2023/74127

Government of **Western Australia**
School Curriculum and Standards Authority

ENGINEERING STUDIES

ATAR course examination 2023

Marking key

Marking keys are an explicit statement about what the examining panel expect of candidates when they respond to particular examination items. They help ensure a consistent interpretation of the criteria that guide the awarding of marks.

Section One: Core content **40% (80 Marks)**

Part A: Multiple-choice **10% (10 Marks)**

Question	Answer
1	b
2	c
3	d
4	c
5	a
6	b
7	d
8	b
9	a
10	d

Part B: Extended response **30% (70 Marks)**

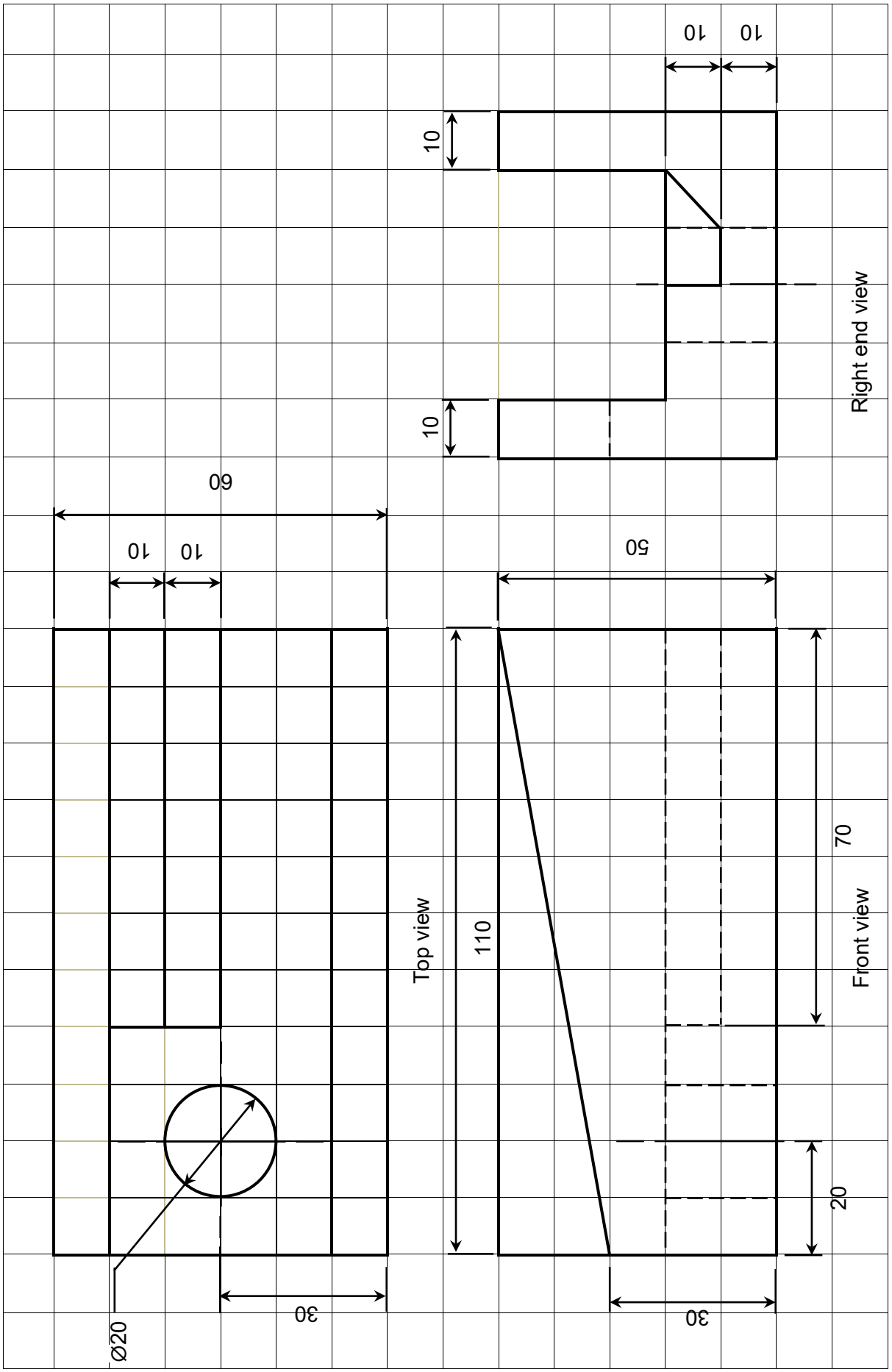
Question 11 **(24 marks)**

(a) Use the grid on page 7 to draw a fully dimensioned top, front and right end view of the machined block. Each square of the grid represents 10 mm × 10 mm. The drawing is full size and must follow 3rd angle orthographic conventions. Each view must be labelled.

To fit the drawing on the grid the page must be turned to a landscape orientation, i.e. sideways. The circle that is printed on the grid is the diameter 20 mm hole as seen in the top view. (11 marks)

Description	Marks
Locates and labels all three views correctly	1
Outlines for top view correct	1
Outlines for front view correct	1
Hidden details for front view correct	1
Outlines for right end view correct	1
Hidden details for right end view correct	1
All centre lines correct	1
Hole correctly dimensioned	1
Location of centre of hole can be determined	1
Sufficient dimensions to determine overall size of machined block	1
Sufficient dimensions to determine size of chamfered groove	1
Total	**11**

Question 11 (continued)



(b) Calculate the volume of metal in the machined block. Answer in units of mm^3. (5 marks)

Description		Marks
Base (excluding sides) =	(20 × 110 × 40) = 88 000	1
Sides =	2(50 × 110 × 10) – 0.5(20 × 110 × 10)	1
=	110 000 – 11 000	
=	99 000	
Hole =	$\pi r^2 h = \pi \times 10^2 \times 20 = 6283$	1
Groove =	(10 × 70 × 20) – 0.5(10 × 70 × 10)	1
=	14 000 – 3500	
=	10 500	
Total volume =	88 000 + 99 000 – 6283 – 10 500	1
=	170 217 mm^3	
	Total	**5**
Accept other valid methods of calculation and allow for minor rounding.		

(c) The machined block is made from aluminium. Calculate the mass of the machined block in units of kg. If you could not calculate an answer for part (b), use 165 000 mm^3. (3 marks)

Description		Marks
Density (ρ) of aluminium =	2710 kg m^{-3}	1
170 217 mm^3 =	0.000 170 217 m^3	1
m =	$\rho \times V$	1
=	2710 × 0.000 170 217	
=	0.461 kg	
	Total	**3**
Note: if used 165 000 mm^3 then mass will be 0.447 kg.		

(d) Calculate the total area of the surfaces that are directly seen only in the top view of the machined block. Answer in units of mm^2. (5 marks)

Description		Marks
Horizontal surfaces excluding hole and both sloping surfaces =	(110 × 50) – (10 × 70) = 5500 – 700 = 4800	1
Hole =	$\pi r^2 = \pi \times 10^2 = 314$	1
Sloping surface (groove) =	$70 \times \sqrt{10^2 + 10^2}$	1
=	$70 \times \sqrt{200}$	
=	70 × 14.142 = 990	
Sloping surface (rib) =	$10 \times \sqrt{20^2 + 110^2}$	1
=	$10 \times \sqrt{12\,500}$	
=	10 × 111.8 = 1118	
Total area =	4800 – 314 + 990 + 1118	1
=	6594 mm^2	
	Total	**5**
Accept other valid methods of calculation.		

