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Answers Key:

5 Marks

1. **Use of screw gauge in measuring radius of a thin wire in the range of 10^{-5} m**

The wire whose diameter is to be determined should be clamped between the jaws of the screw gauge. The reading on pitch scale (P.S.R) is noted. Then the reading of the reading of the head scale coinciding with the pitch scale is noted (A.S.C.) The zero correction is applied to head scale incidence. (C.H.S.S.). The total reading is given by

T.R = P.S.R + (C.H.S.C. X L.C)

The procedure is repeated for at least six different positions of the wire. The mean of the reading taken gives the diameter of the wire. Half of this gives radius of the wire 'r' in the range of 10^{-5} m.

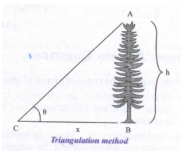
Use of vernier caliper in measuring smaller distances in the range of 10^{-4} m

The sphere is kept between the two jaws. The main scale reading (MSR) is noted (i.e), the main scale division immediately before the zero of the vernier scale. Then the vernier scale division which coincides with some main scale division (VSD) is noted. Zero correction made with this VSD gives VSR. Multiply this VSR by least count and add with MSR. This will give the diameter of the sphere. Observations for different positions of the sphere is hence forth recorded. The mean of the readings taken gives the diameter of the sphere. Half of this gives the diameter of the sphere. Half of this gives radius in the range of 10^{-4} am

(ii) Write a note on triangulation method and radar method to measure larger distances.

Triangulation method for the height of an accessible object

Let AB = h be the height of the tree or tower to be measured. Let C be the point of observation at distance x from B. Place a range finder at C and measure the angle of elevation, ∠ACB = θ as shown in Figure



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From right angled triangle ABC,

$\tan\theta = \frac{AB}{BC} = \frac{h}{x}$

(or) height h = x tan θ

Knowing the distance x, the height h can be determined.

Radar Method: In Radar method radio waves are sent from transmitters which, after reflection from the planet, are detected by the receiver. By measuring, the time interval (r) between the instants the radio waves are sent and received, the distance of the planet can be determined as to get the actual distance of the object. This method can also be used to determine the height, at which an aeroplane flies from the ground.

$Speed = \frac{\text{Distance travelled}}{\text{Time taken}}$ (Speed is explained in unit 2)

Distance (d)= Speed of radio waves x Time taken

$d = \frac{v \times t}{2}$

where v is the speed of the radio wave. As the time taken (r) is for the distance covered during the forward and backward path of the radio waves, it is divided by 2 to get the actual distance of the object. This method can also be used to determine the height, at which an aeroplane flies from the ground.

2. **i) Systematic errors**

Systematic errors are reproducible inaccuracies that are consistently in the same direction. These occur often due to a problem that persists throughout the experiment. Systematic errors can be classified as follows

1) Instrumental errors

When an instrument is not calibrated properly at the time of manufacture, instrumental errors may arise. If a measurement is made with a meter scale whose end is worn out, the result obtained will have errors. These errors can be corrected by choosing the instrument carefully.

2) Imperfections in experimental technique or procedure

These errors arise due to the limitations in the experimental arrangement. As an example, while performing experiments with a calorimeter, if there is no proper insulation, there will be radiation losses. This results in errors and to overcome these, necessary correction has to be applied.

3) Personal errors

These errors are due to individuals performing the experiment, may be due to incorrect initial setting up of the experiment or carelessness of the individual making the observation due to improper precautions.

4) Errors due to external causes

The change in the external conditions during an experiment can cause error in measurement. For example, changes in temperature, humidity or pressure during measurements may affect the result of the measurement.

5) Least count error

Least count is the smallest value that can be measured by the measuring instrument, and the error due to this measurement is least count error. The instrument's resolution hence is the cause of this error. Least count error can be reduced by using a high precision instrument for the measurement.

ii) Random errors

Random errors may arise due to random and unpredictable variations in experimental conditions like pressure, temperature, voltage supply etc. Errors may also be due to personal errors by the observer who performs the experiment. Random errors are sometimes called "chance error". When different landings are obtained by a person every time he occurs. For example, consider the case of the thickness of a wire measured using a screw gauge. The readings taken may be different for different trials. In this case, a large number of measurements are made and then the arithmetic mean is taken.

