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

ENGINEERING STUDIES

ATAR course examination 2021

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

2021/67215

Section One: Core content **40% (87 Marks)**

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

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

Part B: Extended response **30% (77 Marks)**

Question 11 **(21 marks)**

(a) Calculate the mass of the fish pond when it is empty of water. (7 marks)

Description		Marks
Volume of material in cylinder	= $(\pi r^2 \times h) - (\pi r^2 \times h)$	
	= $(\pi \times 0.8^2 \times 0.4) - (\pi \times 0.72^2 \times 0.4)$	
	= 0.804248 – 0.651441	1
	= 0.152807 m^3	1
Volume of material in hemisphere	= $(0.5 \times {}^4/_3\pi r^3) - (0.5 \times {}^4/_3\pi r^3)$	
	= $(0.5 \times {}^4/_3\pi \times 0.8^3) - (0.5 \times {}^4/_3\pi \times 0.72^3)$	
	= 1.07233 – 0.78173	1
	= 0.2906 m^3	1
Total volume of material	= 0.152807 + 0.2906	
	= 0.443407 m^3	1
Mass	= (0.443407 × 2400 × 0.97) + (0.443407 × 7850 × 0.03)	
	= 1032.25 + 104.42	1
	= 1136.67 kg	1
	Total	**7**

(b) The fish pond is filled to 85% of its capacity with water. Calculate the distance between the surface of the water and the rim of the fish pond. (6 marks)

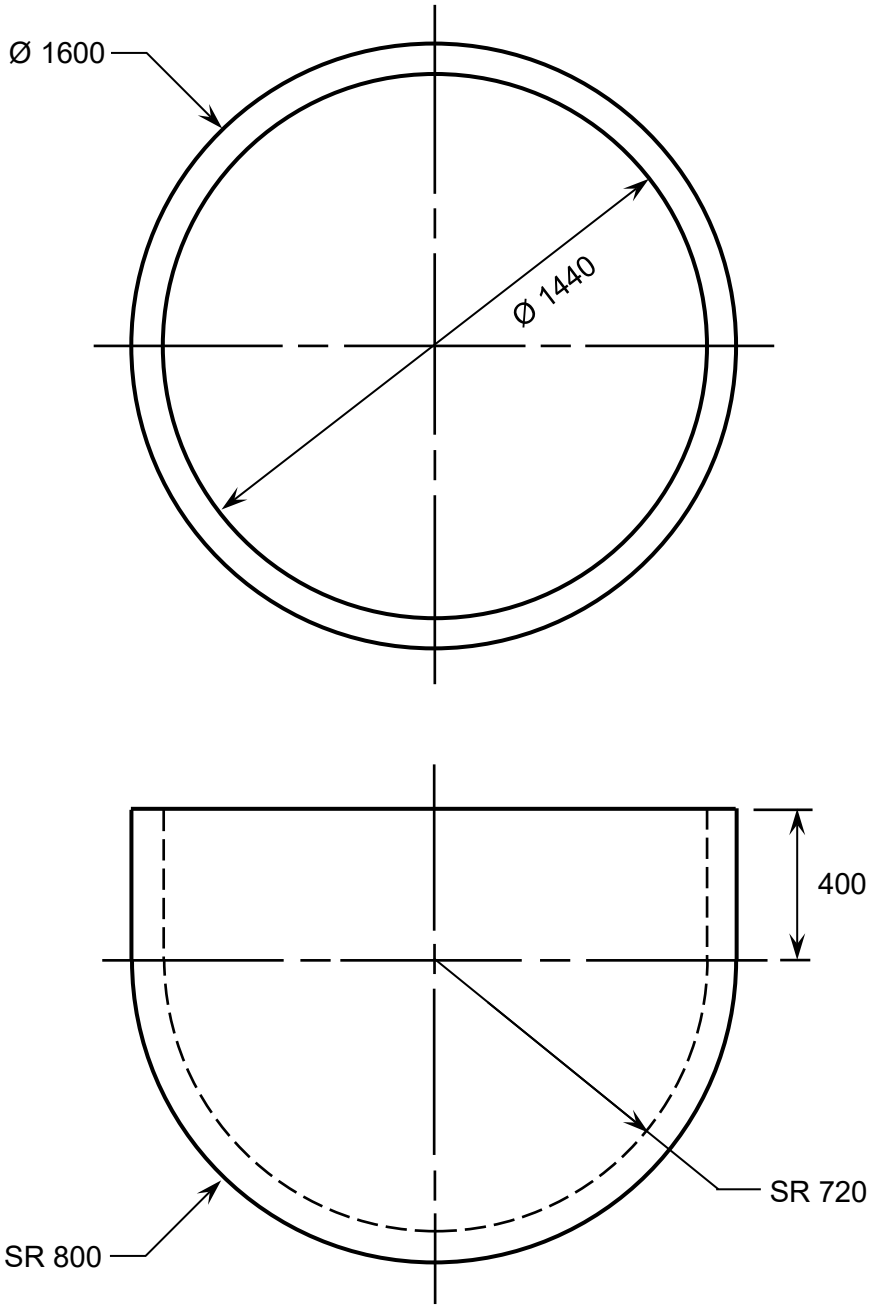
Description		Marks
85% volume cylinder and hemisphere	= (0.651441+ 0.78173) × 0.85	
	= 1.433171 × 0.85	
	= 1.21819535 m^3	1
Volume of water in cylinder	= answer above – internal volume hemisphere	
	= 1.21819535 – 0.78173	
	= 0.43646535 m^3	1
Height of water in cylinder	$= \frac{0.43646535}{\pi \times 0.72^2}$	1–2
	= 0.268 m	1
Water level below rim	= 0.4 – 0.268	
	= 0.132 m	1
	Total	**6**

(c) Use the grid provided on page 7 to draw a fully dimensioned top and front view of the assembled fish pond. The layout, types of lines and method of dimensioning must comply with the conventions for a third angle orthographic projection. All dimensions are in millimetres.

Use a ruler for straight lines. Circular features can be drawn in freehand.

Note: The larger squares of the grid represent 200 mm × 200 mm. (8 marks)

Question 11 (continued)



Description	Marks
Correct orientation of views	1
Both circles correct size (top view)	1
Centrelines for circles drawn correctly (top view)	1
Dimensioning of both circles correct (top view)	1
Cylinder and hemisphere are correct size and, outlines and hidden detail lines are used correctly (front view)	1
Centrelines drawn correctly (front view)	1
Height of cylinder and radii of internal and external hemispheres are correctly dimensioned	1–2
Total	**8**

Question 12 **(21 marks)**

(a) Define the term 'composite material'. (2 marks)

Description	Marks
A composite material is one which is made up of two or more materials	1
that has (beneficial) properties that are different to those of its constituent materials.	1
Total	**2**
Accept other wording of these descriptions provided the meaning is correct.	

(b) Give an example of a composite material and explain why it fits this class of materials. (3 marks)

Description	Marks
Examples include concrete (also reinforced concrete), glass or fibre reinforced plastic (accept fibreglass), plywood and many others.	1
Explanation needs to name the constituent materials	1
and refer to the individual properties of the constituents and how these are different to those of the composite material.	1
Total	**3**
Accept other wording of these descriptions provided the meaning is correct.	

Properties of materials are an especially important consideration when selecting the best material for a particular engineered product.

