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

ENGINEERING STUDIES

ATAR course examination 2022

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% (75 Marks)

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

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

Part B: Extended response **30% (65 Marks)**

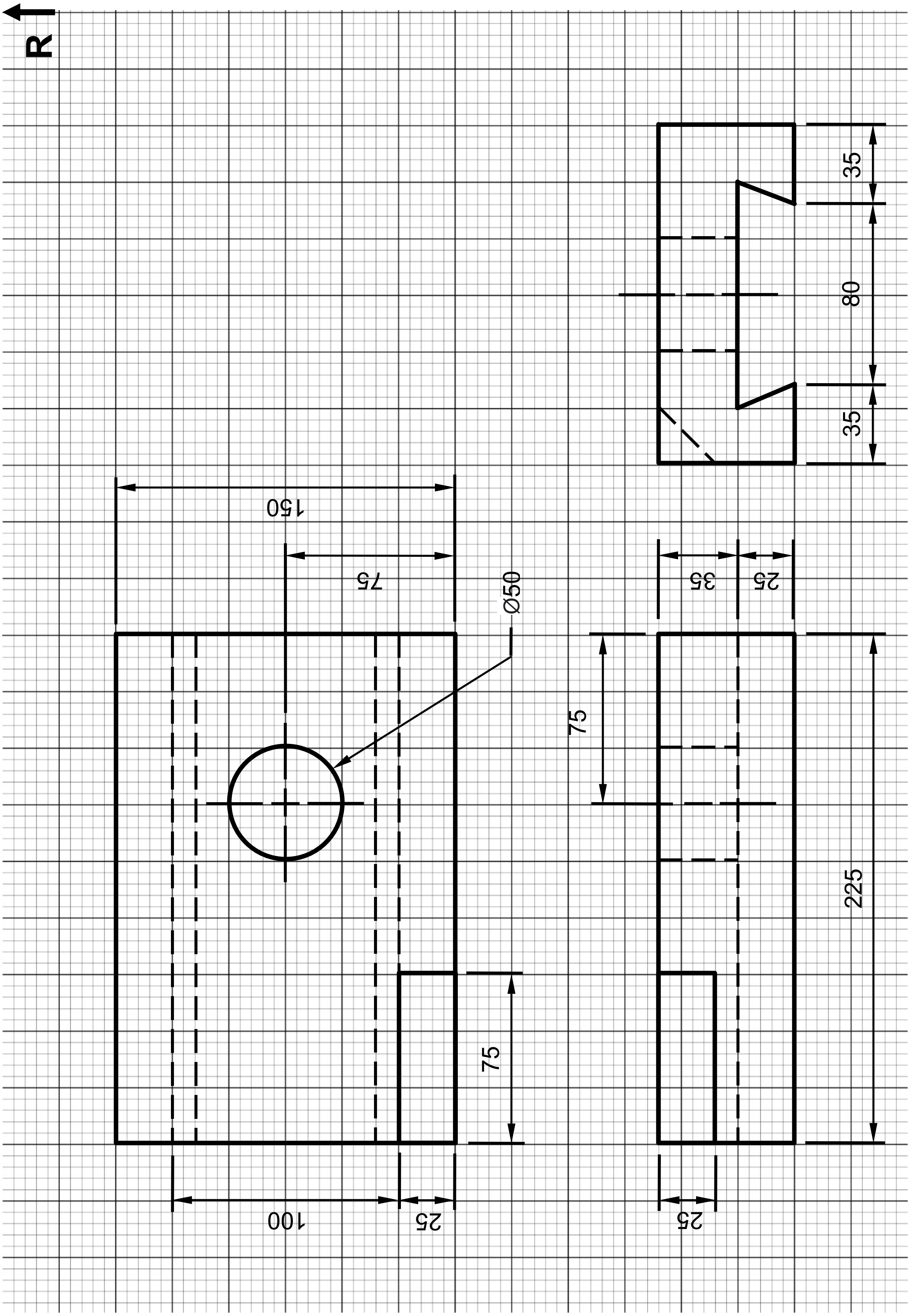
Question 11 **(18 marks)**

(a) Using 3rd angle orthographic conventions, complete fully-dimensioned drawings of the top, front and right-hand end views on the grid provided on page 7. The hole, as seen on the top view, is already given. (12 marks)

Note 1: The larger squares of the grid represent 25 mm × 25 mm
Note 2: To fit the required three views, use the grid sideways. The top right corner of the grid is indicated by an arrow and letter R.

Description	Marks
correct placement of three views	1
top view outlines complete and correct	1
front view outlines complete and correct	1
right-hand end view outlines complete and correct	1
hidden detail for all three views complete and correct	1–2
centrelines for all three views complete and correct	1–2
sufficient dimensions to determine overall length, height and width	1
sufficient dimensions to determine length, height and width of dovetail slot	1
sufficient dimensions to determine length, height and width of bevelled section	1
hole and its location correctly dimensioned	1
Total	**12**

Question 11 (continued)



(b) Calculate the density of the material used for the machined block, in units of kg m^{-3}, given that its mass is 3922 g. (6 marks)

Description		Marks
Volume: block	$= 0.225 \times 0.15 \times 0.06 = 0.002025$ m^3 Alternatively 2025000 mm^3	1
Volume: dovetail slot	$= 0.225 \times \dfrac{(0.1 + 0.08)}{2} \times 0.025$ $= 0.225 \times 0.09 \times 0.025 = 0.00050625$ m^3 Alternatively 506250 mm^3	1
Volume: hole	$= \pi r^2 h = \pi \times 0.025^2 \times 0.035 = 0.000068722$ m^3 Alternatively 68722 mm^3	1
Volume: triangular prism	$= \dfrac{(0.025 \times 0.025 \times 0.075)}{2} = 0.0000234375$ m^3 Alternatively 23 437.5 mm^3	1
Volume: machined block	$= 0.002025 - 0.00050625 - 0.000068722 - 0.0000234375$ $= 0.0014265905$ m^3 Alternatively 1426590.5 mm^3	1
p	$= \dfrac{m}{V} = \dfrac{3.922}{0.0014265905} = 2749$ kg m^{-3}	1
	Total	**6**
Accept other valid methods of calculation and allow for rounding.		

Question 12 **(13 marks)**

(a) Decisions are made throughout the engineering design process that focus on selecting the best option from multiple considerations for a particular aspect of the design.

Explain how you would made the best choice between alternative options during the process. (4 marks)

Description	Marks
develop common criteria to compare the alternatives	1
weight these criteria	1
score each of the criteria	1
the option with the highest score will be the preferred option	1
Total	**4**
Accept other relevant answers.	

(b) List **three** components that are the focal points when analysing the stages of the life cycle of an engineered product. (3 marks)

Description	Marks
energy inputs	1
material inputs	1
environmental considerations	1
Total	**3**
Accept other relevant answers.	

