

Applied Physics 1

Chapter: Physical World, Units and Measurements

Exercise Notes: Important Questions, Solution Steps and Numericals

For Engineering Students (Short and Broad, Exam Oriented)

Topics covered: Physical quantities (fundamental and derived); units and systems of units (CGS and SI); dimensions and dimensional formulae; principle of homogeneity; applications of dimensional equations (unit conversion, checking equations, deriving simple equations); limitations of dimensional analysis; measurements (need, instruments, least count, direct and indirect); errors (systematic, random, absolute, relative, propagation, estimation); significant figures.

1. Physical Quantities: Fundamental and Derived

Q1. What is a physical quantity? Classify it with examples. (Short)

A physical quantity is any quantity that can be measured and used to describe the laws of physics. It is expressed as a numerical value multiplied by a unit.

- **Fundamental (base) quantities:** independent of other quantities. Examples: length, mass, time, electric current, temperature, amount of substance, luminous intensity.
- **Derived quantities:** obtained by combining fundamental quantities. Examples: area, volume, velocity, acceleration, force, work, power, pressure.

Q2. Differentiate between fundamental and derived quantities. (Short)

Fundamental quantity	Derived quantity
Independent of other quantities	Depends on one or more fundamental quantities
Only 7 in SI	Unlimited in number
Unit is a fundamental unit (m, kg, s)	Unit is a derived unit (m/s, N, J)
Example: mass	Example: force = mass $\times$ acceleration

Q3. Differentiate between scalar and vector quantities. (Short)

- **Scalar:** magnitude only (mass, time, work, energy, temperature).
- **Vector:** magnitude and direction (displacement, velocity, force, momentum).

2. Units and Systems of Units (CGS and SI)

Q4. What is a unit? What are the requirements of a good unit? (Short)

A unit is a standard of reference chosen to measure a physical quantity. A good unit should be well defined, of convenient size, reproducible, unchanging with time and place, and internationally accepted.

Q5. Name the systems of units and state their base units. (Broad)

- **CGS system:** centimetre (length), gram (mass), second (time).
- **MKS system:** metre, kilogram, second.
- **FPS system:** foot, pound, second.
- **SI system (International System):** adopted in 1971, based on MKS, with seven base units and two supplementary units.

SI base units

Quantity	Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Supplementary units: radian (plane angle, rad) and steradian (solid angle, sr).

Q6. Write the CGS and SI units of some derived quantities. (Short)

Quantity	CGS unit	SI unit	Conversion
Force	dyne	newton (N)	$1 \text{ N} = 10^5 \text{ dyne}$
Work / Energy	erg	joule (J)	$1 \text{ J} = 10^7 \text{ erg}$
Power	erg/s	watt (W)	$1 \text{ W} = 10^7 \text{ erg/s}$
Pressure	dyne/cm^2	pascal (Pa)	$1 \text{ Pa} = 10 \text{ dyne/cm}^2$
Density	g/cm^3	kg/m^3	$1 \text{ g/cm}^3 = 1000 \text{ kg/m}^3$

Q7. Why is SI preferred over other systems? (Short)

- It is a coherent system (derived units follow from base units without extra factors).
- It is rational, with one unit for each physical quantity.
- It uses decimal multiples and prefixes, so conversion is simple.
- It is accepted worldwide.

Common prefixes: kilo (10^3), mega (10^6), giga (10^9), milli (10^{-3}), micro (10^{-6}), nano (10^{-9}), pico (10^{-12}).

3. Dimensions and Dimensional Formulae

Q8. Define dimensions and dimensional formula. (Short)

Dimensions of a physical quantity are the powers to which the fundamental quantities must be raised to represent that quantity. The expression showing these is the dimensional formula. Mass, length and time are written as [M], [L], [T].

Example: force = mass $\times$ acceleration, so the dimensional formula of force is $[M L T^{-2}]$, with dimensions 1 in mass, 1 in length and -2 in time.

