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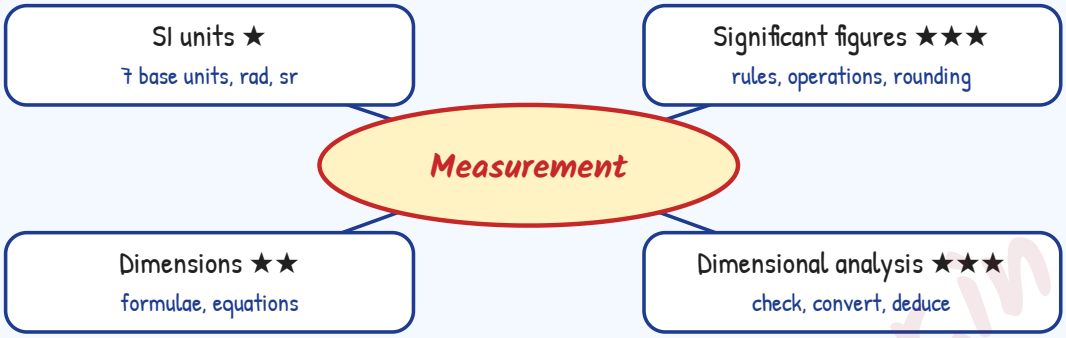
# Chapter 1
# Units and Measurement

[M L T]



NCERT Physics Part I, Reprint 2026-27

## Chapter map (★ = very often asked in school exams)




## What is inside

1. Concept notes with worked NCERT examples
2. NCERT exercises (all 17), fully solved
3. Important exam questions, fully solved
4. Quick-reference sheet; practice A–G, 20 MCQs, 6 A–R, answers, summary

## Colour code used

red = key term  green = definition

purple = sub-heading  black = explanation

★ = high-frequency exam topic

1 = mark the examiner gives for that point

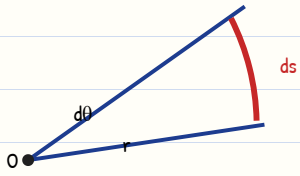
★ **Exam tip:** Counting significant figures, the rules for multiplication/division and addition/subtraction, rounding off, dimensional formulae, checking an equation, converting units and deducing a formula (pendulum) are asked again and again.

NB **Prepared by Notes Bazar** · Every answer written and checked by hand against NCERT and the CBSE marking schemes. Doubt or mistake? WhatsApp 88240 98091.

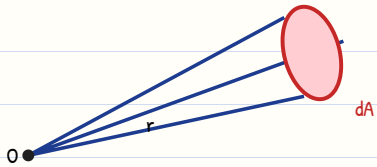
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# 1.1 Units; 1.2 the SI; 1.3 significant figures ★★★

(a) plane angle dθ = ds/r (rad)




(b) solid angle dΩ = dA/r² (sr)




method of dimensions (pendulum)

assume $T = k\,l^x g^y m^z$

$[T] = [L]^x [L\,T^{-2}]^y [M]^z$

compare: $x + y = 0$, $-2y = 1$, $z = 0$

$x = \tfrac{1}{2}$, $y = -\tfrac{1}{2}$, $z = 0$

$T = k\sqrt{(l/g)}$; experiment: $k = 2\pi$

*The two supplementary SI units (radian and steradian) are dimensionless; right: deducing T for a simple pendulum by dimensions*

## Units

Measuring a physical quantity means comparing it with an internationally accepted reference standard, the **unit**. A result = **number × unit**. Units of the **fundamental (base) quantities** are **base units**; units of all other quantities, written as combinations of base units, are **derived units**. Base + derived units form a **system of units**: CGS (cm, g, s), FPS (foot, pound, s), MKS (m, kg, s).

**SI** (Système International d'Unités, BIPM 1971, revised November 2018) uses the decimal system. **Seven base units**:

| Quantity | Unit | Symbol |
|---|---|---|
| length | metre | m |
| mass | kilogram | kg |
| time | second | s |
| electric current | ampere | A |
| thermodynamic temperature | kelvin | K |
| amount of substance | mole | mol |
| luminous intensity | candela | cd |

Since 2018 the units are defined by fixing constants: c (metre), h (kilogram), caesium-133 frequency (second), e (ampere), $k_B$ (kelvin), $N_A$ (mole), $K_{cd}$ (candela). Two more dimensionless units: **plane angle** $d\theta = ds/r$ in **radian (rad)**; **solid angle** $d\Omega = dA/r^2$ in **steradian (sr)**. Units retained for general use (outside SI): minute, hour, day, litre, tonne, etc. When using the mole, the elementary entities (atoms, molecules, ions, electrons) must be specified.

## Significant figures

Every measurement has error, so a result is reported with all **reliably known digits plus the first uncertain digit**: the **significant figures**. Period 1.62 s: 1 and 6 certain, 2 uncertain → 3 s.f. They show the **precision**, which depends on the **least count** of the instrument. A change of units does not change the number of s.f. (2.308 cm = 0.02308 m = 23.08 mm: four).

**Rules**: (i) all **non-zero digits** are significant; (ii) **zeros between** two non-zero digits are significant; (iii) for a number less than 1, zeros right of the decimal point but **left of the first non-zero digit** are not significant (0.002308: four); (iv) **trailing zeros without a decimal point** are not significant (123 m = 12300 cm: three); (v) **trailing zeros with a decimal point** are significant (3.500, 0.06900: four each); (vi) the 0 left of the decimal in 0.1250 is never significant; (vii) exact numbers (2 in $r = d/2$, $n$ in $T = t/n$, $2\pi$) have infinite s.f.

