MECHANICS I

UNITS AND MEASUREMENT

- **Measurement:** are basically means of communication and are used by scientist and engineers for understanding **unaural phenomenon**, by the society for business transactions.

- **Fundamental Quantities and Units**

  - **Fundamental Quantities:** are the basic quantities that are independent of others and cannot be defined in terms of other quantities or derived from them. They are the basic quantities upon which most {though not all} quantities depend. The three must important fundamental quantities are; ***Length, Mass, and Time.***
  - **Fundamental Units:** are the basic units upon which other units depend. They are the units of the fundamental quantities.

Table 1.1: Fundamental Quantities and Units

Quantity	Unit	Unit abbreviation
Length	Meter	M
Time	Second	S
Mass	Kilogram	Kg
Temperature	Kelvin	K
Electric Current	Ampere	A

- **Derived Quantities and Units**

  - **Derived Quantities:** are obtained by simple combination {Multiplication, Division & Addition} of the fundamental quantities and units. They are those dependent on the fundamental quantities and units.

- **Derived Units:** They are the units of the derived quantities.

Table 1.2: Derived Quantities and Units

Derived quantity	Derivation	Derived unit
Area	Length × Breath	M^2
Volume	Length × Breath ×Height	M^3
Force	Mass × Acceleration	Newton, N
Energy/Work	Force × Distance	Joule {Nm}
Power	$\frac{\text{Work}}{\text{Time}}$	$J.s^1$ {or Watt, W}
Velocity	$\frac{\text{Displacement}}{\text{Time}}$	$m.s^1$

☐ **Measurement:**

- **Length**

✔ **Metre Rule:**

- A simple tool used to measure lengths.
- Smallest graduation: 1 mm (0.1 cm)

✔ **Calipers**:

- Are a versatile measuring instrument used to measure the dimensions of objects.
- They come in various types, but the most common is the Vernier caliper.

✔ **Dial Calipers**:

- Use a dial indicator to display measurements.

✔ **Digital Calipers**:

- Provide digital readouts for easy and accurate measurements.

✔ **Vernier Calipers:**

- More precise than a metre rule.
- Used to measure internal and external dimensions of objects.
- Smallest graduation (least count): 0.1 mm

✔ **Micrometer Screw Gauge:**

- Highly precise instrument for measuring very small distances.
- Used to measure the thickness of thin sheets, wires, etc.
- Smallest graduation (least count): 0.01 mm

- **Mass**
  - ✔ Beam Balance
  - ✔ Spring Balance
  - ✔ Electronic Balance
  - ✔ Analytical Balance
- **Time**
  - ✔ **Atomic Clocks**:
    - Use the vibrations of atoms to measure time, making them incredibly precise.
  - ✔ **Mechanical Clocks:**
    - These use gears and springs to keep time.
  - ✔ **Quartz Clocks**:
    - These use a quartz crystal that vibrates at a precise frequency to keep time.
  - ✔ **Digital Clocks**:
    - These display time digitally, often using electronic components.

MOTION

Motion

- **Motion:** involves change in position of a body with time. It also involves how objects move and what makes it to move.
- **Kinematics:** is the description of how objects move **without regard to force causing** their motion.
- **Dynamics:** deals with **why** objects move as they do.

Types of Motion

- **Random motion:** is the type of motion in which objects move irregularly or at random, disorderly with no preferred direction. E.g.:
  - Smoke particle suspended in air.
  - Motion of gas particles.
  - Motion of particles of various kind suspended in water.

- **Translational motion:** is the type of motion in which objects move from one point to another without rotating. E.g.:
  - Car travelling from Gombe to Bauchi.
  - Bee flying from one flower to another.
- **Rotational motion:** is the type in which the all points in a body move in concentric circles.
  - Rotation of an electric fan.
  - Earth rotation.
  - Wheel of moving car.
- **Oscillatory {Vibratory} motion:** is the type of motion in which a body moves to and fro, reversing the direction of its motion and returning regularly to its original position. Such a motion is known as **Periodic {it repeats itself}**. E.g.:
  - Motion of pendulum as it swings back and forth.
  - The prongs of turning fork struck with a hard objects
  - Vertical movement of a disturbed mass on a spiral spring
- **Relative Motion:** is the concept that motion is observed and measured relative to a specific frame of reference. This means that the motion of an object can appear different depending on the perspective of the observer.

