Basics of Mechanical Engineering

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Basics of Mechanical Engineering: Fundamental concepts of Mechanics, measurement systems, control systems, mechanical design, discrete linear systems.

- **Mechanical engineering** is an engineering branch that combines engineering physics and mathematics principles with materials science, to design, analyze, manufacture, and maintain mechanical systems.
- It is one of the oldest and broadest of the engineering branches.
- It is the branch of engineering that involves the design, production, and operation of machinery.
- Mechanical engineering emerged as a field during the Industrial Revolution in Europe in the 18th century; however, its development can be traced back several thousand years around the world.

The **fundamental subjects** required for mechanical engineering:

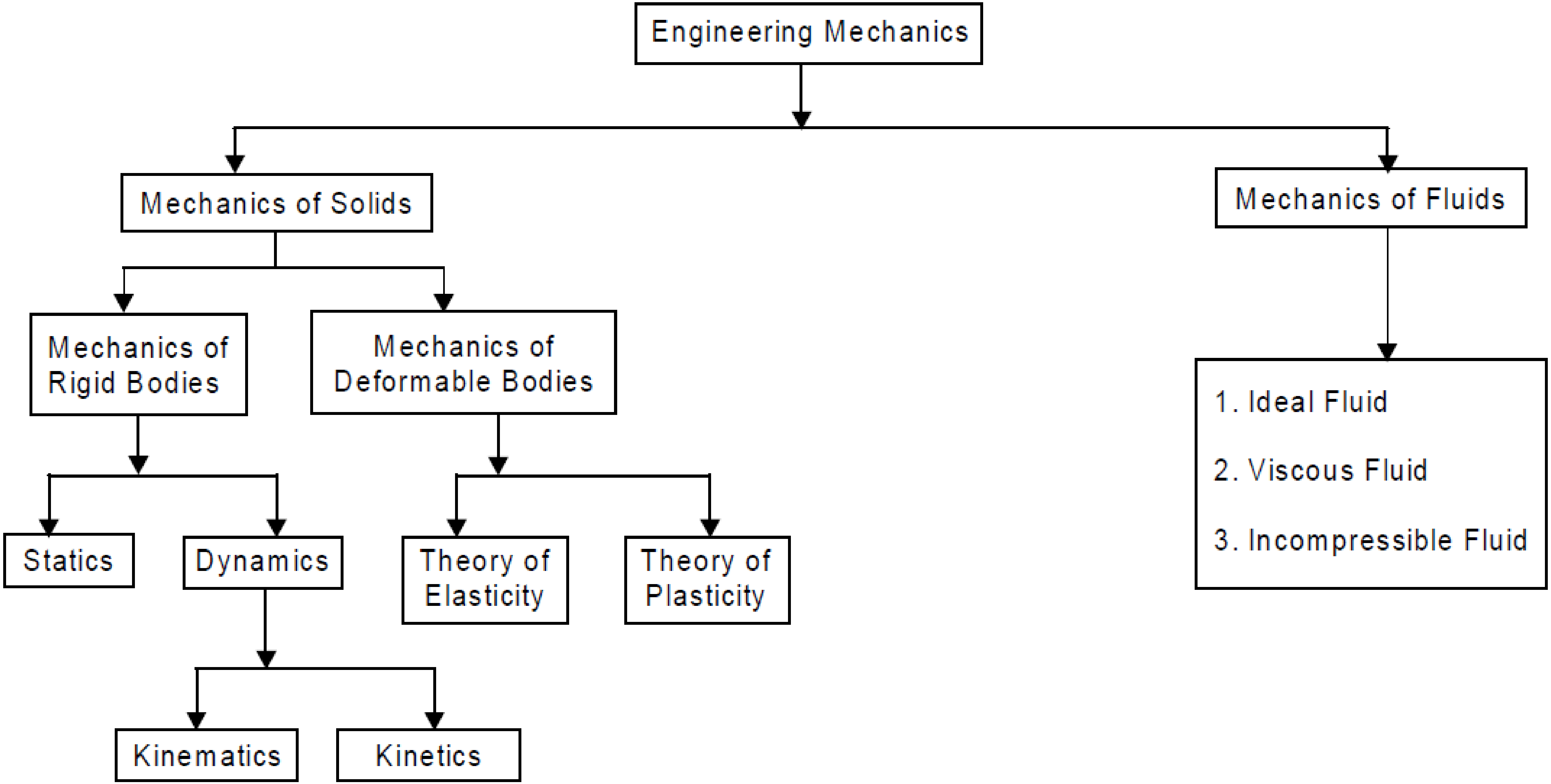
- Mathematics (calculus, differential equations, linear algebra etc.)
- Basic physical sciences (including physics and chemistry)
- Statics and dynamics
- Strength of materials and solid mechanics
- Materials engineering, composites
- Thermodynamics, heat transfer, energy conversion, and HVAC
- Fuels, combustion, internal combustion engine
- Fluid mechanics (including fluid statics and fluid dynamics)

- Mechanism and Machine design (including kinematics and dynamics)
- Instrumentation and measurement
- Manufacturing engineering, technology, or processes
- Vibration, control theory and control engineering
- Hydraulics and Pneumatics
- Mechatronics and robotics
- Engineering design and product design
- Drafting, computer-aided design (CAD) and computer-aided manufacturing (CAM)

What is Mechanics?

- Mechanics is, in the most general sense, the study of forces and their effect upon matter.
- Mechanics is the science which describes and predicts the conditions of rest or motion of bodies under the action of forces.
- Mechanics is an applied science - it is not an abstract or pure science but does not have the empiricism found in other engineering sciences.
- Mechanics is the foundation of most engineering sciences and is an indispensable prerequisite to their study.

Classification of Engineering Mechanics



Statics vs Dynamics

- Dynamics is the branch of mechanics that deals with the analysis of physical bodies in motion.
- Statics deals with objects at rest or moving with constant velocity.
- This means that dynamics implies change and statics implies changelessness, where change in both cases is associated with acceleration

Statics

- Statics is concerned with the forces that act on bodies at rest under equilibrium conditions.
- This is expressed in the first part of Newton's first law of motion, where equilibrium conditions are met:

  A body will remain at rest (zero displacement).

  A body will remain in uniform motion.
- Acceleration is always zero in statics, so the right-hand side of the equation of Newton's second law of motion will always amount to zero as well.

  $F = ma, \ \ a = 0$
- This means that most statics problems are going to be associated with the analysis of force – on the left-hand side of Newton's second law of motion.

