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

ENGINEERING STUDIES

ATAR course examination 2024

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 **10% (10 Marks)**

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

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

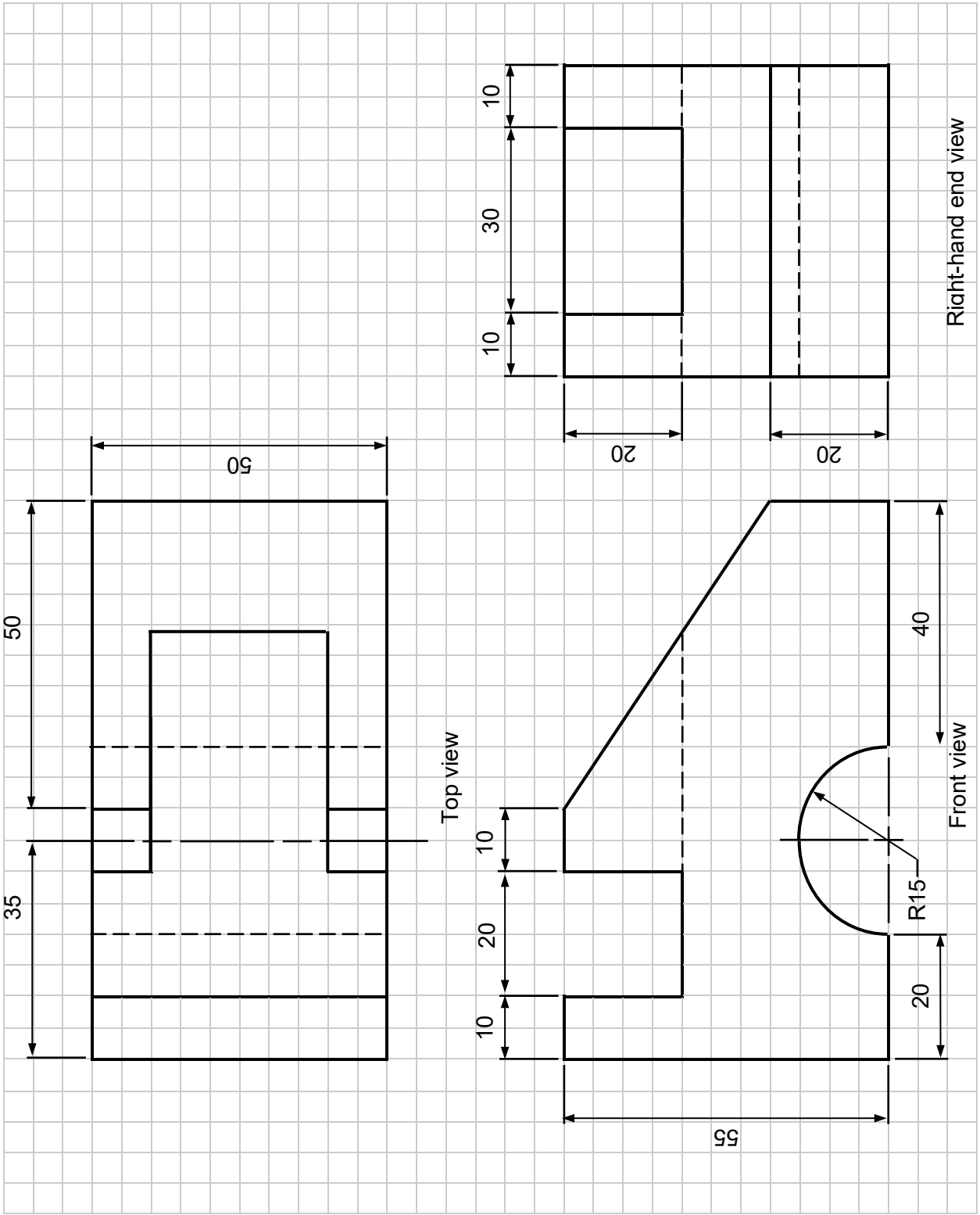
Part B: Extended response **30% (65 Marks)**

Question 11 **(22 marks)**

(a) Using 3rd angle orthographic projection conventions, complete fully dimensioned* and labelled drawings of the top, front and right-hand end views of the block on the grid provided on page 7. The semicircular groove, as seen in the front view, is given. Each square of the grid represents 5 mm × 5 mm. (9 marks)
* No need to dimension angles.

Description	Marks
Positions all the three views correctly	1
Labels all the three views correctly	1
Front, top and right-hand end view outlines correct	1
Hidden detail for front, top and right-hand end views correct	1
Centrelines for front and top views correct	1
Sufficient dimensions to determine overall height, length and width of block Note: These can be direct, indirect or a combination	1
Sufficient dimensioning to determine size of splay, ribs and 'T' section located at top of block	1
Correct dimensioning for radius of semicircular groove	1
Location of centre for semicircular groove dimensioned correctly	1
Total	**9**

Question 11 (continued)



(b) Calculate the perimeter of the surface labelled 'A' on the drawing on page 6. Answer in units of millimetres (mm). (3 marks)

Description	Marks
sloping edge = $\sqrt{35^2 + 50^2}$ = $\sqrt{3725}$ = 61.033 mm	1
semicircle = $0.5\pi d$ = $0.5\pi \times 30 = 47.124$ mm	1
perimeter = 55 + 10 + 20 + 20 + 20 + 10 + 61.033 + 20 + 40 + 47.124 + 20 = 323.157 mm	1
Total	**3**
Accept other valid methods for calculating the answer, e.g. sloping edge = $\frac{35}{\sin 34.992°}$ = 61.033 mm	

(c) Prove by calculation that the area of the surface labelled 'B' is very close to 486 mm^2 (3 marks)

Description	Marks
triangular area = $0.5 \times \frac{20}{\tan 34.992°} \times 20$	1
= 285.714 mm^2	1
small rectangle = $10 \times 20 = 200$	1
area of surface B = $285.714 + 200 = 485.714$ mm^2	
Total	**3**

Question 11 (continued)

(d) The block is 3D-printed using acrylonitrile butadiene styrene (ABS). The density of ABS is 1050 kg m^3 and the block is printed as a solid, i.e. 100% fill. Calculate the mass of the block. Answer in units of kilograms (kg). (7 marks)

Description		Marks
enclosing rectangular prism =	$55 \times 90 \times 50 = 247\,500$ mm^3	1
semicircular groove =	$0.5\pi r^2 \times 50$ $0.5\pi \times 15^2 \times 50 = 17\,671.459$ mm^3	1
large triangular wedge =	$0.5 \times 35 \times 50 \times 50 = 43\,750$ mm^3	1
smaller triangular wedge and rectangular prism =	area of surface B × 30	
=	$485.714 \times 30 = 14\,571.42$ mm^3	1
larger rectangular prism =	$20 \times 20 \times 50 = 20\,000$ mm^3	1
block volume (v) =	$247\,500 - 17671.459 - 43\,750$ $- 14\,571.42 - 20\,000$	1
=	151 507.121 mm^3	
m =	$\rho \times v = 1050 \times 0.000\,151\,507\,121$	
=	0.159 kg	1
	Total	**7**

Question 12 **(23 marks)**

(a) For each of the following engineered products, name and define a requisite property of the material it is made from. For each property, explain how it ensures the product functions as it is intended **and** explain the outcome to the functionality of the product if the material does not contain that property. Do **not** repeat a property when answering this question. (12 marks)

Description	Marks
For each engineered product (4 x 3 marks)	
Names and defines the property of the material	1
Explains how the property ensures the product functions as it is intended	1–2
Subtotal	**3**
Total	**12**

Answers could include:

Handle of hammer
- Property and definition: stiffness – ability of a material to resist deformation under load
- Explanation: When moving the hammer to strike its target, the head and handle need to remain aligned. Otherwise, the target would be missed and its energy not transferred to do the intended work.