If n number of trial readings are taken in an experiment, and the readings are a_1, a_2, a_3,.....a_n. The arithmetic mean is

$a_m = \frac{a_1+a_2+a_3+\ldots\ldots\ldots\ldots\ldots a_n}{n}$ or

$a_m = \frac{1}{n}\sum_{i=1}^{t=n} a_i$

Usually this arithmetic mean is taken as the best possible true value of the quantity.

Certain procedures to be followed to minimize experimental errors, along with examples are shown in Table.

Type of error Example How to minimize it Random error Suppose you measure the mass of a ring three times using the same balance and get slightly different values. 15.46 g, 15.42 g, 15.44 g Take more data. Random errors can be evaluated through statistical analysis and can be reduced by averaging over a large number of observations. Systematic error Suppose the cloth tape measure that you use to measure the length of an object has been stretched out from years of use. (As a result all of the length measurements are not correct). Systematic errors are difficult to detect and cannot be analysed statistically, because all of the data is in the same direction. (Either too high or too low) **iii) Gross Error**

The error caused due to the sheer carelessness of an observer is called gross error.

For example

(i) Reading an instrument without setting it properly.

(ii) Taking observations in a wrong manner without bothering about the sources of errors and the precautions.

(iii) Recording wrong observations.

(iv) Using wrong values of the observations in calculations.

These errors can be minimized only when an observer is careful and mentally alert.

3. **Propagation of errors**

A number of measured quantities may be involved in the final calculation of an experiment. Different types of instruments might have been used for taking readings. Then we may have to look at the errors in measuring various quantities, collectively.

The error in the final result depends on

(i) The errors in the individual measurements

(ii) On the nature of mathematical operations performed to get the final result. So we should know the rules to combine the errors.

The various possibilities of the propagation or combination of errors in different mathematical operations are discussed below:

(i) Error in the sum of two quantities:

Let A△ and △B be the absolute errors in the two quantities A and B respectively. Then,

Measured value of A = A ±△ A

Measured value of B = B ±△ B

Consider the sum, Z = A + B

The error △ Z in Z is the given by

Z ±△ Z = (A ±△A) + (B ±△ B)

= (A + B) ± (△A+ △ B)

= Z ± (△ A + △ B)

(or) △Z = △ A+ △ B

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The maximum possible error in the sum of two quantities is equal to the sum of the absolute errors in the individual quantities.

(ii) Error in the difference of two quantities:

Let △A and △B be the absolute errors in the two quantities, A and B, respectively. Consider the product Z = AB

Let △A and △B be the absolute errors in the two quantities, A and B, respectively. Consider the product Z = AB

The error △Z in Z is given by $Z \pm \Delta Z = (A \pm \Delta A)(B \pm \Delta B)$

$= (AB) \pm (A\Delta) \pm (B\Delta A) \pm (\Delta A.\, \Delta B)$

Dividing L.H.S by Z and R.H.S by AB, we get,

$1 \pm \frac{\Delta Z}{Z} \cdot 1 \pm \frac{\Delta B}{B} \pm \frac{\Delta A}{A} \pm \frac{\Delta A}{A} \cdot \frac{\Delta B}{B}$

As △A/A, △B/B are both small quantities, their product term $\frac{\Delta A}{A} \cdot \frac{\Delta B}{B}$ can be neglected. The maximum fractional error in Z is

$\frac{\Delta Z}{Z} = \pm \left(\frac{\Delta A}{A} + \frac{\Delta B}{B}\right)$

The maximum error in difference of two quantities is equal to the sum of the absolute errors in the individual quantities.

(iii) Error in the division or quotient of two quantities

Let △A and △B be the absolute errors in the two quantities A and B respectively.