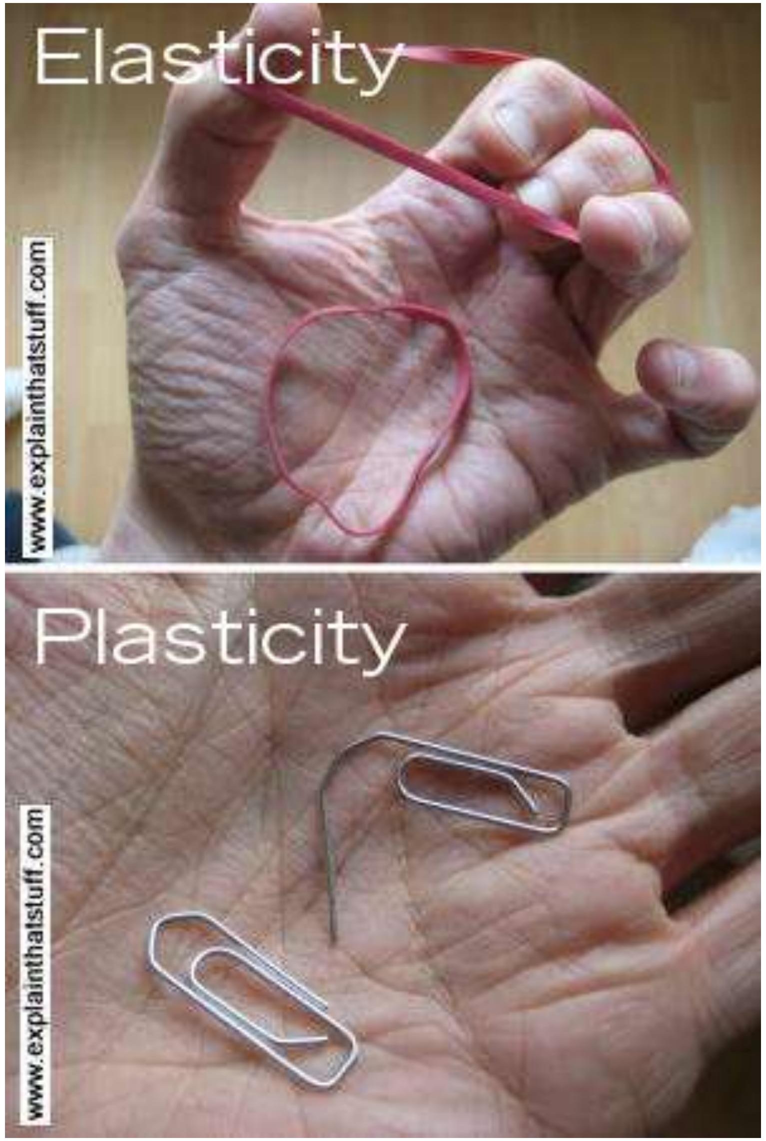
Dynamics

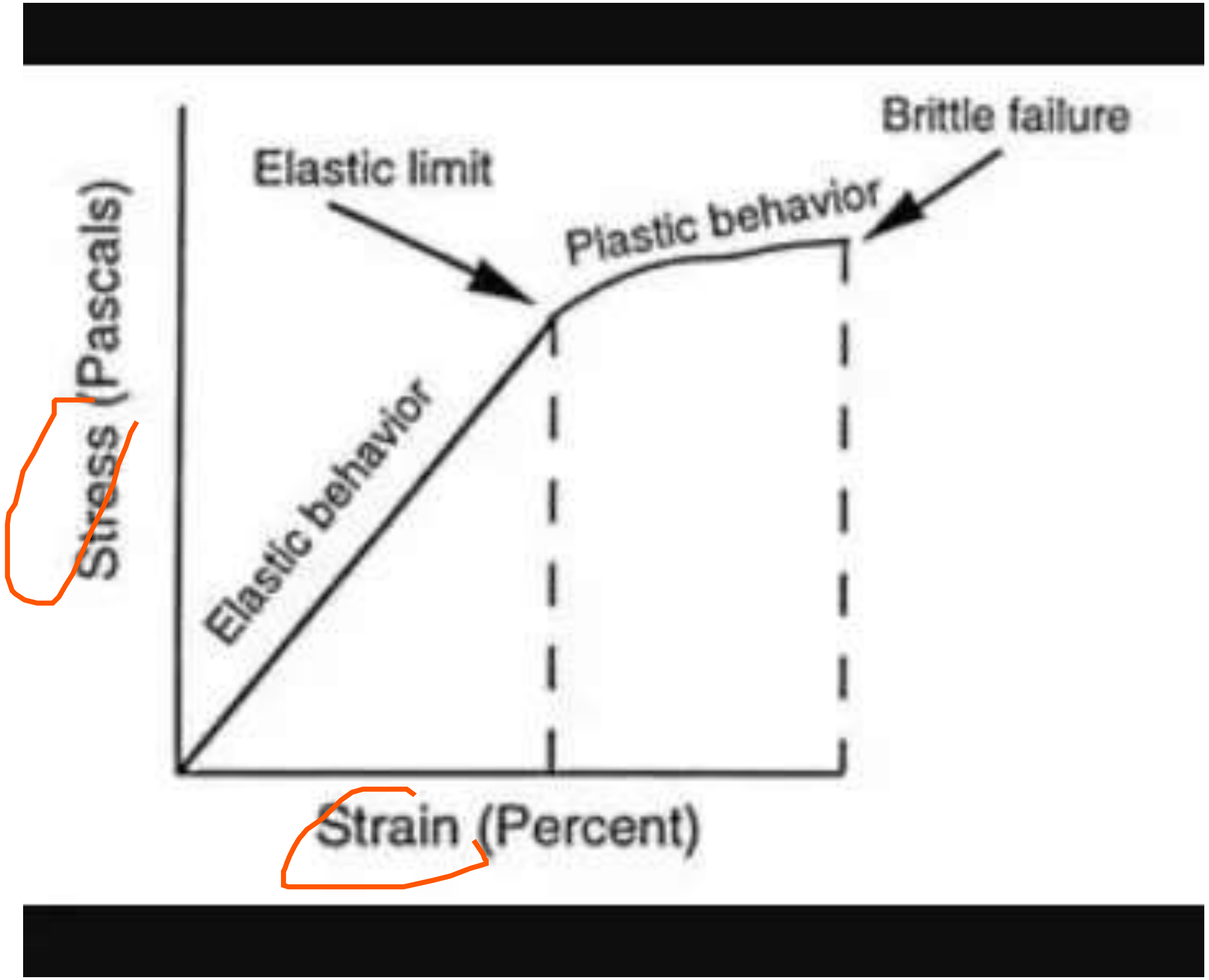
- Dynamics in mechanics studies the forces that cause or modify the movement of an object. Therefore, acceleration is a factor in these problems.
- Dynamics can be subdivided into **Kinematics and Kinetics**.
- **Kinematics** is an area of study that focuses on the movement of objects, disregarding the forces that cause the movements. It studies motion that relates to displacement, velocity, acceleration, and time.
- **Kinetics** on the other hand studies motion that relates to the forces that affect these motions.

Elasticity vs Plasticity

- Elasticity is the property of a solid material that allows it to restore its shape after an external load is removed.
- Plasticity is the property of a solid substance that allows it to keep its deformed shape even when the external load is removed.

Elasticity vs Plasticity





Fluid

Ideal Fluid:

- An ideal fluid is a fluid that is incompressible and no internal resistance to flow (zero viscosity).
- Ideal fluid is not found in reality so it is termed as an imaginary fluid since all the fluids that exist in the environment have some viscosity.

Viscous Fluid :

- Fluids that have higher viscosity are known as viscous fluid.
- Examples of viscous fluids are honey and glycerol ketchup.
- The fluid that has more flow resistance is referred to as viscous fluid.