Bicycle helmet
- Property and definition: toughness (alternatively low density) – ability of a material to absorb energy when being plastically deformed without failure or rupture
- Explanation: by absorbing energy from a sudden impact, injury to the wearer will be reduced.

Ladder to clean second storey windows
- Property and definition: strength – ability of a material to not fail under load
- Explanation: The ladder must support the load of a worker when working at height. Otherwise, they would fall, resulting in serious injury.

Staples to bind paper
- Property and definition: plastic deformation – ability of a material to undergo permanent deformation without rupture occurring
- Explanation: to perform its function, the ends of the staple must permanently deform (fold) without snapping.

Accept other valid properties with definitions and explanations.

Question 12 (continued)

(b) Referring to properties other than corrosion, describe **two** reasons why stainless steel is preferred to aluminium. (4 marks)

Description	Marks
stainless steel is stronger than aluminium and is much less likely to fail when supporting the load of a swimmer grasping the handrail	1–2
stainless steel is a poorer conductor of heat than aluminium and, when exposed to the sun, will be cooler and more comfortable to grasp	1–2
Total	**4**
Accept other relevant answers.	

(c) Describe what is meant by the term 'composite material'. (3 marks)

Description	Marks
material which is produced from two or more constituent materials	1
constituent materials have dissimilar properties	1
and are combined to create a material with properties unlike the individual elements that make it a superior material for a particular engineering application	1
Total	**3**
Accept other relevant answers.	

(d) Identify the location (A, B or C) that should be used for the mesh. Justify your choice. (4 marks)

Description	Marks
A	1
the load (car) will cause the top of the concrete driveway to be under tension	1
since concrete is likely to crack when placed under tension	1
it is best to position the reinforcement mesh, which is very strong under tension, in position A, to prevent the top surface of the concrete driveway from cracking	1
Total	**4**

Question 13 **(20 marks)**

(a) Prove by calculation that the power station using the supplied fuel rods should be able to deliver to an electricity grid a daily supply very close to 23.3 GW h of electrical energy. (3 marks)

Description	Marks
$E_T = \eta\beta m\kappa$	
$= 0.33 \times 0.043 \times (67 \times 1000) \times 24\,475$	1–2
$= 23\,269\,116.75$ kW h	
$= \dfrac{23\,269\,116.75}{1\,000\,000} = 23.269$ GW h	1
Total	**3**
Allow for rounding.	

A typical household uses an average of 73.8 MJ of energy each day.

(b) Determine the maximum number of households the power station could supply if production meets the daily target from part (a) of 23.3 GW h. (3 marks)

Description	Marks
Converting from MJ to W h	
$73.8 \text{ MJ} = \dfrac{73\,800\,000}{3600} = 20\,500$ W h	1
Converting to GW h	
20 500 W h = 0.000 020 5 GW h	1
Determining number of households	
number of households $= \dfrac{23.269}{0.000\,020\,5} = 1\,135\,073$	1
Total	**3**
Allow for rounding. If using 23.3 GW h, then the answer is 1 136 585 households.	

(c) (i) Calculate the future daily output that will be required by the power station. Answer in units of gigawatt hours (GW h). (1 mark)

Description	Marks
Future daily output = 0.000 020 5 × 1 400 000 = 28.7 GW h	1
Total	**1**

(ii) Calculate η, the new efficiency value necessary for the power station to meet this target. Answer as a percentage (%). (3 marks)

Description	Marks
$E_T = \eta\beta m\kappa$	
$\eta = \dfrac{E_T}{\beta m\kappa} = \dfrac{28\,700\,000}{0.043 \times (67 \times 1000) \times 24\,475}$	1
$= 0.407$	1
$= 40.7\%$	1
Total	**3**
Allow for rounding. Accept alternative methods for correctly calculating the answer.	

Question 13 (continued)

(d) State **two** advantages of producing electrical power using nuclear energy and, for each advantage, state **one** reason why this is viewed as being beneficial. (4 marks)

Description	Marks
Advantage one: no greenhouse gases are released to the environment – only water vapour	1
Reason: this reduces the effects of global warming that if unchecked will result in detrimental weather patterns	1
Advantage two: extremely high energy content	1
Reason: large scale production of electrical energy is available 24/7	1
Total	**4**
Accept other relevant answers.	

(e) State **two** disadvantages of using nuclear energy to produce electricity. For each disadvantage, state **two** reasons why this is viewed as being detrimental. (6 marks)

Description	Marks
Disadvantage one: huge quantities of water are required to condense steam back into water as a part of the production of electrical energy	1
Reason one: when released back into the environment this can disrupt ecosystems	1
Reason two: the consumption of so much water might become unsustainable if other priorities must be met e.g. drinking or agriculture	1
Disadvantage two: radioactive waste	1
Reason one: radioactive waste takes a very long time before it becomes safe for contact with the environment and ecosystems	1
Reason two: there is a risk that long-term storage will be compromised and dangerous material will escape	1
Total	**6**
Accept other relevant answers.	

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

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

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

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

Question 24 **(15 marks)**

(a) A stress of 75 N mm^{-2} is applied to wire samples of aluminium, brass and copper.