(c) For each of the **four** properties listed below, provide a definition of the property, give an example of an engineered product where this property is crucial for its intended use, and provide a reason why it is used for this purpose. Your focus must be on how or where the engineered product is used and **not** on its manufacture.

Note: You are required to provide a different example for each of the four listed properties. A selected engineered product cannot be repeated.

(i) Stiffness (4 marks)

Description	Marks
Definition: Ability of a material to resist deformation under load.	1
Example: There are many e.g. scaffolding plank. Accept any reasonable example provided stiffness of the material is a crucial property for how the engineered product is used (including its service conditions).	1
A sensible reason is given	1
and it is justified by an explanation.	1
Total	**4**

Question 12 (continued)

(ii) Toughness (4 marks)

Description	Marks
Definition: Ability of a material to absorb energy when being deformed (elastic and/or plastic) without fracture or failure.	1
Example: There are many e.g. a hammer. Accept any reasonable example provided toughness of the material is a crucial property for how the engineered product is used (including its service conditions).	1
A sensible reason is given	1
and it is justified by an explanation.	1
Total	**4**

(iii) Elasticity (4 marks)

Description	Marks
Definition: Ability of a material to return to its original shape and size after a deforming force is removed.	1
Example: There are many e.g. a diving board. Accept any reasonable example provided elasticity of the material is a crucial property for how the engineered product is used (including its service conditions).	1
A sensible reason is given	1
and it is justified by an explanation.	1
Total	**4**

(iv) Plasticity (4 marks)

Description	Marks
Definition: Ability of a material to undergo permanent deformation (without rupture occurring).	1
Example: There are many e.g. a staple, twist tie, cotter pin, rip top can. Accept any reasonable example provided plasticity of the material is a crucial property for how the engineered product is used (including its service conditions).	1
A sensible reason is given	1
and it is justified by an explanation.	1
Total	**4**

Question 13 **(18 marks)**

(a) Name a suitable product for each action and describe how that action might be carried out for that product.

Note: You are required to provide a different engineered product for each of the three listed actions.

(i) Reuse (3 marks)

Description	Marks
Product: Suitable product is identified e.g. television, bicycle	1
Description: The product is 'handed down' or sold on the second-hand market or parts removed (any one of these).	1
where it continues to be used for its original purpose or as parts to repair or create a product (any one of these).	1
Total	**3**

(ii) Recycle (3 marks)

Description	Marks
Product: Suitable product is identified e.g. aluminium soft drink can, glass bottle	1
Description: The material is returned to the production stream	1
where it is used to create new products.	1
Total	**3**

(iii) Disposal (3 marks)

Description	Marks
Product: Suitable product is identified e.g. computer, mobile phone	1
Description: The product is sent to landfill or incineration	1
after hazardous materials are removed/neutralized.	1
Total	**3**

(b) Identify **three** benefits that arise if an unwanted engineered product is reused or recycled. For each benefit describe why it is significant. (9 marks)

Description	Marks
Benefit 1: Reduces the demand for more raw materials.	1
Significance: This reduces disruption to the environment to 'win' the materials and	1
energy inputs to process the raw material into useful forms will also be lowered.	1
Benefit 2: Less material will go to landfill.	1
Significance: The volume of materials going to landfill will be reduced and	1
this means less land needs to be reserved for this purpose thus providing other options for land use.	1
Benefit 3: Employment opportunities are created.	1
Significance: Greater sense of worth or satisfaction for the worker and	1
improved economic stability for society or the state/country.	1
Total	**9**
The above are indicative of what is expected. Award marks for other sensible benefits with descriptions e.g. reduces pollution, reduces toxins in the soil (landfill) or air (incineration), and other relevant benefits	

Question 14 **(17 marks)**

(a) Identify and describe briefly **two** safety issues that have, in part, influenced changes to bulb design. (2 marks)

Description	Marks
One: Fragile glass used less (less chance of cuts)	1
Two: Newer technologies do not get so hot (burns, fire)	1
Total	**2**
Accept other sensible issues e.g. hazardous materials like mercury (toxins)	

(b) Using the information provided on page 12, calculate the cost of running an incandescent bulb continuously for 120 days and contrast this with the cost of running an LED bulb for the same duration. The light output of both forms of bulb is 840 lumens and the cost of electricity is 26.2 cents per kilowatt hour. (4 marks)

Description		Marks
Incandescent bulb		
60 × 120 × 24	= 172 800 Wh = 172.8 kWh	1
172.8 kWh @ 26.2 cents	= $45.27	1
LED bulb		
7 × 120 × 24	= 20 160 Wh = 20.16 kWh	1
20.16 kWh @ 26.2 cents	= $5.28	1
	Total	**4**
Award full marks for other valid and correct methods of calculation.		

(c) Calculate how much extra carbon dioxide is produced by a power station to run a 75 W incandescent bulb for 2500 hours compared with the equivalent light output LED bulb. (5 marks)

Description		Marks
915 kg per 1 MWh	= 0.915 kg per kWh	
Incandescent bulb		
75 × 2500	= 187 500 Wh = 187.5 kWh	1
187.5 × 0.915	= 171.5625 kg of CO^2	1
LED bulb		
10 × 2500	= 25,000 Wh = 25 kWh	1
25 × 0.915	= 22.875 kg of CO^2	1
Extra CO^2	= 171.5625 – 22.875 = 148.6875 kg	1
	Total	**5**
Award full marks for other valid and correct methods of calculation.		

(d) Calculate the required length of a turbine blade, as measured from the centre of the rotor hub, such that the collected wind power is 3.46 MW. (6 marks)

Description		Marks
3 460 000	= 0.5 × 1.2 × A × 10^3 × 0.6	1–2
A	= 3 460 000 / (0.5 × 1.2 × 10^3 × 0.6)	
	= 3 460 000 / 360	
	= 9611.11	1
r^2	= 9611.11 / π	1
	= 3059.31	1
r = length of blade	= 55.31 m	1
	Total	**6**
Award full marks for other valid and correct methods of calculation.		

Section Two: Specialised field – Mechanical **60% (115 Marks)**

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

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

*Question 20 – all distractors were deemed incorrect; all candidates awarded 1 mark.

Part B: Extended answer **50% (105 Marks)**

Question 25 **(16 marks)**

(a) Calculate the potential energy of a 120 kg rider as they are about to set off from the bridge on the flying fox. The height is determined by the difference between the top of the flying fox and the top of the first frame. (2 marks)

Description	Marks
$Ep = mgh$ Ep = 120 × 9.8 × 40	1
Ep = 47 040 J	1
Total	**2**

(b) Calculate the kinetic energy of a 120 kg rider as they pass the first riverbank frame while travelling on the flying fox. Assume total energy losses of 5%. (2 marks)

Description	Marks
Ek = 0.95 × Ep	1
Ek = 44 734 J	1
Total	**2**

(c) Calculate the magnitude of the velocity with which the 120 kg rider passes the first riverbank frame in km h^{-1}. If you could not determine a value in part (b), assume the person has 50 kJ of kinetic energy. (4 marks)

Description	Marks
$Ek = 0.5 \times m \times v^2$	1
$v = \sqrt{\frac{44734}{0.5 \times 120}}$	1
v = 27.3 m s^{-1}	1
v = 27.3 × (3600/1000) = 98.3 km h^{-1} (@50 kJ = 103.9 km h^{-1}	1
Total	**4**

(d) State **two** possible sources of energy loss in operating the flying fox. (2 marks)

Description	Marks
Cable friction.	1
Wind resistance.	1
Total	**2**
Accept other reasonable answers.	

