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.

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.

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

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

By the end of 19^{th} century many physicists started believing that everything about physics has been discovered. However, about the beginning of the 20^{th} 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).

Interdisciplinary Areas of Physics

- Astrophysics
- Biophysics
- Chemical physics
- Engineering physics

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.

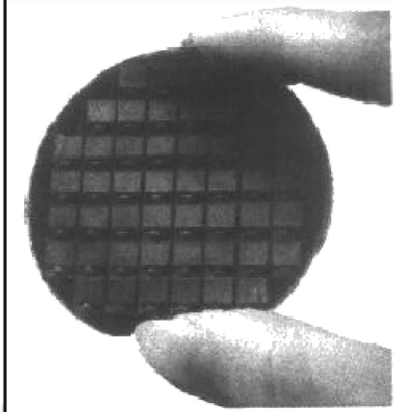
(3) Relativistic Mechanics

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.

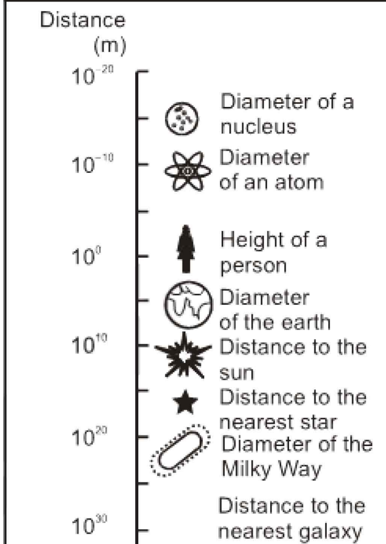
(i) Base quantities.

(ii) Derived quantities.

(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.

Do You Know?



Order of magnitude of some distances

(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**

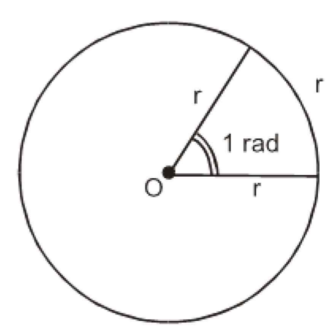
The general conference on weights and measures has not yet classified certain units of the SI under either base units or derived units. These SI units are called supplementary units. This class contains two units, which are:

(1) Radian (Plane angle)

(2) Steradian (Solid angle)

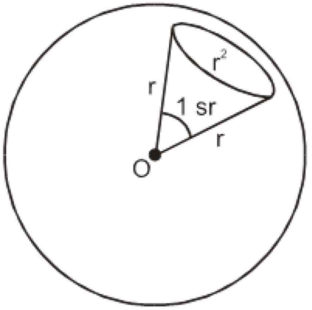
Radian

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, $1\text{km}^2 = 1\ (\text{km})^2 = 1 \times 10^6\text{m}^2$.

(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.

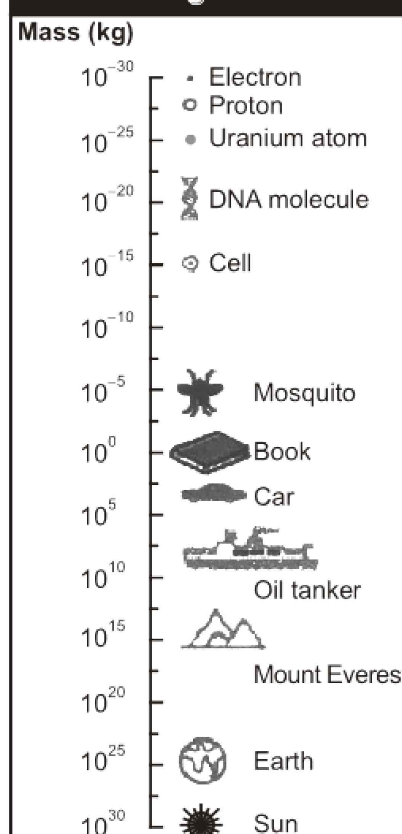
(c) If the digit to be droped is 5, and the number following 5 is not zero then the last digit to be retained is increased by one e.g. 12.51 is rounded off as 13.