Real Fluid:

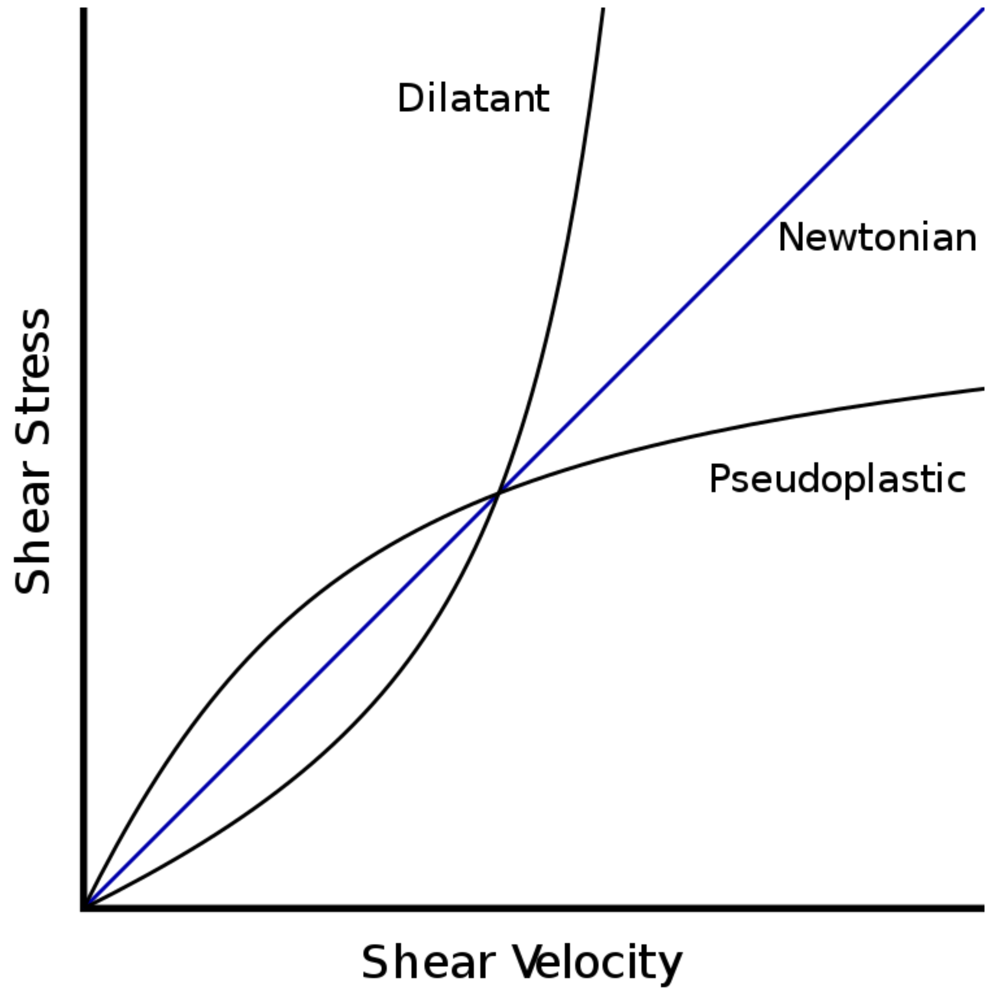
- A fluid which possesses at least some viscosity is termed as real fluid.
- Actually, all the fluids existing or present in the environment are called real fluids. Some of its examples are petrol, air etc.

Incompressible Fluid:

- Fluid which is not compressed or expanded, and its volume is always constant.
- In reality, a rigorous incompressible fluid does not exist.

Newtonian Fluid:

- If a real fluid obeys the Newton's law of viscosity i.e. the shear stress is directly proportional to the shear strain or velocity gradient then it is known as a Newtonian fluid.
- Some of its examples are water, air, alcohol, glycerol, thin motor oil etc.



Types of Mechanics

- **Mechanics of materials**: the study of how different materials deform under various types of stress
- **Fluid mechanics**: the study of how fluids react to forces.
- **Continuum mechanics**: a method of applying mechanics that assumes that objects are continuous (rather than discrete)
- Mechanical engineers typically use mechanics in the design or analysis phases of engineering.

- If the engineering project were the design of a vehicle, statics might be employed to design the frame of the vehicle, in order to evaluate where the stresses will be most intense.
- Dynamics might be used when designing the car's engine, to evaluate the forces in the pistons and cams as the engine cycles.
- Mechanics of materials might be used to choose appropriate materials for the frame and engine.
- Fluid mechanics might be used to design a ventilation system for the vehicle (see HVAC), or to design the intake system for the engine.

Basic Terminologies

- **Mass :** The quantity of matter possessed by a body. Total mass of a body is conserved.
- **Time :** Time is the measure of succession of events.
- **Space:** The geometric region in which study of body is involved.
- **Length:** concept to measure linear distances.
- **Displacement:** distance moved by a body/particle in the specified direction.
- **Force:** represents the action of one body on another.

  A force is characterized by its point of application, magnitude, and direction.

  Force is a vector quantity.

Basic Terminologies

Velocity : Rate of change of displacement with respect to time. $v = \frac{dx}{dt}$

Acceleration : Rate of change of velocity with respect to time. $a = \frac{dv}{dt}$

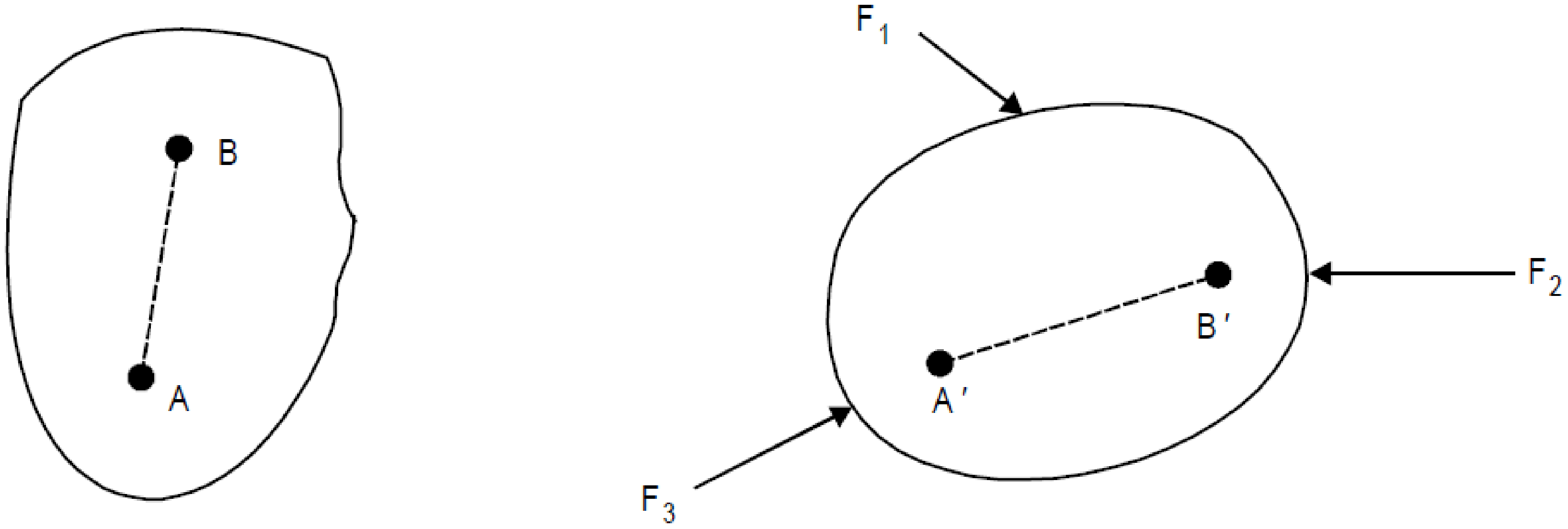
Momentum: Product of mass and velocity.

