STUDENT COMPANION · DATA BOOK · REVISION GUIDE

Engineering Companion Handbook

Everything you need, on one shelf — formulae, data, design & project tools.

Unit 1
Engineering Principles

Unit 2
Engineering Applications

Unit 3
Engineering Design

Unit 4
Engineering Project

Pearson Level 3 Alternative Academic Qualification (AAQ)

BTEC National Extended Certificate in Engineering · QN 610/3962/7 · First teaching Sept 2025

START HERE

How to use this handbook

What this is

A **quick-reference data book** covering all four units. It is built for repeated use — the formulae, tables, templates and checklists you reach for again and again.

It is **not** a textbook. It assumes your teacher and class notes provide the explanation; this gives you the tools.

How to find things fast

- Each unit has a **coloured section divider**.
- Formulae are in **cards** with variables, units and a worked example.
- Look for the labelled boxes below.

COMMON MISTAKE — the errors that lose easy marks.

WORKED EXAMPLE — a full method you can copy.

EXAM TIP — how to bank the marks.

Contents

The qualification at a glance

Unit	Title	GLH	Assessment	How it is marked
1	Engineering Principles	120	External exam — 90 marks, 2h 15m	Short & long calculations; applied maths, mechanical & electrical principles
2	Engineering Applications	60	External exam — 70 marks, 2h	Multiple-choice, short & long answers on sectors, materials & processes

3	Engineering Design	120	Internal — Pearson-Set Assignment (32h)	Coursework portfolio: PDS, sketches, 3D CAD, 2D drawings, review
4	Engineering Project	60	Internal — Pearson-Set Assignment	Project portfolio: feasibility, planning, build, test, reflection

Equivalent in size to one A Level (360 GLH). Units 1 & 2 are examined; Units 3 & 4 are coursework. Knowledge from Units 1 & 2 is reused in the Unit 3 and Unit 4 assignments — this handbook is built around that overlap.

01

Quick Reference

Units, prefixes, conversions and the maths techniques students forget most — each with a worked example. Use this in every unit and every exam.

- SI base & derived units
- Multiplier prefixes
- Engineering conversions
- Standard form & significant figures
- Percentages & ratios
- Rearranging equations
- Area & volume formulae
- Trigonometry basics

SECTION 1

SI units, prefixes & conversions

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

SI prefixes (multipliers)

Prefix	Symbol	Factor
giga	G	10^9
mega	M	10^6
kilo	k	10^3
(unit)	—	$10^0 = 1$
milli	m	10^{-3}
micro	µ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

Derived units used across the course

Quantity	Unit	Symbol	In base / other units
Force, weight	newton	N	$kg \cdot m/s^2$
Pressure, stress	pascal	Pa	N/m^2
Energy, work	joule	J	N·m
Power	watt	W	J/s
Frequency	hertz	Hz	1/s
Electric charge	coulomb	C	A·s
Potential difference	volt	V	W/A = J/C
Resistance	ohm	Ω	V/A
Capacitance	farad	F	C/V
Inductance	henry	H	Wb/A = V·s/A
Magnetic flux	weber	Wb	V·s
Magnetic flux density	tesla	T	Wb/m^2
Plane angle	radian	rad	m/m (ratio)
Torque, moment	newton metre	N·m	—

Engineering conversions

Length

1 m	= 1000 mm	= 100 cm
1 cm	= 10 mm	
1 mm	= 0.001 m	= 10^{-3} m
1 km	= 1000 m	

mm → m: ÷1000 | **m → mm:** ×1000 | **mm → cm:** ÷10

Mass & force

1 kg	= 1000 g
1 g	= 0.001 kg = 10^{-3} kg
1 tonne	= 1000 kg
1 kN	= 1000 N
1 N	= 0.001 kN

N → kN: ÷1000 | **kN → N:** ×1000 | **g → kg:** ÷1000

Area & volume (watch the powers!)

1 m^2	= 10^6 mm^2 (1 000 000)
1 cm^2	= 100 mm^2
1 m^3	= 10^9 mm^3
1 litre	= 1000 cm^3 = 0.001 m^3

COMMON MISTAKE Converting mm→m by ÷1000 but forgetting that **area** needs ÷1000^2 and **volume** needs ÷1000^3.

Pressure, energy, angle

1 kPa	= 1000 Pa
1 MPa	= 10^6 Pa = 1 N/mm^2
1 kJ	= 1000 J
1 kWh	= 3.6 × 10^6 J
180°	= π rad ≈ 3.142 rad
1 rad	≈ 57.30°

EXAM TIP Always convert to **SI base units** (m, kg, s, N, Pa) *before* substituting into a formula, then convert the answer back if the question asks for kN, mm, etc. Mixed units are the single biggest cause of lost calculation marks.

SECTION 1

Engineering maths survival guide

The techniques students forget under pressure. Each comes with a worked example you can copy.

Standard form

Write a number as $a \times 10^n$ where **$1 \le a < 10$**.

$$48\ 000 = 4.8 \times 10^4 \qquad 0.00037 = 3.7 \times 10^{-4}$$

WORKED EXAMPLE

Resistance 4 700 000 Ω in standard form:

$4\ 700\ 000 = 4.7 \times 10^6\ \Omega = 4.7\ \text{M}\Omega$

Multiplying: $(2\times10^3)\times(3\times10^4) = 6\times10^7$ (multiply numbers, **add** powers)

Significant figures (s.f.)

- First non-zero digit is the 1st s.f.
- Round the final answer, not the working.
- 3 s.f. is the usual engineering default.

WORKED EXAMPLE

0.0040827 → 3 s.f. = 0.00408

125 740 → 3 s.f. = 126 000

9.0461 → 2 s.f. = 9.0

COMMON MISTAKE Rounding part-way through a multi-step calculation — keep full precision until the end.

Percentages

$$\%\ \text{change} = (\text{change} \div \text{original}) \times 100$$

WORKED EXAMPLE

A shaft is machined from 50.0 mm to 48.5 mm diameter. % reduction:

$= (1.5 \div 50.0) \times 100 = 3.0\ \%$

Efficiency as %: P_{out}=750 W, P_{in}=1000 W → (750/1000)×100 = 75 %

Ratios

Simplify by dividing both sides by the highest common factor. Scale both sides equally.

WORKED EXAMPLE

Gear ratio — driver 20 teeth, driven 60 teeth:

20 : 60 = 1 : 3 (divide by 20)

If driver turns at 900 rev/min, driven = 900 ÷ 3 = 300 rev/min

Rearranging (transposing) equations

Do the **same operation to both sides** to isolate the subject. Reverse the order of operations (undo +/− first, then ×/÷, then powers/roots).

MAKE *A* THE SUBJECT OF F = MA

$F = ma$

$F \div m = a$

$\mathbf{a = F / m}$

MAKE *R* THE SUBJECT OF A = ΠR²

$A = \pi r^2$

$A \div \pi = r^2$

$\mathbf{r = \sqrt{A / \pi}}$

COMMON MISTAKE Only dividing one side, or taking a root of just one term. Whatever you do to the left, do to the **whole** right-hand side.

Area formulae

Shape	Area	Shape	Area
Rectangle	$A = b \times h$	Circle	$A = \pi r^2 = \pi d^2/4$
Triangle	$A = \frac{1}{2}\, b \times h$	Sector (rad)	$A = \frac{1}{2} r^2\theta$
Trapezium	$A = \frac{1}{2}(a + b)h$	Ring / annulus	$A = \pi(R^2 - r^2)$
Parallelogram	$A = b \times h$	Arc length (rad)	$s = r\theta$

Volume & surface-area formulae

Solid	Volume	Surface area
Cuboid	$V = l \times w \times h$	$SA = 2(lw + lh + wh)$
Cylinder	$V = \pi r^2 h$	Total $SA = 2\pi rh + 2\pi r^2$
Cone	$V = \frac{1}{3}\pi r^2 h$	Curved $SA = \pi rl$ (l = slant)
Sphere	V = &frac43;πr^3	$SA = 4\pi r^2$
Prism	V = cross-section area × length	SA = 2×ends + perimeter×length

WORKED EXAMPLE — VOLUME & MASS OF A STEEL BAR

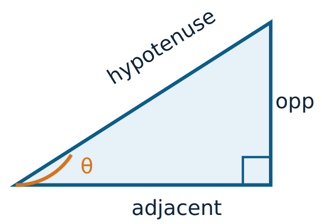
Solid cylinder, d = 40 mm, length = 250 mm, steel density ρ = 7850 kg/m³. Find the mass.