(i) Which of the samples will enter the plastic region of deformation and which will remain within the elastic region by circling the correct answer. (3 marks)

Description	Marks
aluminium – elastic region	1
brass – plastic region	1
copper – plastic region	1
Total	**3**

(ii) Explain the reasoning for your answers. (2 marks)

Description	Marks
aluminium has a yield stress greater than the applied stress and so will remain within the elastic region	1
the applied stress exceeds the yield stress of brass and copper and so these materials will enter the plastic region of deformation	1
Total	**2**

(b) Calculate the diameter of a spoke used for the bicycle wheel. The tensile loading of the spoke is 150 N and the stress is 52.91 N mm^{-2}. Answer in units of millimetres (mm). (5 marks)

Description	Marks
$\sigma = \frac{F}{A}$	
$A = \frac{F}{\sigma} = \frac{150}{52.91}$	1
$= 2.835 \text{ mm}^2$	1
$A = \pi r^2$ $r^2 = \frac{2.835}{\pi} = 0.9024$	1
$r = \sqrt{0.9024}$ $= 0.95 \text{ mm}$	1
diameter = 1.9 mm	1
Total	**5**

(c) Calculate the elongation of a spoke under the conditions described. Answer in units of millimetres (mm). (5 marks)

Description	Marks
$\Delta L = \frac{FL}{AE}$	
$= \frac{150 \times 293}{2.835 \times 200\,000} = \frac{43\,950}{567\,000}$	1–4
$= 0.0775 \text{ mm}$	1
Alternative solution	
$\varepsilon = \frac{\sigma}{E} = \frac{52.91}{200\,000}$	1–2
$= 0.000\,264\,55$	1
$\Delta L = \varepsilon \times L = 0.000\,264\,55 \times 293$	1
$= 0.0775 \text{ mm}$	1
Total	**5**
Allow for rounding.	

Question 25 **(12 marks)**

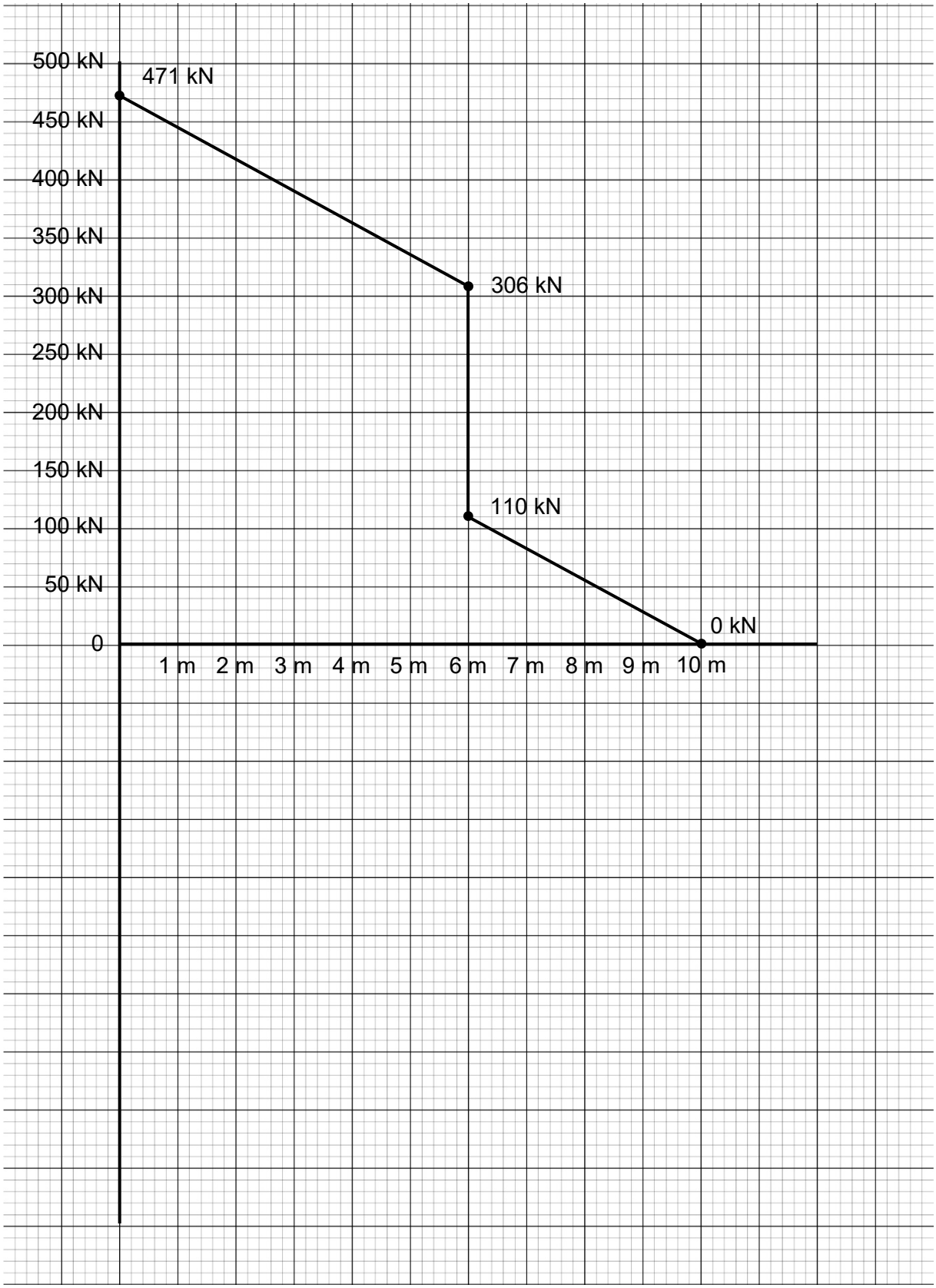
(a) Calculate the shear forces at the following four locations. Answer in units of kilonewtons (kN). (7 marks)

SF_1 = the supported end
SF_2 = just to the left of the 20 000 kg mass
SF_3 = just to the right of the 20 000 kg mass
SF_4 = the unsupported end

Description	Marks
SF_1 = vertical reaction at supported end i.e. 20(9.8) + 27.5(10)	1
= 471 kN	1
SF_2 = 471 – 27.5(6) = 471 – 165	1
= 306 kN	1
SF_3 = 306 – 20(9.8) = 306 – 196	1
= 110 kN	1
SF_4 = 110 – 27.5(4)	
= 110 – 110	
= 0 kN	1
Total	**7**

(b) On the grid provided below, sketch a suitably scaled and fully labelled shear force diagram of the loaded beam. Both axes for the shear force diagram have been provided. (5 marks)

Description	Marks
Label axes with correct units i.e. kN on vertical axis and m on horizontal axis	1
Draws diagram using suitable scale for both axes	1
Shows all calculated SF values on diagram	1
Straight line behaviour for point loads	1
Sloping line for UDL	1
Total	**5**


500 kN
450 kN
400 kN
350 kN
300 kN
250 kN
200 kN
150 kN
100 kN
50 kN
0
471 kN
306 kN
110 kN
0 kN
1 m
2 m
3 m
4 m
5 m
6 m
7 m
8 m
9 m
10 m