Question 12 **(24 marks)**

(a) Name **one** of the properties that stainless steel must possess if the pot is to be formed in the manner described above. Define the property and explain why it is essential for this method of manufacture. (4 marks)

Description	Marks
ductility	1
the ability of a material to be plastically deformed by predominately tensile forces	1
the material of the blank must stretch around the punch as it is forced into the die. It must do so and retain its new shape without rupturing	1–2
Total	**4**
Accept other relevant answers.	

Alternate answer

Description	Marks
toughness	1
the ability of a material to absorb energy without rupture or failure	1
it is essential that the material does not fracture when absorbing the energy transferred by the press to the blank, while the blank is pressed into the form of the pot	1–2
Total	**4**

(b) Considering how and where a saucepan is used, name **three** properties that make stainless steel a good choice of material for the pot of a saucepan. Define each property and provide a justification for its inclusion. (12 marks)

Description	Marks
One	
corrosion resistant	1
ability of a material to resist degradation due to chemical or electrochemical reactions	1
the liquids in the pot (including when washed) create conditions where corrosion can occur. If holes appear in the pot, then it will leak and this will render the saucepan unusable	1–2
Subtotal	**4**
Two	
toughness	1
the ability of a material to absorb energy without fracture or failure when undergoing plastic deformation	1
the pot is likely to be knocked or even accidentally dropped. If this occurs, although the pot may suffer a dent, it must not shatter as this would spill hot liquids and/or sharp broken pieces could present a safety hazard	1–2
Subtotal	**4**
Three	
stiffness (rigidity)	1
ability of a material to resist deformation when under load	1
the pot must retain its shape when filled with liquid. Otherwise, it cannot be handled in a controlled and safe manner and its contents will spill out and create a mess and/or (if hot) present a safety hazard	1–2
Subtotal	**4**
Total	**12**
Accept other relevant answers.	

Alternate answer

high melting point	1
the temperature at which a material will change from a solid into a liquid	1
the gas flame is very hot. If the pot softens and melts, then the liquids will not be contained and this, plus the melted pot, will become a scalding/burns hazard	1–2
Subtotal	**4**

Question 12 (continued)

(c) The handle of the saucepan is often made from stainless steel or a polymer, but the base is clad with copper or aluminium. Outline a reason for using these choices of material for the handle and the base of the pot. (4 marks)

Description	Marks
Stainless steel or polymer handle	
for a metal, stainless steel is a relatively poor conductor of heat and polymers are very poor	1
therefore heat transferred to the handle will not be at a dangerously high level, making it safe to hold when cooking	1
Subtotal	**2**
Copper or aluminium clad base	
both copper and aluminium are excellent conductors of heat	1
and therefore heat from the gas burner will be transferred to the contents of the pot in an efficient manner	1
Subtotal	**2**
Total	**4**
Accept other relevant answers.	

(d) Stainless steel, copper and aluminium are all forms of metal. List **four** characteristics that identify a material as being a typical metal. (4 marks)

Description	Marks
Any four of	
• shiny when cut • good conductor of heat • good conductor of electricity • ductile • malleable • usually a solid at room temperature	1–4
Total	**4**
Accept other relevant answers.	

Question 13 **(22 marks)**

(a) List and describe **two** challenges associated with implementing and operating a wave energy converter located in deep water. (6 marks)

Description	Marks
Challenge one	
much of the equipment is installed underwater	1
this will make it difficult, and probably dangerous, to construct or maintain (need to use divers)	1–2
Subtotal	**3**
Challenge two	
equipment operates in a corrosive environment, i.e. sea water and salty spray	1
this will degrade parts that are not made of highly corrosion resistant materials and will lead to failure of the wave energy converter or, as a minimum, require a high level of inspection and maintenance	1–2
Subtotal	**3**
Total	**6**
Accept other relevant answers.	

Alternate answers

operating conditions vary widely from calm waters to stormy seas	1
equipment will need to be able to withstand these conditions. This requires the wave energy converter to be constructed using a very robust design that will, for most of the time, be 'over engineered'	1–2
Subtotal	**3**

transportation	1
the distances from the shore to the wave energy converter and from the electricity it generates to the population centres are very large, and developing methods of transportation may be challenging	1–2
Subtotal	**3**

(b) Calculate α for a wave height of 4 m. Answer using units of kilojoules per square metre (kJ m^{-2}). (4 marks)

Description	Marks
$\alpha = \frac{\rho g H^2}{8}$ $= \frac{1022 \times 9.8 \times 4^2}{8} = \frac{160\ 249.6}{8}$	1–2
$= 20\ 031.2$ J m^{-2}	1
$= 20.031$ kJ m^{-2}	1
Total	**4**

Question 13 (continued)

(c) Calculate the sea surface area of the wave from part (b) required to supply sufficient energy to operate a 2 kW heater for 2 hours. Assume an energy conversion efficiency of 86%. Answer using units of square metres (m^2). If you could not calculate an answer for part (b), use 20 kJ m^{-2}. (3 marks)

Description	Marks
Energy used by heater = $2000 \times 2 \times 60 \times 60 \div 0.86$ = 16 744 186 J alternatively 16 744 kJ	1
Sea surface area = $\frac{16\ 744\ 186}{20\ 031.2}$ alternatively $\frac{16\ 744}{20.0312}$	1
= 835.9 m^2	1
Total	**3**
Note: if used 20 000 J m^{-2} then sea surface area = 837.2 m^2.	

(d) Calculate the power of a wave of height 4 m and wave period 8 seconds assuming that the crest width is 7 m. Answer in units of kilowatts (kW). (5 marks)

Description	Marks
$P = \frac{\rho g^2 H^2 T(7)}{32\pi}$ $= \frac{(1022)(9.8^2)(4^2)(8)(7)}{32\pi}$ $= \frac{87\ 944\ 980}{32\pi}$	1–3
= 874 805 W	1
= 874.8 kW	1
Total	**5**

(e) For a wave energy converter (WEC), select any **two** of the seven LCA stages, and for each selected stage formulate a specific, well-reasoned question that would require answering by the manufacturer of the WEC to inform the public that impacts will be minimised. The two questions must each have a different theme, i.e. do **not** repeat the same (or very similar) question. (4 marks)

Description	Marks
One	
Materials acquisition	
is it possible to reduce the depletion of the source of materials and/or disruption to the environment	1
by using reclaimed/recycled materials instead of acquiring new raw materials to build the WEC?	1
Subtotal	**2**
Two	
Processing materials	
is it possible to reduce pollution of the environment when converting the raw materials into useable forms	1
by using techniques that trap or filter harmful by-products?	1
Subtotal	**2**
Total	**4**
Accept other relevant answers.	
Note: each question must relate to the named stage and identify the impact that is to be investigated and provide a specific example to give the question context.	