**Scientific notation** $a \times 10^b$ $(1 \le a < 10)$ removes ambiguity: 4.700 m = $4.700 \times 10^2$ cm (four s.f.); the power of 10 is irrelevant, all zeros in $a$ are significant. **Order of magnitude**: round $a$ to 1 if $a \le 5$, to 10 if $5 < a \le 10$: Earth's

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diameter $1.28 \times 10^{7}$ m is of order $10^{7}$ m; H atom $1.06 \times 10^{-10}$ m of order $10^{-10}$ m: 17 orders smaller.

**Arithmetic**: (1) in **multiplication or division**, keep as many **s.f.** as the number with the **least s.f.**: density = 4.237 g / 2.51 $cm^3$ = 1.69 g $cm^{-3}$; light year with c = $3.00 \times 10^{8}$ m $s^{-1}$ → $9.47 \times 10^{15}$ m. (2) In **addition or subtraction**, keep as many **decimal places** as the number with the least decimal places: 436.32 + 227.2 + 0.301 = 663.821 → **663.8 g**; 0.307 m − 0.304 m = 0.003 m.

**Rounding off**: drop the extra digit if it is less than 5; raise the preceding digit by 1 if it is more than 5 (2.746 → 2.75; 1.743 → 1.74). If it is exactly 5: leave an **even** preceding digit unchanged, raise an **odd** one (2.745 → 2.74; 2.735 → 2.74). In multi-step work keep **one extra digit** in intermediate steps.

**Uncertainty in results**: l = 16.2 ± 0.1 cm (± 0.6%), b = 10.1 ± 0.1 cm (± 1%); l × b = 163.62 $cm^2$ ± 1.6% = 164 ± 3 $cm^2$. Subtraction can reduce s.f.: 12.9 g − 7.06 g = **5.8 g**. The relative error depends on the number itself: ± 0.01 in 1.02 g is ± 1%, in 9.89 g only ± 0.1%.

**Example 1.1** Side of a cube 7.203 m: surface area $6(7.203)^2 = 311.299254$ → **311.3 $m^2$**; volume $(7.203)^3 = 373.714754$ → **373.7 $m^3$** (four s.f.). **Example 1.2** 5.74 g in 1.2 $cm^3$: density = 5.74/1.2 = 4.78 → **4.8 g $cm^{-3}$** (two s.f., as 1.2 has two).

# 1.4 Dimensions; 1.5 dimensional formulae; 1.6 dimensional analysis ★★★

## Dimensions

All derived quantities can be expressed in terms of the seven base quantities, the **seven dimensions** of the physical world: [L], [M], [T], [A], [K], [cd], [mol]. The **dimensions** of a quantity are the **powers to which the base quantities are raised** to represent it. Square brackets [ ] mean "the dimensions of". In mechanics only [M], [L], [T] are needed. Magnitudes are not considered: change in velocity, initial, average and final velocity and speed all have [$L\,T^{-1}$].

Volume = length × breadth × height: [$L^3$], i.e. zero dimension in mass and time. Force = mass × acceleration = [M] [L]/$[T]^2$ = **[$M\,L\,T^{-2}$]**.

**Dimensional formula**: the expression showing which base quantities, with which powers, make up a quantity: volume [$M^0\,L^3\,T^0$], speed [$M^0\,L\,T^{-1}$], acceleration [$M^0\,L\,T^{-2}$], density [$M\,L^{-3}\,T^0$]. **Dimensional equation**: the quantity equated to its formula: [F] = [$M\,L\,T^{-2}$].

| Quantity | Formula | Dimensions |
|---|---|---|
| work, energy | F × d | [$M\,L^2\,T^{-2}$] |
| power | W/t | [$M\,L^2\,T^{-3}$] |
| pressure, stress | F/A | [$M\,L^{-1}\,T^{-2}$] |
| momentum, impulse | mv, Ft | [$M\,L\,T^{-1}$] |
| G | $Fr^2/(m_1m_2)$ | [$M^{-1}\,L^3\,T^{-2}$] |
| Planck's h | E/v | [$M\,L^2\,T^{-1}$] |
| surface tension | F/l | [$M\,T^{-2}$] |
| angle, strain, refractive index | ratios | dimensionless |

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### 1.6.1 Checking dimensional consistency

Only quantities with the **same dimensions** can be added or subtracted, and both sides of an equation must have the same dimensions: the **principle of homogeneity**. In $x = x_0 + v_0 t + \frac{1}{2}at^2$ every term is [L]: consistent. Arguments of trigonometric, exponential and logarithmic functions must be dimensionless. A dimensionally correct equation **need not be correct** (constants are not checked), but a dimensionally wrong one is certainly wrong.

**Example 1.3** Is $\frac{1}{2}mv^2 = mgh$ correct dimensionally? LHS: $[M][LT^{-1}]^2 = [ML^2T^{-2}]$; RHS: $[M][LT^{-2}][L] = [ML^2T^{-2}]$. Same, so it is dimensionally correct.

**Example 1.4** K has [M L$^2$ T$^{-2}$]. (a) $m^2v^3$: [M$^2$ L$^3$ T$^{-3}$] ✗; (b) $\frac{1}{2}mv^2$ and (d) $\frac{3}{16}mv^2$: [M L$^2$ T$^{-2}$] ✓; (c) $ma$: [M L T$^{-2}$] ✗; (e) $\frac{1}{2}mv^2 + ma$ adds unlike quantities ✗. So (a), (c), (e) are ruled out; dimensions cannot choose between (b) and (d) (the definition gives (b)).