- **Position, Distance and Displacement**

  - **Position:** where an object is located compared to a reference point. It includes both **location** and **direction**.
  - **Distance:** how far an object has traveled. It only cares about the **total length covered**, not the **direction**.
  - **Displacement:** is defined as distance travelled in a specified direction.

- **Speed, Velocity and Acceleration**

  - **Speed:** is the **rate** at which a body covers a distance or the **rate** of **change** of **distance** {with **time**}.

$$\textbf{Speed} = \frac{\textbf{Distance}}{\textbf{Time}}$$

The S.I unit of Speed is metre/second m/s^1.

Example: If a bus covers a distance of 200m in 20 seconds, its average speed is $200m/20s = 20m/s^1$

  - **Uniform Speed:** when a body covers equal distance in equal time interval, no matter how small the time interval may be, the speed is said to be **uniform speed** or **constant speed.**
  - **Velocity:** is the **rate** of change of **displacement** {with **time**}.

$$\textbf{Velocity } \{v\} = \frac{\textbf{Displacement } \{s\}}{\textbf{Time } \{t\}}$$

The S.I unit of Velocity is metre/second m/s^1. The difference between speed and velocity is the **specification** *of direction*.

- **Example**: a car travels at an average speed of $100kmh^{-1}$, what distance does it covers in 5 minutes?

  Solution:

  100km per hour = 100/60 km per min

  Speed = distance/time

  Distance = speed × time

  = 100/60 × 5

  = 8.3km

- **Uniform Velocity:** when a body moves with equal displacement in equal time interval, no matter how small the time interval may be, the velocity is said to be uniform velocity or constant velocity.
- **Instantaneous Velocity:** is defined as velocity at any instant of time.
- **Acceleration:** is defined as the rate of change of velocity with time. Its unit is metre per second per second $\{ms^{-2}\}$.

$$\textbf{Acceleration} = \frac{\text{Velocity change}}{\text{Time}}$$

$$\text{Acceleration} = \frac{\text{final velocity} - \text{Initial velocity}}{\text{Time}}$$

$$\alpha = \frac{v - u}{t}$$

$$\text{Or } v = u + \alpha t$$

Example: Thus, suppose a car moves from a velocity of $20ms^{-1}$ to a velocity of $30ms^{-1}$ in 5 seconds, its average acceleration is given by:

$$\boldsymbol{\alpha} = \frac{30 - 20}{5}$$

= 2 metre per sec per sec

$= 2ms^{-2}$.

That means the velocity of the car increases by $2ms^{-1}$ per second.

- **Uniform acceleration:** When the velocity of a moving body increases by equal amounts in equal time interval, no matter how small the time interval may be, it is said to move with uniform acceleration.
- **Retardation:** is negative acceleration i.e. the velocity decreases with time.
- **Uniform deceleration:** means that the velocity decreases by equal amounts in equal times, no matter how small the time interval may be.

Equations of {Uniformly Accelerated} Motion

- ***First equation of motion:***

$$v = u + \alpha t$$

- ***Second equation of motion:***

$$s = ut + \tfrac{1}{2}\alpha t^2$$

- ***Third equation of motion:***

$$V^2 = u^2 + 2\alpha s$$

Where:
u = initial velocity *v = final velocity*
t = time *s = distance* *α = uniform acceleration*

Also s = average velocity × time

$$s = \tfrac{1}{2}(u + v)t$$

Motion Under Gravity – Free fall:

$$v = u \pm gt$$
$$s = ut \pm \tfrac{1}{2}gt^2$$
$$v^2 = u^2 \pm 2gh$$

Where:
u = initial velocity v = final velocity t = time
h = height/distance g = uniform acceleration

Circular Motion

- **Circular motion**: an object moving with a constant speed along a circular path is said to have a uniform circular motion. Example of such motion are:
  - Earth moving round the sun.
  - Moon circling the earth.
  - Planets moving round the sun.
  - Satellite circling round the earth.
- **Centripetal acceleration α**: is the acceleration that is directed toward the center of the circular path.

$$\alpha = \frac{v^2}{r}$$

v: is the uniform speed. r: is the radius of the circular path.