(c) For **two** of the key components identified in part (b), provide an example of where or how each would be used, **and** an explanation of why it is beneficial. (6 marks)

Description	Marks
One	
use wind farms and/or photovoltaic arrays to produce hydrogen	1
that can either be combusted or used in a fuel cell to provide energy where the by-product (water) will not contribute to problems with atmospheric pollution	1–2
Subtotal	**3**
Two	
by reducing waste of materials by returning these, and perhaps recycled material, to the production stream	1
then less needs to be sourced as raw input thereby reducing how much needs to be taken from resources that may be finite and diminishing	1–2
Subtotal	**3**
Total	**6**
Accept other relevant answers.	

Alternate answer:

Description	Marks
All phases of the life cycle of an engineering product impact the environment. For example, sourcing raw materials and energy leads to destruction or alternation of the habitats of flora, fauna and other organisms.	1
LCA can lead to practices that lessen disruptions to the enviornment plus result in better rehabilitation or more effective preservation of the land and the plants, animals and organisms that depend on the local ecosystem.	1–2
Subtotal	**3**

Question 13 **(16 marks)**

(a) Name and define **three** of these properties and justify why each is a requirement of the material used in the gas bottle body. (12 marks)

Description	Marks
Property one	
stiffness	1
ability of a material to resist deformation under load	1
the pressure of the liquified petroleum must not distort the shape of the gas bottle	1
otherwise it will potentially lose stability and tip over or not remain correctly fitted into its storage space	1
Subtotal	**4**
Property two	
density	1
mass per unit volume	1
the gas bottles, especially when full, can be heavy and difficult to move or transport	1
therefore to reduce the overall mass it would be preferable to use a construction material that is not too dense, or, if it is dense, be very strong so that less volume of material is required	1
Subtotal	**4**
Property three	
toughness	1
ability of a material to absorb energy without rupture or failure	1
the gas bottle might be dropped or tip over when being handled or transported and it must not rupture	1
otherwise dangerous flammable gas could result in an explosion or fire or gas inhalation incident	1
Subtotal	**4**
Total	**12**
Accept other relevant answers.	

Alternate answer:

Description	Marks
tensile strength	1
ability of a material to resist a load that stretches it without fracture or failure	1
the pressure of the liquified petroleum must not cause the construction material to split and leak gas	1
that becomes a fire or explosive danger and/or health hazard due to inhalation	1
Subtotal	**4**
Accept other relevant answers.	

(b) While the gas bottle is made from steel, the valve at the top of the bottle is brass. Classify these materials into separate categories and outline the main similarity and difference between these classifications. (4 marks)

Description	Marks
steel is ferrous (alloy)	1
brass is non-ferrous (alloy)	1
both are alloys i.e. mixtures of a metal with another metal or non-metal	1
ferrous alloys are predominately iron based (non-ferrous alloys do not contain iron)	1
Total	**4**
Accept other relevant answers.	

Question 14 **(18 marks)**

(a) Explain **two** advantages that hydroelectric systems have compared with solar panels. (6 marks)

Description	Marks
Advantage one	
hydroelectric systems can supply electricity 24/7	1
whilst solar panels can only create electricity when sufficient sunlight is available	1
unless expensive battery storage is installed then the consumers will then need to draw energy from the 'grid'	1
Subtotal	**3**
Advantage two	
hydroelectric systems can supply large quantities of electricity	1
required for intensive energy use applications like heavy industry, large commercial buildings and high-density housing.	1
to match this, a huge number of solar panels would be required and these would need a vast surface area for installation	1
Subtotal	**3**
Total	**6**
Accept other relevant answers.	

(b) State **three** requirements for selecting a suitable location to install a large-scale dam with a hydroelectric system. (3 marks)

Description	Marks
reliable rain and/or snowmelt of sufficient quantity	1
suitable landscape contours to trap water behind a dam wall	1
close enough to populations and or industry to make it economically viable	1
Total	**3**
Accept other relevant answers.	

Question 14 (continued)

(c) Calculate the efficiency of a hydroelectric system that has the following parameters:
- power generated by the turbine is 514 kW
- the entry and exit heights of the system are 415 m and 378 m respectively
- 2.1 cubic metres of pure water flows through the turbine every second. (4 marks)

Description	Marks
$P = m \times g \times H_{NET} \times \eta$ $\eta = \dfrac{P}{m \times g \times H_{NET}}$ $= \dfrac{514000}{(2.1 \times 1000) \times 9.80 \times (0.9 \times (415 - 378))}$ $= \dfrac{514000}{2100 \times 9.80 \times 33.3}$ $= \dfrac{514000}{685314}$	1–3
= 0.75 (accept 75%)	1
Total	**4**
Accept other valid methods of calculation.	

(d) (i) Provide **two** reasons why the environmental agencies might place such a restriction on the operators of the hydroelectric system. (2 marks)

Description	Marks
to reserve water for recreational activities in the reservoir behind the dam	1
to reserve water available for release downstream for agricultural irrigation	1
Total	**2**
Accept other relevant answers.	

(ii) Calculate, in MWh, how much energy would be produced by the 514 kW turbine over a 365 day year, if its output is half the theoretical maximum. (3 marks)

Description	Marks
$E = P \times t \times 0.5$ $= \dfrac{514}{1000} \times (24 \times 365) \times 0.5$ $= 0.514 \times 8760 \times 0.5$	1–2
= 2251.32 MWh	1
Total	**3**
Accept other valid methods of calculation.	

Section Two: Specialised field – Mechanical **60% (120 Marks)**

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

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

Part B: Extended answer **50% (110 Marks)**

Question 25 **(15 marks)**

(a) Calculate the force that must be applied to drag the empty trolley from P to Z up the incline. Ignore friction in your calculations. (5 marks)

Description	Marks
$s = h/\sin\theta$ = 12/sin 15°	1
= 46.36 m	1
$W = Fs = mgh$	1
F × 46.36 = 70 × 9.8 × 12 = 8232 N	1
F = 8232/46.36 = 177.6 N	1
Total	**5**

(b) Calculate the magnitude of the trolley's velocity at point P (the bottom of the slope), assuming the system is frictionless and only under the influence of gravity. (4 marks)

Description		Marks
KE gained = PE lost $0.5mv^2 = mgh$ 0.5 × (70 + 50) × v^2 = (70 + 50) × 9.8 × 12	alternatively if cancelling out mass (m) 0.5 × v^2 = 9.8 × 12	1–2
= 14 112/60 $v = \sqrt{14\,112/60}$	= 235.2 $v = \sqrt{235.2}$	1
= 15.3 m s^{-1}	= 15.3 m s^{-1}	1
	Total	**4**

(c) Calculate the minimum distance required for it to come to rest at point O. If you did not calculate a velocity in part (b), use 20 m s^{-1}. (3 marks)

Description	Marks
$v^2 = u^2 + 2as$	1
0 = (15.3)^2 + 2 × –2 × s; alternative 0 = (20)^2 + 2 × –2 × s	1
s = (15.3)^2/4; alternative s = (20)^2/4 = 58.8 m; alternative s = 100 m	1
Total	**3**

(d) Determine the acceleration due to gravity acting on the trolley in the direction of the incline, as it rolls from Z to P. (3 marks)

Description	Marks
$a = g\sin\theta$	1
= 9.8 × sin 15°	1
= 2.54 m s^{-2}	1
Total	**3**

