1. **Details of Module and its structure**

Module Detail	
Subject Name	Physics
Course Name	Physics 01 (Physics - Part 1, Class XI)
Module Name/Title	Unit 1,Module 2, **Units and Measurement** Chapter 2, Units and Measurements
Module Id	Keph_10201_eContent
Pre-requisites	Physical world, meaning of science
Objectives	**After going through this module, the learners will be able to :** • Develop an understanding of the physical quantities. • Understand the need of measurement of physical quantities. • Appreciate the history of development of Units of measurement. • Know the System of units (SI system). • Distinguish between fundamental and derived units. • Know the challenges of measurement of length, mass and time.
Keywords	Measurement, Unit, S.I units, Fundamental units, Derived units

2. **Development Team**

Role	Name	Affiliation
National MOOC Coordinator (NMC)	Prof. Amarendra P. Behera	Central Institute of Educational Technology, NCERT, New Delhi
Programme Coordinator	Dr. Mohd. Mamur Ali	Central Institute of Educational Technology, NCERT, New Delhi
Course Coordinator / PI	Anuradha Mathur	Central Institute of Educational Technology, NCERT, New Delhi
Subject Matter Expert (SME)	Vandita Shukla	Kulachi Hansraj Model School Ashok Vihar, New Delhi
Review Team	Prof. V. B. Bhatia (Retd.) (Associate)Prof. N.K. Sehgal (Retd.) Prof. B. K. Sharma (Retd.)	Delhi University Delhi University DESM, NCERT, New Delhi

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1. UNIT SYLLABUS

Unit 1: Physical World and Measurement

Chapter 1: Physical World

Physics-scope and excitement; Nature of physical laws; Physics, technology and society.

Chapter 2: Units and Measurements

Need for measurement: Units of measurement; Systems of units; Si units, fundamental and derived units. Length, mass and time measurements; Accuracy and precision of measuring instruments; Errors in measurement; Significant figures.

Dimensions of physical quantities; Dimensional and analysis and its applications.

2. MODULE-WISE DISTRIBUTION OF UNIT SYLLABUS 4 Modules

This unit is divided into four modules for better understanding .

Module 1	• Physical world • Meaning of physics • Scope and excitement of physics
Module 2	• Need of measurement • SI units • Fundamental and derived units • Measurement of mass ,length and time
Module 3	• Accuracy, precision • Significant figures • Errors
Module 4	• Expressing physical quantities dimensionally • Dimensional analysis • Application of dimensional analysis

Module 2

3. WORDS YOU MUST KNOW

- Science: Science is a systematic attempt at understanding natural phenomena, and then utilizes this gained knowledge to predict, modify and control these phenomena.
- Physics: Physics is a study of basic laws of nature and their application to various phenomena. Physics includes the study of all forms of matter, and its interaction with other matter and with energy in various forms.

4. INTRODUCTION

Science and engineering are based on measurements and comparisons. Thus we need rules which inform us how things are measured and compared. We also need the experiments to establish the units for these measurements and comparisons. In physics we need to design and conduct these experiments. For example, physicists strive to develop clocks of extreme accuracy so that time can be precisely measured.

You may wonder whether such accuracy is actually needed or worth the effort, one example of this requirement, the Global Positioning System (GPS) is shown above, that is now vital for worldwide navigation.

The Global Positioning System

In this module we will learn how to measure the quantities involved in physics. For each physical quantity, we have standard unit and we make measurements by comparing with this unit.

5. NEED OF MEASUREMENT

WHAT IS MEASUREMENT?

We already know that observations are an important part of the scientific method. Hypotheses are accepted or rejected based on how well they explain observations. Some observations, such as "the plant turned yellow" are **qualitative**; these observations have no associated numbers. A **quantitative** measurement based on observations includes numbers. A measurement is obtained by comparing a physical quantity with its own standard. All observations are useful to a scientist, but quantitative observations are more useful. Even if they can make an estimate, scientists usually make quantitative measurements in their experiments.

Consider the following pair of observations.

1. **When the volume of a gas is decreased at constant temperature, its pressure is increased.**

2. When the volume of a gas at constant temperature is reduced from 4.0 liters to 2.0 liters, the pressure increases from 4.0 atm to 8.0 atm.

More useful information, is available in the second observation.

Since an accurate measurement is a vital tool for scientific observations, a consistent set of units for measurement is necessary.

