Universal Convent Sr Sec School Kaladhungi
Subject Physics
Class 11th
Topic: Unit and Measurement

Physics Notes Class 11 CHAPTER 2 UNITS AND MEASUREMENTS

The comparison of any physical quantity with its standard unit is called **measurement.**

Physical Quantities

All the quantities in terms of which laws of physics are described, and whose measurement is necessary are called physical quantities.

Units

- A definite amount of a physical quantity is taken as its standard unit.
- The standard unit should be easily reproducible, internationally accepted.

Fundamental Units

Those physical quantities which are independent to each other are called fundamental quantities and their units are called fundamental units.

S.No.	Fundamental Quantities	Fundamental Units	Symbol
1.	Length	metre	m
2.	Mass	kilogram	kg
3.	Time	second	S
4.	Temperature	kelvin	kg
5	Electric current	ampere	A
6	Luminous intensity	candela	cd
7	Amount of substance	mole	mol

Supplementary Fundamental Units

Radian and steradian are two supplementary fundamental units. It measures plane angle and solid angle respectively.

S.No.	Supplementary Fundamental Quantities	Supplementary Unit	Symbol
1	Plane angle	radian	rad
2	Solid angle	steradian	Sr

Derived Units

Those physical quantities which are derived from fundamental quantities are called derived quantities and their units are called derived units.
e.g., velocity, acceleration, force, work etc.

Definitions of Fundamental Units

The seven fundamental units of SI have been defined as under.

1. **1 kilogram** A cylindrical prototype mass made of platinum and iridium alloys of height 39 mm and diameter 39 mm. It is mass of 5.0188×10^{25} atoms of carbon-12.
2. **1 metre** 1 metre is the distance that contains 1650763.73 wavelength of orange-red light of Kr-86.
3. **1 second** 1 second is the time in which cesium atom vibrates 9192631770 times in an atomic clock.
4. **1 kelvin** 1 kelvin is the (1/273.16) part of the thermodynamics temperature of the triple point of water.
5. **1 candela** 1 candela is (1/60) luminous intensity of an ideal source by an area of cm' when source is at melting point of platinum (1760°C).
6. **1 ampere** 1 ampere is the electric current which it maintained in two straight parallel conductor of infinite length and of negligible cross-section area placed one metre apart in vacuum will produce between them a force 2×10^{-7} N per metre length.
7. **1 mole** 1 mole is the amount of substance of a system which contains a many elementary entities (may be atoms, molecules, ions, electrons or group of particles, as this and atoms in 0.012 kg of carbon isotope $_6C^{12}$.

Systems of Units

A system of units is the complete set of units, both fundamental and derived, for all kinds of physical quantities. The common system of units which is used in mechanics are given below:

1. **CGS System** In this system, the unit of length is centimetre, the unit of mass is gram and the unit of time is second.
2. **FPS System** In this system, the unit of length is foot, the unit of mass is pound and the unit of time is second.
3. **MKS System** In this system, the unit of length is metre, the unit of mass is kilogram and the unit of time is second.
4. **SI System** This system contain seven fundamental units and two supplementary fundamental units.

Relationship between Some Mechanical SI Unit and Commonly Used Units

S.No.	Physical Quantity	Unit
1	Length	(a) 1 micrometre = 10^{-6} m (b) 1 angstrom = 10^{-10} m
2	Mass	(a) 1 metric ton = 10^3 kg

		(b) 1 pound = 0.4537 kg
		(c) 1 amu = 1.66×10^{-23} kg
3	Volume	1 litre = 10^{-32} m^3
4.	Force	(a) 1 dyne = 10^{-5} N
		(b) 1 kgf = 9.81 N
5.	Pressure	(a) 1 $kgfm^2$ = $9.81 Nm^{-2}$
		(b) 1 mm of Hg = 133 Nm^{-2}
		(c) 1 pascal = 1 Nm^{-2}
		(d) 1 atmosphere pressure = 76 cm of Hg = 1.01×10^5 pascal
6.	Work and energy	(a) 1 erg = 10^{-7} J
		(b) 1 kgf-m = 9.81 J
		(c) 1 kWh = 3.6×10^6 J
		(d) 1 eV = 1.6×10^{-19} J
7.	Power	(d) 1 kgf- ms^{-1} = 9.81W
		1 horse power = 746 W

