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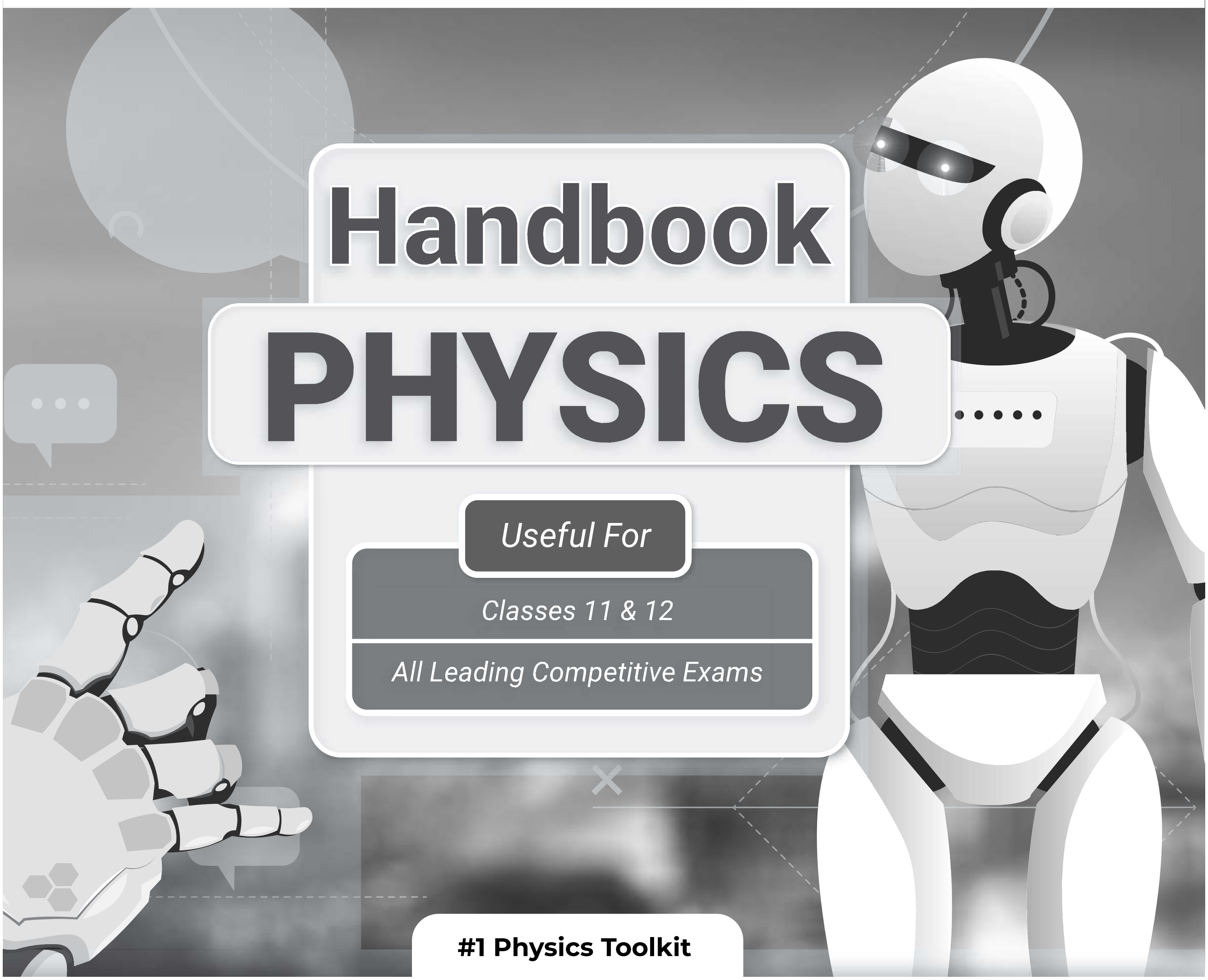

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We hope that OSWAAL HANDBOOKS will help you at every step as you move closer to your educational goal. We wish you all great success ahead!

All the Best!!

TEAM OSWAAL

CONTENTS

❑❑

SYLLABUS

- **Physical World:-** Science and Its Origin, Physics-Scope, Progress, Technology, Nature of physical laws.
- **Units and Measurement:-** Need for measurement: Units of measurement, Fundamental and derived units, Systems of units, Dimensions of physical quantities, Length, mass and time measurements, Accuracy and precision of measuring instruments; Errors in measurement, Significant figures, Dimensional analysis and its applications.
- **Motion in a Straight Line**:- Frame of reference, Motion in a straight line, Position, Displacement, Distance, speed and velocity.
- Average speed and Velocity, instantaneous speed and velocity, uniform, average and instantaneous acceleration.
- Graphical Representation – Position, time, velocity – time, motion with variable acceleration.
- **Motion in a 2 - Dimension**:- Scalar and vectors, Unit Vector, Scalar - Addition, Subtraction and Multiplication with Vectors, Parallel Vectors, Equality of Vectors, Addition of Vectors, Subtraction of Vectors, Zero Vector.
- Resolution of a vectors, Scalar Product of Vector, Cross Product of Vector, Rectangular components, Scalar and Vector product of vectors.
- Motion in 2D (Plane) - Position Vector and Displacement, Average Velocity, Instantaneous Velocity, Average Acceleration, Instantaneous Acceleration.
- Projectile Motion - Maximum Height, Range and Time of Flight of a Projectile.
- Uniform Circular Motion – Angular Displacement, Angular Velocity, Angular Acceleration, Centripetal Acceleration.
- Relative Motion - River Boat Problems, Relative Velocity of Rain.
- **Laws of Motion**:- Concept of force, Inertia, Newton's first law of motion; Newton's second law of motion, Newton's third law of motion, Momentum, Impulse.
- Law of conservation of linear momentum and its applications.
- Equilibrium of concurrent forces, Static, kinetic and limiting frictions, Laws of limiting friction, Rolling friction, Method of changing friction.
- Dynamics of uniform circular motion : Centripetal force, examples of circular motion,Pseudo Force.
- **Work, Energy and Power**:-Work done by a constant force and a variable force; kinetic energy, work energy theorem,power.
- Potential energy, potential energy of a spring,conservative and non - conservative forces : mechanical energy and its conservation(kinetic and potential energies); different forms of energy: mass energy equivalence; dynamics of circular motion; Collision: elastic and inelastic collisions in one and two dimensions.
- **System of Particle and Rotational Motion**:- Centre of mass of a two-particle system, momentum conservation and centre of mass motion. Centre of mass of a rigid body; centre of mass of a uniform rod.
- Moment of a force, torque, angular momentum , law of conservation of angular momentum and its applications. Equilibrium of rigid bodies, rigid body rotation and equations of rotational motion, comparison of linear and rotational motions.
- Moment of inertia, radius of gyration, values of moments of inertia for simple geometrical objects (no derivation). Statement of parallel and perpendicular axes theorems and their applications.
- **Gravitation**:-Newton's universal law of gravitation, Acceleration due to gravity and its variation with altitude, depth, shapes and rotation of Earth, Kepler's laws of planetary motion.
- Orbital velocity, Escape velocity of a satellite, Time period of satellite
- Gravitational potential, Gravitational Field and Intensity, Gravitational potential energy, Energies of satellite (Binding,Kinetic and Potential), geostationary satellites, Weightlessness.
- **Elasticity**:- Elastic behaviour, Stress-strain relationship, Hooke'slaw, young's modulus, bulk modulus, modulus of rigidity. Poisson's ratio; elastic energy;
- **Mechanical Properties of Solids**:- This chapter will help you understand
- Elastic behaviour, Stress-strain relationship, Hooke's law, young's modulus, bulk modulus, modulus of rigidity.
- Poisson's ratio; elastic energy;x
- **Mechanical Properties of Fluids**:-Fluid Mechanics; Pressure at various Level; Pascal's law; Application of Pascal's law (hydraulic lift and hydraulic brakes).
- Viscosity, Stokes' law, terminal velocity, streamline and turbulent flow, Critical velocity, Equation of Continuity, Bernoulli's theorem and its applications.
- Surface energy and surface tension, angle of contact, excess of pressure across a curved surface, Application of surface tension Concept of Capillarity
- **Thermal Properties of Matter**:-Heat, temperature, thermal expansion; thermal expansion of solids, liquids and gases, anomalous expansion of water;
- Heat and calorimetry; specific heat capacity; change of state - latent heat capacity.

.....Contd Syllabus

- Heat transfer-conduction, convection and radiation, thermal conductivity.
- Absorptive and emissive powers; Kirchhoff's law; Newton's Law of cooling
- Qualitative ideas of Blackbody radiation, ein's displacement Law, Stefan's law, Greenhouse effect.

➢ **Thermodynamics**:- Thermodynamics: Thermal equilibrium, Zeroth Law of Thermodynamics, Concept of temperature, heat, work and internal energy; First law of thermodynamics, isothermal, isochoric, isobaric and adiabatic processes.

- Second law of thermodynamics: reversible and irreversible processes, Heat engine and refrigerator, Carnot theorem, Carnot engine and its efficiency.

➢ **Kinetic Theory of Gases** :- Equation of state of a perfect gas, work done in compressing a gas, Kinetic theory of gases - assumptions, concept of pressure. Kinetic interpretation of temperature; rms speed of gas molecules; degrees of freedom, law of euipartition of energy(statement only) and a plication to specific heat capacities of gases;concept of mean free path, Avogadro's number.

➢ **Oscillation**:- Periodic motion - time period, frequency, displacement as a function of time periodic functions. Simple harmonic motion (S.H.M) and its equation; phase; oscillations of a loaded spring- restoring force and force constant; energy in S.H.M. Kinetic and potential energies; Angular Oscillation; Simple pendulum derivation of expression for its time period.

- Free, forced and damped oscillations (qualitative ideas only), resonance.

➢ **Waves :-** Wave motion : Transverse and longitudinal waves, speed of travelling wave, displacement relation for a progressive wave,principle of superposition of waves, reflection of waves,standing waves in strings and organ pipes, fundamental mode and harmonics, Beats,Doppler effect

➢ **Electric Charges and Fields:-** Electric Charges; Conservation of charge, Coulomb's law-force between two point charges, forces between multiple charges; superposition principle and continuous charge distribution.

- Electric field, electric field lines, electric field due to a point charge, electric dipole, electric field due to a dipole, torque on a dipole in uniform electric field
- Electric flux, statement of Gauss's theorem and its applications to find field due to infinitely long straight wire, uniformly charged infinite plane sheet and uniformly charged thin spherical shell (field inside and outside).

➢ **Electrostatic Potential and capacitance:-** Electric potential, potential difference, electric potential due to a point charge, Electrostatic Potential Energy, dipole and system of charges; equipotential surfaces, electrical potential energy of a system of two point charges and of electric dipole in an electrostatic field.

- Conductors and insulators, free charges and bound charges inside a conductor. Dielectrics and electric polarisation,
- Capacitors and capacitance, combination of capacitors in series and in parallel, capacitance of a parallel plate capacitor with and without dielectric medium between the plates, energy stored in a capacitor. Van de Graff generator.

➢ **Current Electricity:-** Electric current, flow of electric charges in a metallic conductor, drift velocity, mobility and their relation with electric current; Ohm's law, electrical resistance, V-I characteristics (linear and non-linear), electrical energy and power, electrical resistivity and conductivity, Carbon resistors, colour code for carbon resistors; series and parallel combinations of resistors; temperature dependence of resistance.

- Internal resistance of a cell, potential difference and emf of a cell, combination of cells in series and in parallel, Kirchhoff's laws and simple applications, Wheatstone bridge, metre bridge.
- Potentiometer - principle and its applications to measure potential difference and for comparing EMF of two cells; measurement of internal resistance of a cell.

➢ **Magnetic Effects of Current:-** Concept of magnetic field, Oersted's experiment. Biot - Savart law and its application to current carrying circular loop. Ampere's law and its applications to infinitely long straight wire. Straight and toroidal solenoids (only qualitative treatment), force on a moving charge in uniform magnetic and electric fields, Cyclotron.

- Force on a current-carrying conductor in a uniform magnetic field, force between two parallel current-carrying conductors– definition of ampere, torque experienced by a current loop in uniform magnetic field; moving coil galvanometer–its current sensitivity and conversion to ammeter and voltmeter.

➢ **Magnetism and Matter:-** Magnetism – Introduction, Current loop as a magnetic dipole and its magnetic dipole moment, magnetic dipole moment of a revolving electron, magnetic field intensity due to a magnetic dipole (bar magnet) along its axis and perpendicular to its axis.

- Torque on a magnetic dipole (bar magnet) in a uniform magnetic field; bar magnet as an equivalent solenoid, magnetic field lines; Earth's magnetic field and magnetic elements.
- Para-, dia- and ferro - magnetic substances with examples. Magnetic Susceptibility, Permeability, Hysteresis,
- Electromagnets and factors affecting their strengths, permanent magnets.

➢ **Electromagnetic:-** Experiments Involved, Electromagnetic induction; Faraday's laws, induced EMF and current; Lenz's Law, Eddy currents. Self and mutual induction. Applications

➢ **Alternating Current**:- Alternating Current : Mean or Average value and Root mean square (rms) value of alternating current/voltage. Basic elements of an AC circuit : Reactance, Impedance, Average Power, Power Factor, Watt-less current, Quality Factor, Bandwidth and Phasor Diagrams. Different Types of Alternating Circuits : R-circuit, C-circuit, L-circuit, LR-circuit, RC-circuit, and LCR-circuit. Electric Resonance. AC Generator or Dynamo and Transformer.

- **Electromagnetic Waves**:-Electromagnetic Waves and its Characteristics, Ampere-Maxwell's Law, Displacement Current, Maxwell's Equations. Nature and Energy of EM waves, Total Radiant Flux, Poynting vector and Polarization.
- Electromagnetic spectrum (radio waves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays) and Energy of EM spectrum.
- **Ray Optics and Optical Instruments**:- Reflection of light, spherical mirrors, mirror formula, refraction of light, total internal reflection and its applications, Optical fibre.
- Refraction at spherical surfaces, lenses, thin lens formula, lensmaker's formula, Magnification, power of a lens, combination of thin lenses in contact, refraction of light through a prism, Scattering of light - blue colour of sky and reddish appearance of the sun at sunrise and sunset.
- Optical instruments : Microscopes and astronomical telescopes (reflecting and refracting) and their magnifying powers.
- **Wave Optics**:-Wave front and Huygen's principle, reflection and refraction of plane wave at a plane surface using wave fronts. Proof of laws of reflection and refraction using Huygen's principle, Principle of Superposition of waves, Important terms related to waves, Resultant Amplitude and Intensity. Interference, Young's double slit experiment and expression for fringe width, coherent sources and sustained interference of light, diffraction due to a single slit, width of central maximum. Polarisation, plane polarised light, Brewster's law, uses of plane polarised light and Polaroids. Resolving power of microscope and astronomical telescope.
- **Dual Nature of Radiation and Matter**:-Electron emission, Work Function, Photoelectric Effect: Experimental Study of Photoelectric Effect, Hertz and Lenard's observations, Laws of Photoelectric Effect, Compton Effect, Einstein's photoelectric equation, Dual nature of radiation, Dual nature of Matter : de-Broglie wave equation. Davisson and Germer's experiment.
- **Atoms**:-Thomson's Atomic-Model, Rutherford's α-particle scattering experiment, Rutherford's model of atom; Bohr model, Energy levels, hydrogen spectrum.
- **Nuclei:-** Nucleus and about its attributes, radioactivity, alpha, beta and gamma particles/rays and their properties; radioactive decay law.
- Mass-energy relation, mass defect; binding energy per nucleon and its variation with mass number; nuclear fission, nuclear fusion.
- **Semiconductors Electronics:-** Energy bands in conductors, semiconductors and insulators, Semiconductor diode - V-I characteristics in forward and reverse bias, diode as a rectifier; Special purpose p-n junction diodes : LED, photodiode, solar cell and Zener diode and their characteristics, Zener diode as a voltage regulator. Transistor-types, working, characteristic and configuration.
- Digital Signals-Logic gates and combination of Logic gates.

❑❑❑

WHAT IS A MNEMONIC?

A Mnemonic is an easy learning trick to memorise something complex.

Mnemonics help you to remember concepts for a long time.

During your exam, these Mnemonics will prove very useful to recollect concepts quickly and easily.

This is one more cognitive learning tool that fulfils our aim of 'making learning simple' for you.

Each unit is picked from your syllabus. A concept is identified from it and relevant Mnemonics are developed for it by the "Oswaal Editorial Board".

Descriptions are also provided for each Mnemonic for clarity.

M. N. E. M. O. N. I. C.

Making a Nice and Easy, Memorable, Optical 'N' Illustrative representation of Concepts

Class - 11, Unit-I

Physical World

Good **W**orkers **w**ork **f**or **E**xtended **S**ession.

Strength wise arrangement of fundamental forces in ascending order : **G**ravitation < **W**eak Nuclear force < **E**lectromagnetism < **S**trong Nuclear force

Class - 11, Unit-II

Motion In A Straight Line

Delhi **t**o **V**adodara **v**ia **T**undla **A**gra.

Displacement/**t**ime = **V**elocity

Velocity / **t**ime = **a**cceleration

Class - 11, Unit-III

(a) **Newton's Laws of Motion**

Newton, Newton don't kick cow
She may move ahead little bit now*
Newton hears her MAAA sound**
Cow gives Newton a kick rebound***

* Newton's 1st law. A body continues its state of rest or state of motion unless it is acted upon by an unbalanced force.

** Newton's 2nd law F = ma

*** Newton's 3rd law : Every action has its equal and opposite reaction

Interpretation :

1st two lines of the rhyme depicts the 1st law of motion

3rd line depicts the 2nd law of motion

i.e. F = m × l

Lat the depicts the 3rd law of motion

(b) **Motion In A Straight Line (2)**

A will be **I**, when 0 is close to **T**
Replace the "Δ" simply with "d"

Average Velocity = ΔD/ΔT

$$\lim_{\Delta T \to 0} \frac{\Delta D}{\Delta T}$$ = **I**nstantaneous velocity = dD/dT

Average Acceleration = ΔV/ΔT

$$\lim_{\Delta T \to 0} \frac{\Delta V}{\Delta T}$$ = Instantaneous velocity = dV/dT

Class - 11, Unit-IV

Work, Energy And Power

Fernandez **d**'souza **o**rdered **n**oodles, **b**ut **w**as **s**erved **p**izza **a**nd **p**izza **w**as **a** **z**est.

If **f**orce and **D**isplacement are in **o**pposite direction, then work done is **n**egative.

If **f**orce and **D**isplacement are in **s**ame direction, then work done is **p**ositive.

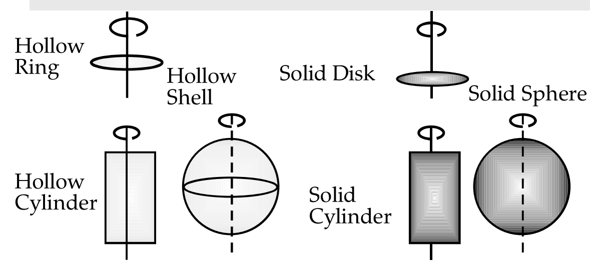
If force and Displacement are **p**erpendicular to each other, then **w**ork done is **z**ero.

Class - 11, Unit-V

Motion Of System Of Particles & Rigid Body

How **r**hino **c**ame **s**wift? **S**ince **d**ino **c**ame **s**low.

Write $2MR^2$ under each figure and then divide by 2, 3, 4, 5 respectively.



Class - 11, Unit-VI

Kelper's Laws of Planetary motion :

Take **E**ssential **F**oods **E**veryday **2/3 T**imes

1st Law: Planets move in **elliptical** orbits

Sun is at one of **foci** of the orbit

2nd Law: A planet covers the **equal** area of space in **equal** interval of time no matter where it is in its orbit

3rd Law: Square of the **Time-period** of the planet is proportional to the cube of the semi major axes of the orbit. $T^2 \propto R^3$

Interpretation:

Letter E and F of Essential Food represents ''Elliptical'' and ''Foci".

1st Law : Planets move in **elliptical** orbits with Sun at one of the foci.