(e) The velocity as the rider enters the braking portion of the ride is considered to be too fast. It is decided that the maximum velocity of the rider will be reduced to 50 km h^{-1} by adjusting the height of the first riverbank frame.

(i) Calculate the new height of the first riverbank frame. (4 marks)

Description	Marks
$0.95 \times m \times g \times h = 0.5 \times m \times v^2$	1
50 km h^{-1} = 13.9 m s^{-1}	1
$h = (0.5 \times 13.9^2)/(0.95 \times 9.80)$	1
$h = (60 - 10.4) = 49.6$ m	1
Total	**4**

(ii) Explain what changes, if any, would need to be made to the height of the riverbank frame, if the rider's design weight was changed to 150 kg. (2 marks)

Description	Marks
No change.	1
The mass in the energy equation cancels out so the velocity is independent of mass.	1
Total	**2**

Question 26 **(12 marks)**

(a) Calculate the displacement of a rider who has set out from the bridge at the moment they pass the first frame on the riverbank. (3 marks)

Description	Marks
$c^2 = a^2 + b^2$ (concept that displacement occurs along line)	1
$c = \sqrt{(40^2 + 300^2)}$	1
c = 302.7 m	1
Total	**3**

(b) Between the bridge and the first frame on the riverbank where braking starts, the rider experiences a constant acceleration of 1.23 m s^{-2}. Calculate the maximum velocity of the rider. If you could not determine an answer for part (a), Use 300 m as the displacement. (2 marks)

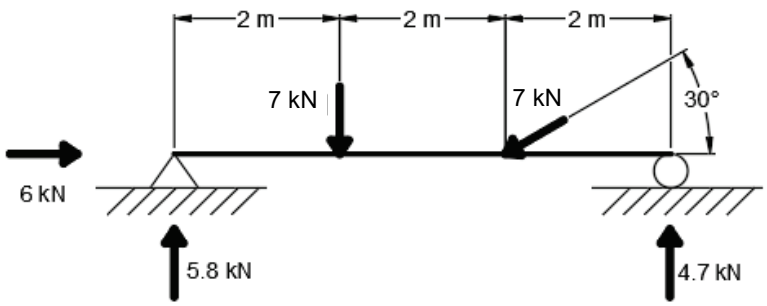
Description	Marks
$v = \sqrt{}$ (2 × a × s)	1
v = 27.3 m s^{-1} (@300m = 27.2 m s^{-1})	1
Total	**2**

(c) If the deceleration in the breaking portion of the ride is a constant 4 m s^{-2} calculate how long the whole ride takes. If you could not determine an answer for part (b), Use 25 m s^{-1} for the maximum velocity. (7 marks)

Description	Marks
Accelerating portion s = 0.5 at^2 $t = \sqrt{(s / 0.5 \times a)}$	1
$t = \sqrt{(302.7 / 0.5 \times 1.23)}$	1
t = 22.2 s (@300m = 22.1 s)	1
Decelerating portion $t = (v\text{-}u) / a$	1
t = (0-27.3) / -4	1
t = 6.8 s (@300 = 6.8 s)	1
Total = 22.2 + 6.8 = 29 s (@300 = 28.9 s)	1
Total	**7**

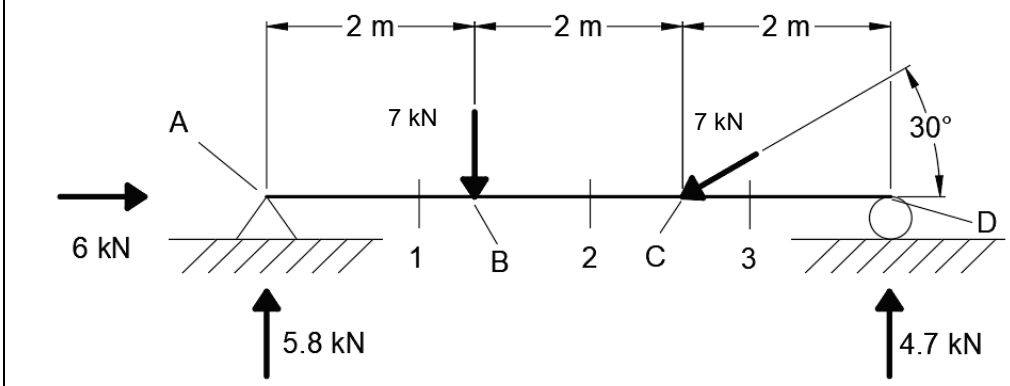
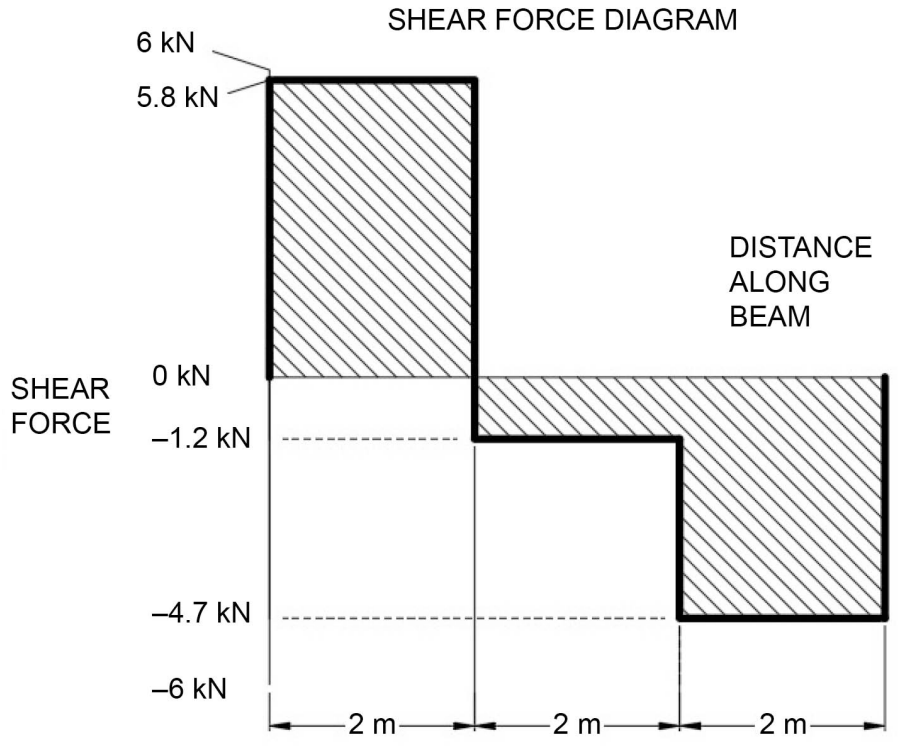
Question 27 **(26 marks)**

(a) Draw the beam diagram on the grid provided below. Include all relevant beam information that will be required for the construction of its shear and bending moment diagrams. All defining lengths must be included in metres. (7 marks)

