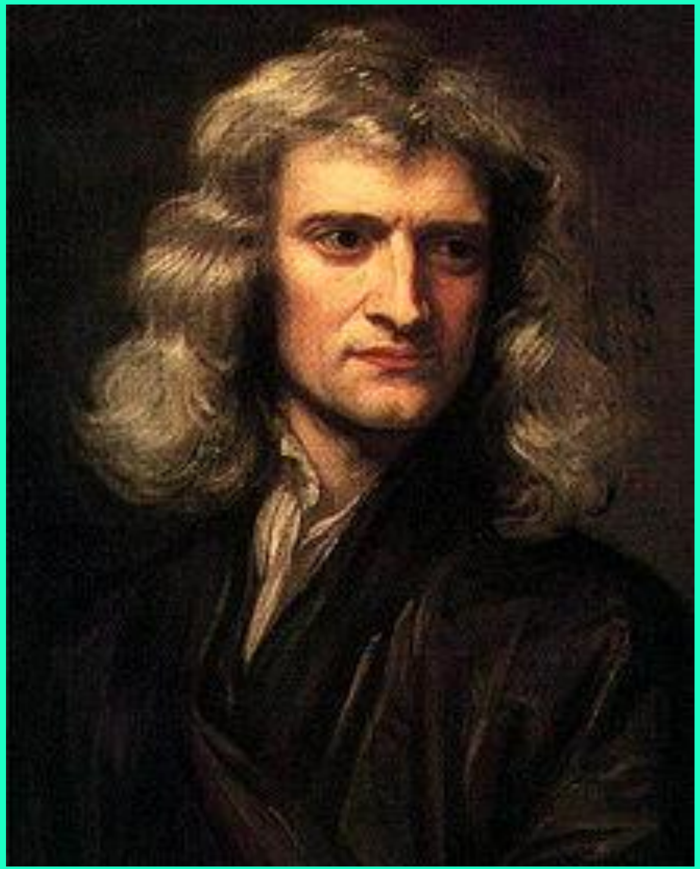
What is Engineering Mechanics?

- Engineering Mechanics or *rigid-body mechanics* is the science that consider the motion of bodies and effect of forces on that motion.
- Engineering Mechanics is classified as:
  - *Statics – bodies at rest or at constant velocity*
  - *Dynamics – accelerating bodies*

- Mechanics is an applied science, closely related to physics, so many of the concepts will build on that prior knowledge.
- Mechanics is the foundation of many engineering topics and is an indispensable prerequisite to their study.

Introduction

Two great milestones in the field of Engineering Mechanics



Sir Isaac Newton (1642-1727)

Stephen P. Timoshenko (1878-1972)

What can you do with statics knowledge?

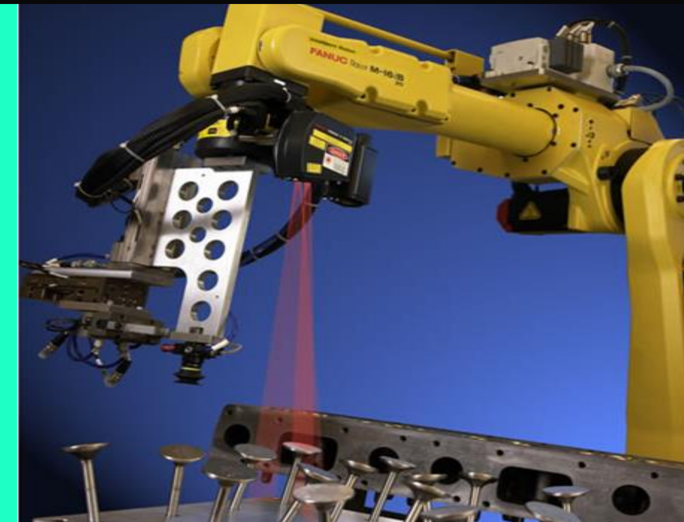
Calculate the force in each member of this structure (a truss) in order to design it to withstand the loads that it will experience due to self weight of the structure and weights due to moving vehicles etc.

What can you do with statics knowledge?

Determine the forces that this prosthetic arm will need to withstand to make exercise possible for the wearer.

What can you do with statics knowledge?

- In industry robots are used for repeat tasks like piking an object from one location and placing it at other location. They never get bored and never tire. They can survive in places where people can't. They can carry out tasks too dangerous for people.



- Your tasks is to decide speed, find power, calculate different forces acting on the body. The forces involved are inertia force, friction force due to wind, rolling resistance etc. Overall, your design should satisfy all practical needs. To perform the above satisfactorily you must gain sound knowledge on mechanics.