- **Centripetal Force F_T**: is defined as that inward force required to keep an object moving with constant speed in a circular path.

$$F_T = \frac{mv^2}{}$$

r

- **Centrifugal force:** act in opposite direction to the centripetal force.
- **Angular velocity {ω*}*:** is defined as the angle turned through, divided by the elapse time.
- **Radian:** is defined as the angle suspended by the arc of circle whose length is equal to the radius of same circle.

$$\omega = \Theta/t$$

$$v = r\omega$$

ω is the angular velocity, Θ is the angle covered by moving object, t is the time of motion, v is the linear velocity.

Force

- **Force:** is that which changes the state of rest or of uniform motion of a body.
  - **Contact force:** are forces which are in contact or in touch with the body to which they are applied. Examples are forces of push, pull, tension, reaction and **frictional forces**.
  - **Force field:** These are forces whose sources do not require contact with the body to which they are applied. Examples are *gravitational force, electric {electrostatic} force and magnetic force.*
    - **Gravitational force** is the force with which the earth attract object toward its center.
    - **Electrostatic force** is the force that exit round charged bodies.
    - **Magnetic force** exists around a bar magnet.

Friction

- **Friction:** is defined as a force which acts at the surface of separation between two objects in contact and tend to oppose the motion of one over the other. It has both desirable and undesirable effect and it is independent of the area of surface in contact.
- **Static or limiting friction:** is the maximum force that must be overcome before a body can just start to move over another.
- **Kinetic or dynamic friction:** is the force that must be overcome so that a body can move with uniform speed over another body.

$$F = \mu R$$

The constant μ is known as coefficient of friction.

$$\mu = \frac{F}{R}$$

$$\mu = \frac{\text{frictional force } F}{\text{normal reaction } R}$$

- **Advantages of Friction**
  - Friction is used in the grindstone to sharpen knives and chisels.
  - Friction enables the break to stop the car, and the locomotive to pull the train.
  - Friction enables a screw or a nail to remain in place after being screwed into position.
  - Friction enables the automobile tyres to make a firm grip on roadway, thus aiding their movement.
  - Without friction it will be impossible to walk or stop walking after getting started. We walk only with the help of friction between our feet and the ground.
- **Disadvantages of Friction**
  - Friction leads to much wear and tear on the moving part of machines.
  - Friction causes loss of energy in machines and therefore, reduces their efficiency.
  - Friction causes the heating of engines. This because the energy which must be used to overcome friction is converted into heat.
  - Friction also causes sound {squeaks and groans} in machines.
- **Methods of reducing friction**
  - Use of **lubricants** like oil, grease, air and graphite.
  - Use of ball or roller bearings.
  - The streamlining of body shapes of moving objects.

Scalar and Vectors

- **Scalar quantities:** are those which have only magnitude or numerical value but no direction. Examples are length {or distance}, mass, volume, density, time, speed, temperature, and energy.
- **Vector quantities:** are those which have both magnitude {and size} and direction. Examples are displacement, velocity, acceleration, weight, force, momentum, electric field.
- **Resultant vector:** is that single vector which would have the same effect in magnitude and direction as the original vectors acting together.

  There are in general two methods of adding or compounding vectors to find the resultant. These are

  Parallelogram method, Triangle method, Analytical method {is less used},

  ✔ Parallelogram method: **Parallelogram law** of vectors states that if two vectors are represented in magnitude and direction by the adjacent sides of a parallelogram, the diagonal of the parallelogram drawn from the point of interaction of the vectors represents the resultant vector in magnitude and direction.

  ✔ Triangle method: The **Pythagoras theorem** is used {and only when the two vectors are inclined at right angles to each other}.

✔ Analytical method: The **cosine rule** is used {to obtain the resultant vector}.

