Engineering Physics – I

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Contents

Chapter-1

SI Units and Statics

PHYSICS

The word 'Physics' comes from the Greek word 'phusis' meaning 'nature', introduced by the ancient scientist 'Aristotle'. Man has always been fascinated by nature. So, he questioned and sought answers for every phenomena nature could offer. The branch of science which is devoted to the study of nature and natural phenomena is called Physics. It is expected that all the events in nature takes place according to some basic laws. Physics reveals these basic laws from day-to-day observations.

The knowledge of physics accumulated till 1900 is called classical physics that deals with macroscopic phenomena. It includes subjects like:

- Mechanics
- Thermodynamics
- Electromagnetism, and
- Optics

The recent knowledge (beyond 1900) is termed 'modern physics', consisting of 2 basic theories.

1. Relativity
2. Quantum mechanics

PHYSICS IN RELATION TO SCIENCE, SOCIETY AND TECHNOLOGY

Among the various disciplines of science, the only discipline which can be regarded as being most fundamental is physics.

It has played a key role in the development of all other disciplines.

For example,

Physics in Relation to Chemistry

The study of structure of atoms, radioactivity, X-ray, diffraction, etc., in physics has enabled chemists to rearrange elements in the periodic table and to have a better understanding of chemical bonding and complex chemical structures.

Physics in Relation to Biological Science

The optical microscopes developed in physics are extensively used in the study of biological samples.

Electron microscope, X-rays and radio isotopes are used widely in medical sciences.

Physics in Relation to Astronomy

The giant astronomical telescopes and radio telescopes have enabled the astronomers to observe planets and other heavenly objects.

Physics Related to Mathematics

Mathematics has served as a powerful tool in the development of modern theoretical physics.

Physics Related to other Sciences

The other sciences like Biophysics, Geology, Heterology and Oceanography and Seismology use some of the laws of physics.

Physics Related to Society and Technology

- The development of telephone, telegraph and telex enables us to transmit messages instantly.
- The development of radio and television satellites has revolutionized the means of communication.
- Advances in electronics (computers, calculators and lasers) have greatly enriched the society.
- Rapid means of transport are important for the society.
- Generation of power from nuclear reactors is based on the phenomenon of controlled nuclear chain reaction.
- Digital electronics is widely used in modern technological developments.

UNITS AND DIMENSIONS

Before all the branches of science were clubbed together under the nomenclature ‘Natural philosophy’, under which all observations of subjective nature were being carried out and spirit of enquiry was almost non-existent, we were satisfied with simple explanations.

The subjective interpretation including measurement obviously varies from person-to-person, since the interpretation is based on one’s senses. Gradually, the generations began to ask ‘how’ things are happening. Thus, the observations became more objective and physics – one of the many sciences, became a subject of observation and measurement.

When we quantify, what we are observing, then such an observation is a science or knowledge. However, without the quantification of an observation, thought is simply a process of gaining knowledge, but has yet to reach a stage, to be called a 'science'.

Hence, to call a subject 'science', the thought process ultimately has to be quantified suitably, using appropriate units of measurement.

FUNDAMENTAL AND PHYSICAL QUANTITIES

Length, mass and time are called fundamental physical quantities.

Four Categories of Physical Quantities

Based on dimensions, physical quantity can be classified under four categories.

1. Dimensional Constants

For example, gravitational constant (G), Planck's constant (h) and velocity of light (c)

Their values are always constant.

2. Non-dimensional Constants

The constants having no dimensions.

For example, p, e, 1, 2,3 ....etc.

3. Dimensionless Variables

Angle, specific gravity, strain etc., do not have any dimensions and any constant value and hence, are variables.

4. Dimensional Variable

Velocity, acceleration, density, area, volume, force, etc., have no constant value, but have dimensions.

Measurment

Measurement means comparison of unknown physical quantity with knwon standard fixed quantity.

UNIT

A unit of a quantity is defined as the standard quantity used to measure a physical quantity.

OR

The known fixed standard quantity used to compare unknown physical quantity for its measurement is called as unit of that unknown physical quantity.

The process of measuring a physical quantity has two steps:

(i) Selection of Unit

(ii) To find the numebr of times that unit is contained in that physical quantity.

In order to measusre the length of a table, the unit selected is that of length. If metre is the unit used, a metre rod is used to measure the length and if the table length is thrice the length of the metre rod, then the unmerical value of length of the table is 3.

i.e., Table length $= 3 \times 1$ m = 3m

In general, measure of a physical quantity = numerical value of physical quantity x size of its unit

i.e., x = nu

where x = quantity to be measured for selected unit

n = numerical value of physical quantity

u = size of the unit

If size of the chosen unit is small, then numerical value is large and vice-versa. But measure of physical quantity is always the same.

nu = contant

If n_1 and n_2 are numerical values of physical quantities for units u_1 and u_2., then $n_1 u_1 = n_2 u_2$.