Alternate answers may include

Manufacture	
is it possible to reduce the energy footprint	1
by using machines that are more efficient and require less movement or force to perform a task?	1
Subtotal	**2**

Packaging	
is it possible to eliminate the use of throw-away packaging used to protect the WEC	1
by using coverings that can be reused or repurposed?	1
Subtotal	**2**

Transport to location	
is it possible to reduce the energy footprint and/or air pollutants	1
by using modes of transport that are energy efficient with nil or very low pollution to deliver the WEC to its installation site?	1
Subtotal	**2**

Maintenance/operation	
is it feasible to decrease the energy and materials required to perform servicing and maintenance	1
by increasing the interval between each service without significantly affecting performance?	1
Subtotal	**2**

Reuse/recycle/dispose	
to reduce waste of material and energy required for dismantling	1
can the WEC be designed from materials that can be recycled and can the dismantling be done without using destructive means?	1
Subtotal	**2**

Section Two: Specialised field – Mechanical **60% (110 Marks)**

Part A: Multiple-choice **10% (10 Marks)**

Question	Answer
14	c
15	b
16	c
17	a
18	d
19	b
20	a
21	c
22	b
23	d

Part B: Extended answer **50% (100 Marks)**

Question 24 **(17 marks)**

(a) Calculate v, the velocity of the jumper when the rope is extended to its 'natural' length after they jump off the platform. (3 marks)

Description	Marks
$\Delta K_E = \Delta P_E$ $\frac{1}{2}mv^2 = mgh$ $\frac{1}{2} \times 80 \times v^2 = 80 \times 9.8 \times 30$ $v^2 = 2 \times 9.8 \times 30$ $= 588$	1
$v = \sqrt{588}$	1
$= 24.249$ m s^{-1}	1
Total	**3**
Accept other valid methods of calculation e.g. $v^2 = 2gh$.	

(b) If the mass of the jumper is increased to 100 kg, outline the effect on the velocity of the mass 30 m into the jump. (2 marks)

Description	Marks
increasing the mass does not affect the velocity	1
because mass is cancelled out in the formula	1
Total	**2**

(c) Calculate the elongation of the rope once an 80 kg jumper has come to rest. (5 marks)

Description	Marks
$\sigma = \frac{F}{A} = \frac{mg}{\pi r^2}$	
$= \frac{(80 \times 9.8)}{\pi 25^2} = \frac{784}{1963.49}$	1–2
$= 0.399$ N mm^{-2} (accept 0.4 N mm^{-2})	1
$\Delta L = \frac{\sigma L}{E} = \frac{(0.399 \times 30)}{3} = \frac{11.97}{3} = 3990$ mm	1
$= 3.99$ m	1
Alternative solution	
$F = mg = 80 \times 9.8 = 784$ N	1
$L = 30\,000$ mm	
$E = 3$ N mm^{-2}	
$A = \pi 25^2 = 1963.49$ mm^2	1
$\Delta L = \frac{FL}{EA} = \frac{(784 \times 30)}{(3 \times 1963.49)} = \frac{23\,520}{5890.47}$	1–2
$= 3.99$ m	1
Total	**5**

Question 24 (continued)

(d) If the mass of the jumper was increased from 80 kg to 100 kg, the elongation of the rope (once the jumper comes to rest) would increase. Explain why. (3 marks)

Description	Marks
elongation is proportional to the stress	1
stress = $\frac{\text{force}}{\text{area}}$ and force = mass × gravity	1
by increasing mass then the force must increase and so too must elongation	1
Total	**3**

(e) If we want to limit the deceleration acting on the jumper to 2.5 times gravity, calculate the minimum extension of the rope beyond its 'natural' length (30 m). If you did not get an answer for part (a) use 20 m s^{-1}. (4 marks)

Description	Marks
assume the rope extends a distance s beyond its 30 m length. At s, the velocity of the jumper is zero	
$v^2 = u^2 + 2as$	1
$0 = (24.25)^2 + 2(-2.5 \times 9.8)s$ $s = \frac{-24.249^2}{-49} = \frac{-588}{-49}$	1–2
$= 12$ m	1
Alternative solution if using 20 m s^{-1}	
assume the rope extends a distance s beyond its 30 m length. At s, the velocity of the jumper is zero	
$v^2 = u^2 + 2as$	1
$0 = (20)^2 + 2(-2.5 \times 9.8)s$ $s = \frac{-20^2}{-49} = \frac{-400}{-49}$	1–2
$= 8.163$ m	1
Total	**4**

Question 25 **(20 marks)**

(a) (i) State the correct values of Young's Modulus for each material. (3 marks)

Description	Marks
material A: 380 kN mm^{-2}	1
material B: 250 kN mm^{-2}	1
material C: 300 kN mm^{-2}	1
Total	**3**

(ii) Outline the reason for your answers in part (a)(i). (2 marks)

Description	Marks
a higher Young's Modulus is associated with a steeper slope of the stress strain curve (the slopes in the graph above are such the A > C > B)	1
that is, for a given stress, a higher Young's Modulus leads to less strain of the material	1
Total	**2**

(b) (i) Of the three materials, the brass sample was found to require the lowest maximum tensile force applied to it before it exceeded its yield stress. Explain why. (3 marks)

Description	Marks
the material with the lowest yield stress, will, for the same cross-sectional surface area, require the lowest application of a tensile force before it yields	1–2
brass has the lowest yield stress of the three materials (50 N mm^{-2})	1
Total	**3**

(ii) Calculate F, the value of the tensile force for the brass sample in newtons (N). (3 marks)

Description	Marks
$A = \pi r^2$ $= \pi(5)^2$ $= 78.54\ mm^2$	1
$F = \sigma \times A$ $= (50)(78.54)$	1
$= 3927\ N$	1
Total	**3**

Question 25 (continued)

(c) (i) The copper sample was observed to have the least elongation when placed under the tensile force calculated in part (b)(ii). Outline why. (2 marks)

Description	Marks
the material with the highest Young's Modulus will have the lowest elongation	1
copper has the highest Young's Modulus (112 kN mm^{-2}) of the three materials	1
Total	**2**

(ii) Calculate the elongation of the copper sample in units of mm. If you could not calculate an answer for part (b)(ii), use 4000 N. (3 marks)

Description	Marks
$E = \dfrac{FL}{A\Delta L}$ $\Delta L = \dfrac{FL}{AE} = \dfrac{(3927)(1000)}{(78.54)(112000)} = \dfrac{3\ 927\ 000}{8\ 796\ 480}$	1–2
$= 0.446$ mm	1
Alternative solution	
$\varepsilon = \dfrac{\Delta L}{L} = \dfrac{\sigma}{E}$ $\Delta L = \dfrac{\sigma L}{E} = \dfrac{(50)(1000)}{112\ 000}$	1–2
$= 0.446$ mm	1
Total	**3**
Note: if using 4000 N then $\Delta L = 0.455$ mm.	

(d) Calculate FS, the Factor of Safety for the aluminium sample when subjected to the force calculated in part (b)(ii). If you could not calculate an answer for part (b)(ii), use 4000 N. (4 marks)

Description	Marks
Ultimate tensile strength for aluminium = 150	1
$FS = \dfrac{\sigma_{UTS}}{\sigma_{WORKING}}$ $= \dfrac{150}{\left(\dfrac{3927}{78.54}\right)} = \dfrac{150}{50}$	1–2
$= 3$	1
Total	**4**
Note: if using $F = 4000$ N then $FS = \dfrac{150}{\left(\dfrac{4000}{78.54}\right)} = \dfrac{150}{50.93} = 2.945$.	

