NEET Revision Notes
Physics
Units and Measurements

Physical quantities: The quantities that describe the physics laws are called physical quantities. In physics, a physical quantity is defined as a system that can be quantified and measured using numbers. A physical quantity is completely specified if it has:

- Numerical value only
  Example: Ratio, refractive index, dielectric constant etc.
- Magnitude only
  Example: Scalars, length, mass etc.
- Both magnitude and direction
  Example: Vectors, displacement, torque etc.

In general, expressing the magnitude of a physical quantity, we choose a unit and how many times that unit is contained in the physical quantity.

Types:

- **Fundamental quantities:**
  - The quantities not depend on other quantities for complete definition are called fundamental quantities.
  - Length, mass, time, electric current, temperature, amount of substance and luminous intensity are the seven fundamental quantities.
- **Derived quantities:**
  - The quantities derived from the base or fundamental quantities are called derived quantities.
  - Speed, velocity, electric field etc. are some examples.
  - For example: we define speed to be $\text{speed} = \frac{\text{distance}}{\text{time}}$ i.e. it is derived from two fundamental quantities distance and time. Similarly, we can derive a derived quantity from two or more fundamental quantities.

Unit and its characteristics:

A unit is the quantity of a constant magnitude used to measure the magnitude of other quantities holding the same behaviour.

The magnitude of a physical quantity is expressed as
$\text{physical quantity} = (\text{numerical}) \times (\text{unit})$

- It should be of convenient size.
- It should be well defined.
- It should be easily available so that as many laboratories duplicate it.
- It should not change with time and place.
- It should not change with the change in physical conditions.
- It should be universally agreed upon so that results obtained in different situations are comparable.

Fundamental and Derived units:

- **Fundamental units:** The units chosen for measuring fundamental quantities are known as fundamental units.
  Example: kilogram, metre etc.
- **Derived units:** The units expressed in terms of the base units are called derived units.
  Example: speed, energy etc.

System of units: A complete set of fundamental and derived for all kinds of physical quantities is called a system of units.
A few common systems are

- **CGS (centimetre-gram-second) system:**
  This system is based on a variant of the metric system based on the centimetre as the unit of length, the gram as the unit of mass, and the second as the unit of time.
- **FPS (foot-pound-second) system:**
  This system is based on a variant of the metric system based on the foot as the unit of length, the pound as the unit of mass, and the second as the unit of time.
- **MKS (metre-kilogram-second) system:**
  This system is based on a variant of the metric system based on the metre as the unit of length, the kilogram as the unit of mass, and the second as the unit of time.

An international system of units (SI):

The system of units that is internationally accepted for measurement is abbreviated as SI units.
They are:

Physical quantity	Name of the unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd
Plane angle	radian	rad
Solid angle	Steradian	sr

Radian and steradian:

- Radian is the angle subtended at the centre of a circle by an arc equal in length to the radius of the circle.
- Steradian is the solid angle subtended at the centre of a sphere by that sphere's surface, which is equal in area to the square of the sphere's radius.

Practical units:

Practical Units	Values
1AU	1.496×10^{11} m
1 light-year	9.46×10^{15} m
1 parsec	3.08×10^{16} m
1 micron	10^{-6} m
1 angstrom	10^{-10} m
1 fermi	10^{-15} m
1 amu	1.66×10^{-27} m
1 lunar month	29.5 days
1 solar day	86400 s

Conversion factors:

- To convert a physical quantity from one set of units to the other, the required multiplication factor is the conversion factor.
- Magnitude of a physical quantity = numerical quantity*unit
- It means that the numerical value of a physical quantity is inversely proportional to the base unit.
  Example: 1m = 100cm = 3.28ft = 39.4inch

Dimensional analysis:

- Dimensions of a physical quantity are the powers to which the base quantities are raised to represent the quantity.
- Dimensional formula of any physical quantity is that expression which represents how and which of the basic quantities with appropriate powers in square brackets.
- The equation obtained by equating a physical quantity with its dimensional formula is called a dimensional equation.