Letter E of the word Everyday represents "Equal":

2nd Law : A planet covers the equal area space in equal interval of time no matter where it is in its orbit.

2/3 and T of the last two words represents the "power of Time Period" and "power of semi-major axis:

3rd Law :

Square of the Time-period of the planet is proportional to the cube of the semi major axes of the orbit.

$T^2 \alpha\ R^3$.

Class - 11, Unit-VII

1. Mechanical Properties Of Solid

Young **R**avi **b**ought **a** **p**en.

(1) Relation between **Y**, **B** and σ : (write Y and B(1+ σ) with coefficients and an equal sign in between. 1Y = 3B (1 + σ)

To find the coefficient of σ, refer the anti-clock circle, subtract the coefficients of B from

coefficient of Y i.e. 1 – 3 = -2

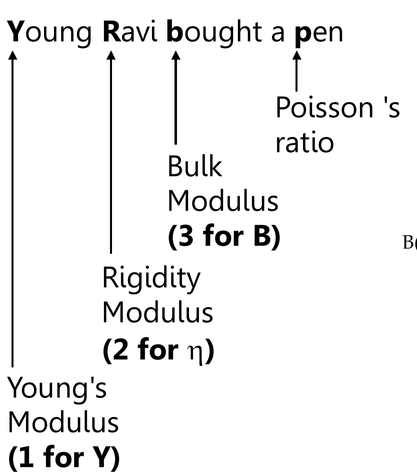
So, the relation is 1**Y** = 3**B** (1 - 2σ) or, **Y** = 3**B** (1 - 2σ)

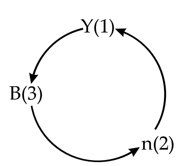
(2) Relation between **Y**, η and σ : (write **Y** and η(1+ σ) with coefficients and an equal sign in between.

1**Y** = 2η (1 + σ)

To find the coefficient of σ, subtract the coefficient of **Y** from coefficient of η i.e. 2 – 1 = 1

So, the relation is 1**Y** = 2η (1 + σ) or, **Y** = 2η (1 + σ)





2. Thermal Properties of Matter

Fingers **w**e **h**ave **f**ive
Cats **h**ave **n**ine **l**ives.
With **160** **m**ore
Cat **w**ill **h**elp **y**ou **s**ure!

Fingers we have five → 5F

Cats have nine lives. → 9C

With 160 more → 9C + 160

Cat will help you sure! → 5F = 9C + 160

Class - 11, Unit-VIII

Thermodynamics

Temperature, **V**olume, **P**ressure **N**o **H**eat **i**s **t**ransferred

Constant **t**emperature → Isothermal process

Constant **v**olume → Isochoric process

Constant **p**ressure → Isobaric process

No **h**eat **t**ransferred → Adiabatic process

Class - 11, Unit-IX

Behaviour of Perfect Gas & Kinetic Theory

Degrees of freedom :
Baa Baa Black Sheep
Have you any wool?
Yes sir, **M**om has **3** bags full.
Dadi needs **5** bags **n**ormally cool
Papa keeps **6** bags **n**ormal rule.
Papa, **D**adi each needs **2** bags more
High **c**old whenever, be very sure.

Mom has **3** bags full → Degrees of freedom of Monoatomic gas is 3.

Dadi needs **5** bags **n**ormally cool

Degrees of freedom of diatomic gas at normal → (room) temperature is 5.

Papa keeps **6** bags **n**ormal rule → Degrees of freedom of Polyatomic gas at normal (room) temperature is 6.

Papa, **D**adi each needs **2** bags more → Degrees of freedom of Polyatomic gas at high temperature is 6+2=8.

High cold whenever, be very sure → Degrees of freedom of Diatomic gas at high temperature is 5+2=7.

Class - 11, Unit-X

Waves

Teacher **P**unished **L**azy **D**og.

Particle oscillation in **T**ransverse wave → **P**erpendicular to the direction of propagation of wave

Particle oscillation in **L**ongitudinal wave → In the **d**irection of propagation of wave

Class - 12, Unit-I

Electric Charge & Field

Equally **d**ivide **c**ost **p**er **a**nnum.

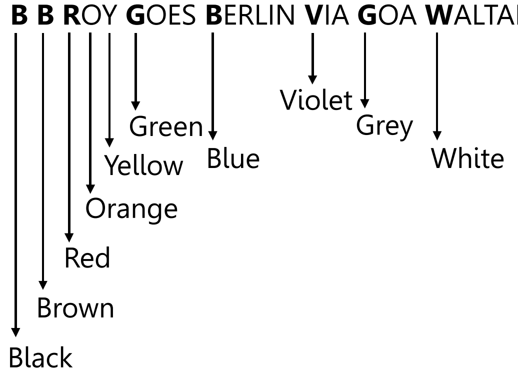
To find **e**lectric field, **d**ivide the **c**harge (enclosed) by the free space **p**ermittivity and **a**rea of the Gaussian

Class - 12, Unit-II

Resistor colour code :

0 1 234 5 6 7 8 9

B B ROY **G**OES **B**ERLIN **V**IA **G**OA **W**ALTAIR.



Interpretation :

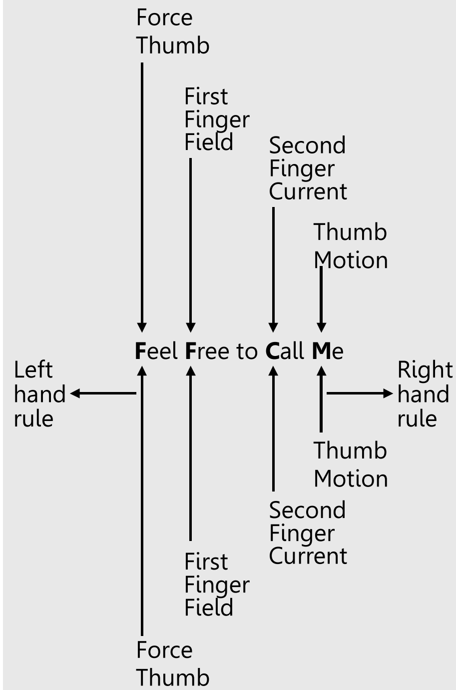
Colour codes of carbon resistors :

Colour	Corresponding number
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Berlin	6
Violet	7
Grey	8
White	9

Class - 12, Unit-III

Moving Charge And Magnetism

Fleming's left and right hand rule:



In Fleming's left hand rule, Thumb indicates FORCE.

In Fleming's right hand rule, Thumb indicates MOTION.

In both rules, first finger indicates Magnetic FIELD and second finger indicates CURRENT

Class - 12, Unit-IV

Alternating Current

Calcutta **C**ity **V**ery **L**ovely **a**nd **V**ery **C**ongested

For **c**apacitive circuit → **C**urrent leads **V**oltage

For **i**nductive circuit → **v**oltage leads **c**urrent

Class - 12, Unit-V

Electromagnetic Waves

Russian **M**agician **s**howed **a**n **I**nteresting **V**ery **U**nusual **X**-ray **e**ye **G**ame

Electromagnetic waves with increasing frequency (decreasing wavelength) is in the order of:

(a) **R**adio wave

(b) **M**icrowave

(c) **I**nfrared

(d) **V**isible light

(e) **U**ltraviolet

(f) **X**-Rays

(g) **G**amma Rays

Class - 12, Unit-VI

(a). Ray Optics & Optical Instruments

M **m**eans **M**ORE **i.e**

Mirror Formula

↓

M means **MORE** i.e+

So, $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$

Magnification will be of opposite sign :

So, $m=-\frac{v}{u}$

(b). Ray Optics & Optical Instruments

L **m**eans **LESS** **i.e**

Lens Formula

↓

L means **LESS** i.e–

So, $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$

Magnification will be of opposite sign :

So, $m=+\frac{v}{u}$

Class - 12, Unit-VII

Einstein's equation of Photoelectric effect :

WE **Unite** to form **P**eople

- W → Work Function
- E → Energy of electron emitted
- Unite → Add
- P → Photon energy

Energy of emitted electron + Work function = Energy of incident Photon

Interpretation :

$E + \varphi = hf$

Or, $E = hf = \varphi$

Class - 12, Unit-VIII

(a). Atom : Hydrogen Spectra

Papa **b**rings **P**astry **f**or **B**abu **a**nd **L**al

When n_i = 1, the series is **L**yman

When n_i = 2, the series is **B**almer

When n_i = 3, the series is **P**aschen

When n_i = 4, the series is **B**rackett

When n_i = 5, the series is **p**-fund

(b). Atom : Hydrogen Spectra

1 **i**s **U**nimportant, **2** **i**s **V**ery **i**mportant **a**nd **r**est **a**re **I**mportant

If n_i = 1, i.e. Lyman series is in **UV** range.

If n_i = 2, i.e. Balmer series is in **VIS**IBLE range.

If n_i = 3, 4 and 5, i.e. Paschen series, Brackett series and p-fund series are in **IR** range

(c). Isotope, Isobar, Isotone

ISO **T**ope **B**ar **T**one

ISO–TOPE: Ⓟ i.e numbers of PROTONs are same and numbers of NEUTRONs different

ISO–BAR: NoⓅNoⓃ i.e. both PROTONs and NEUTRONs differ in number (Total remains same.)

ISO–TONE: Ⓝ i.e. numbers of NEUTRONs are same and numbers of PROTONs different

In isotopes, number of protons are same. Number of neutrons are different.

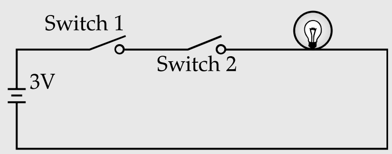
In isotones, number of neutrons are same. Number of protons are different.

In isobars, number of neutrons are different. Number of protons are also different. But the total nucleons remain same.

Class - 12, Unit-IX

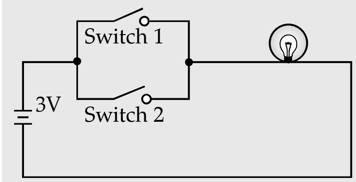
Electronic Devices

Truth **t**able of **A**ND and **OR g**ate



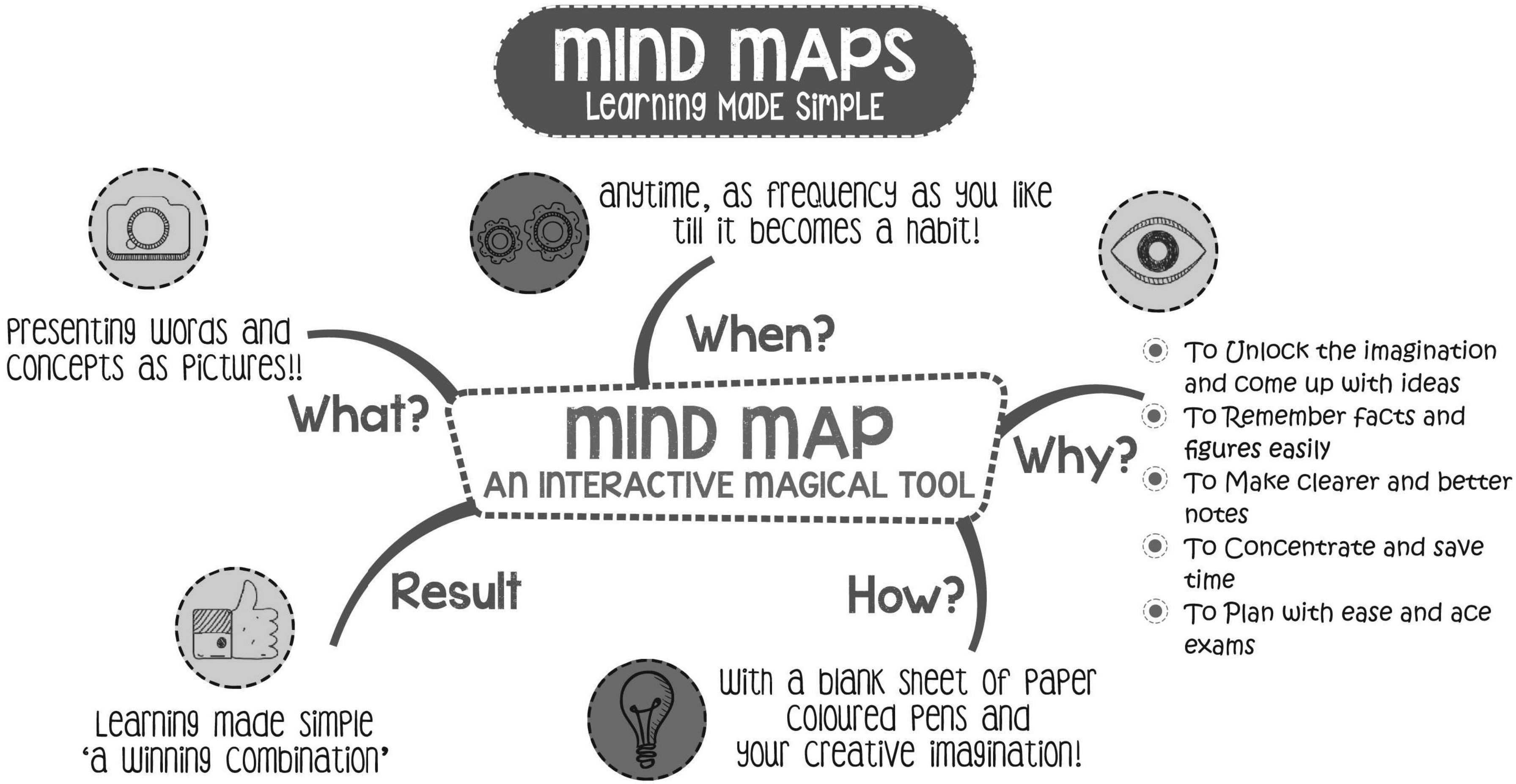
For AND gate, when both the switches are ON, then only the bulb is ON.

i.e. When both the inputs are 1, then only output is 1. Otherwise the output is 0.



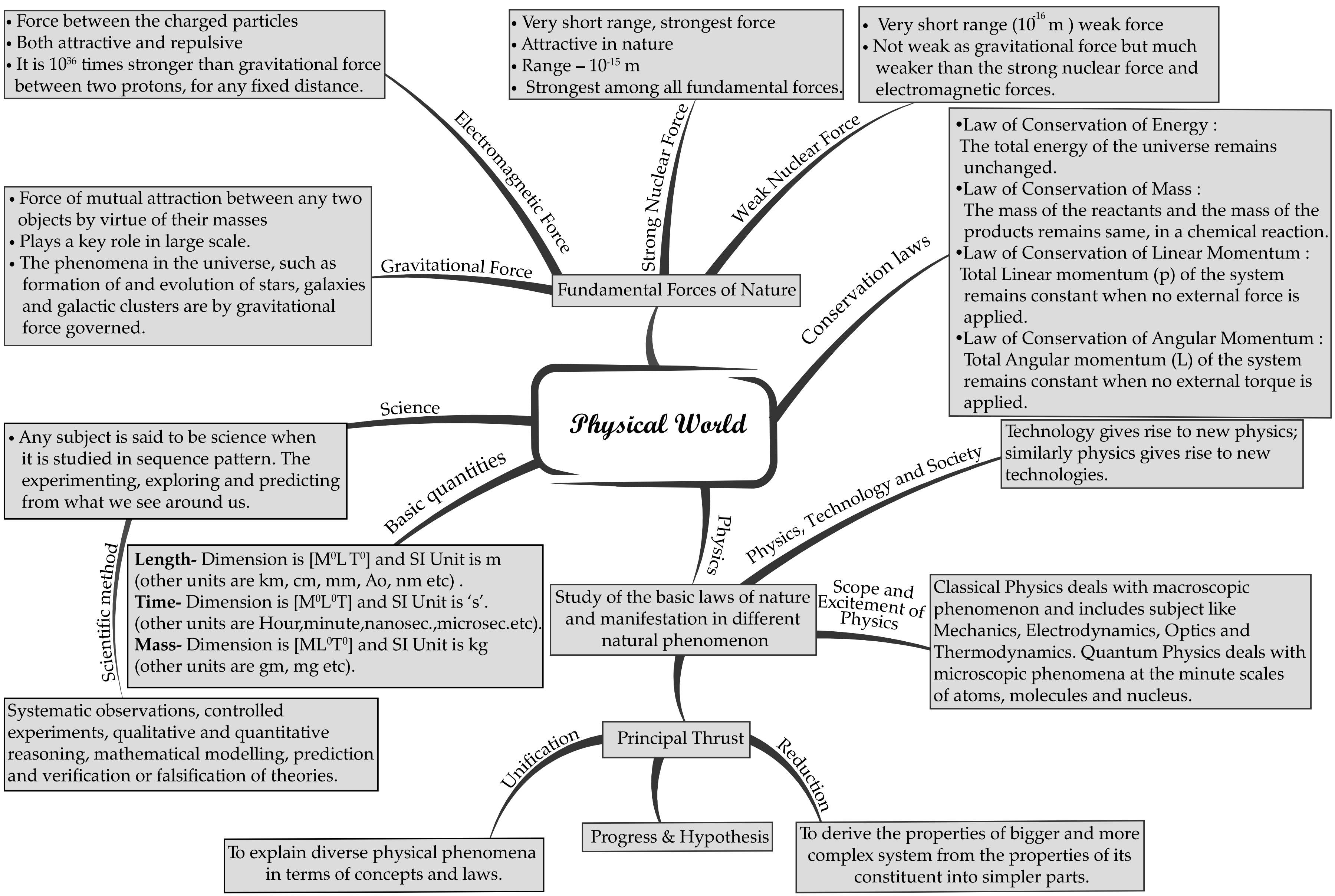
For OR gate, when both the switches are OFF, then only the bulb is OFF.

i.e. When both the inputs are 0, then only output is 0. Otherwise the output is 1



What are Associations?

It's a technique connecting the core concept at the Centre to related concepts or ideas. Associations spreading out straight from the core concept are the First Level of Association. Then we have a Second Level of Association emitting from the first level and the chronology continues. The thickest line is the First Level of Association and the lines keep getting thinner as we move to the subsequent levels of association. This is exactly how the brain functions, therefore these Mind Maps. Associations are one powerful memory aid connecting seemingly unrelated concepts, hence strengthening memory.


Physical World
Fundamental Forces of Nature
Electromagnetic Force
• Force between the charged particles
• Both attractive and repulsive
• It is 10^{36} times stronger than gravitational force between two protons, for any fixed distance.
Strong Nuclear Force
• Very short range, strongest force
• Attractive in nature
• Range – 10^{-15} m
• Strongest among all fundamental forces.
Weak Nuclear Force
• Very short range (10^{16} m) weak force
• Not weak as gravitational force but much weaker than the strong nuclear force and electromagnetic forces.
Gravitational Force
• Force of mutual attraction between any two objects by virtue of their masses
• Plays a key role in large scale.
• The phenomena in the universe, such as formation of and evolution of stars, galaxies and galactic clusters are by gravitational force governed.
Conservation laws
•Law of Conservation of Energy : The total energy of the universe remains unchanged.
•Law of Conservation of Mass : The mass of the reactants and the mass of the products remains same, in a chemical reaction.
•Law of Conservation of Linear Momentum : Total Linear momentum (p) of the system remains constant when no external force is applied.
•Law of Conservation of Angular Momentum : Total Angular momentum (L) of the system remains constant when no external torque is applied.
Science
• Any subject is said to be science when it is studied in sequence pattern. The experimenting, exploring and predicting from what we see around us.
Scientific method
Systematic observations, controlled experiments, qualitative and quantitative reasoning, mathematical modelling, prediction and verification or falsification of theories.
Basic quantities
Length- Dimension is $[M^0 L T^0]$ and SI Unit is m (other units are km, cm, mm, Ao, nm etc) .
Time- Dimension is $[M^0 L^0 T]$ and SI Unit is 's'. (other units are Hour,minute,nanosec.,microsec.etc).
Mass- Dimension is $[M L^0 T^0]$ and SI Unit is kg (other units are gm, mg etc).
Physics
Study of the basic laws of nature and manifestation in different natural phenomenon
Physics, Technology and Society
Technology gives rise to new physics; similarly physics gives rise to new technologies.
Scope and Excitement of Physics
Classical Physics deals with macroscopic phenomenon and includes subject like Mechanics, Electrodynamics, Optics and Thermodynamics. Quantum Physics deals with microscopic phenomena at the minute scales of atoms, molecules and nucleus.
Principal Thrust
Unification
To explain diverse physical phenomena in terms of concepts and laws.
Progress & Hypothesis
Reduction
To derive the properties of bigger and more complex system from the properties of its constituent into simpler parts.

