# 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 $5.0188 \times 10^{25}$ 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 $2 \times 10^{-7}$ 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<br>(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 x$10^{-23}$ kg |
| 3 | Volume | 1 litre = $10^{-32}$ $m^3$ |
| 4. | Force | (a) 1 dyne = $10^{-5}$ N<br>(b) 1 kgf = 9.81 N |
| 5. | Pressure | (a) 1 $kgfm^2$ = $9.81Nm^{-2}$<br>(b) 1 mm of Hg = 133 $Nm^{-2}$<br>(c) 1 pascal = 1 $Nm^{-2}$<br>(d) 1 atmosphere pressure = 76 cm of Hg = 1.01 x $10^5$ pascal |
| **6.** | Work and energy | (a) 1 erg =$10^{-7}$ J<br>(b) 1 kgf-m = 9.81 J<br>(c) 1 kWh = 3.6 x $10^6$ J<br>(d) 1 eV = 1.6 x $10^{-19}$ J |
| 7. | Power | (d) 1 kgf- $ms^{-1}$ = 9.81W<br>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 x $10^{11}$ m (average distance between sun and earth)
4. 1 light year = 9.46 x $10^{15}$ m
5. 1 parsec = 3.08 x $10^{16}$ m = 3.26 light year

## Some Approximate Masses

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

## 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 1= 12.5 m and breadth b = 4.125 m.

Then, area A = l x b = 12.5 x 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.

$\Delta x = \pm(\Delta a + \Delta b)$

(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

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

# Physical World And Measurement

There are four fundamental forces which govern both macroscopic and microscopic phenomena. There are

(i) Gravitational force (iii) Electromagnetic force

(ii) Nuclear force (iv) Weak force

The relative strengths of these forces are

$$Fg :Fw:Fe:Fs=1:10^{25}:10^{36}:10^{38} .$$

All those quantities which can be measured directly or indirectly and in terms of which the laws of physics can be expressed are called physical quantities.

(a) Fundamental quantities (b) Derived quantities.

The units of the fundamental quantities called fundamental units , and the units of derived quantities called derived units.

System of units:-

(a) MKS (b) CGS (c) FPS (d) SI

- *The dimensions of a physical quantity are the powers to which the fundamental quantities are raised to represent that physical quantity.*

- The equation which expresses a physical quantity in terms of the fundamental units of mass, length and time, is called dimensional equation.
- According to this principle of homogeneity a physical equation will be dimensionally correct if the dimensions of all the terms in the all the terms occurring on both sides of the equation are the same.
- If any equation is dimensionally correct it is not necessary that must be mathematically correct too.
- There are three main uses of the dimensional analysis-

(a) To convert a unit of given physical quantities from one system of units to another system for which we use

$$n_2 = n_1[M_1/M_2]^a[L_1/L_2]^b[T_1/T_2]^c$$

(b) To check the correctness of a given physical relation.

(c) To derive a relationship between different physical quantities.

- Significant figures: - The significant figures are normally those digits in a measured quantity which are known reliably plus one additional digit that is uncertain.

For counting of the significant figure rule are as:

(i) All non- zero digits are significant figure.

(ii) All zero between two non-zero digits are significant figure.

(iii) All zeros to the right of a non-zero digit but to the left of an understood decimal point are not significant. But such zeros are significant if they come from a measurement.

(iv) All zeros to the right of a non-zero digit but to the left of a decimal point are significant.

(v) All zeros to the right of a decimal point are significant.

(vi) All zeros to the right of a decimal point but to the left of a non-zero digit are not significant. Single zero conventionally placed to the left of the decimal point is not significant.

(vii) The number of significant figures does not depend on the system of units.

- In addition or subtraction, the result should be reported to the same number of decimal places as that of the number with minimum number of decimal places.

- In multiplication or division, the result should be reported to the same number of significant figures as that of the number with minimum of significant figures.
- Accuracy refers to the closeness of a measurement to the true value of the physical quantity and precision refers to the resolution or the limit to which the quantity is measured.
- Difference between measured value and true value of a quantity represents error of measurement.
  It gives an indication of the limits within which the true value may lie.