Question 26 **(12 marks)**

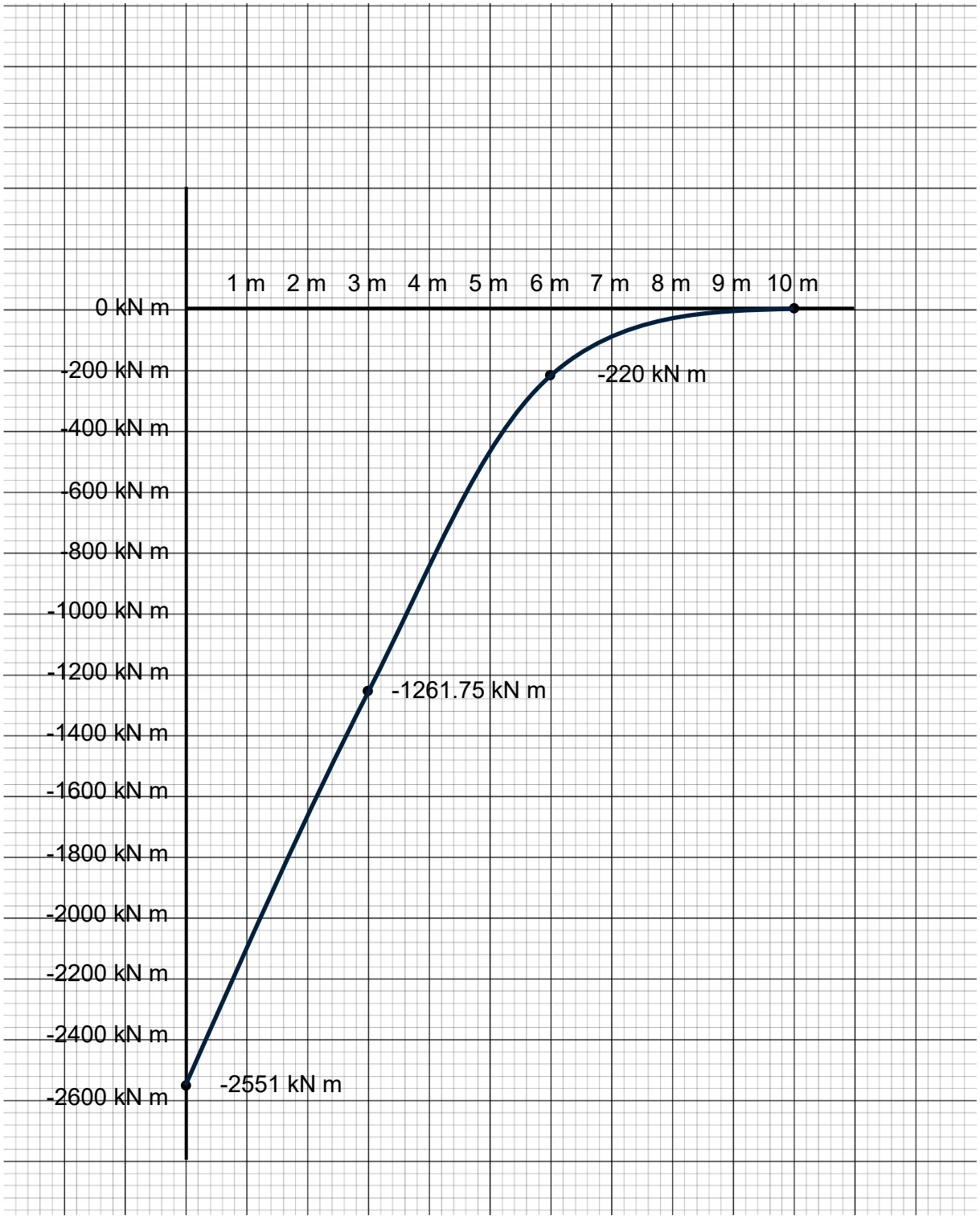
(a) Working from left to right, calculate the bending moments at the following four locations. Answer in units of kilonewtons metres (kN m). (8 marks)

BM_1 = the supported end
BM_2 = 3 m to the right of the supported end
BM_3 = 6 m to the right of the supported end
BM_4 = the unsupported end

Description	Marks
BM_1 = reaction moment at supported end = −2551 kN m Note: working from right to left will give a positive value and is not following the instruction given.	1
$BM_2 = -2551 + 471(3) - \frac{(27.5 \times 3)3}{2}$ $= -2551 + 1413 - 123.75$	1
$= -1261.75$ kN m	1
$BM_3 = -2551 + 471(6) - \frac{(27.5 \times 6)6}{2}$ $= -2551 + 2826 - 495$	1
$= -220$ kN m	1
$BM_4 = -2551 + 471(10) - \frac{(27.5 \times 10)10}{2} - 196(4)$ $= -2551 + 4710 - 1375 - 784$	1–2
$= 0$ kN m	1
Total	**8**

(b) On the grid provided below, sketch a suitably scaled and fully labelled bending moment diagram of the loaded beam. The vertical axis for the bending moment diagram has been provided. (4 marks)

Description	Marks
Labels axes with correct units i.e. kN m on vertical axis and m on horizontal axis	1
Draws diagram using suitable scale for both axes	1
Shows all calculated BM values on diagram	1
Correct shape i.e. parabolic curves	1
Total	**4**


1 m
2 m
3 m
4 m
5 m
6 m
7 m
8 m
9 m
10 m
0 kN m
-200 kN m
-400 kN m
-600 kN m
-800 kN m
-1000 kN m
-1200 kN m
-1400 kN m
-1600 kN m
-1800 kN m
-2000 kN m
-2200 kN m
-2400 kN m
-2600 kN m
-220 kN m
-1261.75 kN m
-2551 kN m

Question 27 **(19 marks)**

(a) Consider one trial where a vehicle accelerates uniformly from rest for the whole 400 m distance, completing the trial in 14.2 seconds.

(i) Calculate a, the uniform acceleration of the vehicle. Answer in units of metres per second squared (m s^{-2}). (3 marks)

Description	Marks
$s = ut + \frac{1}{2}at^2$	
$400 = (0 \times 14.2) + \left(\frac{1}{2} \times a \times 14.2^2\right)$ $= \frac{1}{2} \times a \times 14.2^2$	1
$a = \frac{2 \times 400}{14.2^2}$ $= \frac{800}{201.64}$	1
= 3.967 m s^{-2} (rounded from 3.967 467)	1
Total	**3**

(ii) Calculate v, the velocity of the vehicle, at the 400 m mark. Answer in units of kilometres per hour (km h^{-1}). If you could not obtain an answer for part (a)(i) then use a = 4.0 m s^{-2}. (3 marks)

Description	Marks
$a = \frac{v-u}{t}$	
$3.967 = \frac{v-0}{14.2}$	1
v = 3.967 × 14.2 = 56.338 m s^{-1}	1
convert to km h^{-1}	
$= \left(\frac{56.338}{1000}\right) \times 60 \times 60$	
= 202.817 km h^{-1}	1
Total	**3**
Alternative solution:	
$v^2 = u^2 + 2as$ = $0^2 + 2 \times 3.967 \times 400$ = 3173.973	1
$v = \sqrt{3173.973}$ = 56.338 m s^{-1}	1
convert to km h^{-1} $= \left(\frac{56.338}{1000}\right) \times 60 \times 60$ = 202.817 km h^{-1}	1
Total	**3**
If using 4.0 m s^{-1} = 203.647 km h^{-1}.	