CHAPTER

1 PHYSICAL WORLD

Chapter Objectives

Science and Its Origin, Physics-Scope, Progress, Technology, Nature of Physical Laws.

STUDY MATERIAL

Concepts Clarified :

➢ **Science and Its Origin** : Science is a logical and systematic understanding of phenomena existing naturally so that it can be predicted, controlled and modified. Exploration, Experimentation, Speculation that happens around us is a part of Science.

Science is derived from "***Scientia***" – a Latin word that means "***to know***".

Scientific Method is a way to get and enhance in-depth knowledge. It consists of :

- Systematic Observations.
- Controlled Observations.
- Qualitative and Quantitative Observations.
- Mathematical Modelling.
- Prediction – Speculation.
- Verification and Validation of Theories.

Kaizen is always there in science, there is always an improved observation with accurate tools and more knowledge. **For Example :** Nicolas Copernicus theory was improved by Johannes Kepler using **Tycho Brahe's** Research on Planetary Motion. Every Scientist used the previous works or observation to improve, discover or invent further.

➢ **Natural Science** : It is a branch of Science that is related with prediction, description and understanding of natural Phenomena based on Empirical evidence and Observation. It consists of

- Physics
- Biology
- Chemistry

Physics : Physics is the study of basic laws of nature – Manifestation and application under various phenomena. It is the study of physical world – Its motion through space and time, along with related concept like energy and force.

Physics is derived from "***Phusike***" – a Greek word that means "***nature***".

Approach involved are divided into two heads –

(1) Unification : According to this approach, World's phenomena is a collection of Universal Laws in different condition and domain. **For Example** : Law of Gravitation is responsible for "Planetary motion around the Sun" as well as "Falling of apple from the tree".

(2) Reduction : As per this approach, properties of complex system are derived from its own constituents. **For Example** : Temperature is a constituent of Thermodynamics as well as Kinetic theory (Average kinetic energy of molecules).

Uses and Impacts of Physics :

- Explaining phenomena based on a simple theory but happening over a large magnitude.
- Device development using Laws of Physics.
- Experimenting and finding observations to develop new theories as well as improving existing theories.

➢ **Scope of Physics** : Scope of physics is very vast as it covers all the basic quantities like length, time, mass etc. See below for more details :

Length – From 10^{-14} m or less (Study of Electrons) up to 10^{40} or more (Astronomical Study).

Time – From 10^{-22} s up to 10^{18} s.

Mass – From 10^{-30} kg up to 10^{55} kg.

Scope of Physics is broadly classified into two – Classical and Modern. Modern Physics deals with microscopic phenomena whereas classical physics deals with macroscopic phenomena.

Macroscopic Domain : This domain includes phenomena at large scale like laboratory, terrestrial and astronomical. Subjects included under this domain are as follows :

- **Mechanics** : It is based on Laws of Motion and Gravitation. It is related to motion, equilibrium of particles, rigid and elastic bodies and general system of particles.

  For Example : Sound Waves, Equilibrium of twisted rod under a load, Rocket propulsion by ejecting gases.
- **Electrodynamics** : It deals with electric and magnetic phenomena associated with magnetic and charged body.

  For Example : Motion of current carrying conductor in a magnetic field, Response of circuit to an AC voltage, Propagation of Radio waves in Ionosphere.
- **Optics** : It involves phenomena including light. e.g., Reflection and Refraction of Light, Dispersion of Light, Colour exhibited by thin films.
- **Thermodynamics** : It deals with the system in macroscopic equilibrium and changes in internal energy, temperature, entropy of system under external heat or force interaction. e.g., Efficiency of Heat Engine, Direction of Process – Chemical and Physical.

Microscopic Domain : This domain includes all phenomena at minute scale like atomic and molecular level. It deals with interaction of particle at subatomic level like electron, proton and other related particles. Theories like Quantum Theory are developed to handle such phenomena.

➢ **Progress** : The factors for the progress of the Physics are :

- Qualitative Analysis along with Quantitative Analysis.
- Application of Universal law in different context.
- Approximation Approach (Collection of basic laws as constituents of Complex Phenomena).
- Focusing and Extraction on essential features of phenomena.

Hypothesis, Axiom, Assumption and Models

- Hypothesis is a supposition without assuming it as true. It can be verified with a series of experiment but cannot be proved exactly.
- Axiom is a universal truth that is accepted universally without controversy and question.
- Model is the theory proposed to explain observed phenomena.
- Several phenomena can be explained using this assumption, these assumptions are the basis of Physics. These assumptions are made from experiments, observation and a lot of statistical data.

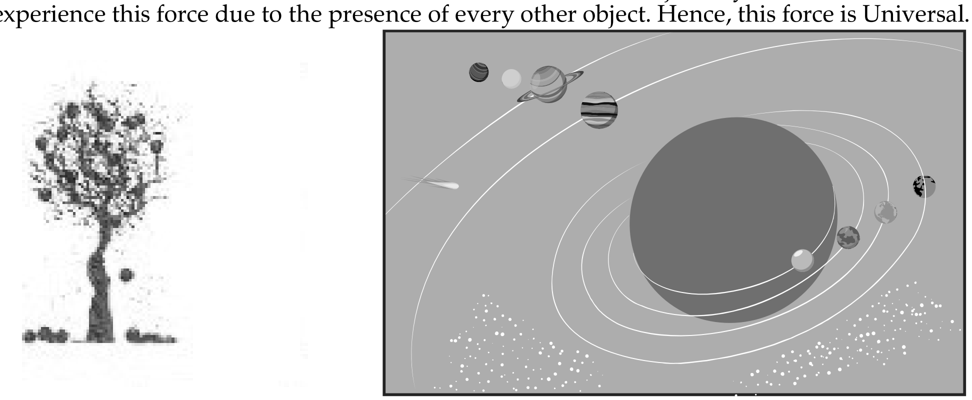
➢ **Technology** : Physics had led to various inventions and discoveries. Some of the examples are as follows :

- In 18^{th} century, Industrial revolution was reason behind development of Steam Engine.
- Conversion of solar, geothermal, wind energy etc. into electricity.
- In 1938, **Hanh** and **Meitner** did the Neuron induced fission of Uranium, that led to the invention of Nuclear Power reactor and Nuclear Weapons.

➢ **Nature of physical laws** :

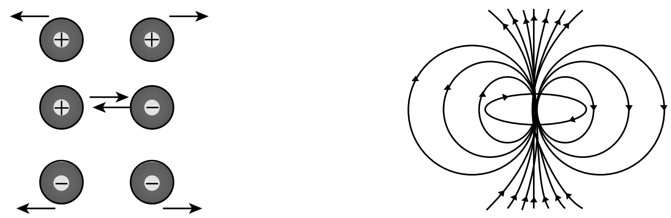
Fundamental Forces of nature : The forces that we observe in day to day life like muscular, friction, elongation of spring, fluid and gas pressure, interatomic and intermolecular forces, force due to compression are originated from the fundamental forces of nature. Few fundamental forces are as follows :

- **Gravitational Force :** The force of mutual attraction between two objects by the virtue of their masses. Every object experience this force due to the presence of every other object. Hence, this force is Universal.



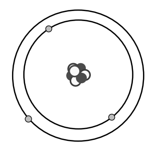
The gravitational force causes the apple to fall as well as planets to revolve around the Sun.

- **Electromagnetic Force :** Force that exist between two charged particles. Charges at rest have electric attraction and repulsion between unlike and like charges respectively. Charges in motion produces magnetic force. All together are known as Electromagnetic Force.



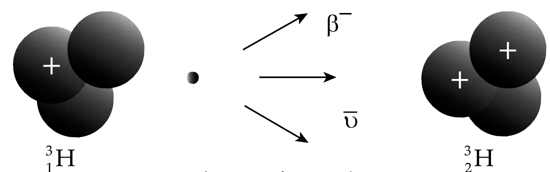
The unlike charges attract each other while like charges repel each other. A current carrying wire generates magnetic field around it giving rise of electromagnetism

- **Strong Nuclear Force :** It is the attractive force between the neutrons and protons in the nucleus. This force is charge independent hence acts equally between every possible combination. Quark is the building unit of the neutron and proton as per recent discovery.



Bohr Model of Lithium Atom. Nucleus is a tightly bound entity with a strong force of attraction between protons and neutrons. Electrons revolve around the nucleus.

- **Weak Nuclear Force :** This force exists in few processes like β-decay of a nucleus. In this process, the nucleus splits into an electron and an uncharged particle called ***Neutrino.*** This was first particle was first predicted by **Wolfgang Paul** in 1931.



β-decay of a nucleus

Difference between Various forces :

Name	Relative Strength	Range	Operates among
Gravitational Force	10^{-39}	Infinite	All objects in universe
Weak Nuclear Force	10^{-13}	Sub-Nuclear Size	Electron and Neutrino
Electromagnetic Force	10^{-2}	Infinite	Charged Nucleons
Strong Nuclear Force	1	Nuclear Size (10^{-15} m)	Elementary Particles

Unification of Forces : There had been few incidences where physicists had tried to combine a few of the above fundamental forces. The list is as follows :

Name of Physicist	Year	Achievement in Unification
Isaac Newton	1687	Unified celestial and terrestrial mechanics.
Hans Christian Oersted and Michael Faraday	1820 and 1830	Unified electric and magnetic phenomena to give rise to electromagnetism.
James Clerk Maxwell	1873	Unified Electricity, magnetism and optics to show light as electromagnetic wave.
Sheldon Glasgow, Abdus Salam, Steven Weinberg	1979	Given the idea of electro weak force (combination of electromagnetic and weak nuclear force).
Carlo Rubbia, Simon van der Meer	1984	Verified the theory of electro-weak force.

Conserved Quantities : Physics laws summarize the observation of phenomena occurring in the Universe.

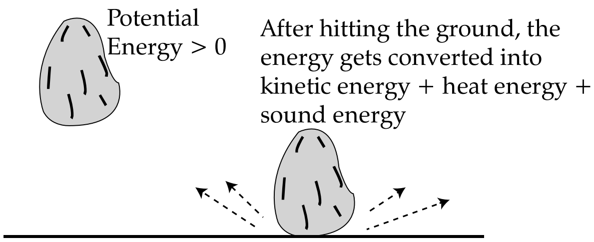
- The Quantities that remain constant with time are called Conserved Quantities.

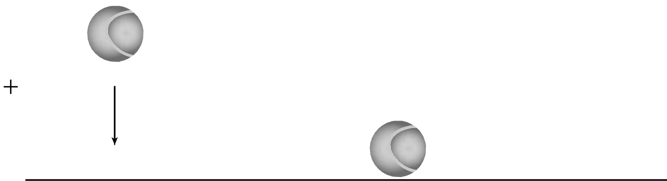
  Example : The mechanical energy for a body remains constant for a body under external forces, the kinetic and potential energies keep changing.
- Conserved Quantities can be scalar (Temperature) or Vector (Temperature Gradient).

Conservation Laws : Conservation law is a hypothesis based on the observation and experiment which cannot be proved mathematically. This can be verified via experiments.

A. Law of Conservation of Energy :

- As, per Law of Conservation of Energy, the energy remains constant over time and convert from one form to another form only.
- This law is universal, and the total energy of the universe remains unchanged.
- Under identical conditions, the nature produces symmetrical results at different points.





A ball in the air falling to ground has some potential energy and zero kinetic energy initially. As soon as it moves the ground the potential energy gets converted into kinetic energy. The total mechanical energy remains same.

B. **Law of Conservation of Mass** : This is the principle used in analysis of chemical reaction.

- Rearrangement of atoms among different molecules is known as Chemical Reaction.
- If the total binding energy of the reacting molecule is less than the total binding energy of the product, the difference is ejected in form of heat and the reaction is known as Exothermic Reaction.
- The opposite of the above reaction is known as Endothermic Reaction.
- Einstein theory related to mass and energy *i.e.*, $E = mc^2$, where c is the speed of light in vacuum.
- In case of reaction, the mass of the reactants and the mass of the products remains same as the atoms are merely rearranged not destroyed.

C. **Law of Conservation of Linear Momentum** :

- Law of Conservation of Linear Momentum explains the symmetry of laws of nature with respect to translation in space.
- Law of Gravitation is same on Earth and Moon even if the acceleration due to gravity at moon is $1/6^{th}$ than that at the Earth. This explains the above law.

D. **Law of Conservation of Angular Momentum :**

- Isotropy of Space (Direction of Space) underlies the Law of conservation of Angular Momentum.

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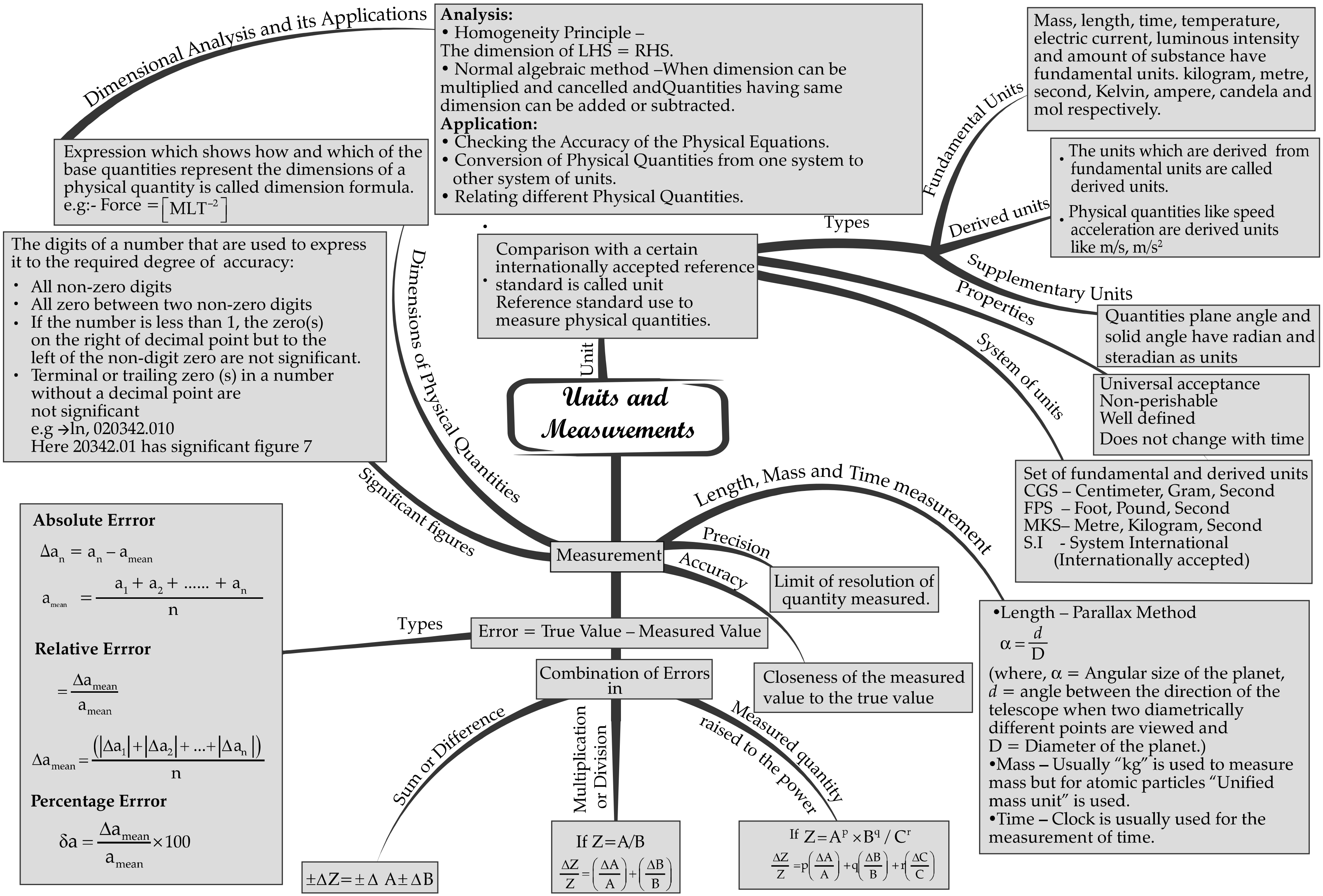
Units and Measurements
Unit
Comparison with a certain internationally accepted reference standard is called unit
Reference standard use to measure physical quantities.
Types
Fundamental Units
Mass, length, time, temperature, electric current, luminous intensity and amount of substance have fundamental units. kilogram, metre, second, Kelvin, ampere, candela and mol respectively.
Derived units
The units which are derived from fundamental units are called derived units.
Physical quantities like speed acceleration are derived units like m/s, m/s^2
Supplementary Units
Quantities plane angle and solid angle have radian and steradian as units
Properties
Universal acceptance
Non-perishable
Well defined
Does not change with time
System of units
Set of fundamental and derived units
CGS – Centimeter, Gram, Second
FPS – Foot, Pound, Second
MKS– Metre, Kilogram, Second
S.I - System International (Internationally accepted)
Dimensional Analysis and its Applications
Analysis:
• Homogeneity Principle – The dimension of LHS = RHS.
• Normal algebraic method –When dimension can be multiplied and cancelled andQuantities having same dimension can be added or subtracted.
Application:
• Checking the Accuracy of the Physical Equations.
• Conversion of Physical Quantities from one system to other system of units.
• Relating different Physical Quantities.
Dimensions of Physical Quantities
Expression which shows how and which of the base quantities represent the dimensions of a physical quantity is called dimension formula. e.g:- Force $= [MLT^{-2}]$
Significant figures
The digits of a number that are used to express it to the required degree of accuracy:
• All non-zero digits
• All zero between two non-zero digits
• If the number is less than 1, the zero(s) on the right of decimal point but to the left of the non-digit zero are not significant.
• Terminal or trailing zero (s) in a number without a decimal point are not significant
e.g →ln, 020342.010
Here 20342.01 has significant figure 7
Measurement
Length, Mass and Time measurement
•Length – Parallax Method
$\alpha = \frac{d}{D}$
(where, α = Angular size of the planet, d = angle between the direction of the telescope when two diametrically different points are viewed and D = Diameter of the planet.)
•Mass – Usually "kg" is used to measure mass but for atomic particles "Unified mass unit" is used.
•Time – Clock is usually used for the measurement of time.
Precision
Limit of resolution of quantity measured.
Accuracy
Closeness of the measured value to the true value
Error = True Value – Measured Value
Types
Absolute Errror
$\Delta a_n = a_n - a_{mean}$
$a_{mean} = \frac{a_1 + a_2 + ... + a_n}{n}$
Relative Errror
$= \frac{\Delta a_{mean}}{a_{mean}}$
$\Delta a_{mean} = \frac{(|\Delta a_1| + |\Delta a_2| + ... + |\Delta a_n|)}{n}$
Percentage Errror
$\delta a = \frac{\Delta a_{mean}}{a_{mean}} \times 100$
Combination of Errors in
Sum or Difference
$\pm\Delta Z = \pm\Delta A \pm \Delta B$
Multiplication or Division
If Z=A/B
$\frac{\Delta Z}{Z} = \left(\frac{\Delta A}{A}\right) + \left(\frac{\Delta B}{B}\right)$
Measured quantity raised to the power
If $Z = A^p \times B^q / C^r$
$\frac{\Delta Z}{Z} = p\left(\frac{\Delta A}{A}\right) + q\left(\frac{\Delta B}{B}\right) + r\left(\frac{\Delta C}{C}\right)$

CHAPTER

2 UNITS AND MEASUREMENTS

Chapter Objectives

Need for measurement : Units of measurement, Fundamental and derived units, Systems of units, Dimensions of physical quantities, Length, mass and time measurements, Accuracy and precision of measuring instruments; Errors in measurement, Significant figures, Dimensional analysis and its applications.

STUDY MATERIAL

Concepts Clarified :

- **Need of measurement :**

  Measurement is a comparison of any physical quantity with its standard unit. This is required in order to get the correct information of all the related attributes of the given physical quantity.

