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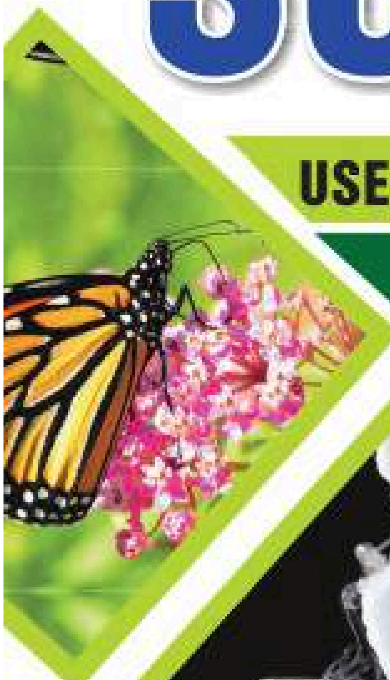

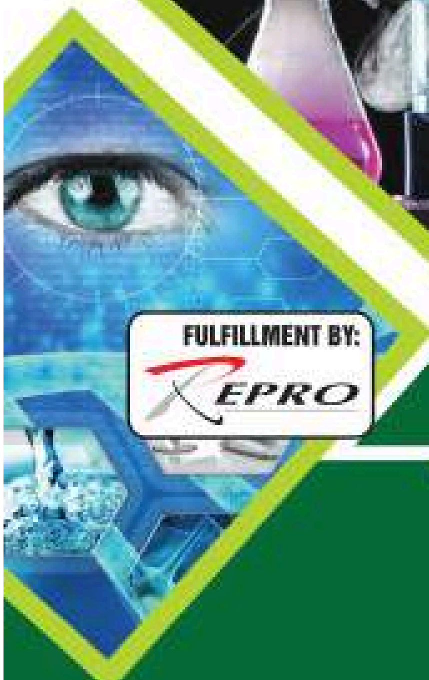

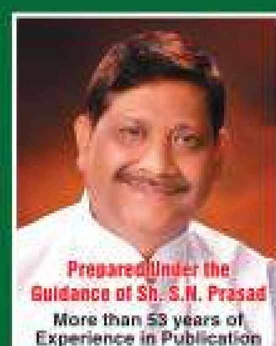

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• SSC CGL (Tier-I), CHSL (10 + 2) & Matric Level Exams • Railway Technical & Non Technical Exam • UPSC Prelim & other Exams • State Civil Services & other State level Exams and other Competitive & Academic level Exams

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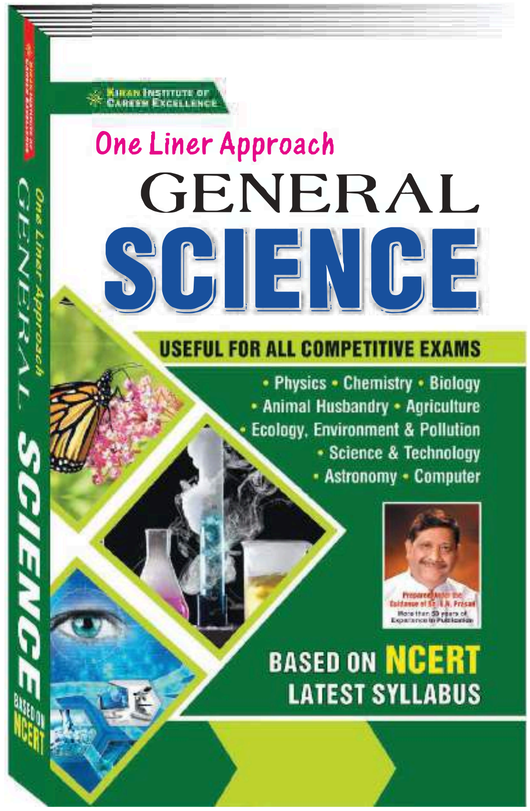

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To The Reader

It is indeed an enthusing experience to present a handy book **Kiran's One Liner Approach General Science** to our discerning readers. You are well abreast of the fact that questions based one General Science have a reasonable share in every competitive exam of today. More importantly its share is being enhanced gradually. One can't deny its importance even in Railway exams. A book that satiates the wide dimension of subject matter well suited to the needs of a wide variety of exams was eagerly felt by the community of true contenders. Our Team of learned authors also thought the same. This book has precisely been prepared after a sincere analysis of the questions of various competitive exams. The length of subject; standard of questions and their variety got a sincere attention. The book is reflection of modernity and essence of fundamentals. No doubt one liner approach gets its reflection in the presentation of this book. Believably , a student with a science background or without it will certainly extract advantage equally with smoothness.

It is well said, 'There is no sweet without sweat'. We , a firm believer of the above too, will assure you that with this edition in your hand you will definitely perspire less while making endeavour to achieve your desired goal i.e. cracking the examination in first attempt. Once you go through the edition attentively, you will not be knocking at the door of success but pushing it hard to open with a smile.

Certainly it will contribute immensely to make you fire on all the cylinders in pursuance of your delicately cherished goal.

The discernible reasons are:

- Very simple and lucid language used to express the fundamental and textual concepts.
- Wide variety of text covered and then compiled into one after analysis of question papers of more than 10 years from SSC to Railways, Banking, etc.
- Division of book into 5-Sections of Physical Sciences including Physics and Chemistry, Biological Sciences , Computers and never ceasing progress/inventions in the field of Science and Technology.
- Each of the 5-Sections divided into Sub-sections in the form of Units, well arranged in a sequential order from A to Z.
- Each Unit with well listed contents covered under its umbrella at the beginning engrossed in *Italics Font* to help you save time while

turning over the pages to look for a particular text.

- Each unit enriched and suspplemented with labeled Pictures, Tables, Flow Charts along with solved numerical problems wherever necessary realizing
- the value of picture/ diagram in proper comprehension of the text.
- the types of numerical based questions that had so far been asked in different spheres of examinations.
- Above all, the points of significance have been highlighted in red colour text, not to scare but draw attention, hence, minimizing any chance of overlooking the text.

With the above listed features and many more, the team of Co-authors wish to extend their gratitude to all the members of the **Kiran Institute of Career Excellence Pvt. Ltd.** , directly or indirectly involved in turning a dream into reality for students of diverse spheres , each with his own needs and requirements but the only goal to hit the bulls eye i.e. grab the 'Grand Success '.

In the end, the team also promises to look into suggestion deeply if any put forth by the reader for the betterment of this book and include the same in the forthcoming editions, rendering appreciation to improvement.

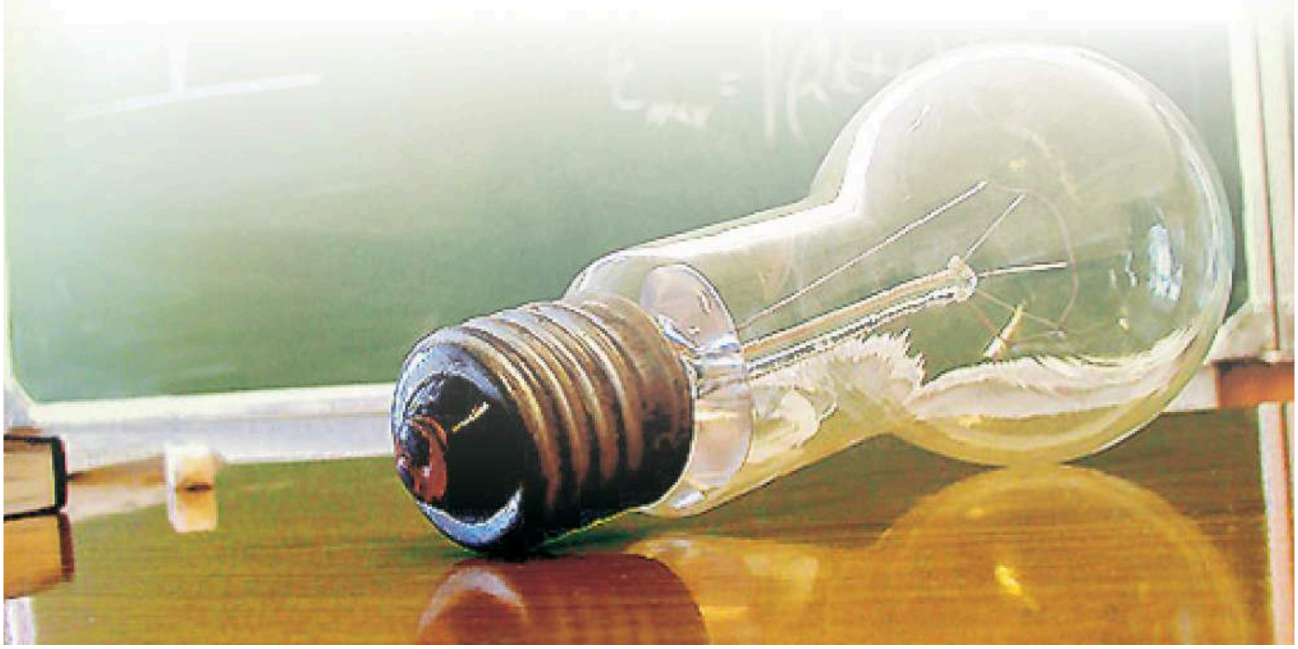
With Thanks.

Publisher

CONTENTS

PHYSICS **GSE-3-192**

1.	Physics and Different Branch	GSE-3
2.	Physical Quantities : S.I. And Derived Units	GSE-7
3.	Commonly Used Basic Units	GSE-11
4.	Dimensional Formulae of Physical Quantities	GSE-16
5.	Measurements and Errors in Physics	GSE-20
6.	Kinematics	GSE-25
7.	Newton's Law of Motion	GSE-31
8.	Circular Motion	GSE-39
9.	Work, Force and Energy	GSE-45
10.	Gravitation	GSE-56
11.	Elasticity	GSE-63
12.	Heat and Thermodynamics	GSE-76
13.	Simple Harmonic Motion	GSE-85
14.	Wave Motion and Sound	GSE-91
15.	Light and Its Properties	GSE-101
16.	Electrostatics	GSE-124
17.	Current Electricity	GSE-135
18.	Electrical Measurements and Used Devices	GSE-145
19.	Electromagnetism	GSE-154
20.	Electromagnetic Waves	GSE-169
21.	Nuclear Physics	GSE-177
22.	Semiconductors And Devices	GSE-187