$r = 20\text{ mm} = 0.020\text{ m} \quad h = 0.250\text{ m}$

$V = \pi r^2 h = \pi \times 0.020^2 \times 0.250 = 3.142 \times 10^{-4}\text{ m}^3$

$m = \rho V = 7850 \times 3.142\times10^{-4} =$ **2.47 kg** (3 s.f.)

Trigonometry basics



Right-angled triangle

SOH CAH TOA → $\sin\theta = opp/hyp \quad \cos\theta = adj/hyp \quad \tan\theta = opp/adj$

Rule	Formula	Use when…
Pythagoras	$c^2 = a^2 + b^2$	right angle, two sides known
Sine rule	$a/\sin A = b/\sin B = c/\sin C$	any triangle; side–angle pairs
Cosine rule	$a^2 = b^2 + c^2 - 2bc\cdot\cos A$	2 sides + included angle

WORKED EXAMPLE — RESOLVING A FORCE

A 200 N force acts at 30° above horizontal. Find horizontal and vertical components.

$F_x = F\cos\theta = 200 \times \cos 30° =$ **173 N**

$F_y = F\sin\theta = 200 \times \sin 30° =$ **100 N**

COMMON MISTAKE Calculator left in **radians** when the question is in degrees (or vice-versa). Check the mode indicator before every trig calculation.

02

Unit 1
Engineering Principles

Your formula handbook. Every required equation with its variables, units and a worked example — grouped exactly as the specification orders them.

UNIT 1 · A

Algebraic, trigonometric & calculus methods

HOW THIS IS ASSESSED Pure-maths questions are never set on their own. These techniques are the **tools** you apply to the mechanical (B) and electrical (C) problems that follow.

Laws of indices

A1.2.1

$$a^m \times a^n = a^{m+n} \quad \cdot \quad a^m \div a^n = a^{m-n} \quad \cdot \quad (a^m)^n = a^{mn}$$

Also: $a^0 = 1$, $a^{-n} = 1/a^n$, $a^{1/2} = \sqrt{a}$

Laws of logarithms

A1.2.2

$$\log A + \log B = \log(AB)$$
$$\log A - \log B = \log(A/B) \quad \cdot \quad \log A^n = n \log A$$

log = base 10; ln = natural log (base e). Used for exponential growth/decay (e.g. RC circuits).

Straight-line graph

A1.3

$$y = mx + c$$

m = gradient (rise ÷ run) **c** = y-intercept

WORKED EXAMPLE
A graph of extension vs load gives gradient 0.04 mm/N through the origin. Extension at 150 N:
$y = 0.04 \times 150 + 0 = 6.0$ mm

Quadratic formula

A1.4.5

$$\text{for } ax^2 + bx + c = 0:$$
$$x = [\ -b \pm \sqrt{(b^2 - 4ac)}\ ] \div 2a$$

Gives the two roots of a quadratic. The term b^2-4ac is the discriminant.

Circular measure (radians)

A2.1

$$\text{arc length } s = r\theta \quad \cdot \quad \text{sector area } A = \tfrac{1}{2}r^2\theta$$

θ in radians. 360° = 2π rad. degrees → rad: ×π/180

WORKED EXAMPLE
Arc of a r = 50 mm pulley over 1.2 rad:
$s = r\theta = 50 \times 1.2 = 60$ mm

Vectors & resolution

A2.3

$$\text{horizontal } F_x = F\cos\theta \quad \cdot \quad \text{vertical } F_y = F\sin\theta$$

Resultant of perpendicular components: $R = \sqrt{(F_x^2 + F_y^2)}$, direction $\theta = \tan^{-1}(F_y/F_x)$

Applies to velocity, force and acceleration.

Calculus standard results

Differentiation

A3.2

Rate of change / gradient of a function. Notation: dy/dx, ds/dt.

y =	dy/dx =
ax^n	nax^{n-1}
sin x	cos x
cos x	−sin x
constant	0

Engineering use: velocity = ds/dt, acceleration = dv/dt; rate of capacitor charge/discharge.

Integration

A3.4–A3.5

Reverse of differentiation; also the area under a curve.

∫ ( )dx of	=
ax^n	$ax^{n+1}/(n+1) + c$
sin x	−cos x + c
cos x	sin x + c

Definite integral (limits a→b) gives area, work done by a force, distance from velocity, and RMS values of waveforms.

WORKED EXAMPLE — CALCULUS IN CONTEXT

Displacement $s = 3t^2 + 2t$ (m). Find velocity and acceleration at t = 4 s.

v = ds/dt = 6t + 2 = 6(4) + 2 = **26 m/s**

a = dv/dt = 6 = **6 m/s²** (constant)

UNIT 1 · B1

Static engineering systems

Force

B1.1.1

$$F = ma$$

F force (N) **m** mass (kg) **a** acceleration (m/s²)

Weight is a force: $W = mg$, with $g = 9.81$ m/s².

WORKED EXAMPLE

Weight of a 12 kg casting:

$W = mg = 12 \times 9.81 = \mathbf{117.7\ N}$

Moment of a force

B1.1.2b

$$M = F \times d$$

M moment (N·m) **F** force (N) **d** perpendicular distance to pivot (m)

WORKED EXAMPLE

A 250 N force on a spanner 0.18 m from the bolt centre:

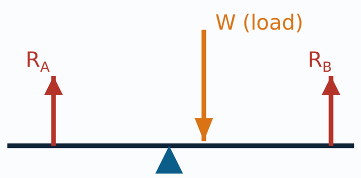
$M = 250 \times 0.18 = \mathbf{45\ N{\cdot}m}$

Resolution of forces & static equilibrium

B1.1.2

$$F_x = F\cos\theta \quad F_y = F\sin\theta \quad | \quad \text{equilibrium: } \Sigma F_x = 0,\ \Sigma F_y = 0,\ \Sigma M = 0$$

A body is in **static equilibrium** when all horizontal forces balance, all vertical forces balance, *and* all moments balance. Use space, vector and free-body diagrams to set the problem up.



Simply supported beam — reactions R_A, R_B

WORKED EXAMPLE — BEAM REACTIONS

A 4 m beam carries a 600 N load 1 m from support A. Take moments about A ($\Sigma M_A = 0$):

$R_B \times 4 = 600 \times 1 \rightarrow R_B = 150$ N

$\Sigma F_y = 0$: $R_A + R_B = 600 \rightarrow R_A = \mathbf{450\ N}$, $R_B = \mathbf{150\ N}$

Beam loads: concentrated (point) loads act at one point; a uniformly distributed load (UDL) of w N/m over length L behaves like a single load wL acting at its midpoint.

Loaded components — stress, strain & elastic constants B1.2

Direct (tensile/compressive) stress

$$\sigma = F / A$$

σ stress (Pa or N/m²) **F** force (N) **A** cross-sectional area (m²)

Direct strain

$$\varepsilon = \Delta L / L$$

ε strain (no units) **ΔL** change in length **L** original length (same units)

Shear stress & shear strain

$$\tau = F / A \qquad \gamma = a / b$$

τ shear stress (Pa) **γ** shear strain (ratio) a, b = shear deflection & depth

Elastic constants

$$\text{Young's Modulus } E = \sigma / \varepsilon$$
$$\text{Modulus of rigidity } G = \tau / \gamma$$

E and G in Pa. Steel E ≈ 200 GPa, aluminium E ≈ 70 GPa.

WORKED EXAMPLE — STRESS, STRAIN & YOUNG'S MODULUS

A steel rod, 10 mm diameter, 2.0 m long, carries 15 kN and stretches 0.96 mm. Find stress, strain and E.

$A = \pi r^2 = \pi(0.005)^2 = 7.854\times10^{-5}\ m^2 \quad F = 15\ 000\ N$

$\sigma = F/A = 15000 / 7.854\times10^{-5} = 1.91\times10^{8}\ Pa =$ **191 MPa**

$\varepsilon = \Delta L/L = 0.00096 / 2.0 = 4.8\times10^{-4}$

$E = \sigma/\varepsilon = 1.91\times10^{8} / 4.8\times10^{-4} = 3.98\times10^{11}... \rightarrow \approx$ **200 GPa**

COMMON MISTAKE Using diameter instead of radius in $A = \pi r^2$, or leaving area in mm² while force is in N (gives a stress in N/mm² = MPa, *not* Pa). Keep units consistent and state them.