Question 26 **(25 marks)**

(a) Using appropriate calculations, show that the magnitude and direction of the reaction force at the cantilever point (fixed end) of the diving board is 788 N upward when a 60 kg diver stands at the extreme end of the board about to dive into the pool. (4 marks)

Description	Marks
reaction force at the fixed point = downward forces due to UDL and 60 kg diver	1
force due to UDL = ωL = 50 N m × 4 m = 200 N	1
force due to diver = 60 kg × 9.8 m s^{-2} = 588 N	1
total downwards force = 200 + 588 = 788 N reaction force at fixed point is 788 N upward	1
Total	**4**

(b) Using appropriate calculations, show that the total bending moment at the fixed point of the diving board is 2752 N m. (3 marks)

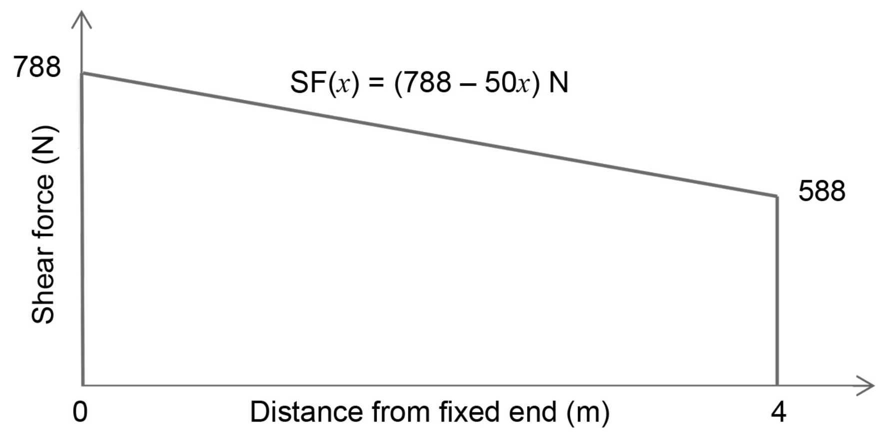
Description	Marks
take moments about the fixed point $M_{\text{fixed point}} = (\omega \times L) \times L/2 + (m_{\text{diver}} \times g \times L)$	1
= (50 × 4) × 4/2 + (60 × 9.8 × 4) = 400 + 2352	1
= 2752 N m	1
Total	**3**

Question 26 (continued)

(c) Draw a shear force diagram of the arrangement as described, using the grid provided below. Show all working including important/critical points **and** formula for shear force (SF) as a function of distance, x, along the diving board (measured from the fixed end). (9 marks)

Description	Marks
Start from the fixed end At x = 0, the fixed end $\Sigma F_y = 0 = 788 - SF(x)$ $SF(x) = 788$ N	1
for $0 < x <$ L = 4 m $\Sigma F_y = 0 = 788 - (\omega \times x) - SF(x)$ $SF(x) = 788 - (\omega \times x)$ $= 788 - 50x$	1–2
Toward very end of board $SF(x) = 788 - 50x = 788 - 50(4) = 788 - 200 = 588$ N	1
at x = L = 4m $\Sigma F_y = 0 = 788 - (\omega \times x) - 588 - SF(x)$ $SF(x) = 788 - (50 \times 4) - 588$ $= 788 - 200 - 588 = 0$ N	1
axes labelled correctly e.g. N vs m.	1
correct quantities/units shown on axes e.g. 788 N etc.	1
shear force formula shown	1
straight line behaviour shown	1
Total	**9**
Note: Accept other sign conventions. If working from free end: at x = 0, then $SF(x) = -588$ N at $0 < x <$ L = 4 m then $SF(x) = (-588 - 50x)$ N at fixed end i.e. x = L = 4m then minimum value is –788 N returning to 0 N	

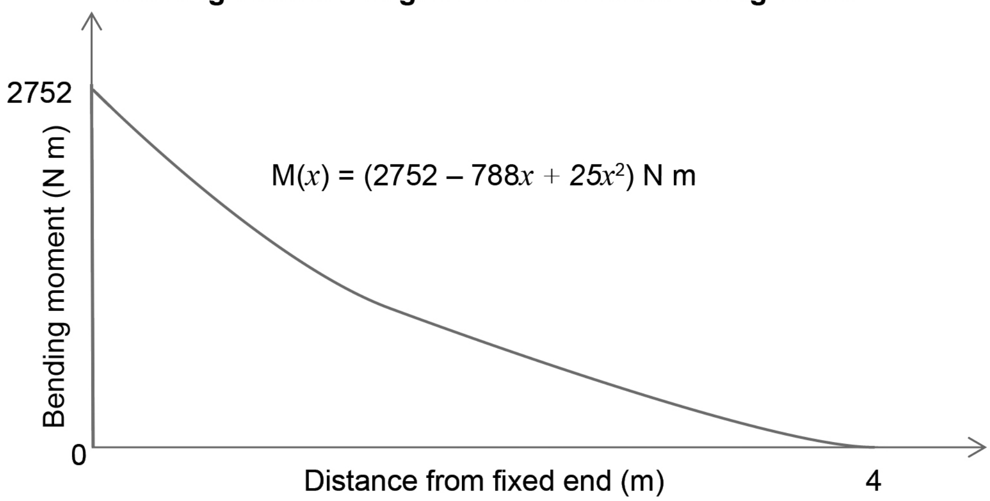
Shear force diagram for the loaded diving board



(d) Draw a bending moment diagram of the arrangement as described, using the grid provided below. Show all working including important/critical points **and** formula for bending moment (BM) as a function of distance, x, along the diving board (measured from the fixed end). (9 marks)

Description	Marks
Start from the fixed end M_{fixed} = 2752 N m (as calculated in part (b) is ACW moment Assume ACW moments are positive At $x = 0$, the fixed end $\Sigma M = 0 = M_{fixed} - M(x)$ $M(x) = 2752$ N m	1
For $0 < x < L = 4$ m $\Sigma M = 0 = 2752 - (788 \times x) + (\omega \times x \times x)/2 - M(x)$ $M(x) = 2752 - (788 \times x) + (\omega \times x \times x)/2$ $= 2752 - (788 \times x) + (50 \times x \times x)/2$ $= 2752 - 788x + 25x^2$ N m Working from fixed end to free end (i.e. moving from left to right and looking at the moments to the left only) and assuming CCW moments are positive 2752 is fixing moment and is positive (CCW moment about the fixed point) $788 \times x$ is negative (CW moment about x, which is to the right of the fixed point) $25x^2$ is positive (ACW moment about x, which is to the right of the fixed point)	1–3
At $x = L = 4$ m $\Sigma M = 0 = 2752 - (788 \times x) + (\omega \times x \times x)/2 - M(x)$ $M(x) = 2752 - (788 \times 4) + (50 \times 4 \times 4)/2$ $= 2752 - 3152 + 25x^2$ $= 2752 - 3152 + 400 = 0$ N m	1
axes labelled correctly e.g N m vs m	1
correct quantities/units shown on axes e.g 2752 N m etc.	1
bending moment formula shown	1
curve/parabolic behaviour shown	1
Total	**9**
Note: Accept other sign conventions. If working from free end, $0 < x < L = 4$ m, $M(x) = 588x + 25x^2$ N m	

Bending moment diagram for the loaded diving board



Question 27 **(27 marks)**

(a) Outline why tests were conducted on several strands of wire and not just a single test on one strand. (2 marks)

Description	Marks
there may be minor manufacturing variations in the strands	1
testing several strands covers such possibilities by averaging the results	1
Total	**2**
Accept other relevant answers.	

