

MEASUREMENTS

LEARNING OBJECTIVES

At the end of this chapter the students will be able to:

Understand what is Physics.

Understand that all physical quantities consist of a numerical magnitude and a unit.

Describe and use base units, supplementary units, and derived units.

Understand and use the scientific notation.

Use the standard prefixes and their symbols to indicate decimal sub-multiplies or multiples to both base and derived units.

Understand and use the conventions for indicating units.

Understand the distinction between systematic errors and random errors.

Understand and use the significant figures.

Understand the distinction between precision and accuracy.

Use dimensionality to check the homogeneity of physical equations.

Derive formulae in simple cases using dimensions.

INTRODUCTION TO PHYSICS

Man has always been curious to know about things. He started to observe, think and wondering about the world around him. He tried to find ways to organize the disorder in observed facts about natural phenomena and material objects things in orderly manner. His attempts resulted in the birth of a single discipline (Branch) of science, called natural philosophy.

There was a huge increase in the volume of scientific knowledge up till the beginning of nineteenth century and it was found necessary to classify the study of nature into two branch.

(i) Biological Sciences.

(ii) Physical Science.

Areas of Physics

Mechanics
Heat & thermodynamics
Electromagnetism
Optics
Sound
Hydrodynamics
Special relativity
General relativity
Quantum mechanics
Atomic physics
Molecular physics
Nuclear physics
Solid-state physics
Particle physics
Superconductivity
Super fluidity
Plasma physics
Magneto hydrodynamics
Space physics

Biological Sciences

The science which deals with living things such as botany, zoology etc are called biological sciences.

Physical Sciences

The science which deals with non living things such as chemistry, astronomy, geology etc are called physical sciences.

Physics is important and basic part of physical science besides its other disciplines such as chemistry, astronomy geology etc. Physics is an experimental science and scientific method emphasizes the need of accurate measurement of different phenomena or of man made objects.

Frontiers of Fundamental Science

At the present time there are three main frontiers of fundamental science.

(1) The world of the extremely large, the universe itself, Radio telescopes now gather information from the far side of the universe and have recently detected, as radio waves, the "fire light" of the big bang which probably started off the expanding universe nearly 20 billion years ago.

(2) The world of extremely small, that of the particles such as, electron, protons, neutrons, mesons and others.

(3) The world of complex matter, it is also the world of "middle sized" things, from molecules at one extreme to the earth at the other. This is all fundamental physics, which is heart of science.

Q.1 Define physics. Give its main branches.

Ans. **PHYSICS**

"The branch of science which deals with the study of matter and energy and the relationship between them is called physics."

The study of physics involves investigating of such things as the laws of motion, the structure of space and time, the nature and type of forces that hold different materials together, the interaction between different particles, the interaction of electromagnetic radiation with matter and so on.

Branches of Physics

Interdisciplinary Areas of Physics

Astrophysics
Biophysics
Chemical physics
Engineering physics

By the end of 19th century many physicists started believing that everything about physics has been discovered. However, about the beginning of the 20th century many new experimental facts showed that the laws formulated by the previous scientists need modifications. Further researches gave birth to many new disciplines (branches)

nuclear physics.

(2) Particle Physics

The branch of physics which is concerned with the ultimate particles of which matter is composed of is called particle physics.

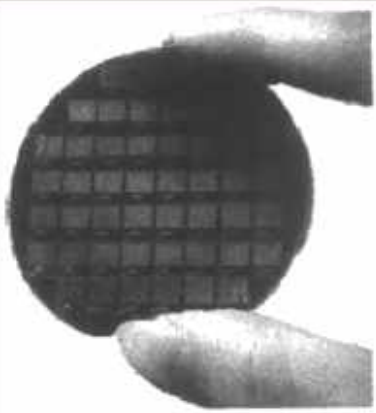
(3) Relativistic Mechanics

The branch of physics which deals with velocities approaching that of light is called relativistic mechanics.

(4) Solid State Physics

The branch of physics which is concerned with the structure and properties of solid materials is called solid state physics.

Do You Know?



Computer chips are made from wafers of the metalloid silicon, a semiconductor.

Other Branches of Science

Physics is the most fundamental of all sciences and provides other branches of science, basic principles and fundamental laws. This overlapping of physics and other fields gave birth to new branches such as physical Chemistry, biophysics, astrophysics, health physics etc.

Q.2 What is the role of physics in technology?

Ans. ROLE OF PHYSICS IN TECHNOLOGY

Physics also plays an important role in development of technology and engineering.

Science and technology are potent force for the change in the outlook of mankind. The information media and fast means of communications have brought all parts of the world in close contact with one another. Events in one part of the world are immediately reverberate round the globe.

We are living in the age of information technology. The computer networks are products of chips developed from basic ideas of physics. The chips are made of silicon. Silicon can be obtained from sand. It is upto us whether we make a sand castle or computer out of it.

Q.3 What do you mean by physical quantities? Also describe its types.

Ans. PHYSICAL QUANTITIES

The foundation of physics rests upon physical quantities in terms of which the laws of physics one expressed. Therefore the qualities have to be measured accurately.

All those quantities which can be measured are called physical quantities.

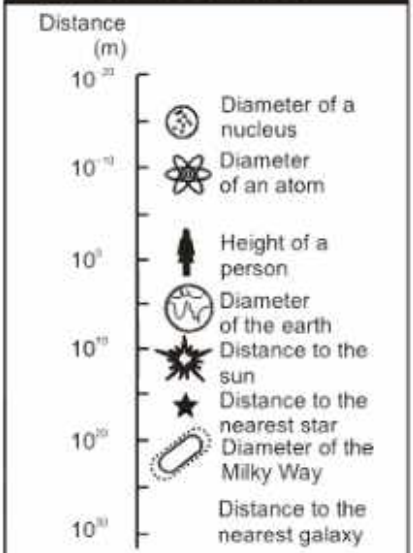
e.g., mass length, time, velocity, force, density temperature, electric current, volume, acceleration etc.

Physical quantities have been divided into two categories.

(i) Base quantities.

(ii) Derived quantities.

Do You Know?



Order of magnitude of some distances

(i) Base Quantities

Base quantities are those quantities which cannot be defined in terms of other physical quantities. These are the minimum number of physical quantities in term of which other physical quantities can be defined. The typical examples of base quantities are length, mass and time.

(ii) Derived Quantities

Those physical quantities whose definitions are expressed in terms of other physical quantities are called derived quantities.

The examples of derived quantities are velocity, acceleration, force, momentum etc.

Measurement of Base Quantities

The measurement of base quantity is based on two steps.

(i) The choice of standard.

(ii) The establishment of a procedure for comparing the quantity to be measured with the standard so that number and a unit are determined as the measure of that quantity.

Characteristics of an Ideal Standard

An ideal standard has two principal characteristics: It is accessible and it is invariable. These two requirements are often incompatible and a compromise has to be made between them.

Unit

To measure a physical quantity, a standard size of that quantity is required. This standard size is known as unit for that particular physical quantity.

Q.4 What is international system of units?

Ans. **INTERNATIONAL SYSTEM OF UNITS**

are being used by world's scientific community in all scientific works. The international system of units (SI) is built up from three kinds of units.

(1) Base units (2) Supplementary units (3) Derived units

Q.5 What are base units? Define the base units of SI.

Ans. BASE UNITS

There are seven base units for various physical quantities namely; length, mass, time, temperature, electric current, luminous intensity and amount of substance (with special reference to the number of particles).

The name of base units for these physical quantities together with symbols are listed in table:

Physical Quantity	SI Unit	Symbol
Length	Metre	m
Mass	Kilogram	kg
Time	Second	s
Electric current	Ampere	A
Thermodynamic temperature	Kelvin	K
Intensity of light	Candela	cd
Amount of substance	Mole	mol

Q.6 What are supplementary units? Define them.

Ans. SUPPLEMENTARY UNITS

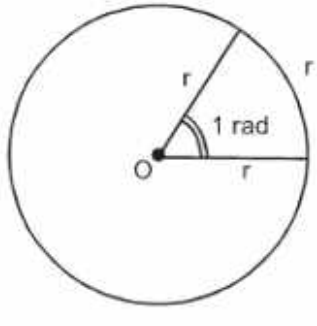
The general conference on weights and measures has not yet classified certain units of the SI under either base units or derived units. These SI units are called supplementary units. This class contains two units, which are:

(1) Radian (Plane angle)

(2) Steradian (Solid angle)

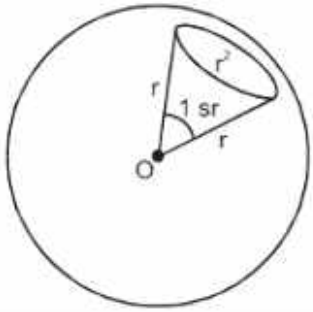
Radian

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, as shown in figure.



Steradian

The steradian is the solid angle (three dimensional angle) subtended at the centre of the sphere by an area of its surface equal to the square of radius of the sphere, as shown in figure.



Q.7 What are derived units? Give some examples.

Ans. **DERIVED UNITS**

SI units for measuring all other physical quantities are derived from the base and supplementary units. Some of the derived units are given below:

Physical Quantity	Unit	Symbol	In terms of base units
Force	Newton	N	$kg\ ms^{-2}$
Work	Joule	J	$N\ m = kg\ m^2\ s^{-2}$
Power	Watt	W	$Js^{-1} = kg\ m^2\ s^{-3}$
Pressure	Pascal	Pa	$Nm^{-2} = kg\ m^{-1}\ s^{-2}$
Electric charge	Coulomb	C	A s

Q.8 What do you understand by term?