Dynamic engineering systems

Equations of linear motion (SUVAT)

B2.1.5

$$v = u + at \quad \cdot \quad s = ut + \tfrac{1}{2}at^2 \quad \cdot \quad v^2 = u^2 + 2as \quad \cdot \quad s = \tfrac{1}{2}(u + v)t$$

s displacement (m) **u** initial velocity (m/s) **v** final velocity (m/s) **a** acceleration (m/s²) **t** time (s)

WORKED EXAMPLE
A car decelerates from 25 m/s to rest in 4 s. Find deceleration and stopping distance.
$a = (v-u)/t = (0-25)/4 = -6.25\ m/s^2$
$s = \tfrac{1}{2}(u+v)t = \tfrac{1}{2}(25+0)(4) = \mathbf{50\ m}$

EXAM TIP List s, u, v, a, t and tick what you know. Pick the SUVAT equation that contains your three knowns and the unknown — no rearranging guesswork.

Torque

B2.2.3

$$T = F \times r$$

T torque (N·m) **F** tangential force (N) **r** radius (m)

Rotational inertia

B2.2.2

$$I = mk^2$$

I moment of inertia (kg·m²) **m** mass (kg) **k** radius of gyration (m)

Work, power & efficiency

B2.2.4–B2.2.5

$$\text{work } W = F \times s \quad \cdot \quad \text{power } P = W / t = F \times v \quad \cdot \quad \text{efficiency } \eta = P_{out} / P_{in}$$

W work (J) **F** force (N) **s** distance (m) **P** power (W) **t** time (s) **η** efficiency (ratio, ×100 for %)

WORKED EXAMPLE
A motor does 24 kJ of work in 8 s, drawing 3.5 kW. Find output power and efficiency.
$P_{out} = W/t = 24000 / 8 = 3000\ W = 3.0\ kW$
$\eta = P_{out}/P_{in} = 3.0 / 3.5 = 0.857 = \mathbf{85.7\ \%}$

Energy — potential & kinetic

B2.2.6

$$PE = mgh \qquad KE = \tfrac{1}{2}mv^2$$

PE/KE energy (J) **m** mass (kg) **g** 9.81 m/s² **h** height (m) **v** speed (m/s)

Conservation of energy: total energy is constant; PE converts to KE as an object falls.

Angular motion

B2.3

$$\omega = \theta/t = v/r \quad \cdot \quad a = \omega^2 r = v^2/r$$
$$P = T\omega \quad \cdot \quad KE_{rot} = \tfrac{1}{2}I\omega^2$$

ω angular velocity (rad/s) **a** centripetal accel (m/s²) **P** power (W) **T** torque (N·m)

Lifting machines & mechanical systems

B2.4

$$VR = \text{distance moved by effort} \div \text{distance moved by load} \quad \cdot \quad MA = \text{load} \div \text{effort} \quad \cdot \quad \text{friction } F = \mu N$$

VR velocity ratio **MA** mechanical advantage **μ** coefficient of friction **N** normal force (N) efficiency $\eta = MA \div VR$

Gear / chain drive: velocity ratio = (driven teeth) ÷ (driver teeth); output speed = input speed ÷ VR.

WORKED EXAMPLE — GEAR TRAIN

Driver gear 24 teeth at 1200 rev/min drives a 72-tooth gear.

VR = 72/24 = 3 → driven speed = 1200/3 = **400 rev/min**

COMMON MISTAKE Confusing **work** (J, force × distance) with **power** (W, work ÷ time). If the question mentions a time, you almost certainly need power. Also: efficiency can never exceed 1 (100 %) — if it does, you have inverted the fraction.

UNIT 1 · B3

Fluid engineering systems

Density & relative density

B3.1.1–3

$$\rho = m / V \qquad RD = \rho_{substance} / \rho_{water}$$

ρ density (kg/m³) **m** mass (kg) **V** volume (m³) $\rho_{water} \approx 1000$ kg/m³

WORKED EXAMPLE

2.5 kg of fluid fills 0.0032 m³:

$\rho = m/V = 2.5 / 0.0032 =$ **781 kg/m³**

Hydrostatic thrust & centre of pressure

B3.1.5

$$F = \rho g A\bar{x} \qquad \text{(centre of pressure } x = h/2\text{)}$$

F thrust (N) **ρ** density **g** 9.81 **A** wetted area (m²) **x̄** depth to centroid (m). For a vertical rectangular surface with one edge at the surface, the resultant acts at depth h/2 from the centroid (2/3 down from the surface).

Fluid flow in a tapering pipe — continuity

B3.1.6

$$\text{volumetric flow } Q = Av \quad \cdot \quad \text{mass flow} = \rho A v \quad \cdot \quad \text{continuity: } A_1v_1 = A_2v_2$$

Q volumetric flow rate (m³/s) **A** cross-sectional area (m²) **v** flow velocity (m/s). For an incompressible fluid, what flows in must flow out: narrower pipe → faster flow.

WORKED EXAMPLE

Pipe narrows from A_1 = 0.02 m² (v_1 = 1.5 m/s) to A_2 = 0.008 m². Find v_2.

$A_1v_1 = A_2v_2 \rightarrow v_2 = (0.02 \times 1.5)/0.008 =$ **3.75 m/s**

Buoyancy / upthrust

B3.1.7

$$F_b = \rho g V$$

F_b buoyant force / upthrust (N) **ρ** fluid density (kg/m³) **V** volume of fluid displaced (m³). An object floats when upthrust = its weight (Archimedes' principle).

Direct current electricity & circuits

Charge & current

C1.1.3

$$I = Q / t$$

I current (A) **Q** charge (C) **t** time (s). Rearrange: Q = It.

Resistivity & temperature

C1.1.6

$$R = \rho L / A \qquad \Delta R / R_0 = \alpha \Delta T$$

ρ resistivity (Ω·m) **L** length (m) **A** area (m²) **α** temperature coefficient (/°C)

Resistors in series & parallel

C1.1.7

$$\text{Series: } R_t = R_1 + R_2 + R_3 + \dots$$
$$\text{Parallel: } 1/R_t = 1/R_1 + 1/R_2 + 1/R_3 + \dots$$

WORKED EXAMPLE

Two parallel resistors, 6 Ω and 3 Ω:

$1/R_t = 1/6 + 1/3 = 1/2 \rightarrow R_t =$ **2 Ω**

Capacitors in series & parallel

C1.1.9

$$\text{Series: } 1/C_t = 1/C_1 + 1/C_2 + \dots$$
$$\text{Parallel: } C_t = C_1 + C_2 + \dots$$

Note: capacitors combine the **opposite** way to resistors.

Ohm's law & electrical power

C1.2.1–2

$$V = IR \quad \cdot \quad I = V/R \quad \cdot \quad R = V/I \quad | \quad P = IV = I^2R = V^2/R$$

V voltage (V) **I** current (A) **R** resistance (Ω) **P** power (W)

WORKED EXAMPLE

A 12 V supply drives 0.5 A through a heater. Find R and power.

$R = V/I = 12 / 0.5 = 24\ \Omega$

$P = IV = 0.5 \times 12 =$ **6 W** (check: $I^2R = 0.25 \times 24 = 6$ W ✓)

Kirchhoff's laws

C1.2.4–5

$$\text{Current (node): } I = I_1 + I_2 + I_3$$
$$\text{Voltage (loop): } V = V_1 + V_2 + V_3$$

Current in = current out at a junction; voltages around a loop sum to the supply.

Capacitor charge & energy

C1.2.6–7

$$Q = CV \qquad W = \tfrac{1}{2}CV^2$$

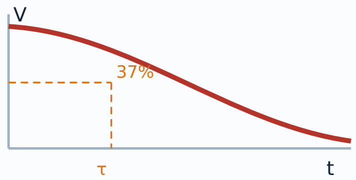
Q charge (C) **C** capacitance (F) **V** voltage (V) **W** stored energy (J)

RC transients — charge & discharge

C1.2.8

$$\text{time constant } \tau = RC \quad \cdot \quad \text{discharge } v_C = V\, e^{(-t/\tau)}$$

τ time constant (s) — time to reach ~63 % of final value when charging, or fall to 37 % when discharging. After 5τ the capacitor is effectively fully charged/discharged.



Capacitor discharge curve

WORKED EXAMPLE

R = 10 kΩ, C = 100 μF. Find the time constant.

$\tau = RC = 10\,000 \times 100{\times}10^{-6} = \mathbf{1.0\ s}$

Fully discharged after ≈ 5τ = 5 s.