(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

Interesting Information



Order of magnitude of some masses

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

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)		(ii)	
	72.1		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.

$$\text{Uncertainty} = \pm 0.05 \pm 0.05 = \pm 0.1\text{cm}$$

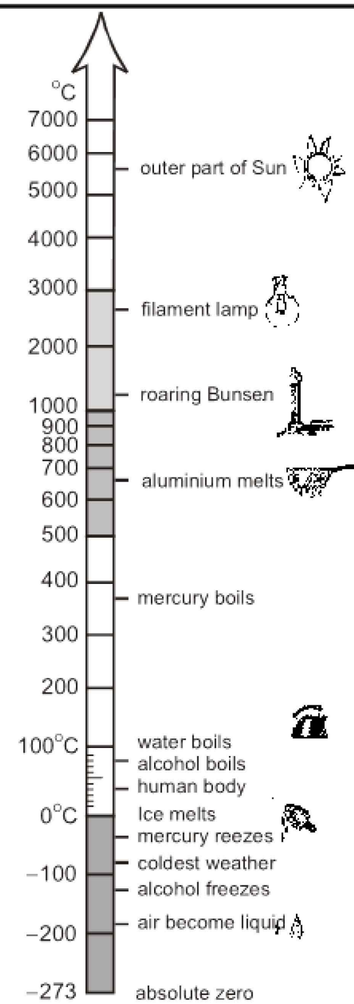
This uncertainty is called absolute uncertainty and absolute uncertainty in effect is equal to least count of the measuring instrument.

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

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

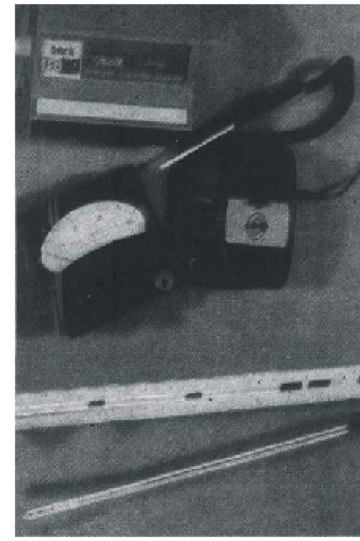
$$\text{Percentage uncertainty} = \frac{0.01\text{cm}}{0.45\text{cm}} \times \frac{100}{100} = \frac{2.0}{100} = 2.0\%$$

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

$$r = 2.25 \pm 0.01\text{cm}$$

Now,

Absolute uncertainty = least count = 0.01cm

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

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

Now,

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

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

$$= 47.689\text{ cm}^3$$

Thus,

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

As, 1.2% of 47.689 = 0.6

$$\therefore \quad V = 47.7 \pm 0.6\text{ cm}^3$$

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

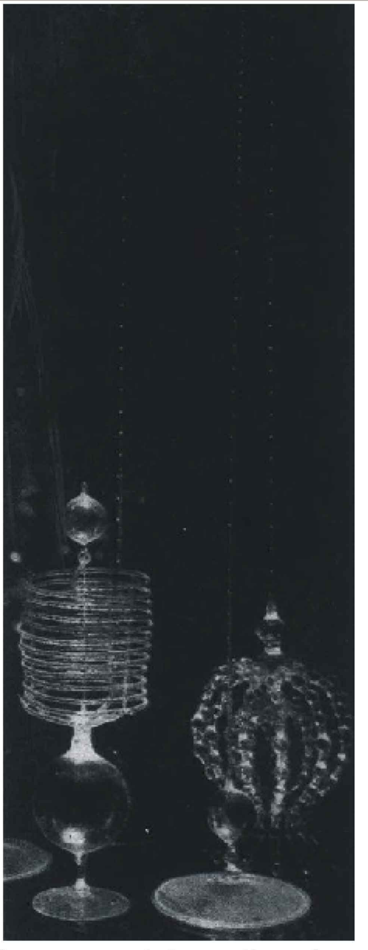
$$\boxed{\text{Diameter} = 1.21 \pm 0.01 \text{ mm}}$$