Ans. **SCIENTIFIC NOTATION**

Numbers are expressed in standard form called scientific notation, which employs power of ten. The internationally accepted practice is that there should be only one non-zero digit left of decimal.

Scientific Notation Explain the Uses of Prefix

Example

The number 134.7 should be written as

$$134.7 = 1.374 \times 10^2$$

Similarly, the number 0.0023 can be written as

$$0.0023 = 2.3 \times 10^{-3}$$

Some Prefixes for Powers of Ten

Factor	Prefix	Symbol
10^{-18}	atto	a
10^{-15}	femto	f
10^{-12}	pico	p
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	mili	m
10^{-2}	centi	c
10^{-1}	deci	d
10^{1}	deca	da
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G
10^{12}	tera	T
10^{15}	peta	P
10^{18}	exa	E

Conventions for Indicating Units

Use of SI units requires special care, more particularly in writing prefixes.

Following points should be kept in mind while using units:

(i) Full name of the unit does not begin with a capital even if named after a scientist e.g. newton.

(ii) The symbol of unit named after a scientist has initial capital letters such as N for newton.

(iv) A combination of base units is written each with one space apart. For example, newton metre is written as N m.

(v) Compound prefixes are not allowed. For example, 1μμF may be written as 1pF.

(vi) A number such as 5.4×10^4 cm may be expressed in scientific notation as 5.0×10^2m.

(vii) When a multiple of a base unit is raised to a power, the power applies to the whole multiple and not the base unit alone. Thus, $1km^2 = 1\ (km)^2 = 1 \times 10^6 m^2$.

(viii) Measurement in practical work should be recorded immediately in the most convenient unit, e.g., micrometer screw guage measurement in mm, and the mass of calorimeter in grams (g). But before calculation for the result, all measurements must be converted to the appropriate SI base units.

Q.9 Explain the phenomenon of errors and uncertainties.

Ans. **ERRORS AND UNCERTAINTIES**

All physical measurements are uncertain or imprecise to some extent. It is very difficult to eliminate all possible errors or uncertainties in a measurement. The errors in a measurement may occur due to.

(1) Negligence or inexperience of a person.

(2) The faulty apparatus.

(3) Inappropriate method or technique.

The uncertainty may occur due to inadequacy or limitations of an instrument, natural variations of the object being measured or natural imperfection of a person's senses. However the uncertainty is also usually described as an error in a measurement.

Types of Errors

There are two types of errors.

(1) Random error.

(2) Systematic error.

(1) Random Error

Random error is said to occur when repeated measurements of a quantity, give different values under the same conditions. It is due to some unknown causes.

Repeating the measurements several times and taking an average can reduce the effect of random errors.

(2) Systematic Errors

Systematic error refers to an effect that influences all measurements of a particular quantity equally. It produces consistent difference in reading.

It occurs due to:

(i) Zero error of instrument.

Systematic error can be reduced by comparing the instrument with an other which is known to be more accurate. Thus for systematic error, a correction factor can be applied to reduce error.

Q.10 Describe the significant figures. Also discuss its rules.

Ans. SIGNIFICANT FIGURES

We know that physics is based on measurements whenever a physical quantity is measured; there is some uncertainty about its determined value. This uncertainty may be due to a number of reasons. One reason is the type of instrument, being used. We know that every measuring instrument is calibrated to a certain smallest division and this fact put a limit to the degree of accuracy while measuring with it.

Suppose that we want to measure the length of a straight line with the help of a meter rod calibrated in millimeters. Let the end point of the line lies between 10.3 and 10.4 cm marks. By convention if the end of line does not touch or cross the midpoint of the smallest division, the reading is confined to the previous division. In case the end of line seems to be touching or have crossed the midpoint, the reading is extended to the next division.

For Your Information

	Interval (s)
Age of the universe	5×10^{17}
Age of the Earth	1.4×10^{17}
One year	3.2×10^{7}
One day	8.6×10^{4}
Time between normal heartbeats	8×10^{-1}
Period of audible sound waves	1×10^{-3}
Period of typical radio waves	1×10^{-6}
Period of vibration of an atom in a solid	1×10^{-13}
Period of visible light waves	2×10^{-15}

Approximate Values of Some Time Intervals

By applying the above rule the position of the edge of line recorded as 12.7cm with the help of a meter rod calibrated in millimeters may lie between 12.65cm and 12.75cm. Thus in this example the maximum uncertainty is ±0.05 cm. It is, infact, equivalent to an uncertainty of 0.1cm equal to the least count of the instrument divided into two parts, half above and half below the recorded reading.

Thus the correct way of recording the above reading is

$$12.7 \pm 0.05 \text{ cm}$$

The recorded value of the length of the straight line i.e. 12.7 cm contains three digits (1, 2, 7) out of which two digits 1 and 2 are accurately known while the third digit i.e. 7 is a doubtful one. Thus significant figures may be stated as:

"In any measurement, the accurately known digits and the first doubtful digit are called significant figures." **(OR)** *"A significant figure is the one which is known to be reasonably reliable".*

If the above mentioned measurement is taken by a better measuring instrument which is exact up to hundredth of a centimeter, it would have been recorded as 12.70cm. In this case number of significant figures is four (1, 2, 7 and 0).

Thus, we can say that as we improve the quality of our measuring instrument and techniques, we extend the measured result to more and more significant figures and correspondingly improve the experimental accuracy of the result.

General Rules

(a) A zero between two significant figures is itself significant.

(b) Zeros to the left of significant figures are not significant. For example, none of the zero in 0.00467 or 02.59 is significant.

(c) Zeros to the right of significant figure may or may not be significant.

(i) In decimal fraction, zeros to the right of a significant figure are significant. For example, all the zeros in 3.570 or 7.4000 are significant.

(ii) In integers, such as 8,000 kg, the number of significant zeros is determined by the accuracy of the measuring instrument. If the measuring scale has a least count of 1kg then there are four significant figures written in scientific notation as 8.000×10^3 kg. If the least count of the scale is 10 kg, then the number of significant figures will be 3 written in scientific notation as 8.00×10^3kg and so on.

(2) Significant Figures in Multiplication and Division of Numbers

In multiplying or dividing numbers i.e.,

$$\frac{5.348 \times 10^{-2} \times 3.64 \times 10^{4}}{1.336} = 1.4576898 \times 10^{3}$$

Let us see, how many numbers should be retained in the answer. As the factor 3.64×10^4, the least accurate in the above calculations has three significant figures, the answer should be written to three significant figures only. The other figures are insignificant and should be deleted. While deleting the figures, the last significant figure to be retained is rounded off.

Rules for Rounding Off Numbers

Following are the rules for rounding off numbers.

(a) If the first digit to be dropped is less than 5, the last digit to be retained should remain unchanged. e.g. 12.4 is rounded off as 12.

(b) If the first digit to be dropped is more than 5, the last digit to be retained is increased by one. e.g. 12.6 is rounded off as 13.

(c) If the digit to be droped is 5, and the number following 5 is not zero then the last digit to be retained is increased by one e.g. 12.51 is rounded off as 13.

(d) If the digit to be droped is 5, and the number following 5 is zero then the last digit to be retained follows odd even rule. i.e., if the digit to be retained is odd it is increased by one but left as it is if it is even.

e.g.,

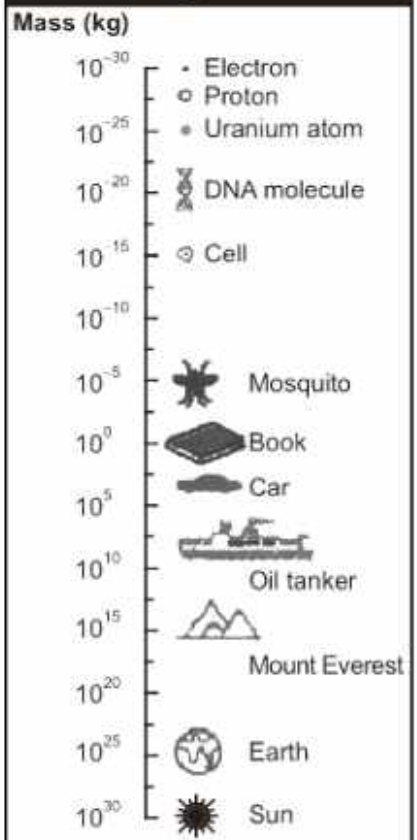
13.50	is rounded off as	14
14.50	is rounded off as	14
15.5	is rounded off as	15
16.5	is rounded off as	16

Examples of Numbers to be Rounded Off

The following numbers are rounded off to three significant figures as follows.

43.75 is rounded off as 43.8

Interesting Information



Order of magnitude of some masses

Following this rule, the correct answer of the computation given in section (2) is 1.46×10^3.

(3) Addition or Subtraction of Numbers

In adding or subtracting numbers, the number of decimal places retained in the answer should be equal to the smallest number of decimal places in any of the quantities being added or subtracted. In this case, the number of significant figures is not important. It is the position of decimal that matters.

For example, we wish to add the following quantities expressed in meters.

(i)	72.1	(ii)	2.7543
	3.42		4.10
	0.003		1.273
	75.523m		8.1273
	75.5m		8.13m

In Case (i) the number 72.1 has the smallest number of decimal places, thus answer is rounded off to the same decimal position which is then 75.5m.

In case (ii) the number 4.10 has the smallest number of decimal places, and hence answer is rounded off to the same decimal position which is then 8.13m.