Q9. Table of dimensional formulae of important quantities. (Important)

Quantity	Formula	Dimensional formula
Area	length × breadth	$[M^0 L^2 T^0]$
Volume	length × breadth × height	$[M^0 L^3 T^0]$
Velocity	displacement / time	$[M^0 L T^{-1}]$
Acceleration	velocity / time	$[M^0 L T^{-2}]$
Force	$m \times a$	$[M L T^{-2}]$
Momentum	$m \times v$	$[M L T^{-1}]$
Impulse	$F \times t$	$[M L T^{-1}]$
Work, Energy	$F \times d$	$[M L^2 T^{-2}]$
Power	work / time	$[M L^2 T^{-3}]$
Pressure, Stress	force / area	$[M L^{-1} T^{-2}]$
Density	mass / volume	$[M L^{-3} T^0]$
Frequency	1 / time	$[M^0 L^0 T^{-1}]$
Angular velocity	angle / time	$[M^0 L^0 T^{-1}]$
Surface tension	force / length	$[M L^0 T^{-2}]$
Coefficient of viscosity	$F d / (A v)$	$[M L^{-1} T^{-1}]$
Gravitational constant G	$F r^2 / (m_1 m_2)$	$[M^{-1} L^3 T^{-2}]$
Planck's constant h	$E / \text{frequency}$	$[M L^2 T^{-1}]$
Strain, refractive index, angle	ratio	Dimensionless

Q10. Name some dimensionless quantities. (Short)

Strain, angle (radian), refractive index, relative density, Poisson's ratio, coefficient of friction.

4. Principle of Homogeneity of Dimensions**Q11. State the principle of homogeneity. (Short)**

In a correct physical equation, the dimensions of every term on both sides must be the same. Only quantities of the same dimensions can be added, subtracted or equated.

Q12. Why can we not add 5 kg and 3 m? (Short)

Their dimensions differ ($[M]$ and $[L]$). By homogeneity, only like quantities can be added or subtracted.

5. Dimensional Equations and Their Applications

There are three main uses: (i) converting units from one system to another, (ii) checking the correctness of an equation, and (iii) deriving simple relations.

5.1 Conversion from One System of Units to Another

Method: if a quantity has dimensional formula $[M^a L^b T^c]$, then

$$n_2 = n_1 [M_1/M_2]^a [L_1/L_2]^b [T_1/T_2]^c$$

where n_1 and n_2 are the numerical values in the two systems.

Q13. Convert 1 newton into dyne. (Numerical)

- Step 1: dimensional formula of force = $[M L T^{-2}]$, so $a = 1$, $b = 1$, $c = -2$.

- Step 2: System 1 is SI ($M_1 = 1 \text{ kg} = 1000 \text{ g}$, $L_1 = 1 \text{ m} = 100 \text{ cm}$, $T_1 = 1 \text{ s}$). System 2 is CGS ($M_2 = 1 \text{ g}$, $L_2 = 1 \text{ cm}$, $T_2 = 1 \text{ s}$).
- Step 3: $n_2 = 1 \times (1000)^1 \times (100)^1 \times (1)^{-2} = 10^5$.

Answer: $1 \text{ N} = 10^5 \text{ dyne}$.

Q14. Convert 1 joule into erg. (Numerical)

- Step 1: work has dimensions $[M L^2 T^{-2}]$.
- Step 2: $n_2 = 1 \times (1000)^1 \times (100)^2 \times (1)^{-2} = 1000 \times 10^4 = 10^7$.

Answer: $1 \text{ J} = 10^7 \text{ erg}$.

Q15. Convert $g = 9.8 \text{ m/s}^2$ into cm/s^2 . (Numerical)

Acceleration is $[L T^{-2}]$. $n_2 = 9.8 \times (100)^1 \times (1)^{-2} = 980$.

Answer: $g = 980 \text{ cm/s}^2$.

Q16. Convert 1 km/h into m/s. (Numerical)

$1 \text{ km/h} = 1000 \text{ m} / 3600 \text{ s} = 5/18 \text{ m/s} = 0.278 \text{ m/s}$.

5.2 Checking the Correctness of Equations

Method: write the dimensions of each term on the left and right side. If they match, the equation is dimensionally correct.