System of Units

Two major systems of units:

(a) The International System (SI)

The basic units are: length, time, and mass. Force is the derived unit.

$$F = ma, \qquad 1N = (1kg)\left(1\frac{m}{s^2}\right).$$

(b) U.S. Customary System (FPS)

The basic units are length, time, and force which are arbitrarily defined as the foot (ft), second (s), and pound (lb). Mass is the derived unit.

$$m = \frac{F}{a}, \qquad 1slug = \frac{1lb}{1\,ft/s}$$

Prefixes for SI units

When using SI units, we express everything metrically, which means they involve factors of 10. For example, we know that, 1000 **milli**meters in a meter, 1000 grams in a **kilo**gram, and so on. The words 'milli' (symbol m)), 'kilo' (symbol k)) are called Greek prefixes and used to maintain brevity. All the prefixed necessary for this course are listed in Table-2. It's worthy to note that most of the symbols in Table-2 are in lowercase (exceptions are T, G and M). No Plurals.

System of Units

Table 1 Basic SI Units

Physical quantity	Unit	Symbol
Length	metre	m
Time	second	s
Mass	kilogram	kg

Table 2 SI Prefixes

Multiple	Prefix	Symbol	Example
10^{12}	tera	T	terabyte
10^{9}	giga	G	gigahertz
10^{6}	mega	M	megapascal
10^{3}	kilo	k	kilometre
10^{2}	hecto	h	hectogram
10^{1}	deca	da	decametre
10^{-1}	deci	d	decilitre
10^{-2}	centi	c	centimetre
10^{-3}	mili	m	millisecond
10^{-6}	micro	µ	microfarad
10^{-9}	nano	n	nanometre
10^{-12}	pico	p	picosecond

Table 3 Derived SI Units

Physical quantity	Unit	Symbol
Force	Newton	$N=kg\ m/s^2$
Energy, Work, Heat	joule	$J=Nm=kg\ m^2/s^2$
Power	watt	$W=J/s=Nm/s$
Pressure, Stress	pascal	$Pa=N/m^2$
Frequency	hertz	$Hz=s^{-1}$

System of Units

Table-4 lists some physical quantity (alphabetically) with correct unit symbol and some common mistakes done by students. Please note that no full stop, plural, dot or dash should be used. Most of the unit symbols are in lowercase. Of course some exceptions are there; e.g. N (newton), J (joule), W (watt), Hz (hertz), Pa (pascal).

Table 4 Units of some common physical quantities at a glance

Physical quantity	Unit symbol	Common mistakes
Angle	rad	Rad
Angular velocity	rad/s	Rad/S
Area	m^2	M^2
Couple	Nm	NM, nm
Density	kg/m^3	Kg/m^3
Displacement	m	M
Energy	J (=Nm)	j
Force	N	n
Frequency	Hz (=/s)	hz, HZ
Length	m	M

Table 4 continued

Physical quantity	Unit symbol	Common mistakes
Mass	kg	Kg, KG
Modulus of Elasticity	N/m^2 (=Pa)	n/m^2, N/M^2
Moment	Nm	nm, NM
Momentum	kg m/s (Ns)	Kg m/s, kg m/sec
Moment of inertia area	m^4	M^4
Moment of inertia mass	kg m^2	Kg m^2
Power	W (=Nm/s)	w
Pressure	N/m^2 (=Pa)	n/m^2
Specific energy	J/kg	J/Kg, j/kg
Specific volume	kg/m^3	Kg/m^3
Speed	m/s	m/sec
Stress	N/m^2 (=Pa)	n/M^2
Time	s	S, sec
Torque	Nm	nm
Velocity	m/s	m/sec

Table 4 continued

Physical quantity	Unit symbol	Common mistakes
Velocity potential	m^2/s	m^2/sec, m^2/S
Viscosity dynamic	Ns/m^2	NS/m^2
Volume	m^3	M^3
Weight	kg	Kg, kgm, kgf
Work	J (=Nm)	j

You're already familiar with the two common ways to describe angles: degrees (^{o}) and radians (rad). When you are concerned with simply an angle, either of them can be used. However in dynamics, when dealing with rotational bodies, you need to sure to use rad/s, or rad/s^2, not $^o/s$ (degree per second) or $^o/s^2$.

