Chapter- 1

PHYSICAL WORLD

SCOPE AND EXCITEMENT OF PHYSICS

Classical Physics deals mainly with macroscopic phenomena and includes subjects like Mechanics, Electrodynamics, Optics, and Thermodynamics. Mechanics founded on Newton's laws of motion and the law of gravitation is concerned with the motion (or equilibrium) of particles, rigid and deformable bodies, and general systems of particles. The propulsion of a rocket by a jet of ejecting gases, propagation of water waves or sound waves in air, the equilibrium of a bent rod under a load, etc., are problems of mechanics. Electrodynamics deals with electric and magnetic phenomena associated with charged and magnetic bodies. Its basic laws were given by Coulomb, Oersted, Ampere, and Faraday, and encapsulated by Maxwell in his famous set of equations. The motion of a current-carrying conductor in a magnetic field, the response of a circuit to an ac voltage (signal), the working of an antenna, the propagation of radio waves in the ionosphere, etc., are problems of electrodynamics. Optics deals with the phenomena involving light. The working of telescopes and microscopes, colors exhibited by thin films, etc., are topics in optics.

Thermodynamics, in contrast to mechanics, does not deal with the motion of bodies as a whole. Rather, it deals with systems in macroscopic equilibrium and is concerned with changes in internal energy, temperature, entropy, etc., of the system through external work and transfer of heat. The efficiency of heat engines and refrigerators, the direction of a physical or chemical process, etc., are problems of interest

in thermodynamics.

The microscopic domain of physics deals with the constitution and structure of matter at the minute scales of atoms and nuclei (and even lower scales of length) and their interaction with different probes such as electrons, photons, and other elementary particles. Classical physics is inadequate to handle this domain and Quantum Theory is currently accepted as the proper framework for explaining microscopic phenomena.

NATURE OF PHYSICAL LAWS

In any physical phenomenon governed by different forces, several quantities may change with time. A remarkable fact is that some special physical quantities, however, remain constant in time. They are the conserved quantities of nature. Understanding these conservation principles is very important to describe the observed phenomena quantitatively.

For motion under an external conservative force, the total mechanical energy i.e. the sum of the kinetic and potential energy of a body is a constant.

The law of conservation of energy is thought to be valid across all domains of nature, from the microscopic to the macroscopic.

In a nuclear process, mass gets converted to energy (or vice-versa). This is the energy that is released in a nuclear power generation and nuclear explosions. According to Einstein's theory, mass m is equivalent to energy E given by the relation, $E = mc^2$ where c is the speed of light in vacuum.

Chapter- 2

UNITS AND MEASUREMENTS

Unit

In measuring a physical quantity we always compare it with some established reference standard. That standard is called the unit of the physical quantity.

Types of physical quantities

Physical quantities are often divided into fundamental quantities and derived quantities.

The physical quantities, which are self-defined and are not defined in terms of other physical quantities, are called fundamental quantities. Examples of quantities usually viewed as fundamental are mass, length, time, etc.

The units of fundamental quantities are called fundamental units. For example kilogram, centimeters, hour, etc. are usually viewed as fundamental units.

The physical quantities whose defining operations are based on other physical quantities are called derived quantities. Examples of quantities usually viewed as derived are force, speed, power, etc.

The units of derived quantities are called derived units. For example, Newton, centimeter per second, horsepower, etc. are usually viewed as derived units.

System of units

Centimeter-gram-second (CGS or cgs or C.G.S. or c.g.s.) System

Meter-kilogram-second (MKS or mks or M.K.S. or m.k.s.) System

British system of measurements (or FPS or f.p.s. or F.P.S.) system

S.I. System

S.I. System has three types of units

Fundamental or base units

	SI base unit	
Base quantity	**Name**	**Symbol**
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
luminous intensity	candela	cd
amount of substance	mole	mol

Derived units

S.I. System has many derived units, some are given below

	SI derived unit		
Derived quantity	**Name**	**Symbol**	**Expression in terms of SI base units**
Speed or velocity	Meter per	m/s	m/s

	second		
force	newton	N	m·kg·s^{-2}
work, energy, quantity of heat	joule	J	m^{2}·kg·s^{-2}
power, radiant flux	watt	W	m^{2}·kg·s^{-3}
etc			

