The International System of Units

The International System of Units (SI system) is a set of seven physical quantities that form the basic units to measure all other physical quantities. How is the length of 1m same everywhere in the world? How long is a second? And why do we use certain SI units to measure specific quantities? Let’s find out the answers.

The International System of Units (SI Units)

A unit is a well defined physical quantity against which we compare other quantities during the process of measurement. The International System of Units, also known as the SI system specifies seven such quantities or fundamental units. The seven quantities and their respective units in the SI units system are as follows:

Mass

In the SI units system, kilograms or kg is the unit of mass. One kilogram is the mass of a Platinum-Iridium cylinder which is 90% Platinum and 10% Iridium. Also, it has its height equal to the diameter and both are equal to 39 mm. This cylinder is the International Prototype Kilogram.

Length

The unit of length in the SI system is the meter or ‘m’. One meter is defined as the length travelled by light in vacuum in

1

299792458

th of a second. This number was chosen to make the distance travelled by light in one second equal to the known value of 299792458 m.

Time

Second is the unit of time in SI system. The time taken by 9,192,631,770 cycles of the radiation emitted by a Cesium-133 atom during its transition between two specified states is a second. It is also equal to the time taken by light to cover 299792458 m in the vacuum.

Browse more Topics under Units And Measurement

- Measurement of Length, Mass and Time
- Significant Figures
- Dimensional Analysis and Its Applications
- Accuracy, Precision of Instruments and Errors in Measurement

Temperature

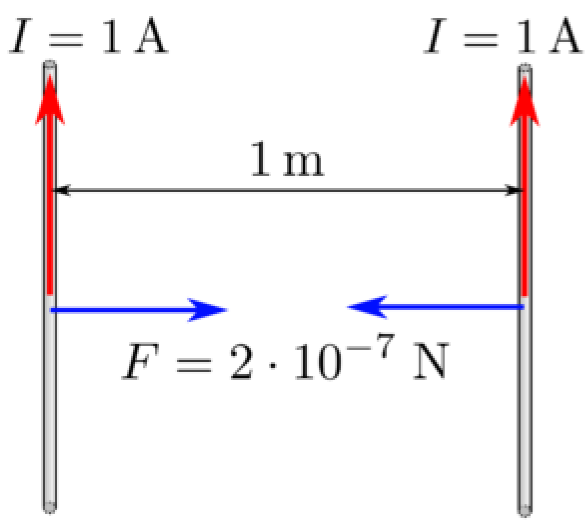
In the SI units system, the unit of temperature is Kelvin or K. 1K is the

1

273.16

th of the temperature of the triple point of water. The triple point is the point at which the three states of a substance (solid, liquid and gas) co-exist.

Current



The SI unit of current is Ampere or A. The ampere is defined as that constant current which, if maintained in two straight parallel conductors of infinite length, a negligible area of cross-section, and placed one metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} N/m.

Suggested Video on Measurement of Mass and Time

Luminous Intensity

The unit of luminous intensity in the SI system is Candela or cd. The luminous power emitted per unit solid angle by a point source of light in a given direction is equal to 1 candela. The luminous intensity of a common candle is almost 1 cd.

Amount of substance

In SI the mole is the unit of the amount of a substance. One mole is the amount of a substance containing as many elementary entities as there are atoms in exactly 0.012 kilogram (or 12 grams) of carbon-12. It is equal to the Avogadro number,