Mean of n measurements

$$a_{mean} = \frac{a_1 + a_2 + a_3 + \cdots ..... + a_n}{n}$$

Absolute error ( $\Delta a$ ) = $a_{mean}$ - $a_i$ Where $a_i$ = measured value

It may be - positive, negative or zero.

(i) Mean absolute error

(ii) Relative error - it is the ratio of the mean absolute error to the true value.

$$\delta a = | \Delta a | / a_{mean}$$

(iii) The relative error expressed in percent is called percentage error.

The error is communicated in different mathematical operations as detailed below:

(i) For $x = (a \pm b)$, $\Delta x = \pm ( \Delta a + \Delta b)$

(ii) For $x = a \times b$ , $\Delta x/x = \pm ( \Delta a/a + \Delta b/b)$

(iii) For $x = a/b$ , $\Delta x/x = \pm ( \Delta a/a + \Delta b/b)$

(iv) For $x = a^n b^m / c^p$ $\Delta x/x = \pm ( n\Delta a/a + m \Delta b/b + p\Delta c/c$

## Very short answer type questions, (1 mark question)

Q1. State one law that holds good in all natural processes.

Ans. One such laws is the Newton's gravitation law, According to this law everybody in this nature are attracts with other body with a force of attraction which is directly proportional to the product of their masses and inversely proportionally To the square of the distance between them.

Q2: Among which type of elementary particles does the electromagnetic force act?

Ans : Electromagnetic force acts between on all electrically charged particles.

Q3. Name the forces having the longest and shortest range of operation.

Ans : longest range force is gravitational force and nuclear force is shortest range force.

Q4. If 'slap' times speed equals power, what will be the dimensional equation for 'slap'?

Ans . Slap x speed = power

Or slap = power/speed = $[MLT^{-2}]$

Q5. If the units of force and length each are doubled, then how many times the unit of energy would be affected?

Ans : Energy = Work done = Force x length

So when the units are doubled, then the unit of energy will increase four times.

Q6. Can a quantity has dimensions but still has no units?

Ans : No, a quantity having dimension must have some units of its measurement.

Q7. Justify L +L = L and L – L =L.

Ans: When we add or subtract a length from length we get length, So L +L =L AND L – L =L, justify.

Q8. Can there be a physical quantity that has no unit and no dimensions?

Ans : yes, like strain.

Q9. Given relative error in the measurement of length is 0.02, what is the percentage error?

Ans: percentage error = 2 %

Q10. If g is the acceleration due to gravity and λ is wavelength, then which physical quantity does represented by $\sqrt{g\lambda}$.

Ans. Speed or velocity.

## Short answer type questions (2 marks)

Q1.If heat dissipated in a resistance can be determined from the relation:

$H = I^2Rt$ joule , If the maximum error in the measurement of current, resistance and time are 2% ,1% , and 1% respectively, What would be the maximum error in the dissipated heat?

Ans: % error in heat dissipated is ±6 %.

Q2. Name any three physical quantities having the same dimensions and also give their dimensions.

Ans : Any group of physical quantities, like work , energy and torque and their dimensions $[ML^2 T^{-2}]$.

Q3. In Van der Wall's equation $(P + a/V^2)(V – b) = RT$, Determine the dimensions of a and b.

Ans : $[a] = [ML^5 T^{-2}]$ and $[b] = [M^0L^3T^0]$.

Q4. Give the limitations of dimensional analysis.

Ans ……………………………

Q5. If $X= a+ bt^2$ , where X is in meter and t is in second . find the unit of a and b?

Ans : unit of a is meter and unit of b is $m/sec^{2}$.

Q6. What is meant by significant figures ? State the rules for counting the number of significant figures in a measured quantity?

Ans. …………………………

Q7. Show that the maximum error in the quotient of two quantities is equal to the sum of their individual relative errors.

Ans : For $x = a/b$ , $\Delta x/x = \pm ( \Delta a/a + \Delta b/b)$

Q8. Deduce the dimensional formulae for the following physical quantities.

A) Gravitational constant.

B) Power

C) coefficient of viscosity

D) Surface tension.

Ans: (A) gravitational constant = $[M^{-1} L^3 T^{-2}]$,

B) Power = $[ML^2T^{-3}]$

C) Coefficient of viscosity = $[ ML^{-1} T^{-1}]$

D) Surface tension = $[ ML^0T^{-2}]$

Q9. Name the four basic forces in nature. Arrange them in the order of their increasing strengths.