### 1.6.2 Deducing relations

If a quantity depends on up to three others (as a product), the relation can be found by equating powers. **Example 1.5**: period T of a pendulum depends on length l, g and mass m: $T = k\,l^x g^y m^z$.

$[L^0M^0T^1] = [L]^x[LT^{-2}]^y[M]^z = L^{x+y}T^{-2y}M^z$

$x + y = 0,\ -2y = 1,\ z = 0 \Rightarrow x = \frac{1}{2},\ y = -\frac{1}{2},\ z = 0$

$T = k\sqrt{l/g}$; experiment gives $k = 2\pi$: $T = 2\pi\sqrt{l/g}$. The period does not depend on the mass.

### Uses and limitations

**Uses**: (i) checking the consistency of equations; (ii) converting units between systems: $n_2 = n_1\left[\frac{M_1}{M_2}\right]^a\left[\frac{L_1}{L_2}\right]^b\left[\frac{T_1}{T_2}\right]^c$; e.g. 1 J = $10^7$ erg, 1 N = $10^5$ dyne; (iii) deducing relations among quantities. Units are treated like algebraic symbols and cancel.

**Limitations**: (i) **dimensionless constants** (½, 2π) cannot be found; (ii) it cannot tell whether a quantity is a vector or scalar; (iii) relations with **sums or differences** of terms ($s = ut + \frac{1}{2}at^2$) or with trigonometric, exponential, logarithmic functions cannot be deduced; (iv) it fails if a quantity depends on more than three quantities in mechanics; (v) quantities with the same dimensions (work and torque) cannot be distinguished.

## NCERT exercises, fully solved

**1.1** Fill in the blanks: (a) The volume of a cube of side 1 cm is ___ m$^3$. (b) The surface area of a solid cylinder of radius 2.0 cm and height 10.0 cm is ___ (mm)$^2$. (c) A vehicle moving at 18 km h$^{-1}$ covers ___ m in 1 s. (d) The relative density of lead is 11.3. Its density is ___ g cm$^{-3}$ or ___ kg m$^{-3}$.

> **Ans.** (a) $(10^{-2}\ \text{m})^3 = 10^{-6}$ m$^3$. (b) $A = 2\pi r(r+h) = 2\pi(20)(20+100) = 1.508 \times 10^4$ mm$^2$ → **1.5 × 10$^4$ mm$^2$** (2 s.f., as 2.0 has two). (c) $18 \times \frac{1000}{3600} = 5$ m s$^{-1}$, so **5 m**. (d) density = 11.3 × density of water = **11.3 g cm$^{-3}$ = 1.13 × 10$^4$ kg m$^{-3}$**.

**1.2** Convert: (a) 1 kg m$^2$ s$^{-2}$ = ___ g cm$^2$ s$^{-2}$ (b) 1 m = ___ ly (c) 3.0 m s$^{-2}$ = ___ km h$^{-2}$ (d) G = 6.67 × 10$^{-11}$ N m$^2$ kg$^{-2}$ = ___ cm$^3$ s$^{-2}$ g$^{-1}$.

> **Ans.** (a) $1 \times 10^3\ \text{g} \times 10^4\ \text{cm}^2\ \text{s}^{-2} = 10^7$. (b) 1 ly = 9.46 × 10$^{15}$ m, so 1 m = **1.06 × 10$^{-16}$ ly**. (c) $3.0 \times 10^{-3}\ \text{km} \times (3600)^2\ \text{h}^{-2} = 3.9 \times 10^4$ **km h$^{-2}$**. (d) N m$^2$ kg$^{-2}$ = kg$^{-1}$ m$^3$ s$^{-2}$ = $(10^3\ \text{g})^{-1}(10^2\ \text{cm})^3\ \text{s}^{-2} = 10^3$ cm$^3$ s$^{-2}$ g$^{-1}$; so G = **6.67 × 10$^{-8}$ cm$^3$ s$^{-2}$ g$^{-1}$**.

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**1.3** A calorie is about 4.2 J (1 J = 1 kg $m^2$ $s^{-2}$). In a system where the unit of mass is α kg, of length β m and of time γ s, show that a calorie is 4.2 $\alpha^{-1}$ $\beta^{-2}$ $\gamma^2$.

> **Ans.** 1 cal = 4.2 kg $m^2$ $s^{-2}$. In the new system 1 kg = $\frac{1}{\alpha}$ new mass units, 1 m = $\frac{1}{\beta}$ new length units, 1 s = $\frac{1}{\gamma}$ new time units. So 1 cal = $4.2\left(\frac{1}{\alpha}\right)\left(\frac{1}{\beta}\right)^2\left(\frac{1}{\gamma}\right)^{-2} = 4.2\,\alpha^{-1}\beta^{-2}\gamma^2$ new units. (Or by $n_2 = n_1[M_1/M_2][L_1/L_2]^2[T_1/T_2]^{-2}$ with $M_2 = \alpha$ kg etc.)

**1.4** Explain: "To call a dimensional quantity 'large' or 'small' is meaningless without a standard for comparison." Reframe: (a) atoms are very small (b) a jet plane moves with great speed (c) the mass of Jupiter is very large (d) the air in this room has a large number of molecules (e) a proton is much more massive than an electron (f) the speed of sound is much smaller than the speed of light.