$$N_A = 6.022\ 141\ 79 \times 10^{23}\ mol^{-1}$$

Solved Examples for You

1. Which of the following does not have a fundamental unit:

   a. Mass
   b. Time
   c. Force
   d. Electric current

Ans. c. Force

2. The units which can neither be derived from one another nor resolved into anything more basic are called

a. Fundamental Unit
b. Scale
c. Derived Unit
d. Standard Unit

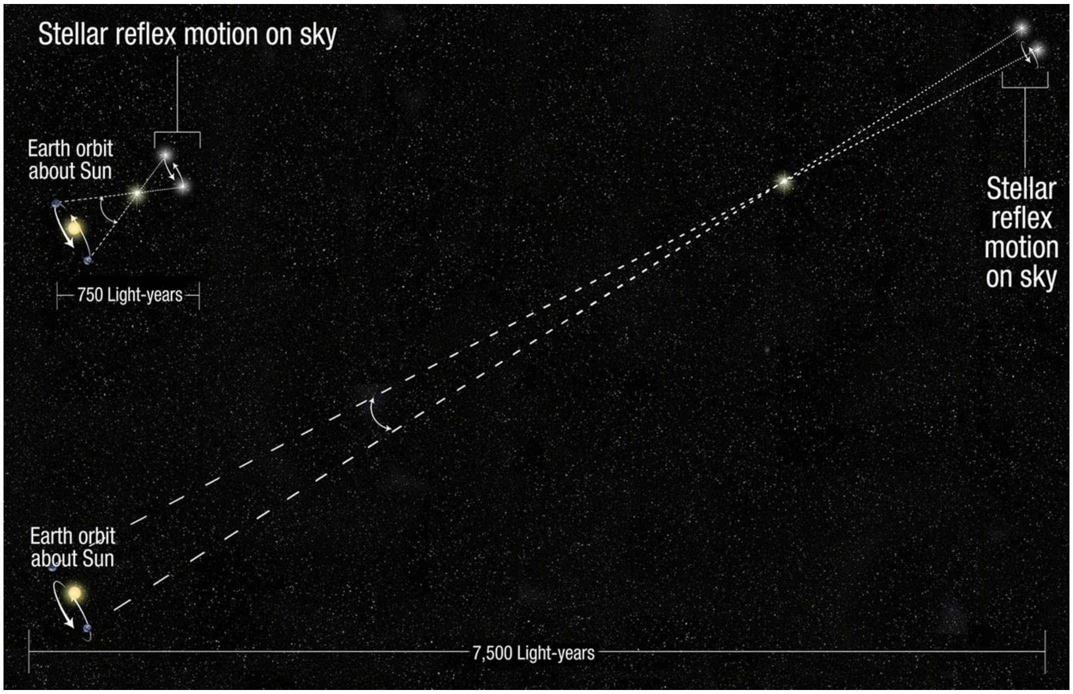
Ans. a. Fundamental Unit.

Measurement of Length, Mass and Time

How do we know the distance between the moon and the earth or the moon and the sun? How did we measure the mass and the diameter of the earth? Length measurement, measurement of mass and time are not always simple and straightforward. We will try and answer these questions below. Furthermore, we will learn about the various ways for the measurement of length, mass and time.

Measurement of Length

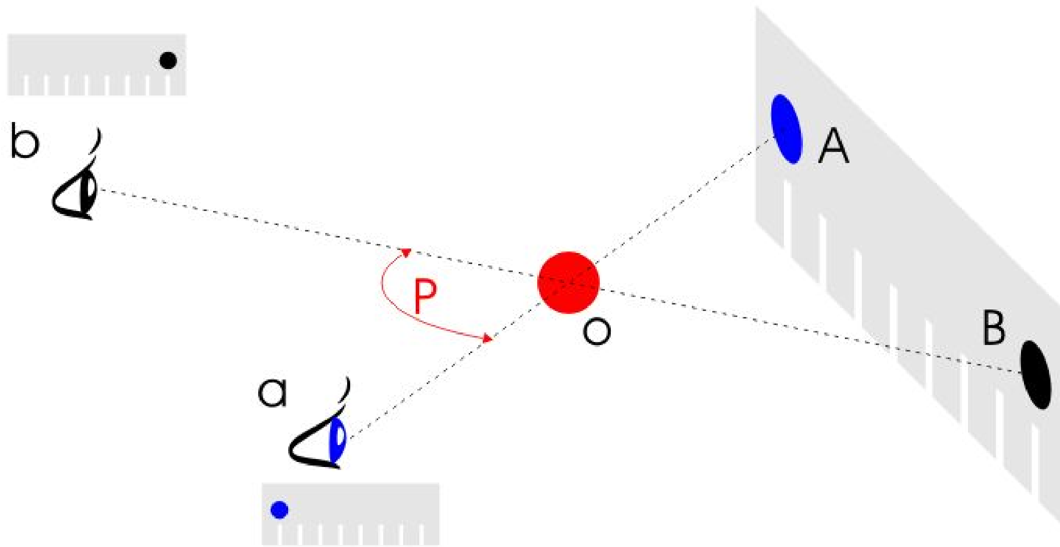
In the SI system of units, we use the meter to measure length. We use a meter scale to measure lengths equal to a few meters. What about longer distances like from your house to the nearest lake or the river? Likewise what about small lengths like the diameter of a cell or size of an atom? We most certainly can't use a meter scale or any scale to measure very large and the very small distances. Lets read about the methods for their measurement.