Particle : Object which has only mass but no size.

Continuum : The body is assumed to consist of a continuous distribution of matter.

Basic Terminologies

Rigid body : A body is said to be rigid, if the relative positions of any two particles do not change under the action of the forces.



(a) (b)

Fundamental Concepts of Mechanics

Newton's Three Laws of Motion

- **Newton's First Law of Motion (Law of Inertia)**

  A body remains at rest, or in motion at a constant speed in a straight line, unless acted upon by a force.

- **Newton's Second Law of Motion (Law of Mass and Acceleration)**

  When a body is acted upon by a force, the time rate of change of its momentum equals the force.

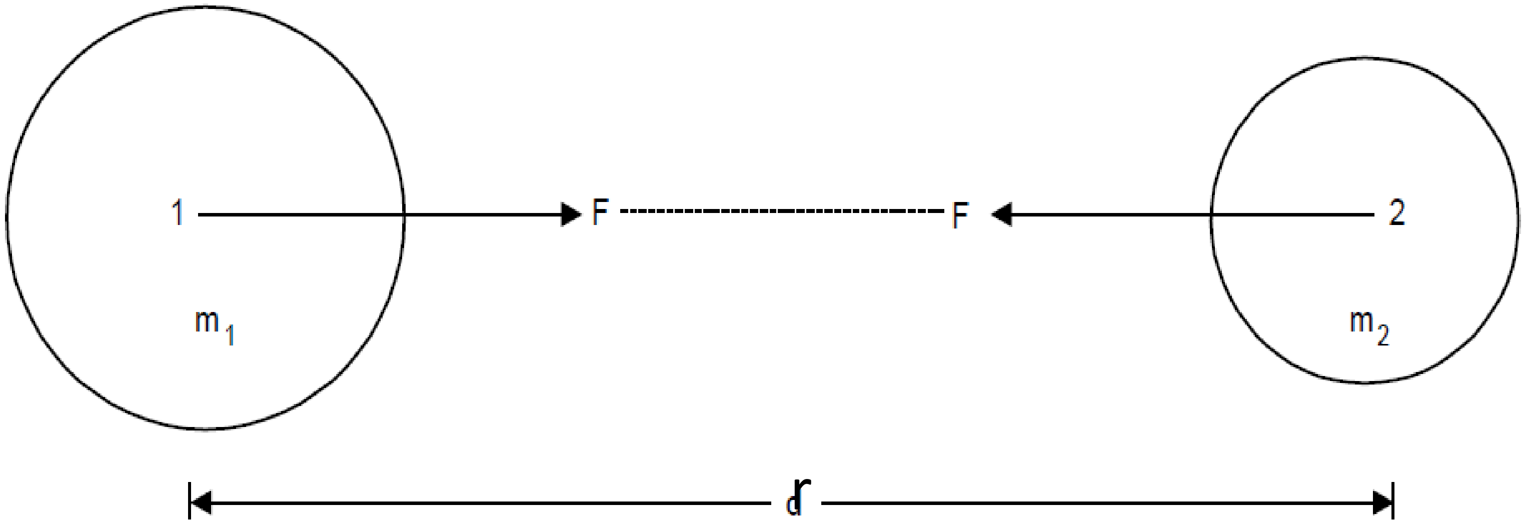
- **Newton's Third Law of Motion**

  If two bodies exert forces on each other, these forces have the same magnitude but opposite directions.

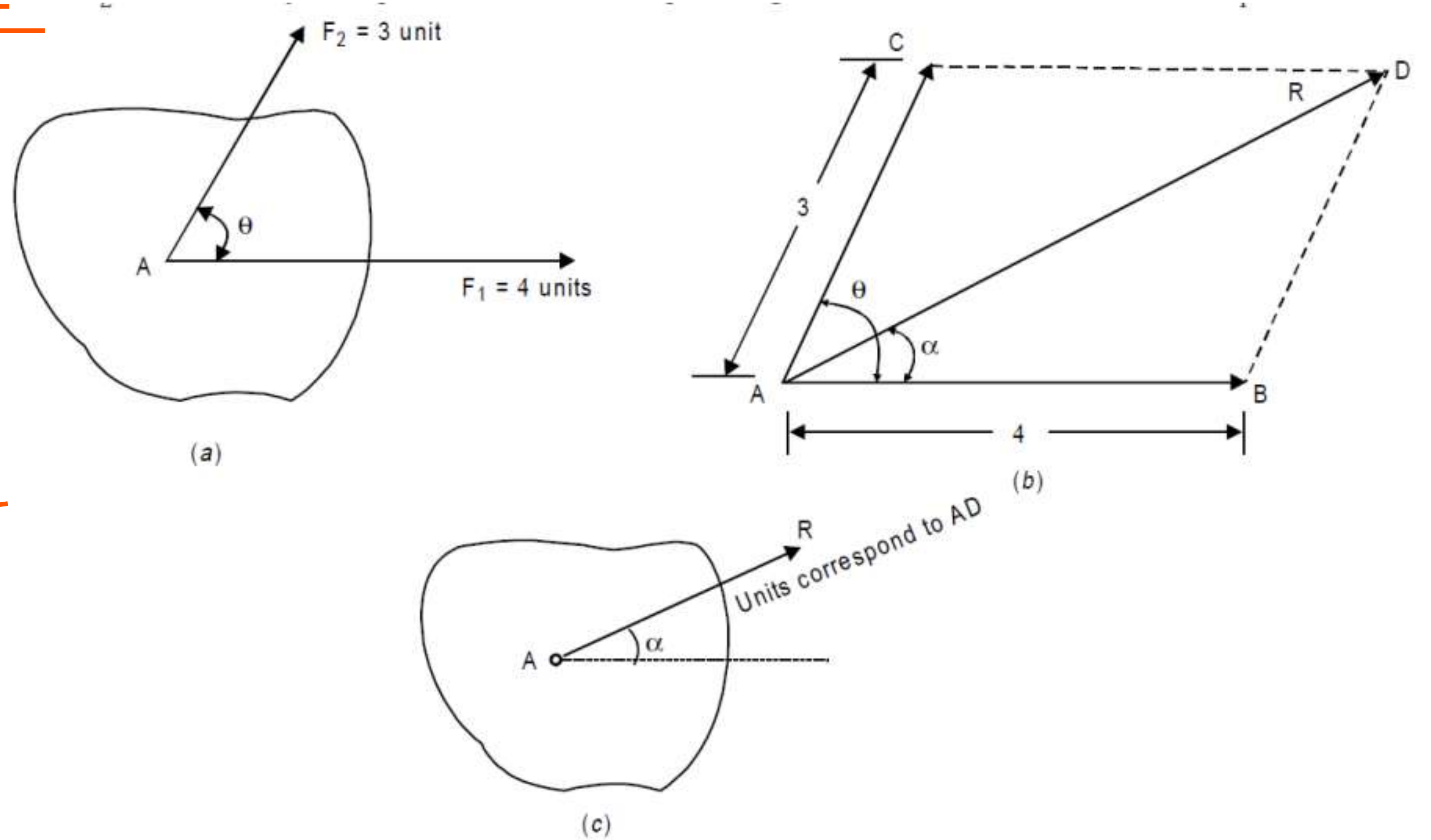
Fundamental Concepts of Mechanics

Newton's law of gravitation: It states that any particle of matter in the universe attracts any other with a force varying directly as the product of the masses and inversely as the square of the distance between them.