COMMON MISTAKE For parallel resistors, forgetting to take the **reciprocal** at the end — $1/R_t = \ldots$ gives $1/R_t$, so you must invert to get R_t. Also: never convert μF to F? you must — 100 μF = $100{\times}10^{-6}$ F.

Magnetism & electromagnetic induction

Magnetic flux density

C2.1.1

$$B = \Phi / A$$

B flux density (T) **Φ** magnetic flux (Wb) **A** area (m^2)

Magnetomotive force & field strength

C2.1.2/5

$$F_m = NI \quad H = NI / l$$

F_m mmf (A or A-turns) **N** turns **I** current (A) **H** field strength (A/m) **l** magnetic path length (m)

Permeability

C2.1.3

$$B / H = \mu_0 \mu_r$$

μ_0 permeability of free space = $4\pi\times10^{-7}$ H/m μ_r relative permeability (no units)

Induced emf

C2.2.1

$$E = BLv \quad E = -N(d\Phi/dt)$$

E emf (V) **B** flux density (T) **L** conductor length (m) **v** velocity (m/s). The minus sign (Lenz's law) shows the emf opposes the change.

Self-inductance & stored energy

C2.2.5

$$L = N\Phi / I \quad W = \tfrac{1}{2}LI^2$$

L inductance (H) **N** turns **Φ** flux (Wb) **I** current (A) **W** energy (J)

Transformer (mutual inductance)

C2.2.6

$$V_1 / V_2 = N_1 / N_2 \quad \cdot \quad \eta = V_{out}/V_{in}$$

WORKED EXAMPLE

Primary 230 V, 800 turns; secondary 200 turns. Find V_2.

$V_2 = V_1 \times N_2/N_1 = 230 \times 200/800 =$ **57.5 V** (step-down)

UNIT 1 · C3

Single-phase alternating current

Period & frequency

C3.1.1

$$T = 1 / f$$

T period (s) **f** frequency (Hz). UK mains f = 50 Hz → T = 0.02 s.

Form factor

C3.1.3c

$$\text{form factor} = \text{r.m.s. value} / \text{average value}$$

For a pure sine wave, form factor = 1.11.

RMS & average values of a sine wave

C3.1.3

$$V_{rms} = V_{peak} / \sqrt{2} \quad \cdot \quad \text{average value} = (2/\pi) \times V_{peak}$$

V_{rms} root-mean-square voltage — the equivalent steady DC value. Peak-to-peak = 2 × peak.

WORKED EXAMPLE

A sinusoid has a peak voltage of 325 V (UK mains). Find the RMS value.

$V_{rms} = 325 / \sqrt{2} = \mathbf{230\ V}$

Impedance of R–L and R–C series circuits

C3.2

$$\text{R–L: } Z = \sqrt{(X_L^2 + R^2)} \quad \cdot \quad \text{R–C: } Z = \sqrt{(X_C^2 + R^2)}$$

Z impedance (Ω) X_L inductive reactance (Ω) X_C capacitive reactance (Ω) **R** resistance (Ω). Combine like the hypotenuse of a right-angled triangle (phasors).

WORKED EXAMPLE

A coil with X_L = 40 Ω in series with R = 30 Ω:

$Z = \sqrt{(40^2 + 30^2)} = \sqrt{2500} = \mathbf{50\ \Omega}$

UNIT 1

Common mistakes & calculation technique

Top mistakes by topic — and how to avoid them

Topic	The mistake	The fix
Force	Using mass in newtons; forgetting weight = mg.	Mass is kg, force/weight is N. Multiply mass by g = 9.81.
Moments	Using the slant distance, not the perpendicular distance to the pivot.	M = F × perpendicular distance. Resolve the force if needed.
Pressure / stress	Area left in mm^2 with force in N, or using diameter for radius.	Convert area to m^2 (or know N/mm^2 = MPa). $A = \pi r^2$, $r = d/2$.
Work	Confusing work (J) with power (W).	Work = F × s (no time). Power = work ÷ time.
Power	Mixing kW and W, or forgetting time.	1 kW = 1000 W. P = W/t = Fv.
Efficiency	Answer greater than 100 %, or output/input inverted.	$\eta = P_{out}/P_{in} \le 1$. Output is always the smaller number.
Density	Volume in cm^3 / litres mixed with mass in kg.	$\rho = m/V$ in kg/m^3. 1 litre = 0.001 m^3; 1 cm^3 = 10^{-6} m^3.
Energy	Using diameter or wrong g; forgetting ½ in KE.	PE = mgh; KE = ½mv^2. Square the velocity *before* halving.
Electrical	Parallel resistors not reciprocated; µF/kΩ not converted.	Invert $1/R_t$ at the end. 1 kΩ = 1000 Ω; 1 µF = 10^{-6} F.
Trig / radians	Calculator in the wrong angle mode.	Check DEG/RAD before every trig step. $s = r\theta$ needs radians.

A reliable method for every calculation question

1 · Set up
- List knowns with units.
- Identify the unknown.
- Sketch / free-body diagram.

2 · Select & convert
- Choose the formula.
- Convert all values to SI base units.
- Transpose for the unknown.

3 · Solve & check
- Substitute — show working.
- State the unit.
- Round to 3 s.f.; sanity-check size.

EXAM TIP Marks are awarded for **method**, not just the answer. Always show the formula, the substitution and the unit — you can earn most of the marks even if the final number is slightly off. A bare answer with no working risks scoring zero.

IN THE EXAM A formulae sheet is provided, but it will *not* include expected lower-level maths (e.g. area of a circle). Know your unit conversions, area/volume formulae and how to transpose — those are assumed.

03

Unit 2 Engineering Applications

A visual knowledge bank: the sectors, the materials, the manufacturing processes and the sustainability ideas you must recall and compare in the exam.

- Engineering sectors
- Functional areas
- Modern & emerging technologies
- Materials database
- Material properties & units
- Heat treatment
- Manufacturing process database
- Sustainability & the 6Rs

UNIT 2 · A1 Engineering sectors

Each sector designs, makes, operates and maintains products/services. Most do R&D, design, manufacture, operation and maintenance — the title shows the main focus.

Aerospace A1.1

Crewed aircraft, drones, satellites, spacecraft.

- **Key tech:** composites, jet/electric propulsion, avionics, CFD.
- **Future:** sustainable aviation fuel, electric/hydrogen flight, autonomous UAVs.

Automotive A1.3

Cars, trucks, vans, motorbikes.

- **Key tech:** robotic assembly, IC & EV powertrains, lightweighting.
- **Future:** electrification, autonomous driving, battery recycling.

Agricultural A1.2

Machinery for farming, horticulture, forestry.

- **Key tech:** GPS guidance, hydraulics, sensors.
- **Future:** precision/robotic farming, autonomous tractors, drone crop monitoring.

Biomedical A1.4

Equipment, tools and devices for healthcare.

- **Key tech:** imaging, biocompatible materials, micro-electronics.
- **Future:** 3D-printed implants, wearable monitors, AI diagnostics.

Chemical A1.5

Plant making pharmaceuticals, food/drink, fuels, lubricants.

- **Key tech:** process control, reactors, distillation.
- **Future:** green chemistry, carbon capture, bio-based feedstocks.

Civil A1.6

Buildings, bridges, tunnels, infrastructure.

- **Key tech:** BIM, reinforced concrete, surveying.
- **Future:** low-carbon concrete, modular construction, smart infrastructure.

Energy generation A1.7

Solar, wind, hydro, gas-fired & nuclear power.

- **Key tech:** turbines, power electronics, grid control.
- **Future:** renewables + storage, smart grids, hydrogen, fusion R&D.

Mechatronic A1.8

Electro-mechanical systems, robots, sensors, appliances.

- **Key tech:** control systems, actuators, embedded electronics.
- **Future:** cobots, smart appliances, IoT-connected machines.

Marine A1.9

Ships and offshore installations.

- **Key tech:** propulsion, naval architecture, corrosion control.
- **Future:** autonomous vessels, LNG/electric propulsion, offshore wind.

Rail A1.10

Trains, rolling stock, signalling.

- **Key tech:** electrification, signalling, bogie design.
- **Future:** digital signalling (ETCS), battery/hydrogen trains, predictive maintenance.