Examples:

$$\text{Velocity } = \frac{\text{Displacement}}{\text{Time}}$$

$$v = \frac{\text{Dimension of length}}{\text{Dimension of time}} = LT^{-1}$$

Other examples:

Physical Quantity	Dimensional Formula	SI Unit
Area	L^2	m^2
Volume	L^3	m^3
Density	ML^{-3}	kgm^{-3}
Frequency	T^{-1}	Hz or s^{-1}
Speed/Velocity	LT^{-1}	ms^{-1}
Force	MLT^{-2}	N
Acceleration	LT^{-2}	ms^{-2}
Strain	$M^0L^0T^0$	No units
Surface tension	MT^{-2}	Nm^{-1}
Torque	ML^2T^{-2}	Nm^1
Critical velocity	LT^{-1}	ms^{-1}
Specific heat capacity	$L^2T^{-2}K^{-1}$	$Jkg^{-1}K^{-1}$
Electric field	$MLT^{-3}A^{-1}$	NC^{-1}
Inductance	$ML^2T^{-2}A^{-2}$	H or Henry
Fluid flow rate	L^3T^{-1}	m^3s^{-1}

Note: Other units are derived from their respective formulas

Applications:

- To check the dimensional correctness of a given physical relation.
- To convert a physical quantity from one system of units to the other

Example:

Pressure is given by the formula $P = \frac{F}{A}$

Thus the dimensional formula of pressure is

$$P = \frac{F}{A} = \frac{MLT^{-2}}{L^2} = ML^{-1}T^{-2}$$

In SI units, 1 Pascal $= kgms^{-2}$.

In CGS units, 1 Pascal $= gcms^{-2}$.

Thus,

$$\frac{1\text{ pascal}}{1\text{ CGS pressure}} = \frac{1kg}{1g} \times \left(\frac{1m}{1cm}\right)^{-1} \times \left(\frac{1s}{1s}\right)^{-2}$$

$$= (10)^3 \times \left(10^2\right)^{-1} = 10\text{CGS pressure}$$

Therefore, 1 Pascal = 10 CGS pressure

- Deducing relationships among the physical quantities
- To find the dimensions of constants in a relation

Limitations:

- If dimensions are given, the physical quantity may not be unique as many physical quantities have same dimensions.
- Numerical constants [K] having no dimensions, cannot be deduced by the method of dimensions.
- The method of dimensions cannot be used to derive relations other than the product of power functions.
- The method of dimensions cannot be applied to derive a formula if a formula depends on more than 3 physical quantities.

Principle of homogeneity:

Principle of homogeneity on dimensions states that the dimensions of equations of each term on both sides of an equation must be the same i.e. LHS = RHS policy in dimensions.

Example:

Consider the formula: $F = \frac{mv^2}{r}$ for centripetal acceleration

We have the dimensions:

$$F = \frac{mv^2}{r}$$

$$MLT^{-2} = \frac{M\left[LT^{-1}\right]^2}{L}$$

$$MLT^{-2} = MLT^{-2}$$

Thus, the formula is dimensionally correct according to the principle of homogeneity.

Errors in measurements:

The difference between the true value and the measured value of a quantity is known as the error of measurement.

Classification:

- **Systematic errors:** Systematic errors are errors whose causes are known. They can be either positive or negative. They are further classified as:
    1. Instrumental errors
    2. Environmental errors
    3. Observational errors
- **Random errors:** Random errors are errors caused due to unknown reasons. Therefore they occur irregularly and are variable in magnitude and sign conventions.
- **Gross error:** Gross error arise due to human carelessness and mistakes in reading the instruments or calculating and recording the measurement values and results.

Representation of errors:

- **Absolute error:** The difference in the magnitude of the true value and the measured value of a physical quantity is called absolute error.
  Absolute error = True value – Measured value
- **Mean absolute error:** The arithmetic mean of absolute error is called mean absolute error.
- **Relative error:** The ratio of mean absolute error to the true value is called Relative error.
  $r = \frac{\overline{\Delta a}}{\overline{a}}$ Where the numerator is absolute error and denominator is the true value.
- **Least count:** The smallest value of a physical quantity measured accurately with an instrument is called the least count of the measuring instrument.

Accuracy and precision:

- The accuracy is a measure of how close the measured value is to the true value.
- Precision tells us to what resolution or limit the quantity is measured by the measuring instrument, which is done by calculating the least count.