  Physical Quantity :

  Laws of Physics are described in terms of certain basic quantities. Such quantities are known as physical quantities.

- **Units of Measurement** :

  The two major points defining a unit are as follows :

  - A definite amount of physical quantity under specified conditions is defined as its Standard Unit.
  - Standard Unit is usually globally accepted and easily reproducible.

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- **Fundamental and Derived Units**

  The physical quantities that are independent to each other are known as Fundamental Quantities and their units are known as Fundamental Units.

S. No	Fundamental Quantity	Fundamental Unit	Symbol
1	Length	Metre	m
2	Mass	Kilogram	kg
3	Time	Second	s
4	Temperature	Kelvin	K
5	Electric Current	Ampere	A
6	Luminous Intensity	Candela	cd
7	Amount of Substance	Mole	mol

Definition of Fundamental Units :

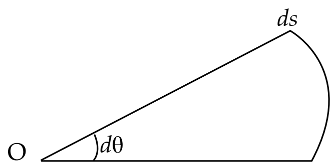
The seven fundamental units of SI have been defined as follow :

- **1 Metre** – It is defined as the distance that contains 1650763.73 wavelength of Orange–red light of Kr–86.
- **1 Kilogram** – The mass of a cylindrical prototype made of Platinum and Iridium alloy of height 39 mm and diameter 39 mm. It is the mass of 5.0188×10^{25} atoms of Carbon–12.
- **1 Second** – It is the time in which caesium atom vibrates 9192631770 times in an atomic clock.
- **1 Kelvin** – It is the (1/273.16) part of the thermodynamic temperature of the triple point of water.
- **1 Ampere** – It is the electric current that is maintained in two straight parallel conductors of infinite length and of negligible cross–sectional area placed one metre apart in vacuum will produce a force of 2×10^{-7}N per metre length.

- **1 Candela** – 1 candela is (1/60) luminous intensity of an ideal source by an area of 1 cm^2, when source is at melting point of platinum (1760°C).
- **1 Mole** – It is the amount of substance of a system which contains an elementary entities (atoms, molecule, electrons, ions or group of particles) in 0.012 kg of carbon isotope ${}_6C^{12}$.

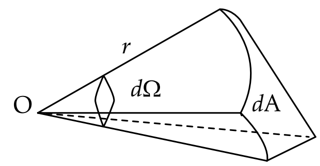
Supplementary Fundamental Units :

Radian and Steradian are two supplementary fundamental units that are used to measure Plane Angle and Solid Angle respectively.



$d\theta = \frac{ds}{r}$ radian

Plane angle : unit → radian



$d\Omega = \frac{dA}{r^2}$ steradian

Solid angle : unit → Steradian

S. No	Supplementary Fundamental Quantity	Supplementary Unit	Symbol
1	Plane Angle	Radian	rad
2	Solid Angle	Steradian	sr

Derived Units : The physical quantity which are derived from the fundamental quantity are called Derived Quantity and these are defined using base units. **Example** – Velocity, Force, Work etc.

➢ System of Units :

A system of Units is a combined set of Fundamental and Derived Units for all kinds of physical quantities. Few generalised systems used in mechanics are mentioned below :

- **CGS System** – Length – Centimetre, Mass – Gram, Time – Second.
- **FPS System** – Length – Foot, Mass – Pound, Time – Second.
- **MKS System** – Length – Metre, Mass – Kilogram, Time – Second.
- **SI System** – This system contains seven fundamental units and two complementary units as mentioned above.

Relationship between Some Mechanical SI unit and Commonly used Units :

S.No	Physical Quantity	Unit
1	Length	1 micrometre $= 10^{-6}$ m
		1 angstrom $= 10^{-10}$ m
2	Mass	1 metric ton $= 10^{3}$ kg
		1 pound = 0.4537 kg
		1 amu $= 1.66 \times 10^{-23}$ kg
3	Volume	1 litre $= 10^{-3}$ m^3
4	Force	1 Dyne $= 10^{-5}$ N
		1 kgf = 9.81 N
5	Pressure	1 kgf-m^{-2} = 9.81 Nm^{-2}
		1 mm of Hg = 133 Nm^{-2}
		1 pascal = 1 Nm^{-2}
		1 atm pressure = 76 cm of Hg $= 1.01 \times 10^5$ Pascal
6	Work & Energy	1 erg $= 10^{-7}$ J
		1 kgf-m = 9.81 J
		1 kWh $= 3.6 \times 10^6$ J
		1 eV $= 1.6 \times 10^{-19}$ J
7	Power	1 kgf-ms^{-1} = 9.81 W
		1 Horse Power = 746 W

➢ Measurement of Length, Mass and Time :

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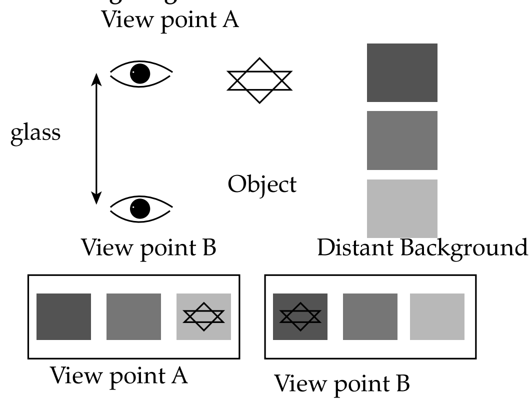
Measurement of Length :

- **Measuring Large Distance – Parallax Method :**



Parallax is defined as the displacement or difference in the virtual position of an object when viewed along two different line of sight. It is measured using an angle of inclination between those two lines. Distance between two viewpoints is called Basis.

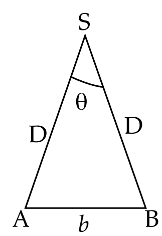
- **Parallax Method – Measuring distance of a Planet :**

Parallax method to determine distance of planet

As, per the given figure :

$\alpha = \frac{d}{D}$ (where, α = Angular size of the planet).

α = angle between the direction of the telescope when two diametrically different points are viewed and d = Diameter of the planet.



S - position of planet

D - distance from the two view points or observant

θ - parallalax or paralatic angle

For another planet by, $D \propto l$

Hence, AB is taken as arc of length b and D is radius with S as center

So, $b = D\theta$ or $D = \frac{b}{\theta}$

- **Estimating size of the molecule of the oleic acid :**

This acid is a soapy liquid with particle size of the order of 10^{-9} m. Below mentioned are the steps to evaluate the size of the molecule –

(1) Dissolve 1 cm^3 volume of oleic acid in alcohol to make it a solution of 20 cm^3. Again, dilute the solution in similar proportion. Now, the concentration of oleic acid in solution is $1/(20 \times 20)$ cm^3.

(2) Sprinkle lycopodium powder on the surface of water in a trough and put one drop of above solution. The solution will spread over water in form of a circular molecular thick film.

(3) The calculation to be used is as follows :

Let n – number of drops of solution, V – volume of drop, t – thickness of film, A – Area of film.

Total Volume of n drops of solution = nV cm^3

Amount of Oleic Acid in this solution $= nV\left(\frac{1}{20 \times 20}\right) cm^3$

Thickness of the film, $t = \frac{\text{Volume of the film}}{\text{Area of the film}} = \frac{nV}{20 \times 20}$ cm

Some Approximated Distances :

(1) 1 fermi = 10^{-15} m

(2) 1 X–ray unit = 10^{-13} m

(3) 1 astronomical unit = 1.49×10^{11} m (average distance between sun and earth)

(4) 1 light year = 9.46×10^{15} m

(5) 1 parsec = 3.08×10^{16} m = 3.26 light year

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Measurement of Mass :

Usually "kg" is used to measure mass but for atomic particles "Unified mass unit" is used.

Note : 1 u = $\frac{1}{12}$ of the mass of atom of carbon –12 isotope (mass of electron included).

Usually normal balance is used to weigh but in case of planetary bodies – "Gravitational Method" is used and in the case of subatomic particles – "Mass Spectrograph" (Proportionality between Radius of Trajectory to the Mass of Charged particle moving in uniform electric and magnetic field).

Object	Kilogram
Our galaxy	2×10^{41}
Sun	2×10^{30}
Moon	7×10^{22}
Asteroid Eros	5×10^{15}
Raindrop	10^{-6}
Dust Particle	10^{-9}
Red Blood Cell	10^{-13}
Proton	1.673×10^{-27}

Measurement of Time :

Clock is usually used for the measurement of time. As per the standard, atomic standard of time is now used where time is measured using Caesium or Atomic Clock. More Information about this system is as follows :

- In Caesium Clock, 1 s = 9192631770 vibrations of radiation from the transition between two hyperfine levels of Caesium – 133 atoms.
- Caesium clock usually works on the vibration of Caesium like the vibration of balance in regular wristwatch and quartz crystal in Quartz Wrist Watch.
- Standard time and frequency are maintained by 4 Atomic Clock. Indian Standard is counted using Caesium Clock at NPL (National Physical Library, New Delhi).
- Uncertainty in Caesium Clock is very low *i.e.*, 1 part of 10^{13} which in general words can be summarised as an error of less than 3 μs in a year (either gain or loss).

Some Important Values :

Range of Time	Time Interval (s)
Life Span of most unstable particle	10^{-24}
Period of Light Wave	10^{-15}
Period of Sound Wave	10^{-6}
Travel Time of Light from moon to earth	1
Rotation period of earth	10^{5}
Average human life span	10^{9}
Time Since Dinosaur Extinction	10^{15}
Age of Universe	10^{27}

➢ Dimensions of Physical Quantities :

Dimension of a physical quantity are the powers which are raised on fundamental units to express the current unit. The expression that exactly shows how and which of the base quantity represent the dimension of a physical quantity is known as Dimensional Formula.

S.No.	Physical Quantity	Dimensional Formula	MKS units
1	Acceleration	$[LT^{-2}]$	ms^{-2}
2	Force	$[MLT^{-2}]$	Newton (N)
3	Work or Energy	$[ML^{2}T^{-2}]$	Joule (J)
4	Power	$[ML^{2}T^{-3}]$	Js^{-1} or W (watt)
5	Pressure or Stress	$[ML^{-1}T^{-2}]$	Nm^{-2}
6	Linear Momentum or Impulse	$[MLT^{-1}]$	kg ms^{-1}
7	Strain	Dimensionless	Unitless
8	Modulus of Elasticity	$[ML^{-1}T^{-2}]$	Nm^{-2}
9	Surface Tension	$[MT^{-2}]$	Nm^{-1}
10	Velocity Gradient	$[T^{-1}]$	s^{-1}
11	Coefficient of Velocity	$[ML^{-1}T^{-1}]$	kg $m^{-1}s^{-1}$
12	Gravitational Constant	$[M^{-1}L^{3}T^{-2}]$	Nm^{2}/kg^{2}
13	Moment of Inertia	$[ML^{2}]$	kg m^{2}
14	Angular Velocity	$[T^{-1}]$	rad/s

15	Angular Acceleration	$[T^{-2}]$	rad/s^2
16	Angular Momentum	$[ML^2T^{-1}]$	kg m^2s^{-1}
17	Specific Heat	$[L^2T^2K^{-1}]$	k cal $kg^{-1}K^{-1}$
18	Latent Heat	$[L^2T^{-2}]$	kcal/kg
19	Planck's Constant	$[ML^2T^{-1}]$	J–s
20	Universal Gas Constant	$[ML^2T^2K^{-1}]$	J/mol–K

➢ Accuracy and Precision of Measuring Instruments :

- Any uncertainty resulting from instrument is counted under random or systematic error.
- Accuracy can be defined as the closeness between true value and measured value.
- Precision can be defined as the resolution or closeness of a series of measurement of a same quantity under similar conditions.

Let there be a certain length of 3.7866 m and is measured using two instrument one gives the value as 3.67 (two digits after decimal) while output from the other is 3.7 (one digit after decimal). The first result is more precise but less accurate whereas second result is less precise but more accurate.

Error in Measurement :

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Lack in accuracy in measurement is due to the limit of accuracy or any other issue. This is known as error. Let us define the types of error one by one :

- **Instrumental Error :** This arise from calibration error or imperfect design.
  Example – Worn off Scale etc.
- **Imperfection in Experimental Technique :** This is the error that arises due to technical inaccuracy.
  Example – Temperature recording placing thermometer in armpit.
- **Personal Error :** This type of error can be related to human error like lack of proper setting, incorrect reading note down etc.
- **Random Error** : Error which occur randomly with respect to sign and size are called Random Errors. Reason for these errors is unpredictable fluctuations.
- **Least Count Error :** Least count is defined as the smallest value that can be measured by that instrument. This error arises due to the resolution of the instrument. This type of error can be minimised by using high precision instrument.

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Error in series of Measurement :

1 **Absolute Error** : Measured value and true value have some difference in values. Such difference is known as Absolute Error.
If $A_1, A_2, A_3, A_4, A_5, A_6, A_7, ..., A_n$ are the measured value of an experiment, then

$$A_m = \frac{(A_1 + A_2 + A_3 + A_4 + A_5 + A_6 + A_7 + ... + A_n)}{n}$$

The absolute error in measured value is :

$$\Delta A_1 = A_m - A_1$$
$$\Delta A_2 = A_m - A_2$$
$$\Delta A_n = A_m - A_n$$

2 **Mean Absolute Error** : The arithmetic mean of the absolute error in all measurement is called Mean Absolute Error.

$$\overline{\Delta A} = \frac{|\Delta A_1| + |\Delta A_2| + |\Delta A_3| + ... + |\Delta A_n|}{n}$$

3 **Relative Error :** Ratio of the Mean absolute error to the true value.

$$\text{Relative Error} = \frac{\text{Mean Absolute Error}}{\text{True Value}} = \frac{\overrightarrow{\Delta A}}{A_m}$$

4. **Percentage Error :** The relative error expressed in % is called Percentage Error.

$$\text{Percentage Error} = \frac{\text{Mean Absolute Error}}{\text{True Value}} \times 100 = \frac{\overrightarrow{\Delta A}}{A_m} \times 100\%$$

Propagation in Error :

- Error in Addition and Subtraction : Let $x = a + b$ or $x = a - b$
  If the measured value of a and b are $a \pm \Delta a$ and $b \pm \Delta b$, then value of absolute error is :

$$\Delta x = \pm (\Delta a + \Delta b)$$

- Error in Multiplication and Division : Let $x = a \times b$ or $x = \frac{a}{b}$

  If the measured value of a and b are $a \pm \Delta a$ and $b \pm \Delta b$, then maximum relative error is :

$$\frac{\Delta x}{x} = \pm\left(\frac{\Delta a}{a} + \frac{\Delta b}{b}\right)$$

For more details, scan the code

➢ Significant Figures :

In evaluated value of the physical quantity, the value of the physical equations about which we are sure plus the next doubtful digits are called Significant Figures.

Rules for finding Significant Figure :

For more details, scan the code

1. All non–zero digits are significant figures, e.g. 7867 m has 4 significant figures.
2. All zero lying between non–zero digits are significant figures, e.g. 1008 had 4 significant figures.
3. All zero to the right of the last zero digit are not significant, e.g. 6770 has 3 significant digits.
4. In digits less than 1, all the zero to the right if the decimal and to the left of the non–zero digit are not significant, e.g. 0.00567 had 3 significant figures.
5. All zero to the right of the non–zero digit in the decimal part are significant, e.g. 1.99870 has 6 significant figures.

Significant figures in Algebraic Operations :

(i) In addition, or subtraction of numerical values the result should be the least decimal place as in various numerical values. e.g. If $l_1 = 6.7566$ m and $l_2 = 0.23$ m, then $l_1 + l_2 = 6.9866$ m.
As l_2 is measured up to two decimal places hence value is $l_1 + l_2 = 6.99$ m.

(ii) In multiplication or division, the result should retain the least significant figure as the numerical values. e.g.
If $l = 2.33$ m and $b = 1.647$ m, area $(l \times b) = (2.33 \times 1.647) = 3.3751$ m^2
It only has three significant digits hence A = 3.84 m$^{2.}$

Rules for Rounding Off Significant Figures :

1. If digit to be dropped is less than 5, then the digit remains unchanged. e.g. – 1.44 is rounded off to 1.4.
2. If digit to be dropped is greater than 5, then the digit is raised by 1. e.g. 2.49 is rounded off to 2.5.
3. If digit to be dropped is 5 followed by digit other than zero, then the preceding digit will be raised by 1, e.g. 3.55 is rounded off to 3.6.
4. If the digit to be dropped is 5 or 5 followed by 0, then preceding digit is raised by 1 if it is odd and left unchanged if it is even. e.g. 4.750 will be 4.8 and 3.650 will be 3.6.

➢ Dimensional Analysis and Its Application :

Analysis :

For more details, scan the code

- Homogeneity Principle : If the dimension of Right–hand side is equal to the dimension on the Left–hand side of the equation, then the equation is dimensionally correct. This is called Homogeneity Principle.

  Hence, LHS = RHS.
- Dimension can be multiplied and cancelled like normal algebraic method.
- Quantities having same dimensions can be added or subtracted.
- Equations are uncertain to an extent of dimensionless quantity.

  For Example : Distance = Speed × Time. In dimension basis, $[L] = [LT^{-1}] \times [T]$

Application :

- Accuracy of the Physical Equations can be checked.
- Physical Quantities can be changed from one system of units to other system of units.
- Different Physical Quantities can be related.

Note : Dimension on both sides get cancelled and becomes equal on both sides. Such dimension is known as Dimensionally Correct Equation.

Deducing relation among physical quantities :

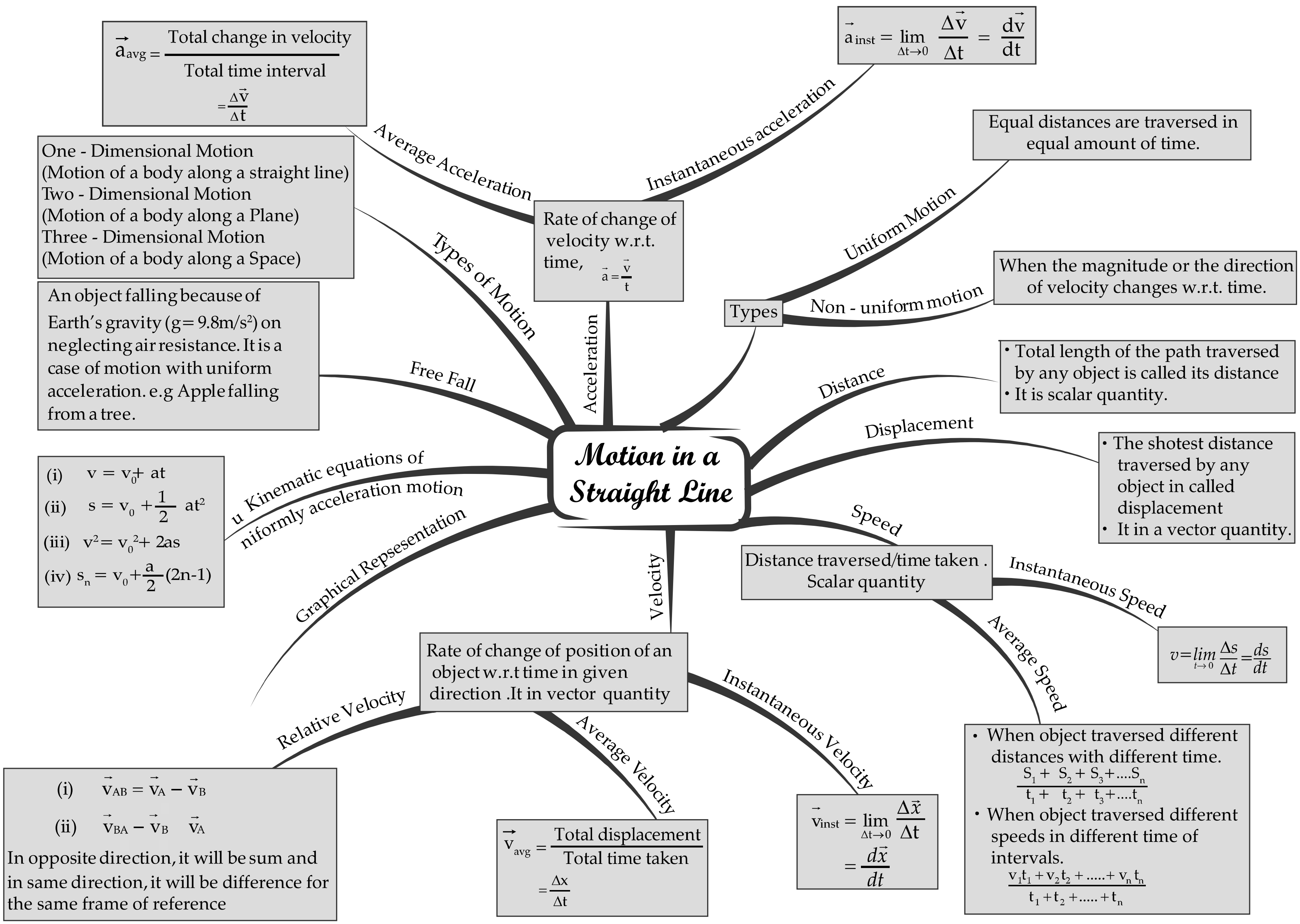
- In order to deduce a relation between two Physical Quantities we should know the dependence of one quantity over other.
- Dimension constant cannot be obtained using this method.