(b) Calculate the area of the cross-section of a single strand of wire. (2 marks)

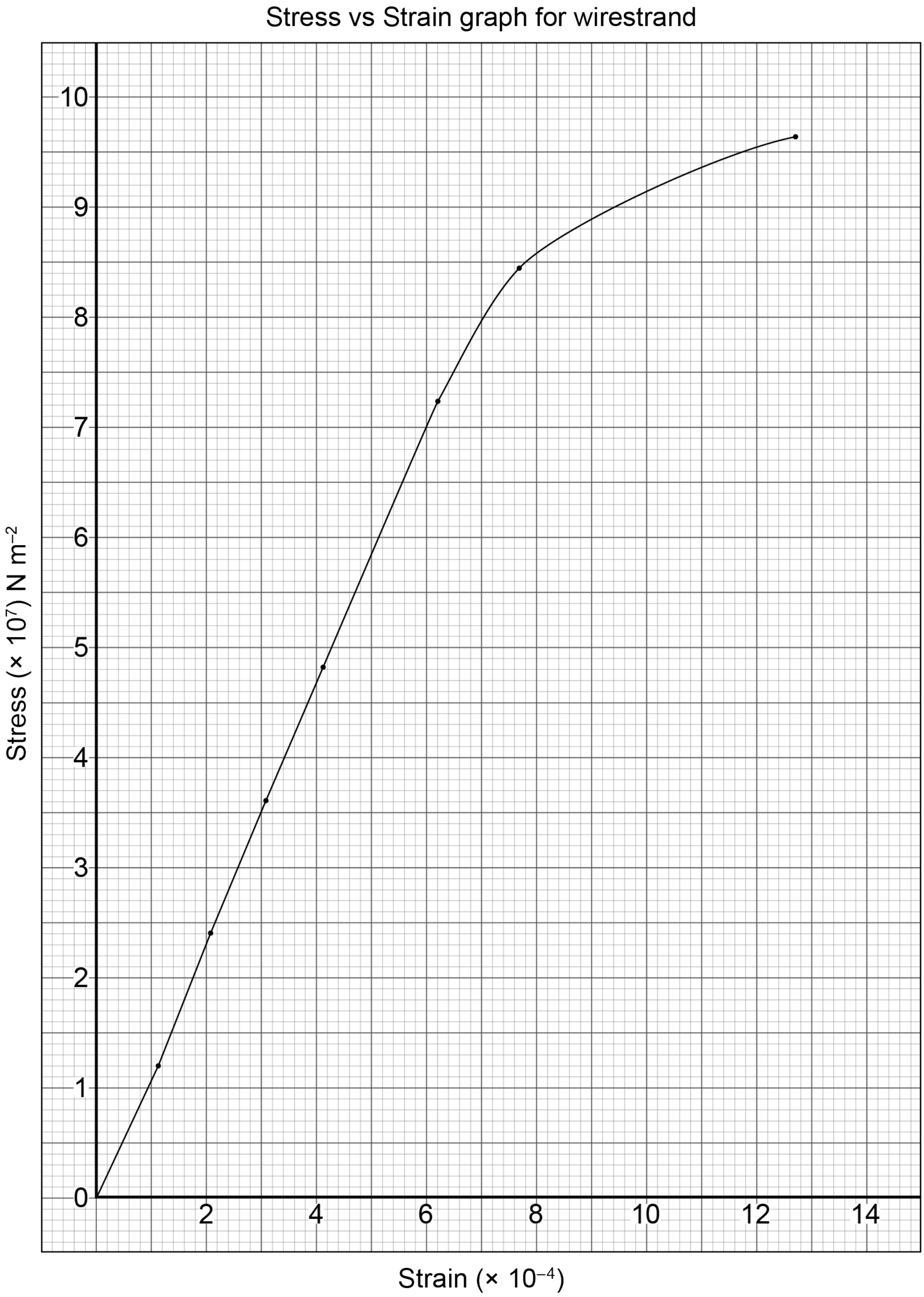
Description	Marks
r = 0.230/2 = 0.115 mm	1
Area = πr^2 = $\pi(0.115 \times 10^{-3})^2$ = 4.15×10^{-8} m^2 or 0.042 mm^2	1
Total	**2**

(c) Complete the table above by determining the **two** missing values. Show all working. (4 marks)

Description	Marks
stress is proportional to Force (weight); with Area fixed, take weight = 0.5 N and stress = 1.2; with weight = 1.5 N, stress = (1.5/0.5) × 1.2 = 3.6×10^7 N m^{-2}	1
stress = 3.6	1
strain = elongation/length = 0.76 mm/1.5m = 5.07×10^{-4}	1
strain = 5.07	1
Total	**4**

(d) Use the data from the table on page 28, and the grid below, to draw a fully-labelled stress/strain graph for this wire. (7 marks)

Description	Marks
choosing a suitable scale to best fit the page	1
stress on vertical, strain on horizontal	1
both axes labelled correctly with dimensions and units	1–2
ruled straight line section	1
neat curve drawn through last two points	1
label on the graph	1
Total	**7**



Question 27 (continued)

(e) From your graph, determine a value for Young's Modulus. Show all working. (3 marks)

Description	Marks
Young's Modulus = Gradient	1
$= (6.02 \times 10^{7} - 0)/(5.07 \times 10^{-4} - 0)$	1
$= 1.19 \times 10^{11}$ N m^{-2} (119 kN mm^{-2})	1
Total	**3**

(f) Refer to the Data book to suggest an appropriate metal that the wire is made of. (1 mark)

Description	Marks
copper	1
Total	**1**
Do not penalise for consequential error arising from candidate's response in part (e).	

(g) From your graph, estimate the stress at which the elastic limit was reached. State a reason for your answer. (2 marks)

Description	Marks
approximately 7.5×10^{7} N m^{-2} (7.5×10^{-2} kN mm^{-2})	1
point at which proportionality finishes	1
Total	**2**

(h) Using the value you determined for the gradient, calculate the strain on the wire when a weight of 0.560 N was hanging from its lower end. (4 marks)

Description	Marks
0.560 N = stress of 1.35×10^{7} N m^{-2}	1–2
gradient = 1.19×10^{11} strain = $1.35 \times 10^{7}/1.19 \times 10^{11}$	1
strain = 1.13×10^{-4}	1
Total	**4**

(i) State the value of Young's Modulus for a cable comprising 100 strands of this same wire and state how you obtained this value. (2 marks)

Description	Marks
1.19×10^{11} N m^{-2} (119 kN mm^{-2}) (Young's Modulus remains the same)	1
it is a property of the material not its dimensions	1
Total	**2**

Question 28 **(22 marks)**

(a) Explain why is important for a static structure, such as a bridge or building, to satisfy the equations 'sum of horizontal/vertical forces equals zero' and 'sum of moments about a point equals zero'. (3 marks)