(b) (i) Calculate E_k, the kinetic energy of the vehicle, at the 400 m mark, assuming it has a mass of 1500 kg. Answer in units of joules (J). (3 marks)

Description	Marks
convert km h^{-1} to m s^{-1} 216 km h^{-1} = $\left(\frac{216 \times 1000}{60 \times 60}\right)$ = 60 m s^{-1}	1
$E_k = \frac{1}{2}mv^2$	
$= \frac{1}{2}1500 \times 60^2$	1
= 2 700 000 J	1
Total	**3**

(ii) Calculate F, the force supplied by the vehicle to reach the 400 m mark at 13.333 seconds after starting. Answer in units of newtons (N). (3 marks)

Description		Marks
W =	Fs	
F =	$\frac{W}{s} = \frac{2\ 700\ 000}{400}$	1–2
=	6750 N	1
	Total	**3**
Alternative solution:		
F =	$ma = m\left(\frac{v-u}{t}\right)$	
=	$1500\left(\frac{60-0}{13.333}\right)$	1–2
=	6750 N	1
	Total	**3**

(iii) Calculate P, the average power of the vehicle, in reaching the 400 m mark. Answer in units of watts (W). (3 marks)

Description	Marks
$P = \frac{Fs}{t} = \frac{6750 \times 400}{13.333}$	1–2
= 202 505 W	1
Total	**3**
Award marks for other valid methods of calculating the correct answer e.g. $E = Pt$ or $P = FV_{av}$	

Question 27 (continued)

Racetrack regulations require a minimum length of track to be installed to cater for brake failure. The average friction of the track is a deceleration of 1 m s^{-2} and the maximum expected velocity at the 400 m mark is 65 m s^{-1}.

(c) Calculate l, the minimum length of track from the start line to cater for brake failure of a vehicle at the 400 m mark. Answer in units of metres (m). (4 marks)

Description	Marks
$v^2 = u^2 + 2as$	
$0 = 65^2 + 2(-1)s$ $= 4225 - 2s$	1
$s = \frac{4225}{2}$	1
$= 2112.5$ m	1
$l =$ 400 + 2112.5 = 2512.5 m	1
Total	**4**

Question 28 **(21 marks)**

(a) The second moment of area, I_{xx}, of the cantilever beam is 14 568 645 mm^{-4}. Prove by calculation that the wall thickness of the circular tube is 5 mm. (6 marks)

Description	Marks
$I_{xx} = \dfrac{\pi\left(D_o^{\,4} - D_{io}^{\,4}\right)}{64}$	
$14\,568\,645 = \dfrac{\pi\left(200^4 - D_i^{\,4}\right)}{64}$ $932\,393\,280 = \pi 200^4 - \pi D_i^4$ $\pi D_i^4 = 5\,026\,548\,245.744 - 932\,393\,280$ $= 4\,094\,154\,966$ $D_i^4 = \dfrac{4\,094\,154\,966}{\pi}$	1–2
$= 1\,303\,210\,001$	1
$D_i = \sqrt[4]{1\,303\,210\,001}$	1
$= 190$ mm	1
wall thickness $= \dfrac{D_o - D_i}{2}$	
$= \dfrac{200-190}{2} = 5$ mm	1
Total	**6**

(b) Prove by calculation that the mass of the cantilever beam (to three decimal places) is 120.225 kg. (5 marks)

Description	Marks
$A_o = \pi r^2 = \pi \times 100^2 = 0.031\,415\,926$ m^2	1
$A_i = \pi r^2 = \pi \times 95^2 = 0.028\,352\,874$ m^2	1
$V = l \times (A_o - A_i)$	
$= 5 \times (0.031\,415\,926 - 0.028\,352\,874)$	1
$= 0.01531526$ m^3	1
$m = V \times \rho = 0.015\,315\,26 \times 7850$	1
$= 120.225$ kg (120.224 823 862 kg)	
Total	**5**

Question 28 (continued)

(c) Calculate y, the deflection of the cantilever beam at its unsupported end due to its self-weight only. Answer in units of millimetres (mm). (5 marks)

Description	Marks
F_{UDL} = 120.225 × 9.8 = 1178.203 N	1
E = 200 000 N mm^2	1
$y = \dfrac{F_{UDL}L^3}{8EI_{xx}}$	
$= \dfrac{1178.203 \times 5000^3}{8 \times 200\,000 \times 14\,568\,645}$	1–2
= 6.318 mm	1
Total	**5**

(d) Calculate the total deflection of the cantilever beam at its unsupported end. Answer in units of millimetres (mm). (5 marks)

Description	Marks
F = 52 × 9.8 = 509.6 N	1
$y = \dfrac{FL^3}{3EI_{xx}}$	
$= \dfrac{509.6 \times 5000^3}{3 \times 200\,000 \times 14\,568\,645}$	1–2
= 7.287 mm	1
total deflection = 7.287 + 6.318	
= 13.605 mm	1
Total	**5**

Question 29 **(21 marks)**

(a) Prove by calculation that reactions R_R and R_L are 52.5 kN and 47.5 kN respectively. (5 marks)

Description	Marks
$\Sigma M_A = 0$	1
$= 20(2.67) + 50(2 \times 2.67) + 30(3 \times 2.67) - R_R (4 \times 2.67)$	1
$10.68R_R = 53.4 + 267 + 240.3$ $= 560.7$	
$R_R = \dfrac{560.7}{10.68}$ $= 52.5$ kN	1
$\Sigma F_y = 0$	1
$= R_R + R_L - 20 - 30 - 50$ $R_L = 100 - 52.5$ $= 47.5$ kN	1
Total	**5**

(b) Prove by calculation that the angle θ is 36.836°. (2 marks)

Description	Marks
$\tan\theta = \left(\dfrac{o}{a}\right)$ $\theta = \tan^{-1}\left(\dfrac{o}{a}\right) = \tan^{-1}\left(\dfrac{2}{2.67}\right)$	1–2
$= 36.836°$	
Total	**2**

(c) By working to the left of section xx', use the method of sections to calculate F_{BD}, the force in Member BD, and identify whether it is in tension or compression. (4 marks)

Description	Marks
$\Sigma M_C = 0$	1
$= 47.5(2.67) + F_{BD}(2)$ $2F_{BD} = -126.825$ $F_{BD} = \dfrac{-126.825}{2}$	1
$= -63.4125$ kN	1
compression	1
Total	**4**
Accept other valid methods of calculation.	

Question 29 (continued)

(d) By working to the left of section xx', use the method of sections to calculate F_{CD}, the force in Member CD, and identify whether it is in tension or compression. (5 marks)

Description	Marks
ΣM_A = 0	1
= $20(2.67) + F_{BD}(2) - \sin 36.836 F_{CD}\ (2.67)$ $53.4 + (-126.825) - 1.6F_{CD}$ $1.6F_{CD}$ = −73 425	1
$F_{CD} = \frac{-73.425}{1.6}$	1
= −45.869 kN	1
compression	1
Total	**5**
Accept other valid methods of calculation.	