WHAT IS A PHYSICAL QUANTITY?

A quantity which can be measured directly or indirectly is called a physical quantity. For example, length, area, volume, speed, weight, mass, temperature, time, *etc*.

The physical quantities are the building blocks of physics in terms of which the basic laws of physics can be expressed in mathematical form.

HOW TO EXPRESS THE RESULT OF MEASUREMENT OF A PHYSICAL QUANTITY?

We measure each physical quantity in its own units, by comparison with the standard. The result of a measurement of a physical quantity is expressed completely by a number or numerical measure accompanied by a unit. The unit is a unique name assigned to a measure of that quantity. For example, **metre** is the unit for measurement of length. The standard corresponds to exactly one unit of the quantity. You will later learn in this module that the standard for length, which is the distance traveled by light in vacuum during a certain fraction 1/299,792,458 of a second.

In nutshell we can say that, for the measurement of a physical quantity completely we need to know:

1. **The unit in which the quantity is measured.**

2. **The numerical value or the magnitude of the quantity i.e. the number of times that unit is contained in the given physical quantity.**

Measuring tape

Now, suppose you measure the length (a physical quantity) of your dining table using a measuring tape shown above and you express your answer as, say, 2 metre.

Then your observation, 2 metre, means a length which is two times the unit of length 1 metre.

So here, 2 represent the numerical value (n) of the given quantity and metre *(u)* represents the unit of quantity under consideration. Thus, in expressing a physical quantity we choose a unit and then find how many times that unit is contained in the given physical quantity, *i.e.*

Physical Quantity

(Q) = Magnitude × Unit =$\boldsymbol{n \times u}$

Where, n represents the numerical value and u represents the unit.

Consider: the length of your study table say it is 2 m, it can be expressed as 200 cm also. Here the unit used is cm and magnitude is 200. Clearly the smaller the size of the unit, the larger is the numerical value associated with a given measurement of a physical quantity- here it is length.

Therefore, physical quantity

$\therefore \quad n \propto \frac{1}{u}$

Or nu = constant

That means when we express the definite amount of physical quantity, then as the unit(u) changes, the magnitude(n) will also change but product ‘nu’ will remain same.

TYPES OF PHYSICAL QUANTITIES

(1) SCALAR QUANTITIES:

The quantities which have **only magnitude** are called scalar quantities. They do not have any direction.

For example: distance travelled, time interval, work, energy are scalar quantities.

Scalar quantities can be added or subtracted algebraically.

(2) VECTOR QUANTITES:

The quantities which have **magnitude as well as direction** are called vector quantities.

For example: displacement, velocity, acceleration, force; are vector quantities.

Vector quantities can be added or subtracted according to vector laws of addition. These laws are different from laws of algebraic addition.

You will learn about vector algebra later in class X1.

6. FUNDAMENTAL AND DERIVED QUANTITIES

Physicists throughout the world use the **International System of Units** (also called the SI). SI is basically a metric system, which is convenient because units of different sizes are related by powers of 10. The system has physical standards for length, mass, time as other physical quantities. These are called **fundamental** units because they are internationally accepted standards.

There are so many physical quantities but they are not all independent.We classify physical quantities in two categories fundamental quantities and derived quantities.

(1) Fundamental or base quantities: Out of a large number of physical quantities which exist in nature, there are only few quantities which are independent and do not require the help of any other physical quantity for their definition. Therefore, these are called **fundamental or base quantities**. As all other quantities are based upon and can be expressed in terms of these quantities.

(2) Derived quantities: All other physical quantities are combination of fundamental quantities. These are therefore called **derived quantities.**

FOR EXAMPLE:

Speed is the ratio of length to time. Therefore it is derived quantity. It is defined in terms of the base quantities length and time and their base standards.

Normally, each physical quantity requires a unit or standard for its specification. So it appears that there must be as many units as there are physical quantities. However, it is not so. It has been found that, in *mechanics*, for example, all physical quantities can be expressed in terms of three base quantities, mass length and time. *Therefore,* standard units of mass, length and time in mechanics are called **fundamental or base units.** Other units which can be expressed in terms of these fundamental units are called **derived units**. For example, *metre* is a fundamental unit of length while m s^{-1} is a derived unit as it is derived from units length and time.