> **Ans.** A quantity is large or small only relative to another of the same kind. (a) Atoms are very small compared with a pin head (or the sharp tip of a pin). (b) A jet plane moves with great speed compared with a car. (c) Jupiter's mass is very large compared with the Earth's. (d) The air in the room contains a large number of molecules compared with the number in a geometry box (or compared with the population of a city). (e) Already a comparison: correct as stated (about 1836 times). (f) Already a comparison: correct as stated.

**1.7** A hair viewed through a microscope of magnification 100 has an average width of 3.5 mm (20 observations). Estimate its thickness.

> **Ans.** Real thickness = observed width/magnification = 3.5 mm/100 = **0.035 mm**.

**1.5** A new unit of length is chosen so that the speed of light in vacuum is unity. What is the Sun–Earth distance in this unit if light takes 8 min 20 s?

> **Ans.** Speed of light = 1 new unit per second, so the new unit is the distance light travels in 1 s. Time = 8 × 60 + 20 = 500 s. Distance = 1 × 500 = **500 new units**.

**1.6** Which is the most precise device for length: (a) vernier callipers with 20 divisions on the sliding scale (b) screw gauge of pitch 1 mm, 100 circular divisions (c) an optical instrument measuring to within a wavelength of light?

> **Ans.** Least counts: (a) 1 mm/20 = 0.05 mm = $5 \times 10^{-5}$ m; (b) 1 mm/100 = 0.01 mm = $10^{-5}$ m; (c) a wavelength of light ≈ $10^{-7}$ m. The smallest least count is (c), so the **optical instrument** is the most precise.

**1.8** (a) How will you estimate the diameter of a thread with a metre scale? (b) A screw gauge has pitch 1.0 mm and 200 circular divisions. Can its accuracy be increased arbitrarily by increasing the divisions? (c) Why do 100 measurements of a brass rod's diameter give a more reliable estimate than 5?

> **Ans.** (a) Wind the thread on a uniform rod (pencil) in close turns, say n turns over a length L measured by the scale; diameter = L/n. (b) No: the least count (pitch/N) falls on paper, but very fine divisions cannot be read by the eye, and backlash and manufacturing errors limit accuracy. (c) Random errors are equally likely to be positive or negative; with more observations they cancel better, so the mean of 100 readings is closer to the true value.

**1.9** A house occupies 1.75 $cm^2$ on a 35 mm slide; on the screen it is 1.55 $m^2$. What is the linear magnification?

> **Ans.** Areal magnification = $\frac{1.55}{1.75\times10^{-4}} = 8.857 \times 10^3$. Linear magnification = $\sqrt{8857} \approx$ **94.1**.

**1.10** Number of significant figures: (a) 0.007 $m^2$ (b) $2.64 \times 10^{24}$ kg (c) 0.2370 g $cm^{-3}$ (d) 6.320 J (e) 6.032 N $m^{-2}$ (f) 0.0006032 $m^2$.

> **Ans.** (a) **1** (leading zeros are not significant) (b) **3** (c) **4** (trailing zero after the decimal counts) (d) **4** (e) **4** (zero between non-zero digits counts) (f) **4**.

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**1.12** A box weighed on a grocer's balance is 2.30 kg. Two gold pieces of 20.15 g and 20.17 g are added. Find (a) the total mass (b) the difference in the masses of the pieces, to correct significant figures.

> **Ans.** (a) Total = 2.30 + 0.02015 + 0.02017 = 2.34032 kg; the least decimal places are two (2.30), so **2.34 kg**. (b) Difference = 20.17 − 20.15 = **0.02 g** (two decimal places).

**1.11** A sheet is 4.234 m long, 1.005 m broad and 2.01 cm thick. Give its area and volume to correct significant figures.

> **Ans.** $t$ = 0.0201 m (3 s.f.). Area (total surface) = $2(lb + bt + tl) = 2(4.25517 + 0.02020 + 0.08510) = 8.7209$ m$^2$ → **8.72 m$^2$** (3 s.f., limited by 2.01). Volume = $lbt = 4.234 \times 1.005 \times 0.0201 = 0.0855289$ → **0.0855 m$^3$**.

**1.13** A boy writes the relativistic relation as $m = m_0/(1 - v^2)^{1/2}$, forgetting where to put c. Guess where c goes.

> **Ans.** $1 - v^2$ must be dimensionless (we subtract it from a pure number), and $m/m_0$ is dimensionless. So $v^2$ must be divided by a squared speed: $m = \dfrac{m_0}{(1 - v^2/c^2)^{1/2}}$.

**1.14** 1 Å = $10^{-10}$ m. The size of a hydrogen atom is about 0.5 Å. What is the total atomic volume in m$^3$ of a mole of hydrogen atoms?

> **Ans.** Taking r = 0.5 Å = 0.5 × $10^{-10}$ m: volume of one atom = $\frac{4}{3}\pi r^3 = \frac{4}{3} \times 3.14 \times (0.5 \times 10^{-10})^3 = 5.24 \times 10^{-31}$ m$^3$. For a mole: $5.24 \times 10^{-31} \times 6.023 \times 10^{23} =$ **3.15 × 10$^{-7}$ m$^3$**.

**1.15** One mole of an ideal gas at STP occupies 22.4 L. What is the ratio of molar volume to the atomic volume of a mole of hydrogen (size of the molecule about 1 Å)? Why is it so large?

> **Ans.** Atomic volume of a mole (r = 0.5 Å) = 3.15 × $10^{-7}$ m$^3$ (Ex. 1.14). Molar volume = 22.4 × $10^{-3}$ m$^3$. Ratio = $\frac{22.4 \times 10^{-3}}{3.15 \times 10^{-7}} \approx$ **7.1 × 10$^4$**. It is large because the separation between gas molecules is very large compared with their size: most of a gas is empty space.