Some Practical Units

1. 1 fermi = 10^{-15} m
2. 1 X-ray unit = 10^{-13} m
3. 1 astronomical unit = 1.49×10^{11} m (average distance between sun and earth)
4. 1 light year = 9.46×10^{15} m
5. 1 parsec = 3.08×10^{16} m = 3.26 light year

Some Approximate Masses

Object	**Kilogram**
Our galaxy	2×10^{41}
Sun	2×10^{30}
Moon	7×10^{22}
Asteroid Eros	5×10^{15}

Dimensions

Dimensions of any physical quantity are those powers which are raised on fundamental units to express its unit. The expression which shows how and which of the base quantities represent the dimensions of a physical quantity, is called the dimensional formula.

Dimensional Formula of Some Physical Quantities

S.No.	**Physical** Quantity	**Dimensional** Formula	**MKS** Unit

1	Area	$[L^2]$	metre^2
2	Volume	$[L^3]$	metre^3
3	Velocity	$[LT^{-1}]$	ms^{-1}
4	Acceleration	$[LT^{-2}]$	ms^{-2}
5	Force	$[MLT^{-2}]$	newton (N)
6	Work or energy	$[ML^2T^{-2}]$	joule (J)
7	Power	$[ML^2T^{-3}]$	J s^{-1} or watt
8	Pressure or stress	$[ML^{-1}T^{-2}]$	Nm^{-2}
9	Linear momentum or Impulse	$[MLT^{-1}]$	kg ms^{-1}
10	Density	$[ML^{-3}]$	kg m^{-3}
11	Strain	Dimensionless	Unitless
12	Modulus of elasticity	$[ML^{-1}T^{-2}]$	Nm^{-2}
13	Surface tension	$[MT^{-2}]$	Nm^{-1}
14	Velocity gradient	T^{-1}	second^{-1}
15	Coefficient of velocity	$[ML^{-1}T^{-1}]$	kg $m^{-1}s^{-1}$
16	Gravitational constant	$[M^{-1}L^3T^{-2}]$	Nm^2/kg^2
17	Moment of inertia	$[ML^2]$	kg m^2
18	Angular velocity	$[T^{-1}]$	rad/s
19	Angular acceleration	$[T^{-2}]$	rad/S^2
20	Angular momentum	$[ML^2T^{-1}]$	kg m^2S^{-1}
21	Specific heat	$L^2T^{-2}\theta^{-1}$	kcal $kg^{-1}K^{-1}$
22	Latent heat	$[L^2T^{-2}]$	kcal/kg
23	Planck's constant	ML^2T^{-1}	J^{-s}
24	Universal gas constant	$[ML^2T^{-2}\theta^{-1}]$	J/mol-K

Homogeneity Principle

If the dimensions of left hand side of an equation are equal to the dimensions of right hand side of the equation, then the equation is dimensionally correct. This is known as **homogeneity principle.**

Mathematically [LHS] = [RHS]

Applications of Dimensions

1. To check the accuracy of physical equations.
2. To change a physical quantity from one system of units to another system of units.
3. To obtain a relation between different physical quantities.

Significant Figures

In the measured value of a physical quantity, the number of digits about the correctness of which we are sure plus the next doubtful digit, are called the significant figures.

Rules for Finding Significant Figures

1. All non-zeros digits are significant figures, e.g., 4362 m has 4 significant figures.
2. All zeros occuring between non-zero digits are significant figures, e.g., 1005 has 4 significant figures.
3. All zeros to the right of the last non-zero digit are not significant, e.g., 6250 has only 3 significant figures.
4. In a digit less than one, all zeros to the right of the decimal point and to the left of a non-zero digit are not significant, e.g., 0.00325 has only 3 significant figures.
5. All zeros to the right of a non-zero digit in the decimal part are significant, e.g., 1.4750 has 5 significant figures.