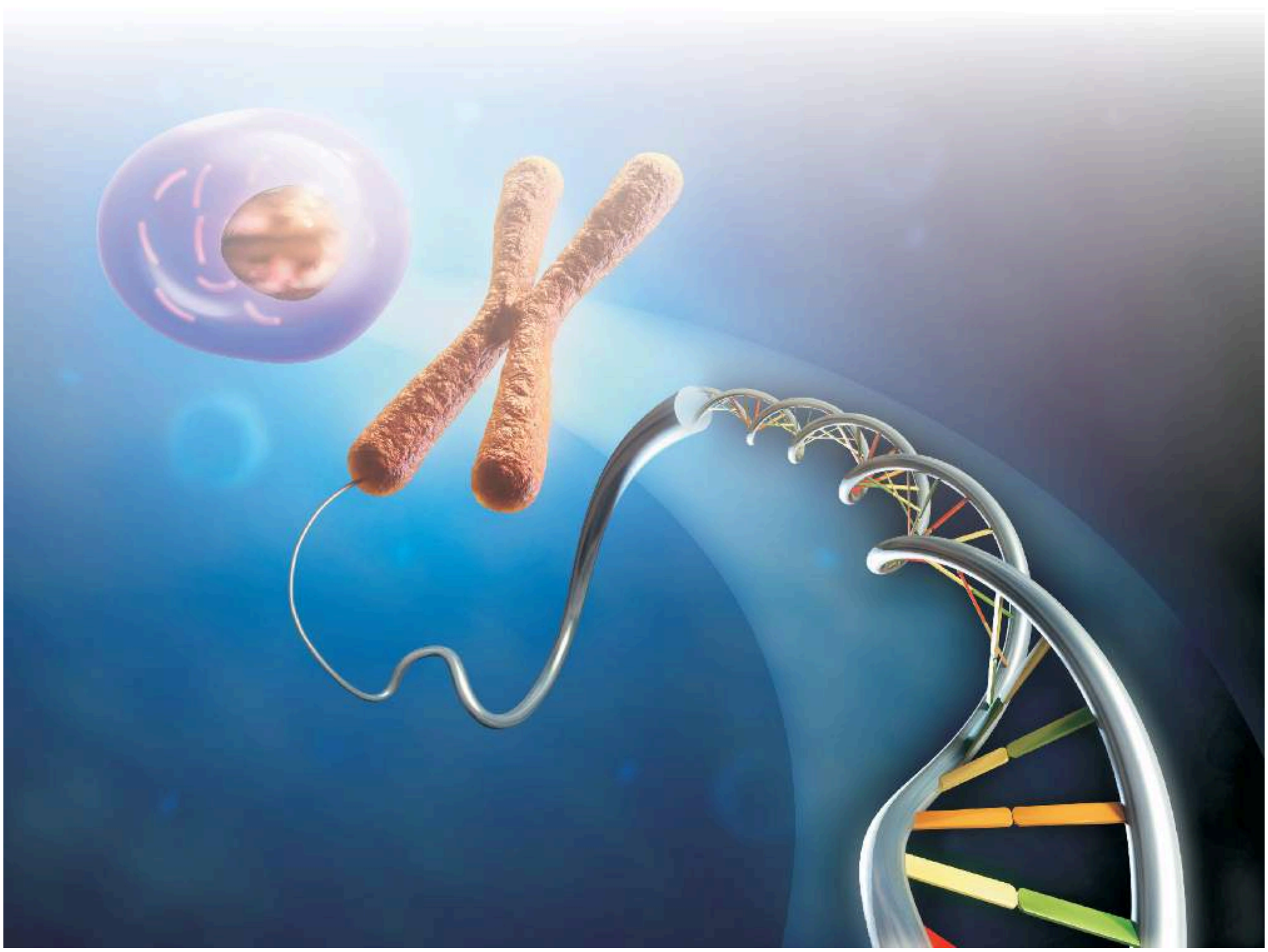


CHEMISTRY GSE-195-402

1. Basic Principles of Chemistry GSE-195
2. Structure of Atom GSE-205
3. Periodic Classification of Elements GSE-216
4. Chemical Bonding And Molecular Structure GSE-222
5. States & Properties of Matter : Solids, Liquids And Gases GSE-238
6. Thermodynamics GSE-251
7. Equilibrium GSE-266
8. Hydrogen and its Properties GSE-284
9. Alkali Metals and Their Properties GSE-288
10. Alkaline Earth Metals and Their Properties GSE-294
11. Carbon Family Elements And Their Properties GSE-298
12. Chalcogens, Members of Oxygen Family GSE-307
13. Pnictogens, Members of Nitrogen Family GSE-315
14. Halogens GSE-322
15. Transition Elements GSE-329
16. Metallurgy GSE-335
17. Solids GSE-343
18. Solutions GSE-350
19. Electrochemistry GSE-357
20. Chemical Kinetics GSE-363
21. Qualitative Analysis GSE-369
22. Organic Chemistry GSE-381

BIOLOGY GSE-405-416

1. Cytology GSE-405
2. Tissues Structure and Functions GSE-416
3. Classification Of Plants and Animals GSE-425
4. Plant Structure and Functions GSE-443
5. Plant Physiology GSE-452
6. Human Physiology GSE-468
7. Plant And Animal Reproduction GSE-506
8. Heredity and Variation GSE-520
9. Evolution, Inorganic and Organic Evolution GSE-531
10. Biotechnology principles and Applications GSE-542
11. Human Health, Diseases and Treatment GSE-546
12. Plant Pathology GSE-564
13. Micro-organisms : Friends To Mankind GSE-571
14. Environment and Ecology GSE-579
15. Pollution : Causes and Effects GSE-598
16. Agriculture & Animal Husbandry GSE-603



SCIENCE & TECHNOLOGY GSE-619-646

- Space Research in India GSE-619
- Types Of Satellites and Their Applications GSE-620
- Science And Technology in Defence sector GSE-627
- Science And Technology In Energy Sector GSE-634
- WiTricity GSE-640
- Digital India GSE-642
- Biotechnology in Medical Sciences GSE-643

COMPUTER KNOWLEDGE GSE-649-704

- Computer: an Introduction GSE-649
- Computer Terminology GSE-653
- Characteristics of Computer GSE-660
- Devices Acting as Both Input and Output Devices GSE-664
- Languages and Specification GSE-699
- Desktop GSE-676
- Computer Networking GSE-680
- Internet GSE-685
- Computer Virus GSE-691
- Hexadecimal Representation of Numbers GSE-695
- Payment Systems and Electronic Banking GSE-698

UNIT-I

PHYSICS

1. PHYSICS AND DIFFERENT BRANCH
2. PHYSICAL QUANTITIES : S.I. AND DERIVED UNITS
3. COMMONLY USED BASIC UNITS
4. DIMENSIONAL FORMULAE OF PHYSICAL QUANTITIES
5. MEASUREMENTS AND ERRORS IN PHYSICS
6. KINEMATICS
7. NEWTON’S LAW OF MOTION
8. CIRCULAR MOTION
9. WORK, FORCE AND ENERGY
10. GRAVITATION
11. ELASTICITY
12. HEAT AND THERMODYNAMICS
13. SIMPLE HARMONIC MOTION
14. WAVE MOTION AND SOUND
15. LIGHT AND ITS PROPERTIES
16. ELECTROSTATICS
17. CURRENT ELECTRICITY
18. ELECTRICAL MEASUREMENTS AND USED DEVICES
19. ELECTROMAGNETISM
20. ELECTROMAGNETIC WAVES
21. NUCLEAR PHYSICS
22. SEMICONDUCTORS AND DEVICES

Chapter 1

PHYSICS AND DIFFERENT BRANCHES

Physics, different branches of physics and their significance in understanding natural phenomena and nature as a whole.

- **Physics :** The word 'physics' comes from the Greek word *phusike* meaning 'knowledge of Nature,' and in general, the field aims to analyze and understand the natural phenomena of the Universe.
- It involves the performing of experiments and their successive repetitions to formulate laws and explain how the universe works. These laws (such as gravity and Newton's laws of motion) are so thoroughly tested that they are accepted as 'truths,' and they can be used to help us predict how other things will behave.
- It is considered to be the most fundamental science. It provides a basis for all other sciences, without physics, one cann't have proper understanding of biology, chemistry or anything else.

BRANCHES OF PHYSICS

- **Classical Physics :** It's a branch of physics that mainly deals with the laws of motion and gravitation of Sir Isaac Newton and James Clark Maxwell's Kinetic theory and thermodynamics. Classical physics is mainly concerned with matter and energy. In classical physics, energy and matter are considered as separate entities.

  Acoustics, Optics, Classical mechanics and Electromagnetics are the traditional branches of classical physics. Moreover, any theory of physics, which is considered null and void in the modern physics, automatically falls under the realm of classical physics.
- **Modern Physics** : It is the branch of physics mainly concerned with the 'Theory of relativity' and 'Quantum mechanics'. Albert Einstein and Max Plank were the pioneers of modern physics. They were the first scientists who laid down the foundations of modern physics by introducing the theory of relativity and quantum mechanics respectively. In modern physics, energy and matter are not considered as separate entities, rather, they are considered as different forms of each other.
- **Nuclear Physics :** It is the branch of physics which deals with constituents, structure, behaviour and interactions of nucleons and atomic nucleius. It Is usually described as "the branch of physics in which the structure, forces and behaviour of the atomic nucleus

are studied". In the modern age, it is used in power generation, nuclear weapons, medicines such as radio therapy, etc.

- **Atomic Physics :** It is the branch of physics which deals with the composition of an atom apart from the nucleus. It is mainly concerned with the arrangement and behaviour of electrons in the shells around the nucleus.
- **Geophysics :** It is the branch of physics which deals with the study of the earth. It is mainly concerned with the shape, structure and composition of the earth. It also studies the gravitational force, magnetic fields, earthquakes, magmas, eruption of volcanoes, etc. their causes and effects.
- **Biophysics :** It is described as the interdisciplinary study of biological phenomena and problems, using the principles and techniques of physics. Biophysics studies only the biological problems and structure of molecules in living organisms in light of the techniques derived from physics. One of the best achievements of biophysics is the structure of DNA (Deoxy-ribonucleic Acid) discovered by, X-ray Crystallography.
- **Mechanics :** It can be classical or modern.
- **Classical mechanics** deals with the laws of motion of physical objects and the forces that cause the motion,
- **Quantum mechanics** deals with the behaviour of the smallest particles, *i.e.* electrons, neutrons and protons. According to Encarta dictionary, "Quantum mechanics is the study evolved in an effort to explain the behaviour of atoms and subatomic particles, which do not obey the laws of classical Newtonian mechanics."
- **Statistical Mechanics** includes the discipline that attempts to relate the properties of macroscopic systems to their atomic and molecular constituents. It especially involves the distribution of energy among them with maximum usage of probability theory.
- **Theoretical physics** includes attempts to understand the world by making a model of reality, used for rationalizing, explaining and predicting physical phenomena through "physical theory".
- **Acoustics :** The word *acoustics* has been derived from a Greek word *akouen*, meaning *to hear*. Hence, acoustics is defined as a branch of physics, which studies how sound is produced, transmitted, received and controlled. It also deals with the effects of sounds in various mediums, *i.e.* gases, liquids and solids.
- **Optics :** It is the branch of physics, which deals with the propagation, behaviour and properties of light, a part of the electromagnetic spectrum that extends from X-rays to microwaves and includes the radiant energy that produces the sensation of vision.

- **Thermodynamics :** It is the branch of physics, which deals with the study of heat and its relation with energy and work. According to National Aeronautics and Space Administration (NASA), USA, "Thermodynamics is the study of the effects of work, heat and energy on a system. It is only concerned with large-scale observations and their analysis".
- **Astrophysics :** The word *astrophysics* is a combination of two words-*astro* which means *star*, while the word *phisis* means *Nature.* Thus, astrophysics is defined as a branch of astronomy concerned with the study of the Universe, *i.e.* stars, galaxies and planets using the laws of physics.
- **Cosmology :** Cosmology, astrophysics and astronomy are the similar fields of study, however, cosmologists wonder particularly about the origins and the future of the universe. It deals with the universe as a whole phenomena such as the Big Bang, dark matter, black holes, wormholes, expansion of the known universe and a potential multiverse, these are the dominant areas of interest in cosmology.
- **Cryophysics (Cryogenics) :** It is also called as low temperature physics and generally pertains to temperatures below -150°C or -238°F (123 K) and how matter behaves to cold conditions. Cryogenicists tend to avoid using the standard temperature formats of Celsius and Fahrenheit but instead use Kelvin or Rankine scale which are considered to be on absolute scale. Cryobiology, cryosurgery, cryonics, cryogenics and cryoelectronics are the subspecialties of cryophysics.
- **Crystallography :** The study of crystallography explores atoms in their solid state of matter with particular focus in molecular and atomic structure. Previously, the study of the geometry of crystals in relation to their axes was necessary to shed light within this field. However, in recent years the development of x-ray diffraction allows a much greater insight into the axis and symmetry of crystals.
- **Electromagnetism :** There are four fundamental forces of nature which determine the interactions between matter and energy which include strong interaction, weak interaction, gravitational force and electromagnetic force. The scientists who specialize in electromagnetism investigate phenomena such as electrically charged particles, magnetic attraction and electromagnetic fields.
- **Electronics :** Electrical circuits, diodes, transistors, integrated circuits and vacuum tubes are all areas of interest for scientists fascinated by electronics. The flow of electrons along with a predesignated pathway to process information and generate signals in telecommunication has helped advance civilization, culture and knowledge of humanity in the modern era.