Example : $T = k\, l^x g^y m^z$

In dimensional terms, $[L^0M^0T^1] = [L^1]^x[L^1T^{-2}]^y[M^1]^z = [L^{x+y}T^{-2y}M^z]$

Hence, $x + y = 0$, $-2y = 1$ and $z = 0$. So, $x = \frac{1}{2}$, $y = -\frac{1}{2}$ and $z = 0$

The original equation reduces to $T = k\sqrt{\frac{l}{g}}$



Motion in a Straight Line
Acceleration
Rate of change of velocity w.r.t. time, $\vec{a} = \frac{\vec{v}}{t}$
Instantaneous acceleration
$\vec{a}_{inst} = \lim_{\Delta t \to 0} \frac{\Delta \vec{v}}{\Delta t} = \frac{d\vec{v}}{dt}$
Average Acceleration
$\vec{a}_{avg} = \frac{\text{Total change in velocity}}{\text{Total time interval}} = \frac{\Delta \vec{v}}{\Delta t}$
Types of Motion
One - Dimensional Motion (Motion of a body along a straight line)
Two - Dimensional Motion (Motion of a body along a Plane)
Three - Dimensional Motion (Motion of a body along a Space)
Free Fall
An object falling because of Earth's gravity ($g = 9.8 m/s^2$) on neglecting air resistance. It is a case of motion with uniform acceleration. e.g Apple falling from a tree.
u Kinematic equations of niformly acceleration motion
(i) $v = v_0 + at$
(ii) $s = v_0 + \frac{1}{2} at^2$
(iii) $v^2 = v_0^2 + 2as$
(iv) $s_n = v_0 + \frac{a}{2}(2n-1)$
Graphical Repsesentation
Types
Uniform Motion
Equal distances are traversed in equal amount of time.
Non - uniform motion
When the magnitude or the direction of velocity changes w.r.t. time.
Distance
• Total length of the path traversed by any object is called its distance
• It is scalar quantity.
Displacement
• The shotest distance traversed by any object in called displacement
• It in a vector quantity.
Speed
Distance traversed/time taken . Scalar quantity
Instantaneous Speed
$v = \lim_{t \to 0} \frac{\Delta s}{\Delta t} = \frac{ds}{dt}$
Average Speed
• When object traversed different distances with different time.
$\frac{S_1 + S_2 + S_3 + ...S_n}{t_1 + t_2 + t_3 + ...t_n}$
• When object traversed different speeds in different time of intervals.
$\frac{v_1t_1 + v_2t_2 + ... + v_nt_n}{t_1 + t_2 + ... + t_n}$
Velocity
Rate of change of position of an object w.r.t time in given direction .It in vector quantity
Instantaneous Velocity
$\vec{v}_{inst} = \lim_{\Delta t \to 0} \frac{\Delta \vec{x}}{\Delta t} = \frac{d\vec{x}}{dt}$
Average Velocity
$\vec{v}_{avg} = \frac{\text{Total displacement}}{\text{Total time taken}} = \frac{\Delta x}{\Delta t}$
Relative Velocity
(i) $\vec{v}_{AB} = \vec{v}_A - \vec{v}_B$
(ii) $\vec{v}_{BA} - \vec{v}_B \quad \vec{v}_A$
In opposite direction, it will be sum and in same direction, it will be difference for the same frame of reference

CHAPTER

3 MOTION IN A STRAIGHT LINE

Chapter Objectives

Frame of reference, Motion in a straight line, Position, Displacement, Distance, Speed and Velocity.
Average speed and velocity, Instantaneous speed and velocity, uniform, average and instantaneous acceleration.
Graphical Representation – Position - time, velocity - time, motion with variable acceleration.

STUDY MATERIAL

Concepts Clarified :

➢ **Mechanics :** It is the branch of Physics which deals with the study of motion in physical bodies. Mechanics can be classified into below mentioned categories :

- **Statics :** It is the branch of Physics which deals with the study of bodies under rest.
- **Dynamics :** It is a branch of Physics which deals with the study of bodies taking factors for the cause of motion under consideration.
- **Kinematics :** It is the branch of mechanics which deals with the study of motion without taking cause of motion into consideration.

Rest and Motion :

For more details, scan the code

Rest : An object is at rest if the position of the object doesn't change with respect to the surrounding.
Example : A painting hung on a wall is at rest with respect to the wall.

Motion : An object is said to be in motion if it changes its position with respect to the surroundings.
Example : A sliding door in motion with respect to the wall.

Note – Rest and Motion both are relative states of an object.

➢ **Frame of Reference** : It is defined as the system with the reference of which the observer defines the event. It is usually defined in terms of co-ordinates.

Points to consider while studying this chapter

- Every object will be treated as Point Mass. Point Mass Object is defined as the object that covers distance much greater than its own size while in motion. It is the smallest part of matter with zero dimension.
- Rectilinear Motion will be taken into consideration only.

Motion in a straight Line :

For more details, scan the code

Position of any object can be explained using two factors *i.e.,* distance from the observer and its direction with respect to the observer. This is the cause of Position Vector that defines the position as the characteristic of an object.

Assume P as a point on *xy* plane and its co-ordinate be (*x*, *y*), then position vector $\vec{r}$ of point P will be $x\hat{i}+y\hat{j}$ and if the point is in (*x*, *y*, *z*) then position vector can be expressed as $x\hat{i}+y\hat{j}+z\hat{k}$.

Types of Motion :

One-Dimensional	Two-Dimensional	Three-Dimensional
Motion of a body in a straight line is called One-Dimensional Motion.	Motion of a body in a Plane is called Two-Dimensional Motion.	Motion of a body in space is called Three-Dimensional Motion.
Only one co-ordinate of the position of the object changes with time.	Two co-ordinates of the position of the object change with time.	All the three co-ordinates of the position of the object change with time.
Example : Motion of Car along a straight road.	**Example :** Motion of Billiard Ball.	**Example :** Motion of Kite in sky.

➢ **Position, Displacement, Distance** :

For more details, scan the code

Position : Position is defined to know the exact position of an object. It is generally taken with respect to a reference, this reference is generally known as Origin. Change in Position is generally defined using two quantities :

Distance : Actual Path travelled by the body during motion.

SI Unit – 'metre'. Dimension – $[M^0 L^1 T^0]$

Displacement : Difference between the **initial point** and the **final point** during the course of motion.

SI Unit – 'metre'. Dimension – $[M^0 L^1 T^0]$

Difference between Distance and Displacement :

Distance	Displacement
Actual Path travelled by the body during motion.	Shortest distance travelled by the body during course of motion.
It is a Scalar Quantity.	It is a Vector Quantity.
Distance travelled can never be negative or zero and is always positive. It will be equal or greater than the displacement. Distance $\geq$ Displacement	Displacement can be positive, negative or zero during motion. The magnitude of displacement may be less than the actual distance travelled.
The distance is the function of path travelled.	The displacement will be less than or equal to the distance.
Speed × Time	Velocity × Time

➢ **Speed and Velocity** :

For more details, scan the code

Speed : Rate of distance covered with time is called Speed.

SI Unit – 'metre/second', Dimension – $[M^0 L^1 T^{-1}]$, Scalar Quantity.

Various types of speed are as follows :

1. **Uniform Speed** : When a particle covers equal distances in equal span of time then it is said to be in Uniform Motion.
2. **Non-Uniform Motion** : When an object covers unequal distances in certain span of time then it is said to be Non-Uniform Motion.

Velocity : Rate of displacement with time.

SI Unit – 'metre/second', Dimension – $[M^0 L^1 T^{-1}]$, Vector Quantity.

1. **Uniform Velocity :** If the magnitude of velocity as well as direction remain same and the particle moves in same direction without reversing then it is known as Uniform Velocity.
2. **Non-Uniform Velocity :** If the magnitude of velocity as well as direction remains changing or change once, such velocity is known as Non-uniform Velocity.

Difference between speed and velocity :

Speed	Velocity
Rate of distance covered with time.	Rate of displacement with time.
It is a Scalar Quantity.	It is a Vector Quantity.
It is positive while in motion.	It can be negative, positive or zero while in motion.
It is greater or equal to the value of velocity.	It is less than or equal to the speed.

Scalar and Vector Quantities :

- The quantities which can be defined using their magnitude only are known as Scalars.
  Example : Temperature, Speed
- The quantities which can be defined using their magnitude as well as direction are known as Vectors. **Example :** Temperature Gradient, Momentum, Torque.

Average Velocity and Average Speed :

For more details, scan the code

Average Velocity : It is defined as the total displacement of the body divided by the total time interval in which it is accomplished.

$$\text{Average Velocity} = \overrightarrow{v_{av}} = \frac{\overrightarrow{\Delta r}}{\overrightarrow{\Delta t}}$$

Average Speed : It can be defined as the ratio of the total distance covered to the total time in which the motion has taken place.

$$\text{Average Speed } (v_{av}) = \frac{\text{Distance travelled}}{\text{Time taken}}$$

$$v = \lim_{t \to 0} \frac{\Delta s}{\Delta t} = \frac{ds}{dt}$$

Instantaneous Velocity and Instantaneous Speed :

Instantaneous Velocity : It is defined as the rate of change of position vector with the time at a certain instant.

$$\text{Instantaneous Velocity } \vec{v} = \lim_{t \to 0} \frac{\overrightarrow{\Delta r}}{\overline{\Delta t}} = \frac{\overrightarrow{dr}}{\overline{dt}}$$

Instantaneous Speed : It is defined as the speed of a particle at any instant.

$$\text{Instantaneous Speed } v = \lim_{t \to 0} \frac{\Delta s}{\Delta t} = \frac{ds}{dt}$$

- **Uniform, Average and Instantaneous Acceleration** :

Average Acceleration : Average acceleration over a time interval is defined as the ratio of change of velocity with time interval.

For more details, scan the code

$$a = \frac{(v_1 - v_2)}{(t_2 - t_1)}$$

where v_1 and v_2 are velocities at time t_2 and t_1.

Instantaneous Acceleration : It is defined as the same way as instantaneous velocity.

For more details, scan the code

$$\text{Instantaneous Accelration, } a = \lim_{t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$$

- When acceleration is uniform, instantaneous acceleration is equal to average acceleration.
- Since velocity is a vector quantity, the acceleration *i.e.*, change in velocity will also depend on magnitude and direction.
- Acceleration can be zero, positive and negative.

Given : If velocity of an object is at $t = 0$ and v at time t, then

For more details, scan the code

$$a = \frac{v - v_0}{t - 0} \text{ or } v = v_0 + at \qquad \text{(This is known as First Kinematic Equation of Motion)}$$

Other Equation of Motion are –

(i) $v = v_0 + at$

(ii) $s = v_0 t + \frac{1}{2} a t^2$

(iii) $v^2 - v_0^2 = 2as$

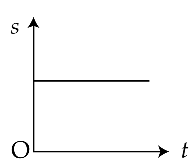
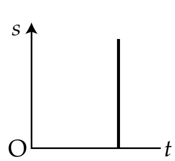
(iv) $s_n = v_0 + \frac{a}{2}(2n - 1)$

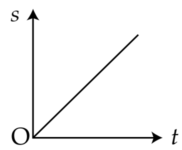
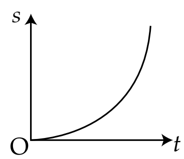
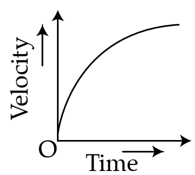
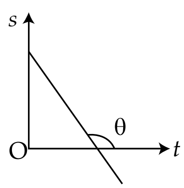
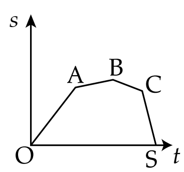
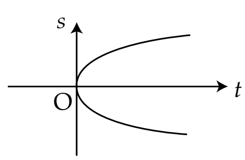
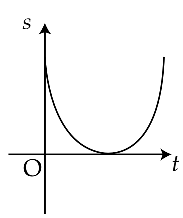
Graphical Representation – Position-Time, Acceleration-Time, Velocity-Time :

Position-Time Graph : This representation will give the variation of position with respect to time. Using this we can also judge the variation in velocity and acceleration as follows :

For more details, scan the code

For more details, scan the code

	$\theta = 0°$ so $v = 0$ *i.e.*, line parallel to time axis represents that the particle is at rest.
	$\theta = 90°$ so $v = \infty$ *i.e.*, line perpendicular to time axis represents that particle is changing its position but time does not change it means particle possess infinite velocity. Practically this is not possible.

	θ = constant so v = constant, $a = 0$ *i.e.*, line with constant slope represents uniform velocity of the particle.
	θ is increasing so v is increasing, a is positive. *i.e.*, line is bending towards position axis represents increasing velocity of particle. It means the particle possess acceleration.
	θ is decreasing so v is decreasing, a is negative. *i.e.*, line is bending towards time axis represents decreasing velocity of particle. It means the particle possess retardation.
	θ is constant but > 90° so v will be constant but negative. *i.e.*, line with negative slope represents that particle returns towards the point of reference. (negative displacement).
	Straight line segments of different slopes represent that the velocity of the body changes after certain interval of time.
	This graph shows that at one instance the particle has two positions which is not possible.
	The graph shows that particle coming towards origin initially and after that is moving away from the origin.

Note :

- If the graph is plotted between distance and time, then it is always an increasing curve as distance always increases with time.
- If graph between displacement and time is plotted with slopes θ_1 and θ_2 possess velocity v_1 and v_2 then

$$\frac{v_1}{v_2} = \frac{\tan\theta_1}{\tan\theta_2}$$

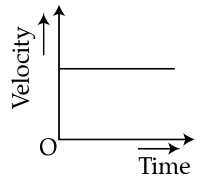
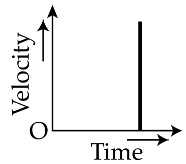
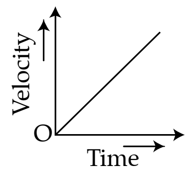
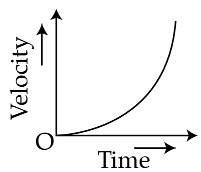
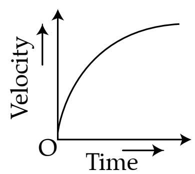
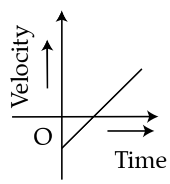
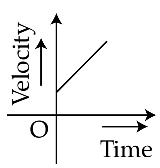
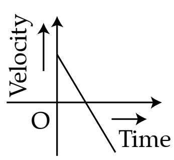
Velocity-Time Graph : This kind of graph is plotted between time and velocity in y and x-axis respectively. This area covered under this graph gives the displacement and distance travelled by the body for given time.

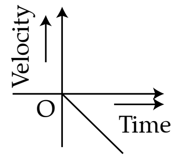
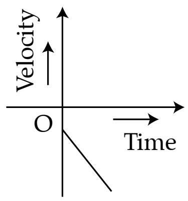
Total distance = Addition of Modulus of different area *i.e.*, $s = \int |v| dt$

Total distance = Addition of various areas considering their sign *i.e.*, $s = \int v\, dt$

Acceleration : The slope of velocity-time graph gives the acceleration of the particle.

Various Velocity-Time graphs and their interpretation :

	$\theta = 0°$, v = constant *i.e.*, line parallel to time axis represents that the particle is moving with constant velocity.
	$\theta = \infty$, $a = \infty$, v = increasing *i.e.*, line perpendicular to time axis represents that particle is increasing its velocity but time does not change. It means particle possess infinite acceleration. Practically this is not possible.
	θ = constant so α = constant and v is increasing uniformly with time, *i.e.*, line with constant slope represents uniform acceleration of the particle.
	θ is increasing so acceleration increasing *i.e.*, line is bending towards velocity axis represent the increasing acceleration in body.
	θ is decreasing so acceleration decreasing *i.e.*, line is bending towards time axis represents decreasing acceleration in body.
	Positive constant acceleration because θ is constant and $< 90°$ but initial velocity of the particle is negative.
	Positive constant acceleration because θ is constant and $< 90°$ but initial velocity of the particle is positive.
	Negative constant acceleration because θ is constant and $> 90°$ but initial velocity of the particle is positive.

	Negative constant acceleration because θ is constant and > 90° but initial velocity of the particle is zero.
	Negative constant acceleration because θ is constant and > 90° but initial velocity of the particle is negative.