Numerical Calculations and Rules for Rounding off Numbers

Always maintain dimensional *homogeneity*; i.e. dimensions have to be same on both sides of an equation. Examples: Distance (m)= Velocity(m/s)× Time(s), Acceleration(m/s^2)=Force(N)/Mass(kg), Work (J) =Force (N) × Displacement(m).

Now that everyone has a calculator that will give a result more than eight figures. It is important that you need to be consistent when rounding off. You may take at least 4 digits after decimal point for intermediate calculations and 3digits for answer. Following are the **general rounding off rules**[†]:

Rule 1: Determine what your rounding digit is (i.e. up to which decimal places you need to round off) and look at the digit to the right of it (underlined digits below). If the underlined digit is 0, 1, 2, 3, 4 simply drop all digits to the right of rounding digit. Examples:

$4.6892\underline{4}895$ may be rounded off to 4.6892 when rounded off to 4^{th} decimal place.

$0.6892\underline{0}895$ may be rounded off to 0.6892 when rounded off to 4^{th} decimal place.

$5.343\underline{3}95$ may be rounded off to 5.343 when rounded off to 3^{rd} decimal place.

$5.340\underline{2}$ may be rounded off to 5.340 when rounded off to 3^{rd} decimal place.

$0.000\underline{4}$ may be rounded off to 0.000 when rounded off to 3^{rd} decimal place.

Rounding Off

Rule 2: Determine what your rounding digit is and look at the digit to the right of it (underlined digit).If the underlined digit is 5, 6, 7, 8, 9 add one to the rounding digit and drop all digits to the right of rounding digit.

4.689250001 may be rounded off to 4.6893 when rounded off to 4^{th} decimal place.

10.689250001 may be rounded off to 10.6893 when rounded off to 4^{th} decimal place.

7.54375 may be rounded off to 7.544 when rounded off to 3^{rd} decimal place.

0.568943 may be rounded off to 0.569 when rounded off to 3^{rd} decimal place.

0.0005 may be rounded off to 0.001 when rounded off to 3^{rd} decimal place.

†*Note: Some teachers prefer the 'Banker's Rule' not discussed here. This rule provides a little more accuracy.*

Method of Problem Solution

- ***Problem Statement:*** Includes given data, specification of what is to be determined, and a figure showing all quantities involved.
- ***Free-Body Diagrams:*** Create separate diagrams for each of the bodies involved with a clear indication of all forces acting on each body.
- ***Fundamental Principles:*** The six fundamental principles are applied to express the conditions of rest or motion of each body. The rules of algebra are applied to solve the equations for the unknown quantities.
- ***Solution Check:*** Test for errors in reasoning by verifying that the units of the computed results are correct, test for errors in computation by substituting given data and computed results into previously unused equations based on the six principles, always apply experience and physical intuition to assess whether results seem "reasonable".

Idealizations in Mechanics

- Most important idealisations are: ***Particle, rigid body and concentrated force***
- Without these idealizations the study of mechanics problems will be unnecessarily complex and involved.

(i) **Particle** Consider mass but zero dimension.

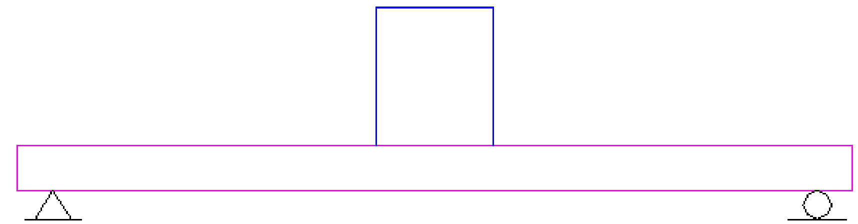
A particle is defined as a body with finite mass but zero physical dimensions. If all the masses of a real body could be compressed to a single point, the resulting object would be a particle. Hence a particle can be considered as a **point mass**.

Fig. While studying the motion of this space vehicle from Earth one may consider it as a particle. *Source: https://www.space.com/32954-india-mini-space-shuttle-test-launch-pictures.html*

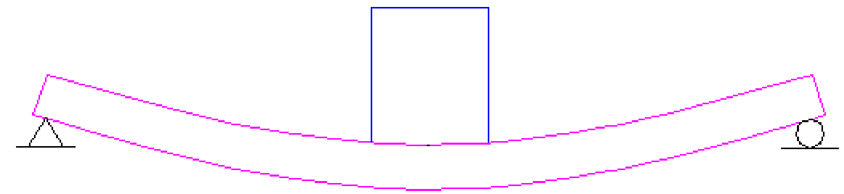
Idealizations in Mechanics

(ii) **Rigid Body** Neglect material property.