Functional areas of an engineering organisation A2

Function	What it does	Function	What it does
Research & development	New tech, products, services	Quality management	Standards, QC checks, trend analysis
Sales & marketing	Market research, promotion, demos	Energy management	Monitor & cut energy use, sustainability
Design	Briefs, drawings, specs, documentation	Health & safety mgmt	Risk assessment, reporting, training
Process monitoring & control	Keep process parameters safe/efficient	Information management	Secure storage, control, distribution

Manufacturing	Convert materials into finished goods	Maintenance	Corrective, preventative, predictive

Modern & emerging technologies A3

Technology	What it is & where it adds value
Robotics (robots, cobots, drones)	Automation of repetitive/dangerous tasks; cobots assist humans directly; drones inspect & survey.
Virtual Reality (VR)	Immersive simulated environments for design review, collaboration and training.
Augmented Reality (AR)	Real-time virtual overlays on the real world for guidance, assembly and maintenance.
Cloud computing	Scalable, secure, low-cost storage and sharing of documents and data.
Internet of Things (IoT)	Connected machines and sensors enabling monitoring, control and automation.
Artificial Intelligence (AI)	Autonomous systems, data analysis, vision/image recognition.
3D printing	Additive manufacturing for rapid prototyping and mass customisation.
Digital twin	Live virtual replica of a physical system for monitoring, simulation and optimisation.

UNIT 2 · B1

Materials database

Ferrous metals & alloys iron-based (Fe)

Material	Composition	Key properties	Applications	Typical processes
Low carbon (mild) steel	Fe + 0.15–0.30% C	Ductile, tough, weldable, cheap; rusts	Car bodies, beams, fasteners	Press work, machining, welding
Medium carbon steel	Fe + 0.30–0.7% C	Stronger, harder, less ductile	Shafts, gears, axles	Forging, machining, heat treatment
High carbon steel	Fe + 0.7–1.4% C	Very hard, brittle, holds an edge	Cutting tools, springs	Forging, grinding, quench hardening
Cast iron	Fe + 2–4% C	Excellent compression & damping; brittle	Machine bases, manifolds	Sand casting
Austenitic stainless steel	Fe + 16–20% Cr, 6–13% Ni	Corrosion resistant, hygienic	Food/medical equipment, cutlery	Machining, laser cutting, AM

Non-ferrous metals & alloys

Material	Composition	Key properties	Applications	Typical processes
Aluminium alloy	Al + 2–10% Cu	Light, good strength-to-weight, corrosion resistant	Aircraft, frames, packaging	Extrusion, casting, machining
Titanium alloy	Ti + 5–7% Al, 3–5% V	Very high strength-to-weight, biocompatible; costly	Aerospace, implants	Investment casting, AM (DMLS)
Brass	Cu + 35% Zn	Corrosion resistant, machinable, decorative	Fittings, valves, electrical pins	Casting, machining
Bronze	Cu + 12% Sn	Hard-wearing, low friction, corrosion resistant	Bearings, bushes, marine parts	Casting, machining
Zinc alloy	Zn + 3–5% Al	Low melting point, fine detail castings	Die-cast toys, fittings, housings	Hot-chamber die casting

Polymers

Type	Polymer	Properties	Applications
Thermoplastic soften on heating, can be remelted & recycled	Polycarbonate (PC)	Tough, transparent, impact resistant	Safety visors, lenses
	Polystyrene (PS)	Cheap, rigid or foamed, brittle	Packaging, casings
	ABS	Tough, rigid, good finish	Casings, toys, 3D printing
	PET	Strong, clear, recyclable	Bottles, packaging
	PLA	Bio-derived, biodegradable, easy to print	FDM 3D printing, packaging
	Nylon 66 (PA66)	Tough, low friction, wear resistant	Gears, bearings, fasteners
Thermoset cure permanently — cannot be remelted	Epoxy resin	Strong adhesive, good chemical/heat resistance	Composites, coatings, PCBs
	Polyester resin	Rigid, cheap, good with glass fibre	GFRP mouldings, panels
	Urea formaldehyde (UF)	Hard, heat resistant, electrical insulator	Plug sockets, switches

Elastomers & composites

Elastomers (flexible, high elasticity)

Elastomer	Properties & uses
Neoprene (TSE)	Oil/weather resistant — seals, wetsuits
Silicone rubber (TSE)	Heat resistant, inert — seals, medical
Nitrile rubber (TSE)	Excellent oil resistance — O-rings, gloves
SBC (TPE)	Rubbery but mouldable/recyclable — grips, overmoulds

Composites (matrix + reinforcement)

Composite	Properties & uses
GFRP (glass fibre)	Strong, light, cheap — boats, panels
CFRP (carbon fibre)	Very high strength-to-weight; costly — aerospace, sports
Cemented carbide	Extremely hard particle composite — cutting tool tips

STRUCTURE MATTERS Aligning fibres gives **anisotropic** strength (strong along the fibres). A higher reinforcement-to-matrix ratio raises strength and stiffness.

WIDER KNOWLEDGE — SMART MATERIALS Beyond the core list, **smart materials** respond to a stimulus: shape-memory alloys (revert to shape when heated — stents, actuators), piezoelectric materials (voltage↔force — sensors), thermochromic/photochromic pigments (colour with heat/light), and quantum tunnelling composites (pressure-sensitive switches).

UNIT 2 · B2

Material properties & heat treatment

Physical properties (know the units)

Property	Unit
Density	kg/m^3
Melting point	°C
Thermal conductivity	W/mK
Electrical resistivity	Ω·m
Ferromagnetism	— (yes/no)
Corrosion / chemical resistance	— (qualitative)
Light transmission	%

Mechanical properties

Property	Unit / measure
Hardness	Rockwell, Shore
Impact toughness	J/m^2
Elastic modulus	N/m^2 (Pa)
Compressive strength	N/m^2 (Pa)
Tensile strength	N/m^2 (Pa)
Ductility	% elongation at failure
Strength-to-weight ratio	— (ratio)

Heat treatment of steels B2.3 — changes grain size & crystal structure

Process	What is done	Effect
Quench hardening	Heat then cool rapidly (in water/oil)	Forms hard, brittle martensite
Tempering	Reheat a hardened part to a lower temperature	Reduces brittleness, restores toughness
Annealing	Heat then cool very slowly (in the furnace)	Softens, relieves stress, maximum ductility
Normalising	Heat then cool in still air	Refines grain, uniform structure, improved toughness
Case hardening	Add carbon to the surface of low-carbon steel, then harden	Hard wear-resistant case, tough core

EXAM TIP Crystal structures to name: **ferrite** (soft), **cementite** (hard, brittle), **austenite** (high-temperature) and **martensite** (very hard, from fast cooling). "Hard but brittle" = quenched; "soft and ductile" = annealed.

UNIT 2 · B3

Manufacturing process database

For each: how it works, suitable materials, pros, cons and examples. Grouped by family.

Machining (cutting away material)

Process	Summary	Materials	Advantages	Disadvantages	Examples
Turning (lathe / CNC)	Workpiece rotates; tool removes material to make round parts (facing, parting, parallel turning)	Metals, some polymers	High accuracy; good finish; CNC = repeatable	Round parts only; waste swarf	Shafts, bolts, pins
Milling (vertical / CNC)	Rotating cutter removes material from a fixed workpiece (faces, slots, shoulders)	Metals, polymers	Complex 2D/3D shapes; CNC accuracy	Slower; tooling cost	Brackets, moulds, housings
Drilling	Rotating drill bit produces round holes	Most materials	Fast, cheap, simple	Round holes only; limited accuracy	Fixing holes, pilot holes
Surface grinding	Abrasive wheel finishes/ flattens hardened surfaces	Hardened steels	Very fine finish & flatness	Slow; small material removal	Gauge blocks, dies
CNC machining	Computer-controlled turning/milling from a CAD model	Metals, polymers	Repeatable, accurate, complex, automated	High set-up/ programming cost	Prototypes, batch parts

Forming, casting & moulding (shaping material)

