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

ENGINEERING STUDIES

ATAR course examination 2020

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.

2020/67031

Section One: Core content **40% (85 Marks)**

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

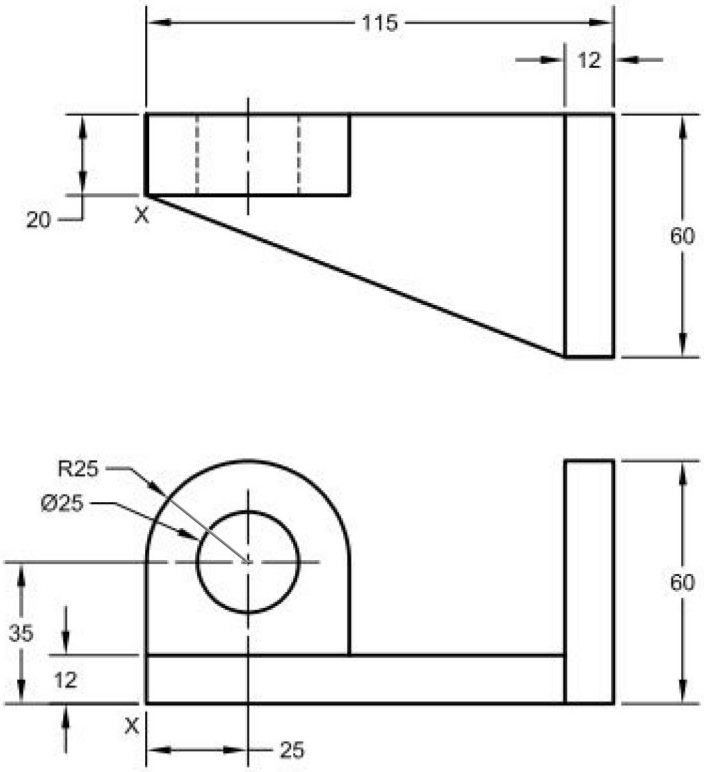
1	a
2	c
3	d
4	d
5	b
6	c
7	a
8	d
9	b
10	b

Part B: Extended response **30% (75 Marks)**

Question 11 **(21 marks)**

(a) Use the grid provided on page 7 to produce a full-sized and labelled 3rd angle orthographic projection of this fitting, showing the front and top views using the correct conventions for line types. You are also required to dimension both views fully. Plan the positioning of the views carefully, as these will fit by keeping the page in its vertical orientation. Use a ruler for straight lines and use a compass or freehand for the circular and radiused features.

(10 marks)



Description	Marks
Top and bottom views line up exactly as per rules of projection (assume third angle)	1
Top view length (115) and width (60) correct	1
Thickness correct for vertical protrusions (20 and 12)	1
Front view length (115) and height (60) correct	1
Thickness of base and vertical block correct (12)	1
Centre position of hole with radius correctly located	1
R25 dimension (using a diameter here even if correct value is wrong)	1
Ø25 (using a radius here even if correct value is wrong)	1
Both centrelines correct	1
Hidden-detail for hole correct	1
Total	**10**

(b) Using calculations, demonstrate that the volume of material in the bracket is very close to 125 500 mm^3. (5 marks)

Description		Marks
Vertical rectangle	= 60 × 60 × 12	
	= 43 200 mm^3	1
Base	= (103 × 60 × 12) – (0.5 × 103 × 40 × 12)	
	= 74 160 – 24 720	
	= 49 440 mm^3	1
Piece with hole	= (50 × 23 × 20) + (0.5 × πr^2 × 20) - (πr^2 × 20)	
	= 23 000 + (0.5 × $\pi 25^2$ × 20) - ($\pi r 12.5^2$ × 20)	
	= 23 000 + 19 635 - 9817	1
	= 32 818 mm^3	1
Total volume	= 43 200 + 49 440 + 32 818	1
	= 125 458 mm^3	
	Total	**5**

(c) Identify the alloy and support your answer with calculations. If you were unable to obtain a value for part (b), use 125 500 mm^3. (4 marks)

Description				Marks
	Brass			1
Mass	= Density × Volume			
Density	=	1.1 / 0.000 125 458	1100 gm = 1.1 kg 125 458 mm^3 = 0.000 125 458 m^3	1
	= 8768 kg m^{-3}			1
	Which is very close to the density of brass (8740 kg m^{-3})			1
			Total	**4**
Accept other logical methods for determining the same conclusion.				