Description	Marks
important to ensure the structure does not move	1
otherwise the structure will fail or not function correctly	1
this could lead to damage or injury	1
Total	**3**

(b) Calculate the reaction forces at the supports Z and T. (5 marks)

Description	Marks
$\Sigma M_T = 0 = (R_Z \times 3) - (12 \times 0.5) - (18 \times 1.5) - (21 \times 2.5)$ $3R_Z = 6 + 27 + 52.5$ $R_Z = 85.5/3$	1–2
$= 28.5$ kN	1
$\Sigma F_y = 0 = R_T + R_Z - 12 - 18 - 21$ $R_T = 12 + 18 + 21 - R_Z$ $= 51 - 28.5$	1
$= 22.5$ kN	1
Total	**5**

(c) Working to the left of the section aa', use the method of sections to calculate the force in member XY. Specify if the member is in tension or compression. (4 marks)

Description	Marks
$\Sigma Fy = 0 = 22.5 - 12 - 18 + F_{xy}(\sin 60^\circ)$ $F_{xy}(\sin 60^\circ) = 12 + 18 - 22.5$ $F_{xy} = 7.5/\sin 60^\circ$ $= 7.5/0.866$	1–2
$= 8.66$ kN	1
member XY is in tension	1
Total	**4**

Question 28 (continued)

(d) Working to the left of the section aa', use the method of sections to calculate the force in member WY. Specify if the member is in tension or compression. (5 marks)

Description	Marks
$\Sigma M_x = 0 = (-22.5 \times 2) + (12 \times 1.5) + (18 \times 0.5) - F_{wy}(\sin 60^\circ)$ $F_{wy}(\sin 60^\circ) = 18 + 9 - 45$	1–2
$F_{wy} = -18/\sin 60^\circ$ $= -18/0.866$	1
$= -20.8$ kN	1
member WY is in compression	1
Total	**5**

(e) Working to the left of section aa', use the method of sections to calculate the force in member XZ. Specify if the member is in tension or compression. (5 marks)

Description	Marks
$\Sigma Fx = 0 = F_{wy} + F_{xy}\cos 60^\circ + F_{xz}$ $F_{xz} = -F_{wy} - F_{xy}\cos 60^\circ$	1
$= 20.8 - (8.66 \times 0.5)$ Note: $-F_{wy} = -(-20.8) = 20.8$ $= 20.8 - 4.33$	1–2
$= 16.45$ kN	1
member XZ is in tension	1
Total	**5**

Question 29 **(17 marks)**

(a) Consider a solid cylindrical beam of diameter D = 400 mm. Calculate the second moment of area for such a beam. (2 marks)

Description	Marks
$I_{xx} = \pi \times D^4/64$	1
$I_{xx} = \pi \times (400)^4/64 = 1\,256\,637\,061$ mm^4	1
Total	**2**

(b) For a tubular cylindrical beam with the outer diameter D_o equal to twice the inner diameter D_i, calculate the values of D_o and D_i if this beam is to have the same second moment of inertia as the solid cylindrical beam in part (a) above. (4 marks)

Description	Marks
$I_{xx} = \pi \times (D_o^4 - D_i^4)/64$ and if $D_o = 2 \times D_i$	1
$I_{xx} = 1\,256\,637\,061 = \pi \times ((2^4 \times D_i^4) - D_i^4)/64$ $= \pi \times (16D_i^4 - D_i^4)/64 = \pi \times (15D_i^4)/64$	1
$15D_i^4 = (1\,256\,637\,061 \times 64)/\pi$ $D_i^4 = 80\,424\,771\,904/15\pi$ $= 80\,424\,771\,904/47.124$ $= 1\,706\,662\,675$ $D_i = \sqrt[4]{1\,706\,662\,675} = 203.25$ mm	1–2
$D_o = 2 \times 203.25$ mm $= 406.5$ mm	1
Total	**4**

(c) If the solid cylindrical beam from part (a), on page 35, is used in a practical application, determine the difference in the volume per unit length of material required compared to the tubular cylindrical beam from part (b). If you could not calculate an answer for part (b), assume the outer diameter D_o is 420 mm and the inner diameter D_i is 210 mm. (4 marks)

Description	Marks
Cross sectional area solid cylindrical beam: Area $= \pi \times r^2 = \pi \times 200^2 = 125\,664$ mm^2 (0.125 664 m^2)	1
Cross sectional area tubular cylindrical beam: Area $= \pi \times (406.5^2 - 203.25^2)/4$ $= \pi \times (165\,242.25 - 41\,310.56)/4$ $= \pi \times 123\,932/4$ $= 97\,336$ mm^2 (0.097 336 m^2)	1
difference in areas = 125 664 – 97 336 mm^2 = 28 328 mm^2 (0.028328 m^2)	1
additional volume per unit length = 28 328 mm^3 per mm length	1
Total	**4**
If used given values: tubular beam area = 103 908 mm^2 (0.103 908 m^2) difference in areas = 21 756 mm^2 (0.021 756 m^2) additional volume per unit length = 21 756 mm^3 per mm length	

Question 29 **(17 marks)**

(d) Calculate the mass of the tubular cylindrical beam if its length is 5 m and it is made of structural steel. (2 marks)

Description	Marks
Density = 7850 kg m^{-3}	1
Mass = Volume × Density = (5 × 0.097336) × 7850 = 0.48668 × 7850 = 3820.44 kg	1
Total	**2**
If used given values from part (c): Mass = 4078 kg	

(e) If the tubular cylindrical beam is simply supported at both ends, determine the maximum deflection of the beam under the influence of its uniformly distributed weight. If you could not calculate an answer for part (a), assume I_{xx} is 1 250 000 000 mm^4. (5 marks)

Description	Marks
for a simply supported beam, the maximum deflection is given by: $Y = (5 \times F_{UDL} \times L^3)/(384 \times E \times I_{xx})$	1
F_{UDL} = 3820 × 9.8 = 37 436 N	1
L = 5000 mm I_{xx} = 1 256 637 061 mm^4 E = 200 000 N mm^{-2}	1
Y = (5 × 37 440 × 5000^3)/(384 × 200 000 × 1 256 637 061)	1
= 0.24 mm	1
Total	**5**
Note 1: If used I_{xx} is 1 250 000 000 mm^4, Y = (5 × 37 440 × 5000^3)/(384 × 200 000 × 1 250 000 000) = 0.24 mm Note 2: If used outer diameter D_o is 420 mm and the inner diameter D_i is 210 mm, F_{UDL} = 4078 × 9.8 = 39 964 N Y = (5 × 39 964 × 5000^3)/(384 × 200 000 × 1 256 637 061) = 0.26 mm Note 3: If used I_{xx} is 1 250 000 000 mm^4, and if used outer diameter D_o is 420 mm and the inner diameter D_i is 210 mm, Y = (5 × 39 964 × 5000^3)/(384 × 200 000 × 1 250 000 000) = 0.26 mm	

Question 30 **(4 marks)**

Describe how the following modifications made to the tubular cylindrical beam in Question 29 would change the maximum deflection.