Process	Summary	Materials	Advantages	Disadvantages	Examples
Press work	Punch & die pierce/blank sheet metal	Sheet metals	Very fast; cheap per part at volume	High tooling cost	Washers, brackets, panels
Drop forging	Heated metal hammered into a closed die	Steels, alloys	Strong grain flow; tough parts	Tooling cost; finishing needed	Spanners, con-rods
Sand casting	Molten metal poured into a sand mould	Cast iron, alloys	Cheap tooling; large/complex parts	Rough finish; porosity	Machine bases, manifolds
Die casting	Molten metal forced into a metal die	Zinc, Al alloys	Fine detail; fast; good finish	Expensive dies; low-melt metals only	Toys, housings, fittings
Investment casting	Wax pattern coated in ceramic, melted out, filled with metal	Titanium, steels	Very accurate; intricate; fine finish	Slow; costly per part	Turbine blades, implants
Injection moulding	Molten thermoplastic injected into a mould under pressure	Thermoplastics	Very fast; complex; low unit cost at volume	Very high tooling cost	Casings, bottle caps, toys
Compression moulding	Thermoset charge squeezed & cured in a heated mould	Thermosets	Strong, heat-resistant parts	Slower cycle than injection	Electrical fittings, handles
Vacuum forming	Heated thermoplastic sheet drawn over a mould by vacuum	Thermoplastic sheet	Cheap tooling; good for large thin shells	One side only; thinning at corners	Trays, packaging, signage
Extrusion	Material forced through a die to make a continuous profile	Al, thermoplastics	Constant cross-section; continuous; efficient	Constant section only	Window frames, pipes, rails
Wet lay-up / RTM		GFRP / CFRP	Strong, light, complex shells	Labour-intensive; curing time	Boat hulls, body panels

	Fibre reinforcement wetted with resin (RTM = resin injected)				

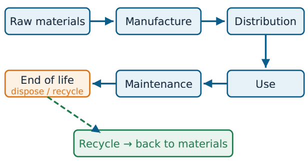
Cutting & additive manufacturing

Process	Summary	Materials	Advantages	Disadvantages	Examples
Laser cutting	Focused laser melts/ vaporises material (CO_2 for plastics, fibre for metals)	Sheet metal, acrylic	Fast, accurate, intricate; no tooling	Edge scorching; thickness limits	Panels, signage, brackets
Water jet	High-pressure water (+ abrasive) cuts plate	Metals, stone, glass	No heat-affected zone; thick material	Slower; wet	Thick plate, heat-sensitive parts
Shearing / sawing	Blade or guillotine cuts sheet/bar	Sheet/bar metal	Fast, cheap, simple	Straight cuts; limited accuracy	Stock cutting
EDM (spark erosion)	Electrical sparks erode very hard metals (wire / die-sink / hole)	Hardened metals	Cuts any conductive hardness; intricate	Slow; conductive materials only	Press dies, mould cavities
Additive (3D printing)	Builds parts layer-by-layer: FDM (PLA filament), DMLS/ MFFF (metal)	Polymers, metal powder	Complex geometry; no tooling; rapid prototyping	Slow for volume; finish/strength limits	Prototypes, jigs, lightweight parts

EXAM TIP "Compare/evaluate" questions reward linking choice to **quantity** (one-off vs mass), **material**, **accuracy/ finish** and **cost** (high tooling cost only pays off at high volume). Always justify with the context given.

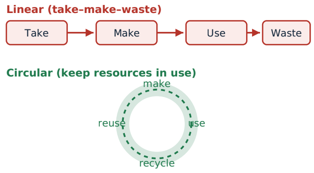
UNIT 2 & 3 Sustainability quick reference

Product life cycle



Cradle-to-grave, with recycling closing the loop

Circular vs linear economy



Circular economy keeps materials cycling, not wasted

The 6 Rs of sustainable design

1 · Rethink

Could the need be met a smarter way? Challenge the whole design.

2 · Refuse

Avoid harmful or unnecessary materials, parts and processes.

3 · Reduce

Use less material, energy and waste; design lighter and simpler.

4 · Reuse

Design parts/products to be used again for the same or new purpose.

5 · Repair

Make products easy to fix and maintain to extend their life.

6 · Recycle

Choose materials that can be reprocessed; mark them for sorting.

SPEC LINK The Unit 3 Product Design Specification asks specifically for the sustainability factors **refuse, reduce, reuse, repurpose, recycle**. Use those five terms in your PDS; the 6Rs above are the wider framework for justifying design decisions.

Sustainable design checklist

- ☐ Minimise material use and waste (efficient nesting, near-net shape)
- ☐ Choose recycled / recyclable / renewable materials
- ☐ Reduce energy used in manufacture and in use
- ☐ Design for disassembly (avoid mixed bonded materials)
- ☐ Extend life through durability and repairability
- ☐ Reduce transport impact (local sourcing, packaging)
- ☐ Avoid toxic substances and pollution
- ☐ Consider whole life cycle, not just manufacture

04

Unit 3
Engineering Design

Your design companion for the Pearson-Set Assignment: how to build a watertight PDS, sketch your ideas, develop them in CAD, and review like a professional.

- Product Design Specification (PDS) guide
- PDS checklist & prompts
- Sketching guide (iso / oblique / ortho)
- Design development toolkit
- Evaluation & selection matrices
- Design review checklist
- CAD reference (software-neutral)
- Reflection frameworks

UNIT 3 · A1

Product Design Specification (PDS) guide

The PDS turns a brief into measurable requirements. Cover every heading below — write each point so it can be **tested** (a number or a clear pass/fail), not just described.

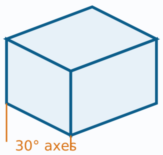
PDS heading	Prompt — ask yourself…	Example (worded so it can be tested)
Function	What must the product *do*? Its primary & secondary purposes?	"Must hold a 0.5 L bottle upright and release it one-handed."
User requirements	Who uses it? What do they need/expect? Skill level?	"Usable by adults aged 18–70 with no tools."
Form — aesthetics	Look, finish, colour, style, brand fit?	"Matte black; smooth edges; modern minimal style."
Form — dimensions	Size limits, weight limit, ergonomics/ anthropometrics?	"≤ 200 × 100 × 80 mm; < 300 g; grip ø 30–40 mm."
Materials	What properties are needed? Sustainable options?	"Impact-resistant, food-safe polymer (e.g. ABS or PP)."
Manufacture	Likely process? Quantity / batch size?	"Injection moulded for a batch of 5,000 units."
Cost	Target unit cost? Material, components, labour, equipment?	"Manufacturing cost ≤ £3.50 per unit."
Quantity	One-off, batch or mass production?	"Initial batch 5,000; scalable to mass production."
Safety	Hazards to design out? Standards to meet?	"No sharp edges; stable; meets relevant BS/EN safety standards."
Maintenance	Cleaning, servicing, replaceable parts?	"Dishwasher safe; no user-serviceable parts."
Reliability	Expected life, duty cycle, durability?	"≥ 10,000 use cycles without failure."
Interactions	How does it fit with other parts/areas?	"Compatible with standard 25 mm shelf brackets."
Legal	Intellectual property, health & safety, environmental law?	"Original design (no IP breach); RoHS compliant."
Sustainability	Refuse, reduce, reuse, repurpose, recycle?	"Single recyclable polymer; minimal packaging."

MARK-BOOSTER Distinction PDS points are **specific, measurable and justified** with research. Replace "must be strong" with "must withstand a 200 N load without permanent deformation, because…".

Sketching guide

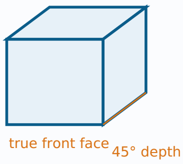
Communicate ideas fast and clearly. Use the right projection for the job; sketch in good proportion and annotate with technical language.

Isometric



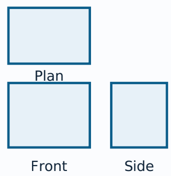
3D pictorial. Vertical edges stay vertical; the other two axes at **30°**. Edges drawn to scale — good for showing a whole product.

Oblique



True-shape front face drawn flat; depth lines back at **45°** (often half-scale). Quick for circular front features.

Orthographic



2D engineering views: **front, plan, side**, aligned. The dimensioned drawing used to manufacture (1st or 3rd angle).

1st angle vs 3rd angle projection

1st angle (UK/EU). Views project *through* the object — side view drawn on the far side.

3rd angle (US). Views project to the near side — side view drawn on the same side as you look.

ALWAYS state the projection used with the standard symbol and work to **BS 8888**.

Detail & assembly drawings

- **Detail drawing:** one part, fully dimensioned with tolerances, material and finish — enough to manufacture it.
- **Assembly drawing:** shows how parts fit together (general arrangement) with a **parts list / BOM** and balloon item numbers.
- **Sectional view:** a "cut-through" to reveal internal features; cut faces are hatched.

Common line types

Continuous thick	Visible edges
Dashed	Hidden edges
Chain (centre line)	Centres & axes of symmetry

EXAM/COURSEWORK TIP Use isometric/oblique to **present ideas**; use orthographic to **manufacture**. Annotate every sketch with sizes, materials and notes — unannotated sketches lose marks.

UNIT 3 · B1 Design development toolkit

Evaluation / decision matrix to choose between ideas objectively

Score each idea against weighted PDS criteria. Score (1–5) × weight; highest weighted total wins. Replace the criteria with your own PDS points.