Significant Figures in Algebric Operations

(i) In Addition or Subtraction In addition or subtraction of the numerical values the final result should retain the least decimal place as in the various numerical values. e.g.,

If $l_1 = 4.326$ m and $l_2 = 1.50$ m

Then, $l_1 + l_2 = (4.326 + 1.50)$ m $= 5.826$ m

As l_2 has measured upto two decimal places, therefore

$l_1 + l_2 = 5.83$ m

(ii) In Multiplication or Division In multiplication or division of the numerical values, the final result should retain the least significant figures as the various numerical values. e.g., If length $l = 12.5$ m and breadth $b = 4.125$ m.

Then, area $A = l \times b = 12.5 \times 4.125 = 51.5625\ m^2$

As l has only 3 significant figures, therefore

$A = 51.6\ m^2$

Rules of Rounding Off Significant Figures

1. If the digit to be dropped is less than 5, then the preceding digit is left unchanged. e.g., 1.54 is rounded off to 1.5.
2. If the digit to be dropped is greater than 5, then the preceding digit is raised by one. e.g., 2.49 is rounded off to 2.5.
3. If the digit to be dropped is 5 followed by digit other than zero, then the preceding digit is raised by one. e.g., 3.55 is rounded off to 3.6.
4. If the digit to be dropped is 5 or 5 followed by zeros, then the preceding digit is raised by one, if it is odd and left unchanged if it is even. e.g., 3.750 is rounded off to 3.8 and 4.650 is rounded off to 4.6.

Error

The lack in accuracy in the measurement due to the limit of accuracy of the instrument or due to any other cause is called an error.

1. Absolute Error

The difference between the true value and the measured value of a quantity is called absolute error.

If a_1 , a_2, a_3 ,…, a_n are the measured values of any quantity a in an experiment performed n times, then the arithmetic mean of these values is called the true value (a_m) of the quantity.

$$a_m = \frac{a_1 + a_2 + a_3 + \ldots + a_n}{n}$$

The absolute error in measured values is given by

$\Delta a_1 = a_m - a_1$
$\Delta a_2 = a_m - a_1$

…………

$\Delta a_m = \Delta a_m - \Delta a_n$

2. Mean Absolute Error

The arithmetic mean of the magnitude of absolute errors in all the measurement is called mean absolute error.

$$\overline{\Delta a} = \frac{|\Delta a_1| + |\Delta a_2| + \ldots + |\Delta a_n|}{n}$$

3. Relative Error The ratio of mean absolute error to the true value is called relative

$$\text{Relative error} = \frac{\text{Mean absolute error}}{\text{True value}} = \frac{\overline{\Delta a}}{a_m}$$

4. Percentage Error The relative error expressed in percentage is called percentage error.

$$\text{Percentage error} = \frac{\overline{\Delta a}}{a_m} \times 100\%$$

Propagation of Error

(i) Error in Addition or Subtraction Let x = a + b or x = a – b

If the measured values of two quantities a and b are (a ± Δa and (b ± Δb), then maximum absolute error in their addition or subtraction.

Δx = ±(Δa + Δb)

(ii) Error in Multiplication or Division Let x = a x b or x = (a/b).
If the measured values of a and b are (a ± Δa) and (b ± Δb), then maximum relative error

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

EXERCISES

Note : In stating numerical answers, take care of significant figures.

2.1 Fill in the blanks

(a) The volume of a cube of side 1 cm is equal to .....m^3

(b) The surface area of a solid cylinder of radius 2.0 cm and height 10.0 cm is equal to ...$(mm)^2$

(c) A vehicle moving with a speed of 18 km h^{-1} covers....m in 1 s

(d) The relative density of lead is 11.3. Its density is ....g cm^{-3} or ....kg m^{-3}.

2.2 Fill in the blanks by suitable conversion of units

(a) 1 kg m^2 s^{-2} = ...g cm^2 s^{-2}

(b) 1 m = ... ly

(c) 3.0 m s^{-2} = ... km h^{-2}

(d) $G = 6.67 \times 10^{-11}$ N m^2 $(kg)^{-2}$ = ... $(cm)^3$ s^{-2} g^{-1}.