Do You Know?

Mass can be thought of as a form of energy. In fact the mass is highly concentrated form of energy. Einstein's famous equation, $E=mc^2$ means

Energy = Mass x Speed of light^2

According to this equation 1 kg mass is actually 9×10^{16} J energy.

Q.11 Explain the term precision and accuracy.

Ans. **PRECISION AND ACCURACY**

In measurements made in physics, the term precision and accuracy are frequently used. The precision of a measurement is determined by the instrument or device being used and accuracy of measurement depends on the fractional or percentage uncertainty in that measurement. Let us make it clear by examples.

Example-I

Let the length of an object is recorded as 25.5cm by using meter rod having smallest division in millimeter. This measurement is difference of two readings that is initial and final positions. In case of single reading uncertainty is taken as ± 0.05cm. But in present reading uncertainty is taken double due to the reading of initial and final position i.e.

Uncertainty = ±0.05 ±0.05 = ±0.1cm

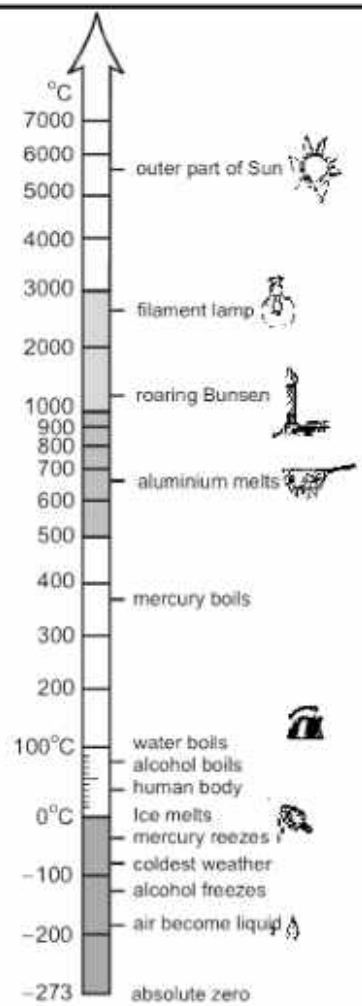
This uncertainty is called absolute uncertainty and absolute uncertainty in effect is equal to least count of the measuring instrument.

Thus,

Precision or absolute uncertainty (least count) = ±0.1cm

$$\text{Fractional uncertainty} = \frac{0.1\text{cm}}{25.5\text{cm}} = 0.004$$

$$\text{Percentage uncertainty} = \frac{0.1}{25.5} \times \frac{100}{100} = \frac{0.4}{100} = 0.4\%$$



Some Specific Temperatures

Example-II

Another measurement is recorded as 0.45cm. It is taken by vernier callipers with least count as 0.01cm.

Now, Precision or absolute uncertainty (least count) = ±0.01cm

$$\text{Fractional uncertainty} = \frac{0.01\text{cm}}{0.45\text{cm}} = 0.02$$

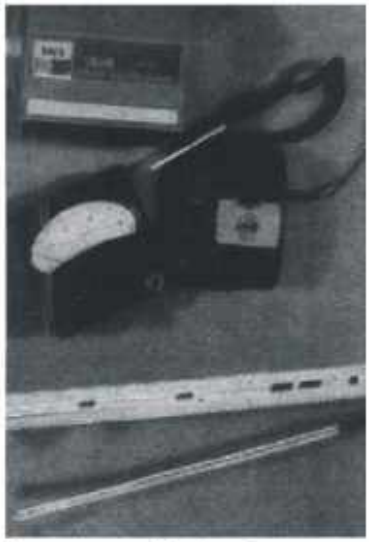
$$\text{Percentage uncertainty} = \frac{0.01\text{cm}}{0.45\text{cm}} \times \frac{100}{100} = \frac{2.0}{100} = 2.0\%$$

Conclusion

The reading 25.5cm taken by meter rule is although less precise but is more accurate having less percentage uncertainty or error where as the reading 0.45cm taken by vernier callipers is more precise but less accurate.

In fact, it is relative measurement which is important. The smaller a physical quantity, a more precise instrument should be used Here the measurement 0.45cm demands that a more precise instrument, such as micrometer screw guage with least count 0.001cm should have been used. Thus we can define precision and accuracy.

For Your Information



We use many devices to measure physical quantities, such as length, time and temperature. They all have some limit of precision.

Precision

A precise measurement is the one which has less absolute uncertainty.

Accuracy

An accurate measurement is the one which has less fractional or percentage uncertainty or error.

Q.12 How will you assess the total uncertainty in the final result? Explain in different cases.

Ans. **ASSESSMENT OF TOTAL UNCERTAINTY IN THE FINAL RESULT**

To assess the total uncertainty or error, it is necessary to evaluate the uncertainties in all the factors involved in that calculation. The maximum possible uncertainty or error in the final result can be found as follows.

(1) For Addition and Subtraction

For addition and subtraction absolute uncertainties are added.

For example, the distance x determined by the difference between two separate position measurements.

$$x_1 = 10.5 \pm 0.1\text{cm}$$

and $$x_2 = 26.8 \pm 0.1\text{cm}$$

The difference between them is recorded as

$$x = x_2 - x_1$$

$$x = 26.8 \pm 0.1 - 10.5 \pm 0.1$$

$$x = 16.3 \pm 0.2\text{cm}$$

(2) For Multiplication and Division

$$R = \frac{V}{I}$$

Where V = Potential difference

and I = Current

The given values of V and I are.

$$V = 5.2 \pm 0.1V$$

and $$I = 0.84 \pm 0.05A$$

The %age uncertainty for V is $= \frac{0.1V}{5.2V} \times \frac{100}{100} = \frac{2}{100} = 2\%.$

The %age uncertainty for I is $= \frac{0.05A}{0.84A} \times \frac{100}{100} = \frac{6}{100} = 6\%$

Hence total uncertainty in the value of R is.

= % age uncertainty for V + % age uncertainty for I.

= 2% + 6%

= 8%

Thus,

$$R = \frac{5.2V}{0.84A} = 6.19\ VA^{-1} = 6.19$$

Ohms with % age uncertainty of 8%.

Now,

$$8\% \text{ of } 6.2 = 6.2 \times \frac{8}{100} = 0.5$$

Thus,

$$R = 6.2 \pm 0.5 \text{ ohms}$$

The result is rounded off to two significant digits because both V and I have two significant figures. Uncertainty being an estimate only, is recorded by one significant figure.

(3) For Power Factor

For power factor multiply the percentage uncertainty by that factor i.e.

Total % age uncertainty = Power factor × % age uncertainy.

Example

Let us calculate the volume of a sphere given by formula.

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

Now,

% age uncertainty in V = power factor × % age uncertainty in r.

∴ % age uncertainty in V = 3 × % age uncertainty in r.

Let the radius of sphere is measured as 2.25 cm by a vernier calliper with least count 0.01 cm, then.

Radius r is recorded as

$$r = 2.25 \pm 0.01\,cm$$

Now,

Absolute uncertainty = least count = 0.01cm

$$\% \text{ age uncertainty in } r = \frac{0.01cm}{2.25cm} \times \frac{100}{100} = \frac{0.4}{100} = 0.4\%$$

$\therefore$ Total % age uncertainty in V = $3 \times 0.4\%$ = 1.2%

Now,

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

$$= \frac{4}{3}(3.14)(2.25cm)^3$$

$$= 47.689\ cm^3$$

Thus,

Volume V = $47.689\ cm^3$ with 1.2% of uncertainty.

As, 1.2% of 47.689 = 0.6

$\therefore$ $V = 47.7 \pm 0.6\ cm^3$

For Your Information

Colour printing uses just four colours-cyan, magenta, yellow and black to produce the entire range of colours. All the colours in this book have been made from just these four colours.

(4) For Uncertainty in the Average Value of Many Measurements

(i) Find the average value of measured values.

(ii) Find the deviation of each measured value from the average value.

(iii) The mean deviation is the uncertainty in the average value.

Example

There are six readings of the micrometer screw guage to measure the diameter of a wire in mm.

The readings are.

1.20, 1.22, 1.23, 1.19, 1.22, and 1.21.

Then,

$$\text{Average} = \frac{1.20 + 1.22 + 1.23 + 1.19 + 1.22 + 1.21}{6}$$

$$= 1.21 \text{ mm}$$

The deviation of each value ie the difference between each recording and average value, without regard of sign, are.

0.01, 0.01, 0.02, 0.02, 0.01, and 0.

$$\text{Mean of deviations} = \frac{0.01 + 0.01 + 0.02 + 0.02 + 0.01 + 0}{6}$$

$$= 0.01 \text{ mm}$$

Thus uncertainty in mean diameter i.e., 1.21 mm is 0.01 mm recorded as

$$\boxed{\text{Diameter} = 1.21 \pm 0.01 \text{ mm}}$$

(5) For the Uncertainty in Timing Experiment

The uncertainty in the time period of a vibrating body is found by dividing the least count of timing device by the number of vibrations ie.

$$\text{Uncertainty in time period} = \frac{\text{Least count}}{\text{No. of vibrations}}$$

For Your Information



These are not decoration pieces of glass but are the earliest known exquisite and sensitive thermometers, built by the Academia del Cimento (1657-1667), in Florence. They contained alcohol, some times coloured red for easier reading.

Example

The time of 30 vibrations of a simple pendulum recorded by a stopwatch accurate up to one tenth of a second (least count) is 54.6 s.