7. SYSTEM OF UNITS

S. I. UNITS:

SI is the abbreviation for the ***systeme international d' unites*** **which is the French equivalent for international system of units**. There are seven fundamental quantities and two supplementary units in this system.

These quantities and their units are given in the following table.

Fundamental SI Quantities and Units are:

Quantity	**Name of 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

Besides the above seven fundamental units two supplementary units are also defined – Radian(rad) for plane angle and Steradian(sr) for solid angle.

http://www.youtube.com/watch?v=oAtDAoqdExw&sns=em

Video shows different units of measurement in the physical world.

8. FUNDAMENTAL AND DERIVED UNITS

Definition of Fundamental and Supplementary units:

S.NO.	Physical quantity	Unit	Definition
1	**length**	**metre**	The metre is the length of the path travelled by light in vacuum during a time interval of 1/299, 792, 458 of a second.
2	**mass**	**kilogram**	1kilogram is the mass of a cylinder made of platinium-iridium alloy kept at International Bureau of Weights and Measures, at Sevres near Paris, France.
3	**time**	**second**	The second is the duration of 9, 192 631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.
4	**electric current**	**ampere**	The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible

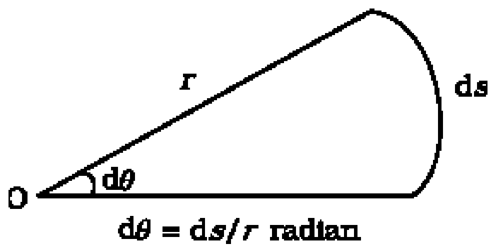
			circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2 x 10^{-7} newton per metre of length.
5	**thermodynamic temperature**	**Kelvin**	The Kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
6	**amount of substance**	**mole**	The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.
7	**Unit of luminous intensity**	**candela**	The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 × 10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per Steradian.

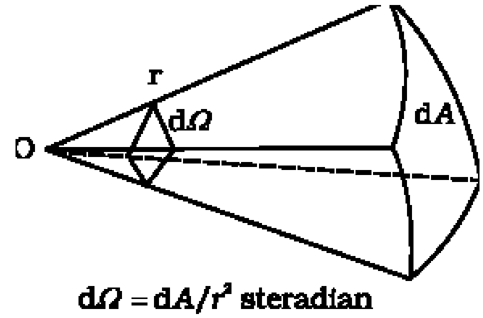
Do see the attached file 'kilogram updates'

SUPPLEMENTARY UNITS

plane angle	radian	rad	The radian is the plane angle between two radii of a circle which cut off on the circumference an arc equal in length to the radius
solid angle	steradian	sr	The steradian is the solid angle which, having its vertex at the centre of a sphere, cuts off an area of the surface of the sphere equal to that of a

			square with sides of length equal to the radius of the sphere





Plane angle $d\theta$ **Solid angle**

Description of plane angle dθ and solid angle dΩ

COMMON SI PREFIXES AND SYMBOLS FOR MULTIPLES AND SUB - MULTIPLES

In physics we have to deal with quantities from very small (*micro*) to very large (*macro*) magnitudes. We talk of the electron, atom while on the other we talk about the size of the universe covering the range from 10^{-16} m to 10^{26} m.

To express such large or small magnitudes we use the following prefixes:

Power of 10	**Prefix**	**Symbol**
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h

10^{1}	deca	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

9. MEASUREMENT OF MASS, LENGTH AND TIME

http://www.ck12.org/book/CBSE_Physics_Book_Class_XI/section/2.2/

We use different methods for measuring different ranges of length. For example,

a) **A meter scale can measure length between 10^{-3} m to 1m.**

b) Vernier caliper can be used to measure smaller distances of the order of 10^{-4} m.

c) Screw gauge can measure lengths as small as 10^{-5} m.

These devices can measure the length in a limited range. We cannot employ these devices to measure lengths of very large or very small magnitudes.

For example, to measure distance between two planets, or to measure the size of a molecule we use special methods given below.

MEASUREMENT OF LARGE DISTANCES

Large distances such as the distance of a planet or a star from the earth cannot be measured directly. An important method in such cases is the parallax method.

PARALLAX METHOD

Parallax is defined as the apparent shift in the position of a body with respect to a specific point in its background, with the shift of the eye sideways.

Let's consider one example to understand the above statement.