(a) A material with a larger value for Young's Modulus. (2 marks)

Description	Marks
decreases	1
provides valid reason	1
Total	**2**

(b) Increasing both the inner and outer diameter of the beam, such that the amount of material in it remains the same. (2 marks)

Description	Marks
decreases	1
provides valid reason	1
Total	**2**

Section Two: Specialised field – Mechatronics **60% (120 Marks)**

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

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

Part B: Extended answer **50% (110 Marks)**

Question 41 **(19 marks)**

(a) Discuss the fundamental difference between an open-loop control system and a closed-loop control system. (4 marks)

Description	Marks
open-loop examples are sequences where an input to a process causes an output that is independent of the input i.e. no feedback	1–2
closed-loop examples incorporate a feedback loop where the actual output is monitored (compared to a reference or fixed point) and maintained at a desired level or condition	1–2
Total	**4**
Accept other relevant answers.	

(b) Give an example of each of these forms of control system and outline why the example you have chosen is relevant to its form of control system. (4 marks)

Description	Marks
electric kettle with boil switch that switches off heating element	1–2
when water boils but does not automatically reheat water as it cools	
aquarium where water heater	1–2
maintains temperature of water kept at a constant level	
Total	**4**
Accept other relevant answers.	
Note: The above are indicative only. There are many possibilities – award marks for correct examples that comply to the explanations given for part (a) of this question.	

(c) (i) Name and state the purpose of the parts labelled A, B, C and D. (8 marks)

	Description	Marks
A	error detector or comparator	1
	compares set point or desired condition/output to actual output from feedback/sensor and sends error signal to controller	1
B	controller or decision	1
	uses signal from error detector to produce the response from the plant or process.	1
C	plant or process	1
	produces the output of the system.	1
D	feedback or sensor	1
	measures the actual output of the system and inputs this to the error detector.	1
	Total	**8**
Accept other relevant answers.		

Question 41 (continued)

(ii) The type of control system on page 41 makes use of 'negative feedback'. Explain how this works. (3 marks)

Description	Marks
negative feedback measures the output	1
compares this to the desired condition	1
and adjusts the system to match as closely as possible	1
Total	**3**
Accept other relevant answers.	

Question 42 **(21 marks)**

(a) (i) Calculate I_{R2}, the current that flows through R2. (3 marks)

Description	Marks
$I_{R2} = I_{R1} = I_{(R1+R2)} = \dfrac{9}{(R_1 + R_2)} = \dfrac{9}{(220 + 680)} = \dfrac{9}{900}$	1–2
$= 0.01$ A or 10 mA or 1.0×10^{-2} A	1
Total	**3**
Accept other valid methods of calculation.	

(ii) Calculate P_{R1}, the power dissipated by R1. (3 marks)

Description	Marks
$P_{R1} = I^2 \times R = 0.01^2 \times 220 = 0.0001 \times 220$	1–2
$= 0.022$ W or 22 mW or 2.2×10^{-2} W	1
Total	**3**
Accept other valid methods of calculation.	

(b) Calculate $R4$, the resistance of R4. (7 marks)

Description	Marks
$V_{R2} = I_{R2} \times R2 = 0.01 \times 680$ $= 6.8$ V	1
$\Sigma\Delta V = 0 = 9 - V_{R3} - V_{AB} - V_{R2}$ $V_{R3} = 9 - 0.58 - 6.8$ $= 1.62$ V	1–2
$\Sigma\Delta V = 0 = 9 - V_{R3} - V_{R4}$ $V_{R4} = 9 - 1.62$ $= 7.38$ V	1
$I_{R4} = I_{R3} = \dfrac{1.62}{180}$ $= 0.009$ A	1
$R4 = \dfrac{V_{R4}}{I_{R4}} = \dfrac{7.38}{0.009}$	1
$= 820\ \Omega$	1
Total	**7**
Accept other valid methods of calculation.	

(c) Calculate I_{AB}, the current that flows from A to B. If you could not calculate an answer for part (b), use $R4$ = 1 kΩ. (8 marks)

Description		Marks
$R_1 \parallel R_3 = \dfrac{(220 \times 180)}{(220 + 180)} = \dfrac{39\ 600}{400} = 99\ \Omega$		1
$R_2 \parallel R_4 = \dfrac{(680 \times 820)}{(680 + 820)} = \dfrac{557\ 600}{1500} = 371.7\overline{3}\ \Omega$		1
$V_{R1} = V_{R3} = 9 \times \dfrac{99}{(99 + 371.7\overline{3})} = \dfrac{891}{470.7\overline{3}} = 1.893$ V		1–2
$V_{R2} = V_{R4} = 9 - 1.89 = 7.107$ V		1
Alternative solutions for calculating I_{AB}		
Using left hand side	or Using right hand side	
$I_{R1} = \dfrac{1.893}{220} = 0.00860$ A	$I_{R3} = \dfrac{1.893}{180} = 0.01052$ A	1
$I_{R2} = \dfrac{7.107}{680} = 0.01045$ A	$I_{R4} = \dfrac{7.107}{820} = 0.00867$ A	1
$\Sigma I = 0 = I_{R1} + I_{AB} - I_{R2}$ $I_{AB} = 0.01045 - 0.0086$ $= 0.00185$ A	$\Sigma I = 0 = I_{R3} - I_{AB} - I_{R4}$ $I_{AB} = 0.01052 - 0.00867$ $= 0.00185$ A	1
Total		**8**

Accept other valid methods of calculation and allow for some rounding.
If using $R4$ = 1 kΩ then:
$R_1 \parallel R_3 = 99\ \Omega$, $R_3 \parallel R_4 = 404.762\ \Omega$, $V_{R1} = V_{R3} = 1.769$ V, $V_{R2} = V_{R4} = 7.231$ V,
Left hand side $I_{R1} = 0.00804$ A, $I_{R2} = 0.01063$ A, $I_{AB} = 0.00259$ A
OR Right hand side $I_{R3} = 0.00983$ A, $I_{R4} = 0.00723$ A, $I_{AB} = 0.0026$ A

Question 43 **(22 marks)**

(a) (i) Explain why the voltage signal detected at pin A0 will change when the spindle of the potentiometer is rotated to a different position. (3 marks)

Description	Marks
RV is a form of voltage divider	1
as the spindle rotates, so too does the relative resistances either side of the wiper	1
voltage is proportional to these relative resistances and thus the voltage at pin A0 will change with rotation of the spindle of RV	1
Total	**3**
Accept other relevant answers.	

(ii) Suppose the spindle of the potentiometer is adjusted such that the resistance between the wiper and the connection to ground is 25 660 Ω. The resolution of the ADC at pin A0 is 10-bit. Calculate, to the nearest whole number, the value registered by the ADC. (3 marks)

Description	Marks
10-bit value = $\frac{25\,660}{50\,000} \times 1023$	1–2
$= 525$	1
Total	**3**
Accept other valid methods of calculation.	

(iii) Pin O5 of the microcontroller utilises 8-bit pulse-width-modulation for speed control of the motor. This 8-bit output is mapped to the 10-bit input from pin A0. Calculate, to the nearest whole number, the 8-bit value produced when the spindle of RV is adjusted as described in part (a)(ii). If you could not calculate an answer for part (a)(ii) assume the 10-bit value is 520. (3 marks)

Description	Marks
8-bit value = $\frac{255}{1023} \times 525$	1–2
$= 131$	1
Total	**3**
Accept other valid methods of calculation. Answer is 130 if using 520 as the 10-bit value.	