(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, $\text{Time period} = T = \dfrac{54.6\ \text{s}}{30} = 1.82\ \text{Sec}$

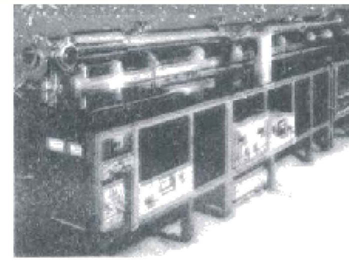
$$\text{Uncertainty} = \frac{\text{Least count}}{\text{No. of vibrations}} = \frac{0.1\ \text{s}}{30} = 0.003\text{S}$$

Thus time period T is

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

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

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

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

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

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

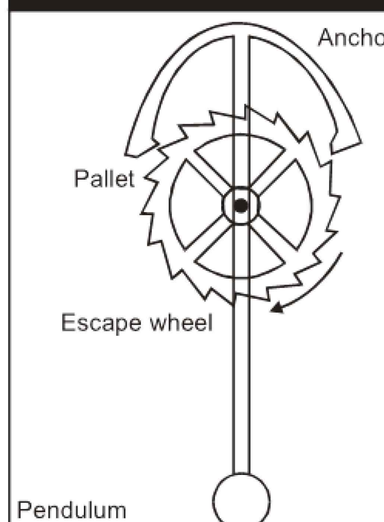
(2) Dimensions of Acceleration

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

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

[V]

Do You Know?



The device which made the

(3) Dimensions of Force

Since, $F = ma$

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

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

$= [MLT^{-2}]$

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 $= l = 3.233\text{m}$

Breadth of sheet $= b = 2.105\text{m}$

Thickness of sheet $= h = 1.05\text{cm} = 1.05 \times 10^{-2}\text{m}$

To Find

Volume of sheet $= V = ?$

SOLUTION

Volume is given by

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

Putting values, we get

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

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

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

Result

Volume of sheet $= V = 7.15\ \text{m}^3$

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 $= m = 2.2\ \text{kg}$

Mass of 1st coin $= m_1 = 10.01\text{g} = 0.01001\text{kg}$

Mass of 2nd coin $= m_2 = 10.02\text{g} = 0.01002\text{kg}$

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

% 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

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

As volume is given by

$$V = \pi r^2 l$$

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

∴ 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, $V = 6.2 \pm 0.1\ cm^3$

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 = $6.2 \pm 0.1\ cm^3$

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 = $\left[\frac{F \times l}{m}\right]^{1/2}$

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

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

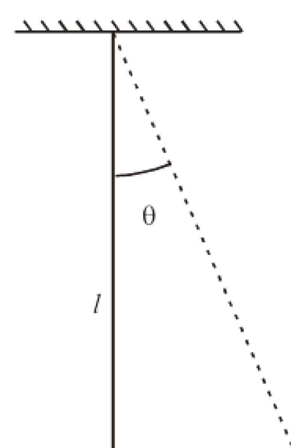
$$= [LT^{-1}]$$

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

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

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

And, Dimensions of $g = [LT^{-2}]$ $\qquad \theta = \frac{S}{r} = \frac{L}{L} = LL^{-1} = 1$

Writing dimensions on both sides, we get.

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

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

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

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 πηrv.

Data

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

To Find

Dimensions of η = ?

Units of η = ?

SOLUTION

We are given

$$F = 6\pi\eta\, rv \qquad \text{...... (1)}$$

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 $m^{-1}s^{-1}$