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



Parallelogram Law of Forces: This law states that if two forces acting simultaneously on a body at a point are represented in magnitude and direction by the two adjacent sides of a parallelogram, their resultant is represented in magnitude and direction by the diagonal of the parallelogram which passes through the point of intersection of the two sides representing the forces.

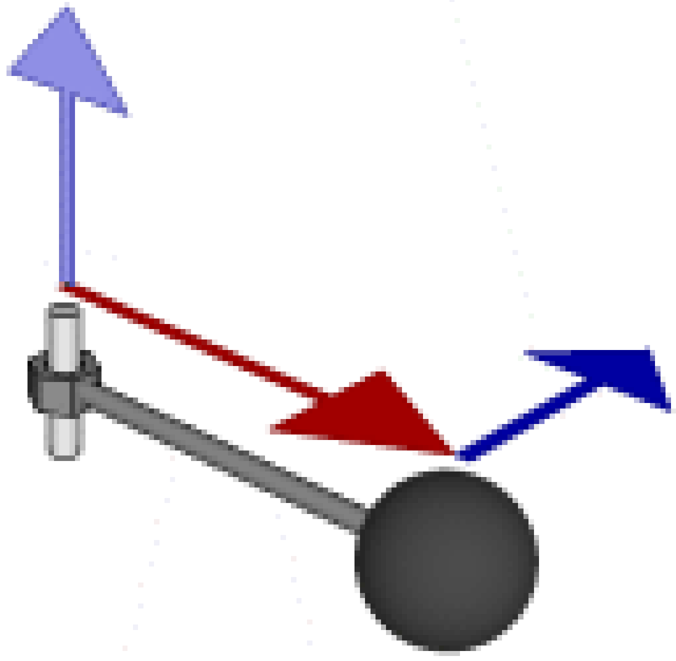


Torque

- In physics and mechanics, **torque** is the rotational equivalent of linear force.
- It is also referred to as the **moment, moment of force**, **rotational force** or **turning effect**, depending on the field of study.
- It represents the capability of a force to produce change in the rotational motion of the body.

Relationship between force **F**, torque **τ**, linear momentum **p**, and angular momentum **L** in a system which has rotation constrained to only one plane (forces and moments due to gravity and friction not considered).

$$\tau = \mathbf{r} \times \mathbf{F}$$
$$\mathbf{L} = \mathbf{r} \times \mathbf{p}$$

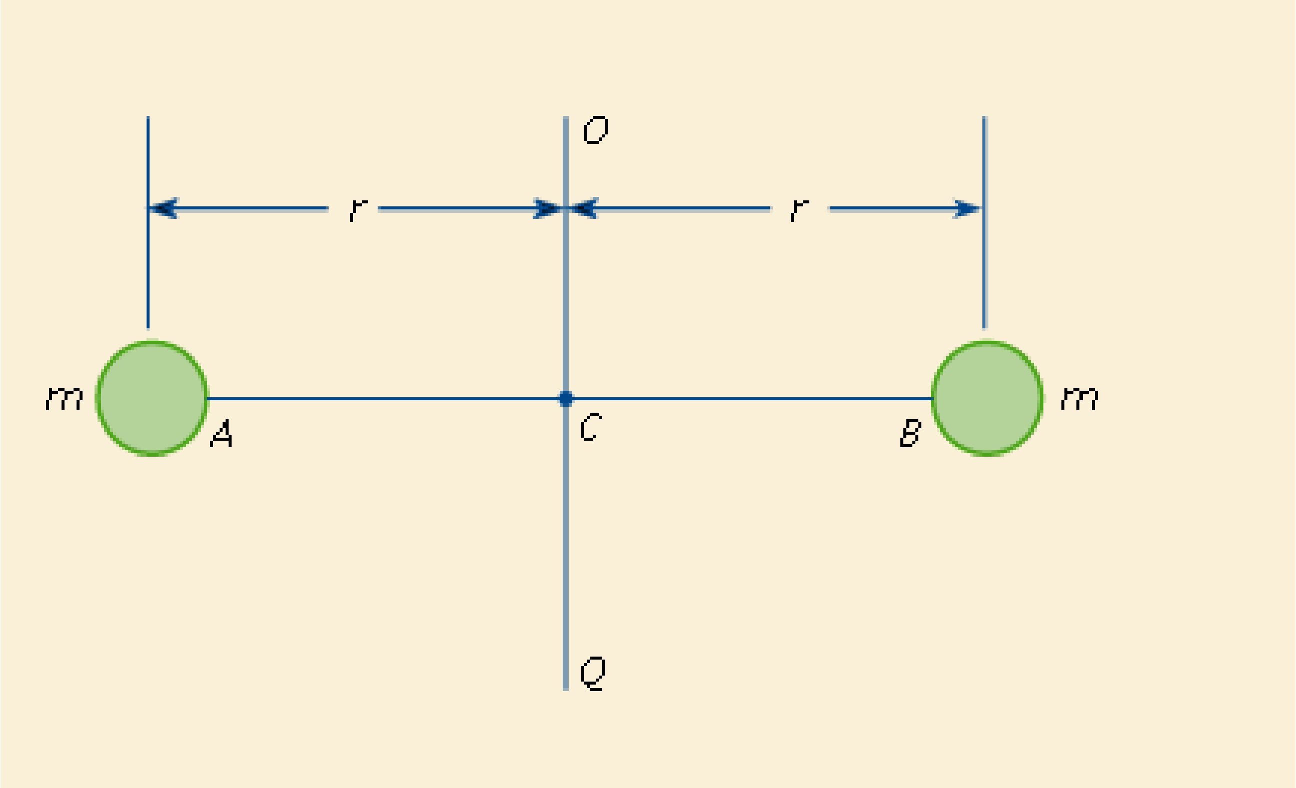


Rotational Systems

Moment of inertia (second moment):

- It is a measure of the tendency of an object to resist rotation.
- **Moment of inertia**, in physics, quantitative measure of the rotational inertia of a body—i.e., the opposition that the body exhibits to having its speed of rotation about an axis altered by the application of a torque (turning force).
- The moment of inertia (*I*) is defined as the sum of the products obtained by multiplying the mass of each particle of matter in a given body by the square of its distance from the axis.