Now, Time period = $T = \frac{54.6\ s}{30} = 1.82$ Sec

$$\text{Uncertainty} = \frac{\text{Least count}}{\text{No. of vibrations}} = \frac{0.1\ s}{30} = 0.003S$$

Thus time period T is

$$\boxed{T = 1.82 \pm 0.003\ S}$$

Note: *It is advisable to count large number of swings to reduce timing uncertainty.*

For Your Information



Atomic Clock

The cesium atomic frequency standard at the National Institute of Standards and Technology in Colorado (USA). It is the primary standard for the unit of time.

Q.13 What do you understand from the dimensions of physical quantities?

Ans. DIMENSIONS OF PHYSICAL QUANTITIES

"The qualitative nature of the physical quantity is considered a dimensions. It is denoted by a specific symbol written within square brackets."

(OR)

Dimensions of physical quantity is a relationship between derived physical quantity and the base quantity.

Different quantities such as length, breadth, diameter, light year which are measured in meter denote the same dimensions and has the dimensions of length [L]. Similarly, the dimensions of mass and time are denoted by [M] and [T] respectively.

Other quantities that we measure have dimensions which are combinations of these dimensions.

(1) Dimensions of Speed

$$\text{Speed} = \frac{\text{length}}{\text{time}} = \frac{L}{T}$$

$$\text{Dimensions of speed} = \frac{\text{dimension of length}}{\text{dimension of time}}$$

$$\text{or} \quad [V] = \frac{[L]}{[T]}$$

$$\Rightarrow \quad [V] = [L][T^{-1}] = [LT^{-1}]$$

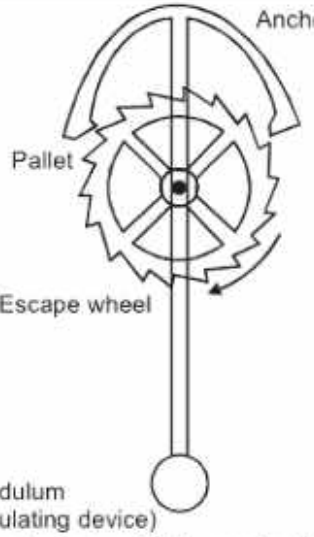
(2) Dimensions of Acceleration

$$\text{Acceleration} = \frac{\text{velocity}}{\text{time}}$$

$$\text{Dimensions of acceleration} = \frac{\text{dimension of V}}{\text{dimension of I}}$$

$$= \frac{[V]}{}$$

Do You Know?



The device which made the

(3) Dimensions of Force

Since, $F = ma$

$\therefore \quad [F] = [m][a]$

$= [M][LT^{-2}] \quad \therefore [a] = [LT^{-2}]$

$= [MLT^{-2}]$

Using the method of dimensions called the dimensional analysis, we can check the correctness of a given formula or an equation and can also derive it. Dimensional analysis makes use of the fact that expression of the dimensions can be manipulated as algebraic quantities.

(i) Checking the Homogeneity of Physical Equation

In order to check the correctness of an equation, we are to show that the dimensions of the quantities on both sides of the equation are the same, irrespective of the form of the formula. This is called the principle of homogeneity of dimensions.

(ii) Derivation of a Possible Formula

The success of this method for deriving a relation for a physical quantity depends on the correct guessing of various factors on which the physical quantity depends.

SOLVED EXAMPLES

EXAMPLE 1.1

The length, breadth and thickness of a sheet are 3.233m, 2.105 m and 1.05 cm respectively. Calculate the volume of the sheet correct upto the appropriate significant digits.

Data

Length of sheet = l = 3.233m

Breadth of sheet = b = 2.105m

Thickness of sheet = h = 1.05cm = 1.05×10^{-2}m

To Find

Volume of sheet = V = ?

SOLUTION

Volume is given by

$$V = l \times b \times h$$

Putting values, we get

$$V = 3.233 \times 2.105 \times 1.05 \times 10^{-2}$$

$$= 7.14573825 \times 10^{-2}\ m^3$$

As the factor 1.05 cm has minimum number of significant figures equal to three, therefore, volume is recorded up to 3 significant figures.

Hence, $\boxed{V = 7.15\ m^3}$

Result

Volume of sheet = V = $7.15\ m^3$

EXAMPLE 1.2

The mass of a metal box measured by a lever balance is 2.2 kg. Two silver coins of masses 10.01 g and 10.02 g measured by a beam balance are added to it. What is now the total mass of the box correct upto the appropriate precision?

Data

Mass of box = m = 2.2 kg

Mass of 1^{st} coin = m_1 = 10.01g = 0.01001kg

SOLUTION

Total mass when silver coins are added.

$$M = m + m_1 + m_2$$
$$= 2.2 + 0.01001 + 0.01002$$
$$= 2.22003 \text{ kg}$$

Since least precise is 2.2 kg having one decimal Place, hence total mass should be to one decimal place which is the appropriate precision. Thus,

Total mass = 2.2 kg

Result

Total mass = 2.2 kg

EXAMPLE 1.3

The diameter and length of a metal cylinder measured with the help of vernier calipers of least count 0.01 cm are 1.22 cm and 5.35 cm. Calculate the volume V of the cylinder and uncertainty in it.

Data

Least count of vernier callipers = 0.01cm

Diameter of cylinder = D = 1.22 cm

Length of cylinder = l = 5.35 cm

To Find

Volume of cylinder = V = ?

Uncertainty in volume = ?

SOLUTION

Absolute uncertainty in length = 0.01 cm

$$\% \text{ age uncertainty in length} = \frac{0.01}{5.33} \times \frac{100}{100} = \frac{0.2}{100} = 0.2\%$$

Absolute uncertainty in diameter = 0.01 cm

$$\% \text{ uncertainty in diameter} = \frac{0.01}{1.22} \times \frac{100}{100} = \frac{0.8}{100} = 0.8\%$$

As volume is given by

$$V = \pi r^2 l$$
$$V = \frac{\pi d^2 l}{4}$$

$\therefore$ Total uncertainty in V = 2 (% uncertainty in d) + (% uncertainty in l)

$$= 2\,(.8) + .2$$

Thus, V = 6.2509079 cm^3 with uncertainty 1.8%.

As, 1.8% of 6.2509079 = 0.1

Thus, V = 6.2 ± 0.1 cm^3

Where 6.2 cm^3 is calculated volume and 0.1 cm^3 is the uncertainty in it.

Result

Volume of cylinder = 6.2509079 cm^3

Uncertainty in volume = 6.2 ± 0.1 cm^3

EXAMPLE 1.4

Check the correctness of the relation $v = \sqrt{\frac{F \times l}{m}}$ where V is the speed of transverse wave on a stretched string of tension F, length *l* and mass m.

SOLUTION

The given formula is

$$V = \sqrt{\frac{F \times l}{m}}$$

Dimensions of L.H.S = [V] = $[LT^{-1}]$

Dimensions of R.H.S = $\left[\frac{F \times l}{m}\right]^{1/2}$

$$= \left[\frac{[F]\,[l]}{[m]}\right]^{1/2} = \left[\frac{[MLT^{-2}]\,[L]}{[M]}\right]^{1/2}$$

$$= [L^2T^{-2}]^{1/2}$$

$$= [LT^{-1}]$$

As Dimensions of LHS = Dimensions of RHS.

Hence formula is dimensionally correct.

EXAMPLE 1.5

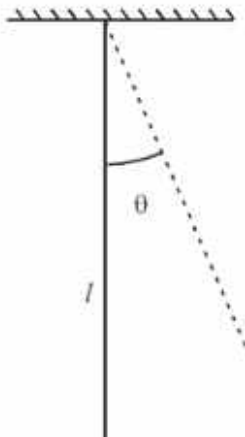
Derive a relation for the time period of a simple pendulum (Fig. 1.2) using dimensionsal analysis. The various possible factors on which the time period T may depend are

(i) Length of the pendulum (*l*).

(ii) Mass of the bob (m).

(iii) Angle θ which the thread makes with the vertical.

(iv) Acceleration due to gravity (g).



Data

Length of the pendulum = *l*

To Find

Relation for time period = T = ?

SOLUTION

The relation for time period T will be of the form

$$T \propto m^a \times l^b \times \theta^c \times g^d$$

or $$T = \text{Constant } m^a l^b \theta^c g^d \quad \ldots\ldots (1)$$

Now we find the values of powers a, b, c and d.

Now, Dimensions of $\theta = [LL^{-1}] = 1$ $\quad \therefore s = r\theta$

And, Dimensions of $g = [LT^{-2}]$ $\quad \theta = \frac{S}{r} = \frac{L}{L}$

$= LL^{-1} = 1$

Writing dimensions on both sides, we get.

$$[T] = \text{Constant } [M]^a [L]^b [1]^c [LT^{-2}]^d$$

$$= \text{Constant } [M]^a [L]^b [1]^c [L]^d [T]^{-2d}$$

$$[T] = \text{Constant } [M]^a [L]^{b+d} [T]^{-2d} \quad ([1]^c = 1)$$

Comparing the exponents of M, L and T on both sides

$$[M]^o = [M]^a \Rightarrow a = 0$$

$$[L]^o = [L]^{b+d} \Rightarrow b + d = 0 \text{ or } b = -d = (-1/2) = ½$$

$$[T]^1 = [T]^{-2d} \Rightarrow -2d = 1 \text{ or } d = -1/2$$

Thus, $a = 0$

$b = 1/2$

$d = -1/2$

Putting values of a, b, d and θ in eq. (1), we get.

$$T = \text{Constant } m^o \times l^{1/2} \times 1 \times g^{-1/2}$$

or $$T = \text{Constant} \frac{l^{1/2}}{g^{1/2}}$$

or $$T = \text{Constant} \sqrt{\frac{l}{g}}$$

$$\boxed{T = \text{Constant} \sqrt{\frac{l}{g}}}$$

EXAMPLE 1.6

Find the dimensions and hence, the SI units of coefficient of viscosity η in the relation of Stokes law for the drag force F for a spherical object of radius r moving with velocity v given as $F = 6\pi\eta rv$.