**1.16** From a fast train, nearby trees seem to move rapidly backwards, but distant objects (hill tops, the Moon, stars) seem stationary. Explain.

> **Ans.** The apparent motion is judged by the angle the line of sight turns through. For a displacement x of the train, a nearby object at distance d turns the line of sight by about x/d, which is large; for a very distant object the angle is negligible, so it seems at rest (or even to move with us, since we know we are moving). This is parallax.

**1.17** The Sun (core above $10^7$ K, surface about 6000 K) is a hot plasma. Do you expect its density to be like solids and liquids or gases? Check: mass 2.0 × $10^{30}$ kg, radius 7.0 × $10^8$ m.

> **Ans.** Density = $\dfrac{M}{\frac{4}{3}\pi R^3} = \dfrac{2.0 \times 10^{30}}{\frac{4}{3} \times 3.14 \times (7.0 \times 10^8)^3} = \dfrac{2.0 \times 10^{30}}{1.44 \times 10^{27}} \approx$ **1.4 × 10$^3$ kg m$^{-3}$**. This is in the range of solids and liquids, not gases: the enormous gravitational pull of the outer layers compresses the inner plasma.

## Quick-reference sheet

| Item | Key fact |
|---|---|
| × and ÷ | least number of s.f. |
| + and − | least number of decimal places |
| dropped digit 5 | even stays, odd goes up |
| radian, steradian | ds/r, dA/r²; dimensionless |
| energy | [M L² T⁻²] |
| pressure | [M L⁻¹ T⁻²] |

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| | |
|---|---|
| G | $[M^{-1} L^{3} T^{-2}]$ |
| h, angular momentum | $[M L^{2} T^{-1}]$ |
| conversion | $n_2 = n_1[M_1/M_2]^a[L_1/L_2]^b[T_1/T_2]^c$ |

✗ **Don't do this:** Changing units never changes the number of significant figures.

✗ **Don't do this:** A dimensionally correct equation is not necessarily correct.

**Case study (practice): a falling stone.** A student guesses that the speed v of a stone dropped from a height h depends on h, g and its mass m.
(i) Write $v = k\,h^x\,g^y\,m^z$ in dimensions. (ii) Find x, y, z. (iii) Does v depend on m? (iv) Can dimensions give k?

## Important exam questions, fully solved

Questions of the kind set in school and annual exams, with complete answers and mark steps.

### A. MCQs and Assertion–Reason (1 mark each)

*Exam-style* The number of significant figures in 0.06900 is (A) 2 (B) 4 (C) 5 (D) 3 [1]

> **Ans.** Leading zeros (0.0) are not significant; 6, 9 and the two trailing zeros after the decimal are: four. **(B)**.

*Exam-style* The dimensional formula of Planck's constant is that of (A) energy (B) power (C) angular momentum (D) force [1]

> **Ans.** $h = E/\nu$: $[ML^2T^{-2}]/[T^{-1}] = [ML^2T^{-1}]$; angular momentum $mvr$ also has $[ML^2T^{-1}]$. **(C)**.

*Exam-style* 2.745 rounded off to three significant figures is (A) 2.74 (B) 2.75 (C) 2.70 (D) 2.80 [1]

> **Ans.** The dropped digit is exactly 5 and the preceding digit 4 is even, so it is left unchanged: 2.74. **(A)**.

*Exam-style* Which pair has the same dimensions? (A) work and power (B) force and momentum (C) velocity and acceleration (D) stress and pressure [1]

> **Ans.** Stress and pressure are both force/area: $[ML^{-1}T^{-2}]$. **(D)**.

*Exam-style* The sum 436.32 g + 227.2 g + 0.301 g, written correctly, is (A) 663.821 g (B) 663.8 g (C) 664 g (D) 663.82 g [1]

> **Ans.** Keep the least number of decimal places (one, in 227.2): 663.821 → 663.8 g. **(B)**.

*Exam-style* Assertion (A): A dimensionally correct equation may still be wrong. Reason (R): Dimensional analysis cannot give dimensionless constants. [1]

> **Ans.** Both are true and R explains A: e.g. $T = \sqrt{l/g}$ is dimensionally correct but the true relation has $2\pi$. **(A)** (both true, R explains A).

*Exam-style* Assertion (A): The number of significant figures changes when 2.308 cm is written as 0.02308 m. Reason (R): Leading zeros are not significant. [1]

> **Ans.** A is false: a change of units does not change the number of significant figures (four in both). R is true. **(D)**.

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## B. Short answer (2 marks)

Exam-style Name the seven SI base quantities with their units, and the two supplementary units. [2]

**Ans.** Length (metre, m), mass (kilogram, kg), time (second, s), electric current (ampere, A), thermodynamic temperature (kelvin, K), amount of substance (mole, mol), luminous intensity (candela, cd) (1½). Supplementary: plane angle (radian) and solid angle (steradian) (½).

Exam-style Define radian and steradian. How many steradians does a full sphere subtend at its centre? [2]

**Ans.** Radian: the plane angle subtended at the centre by an arc equal in length to the radius, $d\theta = ds/r$ (½). Steradian: the solid angle subtended at the centre of a sphere by a surface area equal to $r^2$, $d\Omega = dA/r^2$ (½). Full sphere: $\Omega = 4\pi r^2/r^2 = 4\pi$ sr (1).