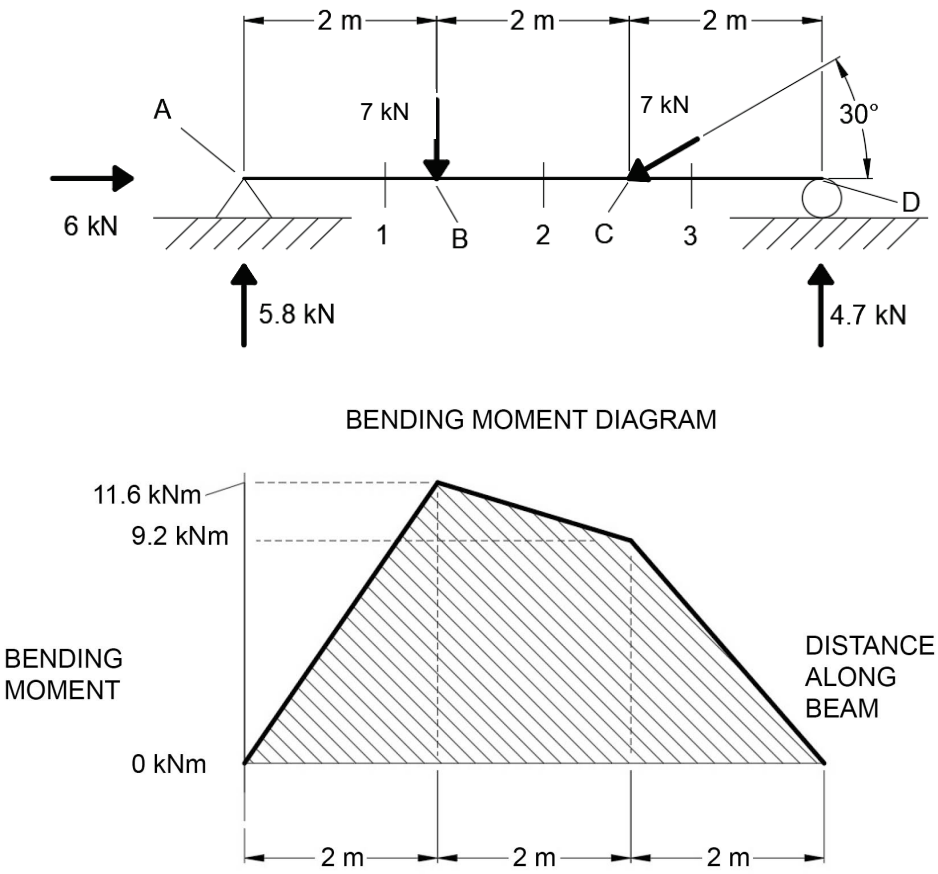
Description	Marks
	
Horizontal reaction forces right way around (a simple moment calculation can be used by student to discover which side is correct for which reaction, no calculation has to be shown for this as it can be logically deduced)	2
Vertical reaction force	1
Two forces included with all their detail	1
Beam diagram showing as simply supported	1
Overall length can be determined or is directly displayed in metre	1
Locations where forces act is displayed in metre	1
Total	**7**

Question 27 (continued)

(b) Draw a shear force diagram for this beam on the grid provided on page 30, under the appropriate heading. In the space below, show all calculations required to construct the shear force diagram. (8 marks)

Description	Marks
 	
0 = 5.8 - *SF1* *SF1* = 5.8 kN	1
0 = 5.8 - 7 - *SF2* *SF2* = -1.2 kN	1
0 = 5.8 - 7 – 7 × sin(30) - *SF3* 1 mark for resolving vertical force. *SF3* = -4.7 kN	1–2
Forces intercepts correctly displayed	1
Length intercepts correctly displayed	1
Correct area indicated by shading	1
Diagram detail like units, labels	1
Total	**8**

(c) Draw a bending moment diagram for this beam on the grid provided on page 30, under the appropriate heading. In the space below, show all calculations required to construct the bending moment diagram. (11 marks)

Description	Marks
	
BMA = 0 kNm	1
0 = 5.8 kN × 2 m - $BM1$ BMB = 11.6 kNm	1–2
0 = 5.8 kN × 4 m + -7 kN × 2 m - $BM2$ BMC = 9.2 kNm	1–2
BMD = 0 kNm	1
Moment intercepts correctly displayed	1
Length intercepts correctly displayed	1
Correct area indicated by shading	1
Diagram detail like units, labels	1-2
Total	**11**

Question 28 **(21 marks)**

(a) Calculate the maximum stress in the beam cross section due to the force acting along the axis of the circular hollow section if it has an OD of 165.1 mm, a wall thickness of 3.5 mm and a cross-sectional area of 1528 mm^2. (2 marks)

Description	Marks
$\sigma = F/A$ = 6000 / 1528	1
σ = 3.92 $N\ mm^{-2}$	1
Total	**2**

(b) Would this beam be an acceptable design choice for the new flying fox? Use details in the table describing the geometry and material properties to justify your choice. (3 marks)

Description	Marks
No	1
It is below the yield in the table.	1
It is so low compared to the yield it would not be efficient.	1
Total	**3**

(c) Using a safety factor of two and the data from pages 32 and 33 calculate, and select the most efficient choice for the design from those available. Only consider stress in the beam cross section due to the force acting along the axial direction only. (4 marks)

Description	Marks
Use FOS = 430 / 2 for allowable stress = 215 $N\ mm^{-2}$	1
$A = F/\sigma$ A = 6000 / 215 Note: Iterating to answer is also acceptable (though wasteful in terms of time).	1
A = 28 mm^2 minimum	1
Smallest cross-sectional area presented in data is 156 mm^2 so the smallest cross section is most efficient. 26.9 x 2.0 CHS	1
Total	**4**

(d) Calculate I_{xx} for the section and state if it matches the data on page 32. (5 marks)

Description	Marks
$I_{xx} = \pi\ (Do^4 - Di^4)/64$	1
Do = 165.1 mm^2	1
Di = 165.1 – (2 × 3.5) = 158.1 mm	1
I_{xx} = 5803041 mm^4	1
Yes, same as table value 5.8 × 10^6 mm^4	1
Total	**5**

(e) Calculate the deflection of the member due to its self-weight. (7 marks)

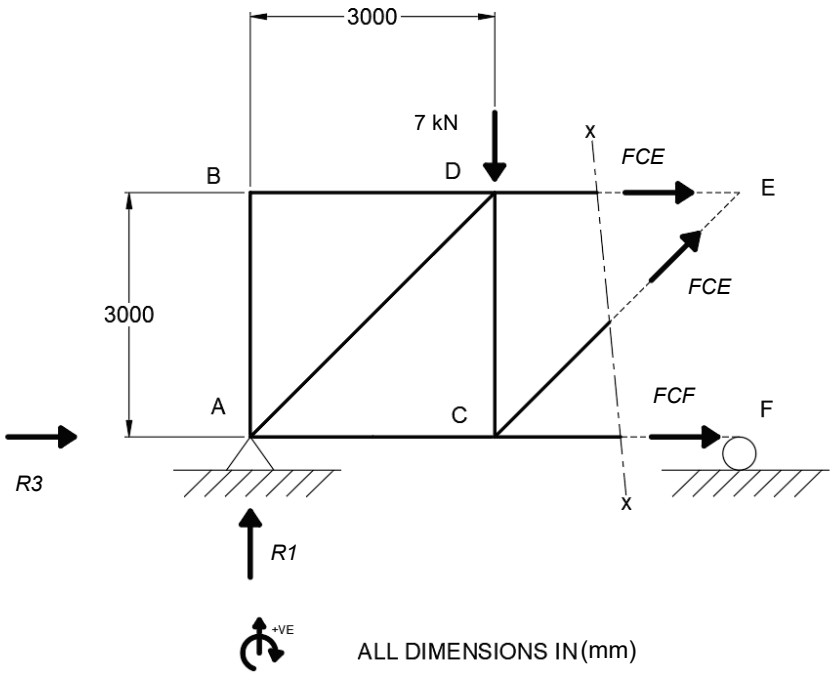
Description	Marks
$y = (5 \times F_{UDL} \times L^3) / (384 \times E \times I_{XX})$	1
Mass per m from table 13.9 kg m^{-1}	1
$F = ma$ F_{UDL} = 13.9 × 9.80 × 6 m = 817.32 N m^{-1}	1
E = 200 000 N mm^{-2}	1
L = 6 000 mm	1
I_{XX} = 580 3041 mm^4	1
y = 1.98 mm	1
Total	**7**