Criterion (from PDS)	Weight	Idea A score	A × wt	Idea B score	B × wt	Idea C score	C × wt
Function / fit for purpose	5	4	20	3	15	5	25
Cost to manufacture	4	3	12	5	20	2	8
Ease of manufacture	3	4	12	4	12	3	9
Aesthetics	2	3	6	3	6	5	10
Sustainability	3	4	12	3	9	4	12
Weighted total	—	—	**62**	—	**62**	—	**64 ★**

A decision matrix makes your "review/assess/evaluate" judgement defensible — cite the scores when justifying your chosen idea.

Design review checklist

- ☐ Does each idea meet the most important PDS points?
- ☐ Have I gathered & recorded peer/client feedback?
- ☐ Are sizes, materials & processes feasible?
- ☐ Have I checked against safety & legal requirements?
- ☐ Is the chosen idea justified with reasons/scores?
- ☐ Have I noted refinements to make next?
- ☐ Is sustainability addressed (6Rs)?

Materials selection matrix

Material	Strength	Cost	Workability	Sustain.	Total
ABS	3	4	5	3	15
Aluminium	4	2	3	4	13
Mild steel	5	3	3	3	14

Score 1–5 against the properties that matter for *your* product, then justify the winner.

Manufacturing process selection matrix

Process	Suits quantity	Tooling cost	Accuracy/ finish	Material fit	Best when…
CNC machining	1–1000	Low	High	Metals/ polymers	Low–mid volume, high accuracy
Injection moulding	10,000+	Very high	High	Thermoplastics	High volume justifies tooling
3D printing (FDM)	1–100	None	Medium	Polymers	Prototypes, complex one-offs
Sand casting	1–1000	Low	Low	Cast metals	Large, complex metal parts

KEY RULE The decision almost always comes down to **quantity vs tooling cost**. High tooling cost (moulding, die casting) only makes sense at high volume; low-volume work suits machining and additive.

UNIT 3 · B2-C1

CAD reference (software-neutral)

The workflow and vocabulary are common to all parametric CAD (Fusion, Inventor, SolidWorks, Onshape). Terms below match the specification.

THE PARAMETRIC WORKFLOW Set up document (units, planes) → **2D sketch** on a plane → **constrain & dimension** the sketch → turn it 3D with a **feature** → add more features → **assemble** components → generate **2D drawings**.

1 · Set up & sketch

- **Configure:** origin, units, snap & grid, planes (XY, XZ, YZ), file type.
- **Sketch commands:** line, arc, circle, centre line, construction line, fillet, dimension.
- **Display:** pan, zoom, orbit.
- **Edit:** erase, extend, trim, rotate, mirror.

2 · Constraints

- **Geometric:** horizontal, vertical, parallel, perpendicular, tangent, equal, coincident, concentric.
- **Dimensional:** length, radius, angle — the parameters that drive the model.
- A **fully constrained** (defined) sketch turns black and can't move accidentally — always aim for this.

3 · Features (2D → 3D)

- **Create:** extrude, revolve (about an axis).
- **Primitives:** cube, cylinder.
- **Modify:** hole, fillet (round edge), chamfer (angled edge), move face, shell, thread.
- **Boolean:** add (union), subtract (cut), intersect.
- **Pattern:** rectangular or circular copy.
- **Analysis:** mass, volume, surface area, stress.

4 · Assemblies

- Place components; control **6 degrees of freedom** (XYZ translation + XYZ rotation).
- **Assembly constraints:** mate, angle, insert, tangent.
- Constraints remove freedom until parts locate correctly.
- Check for clashes / interference.

5 · 2D detailed drawings (to BS 8888)

- Generate orthographic views from the 3D model; add a **sectional view** where needed.
- Set **drawing template, title block, scale, units, precision**.
- Use **layers** (create, switch on/off, freeze, lock) to separate views, dimensions & hatching.
- Add dimensions & dimension styles; line types (centre, dashed, offset).
- Coordinates: absolute, relative, polar.
- Assembly drawing = general arrangement + **parts list / BOM**.

Reviewing & reflecting on the design (Learning aim D)

Review the design solution (D1)

- Compare the final solution against each PDS element.
- Identify stages where requirements were met.
- Identify what could be improved — suggest **feasible** changes and explain the benefit.

Reflect on your performance (D2)

- Strengths, new skills, areas to improve.
- How well you stayed on task and worked independently.
- Use a reflection framework — see **Section 5** (ERA, Driscoll, SWOT/SOAR).

GRADE LADDER Pass = **describe** decisions · Merit = **explain** them · Distinction = **justify** them. For the review: Pass **explains**, Merit **assesses**, Distinction **evaluates**. Match your verbs to the grade you're aiming for.

05

Unit 4
Engineering Project

A project-management toolkit: ready-to-use templates for running an engineering project from idea to tested solution, the way professionals do.

- Project life cycle
- Idea generation tools
- Feasibility study template
- Risk & issue assessment
- Gantt chart & critical path
- Technical specification template
- Testing plan & data analysis
- Reflection frameworks

UNIT 4 · A1

Project life cycle

1 Initiation → **2 Planning** & design → **3 Implementation** → **4 Evaluation**

- **1 Initiation**: problem, research, ideas, feasibility
- **2 Planning & design**: resources, time, Gantt, design
- **3 Implementation**: build, monitor, manage risk
- **4 Evaluation**: review outcome vs requirements

Idea generation & creativity tools A2

Techniques to generate ideas

- Reword the problem; challenge assumptions; think in reverse.
- Mind mapping & diagrams.
- Group discussion & brainstorming.
- Edward de Bono's **Six Thinking Hats**.

De Bono's Six Hats

White	Facts & data	Red	Feelings, intuition
Black	Caution, risks	Yellow	Benefits, optimism
Green	Creativity, ideas	Blue	Process, control

Feasibility study template A3 — compare possible solutions, then pick one

Criterion	Question to answer	Solution 1	Solution 2	Solution 3
Size & complexity	How big/complex is the problem to solve?	—	—	—
Benefit / performance	How well does it solve the problem?	—	—	—
Cost & time	Within available budget & time?	—	—	—
Expertise	Do we have the skills needed?	—	—	—
Risk	Unknowns, unproven tech, equipment?	—	—	—
Sustainability	Environmental impact, waste, materials?	—	—	—
Legal	Data protection, H&S, other legislation?	—	—	—
Decision	**Score each, then select & justify**	**—**	**—**	★

Selection methods: objective testing, cost-benefit/design analysis, and comparison (frequency tables, charts, fitness-for-purpose, process capability).

Planning, monitoring & risk

Risk & issue assessment severity = probability × impact

Risk matrix

	Minor	Moderate	Major
Very likely	Med	High	Extreme
Likely	Low	Med	High
Unlikely	Low	Low	Med

Manage all **medium, high & extreme** risks. Reassess throughout the project.

Mitigation strategies

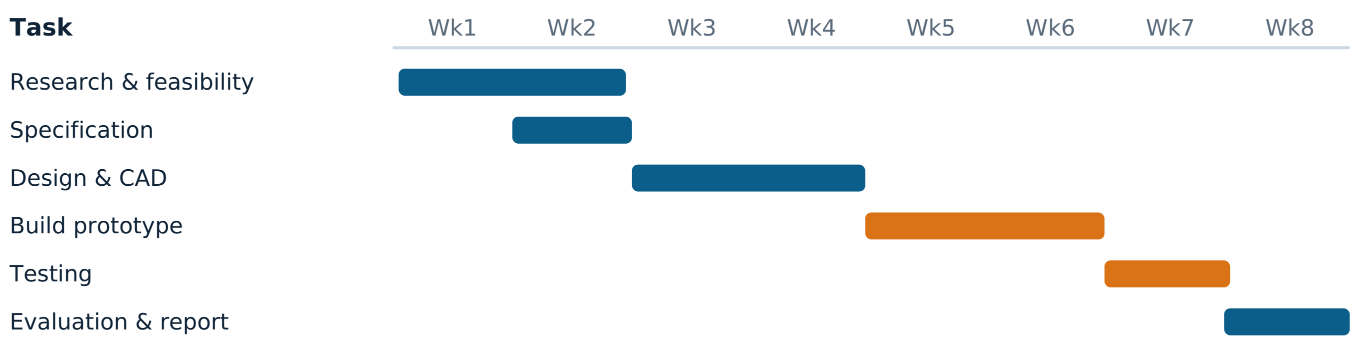
Strategy	Meaning
Prevention	Eliminate the threat entirely
Reduction	Cut the likelihood or the impact
Acceptance	Do nothing (low severity)
Transference	Pass the risk to a third party

A **risk** adversely affects the project; an **issue** is a future event that could affect it positively or negatively.