Q17. Check the equation $v = u + at$. (Numerical)

- LHS: $[v] = [L T^{-1}]$.
- RHS: $[u] = [L T^{-1}]$ and $[at] = [L T^{-2}][T] = [L T^{-1}]$.
- All terms have the same dimensions.

Answer: The equation is dimensionally correct.

Q18. Check the equation $s = ut + \frac{1}{2} a t^2$. (Numerical)

- LHS: $[s] = [L]$.
- RHS: $[ut] = [L T^{-1}][T] = [L]$, and $[\frac{1}{2} a t^2] = [L T^{-2}][T^2] = [L]$ (the factor $\frac{1}{2}$ is dimensionless).

Answer: Dimensionally correct.

Q19. Check whether $v^2 = u^2 + 2as$ is correct. (Numerical)

$[v^2] = [L^2 T^{-2}]$, $[u^2] = [L^2 T^{-2}]$, $[as] = [L T^{-2}][L] = [L^2 T^{-2}]$. All match, so it is dimensionally correct.

Q20. Check the relation $T = 2\pi\sqrt{g/l}$ for a simple pendulum. (Numerical)

- LHS: $[T] = [T]$.
- RHS: $[g/l] = [L T^{-2}] / [L] = [T^{-2}]$, so the square root = $[T^{-1}]$.
- $[T]$ is not equal to $[T^{-1}]$.

Answer: The relation is wrong. The correct one is $T = 2\pi\sqrt{l/g}$, for which $\sqrt{[L] / [L T^{-2}]} = [T]$.

5.3 Derivation of Simple Equations

Method: assume the quantity depends on other quantities as a product of powers, write dimensions on both sides, and equate the powers of M, L and T.

Q21. Derive the expression for the time period of a simple pendulum using dimensions. (Broad)

Step 1: The time period T may depend on mass m , length l and gravitational acceleration g . Assume $T = k m^a l^b g^c$, where k is a dimensionless constant.

Step 2: Write dimensions: $[T] = [M]^a [L]^b [L T^{-2}]^c = [M^a L^{b+c} T^{-2c}]$.

Step 3: Compare powers.

- Mass: $a = 0$.
- Length: $b + c = 0$.
- Time: $-2c = 1$, so $c = -1/2$, and therefore $b = +1/2$.

Step 4: Substitute: $T = k l^{1/2} g^{-1/2}$.

Answer: $T = k\sqrt{l/g}$. Experiment gives $k = 2\pi$, so $T = 2\pi\sqrt{l/g}$. The period does not depend on mass.

Q22. Derive the kinetic energy relation $K = k m^a v^b$. (Numerical)

Dimensions of energy: $[M L^2 T^{-2}] = [M]^a [L T^{-1}]^b = [M^a L^b T^{-b}]$. Comparing: $a = 1$, $b = 2$.

Answer: $K = k m v^2$ (experiment gives $k = 1/2$).

Q23. A body of mass m moves in a circle of radius r with speed v . Derive the centripetal force F by dimensions. (Numerical)

Assume $F = k m^a v^b r^c$. Then $[M L T^{-2}] = [M^a L^{b+c} T^{-b}]$. Comparing: $a = 1$, $b = 2$, and $b + c = 1$, so $c = -1$.

Answer: $F = k m v^2 / r$ (with $k = 1$).

Q24. Find the dimensional formula of G from $F = G m_1 m_2 / r^2$. (Numerical)

$G = F r^2 / (m_1 m_2) = [M L T^{-2}][L^2] / [M^2] = [M^{-1} L^3 T^{-2}]$.

Q25. Find the dimensions of Planck's constant from $E = h f$. (Numerical)

$h = E / f = [M L^2 T^{-2}] / [T^{-1}] = [M L^2 T^{-1}]$.