Significant figures:
All accurately known digits in measurement plus the uncertain digit together form significant figures.
Rules:

- All non-zero digits are significant
- All zeros between two non-zero digits are significant.
- If the number is less than one, the zeros on the right of the decimal are significant, but to the left are not significant.
- If a number is non-decimal, the terminal zeros are non-significant.
- If a number with a solution decimal point and trailing zeros are significant.
- If the ending number is more than 5, we round off to the next number, and less would be the same number.

Example:

- 3.200 has 4 significant figures
- 0.008 has 1 significant figure
- 6.87 is rounded off to 6.9.

Points to remember:

- The quantities that describe the laws of physics are called physical quantities. In physics, a physical quantity is defined as a system that can be quantified and measured using numbers.
- Types of physical quantities are fundamental and derived quantities.
- Unit is the quantity of a constant magnitude used to measure the magnitude of other quantities holding the same behaviour.
- Types of units are fundamental and derived units.
- A complete set of fundamental and derived units for all kinds of physical quantities is called a system of units.
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- Some of them are: FPS, CGS and MKS systems.
- The system of units, which is internationally accepted for measurement, is abbreviated as SI units.
- Some of the SI units are: m, kg, cm, candela etc. and many other units.
- Magnitude of a physical quantity = numerical quantity*unit
- Dimensions of a physical quantity are the powers to which the base quantities are raised to represent the quantity.

- Dimensional formula of any physical quantity is that expression representing how and which of the basic quantities with appropriate powers in square brackets.
- The equation obtained by equating a physical quantity with its dimensional formula is called a dimensional equation.
- It is used to check a physical quantity, convert a quantity from one system to another, Derive relationships between physical quantities etc.
- Principle of homogeneity: The principle of homogeneity on dimensions states that the dimensions of equations of each term on both sides of an equation must be the same, i.e. LHS = RHS policy in dimensions.
- The difference between the true value and the measured value of a quantity is known as the measurement error.
- Types: Absolute error, Mean absolute error, Relative error, Percentage error.
- The smallest value of a physical quantity measured accurately with an instrument is called the least count of the measuring instrument.
- The accuracy is a measure of how close the measured value is to the true value.
- Precision tells us to what resolution or limit the quantity is measured by the measuring instrument, which is done by calculating the least count.
- All accurately known digits in measurement plus the uncertain digit together form significant figures.

Formulas used:

- Absolute error: True value – Measured value
- $r = \frac{\overline{\Delta a}}{\overline{a}}$ where r is relative error
- Mean absolute error: $M = \sum_{0}^{i} \Delta a_i$
- Percentage error: $r_0 = \frac{\overline{\Delta a}}{\overline{a}} \times 100$
- If X= $A^p B^q C^r$ or in any form, Then propagation of error is: $\frac{\Delta x}{x} = \left[p\left(\frac{\Delta A}{A}\right) + q\left(\frac{\Delta B}{B}\right) + r\left(\frac{\Delta C}{C}\right) \right]$.

General points and errors to be noted:

- Please the question twice or thrice before attending them.
- Formulas and their units should be remembered carefully to check dimensions for a given quantity.
- Formula mistake in errors are to be avoided etc.

Example:

1) If the error in the measurement of radius of a sphere is 2%, then the error in determination of volume would be:

a) 8% **b) 2%** **c) 4%** **d) 6%**

Answer: d) 6%

Solution: We know that, Volume of sphere:

$$V = \frac{4}{3}\pi r^3$$

Applying logarithm on both sides;

$$\ln(V) = \ln(\frac{4}{3}\pi r^3)$$

Differentiating - V;

$$\frac{dv}{V} = 3\frac{dR}{R}$$

As, we know the constant value is k=3, then:

Error = $3 \times 2 = 6\%$

2) Given a quantity whose different readings on an experiment where:

NO OF TRIALS	READINGS
1	10.5
2	12

Find the percentage error.

a) 1.23% **b) 0.87%** **c) 0.43%** **d) 0.95%**

Answer: c) 0.43%

Solution:

$$\bar{a} = \frac{10.5 + 12.4}{2} = \frac{22.9}{2} = 11.4$$

$$\Delta a_1 = \bar{a} - a_1 = 11.4 - 10.5 = 0.9$$

$$\Delta a_2 = \bar{a} - a_2 = 11.4 - 12.4 = -1.0$$

$$\overline{\Delta a} = \frac{0.9 - 1.0}{2} = 0.05$$

$$r_0 = \frac{0.05}{11.4} \times 100 = 0.43\%$$