Exam-style Write the dimensions of (a) gravitational constant G (b) coefficient of viscosity η, using $F = 6\pi\eta r v$. [2]

**Ans.** (a) $G = \dfrac{Fr^2}{m_1 m_2} = \dfrac{[MLT^{-2}][L^2]}{[M^2]} = [M^{-1}L^3T^{-2}]$ (1). (b) $\eta = \dfrac{F}{6\pi r v} = \dfrac{[MLT^{-2}]}{[L][LT^{-1}]} = [ML^{-1}T^{-1}]$ (1).

Exam-style Convert 1 newton into dyne using dimensions. [2]

**Ans.** [F] = [M L T$^{-2}$], so a = 1, b = 1, c = −2 (½). $n_2 = n_1\left[\frac{M_1}{M_2}\right]\left[\frac{L_1}{L_2}\right]\left[\frac{T_1}{T_2}\right]^{-2} = 1\left[\frac{1000\text{ g}}{1\text{ g}}\right]\left[\frac{100\text{ cm}}{1\text{ cm}}\right][1]^{-2}$ (1) $= 10^5$: 1 N = $10^5$ dyne (½).

Exam-style Check the correctness of $v^2 = u^2 + 2as$ by dimensions. [2]

**Ans.** $[v^2] = [u^2] = [LT^{-1}]^2 = [L^2T^{-2}]$ (1); $[2as] = [LT^{-2}][L] = [L^2T^{-2}]$ (½). All terms have the same dimensions, so the equation is dimensionally correct (½).

## C. Short answer (3 marks)

Exam-style State the rules for counting significant figures, with one example each. [3]

**Ans.** (i) All non-zero digits are significant: 2.64 has 3 (½). (ii) Zeros between non-zero digits are significant: 6.032 has 4 (½). (iii) In a number less than 1, zeros before the first non-zero digit are not: 0.007 has 1 (½). (iv) Trailing zeros without a decimal point are not: 12300 has 3 (½). (v) Trailing zeros with a decimal point are: 3.500 has 4 (½). (vi) Exact numbers have infinite significant figures: 2 in $s = 2r$ (½).

Exam-style The length and breadth of a sheet are 16.2 ± 0.1 cm and 10.1 ± 0.1 cm. Find its area with the error. [3]

**Ans.** Relative errors: $\frac{0.1}{16.2} = 0.6\%$, $\frac{0.1}{10.1} = 1\%$ (1). For a product, relative errors add: 1.6% (½). Area = 16.2 × 10.1 = 163.62 cm$^2$ (½); error = 1.6% of 163.62 = 2.6 cm$^2$ (½). Area = **164 ± 3 cm$^2$** (½).

Exam-style The frequency ν of a stretched string depends on its length l, tension T and mass per unit length μ. Derive the formula by dimensions. [3]

**Ans.** Let $\nu = k\, l^a T^b \mu^c$ (½). $[T^{-1}] = [L]^a[MLT^{-2}]^b[ML^{-1}]^c = M^{b+c}L^{a+b-c}T^{-2b}$ (1). Equating: $b + c = 0$, $a + b - c = 0$, $-2b = -1$, so $b = \frac{1}{2}$, $c = -\frac{1}{2}$, $a = -1$ (1). $\nu = \dfrac{k}{l}\sqrt{\dfrac{T}{\mu}}$ (experiment: $k = \frac{1}{2}$) (½).

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[3]

Exam-style Give three limitations of dimensional analysis.

**Ans.** Any three (1 × 3): dimensionless constants cannot be found; relations with sums/differences or with trigonometric, exponential and logarithmic functions cannot be derived; it cannot distinguish quantities with the same dimensions (work and torque); it does not tell whether a quantity is a scalar or vector; it fails when a quantity depends on more than three others in mechanics.

## D. Long answer (5 marks)

Exam-style (a) State the principle of homogeneity. (b) Using dimensions, derive the time period of a simple pendulum. (c) State two uses of dimensional analysis. [5]

**Ans.** (a) Every term on both sides of a correct physical equation must have the same dimensions (1). (b) Assume $T = k\,l^x g^y m^z$ (½); $[T] = [L]^x[LT^{-2}]^y[M]^z = L^{x+y}T^{-2y}M^z$ (1); $x + y = 0$, $-2y = 1$, $z = 0$, so $x = \frac{1}{2}, y = -\frac{1}{2}$ (1); $T = k\sqrt{l/g}$, with $k = 2\pi$ found by experiment (½). (c) Checking the correctness of equations; converting a quantity from one system of units to another; deducing relations among quantities (any two) (½ + ½).

## E. Case study (4 marks)

**Case (exam-style):** In a laboratory, a student measures the mass of a body as 4.237 g and its volume as 2.51 $cm^3$. Her calculator shows the density as 1.68804780876 g $cm^{-3}$. She then measures a cube of side 7.203 m.

(a) How many significant figures should the density have, and what is its value? [1] **Ans.** Three (as 2.51 has three): 1.69 g $cm^{-3}$.

(b) Why is it wrong to report all the calculator digits? [1] **Ans.** A result cannot be more precise than the least precise measurement; the extra digits give a false idea of precision.

(c) Find the surface area and volume of the cube to correct significant figures. [2] **Ans.** Area = $6(7.203)^2$ = 311.299 → 311.3 $m^2$; volume = $(7.203)^3$ = 373.715 → 373.7 $m^3$ (four s.f. each).

# Practice set: test yourself Exam-style

Try every question before looking at the answers at the end of the chapter. 64 or more out of 80 means you are ready for the exam.