6. Limitations of Dimensional Analysis

Q26. State the limitations of dimensional analysis. (Short and Important)

1. It cannot give the value of dimensionless constants such as $1/2$, 2π or k .
2. It cannot be used for trigonometric, logarithmic or exponential functions, since their arguments must be dimensionless.
3. It fails when a quantity depends on more than three fundamental quantities (in mechanics), as there are not enough equations to compare.
4. It cannot derive equations containing a sum or difference of terms, such as $s = ut + 1/2 a t^2$.
5. It cannot tell whether a quantity is a scalar or a vector.
6. A dimensionally correct equation need not be physically correct. Example: $s = ut + a t^2$ is dimensionally correct but physically wrong.
7. It cannot distinguish quantities with the same dimensions (for example work and torque).

7. Measurements

Q27. What is the need for measurement? (Short)

Measurement is the process of comparing an unknown quantity with a standard unit. It is needed to verify theories, design and manufacture components with the required accuracy, ensure quality control, maintain safety, and enable trade and standardisation in engineering.

Q28. List common measuring instruments. (Short)

Quantity	Instrument
Length	Metre scale, vernier callipers, screw gauge
Mass	Physical balance, spring balance
Time	Stopwatch, clock
Temperature	Thermometer
Current / Voltage	Ammeter / Voltmeter

Q29. Define least count. How is it found for vernier callipers and screw gauge? (Broad)

Least count (LC) is the smallest value that an instrument can measure accurately.

- **Vernier callipers:** $LC = \text{value of 1 main scale division (MSD)} - \text{value of 1 vernier scale division (VSD)} = 1 \text{ MSD} / \text{total number of vernier divisions}$. Reading = MSR + (VSR $\times$ LC).
- **Screw gauge:** $LC = \text{pitch} / \text{number of circular scale divisions}$, where pitch is the distance moved by the screw in one full rotation. Reading = linear scale reading + (circular scale reading $\times$ LC).
- **Zero error:** true reading = observed reading – zero error (with sign).

Q30. Differentiate direct and indirect measurement. (Short)

Direct measurement	Indirect measurement
Value is read directly from the instrument	Value is calculated from other measured quantities
Example: length with a scale, time with a stopwatch	Example: density = mass / volume, area = l $\times$ b

Q31. A vernier has 10 divisions equal to 9 main scale divisions, 1 MSD = 1 mm. Find LC and the reading if MSR = 23 mm and the 6th vernier division coincides. (Numerical)

- Step 1: $LC = 1 \text{ MSD} / \text{number of VSD} = 1 \text{ mm} / 10 = 0.1 \text{ mm}$.
- Step 2: Reading = MSR + VSR $\times$ LC = 23 + 6 $\times$ 0.1 = 23.6 mm.

Answer: LC = 0.1 mm (0.01 cm), reading = 23.6 mm = 2.36 cm.

Q32. A screw gauge has pitch 1 mm and 100 circular divisions. Linear scale reading = 3 mm, circular reading = 47, zero error = +0.03 mm. Find the correct diameter. (Numerical)

- Step 1: $LC = 1 / 100 = 0.01 \text{ mm}$.
- Step 2: Observed reading = 3 + 47 $\times$ 0.01 = 3.47 mm.
- Step 3: Correct reading = 3.47 – 0.03 = 3.44 mm.

Answer: Diameter = 3.44 mm.

8. Errors in Measurements

Q33. What is an error? Explain systematic and random errors. (Broad)

Error is the difference between the measured value and the true value of a quantity.

Systematic errors follow a definite pattern and always act in the same direction.

- Instrumental error (faulty calibration, zero error).
- Personal error (parallax, habitual reaction delay).
- Environmental error (temperature, humidity).
- Imperfection in method or theory.
- Reduced by calibration, correcting zero error and improving the technique.

Random errors occur irregularly, with no fixed pattern, in both directions.

- Cause: unpredictable changes in conditions or in the observer.
- Reduced by taking many readings and using the mean.

Q34. Define absolute, relative and percentage error. (Short)

- Mean value: $a_{\text{mean}} = (a_1 + a_2 + \dots + a_n) / n$.
- Absolute error: $\Delta a_i = |a_{\text{mean}} - a_i|$.
- Mean absolute error: $\Delta a_{\text{mean}} = (\text{sum of } |\Delta a_i|) / n$.
- Relative error = $\Delta a_{\text{mean}} / a_{\text{mean}}$ (no unit).
- Percentage error = relative error $\times 100$ %.