Consider the quotient, $Z = \frac{A}{B}$

The error △Z in Z is given by

$Z \pm \Delta Z = \frac{A \pm \Delta A}{B \pm \Delta B} = \frac{A(1 \pm \frac{\Delta A}{A})}{B(1 \pm \frac{\Delta B}{B})}$

$= \frac{A}{B}\left(1 \pm \frac{\Delta A}{A}\right)\left(1 \pm \frac{\Delta B}{B}\right)^{-1}$

or $Z \pm \Delta Z = Z\left(1 \pm \frac{\Delta A}{A}\right)\left(1 \pm \frac{\Delta B}{B}\right)$

[using (1+x) n ≈ 1+n x, when x<1]

Dividing both sides by Z, we get,

$1 \pm \frac{\Delta Z}{Z} = \left(1 \pm \frac{\Delta A}{A}\right)\left(1 \pm \frac{\Delta B}{B}\right)$

$= 1 \pm \frac{\Delta Z}{Z} \pm \frac{\Delta B}{B} \pm \frac{\Delta A}{A} \cdot \frac{\Delta B}{B}$

As the terms △A /A and △B/ B are small, their product term can be neglected. The maximum fractional error in Z is given by

$\frac{\Delta Z}{Z} = \left(\frac{\Delta A}{A} + \frac{\Delta B}{B}\right)$

The maximum fractional error in the quotient of two quantities is equal to the sum of their individual fractional errors.

4. The principle of homogeneity of dimensions states that the dimensions of all the terms in a physical expression should be the same. For example, in the physical expression $v^2 = u^2 + 2as$, the dimensions of v^2, u^2 and 2 as are the same and equal to $[L^2T^{-2}]$.

This method is used to

(i) Convert a physical quantity from one system of units to another.

(ii) Check the dimensional correctness of a given physical equation.

(iii) Establish relations among various physical quantities.

(i) **To convert a physical quantity from one system of units to another:** This is based on the fact that the product of the numerical values (n) and its

corresponding unit (u) is a constant. i.e, $n_1[u_1]$ = constant (or) n, $n_1[u_1] = n_2[u_2]$.
Consider a physical quantity which has dimension 'a' in mass, 'b' in length and 'c' in time.
If the fundamental units in one system are M_1, L_1 and T_1 and the other system are M_2, L_2, and T_2 respectively, then we can write, $n_1 [M_1^a L_1^b T_1^c] = n_2 [M_2^a L_2^b T_2^c]$
We have thus converted the numerical value of physical quantity from one system of units into the other system.
Example: Convert 76 cm of mercury pressure into Nm^{-2} using the method of dimensions.
Solution: In cgs system 76 cm of mercury pressure $=76 \times 13.6 \times 980$ dyne cm^{-2}
The dimensional formula of pressure P is $[ML^{-1}T^{-2}]$

$$P_1 \left[M_1^a L_1^b T_1^c\right] = P_2 \left[M_2^a L_2^b T_2^c\right]$$

We have

$$P_2 = \left[\frac{M_1}{M_2}\right]^a \left[\frac{L_1}{L_2}\right]^b \left[\frac{T_1}{T_2}\right]^c$$

$M_1 = 1$ g, $M_2 = 1$ kg
$L_1 = 1$ cm, $L_2 = 1$ m
$T_1 = 1$ s, $T_2 = 1$ s
So a=1, b=1 and c=-2
Then

$$P_2 = 76 \times 13.6 \times 980 \left[\frac{g}{1\,kg}\right]^1 \left[\frac{cm}{1\,m}\right]^{-1} \left[\frac{1\,s}{1\,s}\right]^{-2}$$

$$= 76 \times 13.6 \times 980 \left[\frac{10^{-3}\,kg}{1\,kg}\right]^1 \left[\frac{10^{-2}\,m}{1\,m}\right]^{-1} \left[\frac{1\,s}{1\,s}\right]^{-2}$$

$$= 76 \times 13.6 \times 980 \times \left[10^{-3}\right] \times 10^2$$

$$P_2 = 1.01 \times 10^5 Nm^{-2}$$

(ii) To check the dimensional correctness of a given physical equation:
Example: The equation $\frac{1}{2}$ mv^2 = mgh can be checked by using this method as follows.
Solution: Dimensional formula for