Question 26 **(12 marks)**

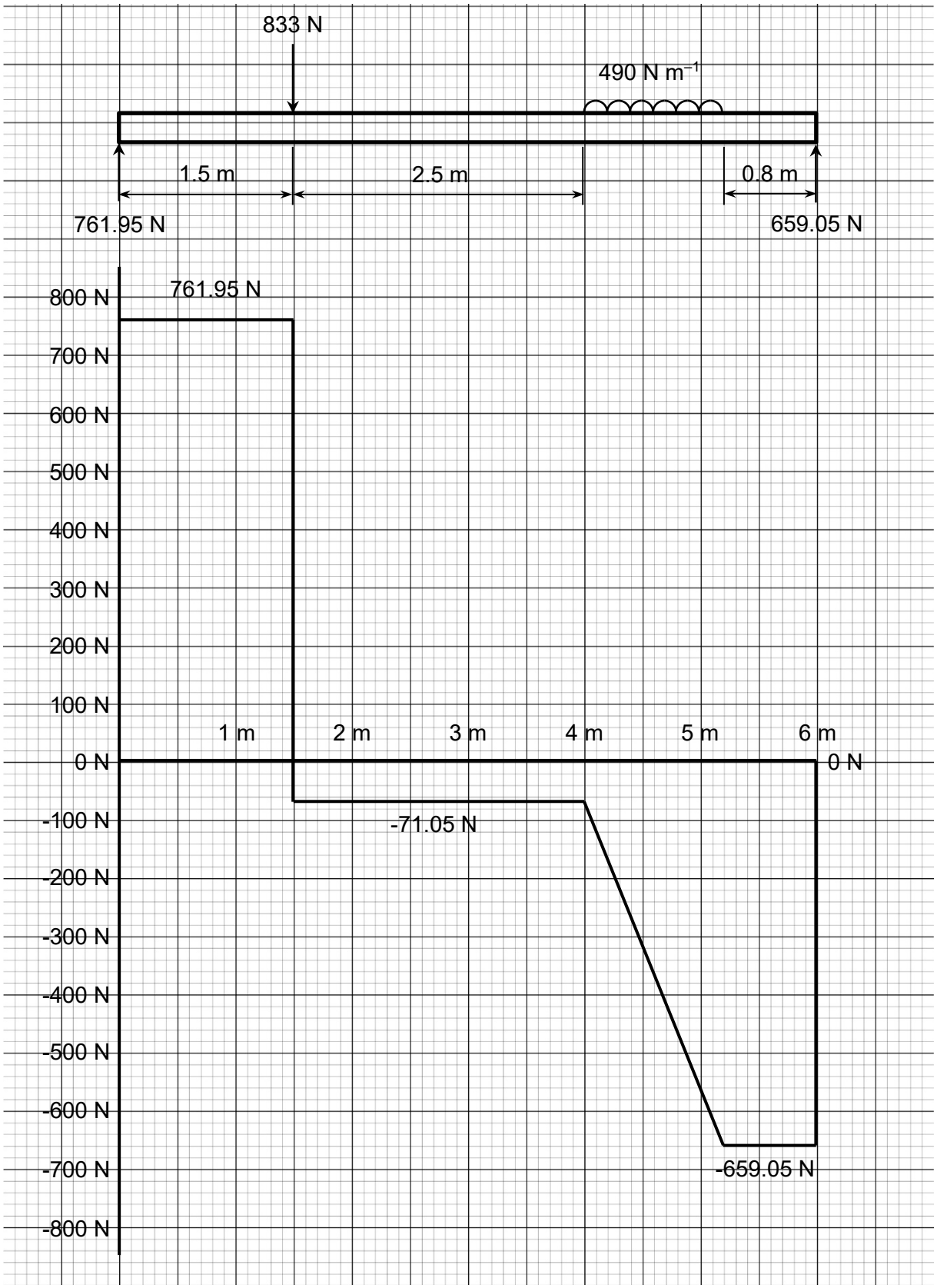
(a) Calculate the shear forces at the **three** cross-sections of the beam, as shown in the diagram above. (7 marks)

Description	Marks
$SF_1 = R_L$ $= 761.95$ N	1
$SF_2 = R_L - 85(9.8)$ $= 761.95 - 833$	1–2
$= -71.05$ N	1
$SF_3 = R_L - 85(9.8) - 490(1.2)$ $= 761.95 - 833 - 588$	1–2
$= -659.05$ N	1
Total	**7**

(b) On the grid below, sketch a fully-labelled and suitably scaled shear force diagram of the loaded beam. The shear forces at either end of the beam must also be included. You may wish to draw a free body diagram at the top of the grid. The axes for the shear force diagram have been provided. (5 marks)

Description	Marks
Axes labelled with correct units, i.e. N on vertical axis and m on horizontal axis, and suitable scale for both axes used	1
Calculated SF values shown on diagram	1
Horizontal lines between point loads	1
Sloping line for UDL	1
Vertical line at termination of beam	1
Total	**5**

Question 26 (continued)



Question 27 **(12 marks)**

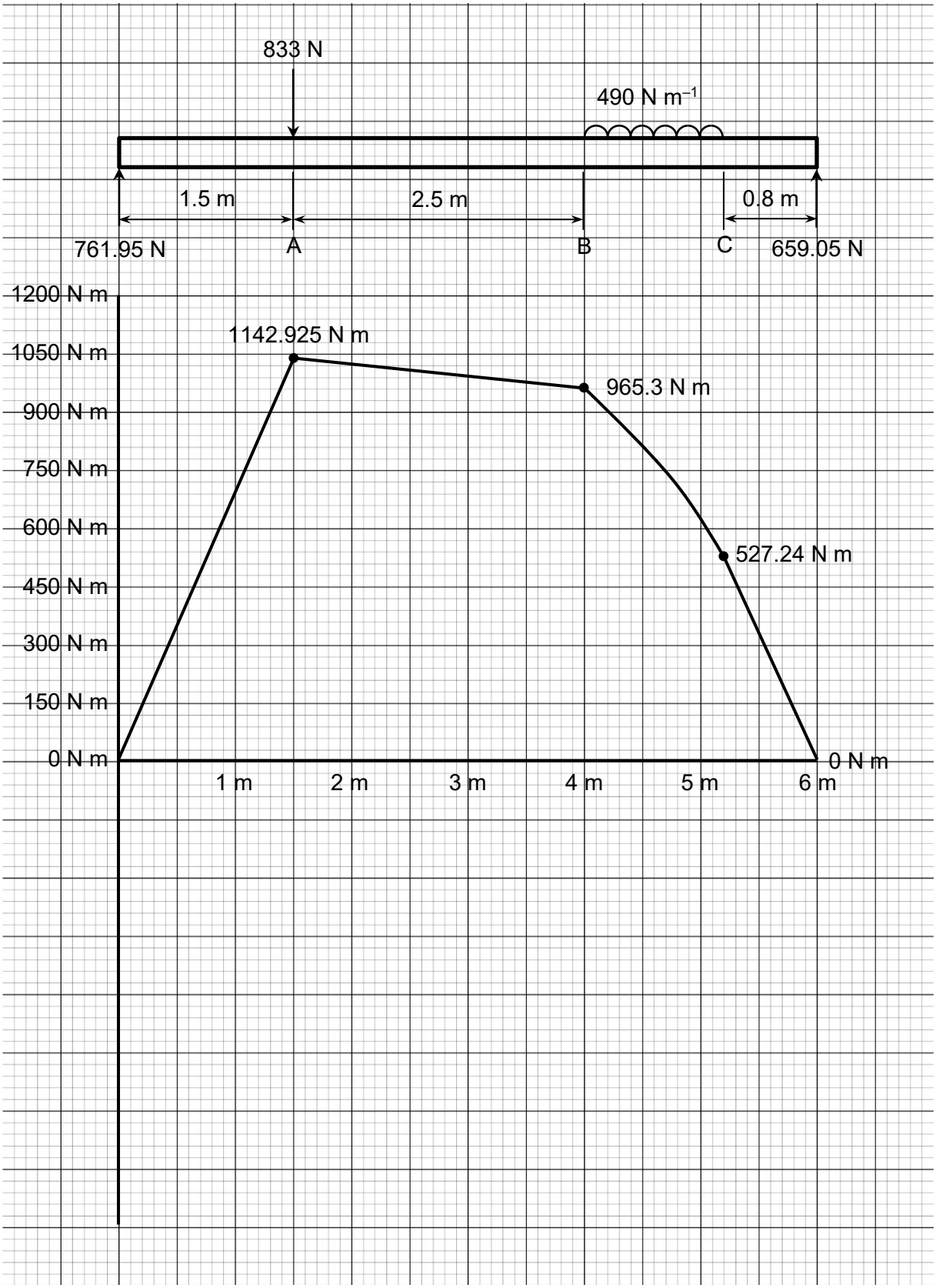
(a) Calculate the bending moments at the **three** locations labelled ‘A’, ‘B’ and ‘C’. (7 marks)

Description	Marks
BM_A = R_L(1.5) = 761.95(1.5) = 1142.925 N m	1
BM_B = 761.95(4) – 85(9.8)(2.5) = 3047.8 – 2082.5	1–2
= 965.3 N m	1
BM_C = 761.95(5.2) – 85(9.8)(3.7) – 490(1.2)(0.6) = 3962.14 – 3082.1 – 352.8	1–2
= 527.24 N m	1
Total	**7**
Allow for rounding.	