(iv) If the frequency of the pulse-width-modulation at pin O5 is 200 Hz, and the spindle of RV is in the position described in part (a)(ii), calculate the duration of each cycle (period), low time and high time. Answer using milliseconds (ms). If you could not calculate an answer for part (a)(iii) assume the 8-bit value is 125. (3 marks)

Description	Marks
period = $\frac{1}{200}$ = 0.005 s = 5 ms	1
low time = 5 – 2.57 = 2.43 ms	1
high time = $\frac{131}{255}$ × 5 = 2.57 ms	1
Total	**3**
Accept other valid methods of calculation. If using 8-bit value 125: high = 2.45 ms and low = 2.55 ms	

(b) (i) Calculate R_{MAX}, the maximum value for the resistor connected to the base of the transistor, R, required to drive the transistor into saturation. (5 marks)

Description	Marks
Because $V_{CE,SAT}$ = 0 V all voltage is held across the motor terminals.	
$I_C = \frac{P_M}{V_M} = \frac{0.81}{9}$ = 0.09 A	1
$I_B = \frac{0.09}{\beta} = \frac{0.09}{40}$ = 0.00225 A	1
$R = \frac{(5 - 0.7)}{0.00225} = \frac{4.3}{0.00225}$	1–2
= 1911 Ω	1
Total	**5**
Accept other valid methods of calculation.	

(ii) For a practical circuit, an E12 preferred value resistor will need to be used. This should be as close to ideal value as possible and still drive the transistor into saturation. State what value would be selected and give its 4-band colour code, assuming a tolerance of ± 5%. If you could not calculate an answer for part (b)(i), assume it is 200 Ω. (2 marks)

Description	Marks
1800 Ω	1
Brown grey red gold	1
Total	**2**
Note: if used 200 Ω, then use 180 Ω so brown grey brown gold	

Question 43 (continued)

(iii) If the resistance of the selected resistor is actually 1.5% lower than its marked value, calculate P_R, the power it dissipates as heat. (3 marks)

Description	Marks
$R = 1800 - \dfrac{(1800 \times 1.5)}{100} = 1800 - 27$ $= 1773\ \Omega$	1
$P_R = \dfrac{V^2}{R} = \dfrac{4.3^2}{1773}$	1
$= 0.01043$ W	1
Total	**3**
Accept other valid methods of calculation.	
Note: if used 180 Ω, $P_R = 0.1043$ W	

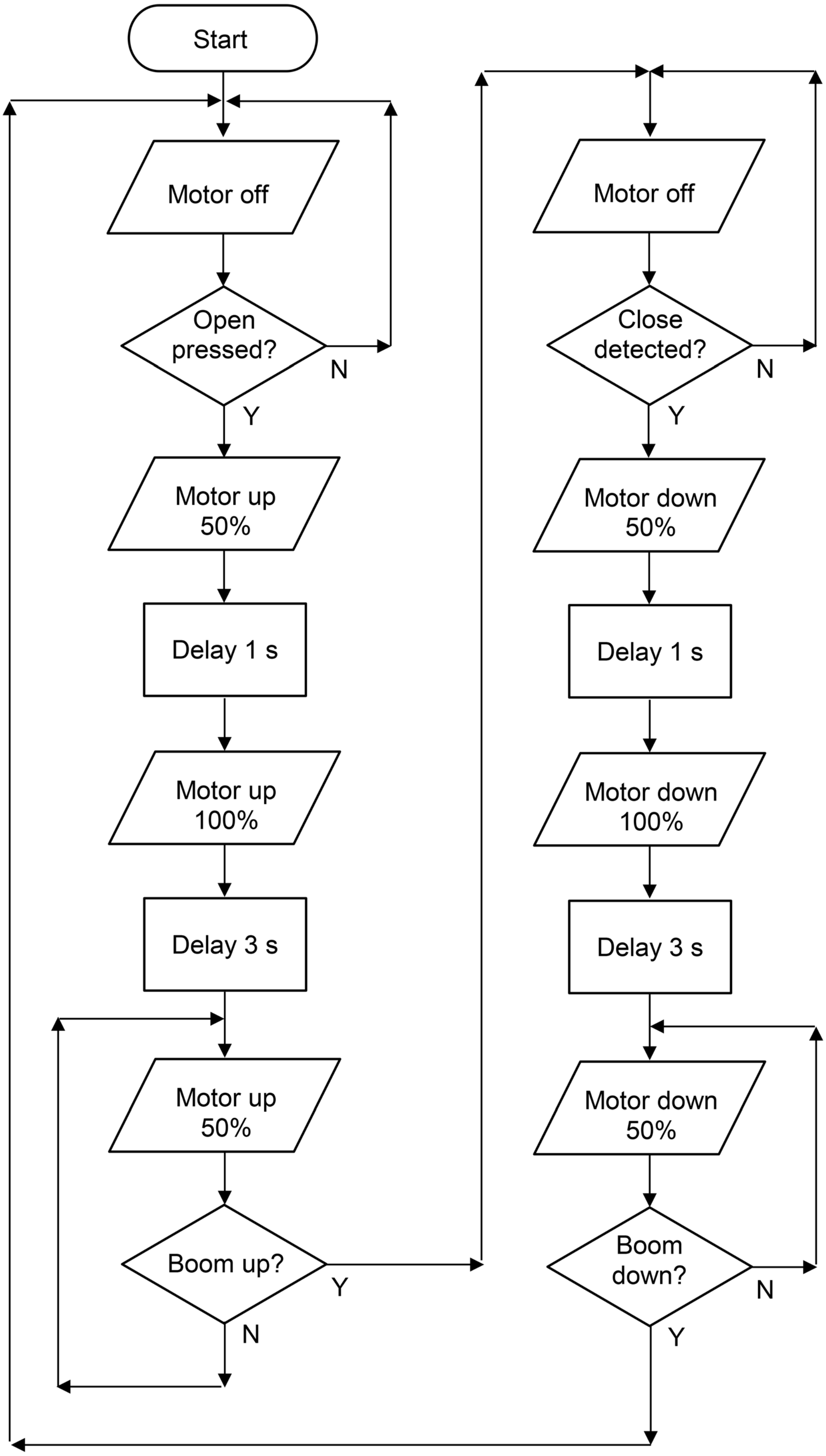
Question 44 **(19 marks)**

(a) Calculate $VR_{GEARBOX}$, the velocity ratio of the gearbox fitted to the 540 r.p.m. reversible electric motor if the boom is to rotate at full speed. Assume the system operates at 100% efficiency. (9 marks)

Description	Marks
$C = \pi d = \pi \times 2 \times 3.25 = 20.42$ m	1
$Output\ speed\ r.p.m. = \dfrac{(1.021 \times 60)}{20.42} = 3$ r.p.m.	1–2
$VR_{WORM} = \dfrac{n^{o}\ teeth\ worm\ wheel}{1} = \dfrac{24}{1} = 24$	1
$VR_{SPROCKET} = \dfrac{n^{o}\ teeth\ follower\ gear}{n^{o}\ teeth\ driver\ gear} = \dfrac{24}{16} = 1.5$	1
$Output\ speed\ r.p.m. = \dfrac{Input\ speed\ r.p.m.}{VR_{Total}}$	1–3
$3 = \dfrac{540}{(VR_{GEARBOX} \times VR_{WORM} \times VR_{SPROCKET})}$	
$= \dfrac{540}{VR_{GEARBOX} \times 24 \times 1.5}$	
$36\ VR_{GEARBOX} = \dfrac{540}{3}$	
$VR_{GEARBOX} = \dfrac{166.667}{36}$	
$= 5$ or 5:1	1
Total	**9**
Accept other valid methods of calculation.	