Question 29 **(30 marks)**

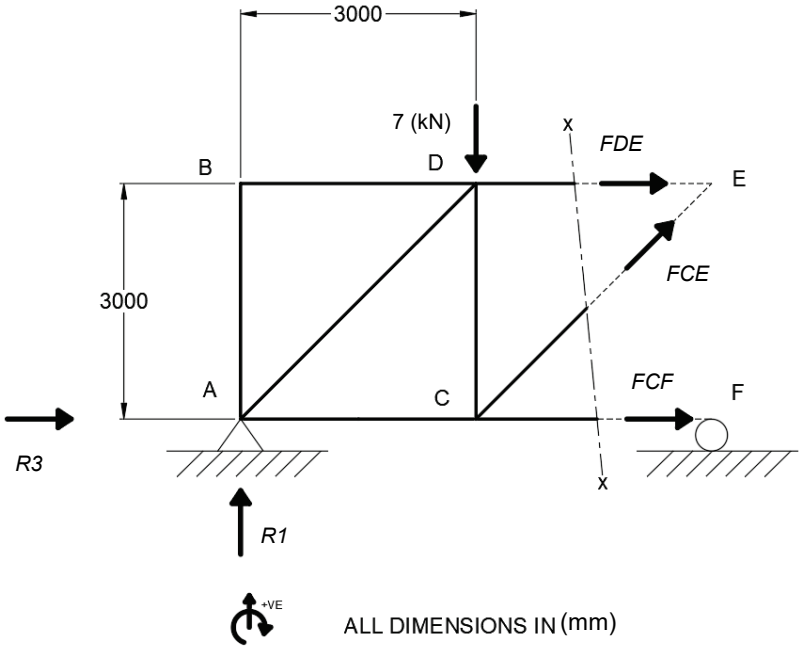
(a) Calculate the reaction forces $R1$, $R2$ and $R3$. (8 marks)

Description	Marks
$\Sigma Fy = 0$	1
$0 = R1 + R2 - 7 - 5$ $0 = R1 + R2 - 12$	1
$\Sigma M@A = 0$	1
$0 = (3 \times -7) + (6 \times -5) + (6 \times R2)$	1
$51 / 6 = R2$ $R2 = 8.5$ kN	1
$R1 = 12 - 8.5$ $R1 = 3.5$ kN	1
$\Sigma Fx = 0$	1
$R3 = 0$ kN	1
Total	**8**

(b) Using the method of sections at x-x calculate the force in the member CF and state if it is in compression or tension. (7 marks)

Description	Marks
 (picking appropriate point)	
Indicate the force direction on diagram or redraw diagram	1
$\Sigma M@E = 0$ (using correct equation)	1
$0 = (3 \times -7) + (6 \times 3.5) + (3 \times FCF)$ (one mark for each correct moment)	1–3
$0 = 0 + 3 \times FCF$ $FCF = 0$ kN - 1 mark for answer (neither compression or tension) – 1 mark for recognising no tension or compression	1–2
Total	**7**

(c) Using the method of sections at x-x, calculate the force in the member CE and state if it is in compression or tension. (15 marks)

Description	Marks
 (picking appropriate point)	
Indicate the force direction on diagram or redraw diagram	1
$\Sigma M@F$ = 0 (using correct equation)	1
AD = 3 / sin(45°) AD = 4.242 m Or calculated in any other way. FCE moment @ F = (0.5×4.242) × (FCE)	1
0 = (3 × -7) + (6 × 3.5) + (2.121 × FCE) + (3 × FDE) (one mark for each correct moment)	1–4
$\Sigma M@C$ = 0 (using correct equation)	1
0 = (3 × 3.5) + (3 × FDE)	1–2
FDE = -3.5 kN (compression) 1 for answer 1 for compression	1–2
0 = (3 × -7) + (6 × 3.5) + (2.1 × FCE) + (3 × -3.5) substitution	1
FCE = 5 kN (tension) 1 mark for magnitude, 1 mark for tension	1–2
Total	**15**

Section Two: Specialised field – Mechatronics **60% (115 Marks)**

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

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

Part B: Extended answer **50% (105 Marks)**

Question 40 **(19 marks)**

The circuit shown above includes SW, an SPST switch that is in open-circuit.

(a) Calculate V_{BATT}, the voltage of the battery. (3 marks)

Description	Marks
$\sum \Delta V = 0$ $= V_{BATT} - V_{R1} - V_{R2}$ V_{BATT} $= (R_1 \times 0.01125) + (R_2 \times 0.01125)$ $(I_{R13} = I_{R2})$ $= (470 \times 0.01125) + (330 \times 0.01125)$ $= 5.2875 + 3.7125$	1–2
$= 9$ V	1
or	or
V_{BATT} $= (R_1 + R_2) \times 0.01125$ $(I_{R3} = I_{R4})$ $= (470 + 330) \times 0.01125$ $= 800 \times 0.01125$	1–2
$= 9$ V	1
Total	**3**
These are the two most likely methods for solving the problem but also accept other valid methods of calculation that may use the resistors to the right of the battery.	

(b) Calculate P_{BATT}, the power supplied to the circuit by the battery. (3 marks)

Description	Marks
P_{BATT} $= V_{BATT} \times (0.01125 + 0.0075)$ $= 9 \times 0.01875$	1–2
$= 0.16875$ W or 168.75 mW or 1.69×10^{-1} W	1
Total	**3**
Accept other valid methods of calculation.	

Question 40 (continued)

(c) Calculate R_3, the resistance of R_3. (7 marks)

Description	Marks
$\Sigma\Delta V = 0 \quad = V_{BATT} - V_{R3} - V_{R6}$ $V_{R3} \quad = 9 - (1000 \times 0.0075)$ $= 9 - 7.5$	1
$= 1.5$ V $\qquad VR_3 = (V_{R4} + V_{R5})$	1
$\Sigma I = 0 \quad = I_{R3} + \frac{1.5}{(150 + 100)} - 0.0075$ $I_{R3} \quad = 0.0075 - 0.006$	1–2
$= 0.0015$ A	1
$R_3 \quad = \frac{1.5}{0.0015}$	1
$= 1000\ \Omega$	1
Total	**7**
Accept other valid methods of calculation.	

The SPST switch, SW, is now in closed-circuit, as shown in the circuit diagram below. The resistance of SW is negligible, i.e. assume it is 0 Ω.