(b) On the grid below, sketch a fully-labelled and suitably scaled bending moment diagram of the loaded beam. The bending moments at either end of the beam must also be included. You may wish to draw a free body diagram at the top of the grid. The axes for the bending moment diagram have been provided. (5 marks)

Description	Marks
Axes labelled with correct units, i.e. N on vertical axis and m on horizontal axis, and suitable scale for both axes used	1
Calculated BM values shown on diagram	1
Straight line behaviour between point loads	1
Parabolic (curved) line for UDL	1
Returns to 0 N m at each end of beam	1
Total	**5**

Question 27 (continued)



Question 28 **(16 marks)**

(a) Calculate ω, the uniformly distributed load per unit length along the lintel. Answer in units of N m^{-1}. Ignore the mass of the lintel. (4 marks)

Description	Marks
Mass of bricks and mortar = $(3 \times 8 \times 2.5) + 13.6 = 60 + 13.6$ = 73.6 kg	1
Weight of bricks and mortar = $73.6 \times 9.8 = 721.28$ N	1
$\omega = \frac{721.28}{1.91}$	1
= 377.633 N m^{-1}	1
Total	**4**

(b) Calculate the deflection of the lintel at its centre. Answer in units of millimetres (mm). If you could not calculate an answer for part (a), use ω = 350 N m^{-1}. (7 marks)

Description	Marks
$I_{xx} = \frac{bh^3}{12} = \frac{110 \times 25^3}{12} = \frac{1\,718\,750}{12}$	1
= 143 229 mm^4	1
F_{UDL} = (377.633)(1.91) = 721.28 N	1
L = 1910 mm	
E = 200 000 N mm^{-2}	1
$y = \frac{5F_{UDL}L^3}{384EI_{XX}}$	1
$= \frac{(5)(721.28)(1910^3)}{(384)(200\,000)(143\,229)}$	1
= 2.284 mm	1
Total	**7**
Note: if using ω = 350 N m^{-1} then F_{UDL} = 350 × 1.91 = 668.5 N and y = 2.117 mm.	

(c) Calculate the new value of the lintel's deflection at its centre. Answer in units of millimetres (mm). (5 marks)

Description	Marks
I_{xx} = 143 229 mm^4 F = 490 N L = 1910 mm E = 200 000 N mm^{-2}	
$y = \frac{FL^3}{48EI_{XX}}$	1
$= \frac{(490)(1910^3)}{(48)(200\,000)(143\,229)}$	1–2
= 2.483 mm	1
Total deflection = 2.483 (point load) + 2.284 (UDL) = 4.767 mm	1
Total	**5**
Note: if using ω = 350 N m^{-1} for part (b) then total deflection = 2.483 + 2.117 = 4.6 mm.	

Question 29 **(23 marks)**

(a) Using calculations, demonstrate that the length of the uneven side of the isosceles triangle is 2.5711 m. (2 marks)

Description	Marks
a = $\cos\theta(h)$ = half length of uneven side Full length of uneven side = $\cos\theta(h)(2)$ $\cos 50°(2)(2)$ = 2.5711 m	1–2
Total	**2**
Accept other valid methods of calculation.	

(b) Using calculations, show that the reactions R_L and R_R are 17.5 kN and 22.5 kN respectively. (6 marks)

Description	Marks
ΣM_F = 0	1
= –5(6.427 75) + R_L(5.1422) –15(3.856 65) –10(1.285 55) + 10(1.285 55) 5.1422 R_L = 32.138 75 + 57.849 75 + 12.8555 –12.8555 $R_L = \frac{89.9885}{5.1422}$	1–3
= 17.5 N	
ΣF_Y = 0	1
= $R_L + R_R – 5 – 15 – 10 – 10$ R_R = 40 – R_L = 40 – 17.5	1
= 22.5 N	
Total	**6**

(c) Working to the left of section xx, use the method of sections to calculate F_{CE}, the force in member CE and indicate whether the force is tension or compression. (5 marks)

Description	Marks
ΣM_D = 0	1
= -5(3.856 65) + 17(2.5711) – 15(1.285 55) + F_{CE}(2 sin 50°) F_{CE}(1.5321) = 19.283 25 – 44.994 25 + 19.283 25 $F_{CE} = \frac{-6.427\ 75}{1.5321}$	1–2
= -4.195 kN	1
Compression	1
Total	**5**
Note: • the above solution assumes CWM are positive and ACWM are negative. Assuming ACWM are positive and CWM are negative is also a valid method of calculation • allow for sensible rounding of answer.	

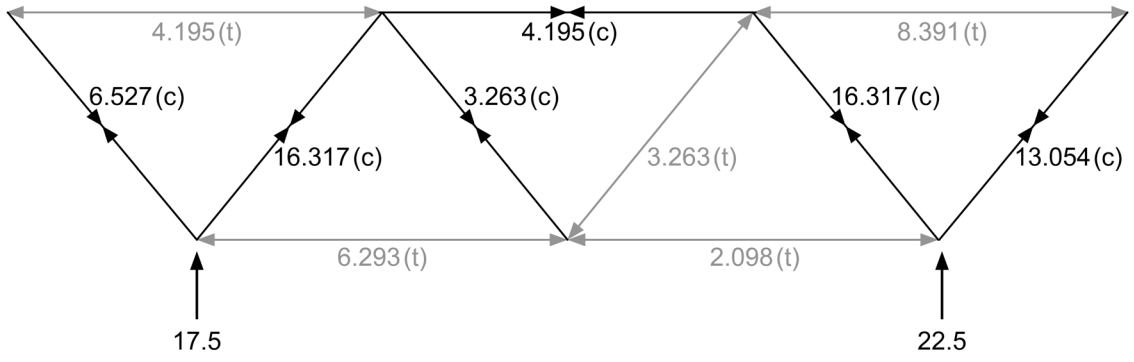
(d) Working to the left of section xx, use the method of sections to calculate F_{DF}, the force in member DF and indicate whether the force is tension or compression. (5 marks)

Description	Marks
$\Sigma M_E = 0$	1
$= -5(5.1422) - 17(3.856\,65) - 15(2.5711) - F_{DF}(2 \sin 50°)$ $F_{DF}(1.5321) = -25.711 + 67.491\,375 - 38.5665$ $F_{DF} = \dfrac{3.213\,875}{1.5321}$	1–2
$= 2.098$ kN	1
Tension	1
Total	**5**
Note: • the above solution assumes CWM are positive and ACWM are negative. Assuming ACWM are positive and CWM are negative is also a valid method of calculation • allow for sensible rounding of answer.	
Alternative answer if candidates answered part (e) before answering part (d)	
$\Sigma F_x = 0$	1
$= F_{DF} + F_{DE}(\cos 50°) + F_{CE}$ $= F_{DF} + 3.263(0.642\,79) + (-4.195)$ $= F_{DF} + 2.097 - 4.195$ $F_{DF} = 4.195 - 2.097$	1–2
$= 2.098$ kN	1
Tension	1
Total	**5**