(d) Calculate the area in mm^2 of the surface indicated by an **X** on the dimensional isometric drawing on page 6. (2 marks)

Description		Marks
Length	= SQRT ($103^2 + 40^2$)	
	= SQRT (10 609 + 1600)	
	= SQRT 12 209	
	= 110.494 mm	1
Area	= 110.494 × 12	
	= 1325.9 mm^2 (Accept variance ± 1 mm^2)	1
	Total	**2**

Question 12 **(17 marks)**

(a) What is meant by the term ‘alloy’ and how is a ‘ferrous alloy’ different from a ‘non-ferrous alloy’? (3 marks)

Description	Marks
An alloy is a material that exhibits metallic properties made by combining two or more metals by melting or by melting metal(s) with non-metals.	1
A ferrous alloy has iron as its principal constituent.	1
A non-ferrous alloy will not contain iron (or at least its presence is so insignificant it can be ignored).	1
Total	**3**
Accept other wording of these descriptions provided the meaning is correct.	

(b) Define the term ‘polymer’. (2 marks)

Description	Marks
A polymer is a non-metallic material made from long-chain molecules.	1
These long-chain molecules (polymers) are formed from the combination of many simpler molecules (mers).	1
Total	**2**
Accept other wording of these descriptions provided the meaning is correct.	

(c) (i) Name **three** properties of steel that make it a good choice of material for the tray of the wheelbarrow. For each property, provide a reason for its inclusion. (6 marks)

Description	Marks
Steel is a tough material i.e. it can survive impacts if the wheelbarrow is knocked over or when large rocks are dropped into the tray. These are likely scenarios when the wheelbarrow is being used on site.	1–2
Steel is a stiff material. Some loads will exert large forces on the tray and if it were to deflect too much then the load would spill or become unstable.	1–2
Steel is very strong, both under compression and in tension. The tray will be subjected to both when being moved and especially with a heavy load and it is imperative for the landscaper that the tray does not break otherwise work cannot be completed efficiently nor safely.	1–2
Total	**6**
Accept other plausible reasons provided these are based on the fitness of purpose of the selected material’s property.	

(ii) Name **three** properties of polyethylene that would make it a good choice of material for the tray of the wheelbarrow. For each property, provide a reason for its inclusion. When answering this question, you must **not** repeat a property that was used previously in part (c)(i). (6 marks)

Description	Marks
Polymers tend to have much lower density than steel. Reducing the mass of the tray will make the wheelbarrow easier to move. This means less effort is required by the landscaper to manoeuvre a load or even when retrieving or storing the wheelbarrow from a trailer or truck.	1–2
Polymers will not corrode. The tray will not lose structural integrity due to exposure to moisture and/or water. This is likely to occur in the service conditions and when washing out the tray with a hose.	1–2
This type of polymer is very durable – exposure to the elements – sun, wind, temperature and rain - is not going to compromise the structural integrity of the tray thus ensuring a long service-life.	1–2
Total	**6**
Accept other plausible reasons provided these are based on the fitness of purpose of the selected material's property.	

Question 13 **(20 marks)**

(a) Calculate the total area of roof covered by these panels. Give your answer in m^2. (3 marks)

Description	Marks
Conversion to metres	1
Area = 1.65 × 0.99 × 20	1
= 32.67 m^2	1
Total	**3**

(b) Calculate the mass per square metre of the panels and mounting hardware on the roof. If you were unable to obtain a value for part (a), use 34.4 m^2. (3 marks)

Description	Marks
Mass of panels = 20 × 18 = 360 kg	
Mass/m^2 = (20 × 18)/32.67 + 7	1–2
= 18.02 kg m^{-2}	1
or 17.47 g m^{-2} if 34.4 used	
Total	**3**

(c) Calculate the output current from the solar panels on a day when the maximum efficiency of the panels is 65%. Note: Power = Voltage × Current (3 marks)

Description	Marks
$I = P/V$ × 0.65 = (6600/24) × 0.65 = 179 A	1–3
Total	**3**

(d) Calculate the average density of the battery in units of kg m^{-3}. (3 marks)

Description	Marks
Conversion to metres V = 1.15 × 0.755 × 0.155 = 0.135 m^3	1
D = M/V = 122/0.135 904 kg m^{-3}	1–2
Total	**3**

(e) Calculate the AC output current when the output power is 7 kW. (2 marks)

Description	Marks
$I = P/V$ = 7000/240 = 29.2 A	1–2
Total	**2**

(f) Calculate the maximum energy input from the battery to the inverter in MJ if the efficiency of the inverter is taken into consideration. (3 marks)

Description	Marks
Energy = (13.2 × 1000 × 60 × 60)/0.89 = 53393000 J = 53.39 MJ	1–3
Total	**3**
If conversion is incorrect maximum is 1 mark.	