PROBLEM Calculate the angle of (a) 1° (1 degree), (b) $1'$ (1 minute of arc or 1 arcmin) and (c) $1''$ (1 second of arc or 1 arc-second) in radian

SOLUTION $1^\circ = 60' = \frac{\pi}{180}\,\text{rad} = 1.745\times10^{-2}\,\text{rad}$

$$1' = \frac{1.745\times10^{-2}}{60}\,\text{rad} = 2.909\times10^{-2}\,\text{rad}$$

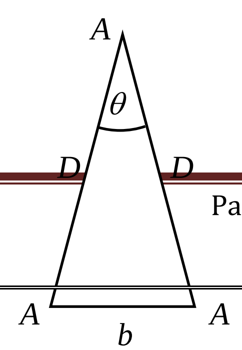
$$1'' = \frac{2.909\times10^{-2}}{60}\,\text{rad} = 4.848\times10^{-2}\,\text{rad}$$

MEASUREMENT OF LENGTHS –

1)**Measurement of large distances**-

Large distances such as the distance of a planet or a star cannot be measured directly with the meter scale. Parallax method is used for this purpose.

When you hold a pencil in front of you against some specific point on the background (a wall) and look at the pencil first through your left eye A(closing the right eye) and then look at the pencil through your right eye B (closing the left



eye), you would notice that the position of the pencil seems to change w.r.t. the point on the wall. This is called parallax. The distance between the two pints of observation is called the basis.

The angle θ is called the parallax or parallactic angle.

$$\theta = \frac{b}{D} \left(\text{since } \theta = \frac{b}{D} \ll 1 \right)$$

where θ is in radian

so, $D = \frac{b}{\theta}$.

If d is the angular diameter of the planet and α the angular size of the planet, we have

$$\alpha = \frac{d}{D}$$

1)**Measurement of small distances**-The solution of oleic acid spreads on the surface of water and forms a very thin layer of thickness t. Then $t = \frac{\text{volume of the film}}{\text{area of the film}}$

This is the diameter of the molecule.

PROBLEM- The moon is observed from two diametrically opposite points A and B on earth. The angle θ subtended at the moon by the two directions of observation is $1°54'$. Given the diameter of the earth to be about $1.276 \times 10^{7}\,\text{m}$, compute the distance of the moon from the earth.

Solution

$$D = \frac{b}{\theta} = \frac{1.276 \times 10^{7}\,\text{m}}{3.32 \times 10^{-2}\,\text{rad}} = 3.84 \times 10^{8}\,\text{m}$$

PROBLEM- The sun's angular diameter is measured to be $1920''$. The distance of the sun from the earth is $1.496 \times 10^{11}\,\text{m}$. What is the diameter of the sun?

Solution $d = \alpha D = 1920'' \times 1.496 \times 10^{11}\,\text{m} = 1.39 \times 10^{9}\,\text{m}$

Astronomical unit (AU)

It is a unit of length used to express astronomical distance. The mean distance between the sun and earth. It is equal to $1.496 \times 10^{11}\ \text{m}$.

Parsec

It is a unit of length used to express astronomical distance. The distance at which the mean radius of the earth's orbit subtends an angle of one second of arc. It is equal to $3.0857 \times 10^{16}\ \text{m}$

Light year

It is a unit of length used to express astronomical distance. The distance travelled by light in a vacuum in one year. It is equal to $9.4650 \times 10^{15}\ \text{m}$.

MEASUREMENT OF MASS

Unified atomic mass unit- $u = \frac{1}{12}th$ of the mass of carbon-12 atom.

MEASUREMENT OF TIME

CESIUM CLOCK-we use an atomic standard of time, which is based on the periodic vibrations produced in a cesium atom. This is the basis of cesium clock or atomic clock.

Precision and accuracy

Precision is the degree of uncertainty in a measurement.

Accuracy is how close a measurement is to the true value.