- **Fluid Dynamics :** The mechanics of motion in fluids in both liquid and gaseous states is investigated in the studies of fluid dynamics. The sub-disciplines of hydrodynamics, relating to liquid in particular, and aerodynamics, its gas equivalent, are also considered to be natural sciences which help understand the interactions between energy and matter on the earth and throughout space.
- **Nanotechnology :** It refers to the ability to manipulate the properties of matter at the molecular, atomic and subatomic levels. The term nanoparticle is used to classify particle types that are between the size scale of 1 – 100 nanometre (1×10^{-9}m). Quantum mechanics theories play an integral role in the investigation of nanotechnology by providing insight into how atomic and subatomic particles interact with each other.
- **Particle Physics :** In recent times, particle physicists have made great strides in their research with the development of advanced technologies such as the large hadron collider developed by CERN. The ability to analyze detailed information by colliding particles together at the high rates of speed has led to the discovery of new types of particles previously theorized by physicists around the world. Research into particle physics has the potential to help scientists better understand the origins of our universe and the complexity of factors that govern the world we know.
- **Plasma Physics :** Plasma is the fourth state of matter which is characterized by heating gases to the point at which ionization occurs altering the number of electrons in the atoms (releasing electrons from the nucleus). Although we are typically taught that only 3 states of matter exist (solids, liquids and gases) yet ironically, plasma is the fourth and most common state of matter throughout the universe which is most commonly visible in the form of stars.
- **Meteorology :** It deals with the understanding of the dynamics of the Earth's atmosphere. Gravity, the Earth's spin, polarity, wind and temperature. They all play a crucial role in the investigation of physical and chemical phenomena in the atmosphere.

The above shows that of physics is inseparable from the study of nature in any form of rows the study of the Universe to a chemical reaction occuring in test tube or global climatic changes from global warming, melting of polar ice, acid rain and depletion of ozone layer. It's all because in physics, one studies both about matter in its varied forms and energy.

❑❑❑

Chapter 2

PHYSICAL QUANTITIES : S.I. AND DERIVED UNITS

Fundamental units, Seven basic S.I. units, Derived units used in different scopes of physics : Electricity and magnetism, Mass and related quantities, Length and dimensional quantities, Time, Amount of substance, Temperature and thermal qualities, Photometry, Radioactivity, Radiometric sources and Fibre optics.

- **Fundamental unit of measurement :** It is a defined unit that cannot be described as a function of any other unit.
- The *International System of Units (SI)* defines seven fundamental units of measurement. They can be applied to the various areas of studying physical science.

SI base units :

- The International System of Units (SI) defined seven basic units of measurment from which all other SI units can be derived.
- These SI base units or commonly called metric units, are:

metre (m)	The metre is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.
kilogram (kg)	The kilogram is the mass of the platinum-iridium prototype which was approved by the *Conference Generale des Poids et Mesures*, held in Paris in 1889, and kept by the Bureau International des Poids et Mesures at Paris in France.
second (s)	The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom.
ampere (A)	The ampere is the intensity of a constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2 x 10^{-7} newton per metre of length.
kelvin (K)	The kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

candela (cd)	The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.
mole (mol)	The mole is the amount of the substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.

Derived units :

- There are numerous derived units that are complementary to the base units. They may have special names (e.g. hertz, pascal, becquerel, etc.) but can always be expressed in terms of the base units. However, there are also some dimensionless derived units.
- These units are linked together to form a consistent system and a coherent system.
- Lastly, each quantity may need to cover a vast range of values. To avoid the need for multiplying factors or values with a large number of zeros, prefixes are used. The prefixes cover a range extending from 10^{24} to 10^{-24} times the units.

Mass and Related Quantities	
The mass	**kilogram (kg)**
density : ρ	$kg.m^{-3}$
volume : V	m^3
force : F	newton (N) (Kg $m.s^{-2}$)
torque : τ	N.m
pressure : p	pascal (Pa) / Nm^{-2}
dynamic viscosity : η	Pa.s
kinematic viscosity : υ	$m^2.s^{-1}$
acoustic pressure : p	pascal (Pa)
dynamic volume : v	m^3
mass flow-rate : qm	$kg.s^{-1}$
volume flow-rate : qv	$m^3.s^{-1}$
air flow-rate : V	$m.s^{-1}$

Length and Dimensional Quantities	
wavelength : λ	metre (m)
length of material standards : L	metre (m)
plane angle : α	radian (rad)
form measurement :	metre (m)

Electricity and Magnetism		
Current intensity		**The ampere (A)**
potential difference, V	:	volt (V = W/A)
electrical capacitance, C	:	farad (F = C/V)
electrical resistance, R	:	ohm (Ω = V/A)
inductance, L	:	henri (H = Wb/A)
electric conductance, G	:	siemens (S = A/V)
quantity of electricity, Q	:	coulomb (C = A.s)
power, P	:	watt (W = J/s)
energy, W	:	joule (J = N.m)
magnetic induction, B	:	tesla (T = Wb/m^2)
electric field, E	:	volt per metre (V/m)
magnetic field strength, H	:	ampère per metre (A/m)
attenuation, η	:	decibel (dB)

Radiometry – Photometry

Photometry	
➢ **Luminous intensity**	**candela (cd) (m)**
luminous flux : ϕ	lumen (lm)
illuminance : E	lux (l*x*)
luminance : L	$cd.m^{-2}$
➢ **Radiometry of sources**	
energy flow : ϕ_e	watt (W)
radiance : L_e	$W.m^{-2}.sr^{-1}$
irradiance : E_e	$W.m^{-2}$
laser source power : P	watt (W)
laser source energy : Q	joule (J)
➢ **Fibre optics :**	
energy flow : P	watt (W)
wavelength : λ	metre (m)
propagation time : t	second (s)
fibre length	metre (m)
linear attenuation factor :	$dB.m^{-1}$
reflectance	dB
detector (or fibre) pass band	hertz (Hz) (or $Hz.m^{-1}$)

➢ **Temperature and thermal quantities :**

➢ **Meterology of thermal quantities**		
thermal conductivity : $\lambda = \alpha.\rho.C_p$	(ρ = density)	$W.m^{-1}.K^{-1}$
thermal diffusivity : $\alpha = \lambda/\rho.C_p$	(ρ = density)	$m^2.s^{-1}$
specific heat capacity : $C_p = (\partial H/\partial T)_p$	(H = enthalpy)	$J.kg^{-1}.K^{-1}$
spectral directional emissivity : ε_λ	dimensionless ratio	
normal spectral emissivity : ε_λ	dimensionless ratio	
Total hemispherical emissivity : ε_λ	dimensionless ratio	

➢ **Hygrometry**		
temperature	dew point : T_d	degree Celsius (°C)
	frost point : T_f	degree Celsius (°C)
Relative humidity	with respect to water : U_w	percentage (%)
	with respect to ice : U_i	percentage (%)

Amount of Substance - Chemical Analysis

➢ The two main SI units used in the measurement of amount of substance contained in a material are the mole and the kilogram. From the definition of the mole (amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12. There is a ratio between them; consequently, they are both used. More precisely, the measurement of an amount of substance is expressed either in mole or in kilogram, or as concentrations (ratio of two quantities: mass / mass, mole / mole, mole /mass, etc.).

Ionizing Radiation	
Radioactivity	
activity : A becquerel	Bq
activity per mass unit : A_m	$Bq.kg^{-1}$
activity per volume unit : A_v	$Bq.m^{-3}$
emission rate :	s^{-1}
emission rate per solid angle unit :	$s^{-1}.sr^{-1}$
neutron fluence rate :	$m^{-2}.s^{-1}$
Time And Frequency	
Time : the second	(s)
frequency : υ	hertz (Hz)
time interval :	second (s)
phase fluctuation spectral density :	(dB/Hz)
rotation speed	(tr/min)
Dimensionless Derived Units	
Plane angle	radian (rad) = $m \cdot m^{-1}$
Solid steradian angle	stéradian (sr) = $m^2 m^{-2}$

□□□

Chapter 3

Commonly Used Basic Units

Commonly used units in measurement of length, area, volume, pressure, temperature and mass of a substance.

Different Units Used In Measurement Of Length

SI unit of length : The base unit in the International System of Units (SI) also called MKS system is the metre, defined as "the length of the path travelled by light in vacuum during a time interval of 1/299,792,458 of a second. It is approximately equal to 1.0936 yards. Other units are derived from the metre by adding prefixes from the table below:

Standard prefixes for the SI units of measure

	Prefix name		deca	hecto	kilo	mega	giga	tera	peta	exa	zetta	yotta
	Prefix symbol		da	h	k	M	G	T	P	E	Z	Y
Multi-ples	Factor	10^0	10^1	10^2	10^3	10^6	10^9	10^{12}	10^{15}	10^{18}	10^{21}	10^{24}
	Prefix name		deci	centi	milli	micro	nano	pico	femto	atto	zepto	yocto
	Prefix symbol		d	c	m	µ	n	p	f	a	z	y
Fract-ions	Factor	10^0	10^{-1}	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}	10^{-18}	10^{-21}	10^{-24}

Non-SI : In the Centimetre–Gram–Second (CGS) system of units, the basic unit of length is the centimetre, or 1/100 of a metre. Other non-SI units are derived from the decimal multiples of the metre.

Name	Symbol	SI value
fermi	fm	1 femtometre
angstrom	Å	100 picometres
micron	µm	1 micrometre
Norwegian/Swedish mil or myriametre		10,000 metres
x unit	xu	0.1 picometre

- The basic unit of length in the Imperial (U.K.) and (U.S.) customary systems is the yard, defined as exactly 0.9144 m by an international treaty in 1959.
- Common Imperial units and U.S. customary units of length include:
  thou or mil = 1/1000 of an inch
  line = 1/12 of an inch
  1 inch = 2.54 cm
  1foot = 12 inches, 0.3048 m
  1 yard = 3 ft, 0.9144 m
  1 (terrestrial) mile = 5280 ft, 1609.344 m
  1 nautical mile = 1852 m

PHYSICS

1 fathom(To measure the depth of an ocean) = 2 yards or 1.8288 m
1 (land) league = 3 miles

Marine length :

- fathom (for depth, only in non-metric countries) =2 yards
  Nautical mile (one minute of arc of latitude) = 1852 m
- Astronomy : Astronomical measure uses:
- Earth radius $R_{\oplus} \approx$ 6,371 km
- Lunar distance *LD* ≈ 384402 km, average distance between the center of the Earth and the centre of the Moon.
- Astronomical unit : AU, or defined as 149597870700 m. Approximately, it is the distance between the Earth and the Sun.
- Light-year (ly) : ≈ 9460730472580.8 km, the distance that light travels in a vacuum in one Julian year.
- Parsec (pc) : ≈ 30856775814671.9 km or about 3.26156 ly
- Hubble length : 14.4 billion light-years or 4.55 giga parsecs

Informal units of interest :

- Football field (generally around 110 metres, depending on the country)
- Thickness of a human hair (around 80 micrometres)
- A beard-second is a unit created as a teaching concept. It is the distance that a beard grows in a second (about 5 nanometres)
- Horse racing and other equestrian activities:
  furlong :≈ 0.125 miles (201 m)
  horse length :≈ 8 feet (2.4 m)

Different Units Used In Measurement Of Area

- There are many different units of area, such as 'square centimetres', 'hectares', 'square feet' and 'acres'.To change the units of a quantity, it is multiplied or divided by some constant value, called a conversion factor.

Unit name	Symbol	Metric equivalent	Imperial equivalent
Square centimetre	cm^2	$1cm^2$= 100 mm^2	$1cm^2$= 0.1550 in^2
Square metre	m^2	$1m^2$= 10,000 cm^2	$1m^2$= 1.1960 yd^2
Hectare	Ha	1ha= 10,000 m^2	1ha= 2.4711 acres
Squre kilometre	km^2	$1km^2$= 100 ha	$1km^2$= 0.3861$mile^2$
Square inch	In^2		$1in^2$ = 6.4516 cm^2
Square foot	ft^2	$1ft^2$= 144 in^2	$1ft^2$= 0.929 m^2
Square yard	yd^2	$1yd^2$ = $9ft^2$	1 yd^2 =0.8361 m^2
Acre	acre	1 acre= 4840 yd^2	1 acre = 4046.9 m^2
Square mile	$mile^2$	1 $mile^2$ =640 acres	$1mile^2$ = 2.59 km^2

Different Units Used In Measurement Of Volume

- In the International System of Units (SI), the standard unit of volume is the cubic metre (m^3). The metric system also includes the litre (L) as a unit of volume, where one litre is the volume of a 10-centimetre cube ($10cm^3$). Thus,

1 litre = (10 cm)^3 = 1000 cubic centimetres = 0.001 cubic metre
1 cubic metre = 1000 litres
1 millilitre = 0.001 litre = 1 cubic centimetre
1 centilitre = 0.01 litre
1 decilitre = 0.1 litre
1 kilolitre = 1000 litres
One teaspoon = 5 ml

➢ Various other traditional units of volume are also in use, including the cubic inch, the cubic foot, the cubic mile, the teaspoon, the tablespoon, the fluid ounce, the fluid dram, the gill, the pint, the quart, the gallon, the minim, the barrel, the cord, the peck, the bushel, and the hogshead.