(g) Calculate the total energy provided by the battery in kWh if it operates at peak power for the allowed maximum time of 10 seconds. (3 marks)

Description	Marks
Energy = Pt = 7000 × 10 J = 70000 J	1
(to kWhr) = (70000/1000)/(60 × 60) = 0.0194	1–2
Total	**3**

Question 14 **(17 marks)**

(a) For each material, identify and provide descriptions of an immediate and a related longer-term problem that can result from either the disposal or manufacture of the packaging material. Note: do not repeat the same answer for any of the three materials.

(i) Cardboard (4 marks)

Description	Marks
Disposal	
Immediate problem: Discarded cardboard requires landfill space. There is limited space available and it may be unfeasible to do so if the volume of unwanted material is too great.	1–2
Long-term problem: This then leads to having to employ other methods of disposal that may create other problems e.g. incineration that releases air pollutants or an increased likelihood of illegal littering or dumping unwanted material.	1–2
Manufacture	
Immediate problem: The manufacture of cardboard requires trees as raw material. To obtain trees the environment must be disrupted, and this disturbs the habitats of vegetation and wildlife.	1–2
Long-term problem: These disruptions could affect the delicate balance of the ecosystem and lead unanticipated 'knock-on' effects e.g. the introduction of disease or pests or non-indigenous plants or animals that place further pressure on the environment.	1–2
Total	**4**
Mention of competing demands for water and issues associated with energy (generation of greenhouse gases) when manufacturing cardboard is likely to be raised by candidates. Accept other plausible impacts and descriptions of why these are significant. A pertinent insight must be evident in the description for full marks.	

(ii) Foam (e.g. polystyrene moulds and beads) (4 marks)

Description	Marks
Disposal	
Immediate problem: Packaging foam is not biodegradable and will remain in the environment for a very long time as landfill or litter.	1–2
Long-term problem: Wildlife may choke or have other problems (e.g. digestive tract) if packaging foam is ingested. This causes unnecessary and inhumane pain for such animals and, for rare species, may contribute to extinction or absence from an otherwise habitable location.	1–2
Manufacture	
Immediate problem: Manufacture of packaging foam requires fossil fuel as a raw material. Aside from disruption to the environment at the location of the oil or gas well (often the seabed), there is the risk of oil spills and/or fire.	1–2
Long-term problem: Oil spills in the ocean have previously caused many deaths and harm for sea creatures and birds. This would be particularly severe if the location of the accident impacted on a breeding ground. and/or An oil or gas fire can last a very long time (days, weeks or even longer) before being extinguished. This will directly contribute to greenhouse gases and thermal pollution.	1–2
Total	**4**
Mention may be made that incorrect burning/incineration of the foam releases sooty pollutants and, according to some sources, potentially harmful chemicals. Also, if not already used as an example, packaging foams take up a lot of landfill space and for this reason may not be accepted thus increasing the likelihood that it will find its way into the environment as litter. It is often mentioned as being found floating in waterways and the oceans. Accept other plausible impacts and descriptions of why these are significant. A pertinent insight must be evident in the description for full marks.	

(iii) Plastic film (4 marks)

Description	Marks
Disposal or manufacture	
Immediate problem	1–2
Long-term problem	1–2
Total	**4**
The responses are likely to be similar to those given as examples for packaging foam. For full marks to be awarded the response should not be identical to the answer to a previous part of this question.	