## A. Fill in the blanks (1 mark each)

1. The SI unit of luminous intensity is the _____.
2. The unit of solid angle is the _____.
3. 3.500 has _____ significant figures.
4. 2.735 rounded to three s.f. is _____.
5. The dimensions of force are _____.
6. Strain has _____ dimensions.
7. 1 J = _____ erg.
8. The order of magnitude of $1.28 \times 10^7$ m is _____.

## B. True or false? (1 mark each)

1. 123 m and 12300 cm have the same s.f.

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2. Exact numbers have infinite s.f.
3. Work and torque have the same dimensions.
4. Dimensional analysis gives $2\pi$ in $T = 2\pi\sqrt{(l/g)}$.
5. The kilogram is defined using Planck's constant.
6. In addition, keep the least s.f.
7. Angle is dimensionless.
8. A trigonometric argument must be dimensionless.

## C. Very short answer (1 mark each)

1. Count s.f. in 0.0006032.
2. Count s.f. in $2.64 \times 10^{24}$.
3. Give the dimensions of power.
4. Give the dimensions of momentum.
5. Write 4.700 m in mm in scientific notation.
6. Find 12.9 g − 7.06 g correctly.
7. Name a dimensionless quantity with a unit.
8. Name a dimensional constant.
9. What does SI stand for?
10. In which year was the SI revised?

## D. Short answer I (2 marks each)

1. Distinguish base and derived units.
2. Why is scientific notation preferred?
3. Find the dimensions of surface tension and pressure.
4. Check $s = ut + \frac{1}{2}at^2$ dimensionally.
5. Convert 1 J to erg using dimensions.
6. Round 1.743 and 2.746 to three s.f.
7. Why keep an extra digit in intermediate steps?
8. Find the density of 5.74 g in 1.2 $cm^3$ correctly.

**My score** (fill in after checking the answers)

| Section | A /8 | B /8 | C /10 | D /16 | E /18 | F /20 | G (bonus) | Total /80 |
|---|---|---|---|---|---|---|---|---|
| My marks | | | | | | | | |

Rough work

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## E. Short answer II (3 marks each)

1. State the rules for arithmetic with significant figures, with examples.
2. Explain the rounding-off rules with examples.
3. Derive the dimensions of G and h.
4. Use dimensions to find how the centripetal force on a body in a circle depends on m, v, r.
5. Show that the relative error depends on the number itself.
6. State three uses of dimensional analysis.

## F. Long answer (5 marks each)

1. Explain significant figures: definition, rules for counting, arithmetic operations and rounding off, with examples.
2. Explain dimensional analysis: dimensional formula, the principle of homogeneity, uses (with one example each) and limitations.

## G. HOTS (higher-order thinking)

1. Why can we not deduce $s = ut + \frac{1}{2}at^2$ by dimensions?
2. If the units of mass, length and time are doubled, what happens to the unit of force?
3. Why is the second now defined by a caesium frequency rather than the Earth's rotation?
4. Why does the measured value 2.30 kg limit the total in Exercise 1.12?

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# 20 MCQs

1. Not an SI base unit:
   (a) kelvin (b) mole (c) newton (d) candela
2. The unit of plane angle is
   (a) radian (b) steradian (c) degree only (d) none
3. Significant figures in 0.007:
   (a) 3 (b) 2 (c) 4 (d) 1
4. Significant figures in 6.320:
   (a) 3 (b) 4 (c) 2 (d) 5
5. 2.746 to three s.f.:
   (a) 2.74 (b) 2.75 (c) 2.70 (d) 2.80
6. In division the result keeps
   (a) least decimal places (b) all digits (c) most s.f. (d) least s.f.
7. 0.307 m − 0.304 m =
   (a) 0.003 m (b) $3.00 \times 10^{-3}$ m (c) 0.0030 m (d) 3 m
8. Dimensions of acceleration:
   (a) $[L\,T^{-1}]$ (b) $[M\,L\,T^{-2}]$ (c) $[L\,T^{-2}]$ (d) $[L^2\,T^{-2}]$
9. Dimensions of density:
   (a) $[M\,L^3]$ (b) $[M^{-1}\,L^3]$ (c) $[M\,L^{-2}]$ (d) $[M\,L^{-3}]$
10. Same dimensions as work:
    (a) power (b) torque (c) force (d) momentum
11. Dimensions of G:
    (a) $[M\,L^3\,T^{-2}]$ (b) $[M^{-1}\,L^2\,T^{-2}]$ (c) $[M^{-1}\,L^3\,T^{-2}]$ (d) $[M\,L^2\,T^{-2}]$

12. A dimensionless quantity:
(a) refractive index (b) velocity (c) force (d) pressure

13. 1 N equals
(a) $10^7$ dyne (b) $10^5$ dyne (c) $10^3$ dyne (d) 10 dyne

14. $T = k\,l^x\,g^y$: x =
(a) 1 (b) −½ (c) ½ (d) 2

15. Dimensional analysis cannot find
(a) units (b) conversions (c) consistency (d) dimensionless constants

16. Density 4.237 g / 2.51 cm³ =
(a) 1.69 (b) 1.688 (c) 1.7 (d) 1.68805 g cm$^{-3}$

17. Order of magnitude of $1.06 \times 10^{-10}$ m:
(a) −10 (b) −9 (c) −11 (d) 10

18. Most precise device:
(a) vernier (0.05 mm) (b) metre scale (c) screw gauge (0.01 mm) (d) optical instrument (≈ wavelength)

19. Dimensions of angular momentum:
(a) [M L² T$^{-2}$] (b) [M L² T$^{-1}$] (c) [M L T$^{-1}$] (d) [M L² T]

20. Number of SI base quantities:
(a) 6 (b) 9 (c) 7 (d) 5

*1 (c) · 2 (a) · 3 (d) · 4 (b) · 5 (b) · 6 (d) · 7 (a) · 8 (c) · 9 (d) · 10 (b) · 11 (c) · 12 (a) · 13 (b) · 14 (c) · 15 (d) · 16 (a) · 17 (a) · 18 (d) · 19 (b) · 20 (c)*

## Assertion–Reason (6)

(a) Both true, R explains A. (b) Both true, R does not explain A. (c) A true, R false. (d) A false, R true.