In general, if two vectors P and Q are inclined at Θ^0 to each other, the resultant vector R is given by

$$\mathbf{R^2 = P^2 + Q^2 + 2PQcos\Theta^0}$$

- The component of a vector in a given direction is its effective value in that direction. It is customary to resolve a vector in the horizontal and vertical direction. If a vector **V** is inclined at Θ^0 to the horizontal, the **horizontal component** of **V** is given by $V_x = V\cos\Theta$.

  The **vertical component** is given by $V_y = V\sin\Theta$.
- Where there are more than two vectors, the resultant can be found by first resolving the system into two perpendicular directions. Let the sum of the X – components by X, and the sum of Y – components by Y. Then **resultant** $R^2 = X^2 + Y^2$ and $\tan\alpha = Y/X$, where α is the inclination angle to the X – direction or the horizontal direction.

Exercise 1

1. Study the distance {displacement} time graph and the velocity-time graphs
2. A bus travelling at 60kmhr^{-1} accelerates uniformly at 5ms^{-2}. Calculate its velocity after 2 minutes.
3. A car accelerates uniformly at a rate of 10ms^{-2} from an initial velocity of 36kmhr^{-1} for 30 seconds. Find the distance covered during this period.
4. A body moving with an initial velocity of 30ms^{-1} accelerates uniformly at a rate of 10ms^{-2} until it attains a velocity of 50ms^{-1}. What is the distance covered during this period?
5. A ball is released from a height above the ground. Find its velocity after 5 seconds. Take as 10ms^{-2}.
6. A bus travels with an average velocity of 60kmh^{-1}. How long does it take to cover a distance of 500km?
7. A mass of 10kg is moving in a circular path of radius 2m with a uniform speed of 50ms^{-1}. Find the centripetal acceleration and the corresponding centripetal force.

WORK, ENERGY AND POWER

Work

- **Work**: is said to be done whenever a force moves its point of application a distance in the direction of the force. Work is measured in joules.
- **Work done**: is defined as the product of the force and the displacement in the direction of the forced. W = F × S

Work = Force × Displacement

{Joules} = {newton} **×** {metre}

- **Work done in a force field**

$$\text{Work} = \text{force} \times \text{distance}$$
$$= mg \times h$$
$$= mgh$$

Where *m* = mass of the body, *g* = acceleration due to gravity {g = 10ms^2} and *h* = height.

- **Energy**

- **Energy:** is defined as the capacity/ability to do work. It is measured in joules. Examples are mechanical energy, heat {thermal} energy, light energy, chemical energy, electrical energy, atomic energy, solar energy.
- **Types of mechanical energy:**
  - ✔ **Potential energy (P.E)**: is simply "stored energy" or the energy possessed by a body by virtue of its position or state. A body may have potential energy due it position in the force field. If the force field is gravitational field, the body is said to possess a **gravitational potential energy E_{gp}**. E_{gp} = mgh. It is also measured in joules. Other examples of potential energy are:
    - A magnet at rest in a magnetic field {magnetic potential energy}.
    - An electric charge at rest in an electric field {electrical potential energy}.
    - A coiled spring when stretched or compressed possess elastic potential energy.
  - ✔ **Kinetic energy (K.E)**: is the energy possessed by a body by virtue of its motion. K.E = $\frac{1}{2}mv^2$. Examples are:
    - A student running a race.
    - An object falling freely under gravity.
    - Wind or air in motion.

- **Power**

- **Power:** is defined as the time rate of doing work. It is measured in **watt**.

$$Power = \frac{Work}{Time}$$
$$1 \text{ watt} = 1 \text{ joules per second}$$

- **One kilowatt – hour:** is the work done in hour by an agent working at the constant rate of one kilowatt.