(e) By working to the left of section xx', use the method of sections to calculate F_{CE}, the force in Member CE, and identify whether it is in tension or compression. (5 marks)

Description	Marks
ΣM_B = 0	1
= $47.5(2.67) - cos 36.836 F_{CD}\ (2) - F_{CE}\ (2)$ = $126.825 - (-73.423) - F_{CE}\ (2)$ $2F_{CE}$ = 200.248	1
$F_{CE} = \frac{200.248}{2}$	1
= 100.124 kN	1
tension	1
Alternative solution	
ΣM_D = 0	1
= $47.5(2 \times 2.67) - 20(2.67) - F_{CE}\ (2)$ = $253.65 - 53.4 - F_{CE}\ (2)$ $2F_{CE}$ = 200.25	1
$F_{CE} = \frac{200.25}{2}$	1
= 100.125 kN	1
tension	1
Total	**5**
Accept other valid methods of calculation.	

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

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

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

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

Question 40 **(15 marks)**

(a) Calculate the input speed of the motor that is attached to the worm gear. Assume the drive system is 100% efficient and answer in units of revolutions per minute (rpm).

(7 marks)

Description	Marks
teeth s^{-1} (rack) = $\frac{n°\,teeth\ m^{-1} \times length\,rack}{t} = \frac{80 \times 4}{20}$	1
= 16 teeth s^{-1} Note: Equates to 0.8 rev s^{-1}	1
output speed (pinion) = $\frac{16 \times 60}{20} = \frac{960}{20}$ = 48 rpm.	1
VR (chain and sprocket) = $\frac{n°\,teeth\ follower}{n°\,teeth\,driver} = \frac{36}{16}$ = 2.25	1
VR (worm drive) = $\frac{n°\,teeth\ follower}{1} = \frac{45}{1}$ = 45	1
VR_{Total} = 2.25 × 45 = 101.25	1
input speed (motor) = *output speed* × VR_{Total} = 48 × 101.25 = 4860 rpm	1
Total	**7**

(b) By referring to the potential difference across the terminals of a DC electric motor, explain how this is achieved by using an H-bridge integrated circuit like an L293D.

(3 marks)

Description	Marks
when one terminal of the motor is high (positive) and the other low (negative or 0 V), the motor will spin in one direction	1
by reversing the polarity of the terminals, the motor will spin in the other direction	1
when there is no potential difference across the terminals, i.e. both are low, the motor will be stationary	1
Total	**3**

(c) If frequency is 80 Hz, calculate the following pwm parameters:

(i) Period. Answer in units of milliseconds (ms). (2 marks)

Description	Marks
Period = t = $\frac{1}{80}$ = 0.0125 s	1
= 12.5 ms	1
Total	**2**

(ii) Duty cycle. Answer as a percentage (%). (2 marks)

Description	Marks
Duty cycle = $\frac{20}{25} \times 100$	1
= 80%	1
Total	**2**

(iii) Low time. Answer in units of milliseconds (ms). (1 mark)

Description	Marks
Low time = 12.5 × 0.2 = 2.5 ms	1
Total	**1**
Answer by itself is insufficient to be awarded a mark.	

Question 41 **(17 marks)**

(a) Identify if Circuit A **or** Circuit B will result in a power dissipation by the load that is greater than the other by circling the correct answer. Provide calculations to support your choice (3 marks)

Description	Marks
Circuit A (series arrangement)	1
Calculations:	
For Circuit A (batteries in series) $P = \frac{V^2}{R} = \frac{12^2}{100} = 1.44$ W	1
For Circuit B (batteries in parallel) $P = \frac{V^2}{R} = \frac{6^2}{100} = 0.36$ W	1
Total	**3**

(b) Identify if Circuit A **or** Circuit B will deliver current to the load for a longer period of time by circling the correct answer. Provide calculations to support your choice. (5 marks)

Description	Marks
Circuit B (parallel arrangement)	1
Calculations:	
For Circuit B (batteries in parallel) $I = \frac{V}{R} = \frac{6}{100} = 0.06$ A	1
and time = $\frac{Ah}{I} = \frac{9}{0.06} = 150$ h	1
For Circuit A (batteries in series) $I = \frac{V}{R} = \frac{12}{100} = 0.12$ A	1
and time = $\frac{Ah}{I} = \frac{4.5}{0.12} = 37.5$ h	1
Total	**5**

(c) The basic structure of a capacitor consists of two plates that store electric charge separated by a thin layer of dielectric material. State **two** purposes of the dielectric material. (2 marks)

Description	Marks
keeps the plates from touching (and releasing the stored electric charge)	1
enables closer plate separation (that results in higher capacitance)	1
Total	**2**

(d) (i) State the numbers used for the 3-digit code printed on C2. (1 mark)

Description	Marks
564	1
Total	**1**

(ii) Describe how you determined the numbers used for the 3-digit code printed on C2. (2 marks)

Description	Marks
5 and 6 are the first two numbers	1
and the third number, 4, is the multiplier to convert to picofarads	1
Total	**2**
Note: 56 is an E12 preferred value.	

(e) The total capacitance required across AB, C_{AB}, is 0.469 μF. Calculate C_3, the unknown capacitance of C3. Answer in units of microfarads (μF). (4 marks)

Description	Marks
$\frac{1}{C_{AB}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$	
$\frac{1}{0.469} = \frac{1}{22} + \frac{1}{0.56} + \frac{1}{C_3}$	1
$\frac{1}{C_3} = \frac{1}{0.469} - \frac{1}{22} - \frac{1}{0.56}$	1
$= \frac{1}{0.301027}$	1
$C_3 = 3.322\ \mu F$	1
Total	**4**
Alternative solution	
$C_{1,2} = \frac{C_1 \times C_2}{C_1 + C_2}$	
$= \frac{22 \times 0.56}{22 + 0.56} = \frac{12.32}{22.56} = 0.5461$	1
$C_{AB} = \frac{C_{1,2} \times C_3}{C_{1,2} + C_3}$	
$0.469 = \frac{0.5461 \times C_3}{0.5461 + C_3}$	1
$0.25612 + 0.469C_3 = 0.5461C_3$ $0.0771C_3 = 0.25612$ $C_3 = \frac{0.25612}{0.0771}$	1
$= 3.322\ \mu F$	1
Total	**4**

Question 42 **(15 marks)**

(a) State **two** reasons why it is good practice to use a separate supply of electricity for the servo (6 V battery in the above circuit) to that used for the microcontroller (5 V power supply). (2 marks)

Description	Marks
servos draw more current than can usually be delivered by the microcontroller power supply	1
the use of a separate supply for the servo will reduce electrical noise (voltage spikes)	1
Total	**2**

(b) State **three** reasons why it is necessary to connect the ground wire of the servo to the GND pin of the microcontroller to enable the circuit to control the servo's movements. (3 marks)

Description	Marks
this provides a common ground used as a reference	1
to detect voltage levels produced by the microcontroller (Pin O5)	1
to accurately position the servo spindle	1
Total	**3**

(c) A rise in temperature is detected by NTC in the circuit on page 46. Identify the effect this will have on the following by circling the correct response. (3 marks)

Description		Marks
voltage across RV	increase	1
resistance of RV	no change	1
current through NTC	increase	1
Total		**3**

(d) Suppose that the 10-bit ADC value produced at Pin A3 is 312 and the resistance of RV is 10 750 Ω. Calculate R_{NTC}, the resistance of NTC. Answer in units of ohms (Ω).