Risk log template

Risk / issue	Probability	Impact	Severity	Mitigation	Owner
3D printer breakdown delays build	Likely	Major	High	Book slot early; have a backup workshop process (reduction)	Me
Material delivery late	Unlikely	Moderate	Low	Order early; keep contingency stock (prevention)	Me
…					

Time planning — Gantt chart & critical path



■ Critical path tasks (a delay here delays the whole project)

Plan & monitor

- Resource & time planning; set priorities.
- **Critical path** = the sequence that sets the minimum project length.
- Build in **contingency** (spare time/budget).
- Monitor vs plan: milestones, logbook, peer/teacher review.

Project constraints

- Time · budget · scope
- Sustainability · ethics · legality

PURPOSE OF RISK MANAGEMENT Avoid "crisis management"; improve the probability of success.

UNIT 4 · B3-C

Specification, testing & reflection

Technical specification template B3 — the measurable definition of your chosen solution

Heading	What to state (with a value/standard where possible)
Function & features	What it does and its key features
Interfaces	Physical, electrical/electronic, software and human interfaces
Materials & tolerances	Chosen materials; dimensional tolerances
Standards	Relevant BS / ISO standards to meet
Performance & capacity	Operating conditions, capacity now & future, process capability
Reliability & maintenance	Expected life, servicing needs
Environment & sustainability	Environmental conditions, sustainability considerations
Security / safety	Safety requirements & relevant H&S legislation

Testing plan template

Test #	What is tested (spec requirement)	Method	Test data (normal / extreme / erroneous)	Expected result	Actual / pass-fail
1	Holds 200 N without permanent deformation	Load test (destructive)	0 N, 200 N, 400 N	No deformation at 200 N	—
2	Fits standard 25 mm bracket	Inspection / measurement (non-destructive)	24.8, 25.0, 25.2 mm	Slides on without force	—
3	…	…	…	…	—

Testing & data types

- **Destructive** vs **non-destructive** tests; inspection & measurement.
- Data: discrete / continuous, grouped / ungrouped.
- Analyse with mean, mode, median.
- Present with line/bar charts, scatter, pie, histogram, distribution curve.

Troubleshooting methods

- **Expected behaviour** — compare actual vs intended.
- **Half-split** — test the middle to halve the search.
- **Cause & effect** (fishbone) diagram.
- **5 Whys** — ask "why?" until the root cause appears.

Reflection frameworks use for Unit 3 (D2) & Unit 4 review

ERA Cycle

- **Experience** — what happened?
- **Reflection** — how did it go & why?
- **Action** — what will I do next time?

Driscoll's "What?" model

- **What?** — describe the event.
- **So what?** — what does it mean / what did I learn?
- **Now what?** — how do I improve?

SWOT / SOAR

- **SWOT:** Strengths, Weaknesses, Opportunities, Threats.
- **SOAR:** Strengths, Opportunities, Aspirations, Results.

Project portfolio checklist (C3)

☐ Thematic title / initial idea

☐ Research & problem clarification

- ☐ Possible solutions & constraints
- ☐ Specification of alternative solutions
- ☐ Feasibility study
- ☐ Technical specification
- ☐ Plans + risk & issues log
- ☐ Logbook of events
- ☐ Design documents (sketches, drawings, flow charts)
- ☐ Artefact / prototype / circuit / program
- ☐ Test documentation & analysis
- ☐ Peer reviews & tutor monitoring
- ☐ Conclusions on success vs the theme

GRADE LADDER Aim A: Pass **explains** · Merit **assesses** · Distinction **evaluates & justifies**. Behaviours (staying on task, resilience, responding to feedback) are assessed in aim C — record evidence of them in your logbook.

06

Exam Success

The two things that turn knowledge into marks: knowing exactly what each command word demands, and structuring high-mark answers the way examiners reward.

- Command words decoded
- What each word demands
- How to answer "explain"
- How to answer "analyse"
- How to answer "evaluate"
- Worked answer examples

SECTION 6

Command words decoded

The command word tells you the **depth** of answer and how many marks are on offer. Read it first, then shape your answer to match.

Command	What you must do	Engineering example
State / Give / Name	Give a brief point of information — no explanation.	"State the SI unit of pressure." → *Pascal (Pa)*.
Identify	Select the correct response from given information.	"Identify the unit of energy loss." → *Joule (J)*.
Define	State the meaning of a term as objective fact.	"Define tensile strength." → *the max tensile stress a material withstands before failure.*
Calculate	Work out a value using data + the right method. Show working & units.	"Calculate the stress…" → $\sigma = F/A = \ldots = 191$ *MPa.*
Describe	Give a clear account of all the features of a process/subject.	"Describe injection moulding." → *melt* → *inject* → *cool* → *eject…*
Explain	Make a point **and give a justification/reason** (point + because…).	"Explain why aluminium is used for aircraft." → *point + reason.*
Analyse	Break down into parts; examine how factors relate & affect each other.	"Analyse the impact of IoT on maintenance." → *factor* → *effect* → *consequence.*
Discuss	Consider different aspects of an issue and how they interrelate.	"Discuss the use of CFRP in cars." → *pros, cons, trade-offs.*
Evaluate	Weigh strengths vs weaknesses, then reach a **justified judgement**.	"Evaluate sand casting vs die casting for 50,000 parts." → *compare* → *conclude.*
Draw / Sketch / Plot / Label	Produce/annotate a diagram or graph (sketch = no scale needed).	"Sketch a free-body diagram…" → *forces with arrows & labels.*
Prove / Determine / Find	Show the working that arrives at a value or fact.	"Determine the reaction at A…" → *take moments, solve.*

MARK GUIDE Roughly: 1 mark = one point (state/identify) · 2 marks = point + reason (explain) · 4+ marks = developed analysis or evaluation with a judgement. Match the number of developed points to the marks available.

SECTION 6 High-mark answer structures

Answering "Explain" questions — Point + Reason

Structure: **`make a point`**, then **`justify it`** with "because… which means…". One developed point per mark.

EXAMPLE — "EXPLAIN WHY ALUMINIUM ALLOY IS CHOSEN FOR AIRCRAFT PANELS (2 MARKS)"
Point: Aluminium alloy has a high strength-to-weight ratio. **Reason:** this means panels are strong enough to carry loads while keeping the aircraft light, which reduces fuel use. ✓ 2 marks

Answering "Analyse" questions — Factor → Effect → Consequence

Break the topic into factors. For each: state it, explain its effect, then follow the chain of consequences. Show how factors **`interrelate`**.

EXAMPLE — "ANALYSE THE IMPACT OF USING A DIGITAL TWIN ON THE MAINTENANCE FUNCTION"
Factor: a digital twin gives real-time data on component condition. **Effect:** this enables predictive (not just reactive) maintenance. **Consequence:** parts are replaced just before failure, so unplanned downtime falls and reliability rises — but it requires sensors, data infrastructure and staff training, raising initial cost.

Answering "Evaluate" questions — For / Against → Judgement

Give strengths **`and`** weaknesses (advantages vs disadvantages), weigh them against the **`context`**, then reach a clear, justified conclusion. The judgement is essential — sitting on the fence loses the top marks.

EXAMPLE — "EVALUATE SAND CASTING VS DIE CASTING TO MAKE 50,000 ALUMINIUM HOUSINGS"
For die casting: excellent finish & accuracy, very fast cycle, low unit cost at volume. **Against:** very high die cost. **For sand casting:** cheap tooling, but rough finish & slow. **Judgement:** for 50,000 parts the high die cost is spread thinly and the fast cycle dominates, so **die casting is the better choice** — the volume justifies the tooling investment.

DO

- Read the command word first.
- Use the context/data given in the question.
- Use correct technical terms.
- For calculations: formula → substitution → unit.
- Always reach a judgement on "evaluate".

DON'T

- Just "describe" when asked to "explain/evaluate".
- List advantages with no conclusion.
- Give one-word answers to multi-mark questions.
- Forget units, or leave the calculator in the wrong mode.
- Write more than the marks justify.

FINAL WORD Knowledge wins marks only when it answers the question asked. Decode the command word, match your structure and depth to the marks, and always show your reasoning. Good luck.