TYPES OF UNITS

Fundamental and Derived Units

The units used to measure three fundamental physical quantities, mass length and time are called **fundamental units.** They are m, kg and sec. These units can neither be derived from one another nor can be resolved into other units. They are independent to each other.

Derived Units

The units which are derived from fundamental units to measure all physical quantities except mass, length and time.

Units of physical quantities can be expressed in terms of fundamental units and such units are called derived units.

Unit of area can be an example for derived unit. If L is the length of square then $L \times L = L^2$ is its area. Similarly, the volume of a cube is $L \times L \times L = L^3$ cubic area. Units of any physical quantity can be derived from its defining equation.

For example, $\text{Speed} = \dfrac{\text{Distance covered}}{\text{Time taken}}$

$$\text{Unit of speed} = \frac{\text{Unit of distance (length)}}{\text{Unit of time taken}}$$

$$= \frac{\text{Metre}}{\text{Second}}$$

$$= \text{ms}^{-1}$$

The characteristics of several chosen units are:

- they must not vary with place and time.
- should be easily reproducible.
- should be well-defined.
- should be of proper size.
- should not change easily with the changing physical conditions like temperature, pressure etc.
- should be accessible, i.e., not too small when compared to the quantities to be measured.

System of units

Following are the common system of units to measure mass, length and time.

CGS: Fundamental units of length, mass and time are centimeter, gram and second.

MKS: Fundamental units of length, mass and time are metre, kilogram and second. It is a coherent system of units in mechanics.

FPS: Known as British system of units, it is not a metric system. It stands for foot, pound and second. Its use is declining in scientific work.

SI: It is a new system introduced by general conference of Weights and Measures in 1960. It is called “Le Systeme International d’ Unites”.

It has seven basic and three supplementary units

Basic physical quantity	***Unit***	***Symbol***
Length	metre	m
Mass	kilogram	kg
Time	Second	s
Temperature	kelvin	K
Electric current	ampere	A

Luminous intensity	candela	cd
Quantity of matter	mole	mol

Supplementary quantities and their units

Physical quantity	**Unit**	**Symbol**
Plane angle	radian	rad
Solid angle	Steradian	sr
Radioactivity	Curie	ci

Abbreviations in powers of 10 (used in SI units)

Prefixes are used for large and small quantities. The following table gives prefixes, their symbol and their values in powers of 10, as used in SI units.

Prefix	*Symbol*	*Power of* 10
deci	d	10^{-1}
deka	da(D)	10^{1}
centi	c	10^{-2}
hecto	h	10^{2}
milli	m	10^{-3}
kilo	k	10^{3}
micro	ì	10^{-6}
mega	M	10^{6}
nano	n	10^{-9}
giga	G	10^{9}
pico	P	10^{-12}
tera	T	10^{12}
femto	f	10^{-15}
peta	P	10^{15}
atto	a	10^{-18}
exa	E	10^{18}
zepta	z	10^{-21}
zetta	Z	10^{21}
yocto	y	10^{-24}
(yotto)	Y	10^{24}

Among the systems of units mentioned above, the SI units, i.e., Le systeme internationale d' unites, is a new, comprehensive and rationalized system of units, accepted by the 11^{th} conference of weights and measures in 1960. It is used in science and technology all over the world, because of the following advantages over others.

Characteristics of SI Unit

- The units are more logical and coherent.

- The units are more easily reproducible.
- The units do not change with time as they are based on the properties of an atom.
- The units are more rationalized viz., heat energy, electric energy and mechanical energy are measured in joule (J).
- The units are more comprehensive, covering all disciplines of science and technology.
- The units are convertible into CGS system very easily, whenever needed.
- The units are a metric system in multiples and subsequently, can be expressed as the powers of 10.

However, the SI units are governed by the following rules:

- Full names of the units do not begin with capital letter.

For example, newton and not Newton.

- The symbols of units, named after scientists, have initial capital letter.

For example, J for joule, K for Kelvin.

- Symbols do not have plural form.

For example, 5 kg (not 5 kgs), 25 m (not 25 metres).

- A unit symbol is represented by the first letter of the unit name and no full stop, comma or colon is put after the symbol, with a few exceptions like Hz, Pa, cd and mol.
- Multiplication of units is neither shown by leaving a space nor by using crosses or dots.

For example, Nm and not N m or N × m.

- Division of units is indicated by use of a stroke (/) sign (not more than one line) or –ve powers.

For example m/s or ms^{-1} kg/m^3 or kgm^{-3} $wm^{-1}k^{-1}$ and not w/m/k.

- A zero precedes a decimal.