Data

$$F = 6\pi\eta\, rv$$

To Find

Dimensions of η = ?

Units of η = ?

SOLUTION

We are given

$$F = 6\pi\eta\, rv \qquad \ldots\ldots (1)$$

Now, 6π is a number having no dimensions. It is not accounted in dimensional analysis, then.

$$[F] = [\eta\, r\, v]$$

$$\Rightarrow \quad [\eta] = \frac{[F]}{[r]\,[v]}$$

Substituting (putting) the dimensions of F, r and v in R.H.S, we get

$$[\eta] = \frac{[MLT^{-2}]}{[L]\,[LT^{-1}]}$$

$$[\eta] = [ML^{-1}T^{-1}]$$

Units of η

SI unit of η are $kg\ m^{-1}s^{-1}$.

Result

Dimension of η = $[ML^{-1}T^{-1}]$

Unit of η = $kg\ m^{-1}s^{-1}$



MEASUREMENTS

Each question has four possible answers, encircled the correct answer:

1. The study of physics deals with:

(a) Laws of motion **(b)** The structure of space and time

(c) Force present in the nature **(d)** All of the above

2. The science of physics based on:

(a) Hypothesis **(b)** Experiments and measurements

(c) Only definition **(d)** Fundamental quantities

3. The branch of physics "wave mechanics" introduced by:

(a) Einstien **(b)** Max Planck

(c) De-broglie **(d)** Bohr

4. The branch of physics which deals with the nuclear particles such as neutrons, protons and nuclear structure is called:

(a) Particle physics **(b)** Solid state physics

(c) Plasma physics **(d)** Nuclear physics

5. The branch of physics which deals with the properties of gravitational field, electromagnetic field and nuclear field is called:

(a) Aerodynamics **(b)** Acorestics

(c) Hydrodynamics **(d)** Field theory

6. The idea that light is electromagnetic waves was introduced by:

(a) Crooks **(b)** Fermi

(c) Maxwell Planck **(d)** Newton

7. Laws of physics expressed in terms of:

(a) Base quantities **(b)** Derived quantities

(c) Both (a) & (b) **(d)** None of these

8. The study of nature is classified into:

(a) Five branches **(b)** Two branches

(c) Six branches **(d)** None of these

9. Engineering physics, Astrophysics, Bio-physics and Geophysics are:

(a) Branches of Chemistry **(b)** Branches of Physics

(c) Applied physics **(d)** None of these

10. ———— is area of physics:

(a) Chemical physics **(b)** Astrophysics

(c) Mechanics **(d)** None of these

11. The study of physics involves investigating such things as:

(a) Structure of space and time

(b) Laws of motion

(c) The interaction between different particles

(d) All of the above

12. Physist started believing that every thing about physics has been discovered by the end of:

(a) 20^{th} Century **(b)** 19^{th} Century

(c) 15^{th} Century **(d)** None of these

13. The overlapping of physics and other fields gave birth to:

(a) Areas of physics **(b)** Areas of science

(c) Interdisciplinary areas of physics **(d)** All of these

14. The branch of physics which deals with the study of production, propagation and properties of sound waves is called:

(a) Heat and thermodynamics **(b)** Optics

(c) Mechanics **(d)** Acoustics

15. The branch of physics which deals with velocities approaches the velocity of light is called:

(a) Quantum physics **(b)** Wave mechanics

(c) Relativistic mechanics **(d)** None of these

16. Experimentation and practical verification was first introduced by:

(a) The Greek philosophers **(b)** The European scientists

(c) The Muslim scientists **(d)** None of these

17. Physics based on Newtonian mechanics is called:

(a) Astrophysics **(b)** Classical physics

(c) Modern physics **(d)** Meta physics

18. Pascal is famous for his work:

(a) Hydrostatics **(b)** Hydrodynamics

(c) Laws of gases **(d)** Behaviour of elastic bodies

19. System international (SI) was established in:

(a) 1960 **(b)** 1967

(c) 1971 **(d)** 1930

20. The basic quantity among the following is:

(a) Torque **(b)** Force

(c) Mass **(d)** Velocity

21. Which one of the scientist made some contribution to geometrical optics?

(a) Archimedes **(b)** Pythagoras

(c) Euclid **(d)** Plato

22. Which of the following is the derived quantity:

(a) Time **(b)** Area

(c) Length **(d)** Mass

23. Which of the following is a set of supplementary units:

(a) Radian and kilogram **(b)** Stcradian and time

(c) Mole and radian **(d)** Radian and steradian

24. The SI unit for measuring plane angle is:

(a) Radian **(b)** Steradian

(c) Both (a) & (b) **(d)** None of these

25. The present standard metre is defined as:

(a) The distance between two points on an alloy bar

(b) The length of mean solar day

(c) The length equal to 165076373 wavelength of krypton at 86 atm

(d) The distance travel by the light in vacuum during a time of $\frac{1}{299792458}$ second

26. SI units of time was redefined in:

(a) 1900 **(b)** 1960

(c) 1967 **(d)** 1983

27. Physical quantities are divided into:

(a) Six categories **(b)** Three categories

(c) Two categories **(d)** None of these

28. The quantities which are defined in terms of other physical quantities are called:

(a) Derived quantities **(b)** Base quantities

(c) Both (a) & (b) **(d)** None of these

29. The basic units in system international (SI) units are:

(a) Three **(b)** Five

(c) Two **(d)** Seven

30. The fundamental quantities which form basic for M.K.S system are:

(a) Mass, work and time **(b)** Mass, acceleration & time

(c) Velocity, force and time **(d)** Mass, length and time

31. Supplementary units are:

(a) Five **(b)** Three

(c) Two **(d)** One

32. The SI units of solid angle is:

(a) Radian **(b)** Steradian

(c) Degree **(d)** None of these

33. The system international (SI) built up from:

(a) Derived units **(b)** Basic units

(c) Supplementary units **(d)** All of these

34. Metre is the basic unit of:

(a) Length **(b)** Mass

(c) Force **(d)** Velocity

35. The kilogram is the basic unit of:

(a) Length **(b)** Mass

(c) Weight **(d)** Time

36. One mile is equal to:

(a) 1.625 km **(b)** 1.609 km

(c) 1.325 km **(d)** 1.850 km

37. One inch is equal to:

(a) 1.32 cm **(b)** 25.4 cm

(c) 2.10 cm **(d)** 2.54 cm

38. One foot is equal to:

(a) 31.90 cm **(b)** 30.84 cm

(c) 30.48 cm **(d)** 84.30 cm

39. Number of nano second in a year is:

(a) 3.1536×10^7 **(b)** 3.1536×10^9

(c) 3.1536×10^{16} **(d)** None of these

40. One year is equal to:

(a) 3.2×10^7 sec **(b)** 2.25×10^7 sec

(c) 3.35×10^7 sec **(d)** All of these

41. Light year is the unit of:

(a) Light **(b)** Time

(c) Velocity **(d)** Distance

42. The SI unit of force is:

(a) Newton **(b)** Joule

(c) Dyne **(d)** Volt

43. The SI unit of work is:

(a) Newton **(b)** Joule

(c) Dyne **(d)** Volt

44. The SI unit of power is:

(a) Newton **(b)** Watt

(c) Dyne **(d)** Ampere

45. The SI unit of intensity of light is:

(a) Joule **(b)** Mole

(c) Kilomole **(d)** Candila

46. The SI unit of amount of substance is:

(a) Joule **(b)** Mole

(c) Volt **(d)** Ohm

47. The SI units of angular momentum is:

(a) kg m/s **(b)** kg m/s^2

(c) kg m^2/s **(d)** None of these

48. Time taken by light to reach from sun to earth is:

(a) 7 min 20 sec **(b)** 8 min 20 sec

(c) 9 min 20 sec **(d)** None of these

49. Time taken by light to reach from moon to earth is:

(a) 1 min 20 sec **(b)** 8 min 20 sec

(c) 2 min 20 sec **(d)** 3 min 20 sec

50. Number of seconds in a day is:

(a) 9000 sec **(b)** 86400 sec

(c) 43200 sec **(d)** 3600 sec

51. The unit of pressure in base units is:

(a) $kg/m\text{-}s^2$ **(b)** kg/ms

(c) $kg\ ms^2$ **(d)** None of these

52. Mean radius of the earth is:

(a) 6.4×10^9 mm **(b)** 6.4×10^3 mm

(c) 6.4×10^6 m **(d)** None of these

53. Solid angle subtended at the centre by a sphere of radius r is:

(a) 2π **(b)** 6π

(c) 6π **(d)** 4π

54. Steradian is defined by:

(a) $\frac{\text{Area of a strip}}{(\text{radius})^2}$ **(b)** $\frac{\text{Arc length}}{\text{radius}}$