Parallax observed by the Hubble Telescope (Source: Wikipedia)

Measurement Of Large Distances

Distances like the distance of the Sun from the Earth or the distance of, say Alpha Centauri from Earth is measured indirectly by the Parallax method. Parallax is the shift in the position of an object with the shift in the position of the observer.



Parallax observed from two positions ‘a’ and ‘b’

Let the angle subtended by the arc-ab at O be = P. Imagine a circle that has its centre at O and passes through A and B. Then from the definition of an angle, we can write

P = [length of arc ‘AB’]/[radius of the circle (OA or OB)]

If we know any two variables in the above equation, we can find the third one. Imagine the point a and b are two diametrically opposite points on Earth and O is Alpha Centauri. We can measure the distance between a and b (known as the basis) and also the angle aOb – the parallax angle or the parallactic angle. As a result, we can find the distance to the star.

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Measurement of Very Small Distance

Very small distances like the diameter of a molecule are done indirectly by taking advantage of equations that include these parameters. Let’s take the example of the Oleic acid ($C_{18}H_{34}O_2$) molecule. It is a fairly big molecule with a size of approximately 10^{-9} m. Firstly, we make a very dilute solution of Oleic acid in alcohol.

Secondly, we sprinkle a very small quantity of lycopodium powder (highly hydrophobic) on the surface of the water. After this, we add one drop of the Oleic acid – alcohol solution to the lycopodium-water mixture. The drop spreads into a large film. The container that has the lycopodium-water mixture is made very large. The Oleic acid-alcohol solution will form a thin film on the surface. As this film spreads, its thickness will approach the size of one molecule.

The ratio of the volume of the drop (volume of a sphere) to the area of the film produced (area of a circle) from the drop will give the thickness of the film and hence the size of the molecule.

Size of the Oleic Acid molecule = [Volume of the drop]/[area of the film]

Measurement of Mass

The mass of an object is defined by Newton's Laws. It is the resistance offered by an object to acceleration. In SI system we use kilogram to measure mass. But large quantities of matter like the mass of a mountain or the Earth or stars or the entire Universe is measured indirectly by using Newton's Law of gravitation or other such equations. The law says that two bodies of mass M_1 and M_2 (say) attract each other with a Force F given by

$F = GM_1M_2/R_2$ ……. where R is the separation between the two.

As a result, the value of mass obtained from this equation is sometimes called the Gravitational mass. We measure small masses like that of an electron or a proton by observing their acceleration. We use an electromagnetic force of known value to accelerate these particles in a device known as the mass spectrometer. The lighter particles accelerate easily while as the heavier particles are pretty, let us say lazy to move around.

Measurement of Time

We need a clock to measure time. By a clock, we mean any natural or man-made phenomenon that is repetitive and regular in nature. Galileo used his heartbeat to measure the time period of a simple pendulum and laid the foundation of Classical mechanics. We can say that he literally put his heart into Physics. Today we have very accurate timekeeping devices or clocks like the atomic clocks.

The time interval required for 9192631770 vibrations of the radiation corresponding to the transition between two hyperfine states of the cesium-133 atom is one second.

Suggested Videos

Solved Examples For You

Which of the following principle helps in the measurement of the mass of the planets?

a) Einstein's Theory of Relativity b) Newton's Law of Gravitation

c) Newton's Law of Cooling d) Parallax Method

Solution: b) Newton's Law of Gravitation

Newton's law of gravitation states that every mass in the universe attracts every other mass with a force given by the equation of the Universal Law of Gravitation.