For example, 0.7 kg and not .7 kg

- Compound prefixes should be avoided.
- A hyphen is not put in-between the number and the unit, when the number is used as an adjective.

For example, 16 mm film. For writing the thickness of a glass of 10 mm, it is written as 10 mm and not 10-mm.

- A space must be left between a number and a unit.

For example, 6 kg and not 6kg

L, M, T UNITS

Length

The shortest distance between the two ends of a body is its length. During 1120 A.D., the King of England had enforced the usage of 'Yard' in his country, as the unit of length, which was equal to the distance from the tip of his nose to the end of his out stretched arm. Similarly, the King of France had declared the length of the Royal foot of the King as a measure and called it one foot. But in 1799, the foot was replaced by 'metre', equal to one-tenmillionth the distance of the equator to the north pole along a longitudinal line that passes through Paris.

In 1889, 1 metre was defined as the distance between 2 lines on a specific platinum-iridium bar stored under controlled conditions near Paris. Since the *S* and *T* demanded more precise standard, in 1960, 1 metre was redefined as 1, 650, 763.73 wavelengths of a particular orange-red light emitted by atoms of krypton-86 in a gas discharge tube. But of late, 1 metre is defined as the length of the path travelIed by light in vacuum during a time interval of 1/299, 792, 458 of a second. This unit is believed to be absolutely constant.

OTHER UNITS OF LENGTH IN VOGUE

Planck length

Distance travelled by light in a time interval of one planck time, the shortest distance possible, is 10^{-43} m.

Fermi (F)

One fermi = 10^{-15} m used to measure nuclear dimensions.

Angstrom (A)

One angstrom = 10^{-10} m used to measure atomic dimensions.

Astronomical unit (AU)

It is used in measuring long distances converted with solar studies in astronomy.

1 Au = 1.496×10^{11}m, the mean distance between the Sun and the Earth.

Light year (1 yr) is the distance travelled by light in vacuum in one year.

$$\begin{aligned} \text{Distance} &= \text{velocity} \times \text{time} \\ \text{One light year} &= 3 \times 10^{8} \text{ m/s} \times 1 \\ &= 3 \times 10^{8} \times 365 \times 24 \times 60 \times 60 \times \text{m/s} \times \text{s} \\ &= 9.46 \times 10^{15} \text{ m} \end{aligned}$$

This unit is used to measure intergalactic distances as well as stellar distances.

Parallactic second

The distance at which the mean radius of the Earth's orbit subtends an angle of one second of arc.

$$\text{Radius} = \frac{\text{Arc length}}{\text{Angle between the radii}}$$

$$1 \text{ parsec} = \frac{1 \text{ AU}}{1 \sec \text{of arc}}$$

$$= \frac{1.496 \times 10^{11}}{\pi/180 \times 1/3600}$$

$$= 3.0857 \times 10^{16} \text{ m}$$

Note:

- 1 Au = 1.496×10^{11} m
- 1 ly = 9.46×10^{15} m
- 1 parsec = 3.0857×10^{16} m
- 1 F = 10^{-15} m
- •$1 \mathring{A} = 10^{-10}$ m
- 1 micron or 1mm = 10^{-6} m

DIMENSIONAL FORMULAE AND DIMENSIONAL EQUATION

Dimensional Formula

It is the term which tells about the power with which a fundamental quantity is contained in a physical equation i.e. how much is the value of M,L, and T in any pysical quantity.

E.g., Dimensional formula of velocity is [LT^{-1}] that of density is [ML^{-3}] it means velocity has one unit of lenght, one inverse unit of time and zero unit of mass. Density has one unit of mass, three inverse unit of length and zero unit of time.

Dimensional equation 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.

Derivation of Dimensional Formula

When velocity is defined using the fundamental units of mass, length and time, we have 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.
- In the unit of velocity, the power of L and T are 1 and –1 respectively.

For example, 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 is given below:

Physical quantity	***Relation with other qauntities***	***Dimensional formula***
Areas	Length × Breadth	$L \times L = L^2 = [M^0L^2T^0]$
Volume	Length × Breadth × Height	$L \times L = L^3 = [M^0L^3T^0]$
Density	$\frac{\text{Mass}}{\text{Volume}}$	$\frac{M}{L^3} = \left[ML^{-3}T^0\right]$
Speed of velocity	$\frac{\text{Distance}}{\text{Time}}$	$\frac{L}{T} = \left[M^0LT^{-1}\right]$
Acceleration	$\frac{\text{Velocity}}{\text{Time}}$	$\frac{LT^{-1}}{T} = \left[M^0LT^{-2}\right]$
Momentum	Mass × Velocity	$M \times LT^{-1} = \left[MLT^{-1}\right]$
Force	Mass × Acceleration	$M \times LT^{-2} = \left[MLT^{-2}\right]$
Pressure	$\frac{\text{Force}}{\text{area}}$	$\frac{MLT^{-2}}{L^2} = \left[ML^{-1}T^{-2}\right]$
Work	Force × distance	