Motion with Variable Acceleration :

1. If the acceleration is a function of time

$a = f(t)$, then $v = u + \int_0^t f(t)$ and $s = ut + \int\left(\int f(t)(dt)\right)dt$

2. If the acceleration is a function of distance

$a = f(x)$, then, $v^2 = v_0^2 + 2\int_{v_0}^{v} f(x)dx$

3. If the acceleration is a function of velocity

$a = f(v)$, then $t = \int_{v_0}^{v} \frac{dv}{f(v)}$ and $x = x_0 + \int_{v_0}^{v} \frac{vdv}{f(v)}$

II. Important Formulae

1. Displacement $\Delta x = x_2 - x_1$

2. Average Velocity $\overrightarrow{v_{av}} = \frac{\overrightarrow{\Delta r}}{\overline{\Delta t}}$

3. Average Speed $(v_{av}) = \frac{\text{Distance travelled}}{\text{Time taken}} = \frac{\Delta s}{\Delta t}$

4. Instantaneous Velocity $\vec{v} = \lim_{t \to 0} \frac{\overrightarrow{\Delta r}}{\overline{\Delta t}} = \frac{\overrightarrow{dr}}{\overline{dt}}$

5. Instantaneous Speed $v = \lim_{t \to 0} \frac{\Delta s}{\Delta t} = \frac{ds}{dt}$

6. Instantaneous Acceleration $a = \lim_{t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt}$

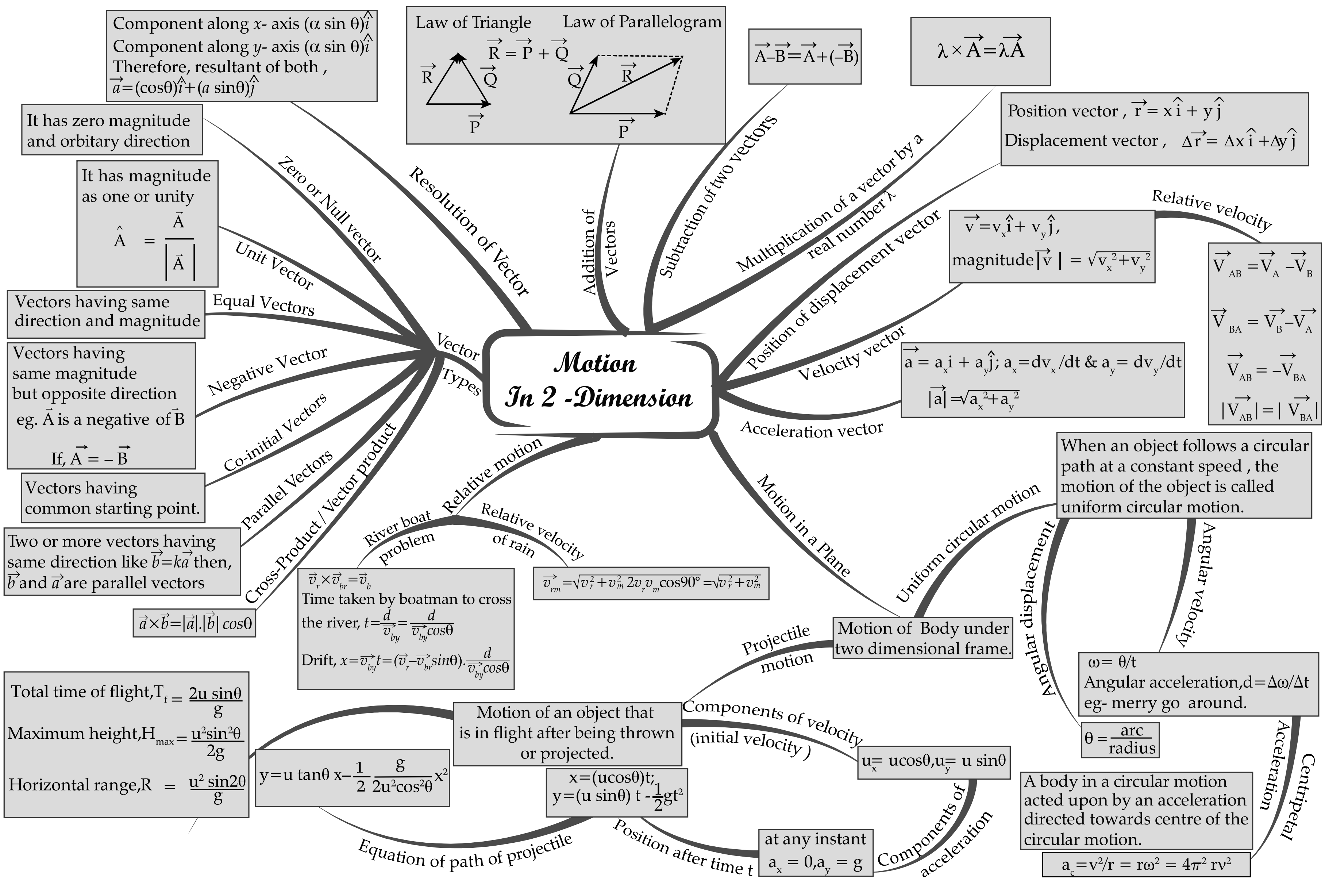
7. Average Acceleration $a = \frac{(v_1 - v_2)}{(t_2 - t_1)}$

8. Kinematic Equation of Motion $a = \frac{v - v_0}{t - 0}$

$$s = v_0 t + \frac{1}{2}at^2$$

$$v^2 - {v_0}^2 = 2as$$

$$s_n = v_0 + \frac{a}{2}(2n - 1)$$


Motion In 2 -Dimension
Vector Types
Resolution of Vector
Component along x- axis $(\alpha \sin\theta)\hat{i}$
Component along y- axis $(\alpha \sin\theta)\hat{i}$
Therefore, resultant of both , $\vec{a}=(\cos\theta)\hat{i}+(a \sin\theta)\hat{j}$
Zero or Null vector
It has zero magnitude and orbitary direction
Unit Vector
It has magnitude as one or unity
$\hat{A} = \frac{\vec{A}}{|\vec{A}|}$
Equal Vectors
Vectors having same direction and magnitude
Negative Vector
Vectors having same magnitude but opposite direction eg. $\vec{A}$ is a negative of $\vec{B}$
If, $\vec{A} = -\vec{B}$
Co-initial Vectors
Vectors having common starting point.
Parallel Vectors
Two or more vectors having same direction like $\vec{b}=k\vec{a}$ then, $\vec{b}$ and $\vec{a}$ are parallel vectors
Cross-Product / Vector product
$\vec{a}\times\vec{b}=|\vec{a}|.|\vec{b}|\cos\theta$
Addition of Vectors
Law of Triangle
Law of Parallelogram
$\vec{R} = \vec{P} + \vec{Q}$
R Q P
Q R P
Subtraction of two vectors
$\vec{A}-\vec{B}=\vec{A}+(-\vec{B})$
Multiplication of a vector by a real number λ
$\lambda\times\vec{A}=\lambda\vec{A}$
Position of displacement vector
Position vector , $\vec{r} = x\hat{i} + y\hat{j}$
Displacement vector , $\Delta\vec{r} = \Delta x\hat{i} + \Delta y\hat{j}$
Velocity vector
$\vec{v}=v_x\hat{i}+v_y\hat{j}$,
magnitude $|\vec{v}| = \sqrt{v_x^2+v_y^2}$
Relative velocity
$\vec{V}_{AB} = \vec{V}_A - \vec{V}_B$
$\vec{V}_{BA} = \vec{V}_B - \vec{V}_A$
$\vec{V}_{AB} = -\vec{V}_{BA}$
$|\vec{V}_{AB}| = |\vec{V}_{BA}|$
Acceleration vector
$\vec{a} = a_x i + a_y\hat{j}$; $a_x = dv_x/dt$ & $a_y = dv_y/dt$
$|\vec{a}| = \sqrt{a_x^2+a_y^2}$
Relative motion
River boat problem
$\vec{v}_r\times\vec{v}_{br}=\vec{v}_b$
Time taken by boatman to cross the river, $t=\frac{d}{\vec{v}_{by}}=\frac{d}{\vec{v}_{by}\cos\theta}$
Drift, $x=\vec{v}_{by}t=(\vec{v}_r-\vec{v}_{br}\sin\theta).\frac{d}{\vec{v}_{by}\cos\theta}$
Relative velocity of rain
$\vec{v}_{rm}=\sqrt{v_r^2+v_m^2\,2v_rv_m\cos90^\circ}=\sqrt{v_r^2+v_m^2}$
Motion in a Plane
Motion of Body under two dimensional frame.
Uniform circular motion
When an object follows a circular path at a constant speed , the motion of the object is called uniform circular motion.
Angular displacement
$\theta = \frac{arc}{radius}$
Angular velocity
$\omega = \theta/t$
Angular acceleration, $d=\Delta\omega/\Delta t$
eg- merry go around.
Centripetal Acceleration
A body in a circular motion acted upon by an acceleration directed towards centre of the circular motion.
$a_c = v^2/r = r\omega^2 = 4\pi^2 r v^2$
Projectile motion
Motion of an object that is in flight after being thrown or projected.
Components of velocity (initial velocity)
$u_x = u\cos\theta, u_y = u\sin\theta$
Components of acceleration
at any instant $a_x = 0, a_y = g$
Position after time t
$x=(u\cos\theta)t$;
$y=(u\sin\theta)t - \frac{1}{2}gt^2$
Equation of path of projectile
$y=u\tan\theta\, x-\frac{1}{2}\frac{g}{2u^2\cos^2\theta}x^2$
Total time of flight, $T_f = \frac{2u\sin\theta}{g}$
Maximum height, $H_{max} = \frac{u^2\sin^2\theta}{2g}$
Horizontal range, $R = \frac{u^2\sin2\theta}{g}$

CHAPTER

4 MOTION IN 2-DIMENSION

Chapter Objectives

Scalar and Vectors, Unit Vector, Scalar - Addition, Subtraction and Multiplication with Vectors, Parallel Vectors, Equality of Vectors, Addition of Vectors, Subtraction of Vectors, Zero Vector.
Resolution of a vectors, Scalar Product of Vector, Cross Product of Vector, Rectangular components, Scalar and Vector product of vectors.
Motion in 2D (Plane) - Position Vector and Displacement, Average Velocity, Instantaneous Velocity, Average Acceleration, Instantaneous Acceleration.
Projectile Motion - Maximum Height, Range and Time of Flight of a Projectile.
Uniform Circular Motion – Angular Displacement, Angular Velocity, Angular Acceleration, Centripetal Acceleration.
Relative Motion - River Boat Problems, Relative Velocity of Rain.

STUDY MATERIAL

Concepts Clarified :

➢ **Scalars and Vector :**

- Study of motion is based on various quantities which are used to define physical quantities like Distance, Displacement, Velocity, Acceleration, Energy, Momentum etc. Motion of an object can be 2-Dimension as well as 3-Dimension. In order to grasp the physical world in 3-Dimension, we need to understand the vectors.
- Some of the quantity need to be defined along the direction of their action. Such quantity depends on magnitude and direction of action. Vector notation is used to define such quantities. Based on number of dependants (magnitude and direction), quantities can be classified into two categories :

Scalar & Vector Quantities :

(i) **Scalar Quantity :** The Quantities that can be defined completely using their magnitude only (along with proper unit) can be termed as Scalar Quantity.

Example : Refractive index, Temperature, Frequency, Entropy, Energy, Calories, Length, Time, Work etc.

(ii) **Vector Quantity :** The Quantities that require magnitude and direction both to describe a complete scenario can be termed as Vector Quantity.

Example : Temperature gradient, Dipole Moment, Vector potential, Jounce, Crackle, Polarization, Current density, Magnetic Flux Density, Auxiliary Field, Spin etc.

For more details, scan the code

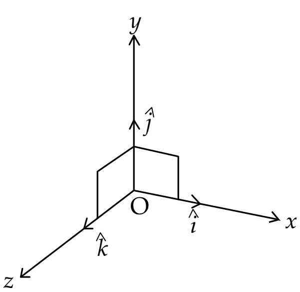
For more details, scan the code

- **For Example :** A is certain distance far from a location B. Then, how far is A from B? It can be defined by Scalar Quantity but how to reach A from B? It can be answered using vectors *i.e.,* we have to define the distance along with the direction.

➢ **Unit Vector :**

- Vector having magnitude equal to unity and in a defined direction. A unit vector mathematically can be defined as the resultant of vector division with its magnitude. Mathematical Term is given by :

$$\hat{a} = \frac{\vec{a}}{|a|}$$



- **Scalar - Addition, Subtraction and Multiplication with Vectors :**

Let there be two unit vectors $\hat{i}$ and $\hat{j}$.

$$\vec{r}_1 = a_1\hat{i} + b_1\hat{j}$$

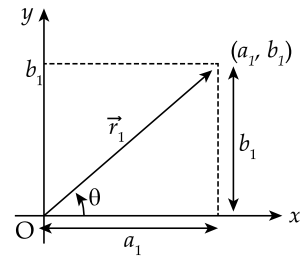
$$\vec{r}_2 = a_2\hat{i} + b_2\hat{j}$$

Addition : $\vec{r}_1 + \vec{r}_2 = (a_1 + a_2)\hat{i} + (b_1 + b_2)\hat{j}$

Subtraction : $\vec{r}_1 - \vec{r}_2 = (a_1 - a_2)\hat{i} + (b_1 - b_2)\hat{j}$

Multiplication with a scalar quantity "c" :

$$c\vec{r}_1 = c(a_1\hat{i} + b_1\hat{j}) = ca_1\hat{i} + cb_1\hat{j}$$



Let's try to plot it on co-ordinate axes :

Magnitude of $\vec{r}_1$ $\quad |r_1| = \sqrt{a_1^2 + b_1^2}$

Direction of r_1 $\quad \tan\theta = \dfrac{b_1}{a_2} = \dfrac{\text{Component along } y-\text{axis}}{\text{Component along } x-\text{axis}} \Rightarrow \theta = \tan^{-1}\dfrac{b_1}{a_1}$

➢ **Parallel Vectors :**

- Two or more vectors having same direction are known as Parallel Vectors. Mathematically, parallel vectors are formed by scalar multiplication of a vector.

  Example : If $\vec{b} = k\vec{a}$ then $\vec{b}$ and $\vec{a}$ are parallel vectors.

Equality of Vectors :

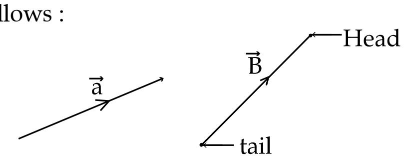
Vectors having same magnitude and direction are known as Equal Vectors.

$(3\hat{i} + 7\hat{j})$ m and $(3\hat{i} + 7\hat{j})$ m/s these vectors cannot be compared as they represent two different quantities.

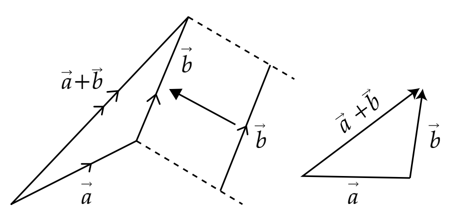
➢ **Addition of Vectors :**

Addition or composition of vectors means finding the resultant of a number of vectors acting on a body. The vectors can be added geometrically and not algebraically vectors, whose resultant is to be calculated behave independent of each other. In other words, each vector behaves $\vec{a}$ if the other vectors were absent.

Graphical Representation is as follows :



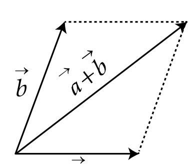
The first vector $\vec{a}$ is drawn first and then tail of the second vector $\vec{b}$ is added to the head. The resultant vector will be equivalent to value of the vector formed by joining tail of $\vec{a}$ to the head of $\vec{b}$ directly.

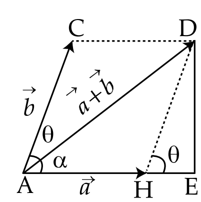


This is known as 'Triangle Rule of Vector Addition'.

Another way to find the addition is "Parallelogram Rule of Vector". In this we draw vectors $\vec{a}$ and $\vec{b}$ joining their tails at a common point. Using adjacent sides, we can form a parallelogram, then diagonal formed is the resultant vector (magnitude and direction).

Finding the magnitude of $\vec{a} + \vec{b}$ as follows:





$$|AD|^2 = AE^2 + ED^2$$

Here, $AE = |a| + |b\cos\theta|$ and $ED = b\sin\theta$

So, $AD^2 = a^2 + b^2\cos^2\theta + 2ab\cos\theta + b^2\sin^2\theta$

$$AD^2 = a^2 + b^2 + 2ab\cos\theta$$

$$AD = \sqrt{a^2 + b^2 + 2ab\cos\theta}$$

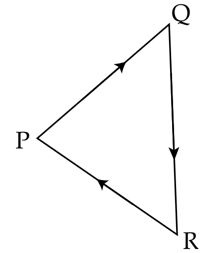
$$\tan\alpha = \frac{ED}{EA} = \frac{b\sin\theta}{a + b\cos\theta}$$

- **Subtraction of Vectors :**

The subtraction of vectors can be handled using addition.

$$\vec{a} - \vec{b} = \vec{a} + (-\vec{b})$$

- **Zero Vector :**



In the given triangle PQR, $\overrightarrow{PQ} + \overrightarrow{QR} + \overrightarrow{PR}$ must be equal to zero as the overall displacement from starting point to end point is zero.

Hence, $\overrightarrow{PQ} + \overrightarrow{QR} + \overrightarrow{PR} = \vec{0}$

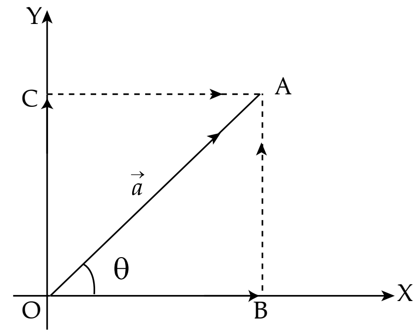
- **Resolution of Vector :**

$\overrightarrow{OA} = \vec{a}$

By Vector Addition Rule,

$\overrightarrow{OA} = \overrightarrow{OB} + \overrightarrow{OC}$

Here, $\left|\overrightarrow{OB}\right| = \vec{a}\cos\theta$ and $\left|\overrightarrow{OC}\right| = \vec{a}\sin\theta$



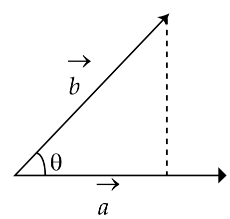
If $\hat{i}$ and $\hat{j}$ represent unit vectors along OX and OY respectively, then

$\overrightarrow{OB} = a\cos\theta\,\hat{i}$ and $\overrightarrow{OC} = a\sin\theta\,\hat{j}$

So, $\vec{a} = (a\cos\theta)\hat{i} + (a\sin\theta)\hat{j}$

- **Scalar or Dot Product of Vectors :**

The scalar product of two vectors can be constructed by taking the component of one vector in the direction of the other and multiplying it times the magnitude of the other vector.



$$\vec{a}.\vec{b} = |\vec{a}||\vec{b}|\cos\theta$$

$$\text{If, } \theta = 0°,\ \vec{a}.\vec{b} = |\vec{a}||\vec{b}|$$

$$\text{If, } \theta = 90°,\ \vec{a}.\vec{b} = |\vec{a}||\vec{b}| \times 0 = 0$$

$$\text{If, } \theta = 180°,\ \vec{a}.\vec{b} = -|\vec{a}||\vec{b}|$$

Note : The Dot Product is Commutative and Distributive.

$$\vec{a}.\vec{b} = \vec{b}.\vec{a} \text{ and } \vec{a}.\left(\vec{b} + \vec{c}\right) = \vec{a}.\vec{b} + \vec{a}.\vec{c}$$

- **Cross or Vector Product of Vectors :**

The cross product of $\vec{a}$ and $\vec{b}$ is defined as a vector $\vec{c}$ such that it is orthogonal to both $\vec{a}$ and $\vec{b}$ with the direction given by right hand thumb rule and the magnitude is equal to the area of the parallelogram in that span.

Mathematically it is defined as :

$\vec{a} \times \vec{b} = |\vec{a}||\vec{b}|\sin\theta\,\hat{n}$

Here, $\hat{n}$ is the unit vector & θ is the angle between $\vec{a}$ and $\vec{b}$.

Properties of Cross / Vector Product :

1. $\vec{A} \times \vec{B} = -\vec{B} \times \vec{A}$

2. $\vec{A} \times (\vec{B} + \vec{C}) = \vec{A} \times \vec{B} + \vec{A} \times \vec{C}$

3. $(\vec{A} \times \vec{B}) + (\vec{C} \times \vec{D}) = (\vec{A} \times \vec{C}) + (\vec{A} \times \vec{D}) + (\vec{B} \times \vec{C}) + (\vec{B} \times \vec{D})$

4. $m\vec{A} \times \vec{B} = \vec{A} \times m\vec{B}$

5. $(\vec{B}+\vec{C})\times\vec{A}=\vec{B}\times\vec{A}+\vec{C}\times\vec{A}$

6. $\vec{A}\times\vec{A}=\vec{0}$

7. $\vec{A}\times(\vec{B}-\vec{C})=\vec{A}\times\vec{B}-\vec{A}\times\vec{C}$

8. $\left|\vec{A}\times\vec{B}\right|^2=\left|\vec{A}\right|^2\left|\vec{B}\right|^2-\left|\vec{A}.\vec{B}\right|^2$

9. $\vec{A}\times(\vec{B}\times\vec{C})=(\vec{C}.\vec{A})\vec{B}-(\vec{B}.\vec{A})\vec{C}$

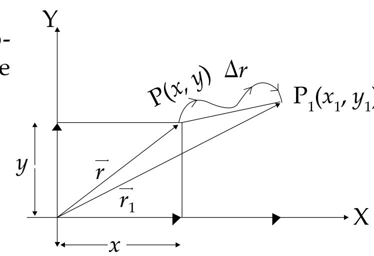
If two vectors $\vec{A}$ and $\vec{B}$ in terms of their rectangular components are $\vec{A}=a_1\hat{i}+b_1\hat{j}+c_1\hat{k}$ and $\vec{B}=a_2\hat{i}+b_2\hat{j}+c_2\hat{k}$

then, $\vec{A}\times\vec{B}=(a_1\hat{i}+b_1\hat{j}+c_1\hat{k})\times(a_2\hat{i}+b_2\hat{j}+c_2\hat{k})$

It can also be found using determinant method : $\vec{A}\times\vec{B}=\begin{vmatrix}\hat{i} & \hat{j} & \hat{k}\\ a_1 & b_1 & c_1\\ a_2 & b_2 & c_2\end{vmatrix}$

➢ Motion in 2D (Plane)

- **Position Vector and Displacement :** Position Vector of a point P in a two-dimensional plane located with reference to origin of an *x-y* co-ordinate system.