Question 29 (continued)

(e) Working to the left of section xx, use the method of sections to calculate F_{DE}, the force in member DE and indicate whether the force is tension or compression. (5 marks)

Description	Marks
ΣM_C = 0	1
= -5(2.5711) + 17.5 (1.285 55) – F_{DF}(2 sin 50°) – F_{DE} (2 sin 80°) F_{DE}(1.9696) = -12.8555 + 22.497 125 – 2.098(1.5321) F_{DF} = $\frac{-12.8555 + 22.497\,125 - 3.214\,345\,8}{1.9696}$ = $\frac{6.427\,279\,2}{1.9696}$	1–2
= 3.263 kN	1
Tension	1
Total	**5**
Note: • the above solution assumes CWM are positive and ACWM are negative. Assuming ACWM are positive and CWM are negative is also a valid method of calculation • allow for sensible rounding of answer.	
Alternative answer	
ΣF_y= 0	1
= 17.5 + F_{DE} (sin 50°) – 5 – 15 F_{DE} (0.766) = 20 – 17.5 = $\frac{2.5}{0.766}$ F_{DE}	1–2
= 3.263 kN	1
Tension	1
Total	**5**



Section Two: Specialised field – Mechatronics **60% (110 Marks)**

Part A: Multiple-choice **10% (10 Marks)**

Question	Answer
30	b
31	c
32	b
33	a
34	c
35	c
36	d
37	a
38	b
39	d

Part B: Extended answer **50% (100 Marks)**

Question 40 **(12 marks)**

(a) The circuit shown above contains three resistors. The value of R1 is known (220 Ω) but the values for R2 and R3 are not. R2 and R3 have identical values, i.e. R2 = R3. Calculate the required values for R2 and R3 such that the circuit will draw 18 mA of current. (5 marks)

Description	Marks
$R_T = \frac{V}{I} = \frac{9}{0.018}$	1
$= 500\ \Omega$	1
$220 + \frac{(R2 \times R3)}{(R2 + R3)} = 500$ $\frac{(R2 \times R3)}{(R2 + R3)} = 280$	1
$\frac{(560 \times 560)}{(560 + 560)} = \frac{313\,600}{1120} = 280$	1
$R2 = R3 = 560\ \Omega$	1
Total	**5**
Alternative Solution	
$R_T = \frac{V}{I} = \frac{9}{0.018}$	1
$= 500\ \Omega$	1
$500 = 220 + \frac{(R \times R)}{(R + R)}$ $280 = \frac{(R \times R)}{(R + R)}$	1
$560R = R^2$ $\frac{560R}{R} = \frac{R^2}{R}$ $560 = R$	1
$R2 = R3 = 560\ \Omega$	1
Total	**5**
Alternative Solution	
$R_T = \frac{V}{I} = \frac{9}{0.018}$	1
$= 500\ \Omega$	1
$500 = 220 + R \mid\mid R$ $280 = R \mid\mid R$ $\frac{1}{280} = \frac{1}{R} + \frac{1}{R}$	1
$= 2 \times \frac{1}{R}$ $\frac{1}{560} = \frac{1}{R}$ $560 = R$	1
$R2 = R3 = 560\ \Omega$	1
Total	**5**

(b) (i) The non-polarised capacitor, C1, has a 3-digit number printed on its side. State these digits. (1 mark)

Description	Marks
C1 3-digit number = 474	1
Total	**1**

(b) (ii) C_{AB}, the capacitance between nodes A and B, is 1.79 µF. Calculate C_2, the capacitance of C2. Answer in units of microfarads (µF). (3 marks)

Description	Marks
$C_{AB} = 1.79 = 0.47 + \frac{(C_2 \times 3.3)}{(C_2 + 3.3)}$ $1.32 = \frac{(C_2 \times 3.3)}{(C_2 + 3.3)}$ $1.32C_2 + 4.356 = 3.3C_2$ $1.98C_2 = 4.356$ $C_2 = \frac{4.356}{1.98}$	1–2
$= 2.2$ µF	1
Total	**3**
Alternative Solution	
$C_{AB} = 1.79 = 0.47 + (C_2 \text{ II } 3.3)$ $1.32 = (C_2 \text{ II } 3.3)$ $\frac{1}{1.32} = \frac{1}{C_2} + \frac{1}{3.3}$ $\frac{1}{C_2} = \frac{1}{1.32} - \frac{1}{3.3}$ $= \frac{1}{0.454545}$	1–2
$C_2 = 2.2$ µF	1
Total	**3**
Accept other valid methods for calculating the answer Note: 2.2 µF is also commonly written as 2µ2 F	

(c) Calculate the minimum required current capacity of the third battery. Answer in units of amp-hours (A h). (3 marks)

Description	Marks
Amp-hours required = 1.8 × 125 × 0.65 = 146.25	1
Existing amp-hours = 60 + 45 = 105	1
Additional amp-hours = 146.25 – 105 = 41.25 A h	1
Total	**3**
Accept other valid methods of calculation.	

Question 41 **(14 marks)**

(a) Calculate the speed of rotation of Pulley A, the driver. Answer in units of revolutions per minute (r.p.m.). (4 marks)

Description	Marks
Distance belt moves per minute = 0.9425×60	1
$= 56.55$ m	1
Pulley A (r.p.m.) = $\frac{56.55}{\pi(0.09)} = \frac{56.55}{0.28274}$	1
$= 200$ r.p.m.	1
Total	**4**
Accept other valid methods of calculation.	

(b) Calculate the speed of rotation of Pulley C, the output of the system. Answer in units of revolutions per minute (r.p.m.). If you could not calculate an answer for part (a), use 220 r.p.m. (4 marks)

Description	Marks
$VR = \frac{F_1 F_2}{D_1 D_2} = \frac{90(50)}{90(120)} = \frac{4500}{10\,800}$	1
$= 0.4167$	1
Output speed r.p.m. = $\frac{\text{Input speed r.p.m.}}{VR} = \frac{200}{0.4167}$	1
$= 480$ r.p.m.	1
Total	**4**
Accept other valid methods of calculation.	
Note: If using 220 r.p.m. then output speed = 528 r.p.m.	

(c) Calculate the displacement of Point X if the cam is rotated 180° from its position as shown in the diagram. Answer in units of millimetres (mm) and include the direction of the displacement in your answer. (2 marks)

Description	Marks
Displacement of Point X = (40 – 10) – 10	1
= 20 mm (up)	1
Total	**2**
Accept other valid methods of calculation.	

(d) The camshaft is connected to the shaft of Pulley C of the drive system. Calculate the average speed of Point X as the cam is rotated by the pulley drive system while the system is running. Answer in metres per second (m s^{-1}). (4 marks)

Description	**Marks**
Average speed of point X = $\frac{\text{distance (m)}}{\text{time (s)}}$ = $\frac{(0.02 \times 2) \times 480 \text{ r.p.m.}}{60}$	1–3
= 0.32 m s^{-1}	1
Total	**4**
Accept other valid methods of calculation.	
Note: if using 220 r.p.m. for part (b) then C rotates at 528 r.p.m. which results in average speed of point X = 0.352 m s^{-1}.	