When you hold a pencil in front of you against some specific point in the background (a wall, window, painting anything) and look at the pencil first through your left eye (closing the right eye) and then look at the pencil through your right eye (closing the left eye), you would notice that the position of the pencil seems to change with respect to the point on the wall. This is called parallax.

To measure the distance of a far off planet using parallax method, we observe it from two different points on the earth, separated by a distance b.

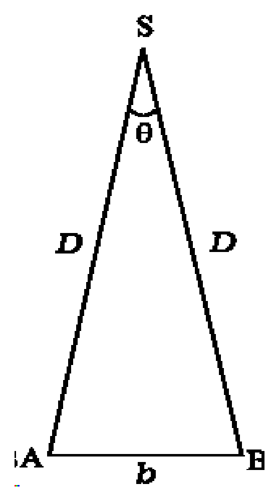
The distance between the two points of observation is called the basis. In the above example involving shifting of the eye the basis is the distance between the eyes.

To measure the distance D of the planet S by the parallax method, we observe it from two different positions (observatories) A and B on the Earth, separated by distance AB = b at the same time as shown in the given figure. We measure the angle between the two directions along which the planet is viewed at these two points. Therefore, θ is very small angle.

Then we approximately take AB as an arc of length b of a circle with centre at P. The radius of the circle is D. Therefore, the angle θ is given by:

$\theta = b/D$

$D = b/\theta$ where, angle θ is in radians.



Parallax method

EXAMPLE

The moon is observed from two diametrically extremes A and B on Earth. The angle of parallax θ subtended at the moon by the two directions of observation is found to be $1°54'$. If the diameter of the Earth is $1.276 \times 10^7\ m$, estimate the distance of the moon from the Earth.

SOLUTION:

Given: angle of parallax θ = 1° 54′ = 114′

$$= \frac{114}{\frac{\pi}{180}\times 60} \text{ rad}$$

$$= \frac{114\times 180}{\pi\times 60} \text{ rad}$$

D = b/θ

$$D = \frac{1.276\times 10^{7}}{114\times 180}\times \pi \times 60$$

$= 3.84\times 10^{8}$ m

ESTIMATION OF VERY SMALL DISTANCE: SIZE OF A MOLECULE

To measure a very small size like that of a molecule (10^{-8}m to 10^{-10} m), we have to adopt special methods. We cannot use a screw gauge or similar instruments. Even a microscope has certain limitations.

VOLUMETRIC METHOD

A simple method for estimating the molecular size of oleic acid is given below. Oleic acid is a soapy liquid with large molecular size of the order of 10^{-9} m.

The idea is to first form mono-molecular layer of oleic acid on water surface. We dissolve 1 cm^3 of oleic acid in alcohol to make a solution of 20 cm^3. Then we take 1 cm^3 of this solution and dilute it to 20 cm^3, using alcohol. So, the concentration of the solution is equal to (1/20 x 20) cm^3 of oleic acid / cm^3 of solution.

Next we lightly sprinkle some lycopodium powder on the surface of water in a large trough and we put one drop of this solution in the water. The oleic acid drop spreads into a thin, large and roughly circular film of molecular thickness on water surface.

Suppose we have to use n drops in the water to make a mono-molecular film. Initially, we determine the approximate volume of each drop (V cm^3).

Volume of n drops of solution= n V cm^3

Amount of oleic acid in this solution= n V (1/20 x 20) cm^3

This solution of oleic acid spreads very fast on the surface of water and forms a very thin layer of thickness t. If this spreads to form a film of area A cm^2, then:

Thickness of the film t =Volume of the film/area of the film

or, t = n V/(20 x 20)A cm

If we assume that the film has mono-molecular thickness, then this becomes the size or diameter of a molecule of oleic acid. The value of this thickness comes out to be of the order of 10^{-9} m.

EXAMPLE:

If the size of a nucleus (in the range of 10^{-15} m to 10^{-14} m) is scaled up to the tip of a sharp pin, what would roughly be the size of an atom?

Assume tip of the pin to be in the range 10^{-5} m to 10^{-4} m.

SOLUTION:

The size of a nucleus is in the range of 10^{-15} m to 10^{-14} m. The tip of a sharp pin is taken to be in the range of 10^{-5} m to 10^{-4} m.

Thus we are scaling up by a factor of 10^{10}. An atom roughly of size 10^{-10}m will be scaled up to a size of 1 m.

Thus a nucleus in an atom is as small in size as the tip of a sharp pin placed at the center of a sphere of radius about a metre long.