- Defined as the body that is not deformed under the action of external forces.
- A rigid body is a collection of particles in firm association and the distances between any pairs of particles do not change.
- In the study of mechanics, we shall assume bodies as absolutely rigid and therefore the material properties will not have to be considered here.



(a) Rigid body assumption: Body does not undergo deformation under loading.



(b) Deformable body: Real bodies undergo deformation when loaded.

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- However, actual structures, machines, mechanisms etc. are not absolutely rigid body and deform to a certain degree when subjected to forces. But these deformations are usually very small, and they can be neglected in rigid body mechanics without appreciable errors.

(iii) **Concentrated Force or Point Force** It is an idealized force assumed to act at a point on a body. All though, all forces are actually distributed over a finite area or volume, they treated as concentrated at a single point of a body.

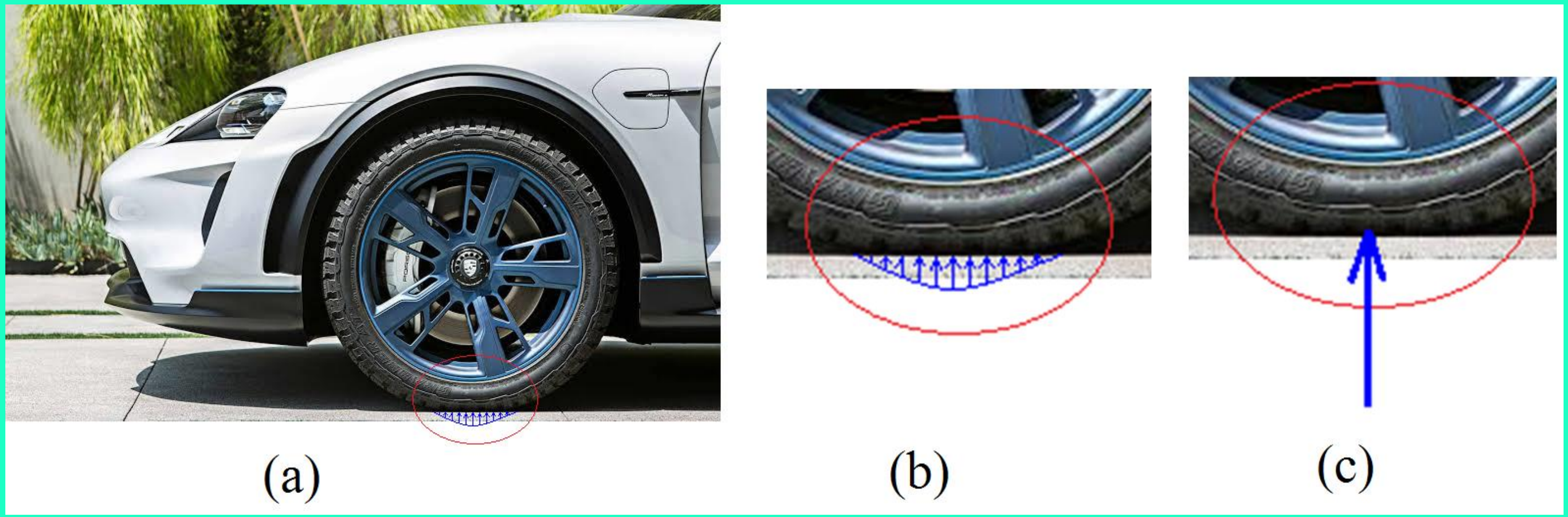


Fig. (a) Reaction force from the road on the car wheel. (b) Practically distributed in nature, (c) Ideally it is frequently assumed to be a concentrated force.

Laws of Mechanics

The entire structure of mechanics rests on a few **fundamental laws**, which are accepted without mathematical proof but obtained as a result of a vast number of experiments. The laws of mechanics are

- Newton's 1st law (**law of inertia**)
- Newton's 2nd law **(law of motion**)
- Newton's 3rd law **(law of action and reaction**)
- **Law of Gravitation** (by Kepler and Newton)
- **The Parallelogram law** (by Varignon and Newton)

Force and Force System

Definition of Force

- A force is the **action of one body on another** which changes or tends to change its motion or deform the body.
- The properties which distinguish one force from a different force is called the characteristics of a force.
- The characteristics of a force are (i) magnitude, (ii) direction, and (iii) line of action.