(b) Choose **one** packaging material and for this material identify and describe a potential strategy that could be implemented to reduce its negative effects on the environment. In addition, provide **two** suggestions that would increase the likelihood that the strategy will be effective. (5 marks)

Description	Marks
Strategy: Do not use foam mouldings and/or beads in packaging. Instead, use biodegradable material e.g. shredded newspaper (has added benefit of reducing pressure on material and energy inputs).	1
Suggestion one: Society could be educated via advertisements and/or broadcast documentaries to demand that manufacturers think more carefully about the materials they use for packaging. By using their buying power to select compliant manufacturers products then change will follow if companies wish to remain profitable.	1–2
Suggestion two: Governments could provide incentives like taxation concessions for companies that use more environmentally friendly packaging materials. Similarly, funding could be prioritized for industry and/or university research that leads to these outcomes.	1–2
Total	**5**
The model answer is indicative of the required response – there are many possibilities. Accept other plausible suggestions and strategies and award marks accordingly.	

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

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

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

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

Question 25 **(14 marks)**

(a) Calculate the potential energy of the elevator when the first passenger weighing 100 kg steps on at ground level. (1 mark)

Description	Marks
0 (J) or (Nm)	1
Total	**1**

(b) Calculate the potential energy of the system when the elevator reaches Level 2 with the first passenger still in the lift, but before anyone else boards. (4 marks)

Description	Marks
Ft = F1 + F2 = 9800 N + 980 N = 10780 N	1
h1 (3300 × 2)/1000 = 6.6 m	1
W = F × h1	1
71150 Nm	1
Total	**4**

(c) Calculate the minimum electrical mains energy the motors running the lift have used over the whole trip, assuming 95% efficiency. (5 marks)

Description	Marks
F3 = 2 x 90 x 9.8 = 1764 N	1
h = 3.3 m	1
W1 = 71150 Nm W2 = (F3 + Ft) × h = (1764 + 10780) x 3.3 = 41395 Nm Efficiency = 95% Wtm = (71150 + 41395) /0.95 = 118 500 Nm	1–3
Total	**5**

(d) All the passengers disembark at Level 3. There was then a catastrophic failure of the elevator cable and redundancy systems, calculate the velocity with which the elevator hit the ground. (4 marks)

Description	Marks
$E_p = E_k$ =9800 N × 9.9 m =97020 Nm	1
$E_k = 0.5mv^2$	1
m = 1000 kg	1
v = 13.93 m s^{-1}	1
Total	**4**

Question 26 **(10 marks)**

(a) Calculate the vertical component of the ball's velocity and then use Pythagoras' theorem to solve the resultant velocity of the ball when it hits the ground. (8 marks)

Description	Marks
$v^2 = u^2 + 2as$	1
$u = 0$	1
a = 1.62 m s^{-2} and s = 1.8 m	1
v = 2.4 m s^{-1} down	1–2
from Pythagoras solution 10 m s^{-1} across + 2.4 m s^{-1} down 10.3 m s^{-1}	1–2
θ = 13.5° down from horizontal	1
Total	**8**

(b) Calculate how many seconds it takes for the ball to hit the ground after it is thrown. (2 marks)

Description	Marks
$s = ut + 0.5at^t$ 1.8 m = 0.5 × 1.62 m s^{-2} × t^2	1
t = 1.49 s	1
Total	**2**

Question 27 **(24 marks)**

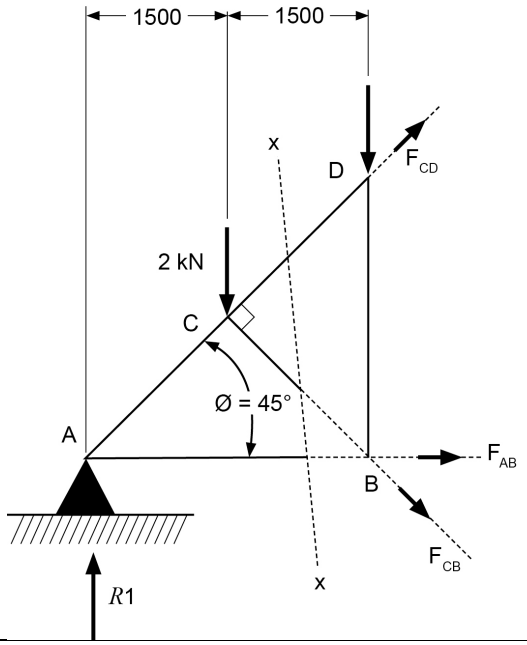
(a) Find the length of segment CB. (1 mark)

Description	Marks
tan(3/3) = 45 degrees L1 = 3 sin(45) L1 = 2.121 m	1
Total	**1**
Other methods of solution acceptable	