$F = GM_1M_2/R_2$

Here, F is the force of Gravitation, M_1 and M_2 are the masses of any two objects. R is the distance of separation between the centres of the two masses. G is the Universal Gravitational constant. Therefore, if we put one of the masses equal to one unit, we can measure the other mass from the above equation.

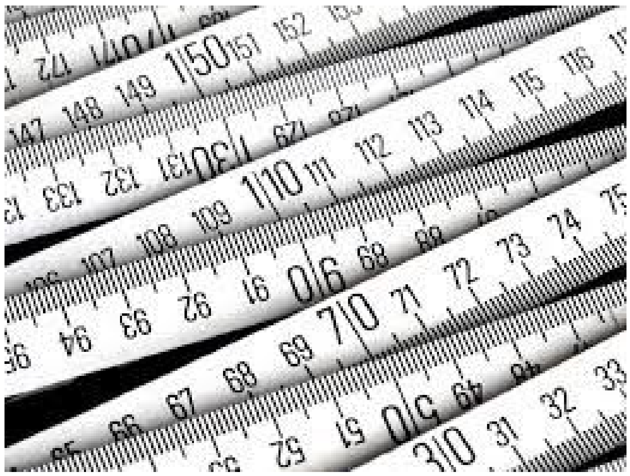
Significant Figures

In physics, measurements are a way of communicating with the Cosmos. Each measurement yields a numeric value. Each digit of a given number is critical to the process of measurement. As a result, some digits are more important or "significant" than others. Let us learn more about these significant figures.

Significant Figures

Your date of birth has three parts: the day, the month and the year you were born in. Suppose I ask you your age in years, which part of your birthdate is is sufficient to answer my question? The least information I need to guess your age is the year of your birth. Therefore, if you tell me the month I can make a more accurate guess of your age and so on.

As a result, we say that each part or each figure improves or decreases the accuracy of a measurement. As a result, we see that each part of the reported number has a definite importance. Thus we say that Significant figures or s.f. are the important digits or digits that improve the accuracy of our measurement. We can identify the number of s.f. in a measured value with the help of some simple rules. Let learn about them.



Rules To Count The Significant Figures

You can count the number of Significant figures from these rules:

- All the reported non-zero numbers in a measurement are significant. For example, 22.13 has 4 and 299792458 has 9 significant digits.
- Zeroes sandwiched anywhere between the non-zero digits are significant. For example, 299007900002400000058 has 21 significant digits, 102.4 has 4 and 1.024 also has 4.
- Zeroes to the left of a first non-zero digit are not significant. For example, 007 has 1 significant figure and 0.0000102 has 3.

- The trailing zeroes or the zeroes to the right of the last non-zero digit are significant if the number has a decimal point otherwise they are insignificant. For example, 0.00001020 has 4 and 70000000000000 has 1 significant figure only.

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Significant figures in the number '10'!

How many significant figures are there in 10? We just laid down the rules and according to them, '10' must have two significant figures. Well, there is something more you need to know. The trailing zeroes in a number without a decimal may or may not be significant.

For example, in the scientific notation we can write 10 as 1×10^1. Since only the non-exponent part is used to count the significant figures. So using our rules, we see that 1×10^1 has only one significant digit. Similarly, 10 can also be written as 1.0×10^1 which has two significant digits.

Furthermore, we say that the number of significant figures depends on the precision of the instrument. Usually greater precision means a greater number of significant digits.

Algebra Of Significant Figures

While performing algebraic operations of measured values, we make sure that the result is not more precise than the least precise value reported. Hence the number of significant figures in the result of our calculation should be equal to the number of significant figures in the least precise value.

Addition And Subtraction

The result should have the same number of significant figures, after rounding off as the reading which has the least number of significant digits.

Example: $7.9391 + 6.263 + 11.1 = 25.3021$

Since the least precise value is 11.1 which has 3 significant digits so the answer will be rounded such that it also has 3 significant digits. i.e. 25.3.

Multiplication And Division

Example: $12.50 \times 169.1 = 2113.75$

Each digit is having 4 significant digits. Therefore, the final answer is rounded off such that it has only 4 significant digits in it i.e. 2114 will be the answer.