Question 42 **(21 marks)**

(a) When the LDR is over the black line, will V_{OUT} be greater or less than when the LDR is over the white background? Outline a reason to support your answer. (2 marks)

Description	Marks
greater	1
over the black line (darker surface) less light is received by the LDR and this will result in an increase of its resistance and so the voltage across the LDR, i.e. V_{OUT} will rise	1
Total	**2**
Accept other relevant answers.	

(b) Calculate R_{LDR}, the resistance of the LDR given V_{OUT} = 2.62 V and R_{RV}, the resistance of RV = 56 700 Ω. (4 marks)

Description	Marks
$V_{OUT} = V_{CC} \times \frac{R_{LDR}}{(R_{RV} + R_{LDR})}$ $2.62 = 5 \times \frac{R_{LDR}}{(56\,700 + R_{LDR})}$	1
$148\,554 + 2.62R_{LDR} = 5R_{LDR}$ $2.38R_{LDR} = 148\,554$	1
$R_{LDR} = \frac{148\,554}{2.38}$	1
$= 62\,417.65\ \Omega$ (allow for rounding)	1
Total	**4**
Accept other valid methods of calculation.	

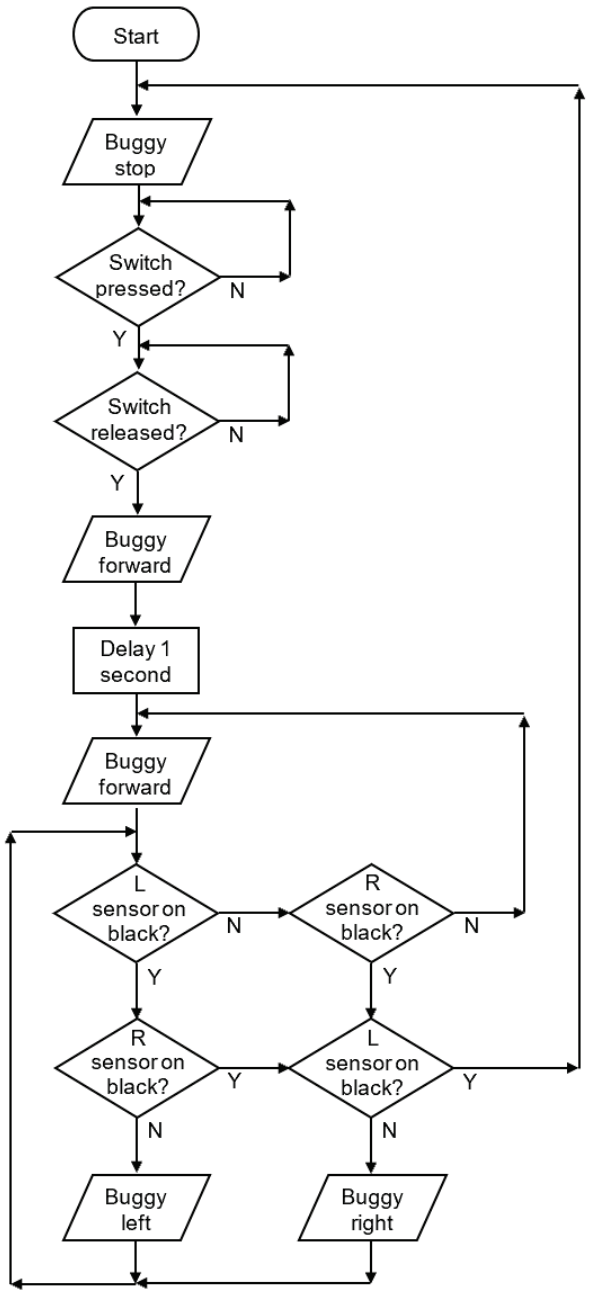
(c) The signal from the sensor of V_{OUT} = 2.62 V is connected to a 10-bit ADC pin of a microcontroller. Calculate the 10-bit value produced by the ADC. Round the answer to the nearest whole number. (3 marks)

Description	Marks
10-bit value $= 1023 \times \frac{V_{OUT}}{V_{CC}}$ $= 1023 \times \frac{2.62}{5} = \frac{2680.26}{5}$	1–2
$= 536$	1
Total	**3**
Accept other valid methods of calculation.	

(d) On page 47, draw a fully-labelled flow chart that will control the buggy when following the black line pathway, such that it will achieve the specifications listed in the above table.

(8 marks)

Description	Marks
After pressing then releasing the switch the buggy will move forwards for 1 second to clear the black bar it is on	1
If neither sensor detects the black line then the buggy continues moving forwards	1
If only the right sensor detects the black line then the buggy turns right	1
If only the left sensor detects the black line then the buggy turns left	1
The flow chart contains loops that keep the buggy in motion following the black line until it detects a black bar	1–2
If both sensors detect a black bar then the buggy stops	1
If the buggy is stopped at a black bar, the flow chart loops to enable the buggy to be returned into motion by pressing then releasing the switch	1
Total	**8**



Question 42 (continued)

(e) Control systems can often be characterised as open-loop or closed-loop.

(i) Describe how the output differs between an open-loop and a closed-loop control system. (2 marks)

Description	Marks
open-loop: the condition of the output is independent of the input for the control system (alternatively, these are sequences of events with no feedback loops)	1
closed-loop: the condition of the output is monitored and a feedback loop returns this as an input of the control system such that the output is maintained at a set or desirable condition	1
Total	**2**

(ii) Is the section of the buggy control system that enables it to track the black line open-loop or closed-loop? Justify your answer. (2 marks)

Description	Marks
closed-loop	1
to successfully track the black line the buggy's actual position relative to the black line must be monitored and the drive motors output adjusted to correct for errors	1
Total	**2**

Question 43 **(18 marks)**

(a) Calculate I_{BA}, the current flowing from node B to node A. Answer using units of amps (A). (2 marks)

Description	Marks
$\Sigma I = 0 = I_{S1} + I_{AB} - I_{S2}$ $I_{AB} = I_{S2} - I_{S1}$ $= 0.044\ 69 - 0.0261$	1
$= 0.018\ 59$ A	1
Total	**2**

(b) Calculate V_{R3}, the voltage across R3. (4 marks)

Description	Marks
$\Sigma \Delta V = 0 = 6 + 9 - V_{R1} - V_{R3} - V_{R5}$ $V_{R3} = 15 - V_{R1} - V_{R5}$ $= 15 - (150 \times 0.044\ 69) - (220 \times 0.0261)$ $= 15 - 6.7035 - 5.742$	1–3
$= 2.5545$ V (accept 2.55 V)	1
Total	**4**
Note: fuse can be ignored as its voltage drop is negligible.	

(c) Calculate P_{R4}, the power dissipated as heat by R4. Answer using units of watts (W). (6 marks)

Description	Marks
$\Sigma \Delta V = 0 = 6 - V_{R4} - V_{R5}$ $V_{R4} = 6 - V_{R5}$ $= 6 - (220 \times 0.0261)$ $= 6 - 5.742$	1–2
$= 0.258$ V	1
$P_{R4} = \frac{V_{R4}^2}{R}$ $= \frac{0.258^2}{470} = \frac{0.066\ 564}{470}$	1–2
$= 0.000\ 1416$ W	1
Total	**6**
Accept other valid methods of calculation.	

(d) Calculate I_{R4}, the current flowing through R4. Answer using units of amps (A). (3 marks)

Description	Marks
$R_T = R_4 + R_5$ $= 470 + 220 = 690\ \Omega$	1
$I_{R4} = I_{S1} = \frac{V_{S1}}{R_T} = \frac{6}{690}$	1
$= 0.0087$ A	1
Total	**3**
Accept other valid methods of calculation.	