Ans : (i) Gravitational force (ii) Electromagnetic force

(iii) nuclear force (iv) Weak force

The relative strengths of these forces are

$$F_g : F_w : F_e : F_s = 1 : 10^{25} : 10^{36} : 10^{38} .$$

Q10. Convert 1 Newton force in to Dyne.

Ans : $1N = 10^5$ Dyne.

## Short answer type questions (3marks)

Q1. If E,M,J and G respectively denote energy, mass, angular momentum and gravitational constant, Calculate the dimensions of $EJ^2/M^5G^2$

Q2. The frequency ν of vibration of stretched string depends on its length L its mass per unit length m and the tension T in the string obtain dimensionally an expression for frequency ν.

Q3. What is meant by significant figures .State the rules for counting the number of significant figures in a measured quantity?

Q4. A physical quantity X is given by $X = A^2B^3/C\sqrt{D}$ , If the percentage errors of measurement in A,B,C and D are 4%,2%,3% and 1% respectively, then calculate the % error in X.

Q5. If two resistors of resistance $R_1=(4 \pm 0.5)\Omega$ and $R_2=(16 \pm 0.5)\Omega$ are connected (1) In series and (2) Parallel . Find the equivalent resistance in each case with limits of % error.

Q6. The length of a rod measured in an experiment was found to be 2.48m, 2.46, 2.50m and 2.48m and 2.49m, Find the average length , the absolute error in each observation and % error.

Q7. A famous relation in physics relates moving mass m to the rest mass $m_0$ of a particle in terms of its speed v and the speed of the light c. A boy recalls the relation almost correctly but forgets where to put the constant c. He writes:

$$m = m_o / (1 - v^2)^{1/2}$$

Guess where to put the missing c.

Q8. A calorie is a unit of heat energy and it equals about 4.2 J, where 1 J = 4.2 $kgm^2s^{-2}$. Suppose we employ a system of units in which the unit of mass equals α kg, the unit of length equals β m, the units of time is ϒ sec. show that a calorie has a magnitude $4.2\ \alpha^{-1}\ \beta^{-2}\ \Upsilon^2$ in terms of the new units.

Q9. In the formula $X = 3YZ^2$, X and Z have dimensions of capacitance and magnetic induction respectively, what are the dimensions of Y in MKS system?

Q10. In an experiment, on the measurement of g using a simple pendulum the time period was measured with an accuracy of 0.2 % while the length was measured with accuracy of 0.5%. Calculate the percentage error in the value of g.

## Long answer question ( 5 marks )

Q1. Explain:

(i) Absolute error

(ii) Relative error

(iii) Mean absolute error

(iv) percentage error

(v) Random error

Q2. Convert:

( i) Gravitational constant (G) = $6.67 \times 10^{-11}\ Nm^2\ kg^{-2}$ to $cm^3\ g^{-1}\ s^{-2}$ (ii) The escape velocity v of a body depends on, the acceleration due to gravity 'g' of the planet and the radius R of the planet, Establish dimensionally for relation for the escape velocity.

Q3. Name the four basic forces in nature. Write a brief note of each, hence compare their strengths and ranges.

## HOTs

Q1. What are the dimensions of $^1/u_0\epsilon_0$, where symbols have their usual meaning.

Ans : $[M^0 L^2 T^{-2}]$

Q2.What is the dimensions of $(^1/_2)\epsilon_0 E^2$ , Where E electric field and $\epsilon_0$ permittivity of free space.

Ans : $[M^1 L^{-1} T^{-2}]$

Q3. The pairs of physical quantities that have the same dimensions are:

(a) Reynolds's number and coefficient of friction,

(b) Curie and frequency of a light wave

(c) Latent heat and gravitational potential

(d) Planck's constant and torque.

Ans : (a), (b).

Q4. If L,C,R represent inductance , capacitance and resistance respectively, the combinations having dimensions of frequency are

(a) $1/\sqrt{CL}$ (b) L/C (c) R/L (d ) R/C

Ans : (a) and (c).

Q5. If the error in radius is 3%, what is error in volume of sphere?

(a) 3 % (b) 27 % (c) 9 % (d) 6 %

Ans : ( c ) 9%.