$$I_y = \sum_{i=1}^{n} m_i r^2$$

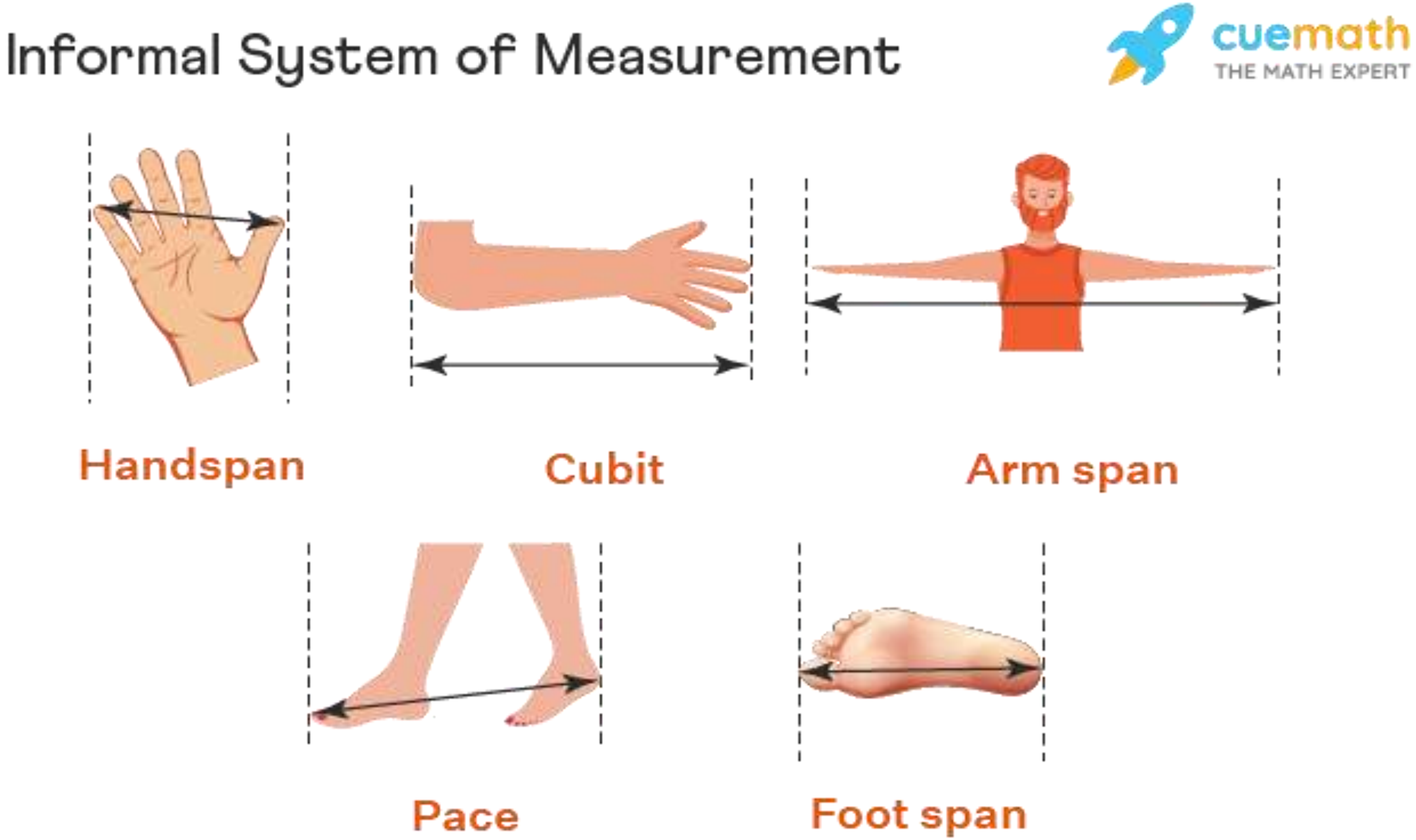


The figure shows two steel balls that are welded to a rod *AB* that is attached to a bar *OQ* at *C*. Neglecting the mass of *AB* and assuming that all particles of the mass *m* of each ball are concentrated at a distance *r* from *OQ*, the moment of inertia is given by

$$I = 2mr^2.$$

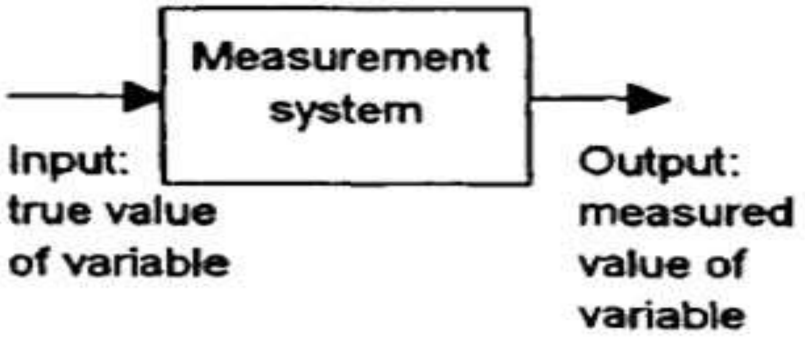
Measurement system

- Measurement involves comparison of an unknown value with a known value.
- A measurement system is used for getting the value of an unknown physical parameter or quantity such as temperature, pressure, force, humidiy, flow etc



Instrumentation Systems

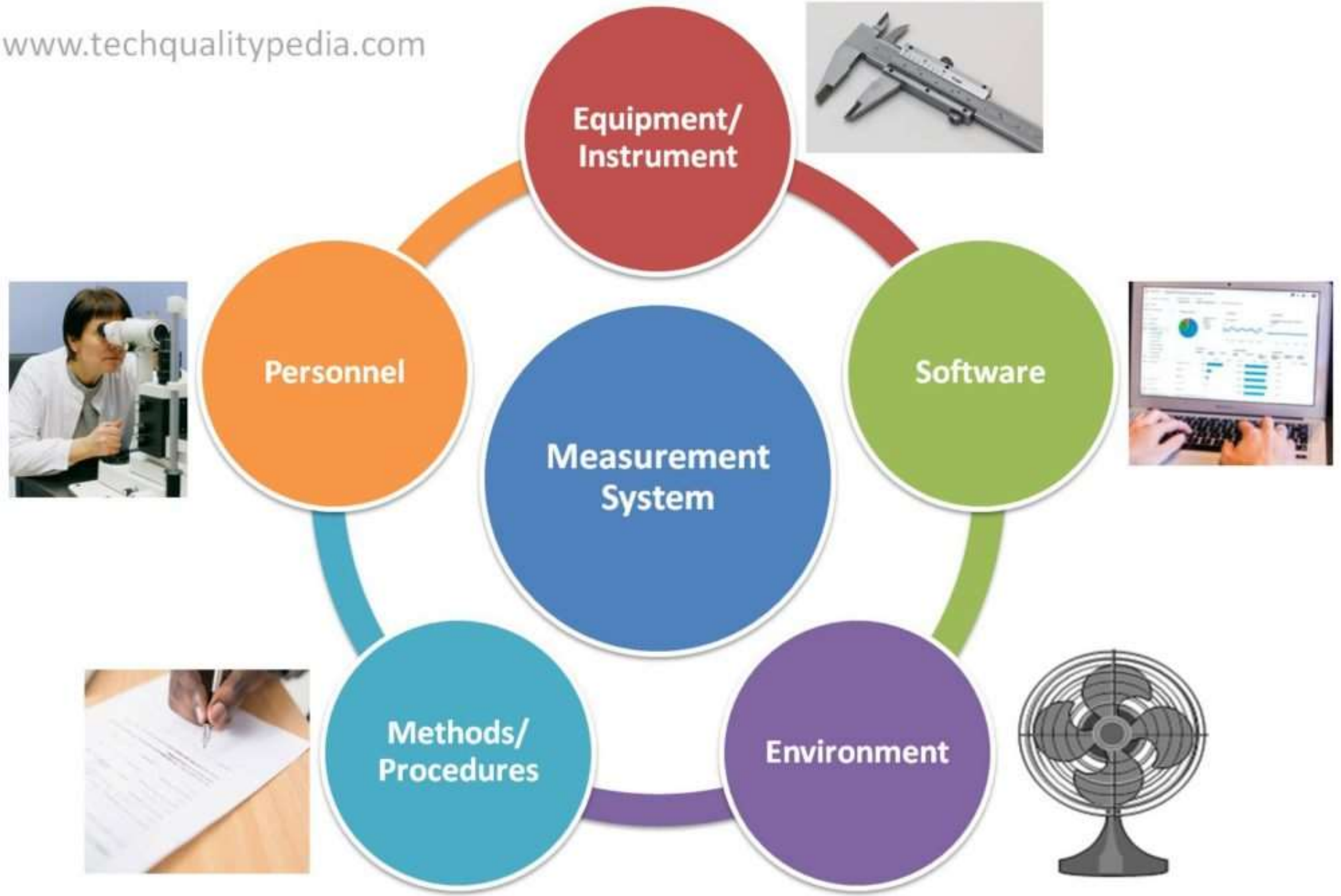
An instrumentation/measurement process can be viewed as a system whose input is the true value of the variable being measured and its output is the measured value.