Question 44 (continued)

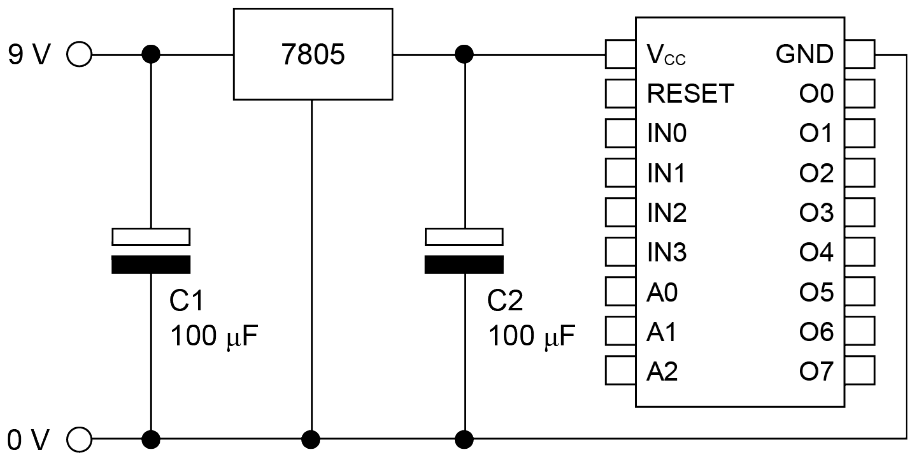
(b) On page 53, create a fully-labelled flow chart that will satisfy all the requirements of the system described above. (10 marks)



Description	Marks
when the boom is at rest (horizontal) the motor is off	1
pressing ‘Open’ causes boom to move upwards	1
motor at 50% speed for 1 second upwards and motor at 100% speed for 3 second upwards	1
motor at 50% speed upwards until boom position is detected by ‘Boom up’	1
motor stops when ‘Boom up’ detects boom in vertical position	1
‘Close’ detecting vehicle leaving boom gate area causes boom to move downwards	1
motor at 50% speed for 1 second downwards and motor at 100% speed for 3 second downwards	1
motor at 50% speed downwards until boom position is detected by ‘Boom down’	1
motor stops when ‘Boom down’ detects boom in horizontal position	1
flow chart loops	1
Total	**10**
It is likely that candidates will present flow charts that differ to the one shown in the marking key. Accept other forms of flow chart but the award of marks must still be as shown above.	

Question 45 **(15 marks)**

(a) To achieve this, the following need to be added to the circuit: 9 VDC power supply unit, 7805 voltage regulator, and **two** 100 µF capacitors. In the space above, complete a fully labelled circuit diagram that correctly connects these additional components to the microcontroller. (5 marks)



Description	Marks
9 VDC power supply unit has labelled 9 V and 0 V (or GND) terminals	1
labelled 7805 voltage regulator symbol has terminal connected to 9 VDC positive terminal of power supply	1
both capacitors have correct symbols, are labelled and in correct positions	1
output terminal of 7805 voltage regulator connected to Vcc pin of microcontroller	1
common 0 V (and/or GND) connections between power supply, voltage regulator, both capacitors and GND pin of microcontroller	1
Total	**5**

(b) (i) For this type of circuit, outline what is meant by 'smoothing'. (2 marks)

Description	Marks
smoothing is the removal or reduction of ripple (spikes and falls) in the voltage supplied to the circuit	1–2
Total	**2**
Accept other relevant answers.	

(ii) State why this is necessary for a microcontroller. (2 marks)

Description	Marks
ripple can be detected as false information (signals)	1
and cause an error or malfunction of the operation of the microcontroller	1
Total	**2**
Accept other relevant answers.	

(c) (i) Calculate $C1$, the capacitance of C1. Answer in units of μF. (5 marks)

Description	Marks
$C_{TOTAL} = C_3 + \dfrac{(C_1 \times C_2)}{(C_1 + C_2)}$ $3.4 = 3.3 + \dfrac{(C_1 \times 10)}{(C_1 + 10)}$	1–2
$0.1 = \dfrac{(C_1 \times 10)}{(C_1 + 10)}$ $0.1C_1 + 1 = 10C_1$ $1 = 9.9C_1$ $\therefore C_1 = \dfrac{1}{9.9}$	1–2
$= 0.1$ μF	1
Total	**5**
Accept other valid methods of calculation.	

(ii) C1 is a non-polarised capacitor, its value is marked using a 3-digit number. What is its 3-digit marking? (1 mark)

Description	Marks
104, or correct 3-digit code for the value obtained in (c)(i)	1
Total	**1**

Question 46 **(14 marks)**

(a) (i) State which of the LEDs will glow when O2 is low. Explain why. (3 marks)

Description	Marks
LED1	1
the potential difference across LED1 and R1 will be 5 V	1
and this will cause a current to flow and hence LED1 will glow	1
Total	**3**

(ii) Outline why the other LED will be off when O2 is low. (2 marks)

Description	Marks
the potential difference across LED2 and R2 will be 0 V	1
and thus no current will flow to cause LED2 to glow	1
Total	**2**

(iii) When O2 changes from low to high, the LED that was previously glowing will now be off. Explain why this occurs. (3 marks)

Description	Marks
the voltage at the top of LED1 is 5 V as is the voltage at the bottom of R1	1
thus the potential difference across LED1 and R1 will be 0 V	1
and therefore no current will flow to cause LED1 to glow	1
Total	**3**

(b) Given that the forward-voltage of LED1 = 1.9 V, and R1 is 330 Ω, calculate P_T, the total power dissipated by these two components when LED1 when it is glowing. (6 marks)

Description	Marks
$I_{R1} = \dfrac{(5 - 1.9)}{330} = \dfrac{3.1}{330} = 0.009394$ A	1–2
$= 0.009394$ A	1
$P_{R1} = I_{R1}^2 \times R = 0.009394^2 \times 330 = 0.02912$ W or $P_{R1} = I_{R1} \times V_{R1} = 0.009394 \times 3.1 = 0.02912$ W	1
since $I_{R1} = I_{LED}$ (KCL) $P_{LED1} = I_{LED} \times V_{LED} = 0.009394 \times 1.9 = 0.0178485$ W	1
$P_T = P_{R1} + P_{LED1} = 0.02912 + 0.0178485 = 0.04697$ W	1
Total	**6**
Accept other valid methods of calculation and allow for appropriate rounding.	

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