Question 43 (continued)

(e) Calculate P_{S2}, the power supplied to the circuit by S2. Answer using units of watts (W).
(3 marks)

Description	Marks
$R_T = R_1 + R_2$ $= 150 + 120 = 270\ \Omega$	1
$P_{S2} = \frac{V_{S2}^2}{R_T} = \frac{9^2}{270}$	1
$= 0.3$ W	1
Total	**3**
Accept other valid methods of calculation.	

Question 44 **(17 marks)**

(a) Describe how the diode protects the circuit if the battery terminals are connected incorrectly. (2 marks)

Description	Marks
if the battery terminals were connected incorrectly then the diode would be reverse-biased	1
and this would block current from flowing the wrong way and thus protect the circuit from damage	1
Total	**2**
Accept other relevant answers.	

(b) When the battery is connected correctly, the load (resistor) dissipates 129.96 mW of power. Calculate P_S, the power supplied to the circuit by the battery. Answer using units of watts (W). (4 marks)

Description	Marks
$I_S = I_R = \sqrt{\frac{P}{R}} = \sqrt{\frac{0.129\,96}{1000}} = \sqrt{0.000\,129\,96}$	1
$= 0.0114$ A	1
$P_S = I_S \times V_S = 0.0114 \times 12$	1
0.1368 W	1
Total	**4**
Accept other valid methods of calculation.	

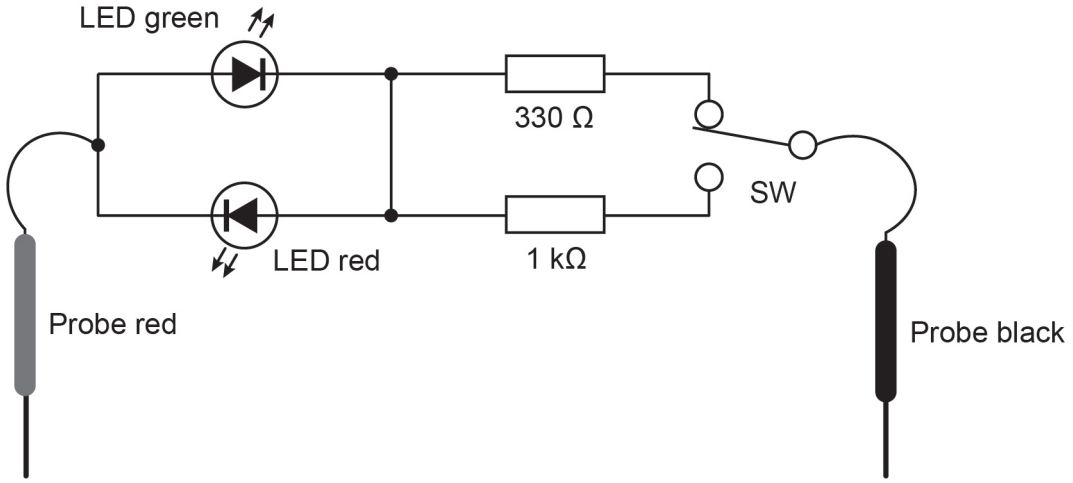
(c) The LEDs have the following parameters: $V_{LED,GREEN} = 1.9$ V and $V_{LED,RED} = 2.1$ V. Calculate P_R, the power dissipated by the resistor, if the probes are placed as shown in the diagram at the top of this page. Answer using units of watts (W). (5 marks)

Description	Marks
$I_R = I_{LED} = \frac{(V_S - V_{LED})}{R}$ $= \frac{(9 - 2.1)}{330} = \frac{6.9}{330}$	1–2
$= 0.020\,91$ A	1
$P_R = I_R^2 R = 0.020\,91^2 \times 330$	1
$= 0.144$ W	1
Total	**5**
Accept other valid methods of calculation.	

Question 44 (continued)

(d) Draw a fully-labelled circuit diagram that uses only the listed components to achieve the operations required of the redesigned polarity tester. You do not need to include a battery or DC power supply in the diagram. (6 marks)

Description	Marks
If polarity is correct only green LED glows	1
If polarity is incorrect only red LED glows	1
330 Ω resistor correctly placed such that it will limit current to whichever of the two LEDs is glowing	1
1 kΩ resistor correctly placed such that it will limit current to whichever of the two LEDs is glowing	1
SPDT switch allows operator to switch between the high and low voltage testing circuits	1
Diagram is neat and symbols are labelled	1
Total	**6**



Accept other relevant answers.

Question 45 **(18 marks)**

(a) Calculate V_{CE}, the collector emitter voltage of the transistor. (4 marks)

Description	Marks
$\Sigma\Delta V = 0 = 9 - V_{R1} - V_{LED,ON} - V_{CE}$ $V_{CE} = 9 - V_{R1} - V_{LED,ON}$ $= 9 - (560 \times 0.010\ 75) - 1.9$ $= 9 - 6.02 - 1.9$	1–3
$= 1.08$ V	1
Total	**4**

(b) Calculate R_2, the resistance of R2. (5 marks)

Description	Marks
$I_B = \frac{I_C}{\beta} = \frac{0.010\ 75}{30}$	1
$= 0.000\ 358\ \overline{3}$ A	1
$\Sigma\Delta V = 0 = 5 - V_{R2} - V_{BE,ON}$ $V_{R2} = 5 - 0.7 = 4.3$ V	1
$I_{R2} = I_B$ $4.3 = R_2 \times I_{R2}$ $R_2 = \frac{4.3}{0.000\ 358\ \overline{3}}$	1
$= 12\ 000\ \Omega$	1
Total	**5**
Accept other valid methods of calculation.	

(c) Calculate I_B, the minimum base current required to cause the transistor to transition from its forward-active region of operation into saturation. Answer using units of amps (A). (6 marks)

Description	Marks
$\Sigma\Delta V = 0 = 9 - V_{R1} - V_{LED,ON} - V_{CE,SAT}$ $V_{R1} = 9 - V_{LED,ON} - V_{CE,SAT}$ $= 9 - 1.9 - 0$	1
$= 7.1$ V	1
$I_{R1} = \frac{V_{R1}}{R_1} = \frac{7.1}{560}$	1
$= 0.126\ 786$ A (Allow for rounding)	1
$I_B = \frac{I_{R1}}{\beta} = \frac{0.126\ 786}{30}$	1
$= 0.000\ 422\ 619$ A (Allow for rounding)	1
Total	**6**
Note: 0.000 422 619 A = 0.423 mA = 422.62 µA = 4.23×10^{-4} A.	

Question 45 (continued)

(d) Calculate R_2, the new value of R2 required to achieve the base current calculated in part (c). If you could not determine an answer for part (c), use 0.000 45 A. State the maximum value E12 resistor that would be used for a practical circuit. (3 marks)

Description	Marks
$\Sigma\Delta V = 0 = \quad 5 - V_R - V_{BE,on}$	
$V_{R2} = \quad 5 - 0.7 = 4.3$ V	1
$R_2 = \dfrac{V_R}{I_B} = \dfrac{4.3}{0.000\,422\,619} = 10\,174.65\ \Omega$	1
Value of E12 resistor = 10 000 Ω (accept 10 kΩ)	1
Total	**3**
Note: if using I_B = 0.000 45 A then R_2 = 9555.55 Ω Value of E12 resistor = 8200 Ω (accept 8.2 kΩ).	

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