Let $\vec{r}$ be the position vector and is given by $\vec{r}=x\hat{i}+y\hat{j}$

Initial Position will be given by :

$$\vec{r}_1=x_1\hat{i}+y_1\hat{j}$$

Displacement = $\vec{r}_1-\vec{r}=(x_1\hat{i}+y_1\hat{j})-(x\hat{i}-y\hat{j})$

From the above fig. we can conclude that

$$\Delta\vec{r}=\vec{r}_1-\vec{r}$$

(By Triangle law of vector addition)

For more details, scan the code

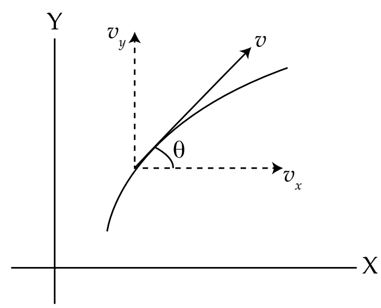
- **Average Velocity** :

$$\vec{v}_{av}=\frac{\Delta\vec{r}}{\Delta t}=\frac{\Delta x\hat{i}+\Delta y\hat{j}}{\Delta t}$$

$$\vec{v}_{av}=v_x\hat{i}+v_y\hat{j}$$

Note : Direction will be same as that of the resultant.

- **Instantaneous Velocity :**



$$\vec{v}=\lim_{\Delta t\to 0}\frac{\Delta\vec{v}}{\Delta t}=\frac{\Delta\vec{r}}{\Delta t}$$

$$\vec{v}=v_x\hat{i}+v_y\hat{j}$$

where, $v_x=\dfrac{dx}{dt}$ and $v_y=\dfrac{dy}{dt}$

$$\left|\vec{v}\right|=\sqrt{v_x^2+v_y^2}$$

$$\tan\theta=\frac{v_y}{v_x}\text{ or }\theta=\tan^{-1}\left(\frac{v_y}{v_x}\right)$$

Note : The instantaneous velocity at any point of the path is represented by the magnitude and directed towards the tangent to the path of the object at that point (in the direction of motion).

- **Average Acceleration** :

$$\vec{a}_{av}=\frac{\Delta\vec{v}}{\Delta t}=\frac{\Delta v_x}{\Delta t}\hat{i}+\frac{\Delta v_y}{\Delta t}\hat{j}$$

$$\Rightarrow\vec{a}_{av}=a_x\hat{i}+a_y\hat{j}$$

- **Instantaneous Acceleration :**

$$\vec{a} = \frac{\overrightarrow{dv}}{dt} = \frac{dv_x}{dt}\hat{i} + \frac{dv_y}{dt}\hat{j}$$

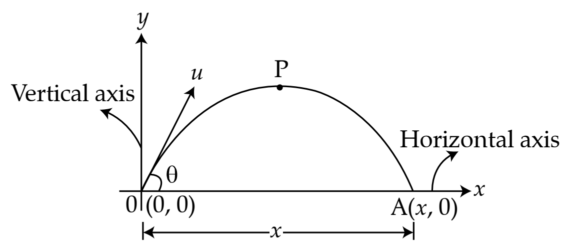
$$\Rightarrow \vec{a} = a_x\hat{i} + a_y\hat{j}$$

➢ Projectile Motion :

This concept was first delivered or observed by Galileo. He tried to show that "Horizontal and vertical movement of a projectile are mutually independent". One can easily understand that by performing the below mentioned activity.

Pick two objects, project one of them with some motion in horizontal direction. Wait for some time and then pick up the second object and drop it down vertically from the same height. Observation are as follows :

We will find that both the objects hit the Ground at same time. This shows that the downward acceleration is same in case of a Projectile as well as Free falling body. Secondly the Measurement of time and distance will show that velocity of Object in Horizontal Direction will continue unchanged.



Both the above observations conclude that the vertical motion and the horizontal motion are mutually independent in case of a Projectile Motion.

There are two important properties of a Projectile motion as mentioned below :

1. Horizontal Velocity Component. (Constant)

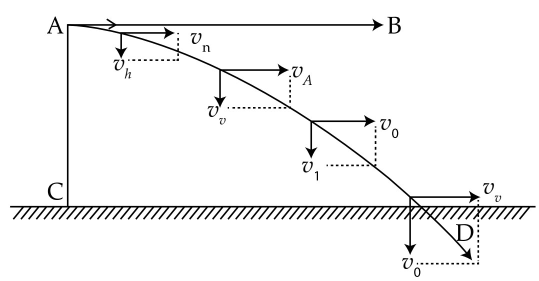
2. Vertically Downward Acceleration Component. (Constant)

Note : The curve in the Projectile Motion is the result of the constant value of two above mentioned values.

Let us take another example to understand this more clear. Suppose a man throws an object from point A with initial horizontal speed. As per Newton's Second Law, considering force as equivalent to product of mass and acceleration. The object motion in horizontal direction will remain unchanged *i.e.*, no acceleration will act unless there is a horizontally directed force acting in an opposite direction. If we ignore the air friction (under the ideal condition), only force acting on the ball will be the "**Force of Gravity**".

Hence the Horizontal Speed v_h of the ball will remain unchanged. As per the figure given, the ball moves with the speed to the right, it will fall under the Action of Gravity, it will be shown by the vector v_v where v_h and v_v are the horizontal and vertical components of the velocity respectively.

The expression for the velocity will be : $\vec{v} = \sqrt{v_h^2 + v_v^2}$ and will be tangential to the trajectory.



As we had defined the Projectile Motion, let us determine the maxima's in horizontal, vertical direction and the flight time *i.e.*, "How high and how far does a projectile go and for how long does it remain in air".

Above mentioned factors will be of great consideration if we must land or project an object to a certain target. **For Example :** Hitting a football in Goal, Hitting a cricket ball to boundary etc.

➢ Maximum Height, Range and Time of Flight of a Projectile :

Now let us determine a Projectile Motion in order to determine the above-mentioned factors like Maximum Height, Time of Flight and Range. The ideal case will be considered i.e., taking air and wind friction as zero.

Note : The Velocity of the Projectile is defined in horizontal and vertical components of the velocity.

Let us define the assumptions as mentioned below :

1. x-axis in horizontal direction and y-axis in vertical direction.

2. Initial position as Origin at $t = 0$, the coordinates will be $x = 0, y = 0$.

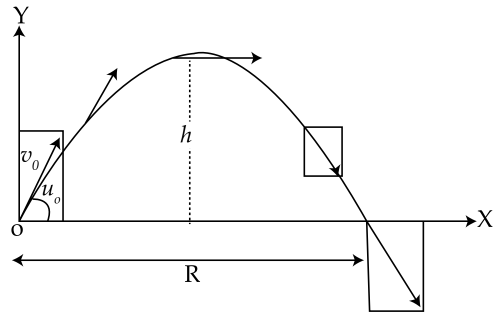
The projectile is launched at an angle θ_0(Angle of Elevation, along the x-axis) and initial velocity as v_o. The components of velocity are as follows :

$$v_{ax} = v_0 \cos \theta_0 \text{ and } v_{ay} = v_0 \sin \theta_0$$

Defining the Projectile's acceleration in horizontal and Vertical Components, then :

$$a_x = 0; \quad a_y = -g = -9.8 \text{ ms}^{-2}$$

As the acceleration is due to gravity, hence it will always appear in downward direction hence, negative sign will be used for a_y always. Secondly, the horizontal component *i.e.*, a_x remain constant.



We can use basic equation for the motion to define the horizontal and vertical components of Projectile's velocity and position at time t. Value is as follow :

For,

Horizontal Motion : $v_{ax} = v_x$, Since $a_x = 0$ ...(i)

$$x = v_{ax}t = v_0 \cos \theta_0 t \quad \text{...(ii)}$$

Vertical Motion : $v_y = v_{ay} - gt = v_0 \sin \theta_0 - gt$ ...(iii)

$$y = v_{ay}t - \frac{1}{2}gt^2 = v_0 \sin \theta_o t - \frac{1}{2}gt^2 \quad \text{...(iv)}$$

The vertical position and velocity component can be illustrated as :

$$-gy = \frac{1}{2}\left(v_y{}^2 - v_{ay}{}^2\right) \quad \text{...(v)}$$

We can note that the motion in horizontal direction is defined in equations (i) and (ii) with constant velocity. The motion in vertical direction is defined by equations (iii) and (iv) with constant downward acceleration.

Velocity and position of the projectile at any instant of time can be defined by the summation of the two respective components.

Using above defined equations to derive the maximum height, time of flight and the range of projectile.

- **Maximum Height** : In Projectile motion through air, the object climbs up to a certain height (h) before downfall. The Vertical component of velocity is considered as 0, when the object is at maximum height under projectile motion. After this instant the object did not move upward and start falling under the action of gravity. Hence, putting $v_y = 0$ in Eqns. (iii) and (v), we get

$$0 = v_{ay} - gt$$

Time taken to reach the maximum height under projectile motion will be given by

$$t = \frac{v_{ay}}{g} = \frac{v_0 \sin \theta_0}{g} \quad \text{...(vi)}$$

We had already defined that at the height defined in Eqn. the vertical component of velocity will be 0. Hence applying $v^2 - u^2 = 2as = 2gh$. Hence, we get :

$$h = \frac{v_0{}^2 \sin^2 \theta_0}{2g} \text{ (where } v = 0 \text{ and } u = v \sin \theta) \quad \text{...(vii)}$$

Note : All the derivations are defined taking air resistance and wind friction as 0. This is a good communication for a projectile with a fairly low velocity.

We can now define the total time (Using Equation (vi)) for which the object will remain in air under the projectile motion. This is termed as Time of Flight.

- **Time of Flight :** The total time spent by the object in air under the projectile motion or the time interval between the launch and the instant when the object touches the ground is known as Time of Flight.

The time t represented in Equation (vi) is the half of the Time of Flight. Therefore, the total time of Flight will be given by :

$$T = 2t = \frac{2v_0 \sin \theta_0}{g} \quad \text{...(viii)}$$

Now, let us calculate the range *i.e.*, the distance travelled horizontally under the projectile.

- **Range :** Range of the projectile can be derived the maximum distance travelled by the object under Projectile Motion. It can be derived by multiplying the time of Flight with the velocity (using Basic method Distance = Speed × Time)

$$R = v_{ax} \times (2t)$$

$$= (v_0 \cos \theta_0) \frac{(2v_0 \sin \theta_0)}{g}$$

$$= v_0{}^2 \frac{(2 \cos \theta_0 \sin \theta_0)}{g} \quad \text{...(ix)}$$

$$= v_0{}^2 \frac{(\sin 2\theta_0)}{g}$$

Using Equation (ix), we can clearly see that the range of a projectile is proportional to Initial Speed v_0 and Direction / Angle θ_0

Let us define the maximum range of the Projectile :

As $R = v_0^2 \frac{(\sin 2\theta_0)}{g}$, value is dependant on sin 2θ, the value of sin θ ranges between – 1 to 1. The maximum value *i.e.*, 1 is attained at 90º.

Comparing the same to get the maximum value 2θ = 90º, hence θ = 45º (for *R* to be maximum).

- **Equation of a Trajectory :**

Path traced by a body under the action of gravity is known as Trajectory. To derive it mathematically we must define it in *x* and *y* directions and relate it by eliminating time.

Horizontal Motion	Vertical Motion
$u_x = u\cos\theta$	$u_y = u\sin\theta$
$a_x = 0$	$a_y = -g$
$s_x = u\cos\theta t$	$s_x = u_y t + \frac{1}{2} a_y t^2$
$t = \frac{x}{u\cos\theta}$	$y = u\sin\theta\left(\frac{x}{u\cos\theta}\right) - \frac{1}{2}g\frac{x^2}{u^2\cos^2\theta}$

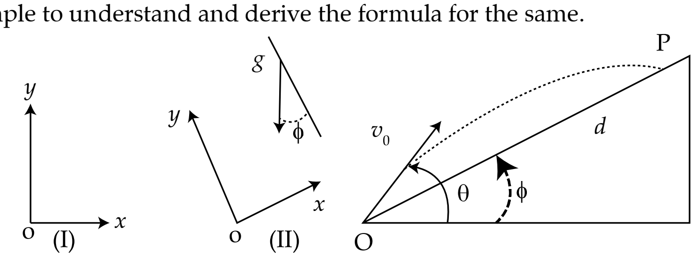
$$y = u\tan\theta\, x - \frac{gx^2}{2u^2\cos^2\theta}$$

$$\Rightarrow y = bx - ax^2$$

Special Case : Projectile Motion in an Incline

The objective involved in this case is to find out the factors or attributes involved when the projectile is launched up an incline (incline angle ϕ) with initial velocity v_i at an angle θ_i with respect to the horizontal ($\theta_i > \phi_i$)

Let us take an example to understand and derive the formula for the same.



Along the base line *i.e.*, Case I, kinematic equation can be :

$$x = (v_0\cos\theta)t$$

$$y = (v_0\sin\theta)t - \frac{g}{2}t^2$$

Point of Impact with Incline is the point of trajectory $y = Y(x)$ with Y being the function evaluated by removing *t* from the above equations. We obtain :

$$y = x\tan\theta - \frac{g}{2}\frac{x^2}{v_0^2\cos\theta}$$

The co-ordinates of $P(x_p, y_p)$ = (dcos θ, dsin θ), putting value in *y*, we get :

$$d\sin\theta = d\cos\theta\tan\theta - \frac{g}{2}\frac{d^2\cos^2\theta}{v_0^2\cos^2\theta}$$

Solving above equation we get, *d* = 0 and other one is :

$$d = -\frac{2v_0^2\cos\theta}{g\cos^2\phi}(\sin\phi - \cos\phi\tan\theta) = \frac{2v_0^2\cos\theta\sin(\theta-\phi)}{g\cos^2\phi}$$

For Case II, Equation of motion can be written as :

$$x = [v_0\cos(\theta-\phi)]t - \frac{g\sin\phi}{2}t^2$$

$$y = \left[v_0 \sin\left(\theta - \phi\right)\right]t - \frac{g\cos\phi}{2}t^2$$

Above two equations show that both x and y are quadratic in t. We have $y = 0$ only at two points $x = 0$ (Point O) and P (where $x = d$), we get

$$0 = t\left(\left[v_0 \sin\left(\theta - \phi\right)\right] - \frac{g\cos\phi}{2}t\right)$$

From this equation we get two solution for the Flight time, t=0 and the other is :

$$t = \frac{v_0 \sin\left(\theta - \phi\right)}{g\cos\phi}$$

Putting the value of t in value of x for Case II, we get distance d along the incline *i.e.,*

$$d = \frac{2v_0 \sin(\theta - \phi)}{g\cos\phi}\left\{v_0\cos\left(\theta - \phi\right) - \frac{g\sin\phi}{2}\frac{2v_0\sin\left(\theta - \phi\right)}{g\cos\phi}\right\} = \frac{2v_0^2 \sin\left(\theta - \phi\right)\cos\theta}{g\cos^2\phi}$$

Note : In order to check the correctness of the derived formula we can check the correctness of the formula. If we put $\phi = 0$, we get $d = \frac{v_0^2 \sin 2\theta}{g}$. Hence, we get the correct result.

Now we will try to find the value of θ for which the d (range) is maximum and value of d_{max}.

One way to find the maxima is to take the derivative of d with respect to θ, while keeping v_0, ϕ, g constant and $\frac{\partial d}{\partial\theta} = 0$. Other way to find the value of d and rewrite in such a way that answer become obvious. We will go with second one.

Keeping v_0, ϕ, g constant, the only factor by which the value of d depends on θ is sin (θ – ϕ) cos θ. This can be structured as :

$$\sin\left(\theta - \phi\right)\cos\theta = \frac{1}{2}\left\{\sin\left(\theta - \phi + \theta\right) + \sin\left(\theta - \phi - \theta\right)\right\} = \frac{1}{2}\left\{\sin\left(2\theta - \phi\right) - \sin\phi\right\}$$

The value will be maximum when sin (2θ – ϕ) = 1, which implies $2\theta - \phi = \frac{\pi}{2}$, we can easily deduce that d will be maximum for $\theta = \frac{\pi}{2} + \frac{\phi}{2}$ and the value of

$$d_{\max} = \frac{v_0^2}{g\cos^2\phi}\left(1 - \sin\phi\right)$$

$$\text{If } \phi = 0,\ d = \frac{v_0^2}{g}$$

For more details, scan the code

Projectile Motion

➢ Uniform Circular Motion :

When a body moves in a circular path with constant speed, the body is said to be in uniform circular motion.

- **Angular Displacement :**

  Angle traced by the radius vector at the centre of the circular path at any instant can be termed as Angular Displacement.

$$\theta = \frac{\text{arc}}{\text{radius}}$$

It is denoted by θ – magnitude of the angular displacement with unit as radian (rad).

- **Angular Velocity :** Rate of change of angular displacement can be defined as Angular Velocity.

  Mathematically it is represented as :

$$\vec{\omega} = \frac{\text{Angular displacement}}{\text{Time}} = \frac{\theta}{t} = \frac{d\vec{\theta}}{dt}$$

  It is denoted by $\vec{\omega}$ and is measured in rad s^{-1} (radian per second).

- **Angular Acceleration :**

  Rate of change of angular velocity is defined as Angular Acceleration. It is represented as :

$$\vec{a} = \frac{\text{Angular Velocity}}{\text{Time}} = \frac{\vec{\omega}}{t} = \frac{d\vec{\omega}}{dt}$$

For uniform acceleration, the equation of motion can be modified as :

(i) $\omega_f = \omega_i + at$ **(ii)** $\omega_f^2 = \omega_i^2 + 2a\theta$ **(iii)** $\theta = \omega_i t + \frac{1}{2}at^2$

Time period is defined as the time taken by an object to complete one revolution in its circular path. The number of revolutions completed in unit time under uniform circular motion is denoted as Frequency (ν). Unit of frequency is Hertz. It can be related as :

$$\nu.T = 1 \text{ or } \nu = \frac{1}{T}$$

The relation between angular velocity, frequency and time period is given by :

$$\omega = \frac{\theta}{t} = \frac{2\pi}{T} = 2\pi\nu$$

- **Centripetal Acceleration :**

In order to maintain the movement of particle in uniform circular motion, an inward continuously inward acceleration is maintained. Such acceleration is known as Centripetal Acceleration.

$$a_c = \frac{v^2}{r} = r\omega^2 = \frac{r.4\pi^2}{T^2} = r.4\pi^2\nu^2$$

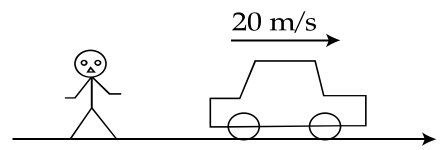
For more details, scan the code

Uniform Circular Motion

➢ Relative Motion :

It is a very general term, technically we use it for "in relation to" or "with respect to"

Example :



Case I – If you see a car moving at 20 m/s in a certain direction, relative velocity will be 20 m/s.

Case II – If you are inside the car and car is moving at 20 m/s, the velocity of the car in relation to your position is 0m/s as it seems to be at rest.

Mathematically, Velocity of B w.r.t. A = $\overrightarrow{V_{BA}} = \overrightarrow{V_B} - \overrightarrow{V_A}$

Being a vector quantity, this is also valid $-\overrightarrow{V_{BA}} = \overrightarrow{V_{AB}}$

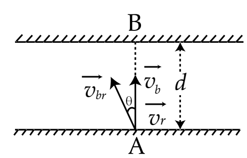
➢ River Boat Problems :

This is one of the most important application of relative motion. Let's try to derive the direct formula to be used in such cases. The terms to be used are as follows :

$\vec{v}_r$ = Absolute velocity of river

$\vec{v}_{br}$ = Velocity of boatman w.r.t river or velocity of boatman in still water.

$\vec{v}_b$ = Velocity of boatman



Hence, $\vec{v}_r + \vec{v}_{br} = \vec{v}_b$

Let us take the case from the figure and keeping all other factors as ideal, we get :

- Time taken by boatman to cross the river : $t = \frac{d}{v_{by}} = \frac{d}{v_{br}\cos\theta}$
- Drift i.e., the displacement along x-axis when he reaches the other bank :

$$x = v_{by}t = (v_r - v_{br}\sin\theta).\frac{d}{v_{br}\cos\theta}$$

For more details, scan the code

Specific Case :

1. Condition when boatman crossed the river in shortest time :

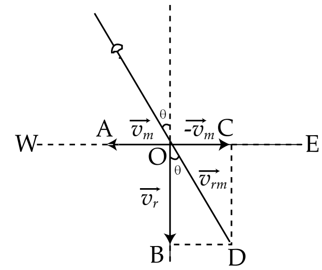
When θ = 0, the boat moves in the perpendicular direction to the main current.