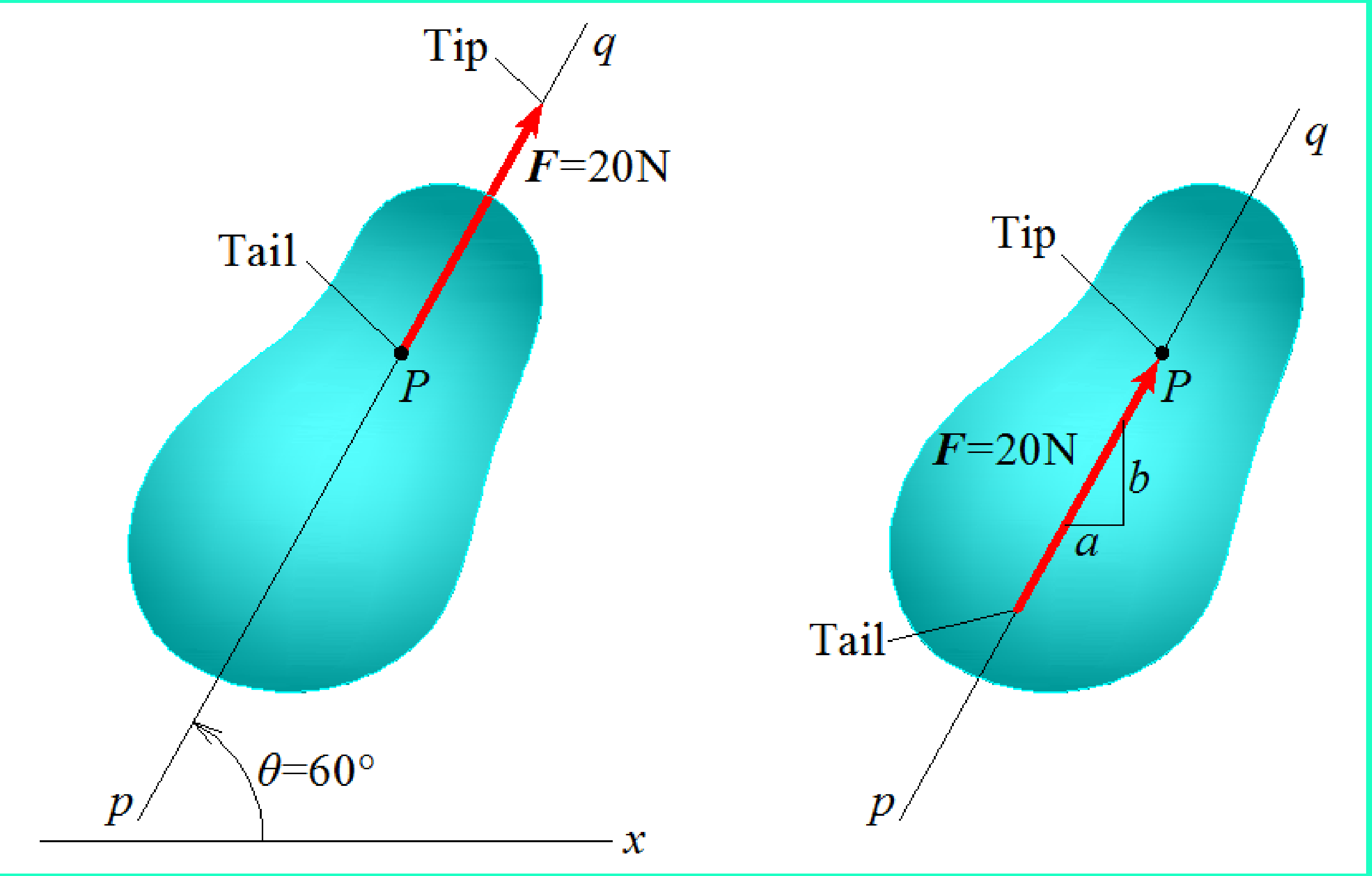
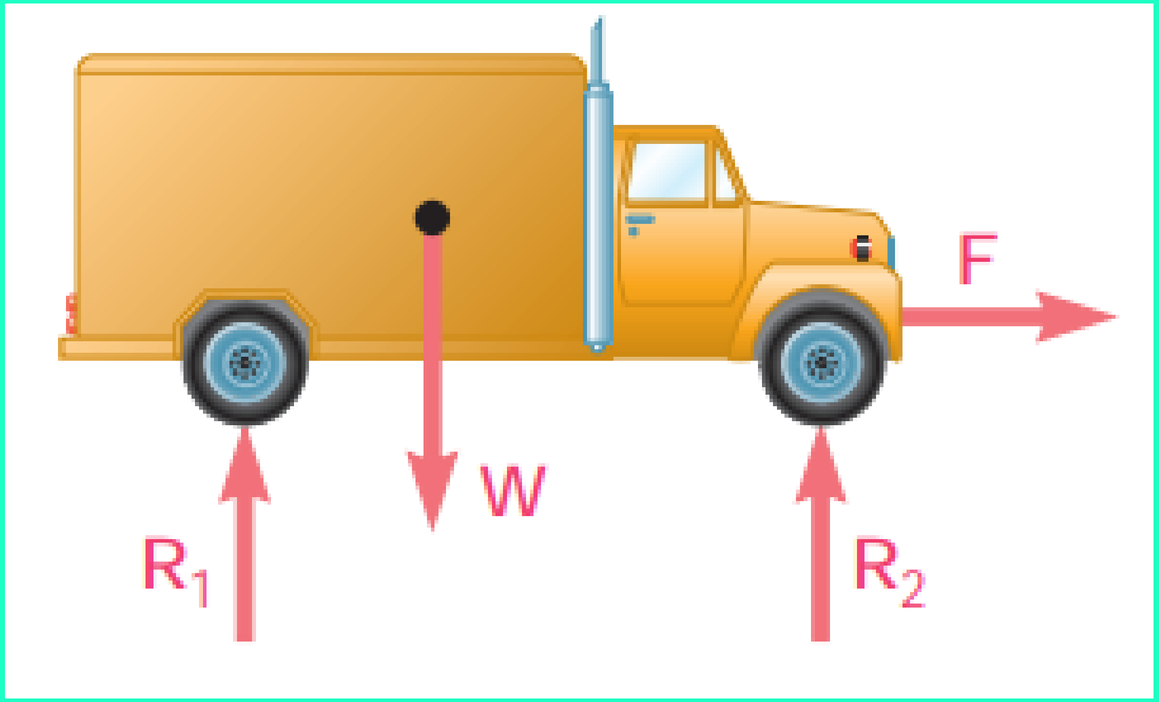