1kw = 1,000 W = 10^3W 1MW = 1,000,000 = 10^6 W 1 horse power =746 W

- **Law of conservation of energy:** states that in an isolated or closed system, the total amount of energy is always constant, although energy may be changed from one form to another.
- **Renewable energy:** are those that can be replaced as they are used. They are continually replenished. Examples are *solar energy, wind energy, water energy, and biomass.*
- **Non – Renewable energy:** such energy are depleting, they cannot be replenished as they are used. Examples are *nuclear energy from radioactive materials, petroleum and natural gas, and coal.*

Exercise 2

1. *A body of mass of mass 50kg runs up a set of steps of total height 3.0m. Find the work done against gravity.*
2. *A loaded sack of total mass 100kg falls down from the floor of a lorry 2.0m high. Calculate the work done by gravity on the load.*
3. *Find the potential energy of a boy of mass 10kg standing on a building floor 10 metres above the ground level.*
4. *An object of mass 5kg is moving at a constant velocity of $15ms^{-1}$. Calculate its kinetic energy.*
5. *A boy of mass 10kg climbs up 10 steps each of height 0.2m in 20 seconds. Calculate the power of the boy.*

ELASTIC PROPERTIES OF SOLIDS

Elasticity and Hooke's Law

- **Elasticity:** is the ability of a substance to regain its original shape and size after being distorted by an external force.
- **An elastic material:** is one that regains its original shape and size after the distorting force has been removed.
- **Hooke's law:** states that provided the elastic limit of an elastic material is not exceeded, the extension, *e*, of the material is directly proportional to the load or applied force, *F*.
- **Elastic limit:** is the limit of force beyond which the stretched wire does not return to its original length when the stretching force is removed.
- **Yield point:** is the point beyond the elastic limit in which the elastic material has yielded all its elasticity permanently and has become plastic.
- **Elastic constant:** of an elastic material is the force required to give unit extension. According to Hooke's law, the force F required to stretch or compress an elastic material is directly proportional to the extension or compression *e,* thus $F \propto e$.

$$F = ke$$

Where k is a constant of proportionality called elastic constant or force constant stiffness of the material. If F is in newton and *e* is in metre, the elastic constant is given by:

$$k = \frac{F}{e}$$

- **Young's modulus:** let a wire of length l {m} and cross – sectional area A {m^2} be extended through e {m} by a force F {N}. *The ratio of the force to the area {F/A} is called the* ***stress*** *or* ***tensile stress*** *of the material, its unit is* Nm^{-2}. *The ratio of the extension to original length {e/l} is the* ***tensile strain,*** *it has no unit.*

$$\textbf{Young's Modulus} = \frac{\textbf{Stress \{F/A\}}}{\textbf{Strain \{e/l\}}}$$

- **Elastic Potential Energy:** is the energy stored in the material as a result of its stretched or compressed state. Elastic potential energy is given by:

$$W = \tfrac{1}{2} Fe \text{ or } W = \tfrac{1}{2} ke$$

Where F is the maximum stretching or compressing force, *e* is the extension or compression, and k is the force constant of the material.

Exercise 3

1. A force of 0.8N stretches an elastic spring by 2cm. Find the elastic constant of the spring.
2. A force of 2N stretches an elastic material by 30mm. What additional forces will stretch the material 35mm? Assume that the elastic limit is not exceeded.
3. A spiral spring is compressed by 0.02m. Calculate the energy stored in the spring, if the force constant is $400Nm^{-1}$

FLUID AT REST AND IN MOTION

Surface Tension

- **Surface tension:** is the force acting along the surface of a liquid, causing the liquid surface to behave like a stretched elastic skin.
- **Application of the effect of surface tension**
  - Water proof materials.
  - Cleansing action of soap and detergents.

Capillarity

- **Capillarity:** or capillary action is the tendency of a liquid to rise or fall in a narrow tube.
- **Cohesion:** is the force of attraction between molecules of the same kind, e.g. the molecule of water.
- **Adhesion:** is the force of attraction between molecules of different kinds, e.g. the molecules of water and glass.
- **Cohesion and Adhesion explains**:

- ✔ The different action of water and mercury when spilled on a clean glass surface.
- ✔ Why does blotting paper absorb ink.
- ✔ Water rises in the stem of plants.
- ✔ Kerosene rises up the wick of a lamp.

Viscosity

- **Viscosity**: is the internal friction between layers of a liquid or gas in motion. It decreases with temperature.
- **Application of viscosity**: viscous oils and air under pressure are used as lubricants.