Types of uncertainties

Random uncertainties

Systematic uncertainties

Absolute, relative and percentage Errors

The absolute value or the modulus or the magnitude of the difference between the measured or inferred value a of a quantity A and its actual value a_0, given by

$$\delta a = |a - a_0|$$

is called the absolute error of the quantity A.

The fractional or relative error of the quantity A is the ratio of the mean absolute error to the absolute value of the actual value a_0 of the quantity A, i.e.,

$\frac{\delta a}{|a_0|}$,

The percentage error in the quantity A is

$$\left(\frac{\delta a}{|a_0|} \times 100\right)\%.$$

Errors in algebraic operation

Rule-1

When two physical quantities are added or subtracted the mean absolute error in the result is the sum of their mean absolute errors.

Rule-2

When two physical quantities are multiplied or divided the fractional relative error in the result is the sum of their fractional errors.

When two physical quantities are multiplied or divided the percentage error in the result is the sum of their percentage errors.

Rule-3

The relative error and hence percentage error in a physical quantity raised to the power k is the k times the relative error and percentage error in the quantity.

PROBLEM

The masses of the two bodies measured are $m_1 = (20 \pm 0.5)\,g$, $m_2 = (50 \pm 0.5)\,g$. Calculate the mass difference and the error therein.

SOLUTION- $\Delta m = m_2 - m_1 = (30 \pm 1)\,g$

PROBLEM

If $V = (100 \pm 5)\,\mathrm{V}$, $I = (10 \pm 0.2)\,A$. Find the percentage error in resistance.

SOLUTION- The percentage error in voltage is 5% and percentage error in current is 2%. So the percentage error in resistance is 7%.

PROBLEM We measure the period of oscillation of a simple pendulum. In successive measurements, the readings turn out to be 2.63s, 2.56s, 2.42s, 2.71s, and 2.80s. Calculate the absolute errors, relative error, or percentage error.

Solution The mean period of oscillation is

$$\bar{T} = \frac{2.63 + 2.56 + 2.42 + 2.71 + 2.80}{5}\,s = 2.62s$$

The absolute errors are

$$\Delta T_1 = \left|\bar{T} - T_1\right| = \left|2.62 - 2.63\right| s = 0.01s$$

$$\Delta T_2 = 0.06s$$

$$\Delta T_3 = 0.20s$$

$$\Delta T_4 = 0.09s$$

$$\Delta T_5 = 0.18s$$

The mean absolute error is

$$\overline{\Delta T} = \frac{(0.01 + 0.06 + 0.20 + 0.09 + 0.18)s}{5} = 0.11s$$

So the period of oscillation of the simple pendulum is $(2.62 \pm 0.11)s$

The relative error is $\frac{0.11}{2.62}$, The percentage error is $\left(\frac{0.11}{2.62}\times 100\right)\%$

PROBLEM Find the relative error in Z if $Z = A^4 B^{1/3} / CD^{3/2}$

SOLUTION $4\frac{\Delta A}{A}+\frac{1}{3}\frac{\Delta B}{B}+\frac{\Delta C}{C}+\frac{3}{2}\frac{\Delta D}{D}$

Significant figures

The digits used in a number to specify its accuracy are called significant figures.

It is important, to be honest when reporting a measurement so that it does not appear to be more accurate than the equipment used to make the measurement allows. We can achieve this by controlling the number of **significant figures,** used to report the measurement.

We have the following rules for counting significant figures.

1. **Digits from 1-9 are always significant.**
2. Zeros appearing between nonzero digits are significant, for example, both 4308 and 40.05 contain four significant figures.
3. **Zeros used solely for spacing the decimal point (place holders) are not significant. So z**eros appearing in front of nonzero digits are not significant, because they are only placeholders, for example, 0.093827 has five significant figures 0.0008 has one significant figure 0.012 has two significant figures.
4. Zeros at the end of a number without a decimal point may or may not be significant, and are therefore ambiguous,
5. Trailing zeros that aren't needed to hold the decimal point, i.e., **the additional zeros to the right of both the decimal place and another significant digit are significant.** For example, 4.00 has three significant figures.