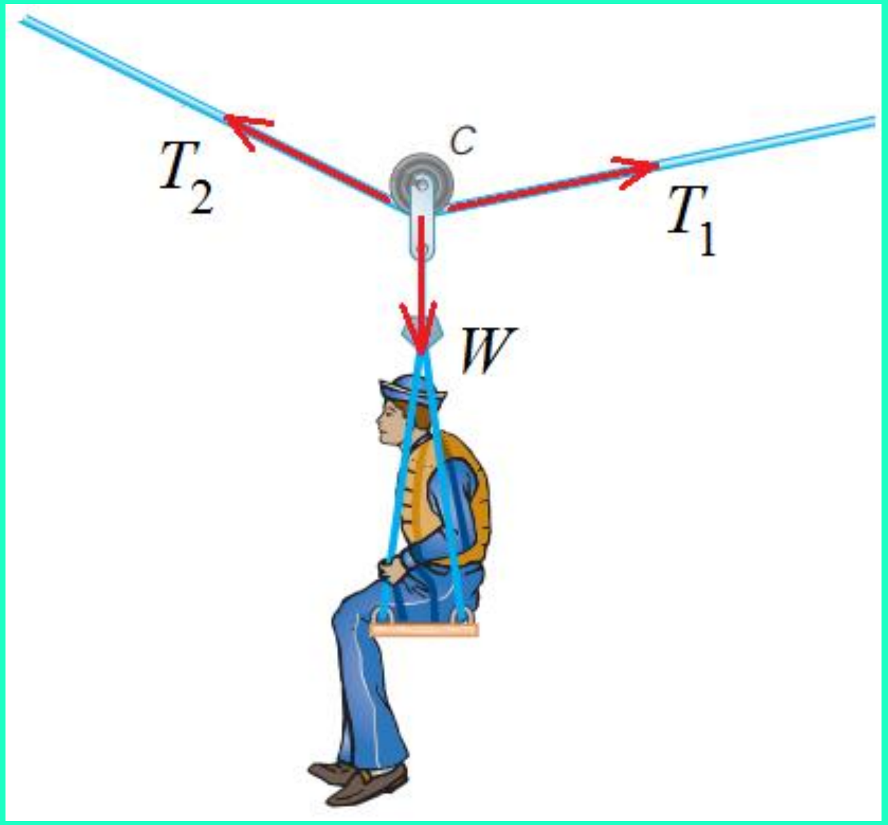