Examples: (a) pressure measurement, (b) *speedometer*

MEASUREMENT SYSTEM

Combination of Equipment, Personnel, Methods, Environment and Software



- **The first measurement unit**: The **Egyptian cubit**, the Indus Valley units of length referred to above and the **Mesopotamian cubit** were used in the 3rd millennium BC and are the earliest known units used by ancient peoples to measure length.

The three standard systems of measurements are

- The International System of Units or SI (the modern form of the metric system)
- The British Imperial System
- The US Customary System.

The International System of Units or SI: commonly known as the metric system.

- It is the international standard for measurement.
- It is established in 1960 and periodically updated since then.
- The SI has an official status in most countries,
- The seven SI base units, which are comprised of:

Length - meter (m)

Time - second (s)

Amount of substance - mole (mole)

Electric current - ampere (A)

Temperature - kelvin (K)

Luminous intensity - candela (cd)

Mass - kilogram (kg)

The British Imperial System:

- It is the system of units first defined in the British Weights and Measures Act 1824 and continued to be developed through a series of Weights and Measures Acts and amendments.
- Examples: inch, feet, fathom, perch, gill etc.
- By the late 20th century, most nations of the former empire had officially adopted the metric system as their main system of measurement.
- But imperial units are still used alongside metric units in the UK and in some other parts of the former empire, notably Canada.

The US Customary System:

- United States, Liberia, and Myanmar have not adopted the metric system as their official system of weights and measures.
- The system is based on the yard as a unit of length, the pound as a unit of weight, the gallon as a unit of liquid volume, and the bushel as a unit of dry volume.

Metric System Metric: to measure International System (SI) Based on # 10

	Unit	Symbol	Tools	English
Mass	gram	g	Balance or Scale	ounce, pound, ton
Length	meter	m	Meterstick or Ruler	inch, foot, yard, mile
Area	meters squared	m2	Meterstick or Ruler	in2, ft2, yd2
Volume	liter	L or cm^3	Graduated Cylinder measuring cups	pint, quart, gallon
Temperature	Degree celsius	°C	Thermometer	Fahrenheit
Time	day, hour, min, sec		Clock, watch	day, hour, min, sec

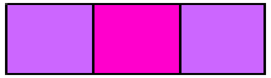
US measurement system

Length

12 inches = 1 foot
3 feet = 1 yard
22 yards = 1 chain
10 chains = 1 furlong
8 furlongs = 1 mile
5280 feet = 1 mile
1760 yards = 1 mile

Area

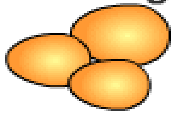
144 square inches = 1 square foot
9 square feet = 1 square yard
4840 square yards = 1 acre
640 acres = 1 square mile or
= 1 section



A 12 x 12 inch large floor tile has an area of 144 square inches or 1 square foot.

Weight

16 ounces = 1 pound
14 pounds = 1 stone
100 pounds = 1 hundredweight
2,000 pounds = 1 ton
20 hundredweight = 1 ton

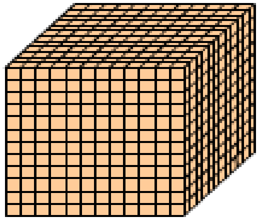


US egg sizes:
Small 1.5 oz, Large 2 oz, Jumbo 2.5 oz.

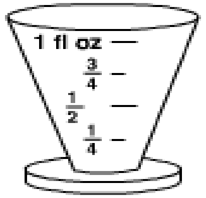
Volume

1728 cubic inches = 1 cubic foot
27 cubic feet = 1 cubic yard

This 1 inch block has a volume of 1 cubic inch, 1 in^3.
So this cube made from 1,728 blocks has a volume of 1,728 cubic inches, or 1 cubic foot, 1 ft^3.



Fluid Volume



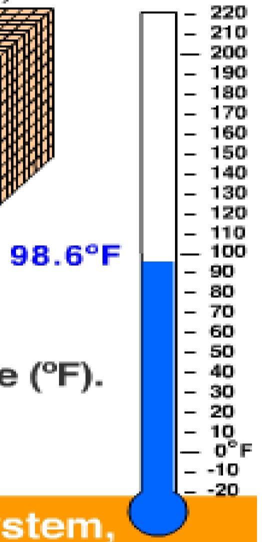
8 fluid ounces = 1 cup
16 fluid ounces = 1 pint
2 pints = 1 quart
8 pints or 4 quarts = 1 gallon

1 gallon = 4 quarts, 8 pints, 16 cups, 128 fluid ounces

Category	°F
• Freezing point of water	32°
• Boiling point of water	212°
• Human body temperature	98.6°

Temperature

The Fahrenheit scale (°F).



also known as US Standard units, US Standard system, Imperial or English sytem or just US units

Mechanical design

- Mechanical design is to design parts, components, products, or systems of mechanical nature.
- For example, designs of various machine elements such as *shafts, bearings*, *clutches*, *gears*, and *fasteners* fall into the scope of mechanical design.
- Numerous criteria have been proposed in mechanical design processes, some primary design criteria include **functions, safety, reliability, manufacturability, weight, size, wear, maintenance, and liability**.
- In general, a mechanical design problem should be formulated with clear and complete statements of ***functions, specifications*, and evaluation *criteria***

- **Functions** are specified for what a product can fulfill.
- Functions are usually described by non quantitative statements.
- Exemplifying product functions are to charge power on electronics (charger), clean floors (vacuum), transport objects (mobile platform), or support loads.

- **Specifications** are detailed requirements described by quantitative statements.
- For example, product specifications can be defined in terms of size, weight, precision, working volume, speed, or load capacity.

- **Evaluation criteria** are the statements of desirable qualitative characteristics.
- Evaluation criteria are treated as design objectives to optimize the solutions.
- Evaluation criteria are set to maximize benefits and minimize disadvantages of mechanical designs.
- Although the numbers and priorities of specifications and criteria vary from one product design to another; some common design considerations are applicable to any mechanical systems.
- These considerations include loading capability, deformation, stability, durability.