(5 marks)

Description			Marks
V_{RV} =	$5 \times \frac{312}{1023}$		1
=	1.525 V	(1.524 926 7 V)	1
1.525 =	$5 \times \frac{10\ 750}{10\ 750 + R_{NTC}}$		1
16 394 + 1.525R_{NTC} =	53 750		1
1.525R_{NTC} =	37 356		
R_{NTC} =	$\frac{37\ 356}{1.525}$		
=	24 496 Ω	(24 497.6Ω)	1
		Total	**5**
Allow for rounding.			

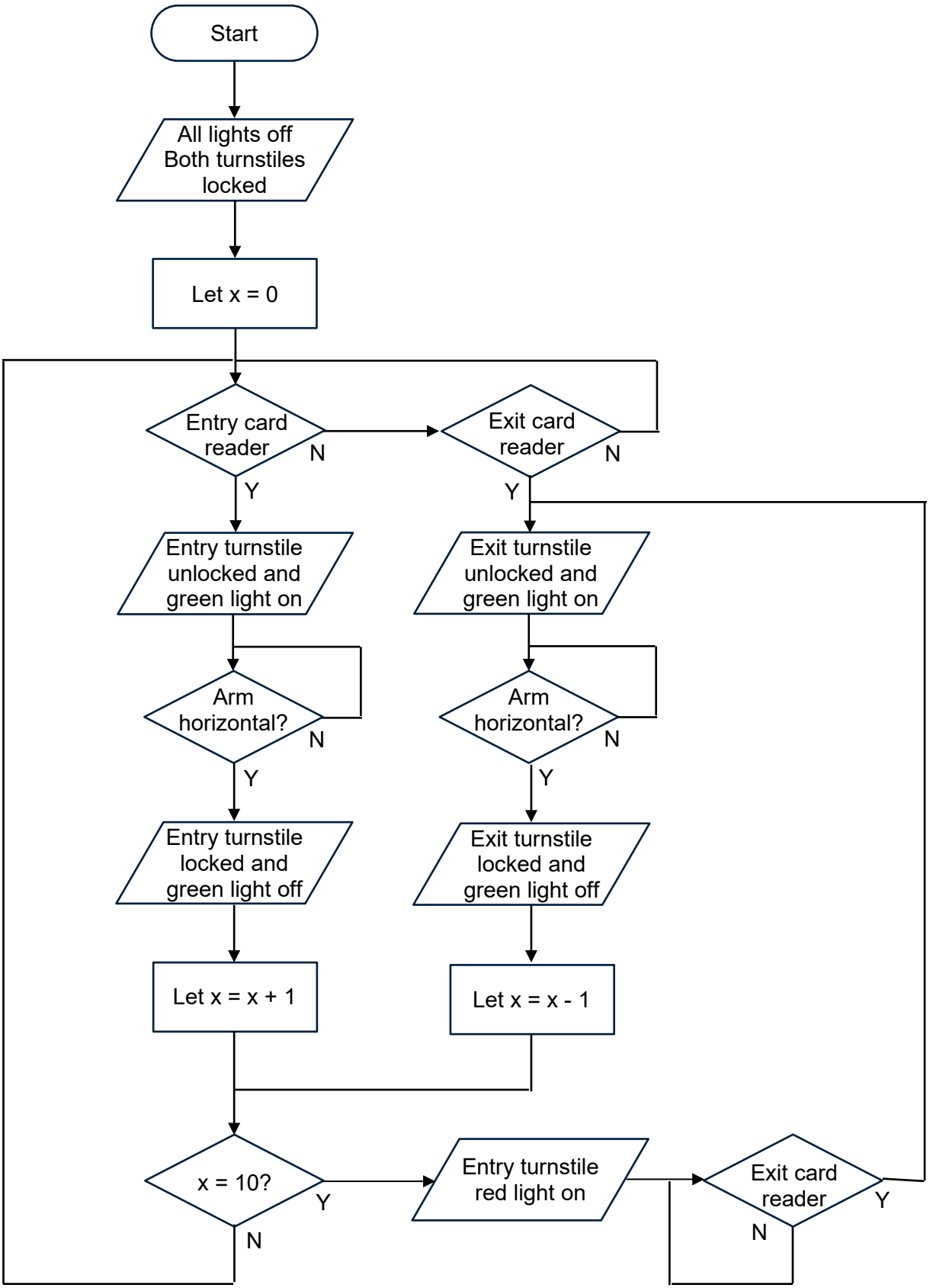
(e) To control the movement of the servo spindle, the full range of values produced by the ADC at Pin A3 is mapped against the servo's 0–180° range of rotation. Calculate x°, the rotation in degrees of the servo spindle when the 10-bit value is as for part (d), i.e. 312.

(2 marks)

Description		Marks
x° =	$180 \times \frac{312}{1023}$	1
=	54.9° (54.897°)	1
	Total	**2**

Question 43 **(15 marks)**

(a) In the space below, draw a fully-labelled flow chart of the system that meets the **four** criteria required to control the turnstiles and coloured light signals by constantly monitoring the number of visitors in the gallery. (12 marks)



Description	Marks
when the flow chart is started, variable 'x' is set to zero (0)	1
both turnstiles lock and all three coloured lights are turned off	1
when a visitor's ticket is placed on the reader at the entrance turnstile, it will unlock and the green light in the sign above the entrance turnstile will turn on	1
provided there are less than 10 visitors already in the gallery	1
when followed arm becomes horizontal, it is detected	1
the entry turnstile will then lock and the green light in the sign above it turns off	1
and variable 'x' to increase by one, i.e. x = x + 1	1
when a visitor's ticket is placed on the reader the exit turnstile, it will unlock and the green light in the sign above the entrance turnstile will turn on	1
when the follower arm becomes horizontal as the visitor exits, it is detected	1
the exit turnstile will then lock and the green light in the sign above it turns off	1
and variable 'x' to decrease by one, i.e. x = x – 1	1
if 10 visitors are in the gallery, then the red light in the sign above the entry turnstile will turn on	1
Total	**12**

(b) Identify whether the turnstile control system is an example of an open loop **or** closed loop system by circling the correct answer. State **two** reasons to support your answer.
(3 marks)

Description	Marks
open loop	1
One: the system counts visitors in and out of the gallery and, although there is a maximum limit, the output is independent of the input	1
Two: it does not maintain a set value by using feedback and error detection – at any time there could be 0–10 visitor in the gallery	1
Total	**3**
Accept other relevant answers.	