(c) $\frac{\text{Area}}{(\text{radius})^2}$ **(d)** None of these

55. The unit of thermodynamic temperature is:

(a) K **(b)** C°

(c) F° **(d)** None of these

56. One atto is:

(a) 10^{-20} **(b)** 10^{-16}

(c) 10^{-14} **(d)** 10^{-18}

57. One femto is:

(a) 10^{-16} **(b)** 10^{-12}

(c) 10^{-15} **(d)** 10^{-9}

58. One pico is:

(a) 10^{-10} **(b)** 10^{-12}

(c) 10^{-18} **(d)** 10^{-10}

59. The number of significant figures, with the increases accuracy of the measuring instruments:

(a) Decreases **(b)** Increases

(c) Remains unchanged **(d)** None of these

60. The number of significant figures, with the increases degree of approximation:

(a) Decreases **(b)** Increases

(c) Remains unchanged **(d)** None of these

61. The number of significant figure in 8.80×10^6 kg is:

(a) 1 **(b)** 5

(c) 3 **(d)** 6

62. The number 64.350 is rounded off as:

(a) 64.35 **(b)** 64.46

(c) 64.36 **(d)** 64.4

63. In scientific notation, the number 0.01 may be written as:

(a) 10^{-2} **(b)** 10^{-4}

(c) 10×10^{-4} **(d)** 1×10^{-4}

64. The number of significant figures in 0.809999 is:

(a) 2 **(b)** 5

(c) 3 **(d)** 4

65. If length = 0.233 m and width = 0.178 m, the most accurate area expressed space of significant figures is:

(a) 0.041 m^2 **(b)** 0.0415 m^2

(c) 0.041747 m^2 **(d)** None of these

66. The number 0.0001 in scientific notation is:

(a) 1×10^4 **(b)** 10^{-3}

(c) 10×10^4 **(d)** 10^{-4}

67. One mega is equal to:

(a) 10^6 **(b)** 10^{-6}

(c) 10^3 **(d)** 10^9

68. Significant figures in 0.000546 are:

(a) 3 **(b)** 4

(c) 5 **(d)** 1

69. The error in a certain measurement occurs due to:

(a) Negligence of a person **(b)** In appropriate technique

(c) Faulty apparatus **(d)** All of the above

70. The uncertainty may occur due to:

(a) Limitation of an instrument **(b)** Natural variance of the object

(c) Personal negligence **(d)** All of the above

71. Systematic error occurs due to:

(a) Instrument **(b)** Zero error of the instrument

(c) Both (a) & (b) **(d)** None of these

72. The least count of a unit meter rod is:

(a) 0.01 cm **(b)** 0.01 mm

(c) Cannot be zero **(d)** Can be zero

73. The significant figure in 0.0010 are:

(a) 4 **(b)** 3

(c) 2 **(d)** 1

74. A precise measurement is one which has:

(a) Less precision **(b)** Maximum precision

(c) Absolute precision **(d)** All of the above

75. Total fractional uncertainty in the period $T = 2\pi\sqrt{\frac{l}{g}}$ will be equal to:

(a) Sum of fractional uncertainty **(b)** Different of uncertainties

(c) Product of uncertainties in l and g **(d)** None of these

76. % uncertainty in the time period of a vibrating body is calculated by:

(a) Least count × Number of vibrations **(b)** Least count / Number of vibrations

(c) Number of vibrations / Least count **(d)** $\frac{\text{Least count}}{\text{Number of vibration}} \times 100$

77. Dimensional analysis helps in:

(a) Finding relation between quantities **(b)** To convert one unit into another

(c) To confirm the correct answer **(d)** All of the above

78. The dimension of force is:

(a) $[ML^2T^{-2}]$ **(b)** $[M^2L^{-2}T]$

(c) $[MLT^{-2}]$ **(d)** [MLT]

79. The dimension $[ML^2T^{-2}]$ belongs to:

(a) Pressure **(b)** Energy

(c) Momentum **(d)** Power

80. $[ML^{-1}T^0]$ is the dimension of:

(a) Surface density **(b)** Linear mass density

(c) Volume mass density **(d)** Weight density

81. The dimensions of weight are:

(a) $[LT^{-2}]$ **(b)** $[LT^{-1}]$

(c) $[MLT^{-2}]$ **(d)** $[ML^2T]$

82. The dimensions of power are:

(a) $[ML^2T^{-3}]$ **(b)** $[ML^2T^{-2}]$

(c) $[MLT^{-1}]$ **(d)** None of these

83. The dimension of density are:

(a) $[ML^{-2}]$ **(b)** $[M^2L^{-2}]$

(c) $[ML^{-3}]$ **(d)** None of these

84. The circumference of the earth was determined by:

(a) Ibn-al-Haitham **(b)** Bohr

(c) Chadwick **(d)** Al-Beruni

85. Hahn discovered uranium fission in:

(a) 1935 **(b)** 1939

(c) 1938 **(d)** 1940

86. Period of audible sound waves is:

(a) 4×10^{2} sec **(b)** 1×10^{-3} sec

(c) 8×10^{-1} sec **(d)** 1×10^{3} sec

87. Errors due to incorrect design of a device are called:

(a) Systematic error **(b)** Random error

(c) Physical error **(d)** None of these

88. The solution of the problem $\frac{6 \times 10^{-8}}{3 \times 10^{-2}} =$ is correct given by:

(a) 2×10^{-4} **(b)** 2×10^{-5}

(c) 2×10^{-10} **(d)** 2×10^{-6}

89. Which of the following is a correct relation:

(a) 1 metre = 10^{-3} centimeter **(b)** 1 decimetre = 10^{2} centimetre

(c) 1 millimetre = 10^{-4} metre **(d)** None of these

90. Density of air is 1.2 kg/m^3. It can be expressed in gm/cm^3 by:

(a) 1.2×10^{-6} **(b)** 12×10^{-4}

(c) 1.2×10^{6} **(c)** 12×10^{3}

91. The period of the earth is equal to:

(a) One solar day **(b)** One lunar day

(c) One astronomical day **(d)** None of these

92. One peta is equal to:

(a) 10^{-12} **(b)** 10^{15}

(c) 10^{-15} **(d)** 10^{9}

93. One exa is:

(a) 10^{18} **(b)** 10^{-15}

(c) 10^{15} **(d)** 10^{-12}

94. The diameter of the milky way is:

(a) 10^{25} m **(b)** 10^{20} m

(c) 10^{30} m **(d)** 10^{-30} m

95. The diameter of an atom is:

(a) 10^{-10} m **(b)** 10^{-12} m

(c) 10^{-5} m **(d)** 10^{-15} m

96. The diameter of a nucleus is:

(a) 10^{-12} m **(b)** 10^{-10} m

(c) 10^{-20} m **(d)** 10^{-15} m

97. Which one of the following scientists made some contributions to geometrical optics:

(a) Euclid **(b)** Plato

(c) Archimedes **(d)** None of these

98. The founder of mathematical physics is:

(a) Archimedes **(b)** Plato

(c) Euclid **(d)** Aristotle

99. The dimensions of $\left[\frac{1}{2}at^2\right]$ are that of:

(a) Velocity **(b)** Force

(c) Time **(d)** Length

100. Which one of the following Muslim Mathematision determined the earths circumference:

(a) Ibn-Sina **(b)** Al-Khawrizmi

(c) Al-Beruni **(d)** None of these

101. ♀ Symbolically solid angle is represented as:

(a) rad **(b)** Sr

(c) θ **(d)** Cd

102. ♀ 73.650 rounded off upto one decimal is:

(a) 73.6 **(b)** 73.7

(c) 74.00 **(d)** 73.65

103. ♀ $[LT^{-2}]$ is demensional formula for:

(a) Velocity **(b)** Force

(c) Acceleration **(d)** Momentum

104. The angle between two radii of a circle which cut off on the circumference an arc, equal in length to the radius, is:

(a) 57.3° **(b)** 3′

(c) 37.5° **(d)** None of these

105. Solid angle is ———— dimensional angle.

(a) 2 **(b)** 3

(c) Both (a), (b) **(d)** None of these

106. The error is constant for ———— error.

(a) Random **(b)** Systematic

(c) Both (a), (b) **(d)** All

107. For 0.0036 no. of significant digits:

(a) 4 **(b)** 3

(c) 2 **(d)** 1

108. For 2.450 no. of significant digits:

(a) 4 **(b)** 3

(c) 2 **(d)** 1

109. For 1.40×10^3, no. of significant digits:

(a) 3 **(b)** 4

(c) 2 **(d)** 1

110. Consider two lengths of (10 ± 0.1) cm out (20 ± 0.1) cm measured by a ruler, which is more accurate:

(a) 1^{st} **(b)** 2^{nd}

(c) Same **(d)** None

111. As $F = 6\pi\eta rv$. Dimensions of coefficient of viscosity η:

(a) $[ML^{-1}T^{-1}]$ **(b)** $[MLT^{-1}]$

(c) $[ML^{-2}T^{-1}]$ **(d)** [ML]

112. Dimensions of specific gravity:

(a) $[M^oL^oT^o]$ **(b)** [MLT]

(c) $[ML^{-1}T]$ **(d)** None

113. Dimensions of specific heat:

(a) $[L^2T^{-2}K]$ **(b)** $[L^2T^{-2}K^{-1}]$

(c) $[MLT^{-2}]$ **(d)** None

114. Dimensions of refractive index:

(a) [MLT] **(b)** $[M^oL^oT^o]$

(c) $[ML^{-1}T^{-2}]$ **(d)** None

115. The time of 30 vibrations of a simple pendulum recorded by a stopwatch accurate upto one both of a second, then uncertainty is:

(a) 0.3s **(b)** 0.003s

(c) 0.0003s **(d)** 0.03s

116. The %age uncertainty for V and I is 2% and 6% respectively. Hence total uncertainty in the value of $R = \frac{V}{I}$ is:

(a) 8% **(b)** $\frac{1}{3}\%$

(c) 4% **(d)** 3%

117. The energy of a photon of light of frequency f is given by hf, where h is the Planck constant. What are the base units of h?