Solved Examples For You

The number of significant figures for a force is four when dyne is the unit. If it is expressed in Newton, the number of significant figures will become: (Given: 10^5 dyne=1 N)

a) 9 b) 5

c) 1 d) 4

Solution: d) 4. To change dyne into Newton, we need to multiply it with a constant 10^{-5}. Since the number of significant digits is not changed upon multiplication by an exponential constant, we see that significant digits will remain the same i.e. 4.

Dimensional Analysis and Its Applications

Dimensional analysis answers some very interesting questions. Which is more, one meter or one second? Are they even comparable? Can you add a kilogram and a dozen eggs to each other? No, right? After studying this section, you will be able to understand how dimensional analysis answers such questions. Let's begin!

Dimensional Analysis

Dimensional analysis is the use of dimensions and the dimensional formula of physical quantities to find interrelations between them. It is based on the following facts:

Browse more Topics under Units And Measurement

- he International System of Units
- Measurement of Length, Mass and Time
- Significant Figures
- Accuracy, Precision of Instruments and Errors in Measurement

The Physical laws

The physical laws are independent of the units in which a quantity is measured.If $n_1 a_1$ is the measured value of a physical quantity in one system of units and $n_2 a_2$ is the value in another system of units then, from the above reasoning, these two must be equal.

n

1

a

1

=

n

2

a

2

…… (1)

The principle of Homogeneity

The equations depicting physical situations must have the same dimensions throughout. If two sides of an equation have different dimensions, that equation can’t represent any physical situation. This is known as the Principle of Homogeneity. For example, if

[M

]

a

[L

]

b

[T

]

c

=

[M

]

x

[L

]

y

[T

]

z

then from the principle of Homogeneity, we have:

a = x; b = y; c = z

Applications of the Dimensional Analysis

Conversion of units

The dimensions of a physical quantity are independent of the system of units used to measure the quantity in. Let us suppose that

M_1, L_1 and T_1 and M_2, L_2

and

T

2

are the fundamental quantities in two different systems of units. We will measure a quantity Q (say) in both these systems of units. Suppose, a, b, c be the dimensions of the quantity respectively.

In the first system of units, Q =

n

1

u

1

=

n

1

$$[M_1^a L_1^b T_1^c] \quad \ldots. (2)$$

In the second system of units, Q =

n

2

u

2

=

n

1

[

M

a

2

L

b

2

T

c

2

] …. (3)

n

1

[

M

a

1

L

b

1

T

c

1

] =

n

2

[

M

a

2

L

b

2

T

c

2

] … (4) [using (1)]

Substitution of the respective values will give the value of

n

1

or

n

2

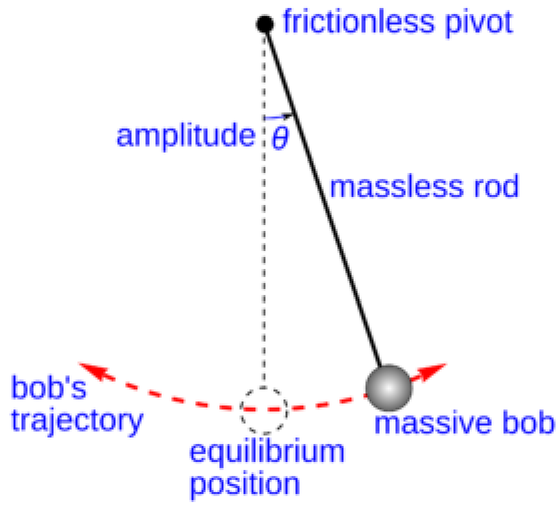
Checking the consistency of an equation

All the physical equations must be consistent. The reverse may not be true. For example, the following equations are not consistent because of the dimensions of the L.H.S. ≠ Dimensions of the R.H.S.

$$F = m^2 \times a$$

$$F = m \times a^2$$

Finding relations between physical quantities in a physical phenomenon



The principle of Homogeneity can be used to derive the relations between various physical quantities in a physical phenomenon. Let us see it with the help of an example.