1. A: 4.700 m has four significant figures. R: Trailing zeros after a decimal point are significant.
2. A: Work and torque cannot be distinguished by dimensions. R: Both have [M L² T$^{-2}$].
3. A: $x = A\sin\omega t$ needs ωt to be dimensionless. R: The argument of a sine must be dimensionless.
4. A: Dimensional analysis can derive $s = ut + \frac{1}{2}at^2$. R: All its terms have dimensions of length.
5. A: The result of 12.9 g − 7.06 g is 5.84 g. R: In subtraction keep the least number of decimal places.
6. A: Radian is a dimensionless unit. R: It is a ratio of two lengths.

*Key: 1 (a) · 2 (a) · 3 (a) · 4 (d) · 5 (d) · 6 (a)*

## Answers to the practice set

**A.** 1. candela 2. steradian 3. four 4. 2.74 5. [M L T$^{-2}$] 6. no 7. $10^7$ 8. 7

**B.** 1. T 2. T 3. T 4. F 5. T 6. F 7. T 8. T

**C.** 1. four 2. three 3. [M L² T$^{-3}$] 4. [M L T$^{-1}$] 5. $4.700 \times 10^3$ mm 6. 5.8 g 7. plane angle (radian) or solid angle 8. G (or h) 9. Système International d'Unités 10. 2018

**D.** 1. Base units are for the seven base quantities, chosen independently; derived units are combinations of base units (N = kg m s$^{-2}$) 2. It removes ambiguity about trailing zeros; the power of 10 does not affect s.f. 3. Surface tension F/l: [M T$^{-2}$]; pressure F/A: [M L$^{-1}$ T$^{-2}$] 4. [s] = [L]; [ut] = [L T$^{-1}$][T] = [L]; [at²] = [L T$^{-2}$][T²] = [L]: consistent 5. [M L² T$^{-2}$]: 1 J = 1 (1000)(100)² = $10^7$ erg 6. 1.74; 2.75 7. To avoid build-up of rounding errors (1/9.58 = 0.104 ⟶ 9.62, but 0.1044 ⟶ 9.58) 8. 5.74/1.2 = 4.78 ⟶ 4.8 g cm$^{-3}$

**E.** 1. × and ÷: least s.f. (4.237/2.51 = 1.69); + and −: least decimal places (663.8 g) 2. Below 5 drop, above 5 raise; exactly 5: even stays (2.745 ⟶ 2.74), odd raised (2.735 ⟶ 2.74) 3. G = Fr²/m²: [M$^{-1}$ L³ T$^{-2}$]; h = E/v: [M L² T$^{-1}$] 4. F = k m$^x$ v$^y$ r$^z$: [M L T$^{-2}$] = M$^x$ L$^{y+z}$ T$^{-y}$: x = 1, y = 2, z = −1: F = k mv²/r 5. ± 0.01 in 1.02 g is 1%; in 9.89 g it is 0.1% 6. Checking equations, converting units, deducing relations

**F.** 1. Reliable digits + first uncertain digit; rules (non-zero, in-between zeros, leading zeros, trailing zeros with/without decimal, exact numbers); × ÷ least s.f., + − least decimals; rounding with the even-odd rule; examples 2. Dimensional

formula, dimensional equation; homogeneity; uses: check ($\frac{1}{2}mv^2 = mgh$), convert (N to dyne), deduce (pendulum); limitations (constants, sums, trig/exp, same dimensions, more than three variables)

**G.** 1. It has a sum of terms and a dimensionless ½; the method works only for a product of powers 2. Force unit = (2)(2)/(2)² = 1: it stays the same 3. The Earth's rotation is irregular and slowing; atomic frequencies are constant and reproducible everywhere 4. 2.30 kg is known only to two decimal places of a kilogram, so the total cannot be more precise

**Case.** (i) $[L\,T^{-1}] = [L]^x\,[L\,T^{-2}]^y\,[M]^z$ (ii) $x + y = 1$, $-2y = -1$, $z = 0$: $x = ½$, $y = ½$, $z = 0$ (iii) No (iv) No; $k = \sqrt{2}$ comes from the equations of motion

## Last-night summary

- SI: 7 base units (m, kg, s, A, K, mol, cd) defined by fixed constants (2018); radian and steradian are dimensionless.
- Significant figures: reliable digits + first uncertain digit; counting rules; scientific notation; order of magnitude.
- × ÷: least s.f.; + −: least decimal places; rounding (5: even stays, odd up); one extra digit in intermediate steps.
- Dimensions: powers of base quantities; dimensional formula and equation; homogeneity.
- Uses: check, convert, deduce ($T = 2\pi\sqrt{(l/g)}$); limitations: constants, sums, functions, same dimensions.

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