(d) Calculate R_T, the total resistance of the entire resistor network. If you could not calculate an answer for part (c), use 1200 Ω. (6 marks)

Description	Marks
$R_T = (R_1 + R_2) \parallel (R_3 \parallel ((R_4 + R_5 + (R_{SW} \parallel R_6)))$ $= (470 + 330) \parallel (1000 \parallel ((150 + 100 + (0 \parallel 1000)))$ $= 800 \parallel (1000 \parallel ((250 + (0 \parallel 1000)))$	
$0 \parallel 1000 = \frac{(0 \times 1000)}{(0 + 1000)} = 0$	1–2
$1000 \parallel 250 = \frac{(1000 \times 250)}{(1000 + 250)} = 200$	1–2
$800 \parallel 200 = \frac{(800 \times 200)}{(800 + 200)} = 160\ \Omega$	1–2
If using $R_3 = 1200\ \Omega$ then first parallel arrangement remains the same, second arrangement becomes $1200 \parallel 250 = 206.9\ \Omega$ (accept 207 Ω), and final arrangement becomes $800 \parallel 206.9 = 164.38\ \Omega$ (accept a value close to this).	
Total	**6**
Accept other valid methods of calculation.	

Question 41 **(20 marks)**

Speed control for up to two motors is achieved by connecting pins 1 and 9 to output pins of a microcontroller that can produce PWM signals.

(a) (i) State the full name for PWM. (1 mark)

Description	Marks
Pulse width modulation	1
Total	**1**

(ii) Provide **three** reasons why this technique of speed control is used for an electric motor rather than by simply adjusting current using a variable resistor between the power supply and the motor. (3 marks)

Description	Marks
Full voltage (in pulses) results in more torque	1
More efficient (power is not wasted as heat or voltage across the variable resistor)	1
Finer or more accurate control	1
Total	**3**
Accept other reasonable answers	

(iii) Assume that the motors are required to operate at a PWM frequency of 490 Hz with an 80% duty cycle. Calculate the duration of the 'high' and 'low' times for each period. (3 marks)

Description	Marks
Frequency (f) $= \frac{1}{t}$	
t (period) $= \frac{1}{490} = 0.002040816$ s	1
'high' $= 0.00204 \times 0.8 = 0.001635$ s	1
'low' $= 0.00204 \times 0.2 = 0.0005$ s or $0.00204 - 0.002 = 0.000408$ s	1
Total	**3**

Gearhead motors like the one shown below are often used for mechatronic applications .

(b) (i) The gearhead is designed to produce a high velocity ratio (VR). Identify and explain briefly **one** significant advantage and **one** significant disadvantage of this system. (4 marks)

Description	Marks
Advantage: Higher torque (turning force) means that larger loads can be moved	1–2
Disadvantage: Slower output speed means work is done more slowly	1–2
Total	**4**
Accept other plausible advantages or disadvantages.	

Question 41 (continued)

(ii) Assume the output shaft of a gearhead motor with a VR of 244 is fitted to the driver pulley of a conveyor belt mechanism similar to that illustrated above. The driver pulley has a diameter of 20 mm and the follower pulley has a diameter of 32 mm. The head and tail pulleys that move and support the conveyor belt are both 50 mm in diameter.

The free-running speed of rotation of the electric motor fitted to the gearhead is 8784 revolutions per minute (r.p.m.). PWM control of the motor is set at a duty cycle of 70%. Losses due to friction, slippage and loading of the motor result in an efficiency of 65%. Calculate the resulting linear speed of the conveyor belt. Answer in units of metres per second (m s^{-1}). (9 marks)

Description	Marks
Output shaft r.p.m. $= \frac{8784}{244} =$ 36 r.p.m.	1
Allowing for 70% PWM duty cycle = 36 × 0.7 = 25.2 r.p.m.	1
VR pulley drive $= \frac{32}{20} =$ 1.6 (1.6:1)	1
Head pulley r.p.m. $= \frac{25.2}{1.6} =$ 15.75 r.p.m.	1
Circumference of head pulley $= \pi d = \pi \times 50 =$ 157.1 mm	1
Linear speed of conveyor belt @ 100% efficiency $= \frac{157.1}{1000} \times \frac{15.75}{60} =$ 0.04123 m s^{-1}	1–2
@ 65% efficiency = 0.04123 × 0.65 = 0.0268 m s^{-1}	1–2
Total	**9**
Accept other reliable methods of calculation and allow for minor rounding.	

Question 42 **(20 marks)**

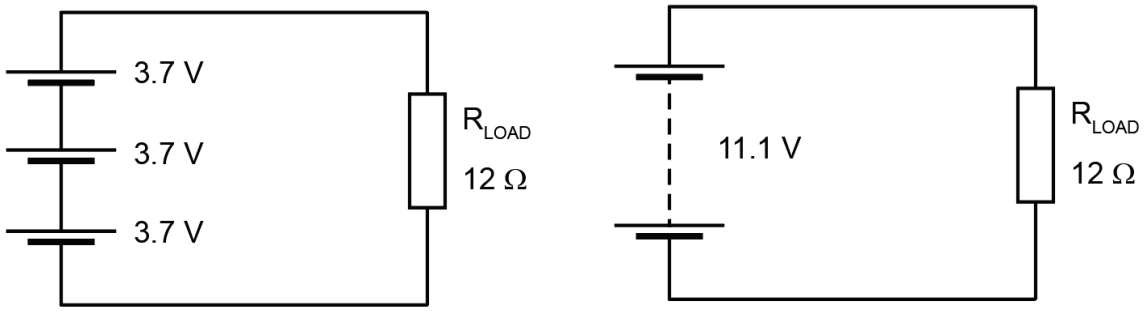
The storage and supply of energy for electrical and electronic circuits is commonly achieved using cells, batteries and capacitors.

(a) The following questions relate to lithium-ion cells marked 3.7 V 2000 mAh.

(i) Lithium-ion cells are described as being 'secondary' cells. State how these differ from 'primary' cells. (1 mark)

Description	Marks
A secondary cell is rechargeable whereas a primary cell is not.	1
Total	**1**

(ii) **Three** of these lithium-ion cells are connected in series and connected to a 12 Ω resistor that acts as the load for this circuit. In the space below, sketch a labelled circuit diagram, using the correct circuit symbols given in Data Book. (2 marks)



Description	Marks
Cells are in series and it is clear from labelling that voltages add to 11.1 V Alternatively, battery symbol is used and it is labelled 11.1 V	1
Load resistor correctly inserted in circuit and labelled.	1
Total	**2**

(iii) Calculate V_R, the voltage held across the load resistor and, I_R, the current that flows through it. (3 marks)

Description	Marks
$\Sigma\Delta V = 0 \quad = 3.7 + 3.7 + 3.7 - V_{RL}$	1
$V_R \quad = 11.1$ V	1
$I_R \quad = \frac{11.1}{12} = 0.925$ A = 925 mA	1
Total	**3**

Question 42 (continued)

(iv) Calculate the time the battery made from the three cells joined in series will be able to supply the current calculated in part (iii) to the circuit. Answer in seconds. (3 marks)
Note: If you could not calculate an answer for part (iii) use 950 mA.