Suggested Video on Order of Magnitude

Solved Example for You

Example 1: The Time period (T) of a simple pendulum is observed to depend on the following factors:

- length of the pendulum (L),
- mass of the Bob (m)

- acceleration due to gravity (g)

Sol. Let T ~ $L^{\alpha}m^{\beta}g^{\gamma}$ or …… (5)

$[T] = [L]^{\alpha}[M]^{\beta}[L]^{\gamma}[T]^{-2\gamma}$ or

Solving the above for α, β and γ we have:

$\beta = 0; \alpha + \gamma = 0;$

$-2\gamma = 1$ or $\gamma = -1/2$

Using these in equation (5), we have:

T ~

L/g

–

–

–

√

Example 2: Convert 1 J to erg.

Sol. Joule is the S.I. unit of work. Let this be the first system if units. Also erg is the unit of work in the cgs system of units. This will be the second system of units. Also

n

1

= 1J and we have to find the value of

n

2

From equation (4), we have:

[

M

a

1

L

b

1

T

c

1

] =

n

2

[

M

a

2

L

b

2

T

c

2

]

The dimensional formula of work is [

M

1

L

2

T

−2

]. As a result a = 1, b = 2 and c = -2.

[

M

1

1

L

2

1

T

–

1

2

] =

n

2

[

M

1

2

L

2

2

T

−2

2

]

Also

M

1

= 1 kg ,

L

1

= 1 m,

T

1

=1 s

and

M

2

= 1 g ,

L

2

= 1 cm,

T

2

=1 s

n

2

= [

M

1

1

L

2

1

T

−2

1

] / [

M

1

2

L

2

2

T

−2

2

]

= [

1k

g

1

1

g

2

1

s

−2

] / [

1

g

1

1c

m

2

1

s

−2

]

n

2

=

10

7

Hence, 1J =

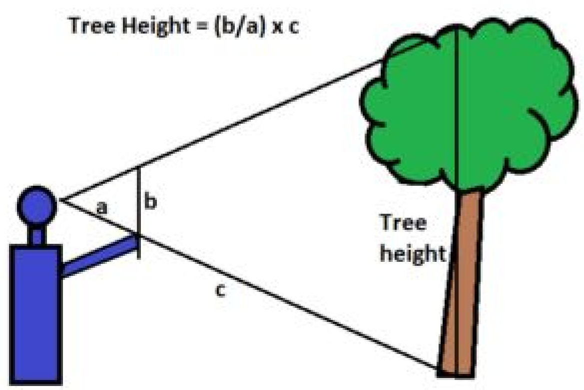
10

7

erg

Accuracy, Precision of Instruments and Errors in Measurement

Repeated measurements often yield different values for the same quantity. What is the accuracy of a measurement and which instrument is the precise one? Let's answer these questions and wander into the realm of measurements.



Accuracy and Precision

The accuracy of a measurement is its "closeness" or proximity to the true value or the actual value (

a

m

) of the quantity. Let

a

1

,

a

2

,

a

3

,

a

4

…

a

n

be the ‘n’ measured values of a quantity ‘a’. Then its true value is defined as:

a

m

= [

a

1

+

a

2

+

a

3

+

a

4

….+

a

n

]/n …. (1)

Suppose your height is 183 cm. If we measure it with some instrument (measuring tape and a fancy laser beam!) it comes out to be 182.9995 cm. Another measurement (with a meter rod and a 6th grader) yields a result of 195 cm. We can see that the value obtained from the first measurement is closer to the actual value (true value) of your height. So the first measurement is more accurate in comparison to the second one.

Browse more Topics under Units And Measurement

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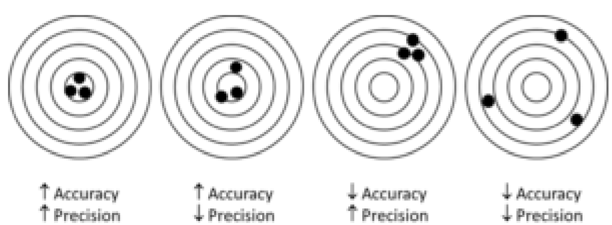
Let's suppose that our 6th grader likes to measure heights. He takes three more measurements of your height and gets the following results: 197 cm, 195.3 cm, and 196.1 cm. Are these measurements accurate? Of course not, they are far from the true value of your height. But we see that all these measurements are close to each other i.e. 197 cm, 195.3 cm, 196.1 cm and 195 cm are close to each other. They are precise measurements.