Approximate conversion to millilitres:			
Unit	Imperial	U.S. liquid	U.S. dry
Gill	142 mL	118 mL	138 mL
Pint	568 mL	473 mL	551 mL
Quart	1137 mL	946 mL	1101 mL
Gallon	4556 mL	3785 mL	4405 mL

Different Units Used In Measrement Of Temperature

➢ SI unit of measuring temperature is Kelvin but other units too are used for expressing temperature as listed below:

Conversion method:

K = °C + 273.15°
C = K – 273.15
$°C = (°F - 32) \times \frac{5}{9}$
$°F = \frac{9}{5}(°C + 32)$
1 °R (Rankine) = 1 °F = ^{5}D × °C = $^{°}$D × K
1 °Rø (Remer) = ^{40}D $_{21}$ °C = ^{24}D $_7$ °F
3.08 (12 °N(Newton) = 37 °C) and 3.03 (33 °N = 100 °C)

	Kelvin	Celsius	Fahrenheit	Rankine
Absolute zero (by definition)	0 K	–273.15°C	–459.67 °F	0 °R
Freezing point of brine	255.37 K	–17.78 °C	0 °F	459.67 °R
Freezing point of pure water	273.15 K	0 °C	32 °F	491.67 °R
Triple point of water (by definition)	273.16 K	0.01 °C	32.018 °F	491.688 °R
Boiling point of pure water (1 atm)	373.1339 K	99.9839 °C	211.97102 °F	671.64102 °R

Common Temperature Reference Points			
	Celsius (°C)	**Kelvin (K)**	**Fahrenheit (°F)**
Surface of the Sun	5600	5900	10100
Boiling Point of Water	100	373	212
Body Temperature	37	310.2	98.6
Sweltering Day	40	313	104
Hot Day	30	303	86
Room Temperature	20	293	68
Cold Day	10	283	50
Freezing Point of Water	0	273	32

Different Units Used In Measurement Of Pressure

- The SI unit for pressure is the pascal (Pa), equal to one newton per square metre Nm^{-2} or $Kg.m^{-1}.s^{-2}$

Pressure units					
	pascal (Pa)	**bar (bar)**	**standard atmosphere (Atm)**	**torr (Torr)**	**pound per square inch (psi)**
1 Pa	a” 1 N/m^2	10^{-5}	9.8692×10^{-6}	7.5006×10^{-3}	145.04×10^{-6}
1 bar	10^5	a” 10^5 Pa	0.98692	750.06	14.5037744
1 at	0.980665×10^5	0.980665	0.96784	735.56	14.223
1 atm	1.01325×10^5	1.01325	a” p_0	760	14.696
1 Torr	133.322	1.3332×10^{-3}	1.3158×10^{-3}	H” 1 mm_{Hg}	19.337×10^{-3}
1 psi	6.895×10^3	68.948×10^{-3}	68.046×10^{-3}	51.715	a” 1 lbf/in^2

Different Units Used In Measurement of Time

- 1 second = A number of oscillations in a Cesium-133 or Iodine-127 atom.
- 1 minute = 60 seconds
- 1 hour = 60 minutes = 3,600 seconds
- 1 day = 24 hours = 1,440 minutes = 86,400 seconds
- 1 year = 365.25 days = 8,766 hours = 525,960 minutes = 31,557,600 seconds
- 1 leap year = 366.25 days (once every four years)
- 1 decade = 10 years
- 1 century = 10 decades = 100 years
- 1 millennium = 10 centuries = 100 decades = 1,000 years

Time in seconds

- decisecond = 1/10 second (10^{-1})
- centisecond = 1/100 second (10^{-2})
- millisecond = 1/1,000 second (10^{-3})
- microsecond = 1/1,000,000 second (10^{-6})
- nanosecond = 10^{-9} second
- picosecond = 10^{-12} second

- femtosecond = 10^{-15} second
- attosecond = 10^{-18} second
- zeptosecond = 10^{-21} second
- yoctosecond = 10^{-24} second
- decasecond = 10 seconds
- shectosecond = 100 seconds
- kilosecond = 1,000 seconds (16.7 minutes)
- megasecond = 1,000,000 seconds (11.6 days)
- gigasecond = 10^{9} seconds (31.7 years)
- terasecond = 10^{12} seconds (31,700 years)
- petasecond = 1^{15} seconds (31.7 million years)
- exasecond = 10^{18} seconds (31.7 billion years)
- zettasecond = 10^{21} seconds (31.7 trillion years)
- yottasecond = 10^{24} seconds (31.7quadrillion years)

Different Units Used In Measurement Of Mass

- The kilogram is the only standard unit to include an SI prefix (*kilo*–) as part of its name. The *gram* (10^{-3} kg) is an SI derived unit of mass. However, the *names* of all SI mass units are based on *gram*, rather than on *kilogram*, thus 10^{3} kg is a *mega gram*.

Name	SI symbol	Value	Name	SI symbol	Value
decigram	dg	10^{-1} g	Decigram	dag	10^{1} g
centigram	cg	10^{-2} g	hectogram	hg	10^{2} g
milligram	mg	10^{-3}	kilogram	kg	10^{3} g
microgram	mg	10^{-8}	megagram (tonne)	Mg	10^{6} g
nanogram	ng	10^{-9} g	gigagram	Gg	10^{9} g
pictogram	pg	10^{-3} g	teragram	Tg	10^{3} g
femtogram	fg	10^{-15} g	petagram	Pg	10^{15} g
attogram	ag	10^{-18} g	exagram	Eg	10^{18} g
zeptogram	zg	10^{-21} g	zettagram	Zg	10^{21} g
yoctogram	yg	10^{-24} g	yottogram	Yg	10^{24} g

- 1 tonne (t) (or "metric ton") = 1000 kg.
- Atomic mass unit (u) = 1/12 of the mass of a carbon-12 atom (1.66×10^{-27} kg)

The atomic mass unit is convenient for expressing the masses of atoms and molecules

- 1 slug (sl) = 14.6 kg
- 1 pound (lb) is a unit of both mass and force = 0.45 kg or 4.5 N
- Planck mass (m_p) is the maximum mass of point particle.

$= 2.18\times10^{-8}$ kg

Units used in particle physics

- Solar ($M_\odot$) (mass of the Sun) ≈ 1.99×10^{30} kg.
- Compton wavelength (1 cm^{-1}) ≈ 3.52×10^{-41} kg.
- Schwarzschild radius (1 cm) ≈ 6.73×10^{24} kg.

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PHYSICS

Chapter 4

Dimensional Formulae of Physical Quantities

Dimensional formula, computation of some common physical quantities, Greek symbols, some physical quantities without any dimensional formula, advantages and limitations in the writing of dimensional formula.

- **Dimensional formula :** It is the term that tells about the power with which a fundamental quantity is contained in a physical quantity.
- **Dimensional equation:** It is obtained when a physical quantity is equated with its dimensional formula.
  In general, $[X] = [M^a L^b T^c]$
- RHS represents dimensional formula of physical quantity X, whose dimensions in mass, length and time are a, b and c respectively.
- When velocity is defined using the fundamental units of mass, length and time, we have

$$\text{Velocity} = \frac{\text{Distance}}{\text{Time}} = LT^{-1} = M^0 LT^{-1}$$

  when there is no mass, $M^0 = 1$ (algebraic theory of indices).
  This is the dimensional formula for velocity and we can draw the following inference :
- Unit of velocity depends on the unit of length and time and is independent of mass.
- E.g., formula for density is ML^{-3}
- Formula for force is MLT^{-2}.

Dimensional Formulae Of Important Physical Quantities

- The dimensional formula of a physical quantity can be obtained by defining its relation with other physical quantities and then expressing these quantities in terms of mass [M], length [L] and time [T].
- **The dimensional formulae of some of the physical quantities are given below.**

Physical quantity	Relation with other quantities	Dimensional formula
Area	Length × breadth	$L \times L = L^2 = [M^0L^2T^0]$
Volume	Length × breadth × height	$L \times L \times L = L^3 = [M^0L^3T^0]$
Density	$\frac{\text{Mass}}{\text{Volume}}$	$\frac{M}{L^3} = [ML^{-3}T^0]$

DIMENSIONAL FORMULAE OF PHYSICAL QUANTITIES

Physical quantity	Relation with other quantities	Dimensional formula
Speed or velocity	$\frac{\text{Distance}}{\text{Time}}$ or $\frac{\text{Displacement}}{\text{Time}}$	$\frac{L}{T} = [M^0LT^{-1}]$
Acceleration	$\frac{\text{Velocity}}{\text{Time}}$	$\frac{LT^{-1}}{T} = [M^0LT^{-2}]$
Momentum	Mass × velocity	$M \times LT^{-1} = [M LT^{-1}]$
Force	Mass × acceleration	$M \times LT^{-2} = [M LT^{-2}]$
Pressure	$\frac{\text{Force}}{\text{Area}}$	$\frac{MLT^{-2}}{L^2} = [ML^{-1}T^{-1}]$
Work, Energy (K.E/ P.E. mechanical, heat, light, etc.)	Force × distance	$MLT^{-2} \times L = [ML^2T^{-2}]$
Power	$\frac{\text{Work}}{\text{Time}}$	$\frac{ML^2T^{-2}}{T} = ML^2T^{-3}$
Moment of force	Force × perpendicular	$MLT^{-2} \times L = ML^2T^{-2}$
Gravitational constant	$\frac{\text{Force} \times (\text{Distance})^2}{\text{Mass} \times \text{mass}}$	$\frac{MLT^{-2} \times L^2}{M \times M} = [M^{-1}L^3T^{-2}]$
Impulse	Force × Time	$MLT^{-2} \times T = [MLT^{-1}]$
Stress	$\frac{\text{Force}}{\text{Area}}$	$\frac{MLT^{-2}}{L^2} = [ML^{-1}\ T^{-2}]$
Strain	$\frac{\text{Change in dimension}}{\text{Original dimension}}$	Dimensionless
Coefficient of elasticity	$\frac{\text{Stress}}{\text{Strain}}$	$\frac{ML^{-1}T^{-2}}{\text{Dimensionless}}$ $= ML^{-1}T^{-2}$
Surface tension	$\frac{\text{Force}}{\text{Length}}$	$\frac{MLT^{-2}}{L} = [ML^{o}\ T^{-2}]$
Surface energy	$\frac{\text{Energy}}{\text{Area}}$	$\frac{ML^{-1}T^{-2}}{L^2}\ [ML^{o}\ T^{-2}]$
Velocity gradient	$\frac{\text{Velocity}}{\text{Distance}}$	$\frac{LT^{-1}}{L}\ [M^{\circ}L^{\circ}T^{-1}]$
Coefficient of kinetic pressure	$\frac{\text{Force}}{\text{Area} \times \text{Velocity gradient}}$	$\frac{MLT^{-2}}{L^2 \times T^{-1}} = [ML^{-1}\ T^{-1}]$

Physical quantity	Relation with other quantities	Dimensional formula
Radius of gyration	distance	$[M^0L\,T^0]$
Moment of inertia	Mass × (radius of gyration)^2	$M \times L^2 = [ML^2T^0]$
Angle	$\frac{\text{Arc}}{\text{Radius}}$	Dimensionless
Angular velocity	$\frac{\text{Angle}}{\text{Time}}$	$\frac{\text{Dimensionless}}{T}$ $[M^\circ L^\circ T^{-1}]$
Angular momentum	$\frac{\text{Angular velocity}}{\text{Time}}$	$\frac{M^\circ L^\circ T^{-1}}{T} = [M^\circ L^\circ T^{-1}]$
Angular momentum	Moment of inertia × angular velocity	$\frac{ML^2}{M^\circ L^\circ T^{-1}} = [ML^2T^{-1}]$
Frequency	$\frac{1}{\text{Time period}}$	$\frac{1}{T} = [M^\circ L^\circ T^{-1}]$