Fig. A force is completely represented by its magnitude (20N), line of action (*pq*) and angle (θ=60°) with respect to a reference (here positive *x* axis). The angle of a force may also be represented by a slope triangle as shown in the second figure in which the angle of the force is calculated by θ=tan-1(b/a).

Force System

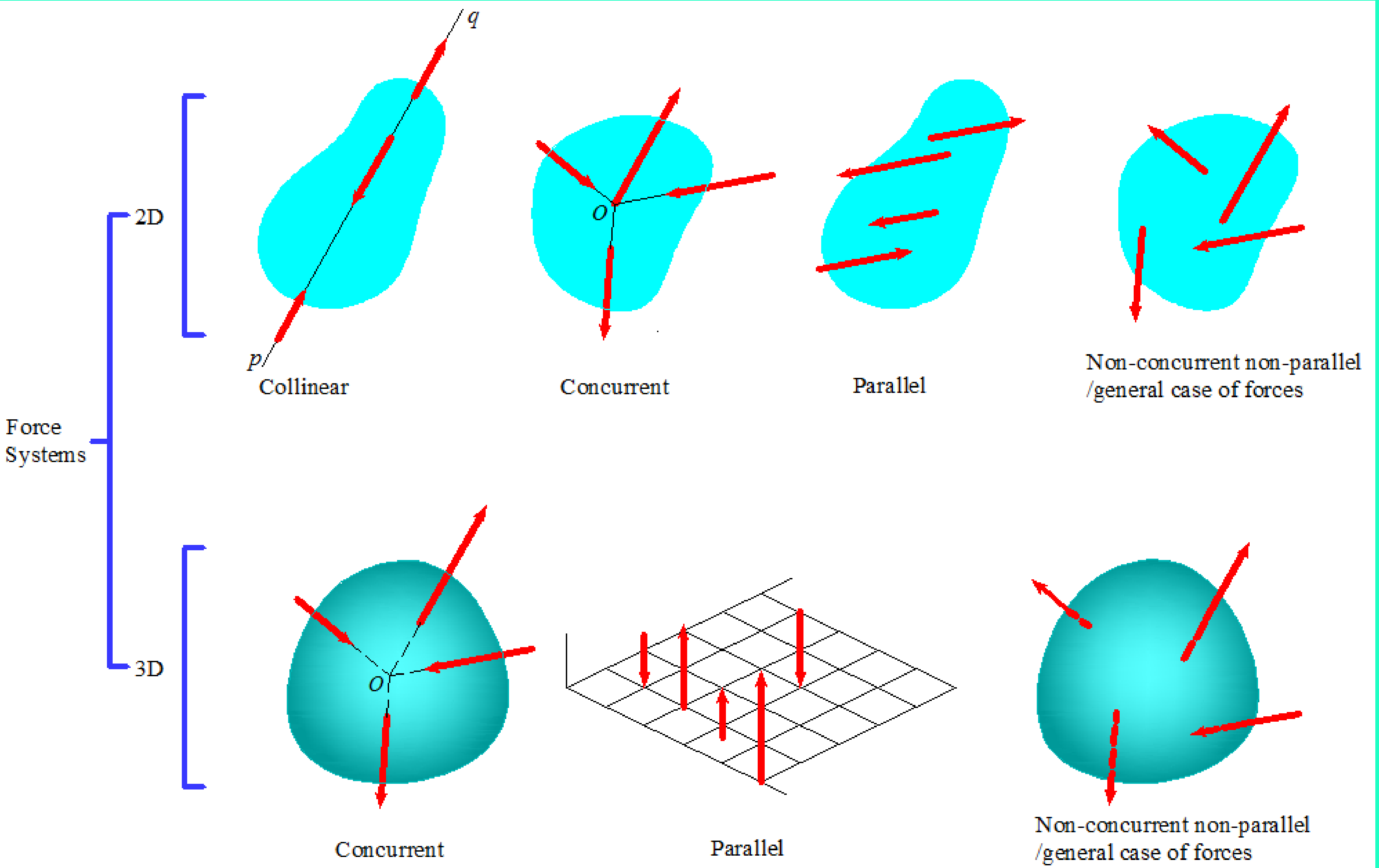
When several forces of various magnitude and direction act on a body they form a force system or system of forces.