$$\boxed{\frac{1}{2}mv^2 = [M][LT^{-1}]^2 = [ML^2T^{-2}]}$$

Dimensional formula for

$$\boxed{mgh = [M][LT^{-2}][L] = [ML^2T^{-2}][ML^2T^2] = [ML^2T^{-2}]}$$

Both sides are dimensionally the same, hence the equations $\frac{1}{2}$ mv^2 = mgh is dimensionally correct.
(iii) To establish the relation among various physical quantities:
If the physical quantity Q depends upon the quantities Q_1, Q_2 and Q_3 ie. Q is proportional to Q_1, Q_2 and Q_3.
Then,

$$Q \propto Q_1^a Q_2^b Q_3^c$$

$$Q = kQ_1^a Q_2^b Q_3^c$$

where k is a dimensionless constant. When the dimensional formula of Q_1, Q_2 and Q_3 are substituted, then according to the principle of homogeneity, the powers of M, L, T are made equal on both sides of the equation. From this, we get the values of a, b, c.
Example:
Obtain an expression for the time period T of a simple pendulum. The time period T depend upon (i) mass 'm' of the bob (ii) length 'l' of the pendulum and (iii) acceleration due to gravity g at the place where the pendulum is suspended. (Constant $k=2\pi$) i.e
Solution:

$$\boxed{T \propto m^a l^b g^c T = k.\, m^a l^b g^c}$$

Here k is the dimensionless constant. Rewriting the above equation with dimensions.

$$\boxed{[T^1] = [M^a][L^b][LT^{-2}]^c[M^oL^oT^1] = [M^aL^{b+c}T^{-2c}]}$$

Comparing the powers of M, L and T on both sides, a = 0, b + C = 0, -2c = 1
Solving for a, b and c a = 0, b = 1/2, and c = -1/2
From the above equation
$T = k.\, m^o\, l^{1/2}\, g^{-1/2}$

$$T = k\frac{1}{g}^{\frac{1}{2}} = k\sqrt{\frac{1}{g}}$$

Experimentally k = 2π , hence $T = 2\pi\sqrt{\frac{l}{g}}$

5. $F \propto m^a v^b r^c$;
$F = k\, m^a v^b r^c$
where k is a dimensionless constant of proportionality. Rewriting above equation in terms of dimensions and taking k= 1, we have
$[MLT^{-2}] = [M]^a [LT^{-1}]^b [L]^c$
$= [M^aL^bT^{-b}L^c]$
$[MLT^{-2}] = [M^aL^{b+c}T^{-b}]$
Comparing the powers of M, L and T on both sides
a = 1 ; b + c = 1; -b =-2
2 + c = 1 ; b = 2;
a = 1 b = 2 and c = -1
From the above equation we get
$F = m^a v^b r^c$
$F = m^1 v^2 r^{-1}$
or $F = \frac{mv^2}{r}$

3 Marks

6. (i) Physical quantities are classified into two types. There are fundamental and derived quantities.
(ii) Fundamental or base quantities are quantities which cannot be expressed in terms of any other physical quantities.

(iii) These are length, mass, time, electric current, temperature, luminous intensity and amount of substance.
(iv) Quantities that can be expressed in terms of fundamental quantities are called derived quantities.
(v) For example, area, volume, velocity, acceleration, force.

7. **Limitations of Dimensional analysis:**
(i) This method gives no information about the dimensionless constants in the formula like 1, 2,..... π, e, etc.
(ii) This method cannot decide whether the given quantity is a vector or a scalar.
(iii) This method is not suitable to derive relations involving trigonometric, exponential and logarithmic functions.
(iv) It cannot be applied to an equation involving more than three physical quantities.
(v) It can only check on whether a physical relation is dimensionally correct but not the correctness of the relation.
For example, using dimensional analysis, s = ut + 1/3 at^2 is dimensionally correct whereas the correct relation is s = ut+1/2 at^2.