Dimensional formulae of important physical constants :

Universal gravitational constant:

$$F = \frac{Gm_1m_2}{r^2} = [MLT^{-2}] = \frac{G.M.^2}{L^2} = [M^{-1}L^3T^{-2}] = Nm^2kg^{-2} = [M^{-1}\,L^3\,T^{-2}]$$

Planck's constant : $\frac{(ML^0T^{-2})}{T^{-1}}$ = J.s. = $[M^\circ L^2\,T^{-1}]$

Reynold's number $(N_R) = [M^0LT^{-1}]$

Hubble's constant : $\frac{(LT^{-1})}{L} = [M^0L^0\,T^{-1}]$

Boltzmann's constant : R/N, where N is Avogadro's number
= (JK^{-1}) = $[M^1L^2T^{-2}K^{-1}]$

Gas constant: $\frac{(ML^{-1}T^{-2})L^3}{k}$ = (JK^{-1}) = $[M^{1}L^2\,T^{-1}K]$

Wein's constant : (mK) = $[M^0L^1T^0K^1]$

Stefan's constant : $(Wm^{-2}K^{-4})$ = $[M^1L^0T^{-3}K^{-4}$

Faraday's constant: 1/mol x AT = (c) = $[M^0L^oT^1A^1mol^{-1}]$

➢ **Physical quantities with no units and dimensions:** Some of the physical quantities which are mostly the ratio have neither units nor any dimension. These are

— Specific gravity	— Strain
— Avogadro's number	— Refractive index
— All trigonometric ratios	— Efficiency
— Dielectric constant	— Relative luminosity

PHYSICS

Symbols and their usual meanings :

- The scientific group in Greece used the following symbols:

Theta - θ	Alpha - α	Beta - β
Gamma - γ	Delta - δ or Δ	Mu - μ
Lambda - λ	Omega - Ω / ω	Pi - π
Phi - ϕ	epsilone - $\in$	Psi - Ψ
Roh- ρ	Eta - η	Sigma - σ
Tau - τ	Kappa - κ	Chi - χ

Advantages and limitations in the writing of dimensional formulae:

- A dimensional formula is useful for the following applications.
  1. To check the correctness of the given equation. This use is based on the principle of homogeneity, *i.e.* only quantities of, the same dimensions can be added, subtracted and equated. Hence, in a physical equation, every term should have the same dimensions.
  2. To convert one system of units into another system of units, e.g., the numerical value of 10 joules in a new system of units in which the unit of mass is 10gm, unit of length 10cm and unit of time 10s can be determined using the concept that $n_1u_1 = n_2u_2$ where n_1, n_2 are the numerical values of a physical quantity and u_1,u_2 are the different units for the same physical quantity.
  3. To derive the equations showing the relation between different physical quantities.

Limitations of dimensional system :

1. Dimensionless quantities cannot be determined by this method. Constant of proportionality cannot be determined by this method. They can be found either by experiment or by theory.
2. This method is not applicable to trigonometric, logarthmic and exponential functions.
3. In case of physical quantities which are dependent upon more than three physical quantities, this method is difficult.
4. In some cases, the constant of proportionality also possesses dimensions. In such cases, one cannot use this system.
5. If one side of equation contains addition or subtraction of physical quantities, one cannot use this method.

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PHYSICS

Chapter 5

Measurements And Errors in Physics

Measurements, use of standard units, fundamental and derived units, significant figure, value of zeros, order and scientific notations, accuracy, reliability and validity in measurements, systematic and random errors, ways to minimize the different types of errors and calculated errors.

- **Measurement :** All science is concerned with measurement to maintain uniformity across the world . Therefore, it's a fact that requires the known standards of measurement.
- **Standards :** In order to make meaningful measurements one needs the standards of commonly measured quantities, such as those of mass, length and time. These standards are as follows:
- The **kilogram** is the mass of a cylinder of platinum-iridium alloy kept at the International Bureau of Weights and Measures in Paris, France. By 2018, however, this standard may be redefined in terms of fundamental constants.
- The **metre** is defined as the length of the path travelled by light in a vacuum during a time interval of 1/299 792 458 of a second.
- The **second** is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom.
- It is necessary for all such standards to be constant, accessible and easily reproducible.
- **SI Units :** The International System of Units, universally abbreviated SI (from the French *Le Système International d' Unités*), is the modern metric system of measurement. The SI was established in 1960 by the 11th General Conference on Weights and Measures (CGPM, *Conférence Générale des Poids et Mesures*). The CGPM is the international authority that ensures the wide dissemination of the SI and modifies the SI as necessary to reflect the latest advances in science and technology.
- Thus, the kilogram, metre and second are the SI units of mass, length and time respectively. They are abbreviated as kg, *m* and *s* respectively. Various prefixes are used to help express the size of quantities, e.g., a nanometre = 10^{-9} of a metre; a gigametre = 10^9 metres.
- **Fundamental and Derived Quantities :** Physical quantities are not generally independent of one another. Many quantities can be expressed in terms of more fundamental quantities. The first three fundamental quantities, we will deal with, are those of mass, length and time. Many derived quantities, can be expressed in terms of these three fundamental quantities. For example, the derived quantity speed can be expressed as length/time.

- **Dimensions :** The expression of a derived quantity in terms of fundamental quantities is called the dimension of the derived quantity. The symbol M is used to denote the dimension of mass, as is L for length and T for time. These dimensions can be used to check, the correctness of an equation. The dimensions of the left-hand side of the equation must equal the dimensions of the right-hand side. They can also be used to verify that different mathematical expressions for a given quantity are equivalent.
- **Significant figures :** Since the precision of all measuring instruments is limited, the number of digits that can be assumed as known for any measurement is also limited. When making a measurement, one needs to read the instrument to its smallest scale division. The figures one writes down for the measurement are called significant figures. For example, if one writes 3.0, it means that he is stating that he is able to estimate the first decimal place of the quantity and he is implying an error of 0.05 unit. If one writes 3, he is unable to determine the first decimal place, hence, implying an error of 0.5 unit.
- A calculated quantity cannot have more significant figures than the measurements or supplied data used in the calculation e.g., if the length, breadth & height of a rectangular prism is each known to 2 significant figures, the volume calculated from these figures cannot have more than 2 significant figures. Let's say the volume = 3.7cm × 2.9cm × 5.1cm = 54.723 cm^3, *i.e.* the volume is 55cm^3 (2 significant figures only).
- **Zeros**
- Zeros between the decimal point and the first non-zero digit are not significant, e.g., 0.00035 has 2 significant figures.
- Zeros that round off a large number are not significant, e.g., 35,000 has 2 significant figures.
- Zeros at the end of a string of decimals are significant. e.g. 0.5500 has 4 significant figures. The last 2 digits are meaningful here. The measurement is 0.5500, not 0.5501 or 0.5499.
- Zeros in between non-zero digits are significant, e.g., 0.7001 has 4 significant figures. The first zero is not significant but the next two are.
- **Order and Scientific notation :** The order of a number is the nearest power of 10 to that number, e.g., 166,000 has an order of 10^5; 756,000 has an order of 10^6; 0.099 has an order of 10^{-1}.
- In Physics, quite often scientific notation is used. Write one non-zero figure before the decimal point and correct the magnitude of the number by using the appropriate power of ten, e.g., 166,000 can be written as 1.66 x 10^5; 0.099 can be written as 9.9 × 10^{-2}.
- **Accuracy, reliability and validity :** These three terms are often used when referring to experiments, experimental results and data sources in science. Hence, it is important to have a good understanding of the meaning and use of these terms.

- **Accuracy (Conformity to truth) :** Scientific texts refer to accuracy in two ways:
- **Accuracy** of a result or experimental procedure can refer to the percentage difference between the experimental result and the accepted value.
- **Accuracy** is also associated with the inherent uncertainty in a measurement.
- **Reliability (Trustworthy or dependable) :** In terms of first-hand investigations reliability can be defined as repeatability or consistency. If an experiment is repeated many times and give identical results each time it is reliable. In terms of second- hand sources, reliability refers to how trustworthy the source is.
- **Validity : (Derived correctly from premises already accepted, eliminated or supported by actual fact)** A valid experiment is one that fairly tests the hypothesis. In a valid experiment, all variables are kept constant apart from those being investigated, all systematic errors have been eliminated and random errors are reduced by taking the mean of multiple measurements. An experiment could produce reliable results but it will be invalid if it gives inaccurate and invalid results because a valid scientific experiment would produce reliable results in multiple trials.
- **Nature of errors :** Errors occur in all physical measurements. When a measurement is used in a calculation, the error in the measurement is carried forward in the result. The two different types of **errors** that can occur in a measured value are:
- **Systematic error :** It occurs to the same extent in each one of a series of measurements, e.g., zero error, where for instance the needle of a voltmeter is not correctly adjusted to read zero, when no voltage is present.
- **Random error :** It occurs in any measurement as a result of variations in the measurement technique (e.g. parallax error, limit of reading, etc).
- **Errors in measured quantity :** The error can be
- **Absolute error :** It is the actual size of the error expressed in the appropriate units
- **Relative error :** It is the absolute error expressed as a fraction of the actual measured quantity.

Improving reliability, accuracy and validity : To reduce the relative error, one must

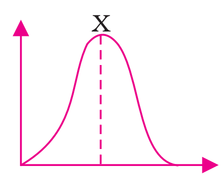
- use appropriate measuring instruments in the correct manner (e.g. using of a micrometer or screw gauge rather than a metre ruler to measure the diameter of a small ballbearing)
- take the mean of multiple measurements. To improve the accuracy and validity of an experiment one needs to keep all variables constant other than those being investigated
- eliminate all systematic errors by careful planning and performance of the activity requiring measurement
- reduce random errors as much as possible by taking the mean of multiple measurements.

Experimental errors : Variations occur in any series of measurements taken with a suitably sensitive measuring instrument. These variations in the different readings of a measurement are called "experimental errors". These variations are normal.

Random errors : These variations are caused by slight variations in the measuring technique such as :

- closing the jaws of the micrometer more or less tightly from one measurement to the next such as obtaining a set of readings in mm such as: 0.73, 0.71, 0.75, 0.71, 0.70, 0.72, 0.74, 0.73, 0.71 and 0.73 while using a micrometer to find the diameter of a wire.
- Similarly, an angle other than perpendicular to the scale that introduces parallax error into the results.
- Such factors cause random variations in the measurements and hence, called Random Errors.
- These errors are avoided or minimized by plotting a distribution curve by making readings or measured values of a quantity lie along the x-axis and the frequencies (number of occurrences) of the measured values along the y-axis.
- The Normal Curve is a smooth, continuous curve and symmetrical about a central "x" value. The peak in frequency occurs at this central x value.
- The effect of random errors on a measurement of a quantity can be largely nullified by taking a large number of readings and finding their mean value. The formula for the mean is as shown below :

$$\overline{X} = \Sigma X$$



- X is mean, Σx is the sum of readings and n is the total number of readings.
- **Effects of random errors:** To take into account the effects of random errors in analysing and reporting the experimental results, one should
  - Take a large number of readings – at least 10, where time and practicality permit.
  - Calculate the mean of the readings as a reasonable estimate of the "true" value of the quantity.
  - Use the largest deviation of any of the readings from the mean as the maximum probable error in the mean value.
  - If all the readings are the same, use half the limit of reading of the measuring instrument as the MPE(Mean Percentage Error) in the result.

- **Systematic errors** : These errors occur to the same extent in each one of a series of measurements. Causes of systematic error include :
  - Using the instrument wrongly on a consistent basis.
  - Built-in error in the instrument may be zero error. In case, the instrument has not been correctly set to zero before commencing the measuring procedure.

    External conditions can introduce systematic errors such as a metallic rule calibrated for use at 25°C will only be accurate at that temperature. If one uses this rule at 5°C, it will produce readings that are consistently larger than they should be since at the lower temperature the metal will have contracted and the distance between each scale division would be smaller than it should be.
- Systematic errors can drastically affect the accuracy of a set of measurements. In order to reduce the incidence of these errors, the experimenter must:
  - Use all measuring instruments correctly and under the appropriate conditions.
  - Check for zero error.
- **Errors in Calculated Quantities :** In scientific experiments the measured values are used of particular quantities for calculating a new quantity. The error in the new quantity depends on the errors in the measured values used for calculating it because of an error in
  - addition or subtraction
  - multiplication or division
  - changing of unit values from MKS to CGS or vice versa.