2.3 A calorie is a unit of heat or energy and it equals about 4.2 J where 1J = 1 kg m^2 s^{-2}. Suppose we employ a system of units in which the unit of mass equals α kg, the unit of length equals β m, the unit of time is γ s. Show that a calorie has a magnitude 4.2 $\alpha^{-1} \beta^{-2} \gamma^{2}$ in terms of the new units.

2.4 Explain this statement clearly :

"To call a dimensional quantity 'large' or 'small' is meaningless without specifying a standard for comparison". In view of this, reframe the following statements wherever necessary :

(a) atoms are very small objects

(b) a jet plane moves with great speed

(c) the mass of Jupiter is very large

(d) the air inside this room contains a large number of molecules

(e) a proton is much more massive than an electron

(f) the speed of sound is much smaller than the speed of light.

2.5 A new unit of length is chosen such that the speed of light in vacuum is unity. What is the distance between the Sun and the Earth in terms of the new unit if light takes 8 min and 20 s to cover this distance ?

2.6 Which of the following is the most precise device for measuring length :

(a) a vernier callipers with 20 divisions on the sliding scale

(b) a screw gauge of pitch 1 mm and 100 divisions on the circular scale

(c) an optical instrument that can measure length to within a wavelength of light ?

2.7 A student measures the thickness of a human hair by looking at it through a microscope of magnification 100. He makes 20 observations and finds that the average width of the hair in the field of view of the microscope is 3.5 mm. What is the estimate on the thickness of hair ?

2.8 Answer the following :

(a) You are given a thread and a metre scale. How will you estimate the diameter of the thread ?

(b) A screw gauge has a pitch of 1.0 mm and 200 divisions on the circular scale. Do you think it is possible to increase the accuracy of the screw gauge arbitrarily by increasing the number of divisions on the circular scale ?

(c) The mean diameter of a thin brass rod is to be measured by vernier callipers. Why is a set of 100 measurements of the diameter expected to yield a more reliable estimate than a set of 5 measurements only ?

2.9 The photograph of a house occupies an area of 1.75 cm^2 on a 35 mm slide. The slide is projected on to a screen, and the area of the house on the screen is 1.55 m^2. What is the linear magnification of the projector-screen arrangement.

2.10 State the number of significant figures in the following :

(a) 0.007 m^2

(b) 2.64×10^{24} kg

(c) 0.2370 g cm^{-3}

Short Answer Type Questions-I

Q.1. (a) Define unit of a physical quantity.

(b) Define:

(i) Fundamental units,

(ii) Derived units.

Ans. (a) It is defined as the reference standard used to measure a physical quantity.

(b) (i) The physical quantity which are treated as independent of other, it means that they cannot be defined in terms of other units, are known as fundamental physical quantity. These are the units of measurement of length, mass, time etc.

(ii) These are the units of measurement of all other physical quantities which can be obtained from fundamental units, e.g. Velocity – (m/s), Acceleration –m/s^2, Pressure – Pa Force – N.

Q.2. (a) What do you mean by 'order of magnitude'? (b) Find the order of magnitude of light year.

Ans. (a) Order of magnitude is defined as the power of 10 used to express the magnitude of a physical quantity under consideration, e.g.,

(i) Order of magnitude of time intervals of 1.2×10^{-6} s is -6.

(ii) Order of magnitude of distance of 4.5×10^{6} is +6.

(b) 1 light year = 9.46×10^{15} m = 10^{16} m

∴ Order of magnitude of light year is 16.

Q.3. What are the advantages of choosing wavelength of light radiation as standard of length?

Ans. (i) It can be easily made available in any standard laboratory as Krypton is available everywhere.

(ii) It is well defined and does not change with temperature, time, place or pressure etc.

(iii) It is invariable.

(iv) It increases the accuracy of the measurement of length (1 part in 10).

Q.4. What is S.I. units? Which conference developed and recommended it for international usage?

Ans. S.I. units is the short (i.e. abbreviated form) of system international (d' unités) which is French for international system of units. It was developed and recommended by general conference on weights and measures in 1971 for international usage in domestic, commercial, industrial, scientific and technical works.

Q.5. Find the number of times the heart of a human being beats in 10 years. Assume that the heart beats once in 0.8 sec.

Ans. in 0.8 s, the human heart make on beat.