8. The speed of sound in water v = 1460 ms^{-1}
Time taken t = 80 s
$= \frac{2d}{t}$
2d = u x t
= 1460 x 80
2d =11680 m
$\therefore$ Distance of enemy submarine $d = \frac{11680}{2}$
= 58.40 km

9. Frequency of a vibrating body $\gamma \alpha \frac{1}{l}\sqrt{\frac{F}{M}}$
a Dimension of frequency $= \mathrm{M^0\ L^0\ T^{-1}}$
Dimension of length $= \mathrm{L = M^0LT^0}$
Dimension of Force $= \mathrm{MLT^{-2}}$
Dimension of Mass $= \mathrm{M^1\ L^0\ T^0}$
Frequency $\gamma = x$
$\gamma = \mathrm{K\,[F^x][M]^y[\,L]^z}$
Using dimensions we get
$\mathrm{M^0\ L^0\ T^{-1} = \left[MLT^{-2}\right]^x[M]^y[\,L]^z}$
$\mathrm{M^0\ L^0\ T^{-1} = M^{x+y}\ L^{x+z}\ T^{-2x}}$
Comparing the powers we get
x + y = 0 z = -x = $\frac{1}{2}$
x + z = 0 y = -x = $\frac{-1}{2}$
-2 x = -1
$\therefore x = \frac{-1}{-2} = \frac{1}{2}$
$\therefore \gamma = 1 \times \mathrm{[F]^{1/2}[M]^{-1/2}[\,L]^{-1/2}}$
$\gamma = \frac{1}{l}\sqrt{\frac{F}{m}}$

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10. Angle θ = 60 °
The distance between the tree and a point
x = 50m
Height of the tree (h)=?
For triangulation method tan$\theta = \frac{h}{x}$
h= x tan θ = 50×tan 60^0 = 50×1.732
h = 86.6m
The height of the tree is 86.6m.

11. Angle θ = 1° 55′= 115′ = (115×60)″× (4.85× 10^{-6}) rad = 3.34×10^{-2} rad
Since 1″ = 4.85×10^{-6} rad
Radius of the Earth = 6.4×10^6m
From the Figure AB is the diameter of the Earth (b) = 2×6.4×10^6m
Distance of the Moon from the Earth x = ?
$x = \frac{b}{\theta} = \frac{2\times6.4\times10^6}{3.34\times10^{-2}}$
x = 3.83×10^8m

12. t_1 = 2.63s, t_2 = 2.56s,
t_3 = 2.42s, t_4 = 2.71s, t_5 = 2.80s
(i) $T_m = \frac{t_1+t_2+t_3+t_4+t_5}{5} = \frac{2.63+2.56+2.42+2.71+2.80}{5}$
T_m = 2.62s (Rounded off to 2nd decimal place)
(ii) Absolute error
$\triangle T = Tm - t$
$\triangle T_I = 2.62 - 2.63 = +0.01s$
$\triangle T_2 = 2.62 - 2.56 = +0.06s$
$\triangle T_3 = 2.62 - 2.42 = +0.20s$
$\triangle T_4 = 2.62 - 2.71 = +0.09s$
$\triangle T_5 = 2.62 - 2.80 = +0.18s$
(iii) Mean absolute error = $\frac{\sum|\triangle T_i|}{n}$
$\triangle T_m = \frac{0.01+0.06+0.20+0.09+0.18}{5}$
$\triangle T_m = \frac{0.54}{5} = 0.108s = 0.11s$ (Rounded off to 2nd decimal place)
(iv) Relative error: $S_T = \frac{\triangle T_m}{T_m} = \frac{0.11}{2.62} = 0.0419$
S_T = 0.04

(v) Percentage error in T = 0.04×100% = 4%
(vi) Time period of simple pendulum = T = (2.62 ± 4%)s

13. R_1 = 100 ± = 3Ω; R_2 = 150 ± 2Ω
Equivalent resistance R =?
Equivalent resistance R = R_1+ R_2 = (100 ± 3) + (150 ± 2) = (100 + 150) ± (3 + 2)
R = (250 ± 5) Ω