Problem : A student while heating water measured the starting temperature to be (35.0 ± 0.5)°C and the final temperature to be (85 ± 0.5)°C. Find the change in temperature.

Solution : The change in temperature is

(85.0 – 35.0)°C ± (0.5+0.5)°C or (50.0 ± 1.0)°C

Problem : Find the volume of a ball bearing in cm^3 of radius 9.53 mm ± 0.05 mm.

Ans. The formula for the volume of a sphere is : $V = 4/3\pi r^3$

Using this formula, the value for the volume of the ball bearing is found to be $3625.50 mm^3$.

Percentage of error in volume = % error in r + % error in r + % error in r. Therefore, % error in volume = 0.5% + 0.5% + 0.5% = 1.5%

The volume of the ball bearing is, therefore, $3625.50\ mm^3$ ± 1.5% or $3625.50 mm^3 \pm 54.38 mm^3$.

Changing mm^3 to cm^3, the volume of the ball bearing is $(3.63 \pm 0.05) cm^3$.

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Chapter 6

KINEMATICS

Kinematics, scalar and vector quantities with examples, Dimensional motion: one, two and three dimensional motions, types of motion, distance (s), displacement, average velocity v/s instantaneous velocity, acceleration, four kinematic equations and projectile motion with equations related to motion in trajectory.

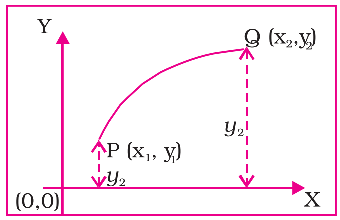
- **Kinematics :** It refers to the study and description of motion, without regard to its mass or physical quantities that depend on mass. One of the basic difference between kinematics and dynamics is that dynamics is the cause of motion and kinematics is the effect.
- Kinematics involves position, velocity and acceleration (and their rotational equivalents)
  - Position is the point in space that an object occupies. It needs to be defined in a coordinate system.
  - Velocity is the rate of the change of position with respect to time.
  - Acceleration is the rate of change of velocity with respect to time.

Scalar and vector quantities	A scalar quantity is a one-dimensional measurement of a quantity, like temperature or weight. A vector has more than one number associated with it. A simple example is velocity. It has a magnitude, as well as a direction, like South or 10 degrees west of North.
Examples of scalar quantities	Mass, distance, time , speed, volume, density, pressure , work, energy, power, charge ,electric current, electric potential, electric conductance, electrical and magnetic flux, inductance, resistance, specific heat, frequency, moment of inertia, radioactivity, Young's modulus, etc.
Examples of vector quantities	Displacement, velocity, acceleration, force, weight, momentum, impulse, electric field, magnetic field, current density, etc.

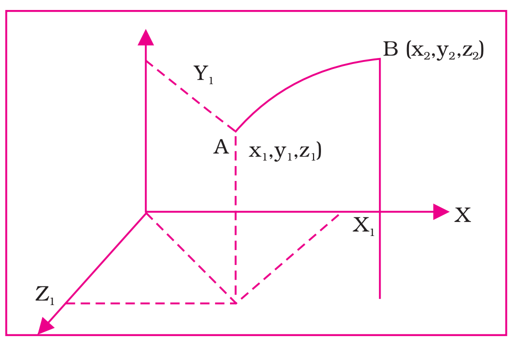
- **Dimensional motion of a body :** A body is said to be in motion if its position changes with respect to its surrounding. In order to completely describe the motion of such objects, we need to specify its position. For this, we need to know the position coordinates. In some cases, three position coordinates are required, in some cases, one or two coordinates are required. Based on these, motion can be classified as one, two or three dimensional motion.
- **Motion in one dimension :** It is also called rectilinear or linear motion in which a particle moves along a straight line such that only one of the three coordinates changes with time so as the motion

of a train along a straight line, upward and downward oscillation of a vertical spring or freely vertically falling of a body under the force of gravity.

- **Motion in two dimensions:** A particle moving along a curved path in a plane shows the two dimensional motion. The figure illustrates a two dimensional motion where a particle moves from $P(x_1,y_1)$ to $Q(x_2,y_2)$ along a curved path. The other examples include :

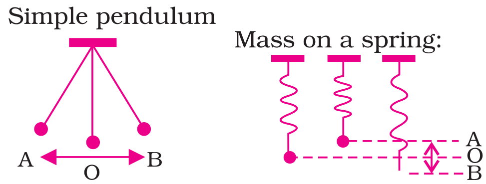


  - a satellite revolving round the earth.
  - an insect crawling on a ball.
  - motion of a particle thrown obliquely into the air like a golf ball after being hit by a golf stick.
  - oscillation of a bob of a simple pendulum in a vertical plane with a large amplitude. In case of a small amplitude the oscillation is almost in a straight line. and the motion is one dimensional.
- **Motion in three dimensions:** A particle moving in space has three dimensional motion. In this type of motion , all the coordinates change with time.
- The figure illustrates this type of motion where the particle moves from A to B and the corresponding rectangular coordinates change from (x_1,y_1,z_1) to (x_2,y_2,z_2) . This type of motion is well exhibited by

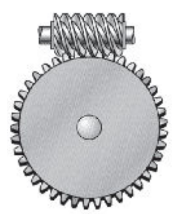


  - a bird or kite flying in the air
  - a fish swimming in water.
- **Types of motion :** Motion may be divided into three basic types — translational, rotational and oscillatory.
- **Translational motion :** It results in a change of location, *i.e.* walking a distance of 400m from point A to point B or a football being kicked by a player to his fellow team mate.

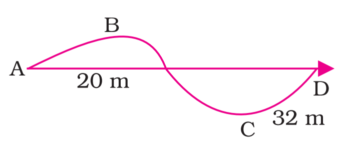
- **Oscillatory motion :** It is repetitive and fluctuates between two fixed locations such as for a person going from home to work to home to work. In the end, it means that the person has not gone anywhere. This type of motion is seen in pendulums , vibrating strings, drawers and doors with hinge joints.



- Oscillatory motion is interesting because it often takes a fixed amount of time for an oscillation to complete. This kind of motion is said to be periodic and the time for one complete oscillation (or one cycle) is called time period.
- **Rotational motion :** It mostly occurs when an object spins about an axis like the earth, hands of a clock or motion of a moving car or bicycle wheel. In this motion, a particle returns to its initial position like oscillatory motion after a particular time to eventually have zero displacement.



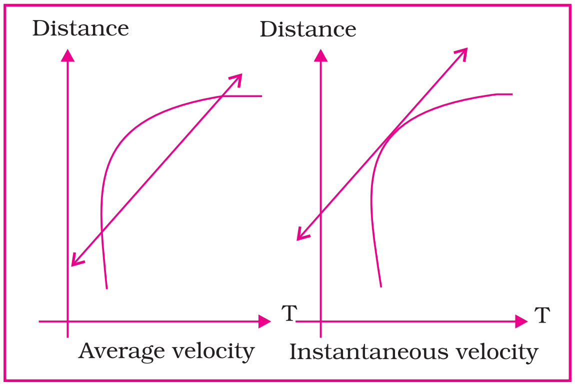
- **Random motion :** It refers to the free undirected, uncertain and unpredictable motion such as the motion of the molecules of a fluid in a container.
- **Distance v/s Displacement :** Distance is the total length travelled along a path. It's a scalar quantity. The displacement is vector connecting a point to the origin or from one point to another point later in time (in SI, abbreviation for displacement is s). It can be considered as the shortest distance from the point of origin.



- ABCD the total path travelled =32 m is the distance while AD = 20m, the shortest distance from the point of origin of motion is the displacement.
- Distance travelled is always positive, displacement can be positive, zero or negative.

PHYSICS

- Distance is a scalar quantity but displacement is a vector quantity.
- **Instantaneous velocity v/s Average velocity :** The speed of a body in motion is the rate of change of distance but velocity is the rate of change of displacement.
- The direction of velocity vector is same as the direction of motion. The average velocity is the change in displacement over a finite duration, (Δ t).
- Graphically, it represents the slope of secant, shown in the figure. The instantaneous velocity (v) is slope (tangent) to the displacement-time curve at a particular instant (t).



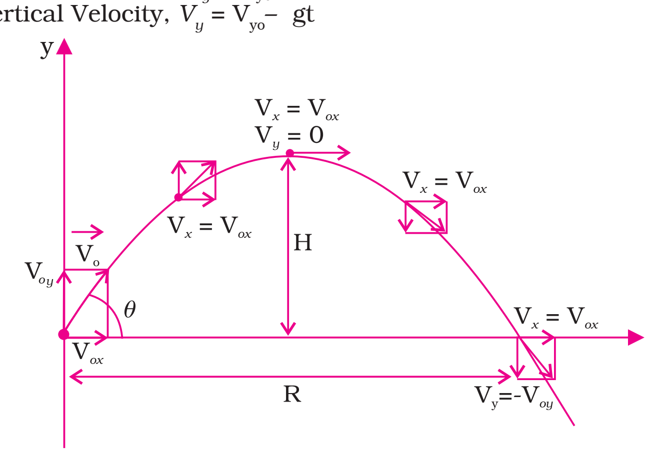
- **Acceleration :** It is a vector quantity that is defined as the rate at which an object changes its velocity. An object is considered to be accelerating if it is changing its velocity. If an object undergoes a change in its velocity, then only the object is said to be accelerating, otherwise not. (acceleration = change in velocity/time).
- When an accelerating object changes its velocity by the same amount, each second, the acceleration is referred to as a constant acceleration since the velocity is changing by a constant amount each second. An object with a constant acceleration should not be confused with an object with a constant velocity. If an object changes its velocity -whether by a constant amount or a varying amount - then it is an accelerating object but an object with a constant velocity may not be accelerating.
- The average acceleration (a) of any object over a given interval of time (t) is calculated using the equation in the S.I. units of m/s^2 or ms^{-2}.

  $$\text{Average acceleration} = \frac{\text{Velocity}}{\text{Time}} = \frac{V_2 - V_1}{t_2 - t_1} = \frac{\Delta \upsilon}{\Delta t}$$

- When an object speeds up with the acceleration in the same direction as the velocity, the object has a positive acceleration. When the object moves in the *positive* direction (*i.e.* has a positive velocity) but slowing down then the acceleration is in the opposite direction as the velocity. The object will be considered to have negative acceleration.

- **Retardation :** If refers to the negative acceleration such as a decline in velocity of a body in motion after applying brakes.
- **Kinematic equations :** The kinematic equations are a set of four equations that can be utilized to predict unknown information about the motion of an object if other information is known. The four kinematic equations that describe the motion of an object are:
  - ❖ $v_f = v_i + at$ or $v = u + at$
  - ❖ $d = v_1 t + ½ at^2$ or $s = ut + ½ at^2$
  - ❖ $v_f^2 = v_i^2 + 2ad$ or $v^2 = u^2 + 2as$
  - ❖ $d = \frac{V_i + V_f}{2} \times t$ or $s = \frac{\Delta V}{2} \times t$
- There are a variety of symbols used in the above equations. Each symbol has its own specific meaning. The symbol 'd' stands for the displacement of the object. The symbol 't' stands for the time for which the object moved. The symbol 'a' stands for the acceleration of the object. And the symbol 'v' stands for the velocity of the object; A subscript of i after the v (as in v_i) indicates that the velocity value is the initial velocity value(u) and a subscript of f (as in v_f) indicates that the velocity value is the final velocity value(v).
- **Projectile motion :** A projectile is an object thrown upward into the air or space. The curved path along which the projectile travels is what is known as trajectory. Projectile Motion is the free fall motion of any body in a horizontal path with constant velocity.