(a) $kg\ ms^{-1}$ **(b)** $kg\ m^2s^{-1}$

(c) $kg\ m^2s^{-2}$ **(d)** $kg\ m^2s^{-3}$

ANSWERS

1.	(d)	**2.**	(d)	**3.**	(c)	**4.**	(d)
5.	(d)	**6.**	(c)	**7.**	(c)	**8.**	(b)
9.	(b)	**10.**	(c)	**11.**	(d)	**12.**	(b)
13.	(c)	**14.**	(d)	**15.**	(c)	**16.**	(c)
17.	(b)	**18.**	(b)	**19.**	(a)	**20.**	(c)
21.	(a)	**22.**	(b)	**23.**	(d)	**24.**	(a)
25.	(c)	**26.**	(c)	**27.**	(c)	**28.**	(a)
29.	(d)	**30.**	(d)	**31.**	(c)	**32.**	(b)
33.	(d)	**34.**	(a)	**35.**	(b)	**36.**	(b)
37.	(d)	**38.**	(c)	**39.**	(c)	**40.**	(a)
41.	(d)	**42.**	(a)	**43.**	(b)	**44.**	(b)
45.	(d)	**46.**	(b)	**47.**	(c)	**48.**	(b)
49.	(a)	**50.**	(b)	**51.**	(a)	**52.**	(c)
53.	(d)	**54.**	(a)	**55.**	(a)	**56.**	(d)
57.	(c)	**58.**	(b)	**59.**	(b)	**60.**	(a)
61.	(c)	**62.**	(d)	**63.**	(a)	**64.**	(c)
65.	(a)	**66.**	(d)	**67.**	(a)	**68.**	(a)
69.	(d)	**70.**	(d)	**71.**	(d)	**72.**	(c)
73.	(c)	**74.**	(a)	**75.**	(a)	**76.**	(d)
77.	(a)	**78.**	(c)	**79.**	(b)	**80.**	(b)
81.	(c)	**82.**	(a)	**83.**	(c)	**84.**	(d)
85.	(c)	**86.**	(b)	**87.**	(a)	**88.**	(d)
89.	(c)	**90.**	(b)	**91.**	(a)	**92.**	(b)
93.	(a)	**94.**	(b)	**95.**	(a)	**96.**	(d)
97.	(a)	**98.**	(a)	**99.**	(d)	**100.**	(c)
101.	(b)	**102.**	(b)	**103.**	(c)	**104.**	(a)
105.	(b)	**106.**	(b)	**107.**	(c)	**108.**	(a)
109.	(a)	**110.**	(a)	**111.**	(a)	**112.**	(a)
113.	(b)	**114.**	(b)	**115.**	(b)	**116.**	(a)
117.	(b)						

SHORT QUESTIONS

1.1 Name several repetitive phenomenon occurring in nature which could serve as reasonable time standard.

Ans. Any natural phenomenon that repeats itself after exactly same time interval can be used as a measure of time. The repetitive phenomenon could serve as reasonable time standard, occurring in nature are as follows:

1. **Sun:** Sun served as reasonable time standard because sunset and sunrises gives the information of time.
2. **Moon:** Moon is also reasonable time standard because it gives the information of time.
3. **Weather:** Changing of weather can also give information about time.
4. Rotation of Earth on its axis.
5. Rotation of Earth around the sun.
6. Oscillation of a simple pendulum.

1.2 Give draw backs to use the period of a pendulum as a time standard.

Ans. As we know that the time period of a simple pendulum depends upon the length and value of g at any place. Since

$$T = 2\pi\sqrt{\frac{l}{g}}$$

(i) It is clear that time period of a simple pendulum depends upon the value of g which is different at different places. So a pendulum of same length may have different time period at difference places. So period of pendulum cannot be taken as standard for measuring time.

(ii) Friction: Time period of a simple pendulum changes due to air resistance.

(iii) Temperature: In summer due to increase in temperature, length of simple pendulum changes so time period changes.

1.3 Why do we find it useful to have two units for the amount of substance, the kilogram and the mole?

Ans. It is very useful to have two units for the amount of substance i.e., kilogram and mole. If we want to consider a specific amounts of mass without considering number of microscopic atoms present in it, it is useful to use **kilogram**. Because one kilogram of different substances contains different number of molecules. While if we want to consider a fixed number of atoms present in it then it is useful to use **mole**. Because one mole of any substance contains the same number of atoms or molecules.

1.4 Three student's measured the length of a needle with a scale on which minimum division is 1 mm and recorded as (i) 0.2145m (ii) 0.21m (iii) 0.214m. Which record is correct and why?

Ans. In these records (iii) 0.214 m is more correct than the other records because the least count of a scale is 1 mm which can be written as 0.001 m. So according to this figure, the student measure that type of record is correct.

1.5 An old saying is that "A chain is only as strong as its weakest link". What analogue statement can you make regarding experimental data used in computation?

Ans. The analogous statement regarding experimental data used in computation is "A result obtained from an experimental data used in computation is only as accurate as its least accurate reading".

1.6 The period of simple pendulum is measured by a stopwatch. What type of errors are possible in the time period?

Ans. When the period of a simple pendulum is measured by a stopwatch, the following types of errors are possible:

1. **Systematic Error:** The error due to the fault in the measuring instrument is called systematic error i.e., zero error.
2. **Personal Error:** The error due to the faulty procedure of an observer is called personal error.

1.7 Does dimensional analysis give any information on constant of proportionality that may appear in an algebraic expression? Explain.

Ans. Dimensional analysis does not give any information about the constant of proportionality or dimensionless constant. For example

$$v = \text{Constant} \times \sqrt{\frac{E}{\rho}}$$

The numerical value of this constant cannot determined by dimensional analysis.

1.8 Write the dimension of:

(i) Pressure (ii) Density

Ans. (i) Dimensions of Pressure:

$$\text{As} \quad P = \frac{F}{A} = \frac{ma}{A}$$

$$\text{Unit of } P = \frac{\text{kg ms}^{-2}}{\text{m}^2} = \text{kg m}^{-1}\text{s}^{-2}$$

$$\Rightarrow \quad [P] = [ML^{-1}T^{-2}]$$

(ii) Dimensions of Density:

$$\text{As} \quad \text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$\text{Unit of density} = \frac{\text{kg}}{\text{m}^3} = \text{kg m}^{-3}$$

$$[\text{Density}] = [ML^{-3}]$$

1.9 The wavelength λ of a wave depends on the speed v of the wave and its frequency f. Knowing that:

$[\lambda] = [L], [v] = [LT^{-1}]$ and $[f] = [T^{-1}]$

Decide which of the following is correct, $f = v\lambda$ or $f = \frac{v}{\lambda}$.

Ans. In 1st case if $f = v\lambda$ where f is frequency. Its dimension is $[T^{-1}]$, v is speed, its dimensions are $[LT^{-1}]$.

λ is the wavelength, its dimension is [L].

So, $[T^{-1}] = [LT^{-1}][L]$

$[T^{-1}] = [L^2T^{-1}]$

Hence the equation $f = v\lambda$ is not dimensionally correct because left hand side dimension is not equal to right hand side dimension.

In second case

$$f = \frac{v}{\lambda}$$

So $$[T^{-1}] = \frac{[LT^{-1}]}{[L]}$$

$$[T^{-1}] = [T^{-1}]$$

Hence the equation $f = \frac{v}{\lambda}$ is dimensionally correct because left hand side dimensions is equal to right hand side dimension.

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$$[T^{-1}] = [T^{-1}]$$

Hence the equation $f = \frac{v}{\lambda}$ is dimensionally correct because left hand side dimensions is equal to right hand side dimension.

To Find

(a) Seconds in one year = ?

(b) Nanosecond in one year = ?

(c) Years in one second = ?

SOLUTION

(a) As we know that

$$1 \text{ year} = 365 \text{ days}$$
$$= 365 \times 24 \times 3600$$
$$= 3.15 \times 10^7 \text{ sec.}$$

Seconds in one year $= 3.15 \times 10^7$ sec.

(b) As $1 \text{ year} = 3.15 \times 10^7 \times 10^9$ n sec. Since $1 \text{ ns} = 10^{-9}$ s

$= 3.15 \times 10^{16}$ nanosecond $\therefore \quad 1 \text{ s} = 10^9$ ns

(c) As $1 \text{ year} = 3.15 \times 10^7$ sec.

$$\frac{1}{3.15 \times 10^7} \text{ year} = 1 \text{ second}$$

$$1 \text{ second} = 0.317 \times 10^{-7} \text{ years}$$
$$= 3.17 \times 10^{-8} \text{ years}$$

Result

(a) Number of seconds in one year $= 3.15 \times 10^7$ seconds

(b) Number of nanoseconds in one year $= 3.15 \times 10^{16}$ nanosecond

(c) Number of years in one second $= 3.17 \times 10^{-8}$ years

PROBLEM 1.3

The length and width of a rectangular plate are measured to be 15.3 cm and 12.80 cm, respectively. Find the area of the plate.

Data

Length of rectangular plate = L = 15.3 cm

Width of rectangular plate = W = 12.80 cm

To Find

Area of the plate = A = ?