Q35. Find the mean, absolute errors, relative and percentage error for the time readings 2.63, 2.56, 2.42, 2.71, 2.80 s. (Numerical)

- Step 1: Mean = $(2.63 + 2.56 + 2.42 + 2.71 + 2.80) / 5 = 13.12 / 5 = 2.624$, taken as 2.62 s.
- Step 2: Absolute errors: 0.01, 0.06, 0.20, 0.09, 0.18 s.
- Step 3: Mean absolute error = $(0.01 + 0.06 + 0.20 + 0.09 + 0.18) / 5 = 0.54 / 5 = 0.108$, about 0.11 s.
- Step 4: Relative error = $0.11 / 2.62 = 0.042$. Percentage error = 4.2 %.

Answer: $t = (2.62 \pm 0.11)$ s, relative error 0.042, percentage error 4.2 %.

Q36. State the rules of error propagation. (Broad, Important)

Let A and B have absolute errors ΔA and ΔB .

- **Sum or difference:** $Z = A + B$ or $Z = A - B$ gives $\Delta Z = \Delta A + \Delta B$ (absolute errors add).
- **Product or quotient:** $Z = A \times B$ or $Z = A / B$ gives $\Delta Z / Z = \Delta A / A + \Delta B / B$ (relative errors add).
- **Power:** $Z = A^n \times B^m$ gives $\Delta Z / Z = n (\Delta A / A) + m (\Delta B / B)$. Powers multiply the relative error; the sign of the power is ignored.

In all cases the maximum possible error is found by adding.

Q37. Two lengths are (10.5 ± 0.1) cm and (26.8 ± 0.1) cm. Find their sum and difference with errors. (Numerical)

Sum = $10.5 + 26.8 = 37.3$ cm, error = $0.1 + 0.1 = 0.2$ cm, so (37.3 ± 0.2) cm.

Difference = $26.8 - 10.5 = 16.3$ cm, error = $0.1 + 0.1 = 0.2$ cm, so (16.3 ± 0.2) cm.

Q38. Mass = (50.0 ± 0.1) g and volume = (20.0 ± 0.1) cm³. Find the density with error. (Numerical)

- Step 1: $\rho = m / V = 50.0 / 20.0 = 2.50$ g/cm³.
- Step 2: Relative error = $0.1 / 50.0 + 0.1 / 20.0 = 0.002 + 0.005 = 0.007$.
- Step 3: $\Delta \rho = 0.007 \times 2.50 = 0.0175$, about 0.02.

Answer: $\rho = (2.50 \pm 0.02)$ g/cm³, that is 0.7 % error.

Q39. Length = (5.0 ± 0.1) cm and breadth = (3.0 ± 0.1) cm. Find the area with error. (Numerical)

- $A = 5.0 \times 3.0 = 15.0$ cm².
- Relative error = $0.1 / 5.0 + 0.1 / 3.0 = 0.02 + 0.033 = 0.053$.
- $\Delta A = 0.053 \times 15.0 = 0.8$ cm².

Answer: $A = (15.0 \pm 0.8)$ cm².

Q40. The side of a cube is measured with 2 % error. Find the error in its volume. (Numerical)

$$V = a^3, \text{ so } \Delta V / V = 3 \times (\Delta a / a) = 3 \times 2 \% = 6 \%$$

Answer: 6 %.

Q41. In $g = 4\pi^2 l / T^2$, l is measured with 1 % error and T with 2 % error. Find the percentage error in g . (Numerical)

$$\Delta g / g = \Delta l / l + 2 (\Delta T / T) = 1 \% + 2 \times 2 \% = 5 \%$$

Answer: 5 %.