Question 44 **(23 marks)**

(a) When SW, a push-to-break switch, is pressed, will the signal detected at Pin IN3 be high **or** low? Referring to your knowledge of circuit behaviour and a relevant electrical law, explain why. (3 marks)

Description	Marks
low	1
by pressing SW, the circuit will be open and therefore no current can flow through R1	1
since voltage is the product of current multiplied by resistance (Ohm's law) then the voltage across R1 will be 0 V, i.e. low	1
Total	**3**

(b) (i) When Pin 06 is high the transistor, Q, will allow the motor to draw a current and its spindle will rotate. The diode will have no effect on the behaviour of the circuit. Describe why this is the case. (2 marks)

Description	Marks
when current is flowing through the motor the diode will be reverse-biased	1
therefore, no current will pass through the diode – it has no effect on the circuit	1
Total	**2**

(ii) When Pin 06 is low the transistor, Q, will block the flow of current through the motor, causing it to stop rotating. The diode will now protect the transistor from overheating due to back e.m.f. that is generated by magnetic energy in the coils of the motor transforming into a very large voltage spike. Explain how the diode achieves this crucial function. (3 marks)

Description	Marks
back e.m.f. has reverse polarity	1
therefore, the diode is now forward-biased	1
and current will now flow in a loop through it and the motor, bypassing the transistor, until all energy is safely dissipated	1
Total	**3**

(c) Suppose O6 is high. Shortly after starting, the motor reaches a constant running speed and, V_{CE}, the collector-emitter voltage of Q is measured as a steady 2 V.

(i) Calculate I_E, the emitter current of Q. Answer in units of amps (A). (4 marks)

Description	Marks
$I_B = \dfrac{5 - V_{BE,ON}}{R_2} = \dfrac{5 - 0.7}{330} = \dfrac{4.3}{330}$	1
$= 0.013\ 03$ A	1
Since $V_{CE} > 0$ V, Q is operating in its forward-active region $I_C = I_B \times \beta = 0.013\ 03 \times 40$ $= 0.521\ 21$ A	1
$I_E = I_B + I_C$ $= 0.013\ 03 + 0.521\ 21$ $= 0.534\ 24$ A (allow for rounding)	1
Total	**4**

(ii) Calculate P_M, the power dissipated as heat by the motor when it is at its constant running speed. Answer in units of watts (W). (3 marks)

Description	Marks
$\Sigma\Delta V = 0 = 12 - V_M - V_{CE}$ $V_M = 12 - 2$ $= 10$ V	1
$P_M = I_C \times V_M$ $= 0.521\ 21 \times 10$	1
$= 5.212$ W (allow for rounding)	1
Total	**3**

Question 44 (continued)

(iii) Calculate $P_{Q,TOTAL}$, the total power dissipated as heat by the transistor when the motor it is at its constant running speed. Answer in units of watts (W). (5 marks)

Description	Marks
$P_{Q,CE}$ = $I_C \times V_{CE}$	
= 0.521 21 × 2	1
= 1.042 W (1.042 424 W)	1
$P_{Q,BE}$ = $I_B \times V_{BE,ON}$	
= 0.013 03 × 0.7	1
= 0.009 W (0.009 121 W)	1
$P_{Q,TOTAL}$ = 1.042 + 0.009 = 1.051 W (1.051 545 W)	1
Total	**5**

Suppose Pin O6 is now low.

(d) Calculate V_{CE}, the collector emitter voltage of Q. (3 marks)

Description	Marks
$I_M = I_C$ = 0 A (Q is in cut-off region of operation) V_M = $I_M \times R_M = 0 \times R_M$ = 0 V	1
$\Sigma\Delta V$ = 0 = $12 - V_M - V_{CE}$ V_{CE} = 12 – 0	1
= 12 V	1
Total	**3**

Question 45 **(15 marks)**

(a) Calculate I_{R2}, the current that flows through R2. Answer in units of amps (A). (4 marks)

Description	Marks
$I_S = \frac{V_{S1}}{R_{AB}} = \frac{9}{274.81} = 0.032\ 75$ A	1
$I_{R1} = \frac{V_{S1}}{R_1} = \frac{9}{680} = 0.013\ 235$ A	1
$\Sigma I = 0 = I_S - I_{R1} - I_{R2}$ $I_{R2} = 0.032\ 75 - 0.013\ 235$	1
$= 0.019\ 515$ A	1
Total	**4**
Accept other valid methods of calculation.	

(b) Calculate V_{R3}, the voltage across R3. If you could not calculate an answer for part (a), then use 0.0196 A. (3 marks)

Description	Marks
$V_{R2} = I_{R2} \times R_2 = 0.019\ 515 \times 100 = 1.9515$ V	1
$\Sigma \Delta V = 0 = 9 - V_{R2} - V_{R3}$ $V_{R3} = 9 - 1.9515$	1
$= 7.0485$ V	1
Total	**3**
Accept other valid methods of calculation. If using 0.0196 A, then $V_{R3} = 7.04$ V.	

(c) Calculate P_{R5}, the power dissipated by R5. Answer in units of watts (W). (4 marks)

Description	Marks
$\Sigma \Delta V = 0 = 9 - V_{R2} - V_{R4} - V_{R5}$ $V_{R4} + V_{R5} = 9 - 1\ 9515$ $= 7.0485$ V	1
Alternative solution	
$V_{R3} = V_{R4} + V_{R5} = 7.0485$ V	1
then	
$R_4 + R_5 = 1000 + 560 = 1560\ \Omega$	1
$I_{R4} = I_{R5} = \frac{7.0485}{1560} = 0.004\ 518$ A	1
$P_{R5} = I^2R = 0.004\ 518^2 \times 560 = 0.011\ 432$ W	1
Total	**4**
Accept other valid methods of calculation. If using 0.0196 A for part (b), then answer is 0.011 405 W.	

Question 45 (continued)

(d) Calculate R_3, the unknown resistance of R3. Answer in units of ohms (Ω). (4 marks)

Description	Marks
$\Sigma I = 0 = I_{R2} - I_{R3} - I_{R4}$ $I_{R3} =$ 0.019 515 – 0.004 518	1
= 0.014 997 A	1
$R_3 = \frac{V_{R3}}{I_{R3}} = \frac{7.0485}{0.014\ 997}$	1
= 470 Ω	1
Total	**4**
Accept other valid methods of calculation. If using 0.0196 A for part (b), then answer is 466.6 Ω.	

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