  Horizontal distance, $x = V_x t$
  Horizontal Velocity, $V_x = V_{xo}$
  Vertical distance, $V_y = V_{yo}t - gt^2$
  Vertical Velocity, $V_y = V_{yo} - gt$



Where,
V_x is the velocity along x-axis,
V_{xo} is the initial velocity along x-axis,
V_y is the velocity along y-axis,
V_{yo} is the initial velocity along y-axis.
g is the acceleration due to gravity and
t is the time taken

- Equations related to trajectory motion (projectile motion) are given by,

  Time of flight , $t = \dfrac{2v_o \text{ Sin } \theta}{G}$

  Maximum height, $H = \dfrac{v_o^2 \text{ Sin}^2 \theta}{2g}$

  Horizontal range, $R = \dfrac{v_o^2 .2\text{Sin } \theta}{g}$

  Where,

  V_o is the initial Velocity,

  sin θ is the component along y-axis,
- Projectile Motion formula is used for finding the distance, velocity and time taken in the projectile motion.

  Problem : Ramesh in his car can accelerate from zero to 60 mph (26.8 m/s) in 4.9 s.

  (i) What is the average acceleration of the car during that period of time?

  (ii) If acceleration of the car is constant, how far does the car travel in those 4.9 s?

  Solution : (i) $v_i = 0$ $v_f = 26.8$ m/s

  $t_1 = 0$ $t_2 = 4.9$ s

  $x_1 = 0$ $x_2 = ?$

  $v_f = v_i + a\Delta t$

  26.8 m/s = 0 + a (4.9 s)

  26.8 m/s /4.9 s = a

  5.5m/s² = a

  (ii) $x_2 = v_i t + ½ at^2$

  $x_2 = 0 \text{ x } t + ½ \times 5.5 \text{ m/s}^2 \text{ x } (4.9 \text{ s})^2$

  $x_2 = 0 + 66$ m

  $x_2 = 66$ m

Problem : A javelin travels in a parabolic arc for 6 seconds before hitting the ground. Compare its horizontal velocity 1 second after being thrown to its horizontal velocity 4 seconds after being thrown.

Solution : Assuming that the air resistance is negligible, there is no acceleration in the horizontal direction during a projectile motion. Therefore, the horizontal velocity of the javelin will not change at any time during the flight. So, its horizontal velocities 1 second and 4 seconds after being thrown will be the same.

Problem : One second after a rock being thrown straight down from the top of a tower falls at 20 m/s. How fast will it fall 2 seconds later?

Solution : Since the initial velocity is in the downward direction, it will have a negative value.

With $v_i = -20$ m/s , a = -9.8m/s², Δt =2 s, $v_f = ?$

$v_f = {}_v i + at$

= – 9.8 × 2 – 20 m/s

= – 19.6 – 20m/s = -39.6m/s

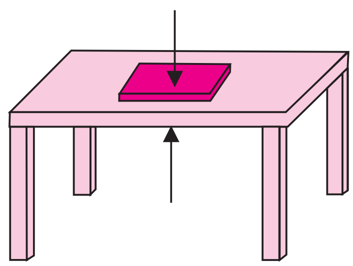
□□□

Chapter 7

NEWTON'S LAW OF MOTION

Newton's first law of motion, external and internal force, net force, balanced and unbalanced force, inertia and its types with examples, Newton's second law of motion and its applications , momentum, law of conservation of momentum, impulse, Newton's third law of motion and its applications.

- **Matter :** At one time, matter was known to be anything that occupies space and has mass but with upcoming of the understanding of Newton's laws of motion developed a new fact about matter defining it to be anything that occupies space and has its own mass and inertia.
- Inertia of a body describes its physical state, *i.e.* state of rest or motion.
- **Newton's first law :** An object at rest remains at rest, or if in motion, remains in motion at a constant velocity, *i.e.* tends to retain its inertia until and unless acted on by a net external force. Hence, Newton's first law of motion also came to be considered as the law of inertia.



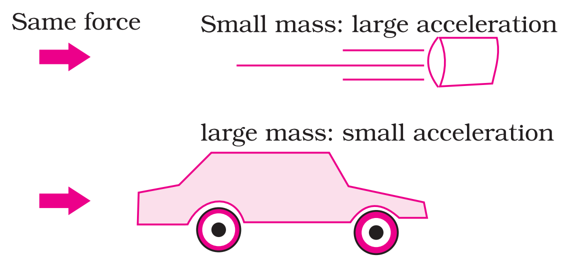
- Force, external force and net force : Force is a push or a pull exerted on one object by another object. The units of force 'F' are called Newtons or simply N.
- The external force is the force acting from outside on an object rather than the force from inside of an object. For instance, the force of gravity that the Earth exerts on the moon is the external force on the moon. However, the force of gravity that the inner core of the moon exerts on the outer crust of the moon is an example of internal force on the moon. Internal forces within an object can't cause a change in the overall motion of that object.
- The net force, written as ΣF, on an object is the sum total forces that acts on an object. If many forces act on an object then the net force is the sum of all the forces. Force F is a vector, to find the net force ΣF, the forces must be added up like vectors using vector addition.
- In other words, if a box lying on a table had a force of magnitude 25 N exerted on it to the right and a force of magnitude 15 N exerted on it to the left, the net force in the horizontal direction would be

$$\Sigma F_{\text{horizontal}} = 25\text{N} - 15\text{N} = 10\text{N}$$

- **Balanced and unbalanced force :** The concept of the net force that acts on a body has brought up the concept of balanced and unbalanced force. A force that fails to bring any change in the inertia of a body is called the balanced force while a force which being greater than the sum of all the forces acting on a body, brings a change in the inertia of a body is called the unbalanced force.
- Newton's first law implies that if the net force on an object is zero (ΣF=0) then that object will have zero acceleration. However, it doesn't necessarily mean the object is at rest, but it means that the velocity is constant. In other words, constant zero velocity - at rest - or constant non-zero velocity - moving with a constant velocity such as a bird gliding in air at a particular height and velocity has zero acceleration.
- **Three types of inertia :** Inertia is that property of a body by virtue of which the body is unable to change its state by itself in the absence of external force. The inertia is of three types :
- **Inertia of rest :** It's ability of the body to resist any change in its state of rest such as
  - A person standing in a bus falls backward when the bus suddenly starts moving because the person initially at rest continues to be at rest even after the bus has started moving .
  - A book on the table or a rock on ground remains at rest, until it is moved by some external agency applying the unbalanced force to displace it.
  - When a carpet is beaten with a stick, the dust particles fall off vertically downward once they are released and do not move along the carpet before falling off.
- **Inertia of motion :** It refers to the inability of the body to change its state of motion by itself such as
  - when a passenger gets down from a moving bus, he tends to fall down in the direction of the motion of the bus.
  - a passenger sitting in a moving car falls forward, when the car stops suddenly. The belt used by the car driver is meant to prevent the same when the driver has to apply sudden brakes.
  - an athlete running a race continues to run for some distance even after reaching the finishing line.
  - ripe fruits fall from a tree in the direction of wind. As the tree sways along with the wind and the inertia of motion makes these fruits sway along with the tree branches. The fruits fall off due to the inertia of motion along the direction of wind.
  - the swirling of milk in a glass continues even after the stirring is stopped due to the inertia of motion of the milk inside the glass.
- **Inertia of direction :** It is the inability of the body to change its direction of motion by itself such as
  - tangentially straight motion of a rock moving in circular path after being released.

- curving of the steering wheel by a car driver when going round on a circular path.
- sideways falling of a passenger sitting in bus when the bus takes a sharp turn or goes round on a circular path.
- protection by an umbrella on a rainy day. The rain drops falling vertically downwards cannot change their direction of motion and so fail to wet us when the umbrella is up.

➢ **Newton's second law of motion:** Newton's first law states that a body tries to retain its inertia unless an unbalanced force is applied on it. But what happens if the unbalanced force is applied; it is described by Newton's Second Law of Motion. It states, "The force acting on an object is equal to the mass of that object times its acceleration."



Force = mass × acceleration

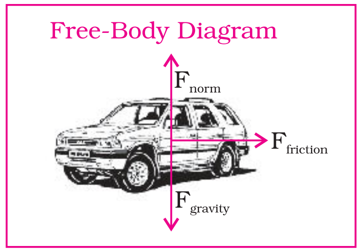
➢ This is written in mathematical form as : $F = ma$

➢ F is force, m is mass and a is acceleration. The relation clearly describes that if one
- increases the force by two times, the acceleration possessed by the body also increases by two times.
- increases the mass by two times, the acceleration is reduced to half of its initial value with $a = F/m$.

➢ The force applied on an object at rest causes it to accelerate in the direction of the force. However, if the object is already in motion, or if this situation is viewed from a moving inertial reference frame, the body might appear to speed up, slow down or change its direction depending on the direction of the force and the directions that the object and reference frame are moving relative to each other.

➢ In the relation $F = ma$ both force and acceleration are vector quantities, *i.e.* they have both magnitude and direction. The force can be a single force or it can be the combination of more than one force. Hence, the equation is to be written as : $\Sigma F = ma$.

➢ The large Σ represents the vector sum of all the forces, or the net force acting on a body.
- Some elevator has a sign saying that only a certain amount of people can use it at a time because it has a maximum acceleration and force with which it move, *i.e.* it can sustain only a maximum mass, which is then translated into a certain number of people.



- Consider a car moving in a horizontal circle on a level surface. Applying the concept of a centripetal force requirement, the net force acting upon the object is directed inwards. Since the car is positioned on the left side of the circle, the net force has to be directed rightwards.

Problem : A 10 kg object is forced to the left with 10 Newton and to the right with 20 Newton force. What is the acceleration of this object?

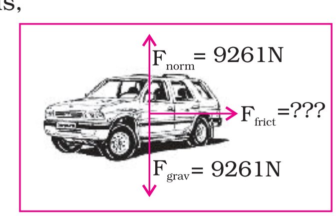
Solution : Mass of object = 10 kg
Force to the left = 10N
Force to the right = 20N
Net force = $F_{Right} - F_{left}$
= 20N –10N = 10N
With $\sum F = m \, x \, a$
$a = \sum F/m$ = 10 N/10 kg = lms^{-2}

Problem : The maximum speed with which a 945 kg car makes a 180-degree turn is 10.0 m/s. The radius of the circle through which the car turns is 25.0 m. Find the force of friction and the coefficient of friction acting upon the car.

Solution :

Known information	Requested information
M = 945 kg	F_{fric} = ?
V = 10.0 m/s	μ (Coefficient of friction) = ?
r = 25 m	

- With no vertical acceleration of the car, the vertical forces balance each other. Thus,



$F_{grav} = m \, g$ when g is 9.8 m/s^2.
$F_{grav} = F_{norm}$ = 945 x 9.8 = 9261 N.

- Hence two of the three forces identified in the free-body are as shown in the diagram. Only the horizontal frictional force remains unknown.

- To determine the net force, the mass and the kinematic information (speed and radius) must be substituted in the equation:

$$F_{net} = m \times v^2/r$$
$$= 945 \times (10)^2/25 = 3780 \text{ N}$$

- Finally the coefficient of friction can be determined using the equation that relates the coefficient of friction to the force of friction and the normal force.

$F_{fric} = \mu \times F_{norm}$

$\mu = F_{Fric} / F_{norm}$

$= 3780/9261 = 0.408$

- Therefore, the coefficient of friction is 0.408.
- Momentum : The momentum of a particle represented by letter *p* is the product of two quantities: the mass (represented by the letter *m*) and velocity (*v*), *i.e.* $p = m.v$
- The units of momentum are the product of the units of mass and velocity. In SI units, if the mass is in kilograms and the velocity in metres per second then the momentum is in kilogram metres/second (kg m/s). In CGS units it is (g cm/s).
- Being a vector, momentum has magnitude and direction. For example, a 1 kg model airplane, traveling due north at 1 m/s in straight and level flight, has a momentum of 1 kg m/s due north measured from the ground.
- **Many particles :** The momentum of a system of particles is the sum of their momenta. If two particles have masses m_1 and m_2, and velocities v_1 and v_2, the total momentum is

$P = p_1 + p_2$

$= m_1v_1 + m_2v_2$

- The momenta of more than two particles can be added more generally with the following :

$p = \Sigma_i m_1 v_1$

- A system of particles has a centre of mass, a point determined by the weighted sum of their positions :

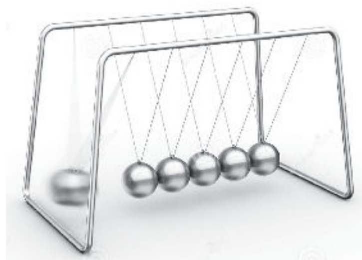
$$r_{cm} = \frac{m_1r_1\ m_2r_2 + \ldots\ldots\ldots\ldots\ldots}{m_1 + m_2 + \ldots\ldots\ldots\ldots\ldots\ldots} = \frac{\sum_i m_1 r_1}{\sum_i m_1}$$

- If all the particles are moving, the centre of mass will generally be moving as well (unless the system is in pure rotation around it). If the centre of mass is moving at velocity v_{cen}, the momentum is : $P = m.\ v_{cen}$
- This is known as Euler's first law.
- **Relation to force :** If a force *F* is applied to a particle for a time interval Δt, the momentum of the particle changes by an amount

$$\Delta p = F\,\Delta\, t$$

PHYSICS

- **Conservation of momentum :** A system of particles has a centre of mass, a point determined by the weighted sum of their positions.