Discrete System

- In theoretical computer science, a discrete system is a system with a countable number of states.
- Discrete systems may be contrasted with continuous systems, which may also be called analog systems.
- A discrete system is one in which the state variable(s) change only at a discrete set of points in time. E.g. customers arrive at 3:15, 3:23, 4:01, etc.
- A continuous system is one in which the state variable(s) change continuously over time. E.g. the amount of water flow over a dam

Discrete Linear Systems:

The term *linear* defines a special class of systems where the output is the superposition, or sum, of the individual outputs had the individual inputs been applied separately to the system.

For example, we can say that the application of an input $x_1(n)$ to a system results in an output $y_1(n)$. We symbolize this situation with the following expression:

$$x_1(n) \xrightarrow{\text{results in}} y_1(n).$$

Given a different input $x_2(n)$, the system has a $y_2(n)$ output as

$$x_2(n) \xrightarrow{\text{results in}} y_2(n).$$

For the system to be linear, when its input is the sum $x_1(n) + x_2(n)$, its output must be the sum of the individual outputs so that

$$x_1(n) + x_2(n) \xrightarrow{\text{results in}} y_1(n) + y_2(n).$$

Control system

- A control system manages, commands, directs, or regulates the behavior of other devices or systems using control loops.
- A control system is a set of mechanical or electronic devices that regulates other devices or systems by way of control loops.
- Typically, control systems are computerized.
- Control systems are a central part of industry and of automation.
- Examples of control systems in your day-to-day life include an air conditioner, a refrigerator, an air conditioner, a bathroom toilet tank, an automatic iron, and many processes within a car – such as cruise control.

There are two types of control systems namely:

Open loop control systems (non-feedback control systems)

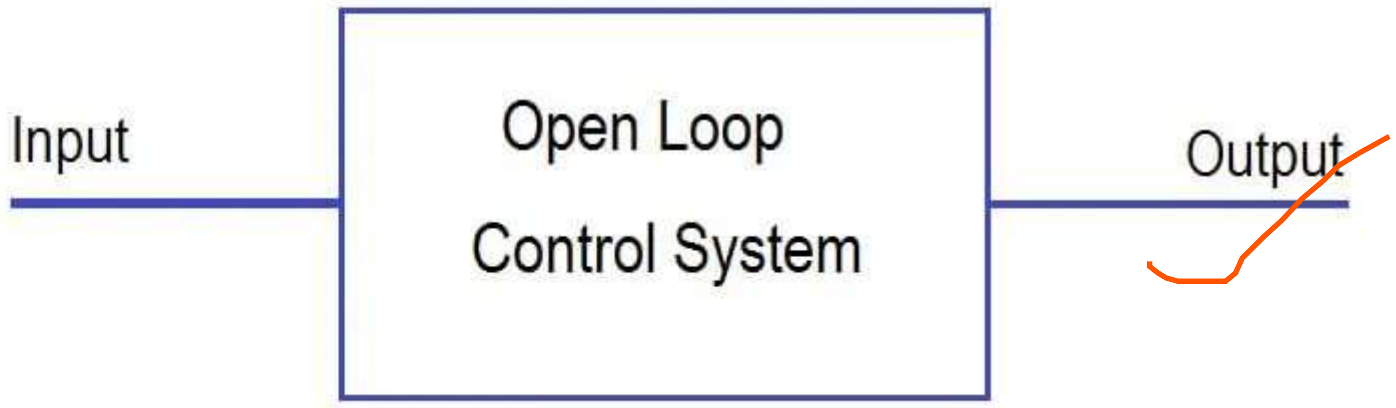
Closed loop control systems (feedback control systems)

Open Loop Control System

- If in a physical system there is no automatic correction of the variation in its output, it is called an open loop control system.
- The system on its own is not in a position to give the desired output .
- In these systems, the changes in output can be corrected only by changing the input.
- These systems are simple in construction, stable and cost cheap.
- But these systems are inaccurate and unreliable.
- These systems do not take account of external disturbances that affect the output and they do not initiate corrective actions automatically.

Examples of open loop control systems: A home furnace control system

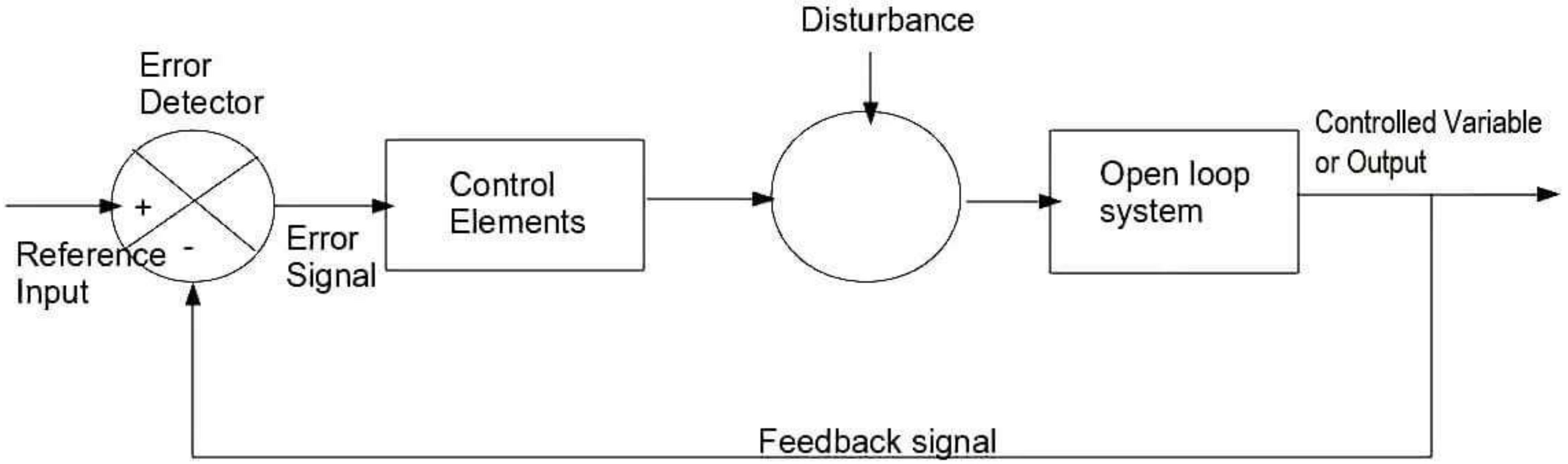
- This system must control the temperature in a room, keeping it constant.
- An open loop system usually has a timer which instructs the system to switch on the furnace for some time and then switch it off.
- Accuracy cannot be achieved as the system does not switch on/off based on the room temperature but it does as per the preset value of time.



Closed Loop Control System

- A closed loop control system is a system where the output has an effect upon the input quantity in such a manner as to maintain the desired output value.
- An open loop control system becomes a closed loop control system by including a feedback.

Closed Loop Control System



- This feedback will automatically correct the change in output due to disturbances.
- This is why a closed loop control system is called as an automatic control system.
- The controlled variable (output) of the system is sensed at every instant of time, feedback and compared with the desired input resulting in an error signal.
- This error signal directs the control elements in the system to do the necessary corrective action such that the output of the system is obtained as desired.
- The feedback control system takes into account the disturbances also and makes the corrective action.
- These control systems are accurate, stable and less affected by noise.
- But these control systems are sophisticated and hence costly.
- They are also complicated to design for stability, give oscillatory response and feedback brings down the overall gain of the control system.