6. The significant digit in a number that is furthest to right is called least significant digit. For example, the least significant digit in 3.456 is 6 and in 0.003400 is the rightmost zero.

Significant figures in algebraic operation

Rule-1

When numbers are multiplied or divided, the result has the same number of significant figures as are in the least precise of the factors.

Rule-2

When numbers are added or subtracted, the least significant digit in the result occupies the same relative position as the least significant digit of the quantities being added or subtracted.

Rule-3

Functions such as the sine, arctangent, and exponential functions have the same number of significant figures as their arguments.

PROBLEM-State the number of significant figures in the following

$0.007m^2$, $2.64\times10^{24}kg$, $0.2370g/cm^3$

Ans-1,3,4

PROBLEM-Each side of a cube is measured to be 7.203m. What are the total surface area and volume of the cube to appropriate significant figures?

Solution- Surface area of the cube is $6\times(7.203)^2\,m^2 = 311.3m^2$

The volume of the cube is $(7.203)^3\,m^2 = 373.7m^3$

PROBLEM-5.74g of a substance occupies $1.2cm^3$. Express its density by keeping the significant figures in view.

Solution $\frac{5.74}{1.2} g/cm^3 = 4.8 g/cm^3$

Dimension

The dimension of a physical quantity represents the fundamental quantities, which are present in that quantity.

The dimension of length is L.

The dimension of mass is M.

The dimension of time is T.

The dimension of the electric current is I.

The dimension of the thermodynamic temperature is Θ.

The dimension of the amount of substance is N.

The dimension of luminous intensity is J.

The dimension of some physical quantities

Area

Area A of a rectangle = length $\times$ breadth

So the dimension or dimensional formula of the area is L^2. Symbolically we will write this

$[A] = \mathrm{L}^2$

Volume

The volume V of a rectangular block = area $\times$ height

So,

$[V] = L^3$

Speed and velocity

Speed u = $\frac{\text{distance}}{\text{time}}$

Velocity v = $\frac{\text{displacement}}{\text{time}}$

So,

$[u] = LT^{-1}$

$[v] = LT^{-1}$

PROBLEM Find the dimension of force, power, volume density of mass

Ans MLT^{-2}, ML^2T^{-3}, ML^{-3}

Principle of homogeneity If an equation truly expresses a proper relationship between variables in a physical process, it will be dimensionally homogeneous; i.e., each of its additive terms will have the same dimensions.

Check the correctness of an equation

Derivation of expression for some quantities dimensionally

Role of dimension in unit conversion

PROBLEM Let us consider an equation $\frac{1}{2}mv^2 = mgh$, where m is mass, v is the velocity of the body, g is the acceleration due to gravity, and h is the height. Check whether this equation is dimensionally correct.

Solution

$$\left[\frac{1}{2}mv^2\right] = ML^2T^{-2}$$

$$\left[mgh\right] = MLT^{-2}L = ML^2T^{-2}$$

So the equation is dimensionally correct.

PROBLEM Consider a simple pendulum having a bob attached to a string that oscillates under the action of the force of gravity. Suppose that the period of oscillation of the simple pendulum depends on its length l, mass of the bob m, and acceleration due to gravity g. Derive the expression for its time period using the method of dimensions.

Solution

Let time period t.

Let

$t \propto l^x m^y g^z$ ---eq.(1)

$\Rightarrow t = kl^x m^y g^z$, where k has no dimension

Writing eq.(1) in dimension form, we get

$[t]=[k][l]^x[m]^y[g]^z \Rightarrow T = L^x M^y L^z T^{-2z} = M^y L^{x+z} T^{-2z}$

$\Rightarrow y=0, x+z=0, -2z=1$

$\Rightarrow y=0, x=\frac{1}{2}, z=-\frac{1}{2}$

So

$t = k\sqrt{\frac{l}{g}}$

PROBLEM Find the dimension of A, and B in the equation $F=(m/A)\sin Bt$, where F is force, m is mass, and t is time.

Solution $[m/A]=[F]$ $[A]=[m/F]=\frac{M}{MLT^{-2}}$, $[B]=T^{-1}$

PROBLEM Considering force, mass as fundamental quantities find the dimension of length.