RANGE OF LENGTHS

There are certain special length units that we use for short and large lengths. These are:

1 fermi = 1 f = 10^{-15}m

1 angstrom = 1 Å = 10^{-10} m

1 astronomical unit = 1 AU (average distance of the Sun from the Earth)

$= 1.496\times10^{11}$ m

1 light year = 1 ly = 9.46×10^{15} m

(Distance that light travels with velocity of 3×10^{8} m /s in 1 year)

1 parsec = 3.08×10^{16} m

(Parsec is the distance at which average radius of earth's orbit subtends an angle of 1 arc second)

MEASUREMENT OF MASS

Mass is a basic property of matter. It does not depend on the temperature, pressure or location of the object in space. The SI unit of mass is kilogram (kg). The proto-types of the International standard kilogram supplied by the International Bureau of Weights and Measures (BIPM) are available in many laboratories of different countries. In India, this is available at the National Physical Laboratory (NPL), New Delhi.

While dealing with atoms and molecules, the kilogram is an inconvenient unit. In this case, there is an important standard unit of mass, called the unified atomic mass unit (u), which has been established for expressing the mass of atoms

1 unified atomic mass unit = 1u

= (1/12) of the mass of an atom of carbon-12 isotope ($^{12}C_6$)

including the mass of electrons = 1.66×10^{-27}kg

Mass of commonly available objects can be determined by a common balance like the one used in a grocery shop. Large masses in the universe like those of planets, stars, etc., can be measured by using gravitational law. For measurement of small masses of atomic/subatomic particles etc., we make use of mass spectrograph in which radius of the trajectory is proportional to the mass of a charged particle moving in uniform electric and magnetic field.

MEASUREMENT OF TIME

To measure a time interval we need a clock. All clocks are ultimately based on the periodic vibrations produced in a cesium atom. This is the basis of the cesium clock, sometimes called atomic clock, used in the national standards. Such standards are available in many laboratories. In the cesium atomic clock, the second is taken as the time taken by 9,192,631,770 vibrations of the radiation corresponding to the transition between the two hyperfine levels of the ground state of cesium-133 atom. The vibrations of the cesium atom regulate the rate of this cesium atomic clock just as the vibrations of a balance wheel regulate an ordinary wristwatch or the vibrations of a small quartz crystal regulate a quartz wristwatch.

The cesium atomic clocks are very accurate. In principle they provide portable standard. The national standard of time interval 'second', used in our clocks and watches in India as well as the frequency of cesium is maintained through four cesium atomic clocks. A cesium atomic clock is used at the National Physical Laboratory (NPL), New Delhi to maintain the Indian standard of time.

In our country, the NPL has the responsibility of maintenance and improvement of physical standards, including that of time, frequency, etc. Note that the Indian Standard Time (IST) is linked to this set of atomic clocks.

The cesium atomic clocks are so accurate that they impart the uncertainty in time measured is as small as $\pm 1 \times 10^{-13}$ i.e. 1 part in 10^{13}.

This implies that the uncertainty gained over time by such a device is less than 1 part in 10^{13}; they lose or gain no more than 3 μs in one year. In view of the tremendous accuracy in time measurement, the SI unit of length has been expressed in terms the path length that light travels in a certain interval of time (1/299,792,458 of a second).

10.SUMMARY

In this module we have learnt

- Physics is a quantitative science, based on measurement of physical quantities. Certain physical quantities have been chosen as fundamental or base quantities. These are length, mass, time, electric current, thermodynamic temperature, amount of substance, and luminous intensity.
- Each base quantity is defined in terms of a certain basic reference standard called unit. These units are metre, kilogram, second, ampere, kelvin, mole and candela.

- Other physical quantities, derived from the base quantities, can be expressed as a combination of the base units and are called derived units. A complete set of units, both fundamental and derived, is called a system of units.
- The International System of Units (SI) based on seven base units is at present internationally accepted system and is widely used throughout the world.
- The SI units are used in all physical measurements, for both the base quantities and the derived quantities obtained from them. Certain derived units are expressed by means of SI units with special names (such as joule, newton, watt, etc).
- The SI units have well defined and internationally accepted unit symbols (such as m for metre, kg for kilogram, s for second, A for ampere, N for newton etc.). Direct and indirect methods are used for the measurement of physical quantities.