Description	Marks
$t = \frac{(2 \times 60 \times 60)}{0.925}$	
$= \frac{7200}{0.925}$	1–2
$= 7784$ s	1
Total	**3**
Accept other valid methods of calculation. Allow for rounding.	
If using 950 mA the answer will be 7579 s.	

(v) Calculate the energy transferred to the resistor by the battery in this time. Answer in units of kilojoules (kJ). (3 marks)

Description	Marks
$E = P \times t$ $= \frac{(11.1 \times 0.925 \times 7784)}{1000}$ $= \frac{79920}{1000}$	1–2
$= 79.92$ kJ	1
Total	**3**
Accept other valid methods of calculation. Allow for rounding.	

Two capacitors are connected to a power supply as shown in the above diagram. One is marked 474 and the other 1 μF. The voltage across C_2 is 1.918 V.

(b) Calculate C_T, the total capacitance of the network. Answer using units of microfarads (μF). (3 marks)

Description	Marks
474 = 470000 pF = 0.47 μF $C_T = \frac{(0.47 \times 1.0)}{(0.47 + 1.0)}$ $= \frac{0.47}{1.47}$	1–2
$= 0.3197$ μF	1
Total	**3**
Accept other valid methods of calculation. Allow for rounding.	

The charge of a capacitor is determined using the formula $Q = CV$ where Q is the charge in units of coulombs, C is the capacitance in units of farads, and V is the voltage across the capacitor.

Additionally, the way that the capacitors are arranged results in $Q_T = Q_{C1} = Q_{C2}$ i.e. total charge of the capacitor network equals the charge of the first capacitor equals the charge of the second capacitor. This is similar to the relationship between parallel resistors and voltage in a resistor network.

(c) Calculate V_S, the voltage of the power supply. (5 marks)

Description	Marks
$Q_T = Q_{C1} = Q_{C2}$ = 0.000 001 × 1.918 = 0.000001918 coulombs	1
$V_{C1} = \frac{0.000001918}{0.00000047}$	1
= 4.081 V	1
$\Sigma\Delta V = 0$ = $V_S - V_{C1} - V_{C2}$ V_S = 4.081 +1.918	1
= 6 V	1
Total	**5**
Accept other valid methods of calculation. Allow for rounding.	

Question 43 **(12 marks)**

The above circuit features **two** potentiometers and **two** servos connected to a microcontroller.

The outputs of the potentiometers are connected to pins of the microcontroller that each incorporate ADCs with a resolution of 10-bits.

(a) (i) State the full name for ADC. (1 mark)

Description	Marks
Analog to digital converter	1
Total	**1**

(ii) The potentiometers are marked as 10 kΩ. If RV1 is adjusted by rotating its spindle such that it produces a value of 812 at pin A0, calculate the resistance between its wiper and 5 V. (3 marks)

Description	Marks
$R_{\text{WIPER,5 V}} = \frac{(1023 - 812)}{1023} \times 10000$ $= \frac{211}{1023} \times 10000$	1–2
= 2063 Ω (allow for some rounding)	1
Total	**3**
Accept other valid methods of calculation	

(b) State **three** reasons why it is necessary to connect the GND wires of the servos to the GND pin of the microcontroller? (3 marks)

Description	Marks
The positioning of the servo is determined by signals from the microcontroller.	1
These signals (a form of PWM) are at sent at a specific voltage level and must be received at the same level.	1
Connecting the grounds (GND) provides/enables both the microcontroller and the servos to share a common reference for ground.	1
Total	**3**
Accept descriptions that are expressed differently but have the same meaning.	

The circuit shown on page 52 could be used to control and move a 'pan and tilt' mechanism for a small camera. The operator could move the camera on remotely two axes – left/right (pan) and up/down (tilt). The flowchart of the control program to achieve this is shown below.

(c) Explain how the control program functions, assuming the servos operate in a 180° arc. (5 marks)

Description	Marks
Variable x is used to map the 10-bit value at A0 to the 180° arc of movement of Servo 1.	1
1023 / 180 = 5.6833˙ or a change of 5.5833 at the ADC = 1° change of position of servo.	1
The mapped position of RV1 will correspond with the positioning of Servo 1's spindle/horn.	1
Variable y is used to map the 10-bit value at A3 to the 180° arc of movement of Servo 2.	1
The mapped position of RV2 will correspond with the positioning of Servo 2's spindle/horn.	1
Total	**5**
Accept descriptions that are expressed differently but have the same meaning.	

Question 44 **(19 marks)**

The circuit shown below includes a microcontroller, IC, and a transistor, Q. It has the following parameters: $V_{\text{OUT,LOW}}$ = 0 V, $V_{\text{OUT,HIGH}}$ = 5 V, transistor gain (β) = 25 and R_{RLY} = 300 Ω.

(a) Assume the output pin is *low*. Calculate V_{CE}, the voltage across the collector-emitter junction of the transistor. (3 marks)

Description	Marks
I = 0 A (Transistor in cut-off)	1
$\Sigma\Delta V = 0$ = 12 – V_{RLY} – V_{CE} V_{CE} = 12 – (300 × 0)	1
= 12 V	1
Total	**3**

(b) Assume the output pin is *high* and P_{RLY}, the power dissipated by the relay is 315 mW.

(i) Calculate V_{CE}, the voltage across the collector-emitter junction of the transistor. (4 marks)

Description	Marks
$I_{\text{C}} = \sqrt{P/R} = \sqrt{0.315/300} = \sqrt{0.00105}$	1
= 0.0324 A	1
$\Sigma\Delta V = 0$ = 12 – V_{RLY} – V_{CE} V_{CE} = 12 – (0.0324 × 300) = 12 – 9.721	1
= 2.279 V	1
Total	**4**
Accept other valid methods of calculation	

(ii) Calculate R, the resistance of the resistor. (5 marks)

Description	Marks
$I_{\text{B}} = \frac{I_{\text{C}}}{\beta} = \frac{0.0324}{25}$	1
= 0.001296 A	1
$\Sigma\Delta V = 0$ = 5 – V_{R} – $V_{\text{BE,ON}}$	
V_{R} = 5 – 0.7 = 4.3 V	1
$R = \frac{4.3}{0.001296}$	1
= 3318 Ω (accept a value close to this)	1
Total	**5**

(c) Calculate the maximum value for R, the resistance of the resistor, required to drive the transistor into saturation when the output from the microcontroller is high. (7 marks)

Description	Marks
$\Sigma\Delta V = 0 \quad = 12 - V_{RLY} - V_{CE,SAT}$ $V_{RLY} \quad = 12 - 0$ $= 12$ V	1
$I_{C,SAT} = I_{RLY} \quad = \frac{12}{300} = 0.04$ A	1
$I_B \quad = \frac{I_C}{\beta} = \frac{0.04}{25}$	1
$= 0.0016$ A	1
$\Sigma\Delta V = 0 \quad = 5 - V_R - V_{BE,ON}$ $V_R \quad = 5 - 0.7 = 4.3$ V	1
$R \quad = \frac{4.3}{0.0016}$	1
$= 2688\ \Omega$ (accept a value close to this)	1
Total	**7**

Question 45 **(15 marks)**

A bird house complex has been built at a zoo. It consists of a bird enclosure and an entrance/exit passageway. This passageway requires a system to control entrance into the bird enclosure. This consists of two sliding doors, one at each end of an enclosed entrance/exit passageway. Door 1 provides access into the entrance/exit passageway and exit from the bird house complex. Door 2 provides access from the entrance/exit passageway into the bird enclosure.