Q42. A physical quantity is $X = a^2 b^3 / (c\sqrt{d})$. Find the maximum relative error in X . (Numerical)

$$\Delta X / X = 2 (\Delta a / a) + 3 (\Delta b / b) + (\Delta c / c) + \frac{1}{2} (\Delta d / d).$$

9. Error Estimation and Significant Figures

Q43. What are significant figures? State the rules to count them. (Broad)

Significant figures are the digits in a measured value that are known reliably plus the first uncertain digit. They indicate the precision of a measurement.

Rules for counting

1. All non-zero digits are significant (2.85 has 3).
2. Zeros between non-zero digits are significant (100.05 has 5).
3. Leading zeros are not significant (0.00450 has 3).
4. Trailing zeros after the decimal point are significant (4.500 has 4).
5. Trailing zeros in a number without a decimal point are ambiguous. Scientific form removes the doubt (1.2×10^3 has 2, 1.200×10^3 has 4).
6. Changing units does not change the number of significant figures ($2.50 \text{ m} = 2.50 \times 10^2 \text{ cm}$, still 3).

Q44. State the rules for rounding off and for arithmetic with significant figures. (Broad)

Rounding: if the digit to be dropped is less than 5, keep the preceding digit unchanged. If it is more than 5, increase the preceding digit by 1. If it is exactly 5, round so that the preceding digit becomes even (common convention).

Addition or subtraction: the result has the same number of decimal places as the term with the fewest decimal places.

Multiplication or division: the result has the same number of significant figures as the factor with the fewest significant figures.

Q45. Count the significant figures: 6008, 0.0230, 3.00×10^5 , 0.1020, 100. (Numerical)

6008 has 4; 0.0230 has 3; 3.00×10^5 has 3; 0.1020 has 4; 100 has 1 (ambiguous, taken as 1 unless written as 1.00×10^2).

Q46. Round off 6.3478 to 3 significant figures. (Numerical)

Digits: 6.34|78. The next digit 7 is more than 5, so 6.34 becomes 6.35.

Answer: 6.35.

Q47. Add $12.11 + 18.0 + 1.013$ and multiply 4.2×3.12 with the correct significant figures. (Numerical)

Sum: $12.11 + 18.0 + 1.013 = 31.123$. The least precise term (18.0) has 1 decimal place, so the answer is **31.1**.

Product: $4.2 \times 3.12 = 13.104$. The least significant factor (4.2) has 2 significant figures, so the answer is **13**.

Q48. Differentiate accuracy and precision. (Short)

- **Accuracy:** closeness of a measured value to the true value.
- **Precision:** closeness of repeated measurements to each other (depends on the least count and repeatability).
- A measurement can be precise but not accurate (for example, with a systematic error).

10. Quick Short-Answer and Objective Questions

1. The SI unit of luminous intensity is the candela.
2. The dimensional formula of work is $[M L^2 T^{-2}]$, the same as that of energy and torque.
3. 1 light year = 9.46×10^{15} m.
4. 1 micron = 10^{-6} m, and 1 angstrom = 10^{-10} m.
5. Which is dimensionless: strain or stress? Strain.
6. The least count of a metre scale is 1 mm.
7. Zero error in an instrument is a systematic error.
8. Increasing the number of observations reduces random error.
9. A quantity with the same dimensions as frequency: angular velocity.
10. Is dimensional analysis enough to prove an equation? No, it only checks dimensional consistency.

11. Formula Sheet for Quick Revision

- Unit conversion: $n_2 = n_1 [M_1/M_2]^a [L_1/L_2]^b [T_1/T_2]^c$
- Vernier: $LC = 1 \text{ MSD} - 1 \text{ VSD}$; reading = $MSR + VSR \times LC$
- Screw gauge: $LC = \text{pitch} / \text{number of circular divisions}$; reading = $LSR + CSR \times LC$
- Percentage error = $(\text{mean absolute error} / \text{mean value}) \times 100$
- Sum or difference: $\Delta Z = \Delta A + \Delta B$
- Product or quotient: $\Delta Z / Z = \Delta A / A + \Delta B / B$
- Power: $Z = A^n$ gives $\Delta Z / Z = n (\Delta A / A)$