14. t_1 = (20 ± 05)°C t_2 = (50 ± 05)°C
temperature difference t = ?
t_1 = t_2-t_1= (50 ± 05.) - (20 ± 05.)°C
(Using equation ∆z = ∆A + ∆B)
= (50 - 20) ± (0.5 + 0.5)
t = (30 ± 1)°C

15. Length l = (5.7 ± 01.) cm
Breadth b = (3.4 ± 02.) cm
Area A with error limit = A ±△A= ?
Area A = I ×b = 5.7×3.4 = 19.38 = 19.4 cm^2
$\frac{\triangle A}{A} = \frac{\triangle l}{l} + \frac{\triangle b}{b}; \triangle A = (\frac{\triangle l}{l} + \frac{\triangle b}{b})$
$\triangle A = (\frac{0.1}{5.7} + \frac{0.2}{3.4})19.4 = (0.0175 + 0.0588) \times 19.4 = 1.48 = 1.5$
Area with error limit A = (19.4 ± 1.5) cm^2

16. Voltage V = (100 ± 5)V
Current I = (10 ± 0.2)A
Resistance R = ?
Then resistance R is given by Ohm's law,
$R = \frac{V}{I} = \frac{100}{10} = 10\Omega$
$\frac{\triangle R}{R} = (\frac{\triangle V}{V} + \frac{\triangle I}{I})$
$\frac{\triangle R}{R} = (\frac{\triangle V}{V} + \frac{\triangle I}{I})R = (\frac{5}{100} + \frac{0.2}{10})10$
= (0.05 + 0.02)10 = 0.07×10 = 0.7
The resistance R = (10 ± 0.7)Ω

17. $T \propto m^a l^b g^c$;
$T = k.m^a l^b g^c$
Here k is the dimensionless constant. Rewriting the above equation with dimensions
$[T^1] = [M^a] [L^b] [LT^{-2}]^c$
$[M^0L^0T^1] = [M^aL^{b+c}T^{-2c}]$
Comparing the powers of M, L and T on both sides, a = 0, b + c = 0, -2c = 1
Solving for a, b and c a = 0, b = 1/2, and c = -1/2
From the above equation $T = k.m^0 l^{1/2} g^{-1/2}$
$T= k\left(\frac{l}{g}\right)^{1/2} = k\sqrt{\frac{l}{g}}$
Experimentally k = 2π hence
$T = 2\pi\sqrt{l/g}$

18. Let G_{SI} be the gravitational constant in the SI system and G_{cgs} in the cgs system. Then
$G_{SI} = 6.6 \times 10^{-11} Nm^2 kg^{-2}$
G_{cgs} = ?
$n_2 = n_1\left[\frac{M_1}{M_2}\right]^a\left[\frac{L_1}{L_2}\right]^b\left[\frac{T_1}{T_2}\right]^c$
$G_{cgs} = G_{SI}\left[\frac{M_1}{M_2}\right]^a\left[\frac{L_1}{L_2}\right]^b\left[\frac{T_1}{T_2}\right]^c$
M_1 = 1 kg L_1 = 1m T_1 = 1s
M_2 = 1 g L_2 = 1 cm T_2 = 1s
The dimensional formula for G is $M^{-1}L^3T^{-2}$
a = -1 b = 3 and c = -2
$G_{cgs} = 6.6 \times 10^{-11}\left[\frac{1kg}{1g}\right]^{-1}\left[\frac{1m}{1\,cm}\right]^3\left[\frac{1s}{1s}\right]^{-2}$
$= 6.6 \times 10^{-11}\left[\frac{1\,kg}{10^{-3}\,kg}\right]^{-1}\left[\frac{1\,m}{10^{-2}\,m}\right]^3\left[\frac{1\,s}{1\,s}\right]^{-2}$
= 6.6 × 10^{-11} × 10^{-3} x 10^6 × 1
G_{cgs} = 6.6 × 10^{-8} dyne cm^2 g^{-2}

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