Each door is moved by its own reversible electric motor driving rack and pinion mechanisms. To prevent birds from escaping, it is imperative that only one door can be open at a time when entering or exiting the entrance/exit passageway. To activate the system, there are button switches on either side of each door.

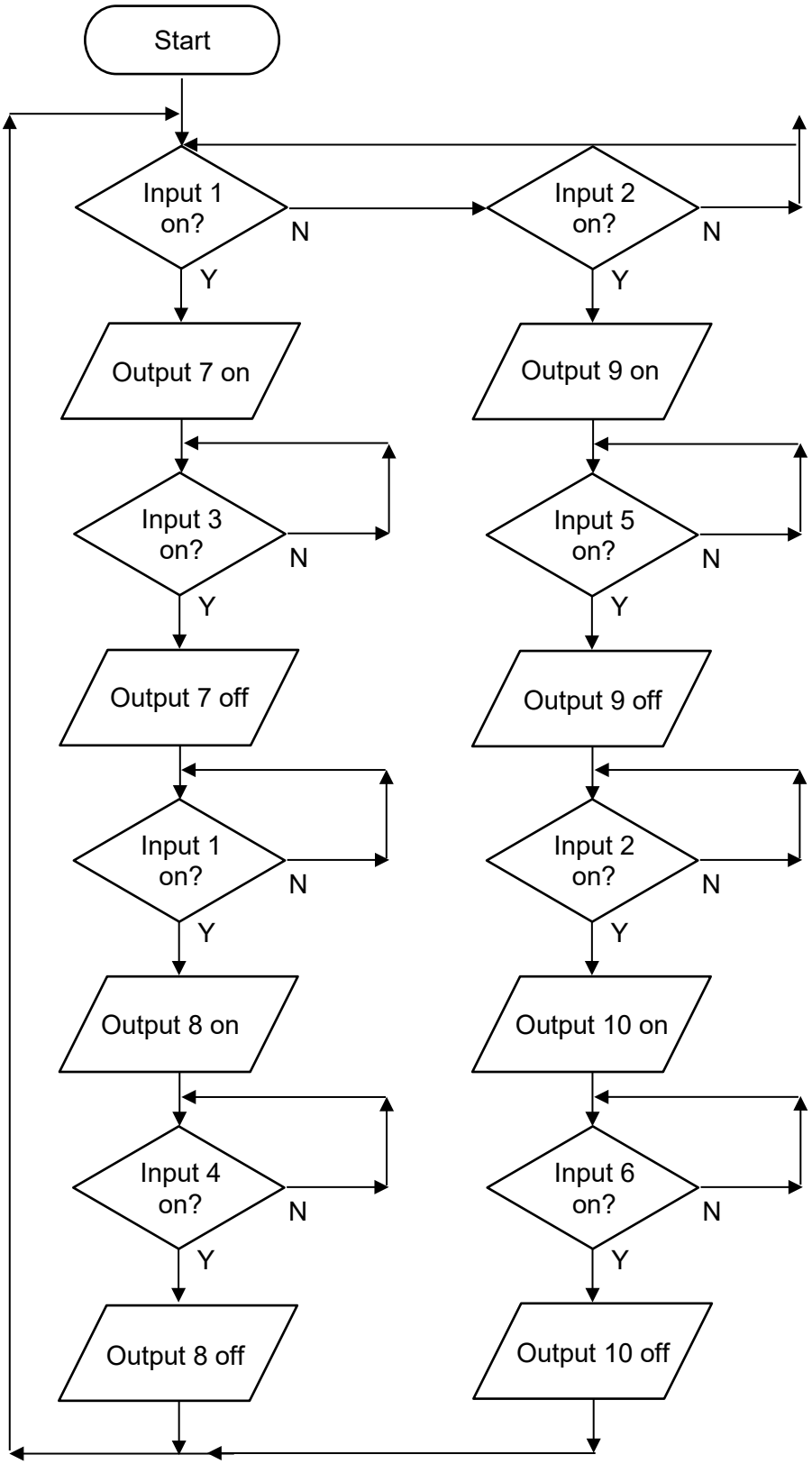
The system works as follows:

1. To enter the entrance/exit passageway from outside the bird house complex, press the button outside Door 1. This will cause the door to open. A limit switch will detect when the door is fully open.
2. To close Door 1, press the button located inside the passageway next to Door 1. Another limit switch will detect when the door is fully closed.
3. The buttons either side of Door 1 are wired in parallel. The limit switches are each wired separately.
4. To exit the entrance/exit passageway and enter the bird enclosure, press the button inside the passageway next to Door 2. This will cause the door to open. A limit switch will detect when the door is fully open.
5. To close Door 2, press the button located inside the bird enclosure next to Door 2. Another limit switch will detect when the door is fully closed.
6. The buttons either side of Door 2 are wired in parallel. The limit switches are each wired separately.
7. Exit from the bird enclosure is achieved by following the above steps in reverse.
8. The control system cannot allow both doors to be open at the same time.

(a) A microcontroller will be used to detect inputs, operate sequences, and control outputs. The microcontroller has **ten** digital pins. These can be programmed either as inputs or as outputs. Complete the chart below to assign the required inputs and outputs to the microcontroller's digital pins and state their functional operation. (5 marks)

Description			**Mark**
Digital pin	**Input or output**	**Functional operation**	
1	Input 1	Buttons on either side of Door 1	1
2	Input 2	Buttons on either side of Door 2	
3	Input 3	Limit switch Door 1 open	1
4	Input 4	Limit switch Door 1 closed	
5	Input 5	Limit switch Door 2 open	1
6	Input 6	Limit switch Door 2 closed	
7	Output 7	Open Door 1	1
8	Output 8	Close Door 1	
9	Output 9	Open Door 2	1
10	Output 10	Close Door 2	
		Total	**5**
Input and outputs are indicative only. Accept other sensible allocations and descriptions of inputs and outputs.			

(b) In the space below, draw a labelled flowchart to operate the bird house entrance system. Use correct flowchart symbols and identify each by using pin allocations from the chart completed in part (a) e.g. Input 1, Output 2. (10 marks)



Question 45 (continued)

Description	Marks
Pressing button outside Door 1 (Input 1) causes Door 1 to open (Output 7 on)	1
Contact with limit switch (Input 3) leaves Door 1 in open position (Output 7 off)	1
Pressing button inside Door 1 (Input 1) causes Door 1 to close (Output 8 on)	1
Contact with limit switch (Input 4) leaves Door 1 in closed position (Output 8 off)	1
Pressing button inside Door 2 (Input 2) causes Door 2 to open (Output 9 on)	1
Contact with limit switch (Input 5) leaves Door 2 in open position (Output 9 off)	1
Pressing button outside Door 2 (Input 2) causes Door 2 to close (Output 10 on)	1
Contact with limit switch (Input 6) leaves Door 2 in closed position (Output 10 off)	1
Doors 1 and 2 cannot be opened at the same time	1
System loops	1
Total	**10**
1. The flow chart can look different to the one in the marking key but is must perform the specified functions to be awarded full marks. 2. Labels should match the candidate's pinout chart. Accept other sensible labels - the marking key drawing is indicative only.	

Published by the School Curriculum and Standards Authority of Western Australia
303 Sevenoaks Street
CANNINGTON WA 6107