SOLUTION

As we know that

$$\text{Area} = \text{Length} \times \text{Width}$$
$$= 15.3 \times 12.80$$
$$= 195.84 \text{ cm}^2$$

Result

Area of rectangular plate = A = 196 cm^2

PROBLEM 1.4

Add the following masses given in kg upto appropriate precision. 2.189, 0.089, 11.8 and 5.32.

Data

The given masses are 2.189, 0.089, 11.8 and 5.32

To Find

Sum of masses upto appropriate precision = ?

SOLUTION

Sum of masses = 2.189 + 0.089 11.8 + 5.32

= 19.398

= 19.4 kg

Result

Sum of masses upto appropriate precision = 19.4 kg

PROBLEM 1.5

Find the value of 'g' and its uncertainty using $T = 2\pi\sqrt{\frac{l}{g}}$ from the following measurements made during an experiment.

Length of simple pendulum l = 100 cm

Time for 20 vibrations = 40.2 s

Length was measured by a metre scale of accuracy upto 1 mm and time by stop watch of accuracy upto 0.1 s.

Data

Length of simple pendulum = l = 100 cm

= 1 m

Time for 20 vibration = t = 40.2 s

Time period = $T = \frac{t}{20} = \frac{40.2}{20}$ = 2.01 sec.

Least count of metre scale = 1 mm = 0.1 cm

To Find

Acceleration due to gravity = g = ?

SOLUTION

As we know that

$$T = 2\pi\sqrt{\frac{l}{g}}$$

Squaring

$$T^2 = 4\pi^2 \times \frac{l}{g}$$

$$\boxed{g = \frac{4\pi^2 l}{T^2}}$$

Putting the values

$$g = \frac{4(3.14)^2 \times 1}{(2.01)^2}$$

$$= \frac{39.4384}{4.04}$$

$$g = 9.76 \text{ m/s}^2$$

Since Uncertainty in length = 0.1 cm

% uncertainty in length = 0.1%

% uncertainty in time $= \frac{0.005}{2.01} \times 100$ Since $\frac{0.1}{20} = 0.005$ sec.

$= 0.25\%$

Thus Total uncertainty in "g" = % uncertainty in time + 2(% uncertainty in time)

$= 0.1 + 2(0.25)$

$= 0.1 + 0.5$

$= 0.6\%$

Thus Uncertainty in calculated value of g $= \frac{0.6}{100} \times 0.97$

$= 0.06 \text{ m/s}^2$

Hence $g = (9.76 \pm 0.06) \text{ m/s}^2$

Result

Acceleration due to gravity = g = $(9.76 \pm 0.06) \text{ m/s}^2$

PROBLEM 1.6

What are the dimensions and units of gravitational constant G in the formula?

$$\mathbf{F = G\frac{m_1 m_2}{r^2}}$$

Data

The given formula is

$$F = G\frac{m_1 m_2}{r^2}$$

To Find

Dimensions of G = ?

Unit of G = ?

SOLUTION

Now for dimensions

$$F = G\frac{m_1 m_2}{r^2}$$

$$G = \frac{F \times r^2}{m_1 m_2} \qquad \text{Since} \quad F = ma$$

$$= \frac{ma \times r^2}{m_1 \times m_2}$$

$$\text{Unit of } G = \frac{kg\,.\,m/s^2 \times m^2}{kg\,.\,kg}$$

$$= \frac{m^3}{kg\,s^2}$$

$$\text{Dimensions of } G = [M^{-1}L^3T^{-2}]$$

For unit of G

$$G = \frac{F \times r_2}{m_1 \times m_1} = \frac{N\text{-}m^2}{kg\,.\,kg}$$

$$G = Nm^2/kg^2$$

Result

$$\text{Dimensions of } G = [M^{-1}L^3T^{-2}]$$

$$\text{Unit of } G = N\text{-}m^2/kg^2$$

PROBLEM 1.7

Show that the expression $v_f = v_i + at$ dimensionally correct, where v_1 is the velocity at $t = 0$, a is acceleration and v_f is the velocity at time t.

Data

The given equation is

$$v_f = v_i + at$$

To Find

Is the equation dimensionally correct = ?

SOLUTION

Now $v_f = v_i + at$

In unit form

$$\frac{m}{s} = \frac{m}{s} + \frac{m}{s^2} \times s$$

$$\frac{m}{s} = \frac{m}{s} + \frac{m}{s}$$

$$\frac{L}{T} = \frac{L}{T} + \frac{L}{T}$$

Where 2 is constant so it is dimensionless

$$\frac{L}{T} = \frac{L}{T}$$

$$[LT^{-1}] = [LT^{-1}]$$

$$[LT^{-1}] = [LT^{-1}]$$

Result

Hence the equation $v_f = v_i + at$ is dimensionally correct.

PROBLEM 1.8

The speed v of sound waves through a medium may be assumed to depend on (a) the density ρ of the medium and (b) its modulus of elasticity E which is the ratio of stress to strain. Deduce by the method of dimensions, the formula for the speed of sound.

SOLUTION

As we know that the speed of sound depends upon the following two factors

(i) Density ρ^a and (ii) Elasticity E^b

Since $v \propto \rho^a E^b$

$$v = \text{Constant} \times \rho^a E^b \quad \ldots\ldots \text{(i)}$$

Writing dimensions of quantities on both the sides.

Dimensions of velocity $v = \left[\frac{S}{T}\right] = [LT^{-1}]$

The dimensions of density $\rho = \frac{\text{Mass}}{\text{Volume}}$

$$\text{Unit of } \rho = \frac{kg}{m^3}$$

$$[\rho] = [ML^{-3}]$$

and Dimensions of elasticity $E = \frac{\text{Stress}}{\text{Strain}} = \frac{F}{A}$

Where strain has no dimensions

$$E = \frac{ma}{A}$$

$$\text{Unit of } E = \frac{kg\ m/s^2}{m^2}$$

$$[E] = \frac{kg}{m.s^2} = [ML^{-1}T^{-2}]$$

Putting in equation (i)

$$[LT^{-1}] = \text{Constant}\ [ML^{-3}]^a\ [ML^{-1}T^{-2}]^b$$

$$[LT^{-1}] = \text{Constant} \times [M^aL^{-3a}][M^bL^{-b}T^{-2b}]$$

$$= \text{Constant} \times [M^{a+b}\ L^{-3a-b}\ T^{-2b}]$$

Comparing the exponents

For L $-3a - b = 1$

For T $-2b = -1$

For M $a + b = 0$

As $-2b = -1$

$$b = \frac{1}{2}$$

and $a + b = 0$

$$a + \frac{1}{2} = 0$$

$$\boxed{a = -\frac{1}{2}}$$

Putting the values in eq. (i)

$$v = \text{Constant} \times \rho^{-1/2} E^{1/2}$$

$$v = \text{Constant} \times \frac{E^{1/2}}{\rho^{1/2}}$$

$$v = \text{Constant} \times \sqrt{\frac{E}{\rho}}$$

Result

The formula for the speed of sound is

$$v = \text{Constant} \times \sqrt{\frac{E}{\rho}}$$

PROBLEM 1.9

Show that the famous "Einstein equation" $E = mc^2$ is dimensionally consistent.

SOLUTION

The given equation is

$$E = mc^2$$

Writing the dimension of both sides

Dimension of energy (E) = Work $= F \cdot d$

$$= ma \cdot d$$

$$\text{Unit of work} = \text{kg} \frac{m}{s^2} \cdot m$$

$$= \text{kg} \frac{m^2}{s^2}$$

$$[W] = [ML^2T^{-2}] \quad \ldots\ldots \text{(i)}$$

$$\text{Unit of } mc^2 = \text{kg}\left(\frac{m}{s}\right)^2$$

$$= \text{kg} \frac{m^2}{s^2}$$

$$[mc^2] = [ML^2T^{-2}] \quad \ldots\ldots \text{(ii)}$$

From eq. (i) and (ii)

$$[ML^2T^{-2}] = [ML^2T^{-2}]$$

Result

Hence the Einstein's equation $E = mc^2$ is dimensionally consistent.

PROBLEM 1.10

Suppose, we are told that the acceleration of a particle moving in a circle of radius r with uniform speed v is proportional to some power of r, say r^n, and some power of v, say v^m, determine the powers of r and v?

SOLUTION

According to statement, the acceleration of particle moving in a circle can be written as

$$a \propto r^n v^m$$

$$a = \text{Constant} \times r^n v^m \quad \ldots\ldots \text{(i)}$$

Writing the dimension of both sides

Dimensions of acceleration = $[a] = [LT^{-2}]$

Dimensions of radius = $[r] = m = [L]$

Dimensions of velocity = $[v] = [LT^{-1}]$

Putting in eq. (i)

$$[LT^{-2}] = \text{Constant} \times [L]^n [LT^{-1}]^m$$

$$[LT^{-2}] = \text{Constant} \times [L^n] [L^m T^{-m}]$$

$$[LT^{-2}] = \text{Constant} \times [L^{n+m} T^{-m}]$$

Comparing the exponents

$$n + m = 1$$

$$-m = -2$$

$$\boxed{m = 2}$$

Putting in above

$$n + 2 = 1$$

$$n = 1 - 2$$

$$\boxed{n = -1}$$

Putting in eq. (i)

$$a = \text{Constant} \times r^{-1} v^2$$

$$a = \text{Constant} \times \frac{v^2}{r}$$

Result

The acceleration of a particle moves with velocity in a circle of radius r is

$$a = \text{Constant} \times \frac{v^2}{r}$$