Energy (mechanical, heat, light etc.)	Work	$M L^2T^2$
Power	$\frac{\text{Work}}{\text{Time}}$	$\frac{ML^2T^{-2}}{T} = ML^2T^{-3}$

Physical quantity	***Relation with other qauntities***	***Dimensional formula***
Moment of force	Force × Perpendicular distance	$MLT^{-2} \times L = ML^2T^{-2}$
Gravitation constant	$\frac{\text{Force} \times (\text{distance})^2}{\text{Mass} \times \text{mass}}$	$\frac{MLT^{-2} \times L^2}{M \times M} = \left[M^{-1}L^3T^{-2}\right]$
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	$\frac{\text{Change in dimension}}{\text{Original dimension}}$	dimensionsless
Coefficienty of elasticity	$\frac{\text{Stress}}{\text{Strain}}$	$\frac{ML^{-1}T^{-2}}{1} = [ML^{-1}T^{-2}]$
Surface tension	$\frac{\text{Force}}{\text{Length}}$	$\frac{MLT^{-2}}{L} = [M^0L^0T^2]$
Surface energy	$\frac{\text{Energy}}{\text{Area}}$	$\frac{ML^2T^2}{L^2} = [M^0L^0T^2]$
Velocity gradient	$\frac{\text{Velocity}}{\text{Distance}}$	$\frac{LT^{-1}}{L} = [M^0L^0T^{-1}]$
Coefficient of velocity	$\frac{\text{Force}}{\text{Area} \times \text{velocity gradient}}$	$\frac{MLT^{-2}}{L^2 \times T^{-1}} = [ML^{-1}T^{-1}]$
Radius of gyration	Distance	$[M^0L T^0]$

Moment of inertia	Mass × (radius of gyration)^2	$M \times L^2 = [ML^2T^0]$
Angle	$\frac{\text{Arc}}{\text{Radius}}$	Dimensions
Angular velocity	$\frac{\text{Angle}}{\text{Time}}$	$\frac{1}{T} = [M^0L^0T^{-1}]$
Physical quantity	***Relation with other qauntities***	***Dimensional formula***
Angular acceleration	$\frac{\text{Anglular velocity}}{\text{Time}}$	$\frac{T^{-1}}{T} = [M^0L^0T^{-2}]$
Angular momentum	Moment of inertia × Angular velocity	$ML^2 \times T^{-1} = [ML^2T^{-1}]$
Torque or couple	Force × perpendicular Distance	$MLT^{-2} \times L = [ML^2T^{-2}]$
Frequency	$\frac{1}{\text{Time period}}$	$\frac{1}{T} = [M^0L^0T^{-1}]$

Principle of Homogeneity of Dimensional

It states that the dimensions of each term on both the sides of any equation must be same.

Uses of dimensional analysis

1. To check the dimensional correctness of a given physical relation
   Example,
   To check the correctness of $v = u +$ at, using dimensions
   Dimensional formula of final velocity $v = [LT^{-1}]$
   Dimensional formula of initial velocity $u = [LT^{-1}]$
   Dimensional formula of acceleration x time, at $= [LT^{-2} \times T]$
   $= [LT^{-1}]$

Dimensions on both sides of each term is the same. Hence, the equation is dimensionally correct.

2. To convert a physical quantity from one system of units to another.
   The value of a physical quantity can be obtained in some other system, when its value in one system is given using the method of dimensional analysis.

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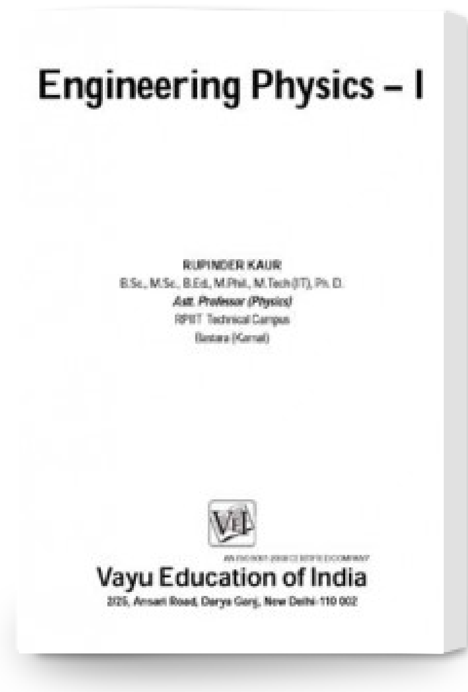

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