Newton's cradle

- In a closed system (one that does not exchange any matter with its surroundings and is not acted on by external forces), the total momentum is constant. This fact, known as the law of conservation of momentum, is implied by Newton's laws of motion. Suppose, for example, when two particles interact because of the third law, the forces between them are equal and opposite. If the particles are numbered 1 and 2, the second law states that $F_1 = dp_1/dt$ and $F_2 = dp_2/dt$.

  Therefore, $(dp_1/dt) = -(dp_2/dt)$ with the negative sign indicating that the forces oppose. Equivalently, $dt(p_1 + p_2) = 0$
- If the velocities of the particles are u_1 and u_2 before the interaction, and afterwards, they are v_1 and v_2, then

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

- This law remains valid no matter how complicated the force is between particles. Similarly, if there are several particles, the momentum exchanged between each pair of particles adds up to zero, so the total change in momentum is zero. This conservation law applies to all interactions, including collisions and separations caused by explosive forces.
- **Law of conservation of momentum :** Conservation of momentum is derived from Newton's laws of motion. Newton's third law states that every action has an equal but opposite reaction *i.e.* the force that one object A exerts on object B is equal but opposite to the force that object B exerts on object A. By Newton's second law, this force is equal to the product of the mass and the acceleration of the objects, so the product of the mass and acceleration of object A is equal but opposite to the product of the mass and acceleration of object B.
- Hence, the law of conservation of momentum states that for two objects colliding in an isolated system, the total momentum before and after the collision is equal. This is because the momentum lost by one object is equal to the momentum gained by the other.

PHYSICS

Problem : Determine the momentum of

(a) 1000 kg car moving northward at 20 m/s.

(b) 40 kg freshman moving southward at 2 m/s.

Solution : (a) p = m x v = 1000 kg x 20 m/s

p = 20,000 kg.m/s, north

(b) p = m x v = 40 kg x 2 m/s

p = 80 kg.m/s

Problem : A mass of 4 kg is moving at a speed of 10 m/s in a frictionless surface. It collides with a 3kg mass moving in the same direction at 5 m/s. What is the final velocity of the system after the collision?

Solution : Using the conservation of momentum,

we see that

$m_1v_1 + m_2v_2 = (m_1+m_2)v_f$

$4 \times 10 + 3 \times 5 = 7kg\ v_f$

$55kgm/s = 7kg\ v_f$

$v_f = 7.857$ m/s

Problem : There are two vehicles moving at a speed of 50 km/s and 70 km/s with mass of 100 kg and 60 kg respectively. Find the final speed of both after collision.

Solution : We've

$m_1v_1+m_2v_2 = (m_1+m_2)v_f$

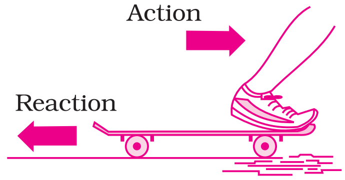
$100 \times 50 + 60 \times 70 = (100 + 60)v_f$

$v_f = 9200 / 160 = 57.5$ km/s

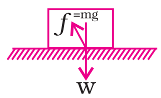
- **Impulse :** It (symbolized as J or Imp) is the integral of a force, F, over the time interval, t, for which it acts.

$$J = F.\Delta t$$

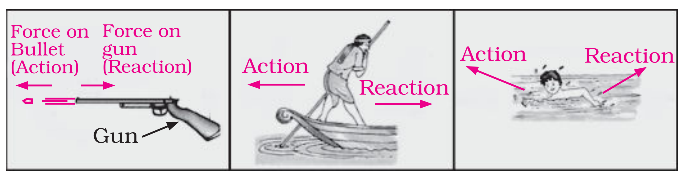
- Since force is a vector quantity, impulse is also a vector in the same direction. Impulse applied to an object produces an equivalent vector change in its linear momentum in the same direction. Impulse has the same units and dimensions (MLT^{-1}) as momentum. In the (SI) International System of Units, these are kg·m/s or N/s.
- **Newton's third law of motion :** Whenever two bodies interact with each other, the force exerted by the first body on the second is called action. The force exerted by the second body on the first body is called reaction. Newton's Third Law of Motion states that in each interaction to every action, there is an equal and opposite reaction. The action and reaction always act on different objects. The Third Law of Motion indicates that when one object exerts force on another object, the second object instantaneously exerts force back on the first object. These two forces are always equal in magnitude, but opposite in direction.



- These action and reaction forces act on different objects and so they do not cancel each other. Thus, Newton's Third Law of Motion describes the relationship between the forces of interaction between two objects.
- For example, when we place a wooden block on the ground, the block exerts force equal to its weight, W = mg acting downwards to the ground. This is the action force. The ground exerts an equal but opposite force W = mg on the block in the upward direction. This is the reaction force.



- **A gun recoils when a bullet is fired from it :** When a bullet is fired from a gun, the gun exerts force on the bullet in the forward direction. This is the action force. The bullet also exerts an equal force on the gun but in the backward direction. This is the reaction force. Due to the large mass of the gun, it moves only a little distance backward by giving a jerk at the shoulder of the gunman or soldier. The backward movement of the gun is called the recoil of the gun.



- Similarly, a sailor rowing a boat, a swimmer swimming in water, a person walking or running on ground or the propulsion of a rocket in the air on its way to a space station are the examples of the applications of Newton's third law of motion.
- In a car crash, the action forces are the cars colliding with each other. The reaction force is the force sent back due to the collision, the one that causes the damage to the car. When two cars are headed straight at each other, they are travelling in opposite directions. When they finally collide, if they apply the same amount of force, they will experience a reaction of equal magnitude. This causes the destruction of the front of both cars. Since force is the product of mass and acceleration. If a heavier car, *i.e.* car with more mass collides with car having comparatively less mass, there if the two are travelling at same acceleration, the heavier car is going to experience less damage compared to the lighter car.

□□□

Chapter 8

CIRCULAR MOTION

PHYSICS

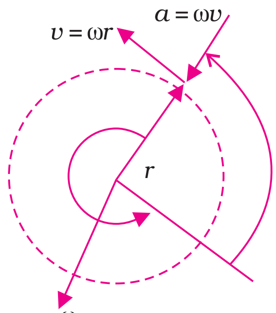
Linear v/s circular motion, circular motion, uniform and non-uniform circular motion, angular velocity, angular acceleration, rigid body motion, centripetal force v/s centrifugal force, banking of curve and advantage, skidding on a curved path.

Motion of a body can be linear or circular. However they differ in number of ways as listed in the table given below:

Linear Motion	**Rotational Motion**
Displacement x	Angular Displacement θ
Velocity $v = dx/dt$	Angular velocity $\omega = d\theta/dt$
Acceleration = $a = dv/dt$	Angular displacement $\alpha = d\omega/dt$
Mass M	Moment of Inertia I
Force $F = Ma$	Torque $\tau = Ix$
Work $dh = Fds$	Work $W = \tau d\theta$
Kinetic Energy $k = \frac{1}{2}mv^2$	Kinetic Energy $K = \frac{1}{2}I\omega^2$
Power $p = Fv$	Power $P = \tau\omega$
Linear momentum $p = mv$	Angular momentum $L = I\omega$

- **Uniform circular motion:** It describes the motion of a body traversing a circular path at constant speed. Since the body describes circular motion, its distance from the axis of rotation remains constant at all times. Though the body's speed is constant yet its velocity is not constant, velocity being a vector quantity, depends on both the speed of the body and its direction of travel. This changing velocity indicates the presence of an accelerated motion. The centripetal acceleration of constant magnitude is directed at all times towards the axis of rotation. This acceleration is, in turn, produced by centripetal force which is also constant in magnitude and directed towards the axis of rotation.
- In case of rotation around a fixed axis of a rigid body that is not negligibly small compared to the radius of the path, each particle of the body describes a uniform circular motion with the same angular velocity, but with velocity and acceleration varying with the position with respect to the axis.(The magnitude of the angular velocity is the angular speed.)
- **Formulas :** The figure shows the vector relationships for uniform circular motion, vector ù representing the rotation is normal

to the plane of the orbit. For motion in a circle of radius r, the circumference of the circle is C = 2π r. If the period for one rotation is T, the angular rate of rotation, also known as angular velocity, ω is :



and the units are radians/second.

$$\omega = \frac{2\pi}{T} = 2\pi f = \frac{\theta}{T}$$

The speed of the object travelling the circle is:

$$v = \frac{2\pi r}{T} = \omega r$$

The angle θ swept out in a time t is :

$\theta = 2\pi f = \omega t$

The angular acceleration, α, of the particle is :

$\alpha = \frac{d\omega}{dt}$

In case of uniform circular motion, α will be zero.

The acceleration due to change in the direction is :

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

The centripetal and centrifugal force can also be found out using acceleration:

$F_c = ma = \frac{mv^2}{r}$

- The vector relationships are shown in Figure given above. The axis of rotation is shown as a vector ω perpendicular to the plane of the orbit and with a magnitude $\omega = d\theta / dt$. The direction of ω is chosen using the right-hand rule. With this convention for depicting rotation, the velocity is given by a vector cross product as $v = \omega \times r$ which is a vector perpendicular to both ω and r(t), tangential to the orbit, and of magnitude ω r. Likewise, the acceleration is given by

  $\alpha = \omega \times v = \omega(\omega \times r) = \omega^2 r$

- which is a vector perpendicular to both ω and $v(t)$ of magnitude $\omega^2 r$ and directed exactly opposite to $r(t)$.

- In the simplest case the speed, mass and radius are constant.

Consider a body of one kilogram, moving in a circle of radius one metre, with an angular velocity of one radian per second, then

- The speed is one metre per second.
- The inward acceleration is one metre per square second, v^2/r.
- It is subject to a centripetal force of one kilogram metre per square second, which is one newton.
- The momentum of the body is one $kg \cdot m \cdot s^{-1}$.
- The moment of inertia is one $kg \cdot m^2$.
- The angular momentum is one $kg \cdot m^2 \cdot s^{-1}$.
- The kinetic energy is 1/2 joule.
- The circumference of the orbit is 2π (~6.283) metres.
- The period of the motion is 2π seconds per turn.
- The frequency is $(2\pi)^{-1}$ or $\frac{1}{2\pi}$ hertz (Hz).

- **Rigid body motion :** In the given figure s is arc, r is the radius and θ is the angle.

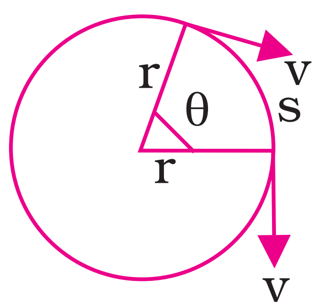
  Angle to be measured in radians: $\theta = s/r$

  Or $\theta = 2\pi r/r = 2\pi$

  $360° = 2\pi$ rad

  So $1° = 0.01745$ rad

  or 1 rad = 57.30^0



- 1rpm = 1 rev/min x $2\pi ra$/rev x 1/60 sec/min = 0.105 rad/sec

Uniform v/s non-uniform circular motion :

S. No.	Uniform Circular Motion	Non-Uniform Circular Motion
1.	Circular motion with constant angular speed.	Circular motion with variable angular speed.
2.	$\alpha = 0$	$\alpha \neq 0$
3.	Work done by tangential force is zero.	Work done by tangential force is not equal to zero.
4.	Revolution of earth in its orbit.	Motion of a body in a vertical circle.