➢ Relative Velocity of Rain :

Let us assume a man walking west with velocity $\vec{v}_m$, represented by $\overrightarrow{OA}$. Let the rain falling with vertical velocity $\vec{v}_r$ represented by $\overrightarrow{OB}$. Relative velocity $\vec{v}_{rm}$ can be found by bringing the man at rest or by imposing the negative velocity $-\vec{v}_m$ on the man as well as rain. Now the relative velocity of rain w.r.t. man will be $\vec{v}_r \left(= \overrightarrow{OB}\right)$ and $-\vec{v}_m = \overrightarrow{OC}$ which will be represented by $\overrightarrow{OD}$ of rectangle OBDC.

Hence, $\overrightarrow{v_{rm}} = \sqrt{v_r^{\,2} + v_m^{\,2} + 2v_r v_m \cos 90^\circ} = \sqrt{v_r^{\,2} + v_m^{\,2}}$

Fig,



If θ is the angle that $\overrightarrow{v_{rm}}$ makes with the vertical, then

$$\tan\theta = \frac{BD}{OB} = \frac{v_m}{v_r} \Rightarrow \theta = \tan^{-1}\frac{v_m}{v_r}$$

Note : In order to protect himself from the rain, man should hold the umbrella in the direction making an angle $\theta = \tan^{-1}\left(\frac{v_m}{v_r}\right)$ towards the west of vertical.

For more details, scan the code

II. Important Formulae :

1. Time of Flight of Projectile $T = 2t = \frac{2v_0 \sin\theta_0}{g}$
2. Time taken to reach maximum height in Projectile Motion : $t = \frac{v_{ay}}{g} = \frac{v_0 \sin\theta_0}{g}$
3. Range of a Projectile : $R = v_0^{\,2}\frac{(\sin 2\theta_0)}{g}$
4. Equation of a Trajectory : $y = u \tan\theta\, x - \frac{gx^2}{2u^2\cos^2\theta}$
5. Value of d for Inclined Projectile : $d = \frac{2v_0^{\,2}\sin(\theta-\phi)\cos\theta}{g\cos^2\phi}$
6. Centripetal Acceleration : $a_c = r.4\pi^2\omega^2$
7. Drift in River Boat : $x = v_{by}t = (v_r - v_{br}\sin\theta).\frac{d}{v_{br}\cos\theta}$
8. Angle in Rain-Man Problem : $\theta = \tan^{-1}\frac{v_m}{v_r}$

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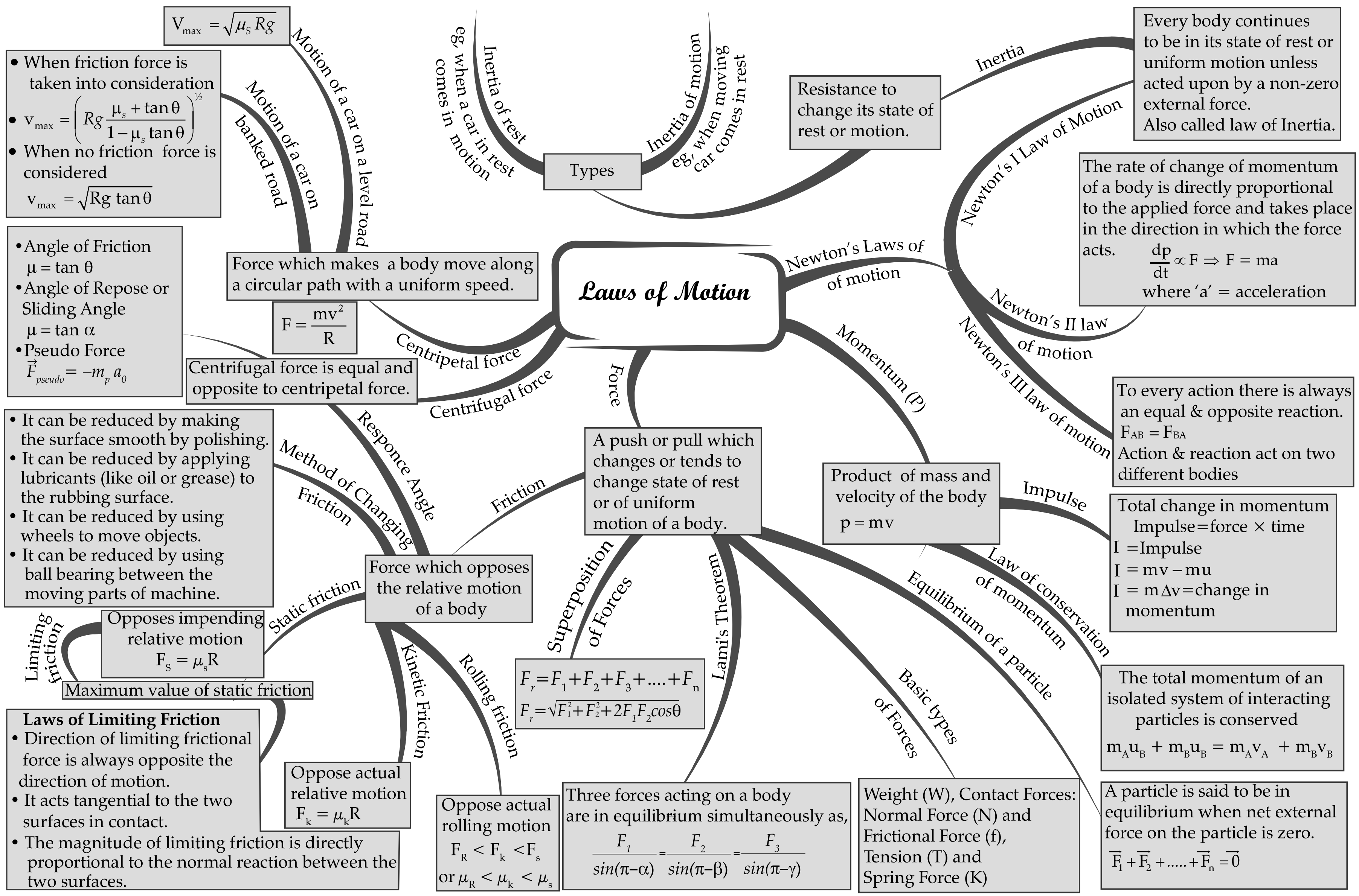

Laws of Motion
Newton's Laws of motion
Newton's I Law of Motion
Every body continues to be in its state of rest or uniform motion unless acted upon by a non-zero external force. Also called law of Inertia.
Inertia
Resistance to change its state of rest or motion.
Types
Inertia of rest
eg, when a car in rest comes in motion
Inertia of motion
eg, when moving car comes in rest
Newton's II law of motion
The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction in which the force acts. $\frac{dp}{dt} \propto F \Rightarrow F = ma$ where 'a' = acceleration
Newton's III law of motion
To every action there is always an equal & opposite reaction. $F_{AB} = F_{BA}$ Action & reaction act on two different bodies
Momentum (P)
Product of mass and velocity of the body $p = mv$
Impulse
Total change in momentum Impulse=force × time
I =Impulse
I = mv – mu
I = mΔv=change in momentum
Law of conservation of momentum
The total momentum of an isolated system of interacting particles is conserved
$m_A u_B + m_B u_B = m_A v_A + m_B v_B$
Force
A push or pull which changes or tends to change state of rest or of uniform motion of a body.
Equilibrium of a particle
A particle is said to be in equilibrium when net external force on the particle is zero.
$\overline{F}_1 + \overline{F}_2 + ... + \overline{F}_n = \overline{0}$
Basic types of Forces
Weight (W), Contact Forces: Normal Force (N) and Frictional Force (f), Tension (T) and Spring Force (K)
Lami's Theorem
Three forces acting on a body are in equilibrium simultaneously as,
$\frac{F_1}{sin(\pi-\alpha)} = \frac{F_2}{sin(\pi-\beta)} = \frac{F_3}{sin(\pi-\gamma)}$
Superposition of Forces
$F_r = F_1 + F_2 + F_3 + ... + F_n$
$F_r = \sqrt{F_1^2 + F_2^2 + 2F_1F_2cos\theta}$
Friction
Force which opposes the relative motion of a body
Rolling friction
Oppose actual rolling motion
$F_R < F_k < F_s$
or $\mu_R < \mu_k < \mu_s$
Kinetic Friction
Oppose actual relative motion
$F_k = \mu_k R$
Static friction
Opposes impending relative motion
$F_S = \mu_s R$
Limiting friction
Maximum value of static friction
Laws of Limiting Friction
• Direction of limiting frictional force is always opposite the direction of motion.
• It acts tangential to the two surfaces in contact.
• The magnitude of limiting friction is directly proportional to the normal reaction between the two surfaces.
Method of Changing Friction
• It can be reduced by making the surface smooth by polishing.
• It can be reduced by applying lubricants (like oil or grease) to the rubbing surface.
• It can be reduced by using wheels to move objects.
• It can be reduced by using ball bearing between the moving parts of machine.
Responce Angle
•Angle of Friction
μ = tan θ
•Angle of Repose or Sliding Angle
μ = tan α
•Pseudo Force
$\vec{F}_{pseudo} = -m_p a_0$
Centripetal force
Force which makes a body move along a circular path with a uniform speed.
$F = \frac{mv^2}{R}$
Centrifugal force
Centrifugal force is equal and opposite to centripetal force.
Motion of a car on a level road
$V_{max} = \sqrt{\mu_S Rg}$
Motion of a car on banked road
• When friction force is taken into consideration
• $v_{max} = \left(Rg\frac{\mu_s + \tan\theta}{1 - \mu_s \tan\theta}\right)^{1/2}$
• When no friction force is considered
$v_{max} = \sqrt{Rg \tan\theta}$

CHAPTER

5 LAWS OF MOTION

Chapter Objectives

Concept of force, Inertia, Newton's first law of motion; Newton's second law of motion, Newton's third law of motion, Momentum, Impulse.
Law of conservation of linear momentum and its applications.
Equilibrium of concurrent forces, Static, kinetic and limiting frictions, Laws of limiting friction, Rolling friction, Method of changing friction.
Dynamics of uniform circular motion : Centripetal force, examples of circular motion, Pseudo Force.

STUDY MATERIAL

Concepts Clarified :

For more details, scan the code

➢ **Concept of Force** :

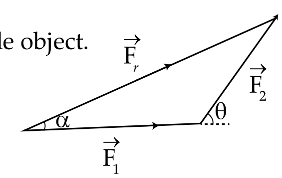
Force can be defined as an interaction between two objects. Physical contact between the objects is not mandatory for the exertion of force. Some common examples of force are Electric Force between two charges, Gravitational Force between any two bodies.

A force is something that changes the state of body in motion or rest. Basically, it causes a body at rest to move and stop a body that is in motion. It is a vector quantity measured in Newton (SI Unit) with dimension as $[MLT^{-2}]$

- **Superposition of Forces :**

Law of vectors is used to find the resultant when a number of forces are acting on a single object.

$$\vec{F_r} = \vec{F_1} + \vec{F_2} + \vec{F_3} + ... + \vec{F_n}$$



The resultant of two forces $\vec{F_1}$ and $\vec{F_2}$ inclined at an angle θ is given by,

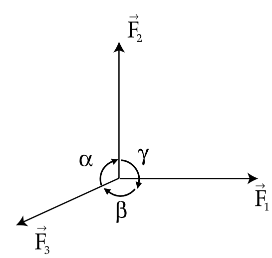
$$F_r = \sqrt{F_1^2 + F_2^2 + 2\,F_1F_2\cos\theta}$$

If resultant of the net forces $\vec{F_1}$ and $\vec{F_2}$ is directed at an angle α w.r.t the force $\vec{F_1}$, then

$$\tan(\alpha) = \frac{F_2\sin\theta}{F_1 + F_2\cos\theta}$$

- **Lami's Theorem** : If three forces $\vec{F_1}$, $\vec{F_2}$ and $\vec{F_3}$ acting on a body are in equilibrium simultaneously, then as per the theorem :

$$\frac{F_1}{\sin(\pi-\alpha)} = \frac{F_2}{\sin(\pi-\beta)} = \frac{F_3}{\sin(\pi-\gamma)}$$



where, α, β and γ are the angles opposite to forces $\vec{F_1}$, $\vec{F_2}$ and $\vec{F_3}$ respectively.

For more details, scan the code

➢ **Inertia** :

It is defined as the resistance of any object to change its state of motion. This includes change to the object's speed or direction of motion. Mass is the measure of inertia of the body.

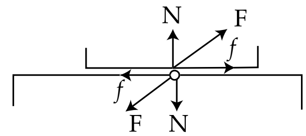
Basic Forces : Commonly known forces are as follows:

A. Weight : Weight of an object is defined as the force with which the Earth attracts it. It is called as Force of Gravity or Gravitational Force.

B. Contact Force : When two bodies are in physical contact then they exert force on each other, this force is known as Contact Force.

1. **Normal Force (N) :** It can be defined as the component of Contact force normal to the surface. It measures the intensity with which the objects are pressed together.

2. **Frictional Force (*f*) :** It can be defined as the component of Contact force parallel to the surface. It opposes the relative motion of the bodies or objects in contact.



C. Tension : Force exerted by the rope, chain or end of the spring; the direction of the tension is to pull the body where normal reaction acts in the push direction.

D. Spring Force : The force exerted by the spring to resist any change in its shape, the more you alter the shape of spring the more is the resistive force. The value of the force is $F = -kx$; where x is the change in length and k is the stiffness constant or spring constant, measured in Nm^{-1}.

➢ Newton's Laws of Motion

For more details, scan the code

A. Newton's First Law of Motion :

Every object continues to be in its original state either in rest or uniform motion unless it is compelled by any non zero external force in order to change its state. This law is also known as "Law of Inertia".

This law is valid in a specific frame of reference known as "Inertial Frame". If a frame of reference is at rest or in uniform motion, it is known as Inertial frame.

B. Newton's Second Law of Motion :

For more details, scan the code

- Newton's Second law states that the rate of change of momentum is directly proportional to the resultant force acting on the body. Second law in mathematical terms defines magnitude of force.

$$\vec{F} \propto \frac{\overrightarrow{dp}}{dt}$$

- The direction of the change in momentum is in the direction of applied force. Momentum $\vec{p} = m\vec{v}$, will give the measure of the sum of the motion contained in the body.
- **Unit Force :** It can be defined as the force which changes the momentum of the body by unity in unit time.

$$\vec{F} = \frac{d\vec{p}}{dt} = \frac{dm\vec{v}}{dt} = m\frac{d\vec{v}}{dt} + \vec{v}\frac{dm}{dt}$$

If the mass of the object remains constant with respect to time, $\frac{dm}{dt} = 0$ then

$$\vec{F} = m\left(\frac{d\vec{v}}{dt}\right) = m\vec{a} = \frac{\left(\overrightarrow{p_2} - \overrightarrow{p_1}\right)}{t}$$

- External Force acting on a body accelerate it in either magnitude or direction or in both.
  - **I.** If the force is parallel or antiparallel to the motion, it doesn't change the magnitude of $\vec{v}$ not the direction. Motion in the straight line will be the result of this change.
  - **II.** If the force implemented is orthogonal in nature and only the direction changes, the path followed by the object will be Uniform circular motion.
  - **III.** If the force acts at an angle to the motion of the body, it changes both the magnitude and direction of motion body. In this case path followed will be elliptical, parabolic and hyperbolic (Non-Uniform).

C. Newton's Third Law of Motion :

For more details, scan the code

- This law states that for every action there is an equal and opposite reaction.

  When two bodies A and B exert force on each other then

$$\vec{F}_{AB} = -\vec{F}_{BA}$$

- The two forces acting on the body are called action and reaction. It will act on different bodies.

➢ Momentum :

For more details, scan the code

Momentum in linear direction is defined as the product of mass of the body and the velocity.

$$\text{Momentum} = \text{Mass} \times \text{Velocity}$$

If the mass of the body is m and is moving with velocity $\vec{v}$, its momentum will be given by :

$$\vec{p} = m\vec{v}$$

It is a vector quantity and its direction is similar to the direction of velocity of the body. It is measured in $kgms^{-1}$ (SI) and $gcms^{-1}$ (cgs).

- **Impulse**

Impulse can be defined as the product of the average force during the impact and the time for which the impact lasts. It is measured by the total change in linear momentum produced by the impact.

Impulse gives the measure of the total impact of the force. The force acting on the body for a shorter period is known as Impulsive Force.

Example : Hitting a ball with the bat, Firing a gun.

An impulse force does not remain constant, initially changes from zero to maximum and then from maximum to zero. Hence the average value of the total effect is taken into consideration to measure the Impulse.

$$\vec{I} = \overrightarrow{F_{av}} \times \Delta t = \overrightarrow{p_2} - \overrightarrow{p_1}$$

- **Law of Conservation of Linear Momentum :**

For more details, scan the code

According to this principle, in an isolated system, the vector sum of linear momentum of all bodies of the system is conserved and is not affected due to their mutual action and reaction.

If explained, in an isolated system (no external force applied), mutual forces between pair of particles in system can cause the linear momentum to change. But in mutual pairs each force cancels the opposite force and the total linear momentum remain unchanged. Hence, we can say that the total linear momentum remains conserved and unchanged in total.

This is an important consequence of second and third law of motion.

Let there be two bodies A and B, with linear momentum $\vec{p}_A$ and $\vec{p}_B$, collision time be Δt and differ with final linear momentum $\vec{P}_A$ and $\vec{P}_B$ respectively.

Let $\vec{F}_{AB}$ is the force on A exerted by B and $\vec{F}_{BA}$ is the force on B exerted by A, then as per Newton's Second Law of Motion.

$\vec{F}_{AB} \times \Delta t$ = Change in linear momentum of A = $\overrightarrow{p_A} - \overrightarrow{p_B}$ and $\vec{F}_{BA} \times \Delta t$ = Change in linear momentum of B = $\overrightarrow{p_B} - \overrightarrow{p_A}$

Secondly as per Newton's third law : $\vec{F}_{AB} = -\vec{F}_{BA}$

By equating all the above equations, we get : $\overrightarrow{p_A} - \overrightarrow{p_B} = -\left(\overrightarrow{p_B} - \overrightarrow{p_A}\right)$

This proves that the Law of conservation of Linear Momentum is valid.

- **Application of Conservation of Momentum** :

Apparent Weight of a body in a lift **:**

A. When the lift is at rest or moving with uniform velocity *i.e.*, $a = 0$:

$mg - R = 0$ or $R = mg$ Hence, $W_{app} = W_0$

B. When the lift moves upward with an acceleration a :

$$R - mg = ma \text{ or } R = m(g+a) = mg\left(1 + \frac{a}{g}\right) = W_{app} = W_0\left(1 + \frac{a}{g}\right)$$

C. When the lift moves downward with an acceleration a :

$$mg - R = ma \text{ or } R = m(g-a) = mg\left(1 - \frac{a}{g}\right)$$

Here if $a > g$, W_{app} will be negative. The body will be move towards roof side instead of floor.

D. When the lift falls freely, $a = -g$

$R = m(g - g) = W_{app} = 0$

(W_{app} = R = Reaction of supporting surface and $W_0 = mg$ = true weight)

- **Equilibrium of Concurrent Forces**

For more details, scan the code

Rigid body is the body in which the distance between the constituent particles remains constant under the action of external forces. When several force acts on a body and if the body is at rest or its centre of mass moves with uniform speed the body is said to be in equilibrium.

If the resultant force acting on a body is zero and if the body is at rest, then it is said to be in Static Equilibrium. Under same condition if the body moves with uniform speed then it is said to be in Dynamic Equilibrium.

- **Friction**

It is an opposing force that is generated or comes into play when one body slide, rolls or moves over the surface of other body. This is a force that is generated when two surfaces come in contact and opposes relative motion.