∴ In 1 s the human heart makes

$= \frac{1}{0.8} = \frac{10}{8}$ beats.

∴ In 10 years the human heart makes

$= \frac{10}{8} \times 10 \times 365 \times 24 \times 60 \times 60$ beats

$= 3.942 \times 10^8$ beats.

Q.6. Which type of phenomenon can be used as a measure of time? Give two examples of it.

Ans. Any phenomenon that repeats itself regularly at equal intervals of time can used to measure time.

The examples are:

(I) Rotation of earth – The time interval for one complete rotation is called a day.

(II)Oscillations of a pendulum.

Q.7. Derive S.I. unit of Joule (J) in terms of fundamental units.

Ans. Joule is a unit of work.

Using the relation,

Work = force × displacement

$= \text{mass} \times \frac{\text{velocity}}{\text{time}} \times \text{displacement}$

$= \text{mass} \times \frac{\text{displacement}}{\text{time} \times \text{time}} \times \text{displacement}$

$= \text{mass} \times \text{displacement}^2 \times \text{time}^{-2}$

Unit of work,

$J = kg \times m^2 \times s^{-2}$

$= kgm^2s^{-2}$.

Q.8. Given conversion of the some commonly used large units of length into metre.

Ans. 1 light year (ly) = 9.46×10^{15} m

1 Astronomical unit (AU) = 1.496×10^{11} m

1 Parallactic second (parsec) = 3.08×10^{16} m

Q.9. How can we find thickness of a sheet or a plant?

Ans. A radiowave is beamed at point A on one side of the sheet. This beam is reflected back from the other side of the sheet. The duration (t) between the transmission and reception of the beam is recorded with a very sensitive time recorder, then $d = \frac{c \times t}{2}$ where, c is the velocity of the radiowave, and d is the thickness of sheet or a plate.

Q.10. Why an optical microscope is not used to measure the size of a molecule?

Ans. Size of molecule ranges from 10^{-8} m to 10^{-10} m. an optical microscope uses visible light of average wavelength 6000 Å, i.e., 6000×10^{-10} m to measure the sizes. Since size of molecule is smaller than the wavelength of light used, so optical microscope cannot resolve a molecule.

Q.11. Why is S.I. unit of length expressed in terms of length of path of light travelled in a certain interval of time?

Ans. The shortest time cannot be measured with great accuracy with the help of caesium atomic clocks. For example, 1/299792438 of a second is measured with such clocks by calculating the distance travelled by light.

Q.12. What are the general guidelines for using symbols in S.I.?

Ans. (i) The unit names should not start with a capital letter, e.g., Newton, Joule, Coulomb etc., however their symbols are written with capital letter e.g., N, J, C etc.

(ii) Symbols cannot be used in plural form, they are used in singular form only.

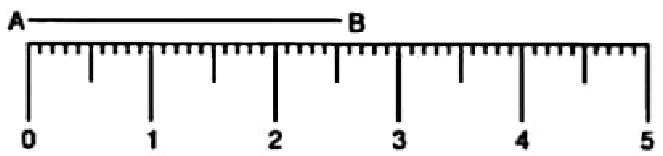
(iii) No full stop should be put at the end of the symbol of the unit.

(iv) No space should be given between a prefix and symbol of a unit, e.g., km, μs, cm etc.

(v) A prefix is not used alone.

Q.13. What is least count error?

Ans. It is an instrumental or random error related with the precision, i.e. limit are resolution of a measuring instrument. The smallest division on the scale of a measuring instrument is called its least count as measuring instrument may give different least counts in different measurements. The approximation made by an observer when the object falls within the smallest division of the scale also leads to this type of error e.g., a line AB is to be measured with a metre scale. Its one end coincides with zero and the other end falls within 2.5 and 2.6 cm, so an approximation has to be made about the length of the line say 2.55 cm.



Q.14. What is scientific notation?

Ans. Reporting a number in the power of ten is called scientific notation, i.e., in this notation, every measurement is written as $a \times 10^x$, where a is a number between 1 to 10 and x is the positive or negative power of 10, e.g.,

1.2 m = 1.20×10^2 cm

= 1.20×10^3 mm