Thus, precision is the closeness of the various measured values to each other. Accuracy, on the other hand, is the closeness of the measured values with the true value of the quantity.

Suggested Video on Least Count

Errors in Measurement

A measurement is reliable if it is accurate as well as precise. The error in a measurement is the deviation of the measured value from the true value,

a

m

of the quantity. Less accurate a measured value, greater the error in its measurement.

The error in a measurement is the uncertainty in its value. This is the amount by which the measurement can be more or less than the original value. It is denoted by putting a delta sign before the symbol of the quantity e.g. Δa denotes the error in the measurement of a quantity 'a'.

Watch Video on Types of Errors

Errors can be classified into the following types:

Systematic errors

In such errors, the measurement deviates from the actual value by a fixed amount. Hence the prediction of these errors can be made. An erroneous instrument, changes in the physical conditions at the time of measurement, human error etc. are the main causes of systematic errors.

Random Error

These errors are due to unknown sources. These type of errors are removed by taking a bunch of readings and finding their mean.

Absolute Error

Absolute error in a measurement

a

1

is given by

Δ

a

1

= |

a

m

–

a

1

|

In general we say that the absolute error in the

a

n

=

Δ

a

n

= |

a

m

–

a

n

|

For example, the absolute error in the measurement of your height is:

|183 cm – 195 cm| = 12 cm for the 195 cm reading =

Δ

a

1

|197 cm – 183 cm| = 14 cm for the 197 cm reading =

Δ

a

2

|183 cm – 195.3 cm| = 12.3 cm for the 195.3 cm reading =

Δ

a

3

|183 cm – 196.1 cm| = 13.1 cm for the 196.1 cm reading =

Δ

a

4

Mean Absolute Error

If

Δ

a

1

,

Δa_2, Δa_3 … a_n are the absolute errors in a_1,

a_2, a_3, … a_n, then:

Mean Absolute Error = [|Δa_1| + |

Δ

a

2

| + |

Δ

a

3

| + … + |

a

n

|]/n

For example in the above case, the mean absolute error = (12 cm + 14 cm + 12.3 cm + 13.1 cm)/4 = 12.85 cm

Relative Error

The ratio of the mean absolute error and the true value of the quantity gives the relative error.

Relative error = (Mean absolute error)/

a

m

In the above case, Relative error = 12.85/183 = 0.07022 cm

Percentage Error

The percentage error is obtained from the relative error by expressing it in terms of percentage i.e. Percentage error = Relative error × 100%

In the above case, Percentage error = 0.07022 cm × 100% = 7.022%

Propagation of Errors

If you are using the measured values in calculations then the errors will also enter your results. Following is the manner in which errors propagate or add up:

Errors in Addition and Subtraction

Let $(a \pm \Delta a)$ and $(b \pm \Delta b)$ be two quantities.

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

Then error in x i.e. $\Delta x = \pm(\Delta a + \Delta b)$

Hence errors add up under addition or subtraction.

Errors in Multiplication and Division

Let $x = (a \pm \Delta a)\times(b \pm \Delta b)$ or $x = (a \pm \Delta a)/(b \pm \Delta b)$

Then the relative error in x is given by:

$\Delta x/x = \pm[(\Delta a/a + \Delta b/b)]$

How to Measure Length using Vernier Calipers

Solved Examples For You

Example 1: The resistance of metal is given by V=IR. The voltage in the resistance is $V=(80.5\pm0.1)V$ and current in the resistance is $I=(20.2\pm0.2)A$, the value of resistance with its percentage error is :

A) 3.98% Ω B) 2.34% Ω

C) 1.11% Ω D) 2.4% Ω

Solution: C) V = IR [Ohm's Law]

V = 80.5 Volt and I = 20.2 A

R = V/I

Relative percentage error in R = $(0.1/80.5 + 0.2/20.2) \times 100 = 1.11\%$