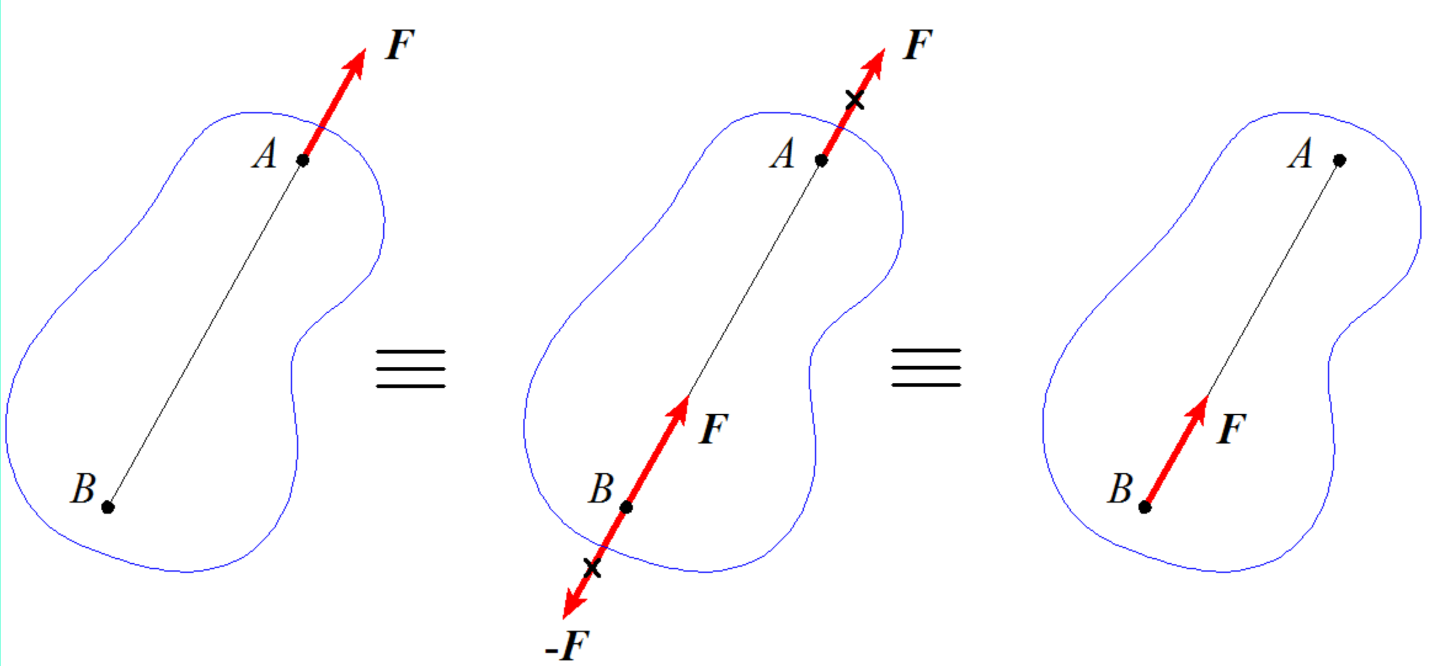
Force and Force System

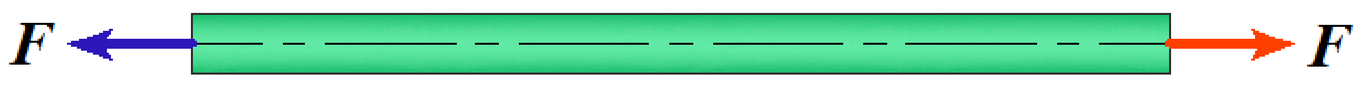
Classification of Force Systems



Principle of Transmissibility

The **external effect** (condition of equilibrium or motion) of a rigid body is not altered if the point of application of any force acting on the body is displaced along the line of action of the force. This is known as principle of transmissibility of a force. **Applicable to Rigid Body Mechanics**/Engineering Mechanics





(*a*) Bar under tension

(*b*) Bar under compression

Be careful

Principle of transmissibility cannot be applied for deformable bodies.

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Next Lecture

Chapter 2 Statics of Particles

Brief outline of the lecture

- Introduction
- Resultant of Two Forces
- Vectors
- Addition of Vectors
- Resultant of Several Concurrent Forces
- Sample Problem 2.1
- Sample Problem 2.2
- Rectangular Components of a Force: Unit Vectors
- Addition of Forces by Summing Components
- Sample Problem 2.3
- Equilibrium of a Particle
- Free-Body Diagrams
- Sample Problem 2.4
- Sample Problem 2.6
- Expressing a Vector in 3-D Space
- Sample Problem 2.7

Thank you!