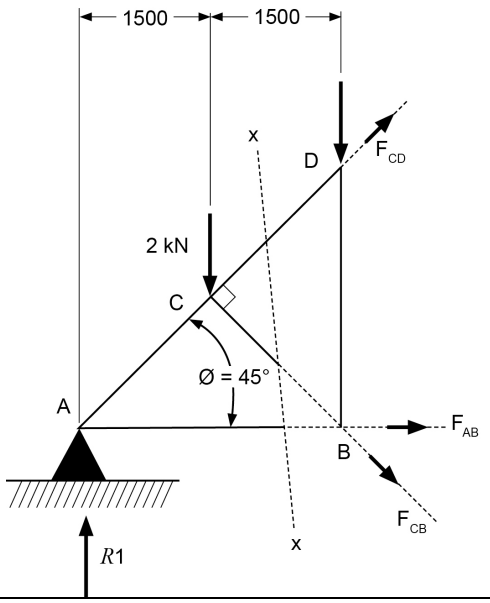
(b) Calculate the reaction forces $R1$ and $R2$. (8 marks)

Description	Marks
$\Sigma F_x = 0$ 0 = –2 kN –7 kN + $R1$ + $R2$	1
$R1$ + $R2$ = 9 kN	1
ΣM @ $R1 = 0$ 0 = 2 kN × 1.5 m + 7 kN × 3 m – $R2$ × 6 m	1–3
$R2$ = 4 kN	1
Solve for $R1$ $R1$ = 9 kN – 4 kN	1
$R1$ = 5 kN	1
Total	**8**

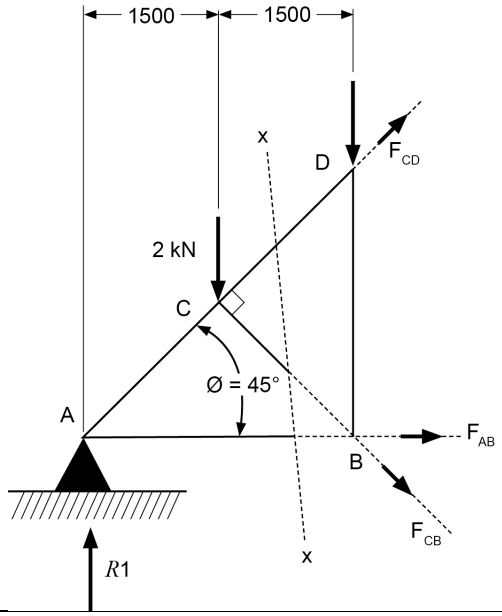
(c) Using the method of sections at x-x, calculate the force in the member CD and state if it is in compression or tension. (5 marks)

Description	Marks
	
Moments @ B	1
0 = 5 kN × 3 m – 2 kN × 1.5 m + 2.121 m × F_{CD} (Note: should not have default value given for 2121 mm in a above as vector component calculation can be used to get this)	1–3
FCD = 5.65771 kN compression	1
Total	**5**
If moments are not taken at these locations this is not method of sections and should carry no marks	

(d) Using the method of sections at x-x, calculate the force in the member AB and state if it is in compression or tension. (5 marks)

Description	Marks
	
Moment @ C	1
$0 = 5\ kN \times 1.5\ m - F_{AB} \times 1.5\ m$	1–2
$F_{AB} = 5\ kN$	1
tension	1
Total	**5**

(e) Using the method of sections at x-x, calculate the force in the member CB and state if it is in compression or tension. (5 marks)

Description	Marks
	
Moments @ A (or D)	1
$0 = 2\ kN \times 1.5\ m + F_{CB} \times 2.121\ m$	1–2
$F_{CB} = -1.41443\ kN$	1
compression	1
Total	**5**

Question 28 **(22 marks)**

(a) Calculate the reaction moment at the support. (3 marks)

Description	Marks
F_r = –5 kN/m × 1.5 m F_r = –7.5 kN	1
ΣM_A = 0 0 = –7.5 × 5.25 + MA	1
MA = 39.375 k Nm CCW (accept negative answer if 7.5 above is positive)	1
Total	**3**
Direction definitions Moments CW negative. Forces positive up, negative down. Taking other direction as positive if directions are handled in consistent manner to produce correct results. Direction definitions Internal beam shear force taken as positive if tend to push left hand side of beam up. Internal beam bending moment taken as positive if tend to push up left side. Taking other direction as positive if directions are handled in consistent manner to produce correct results.	

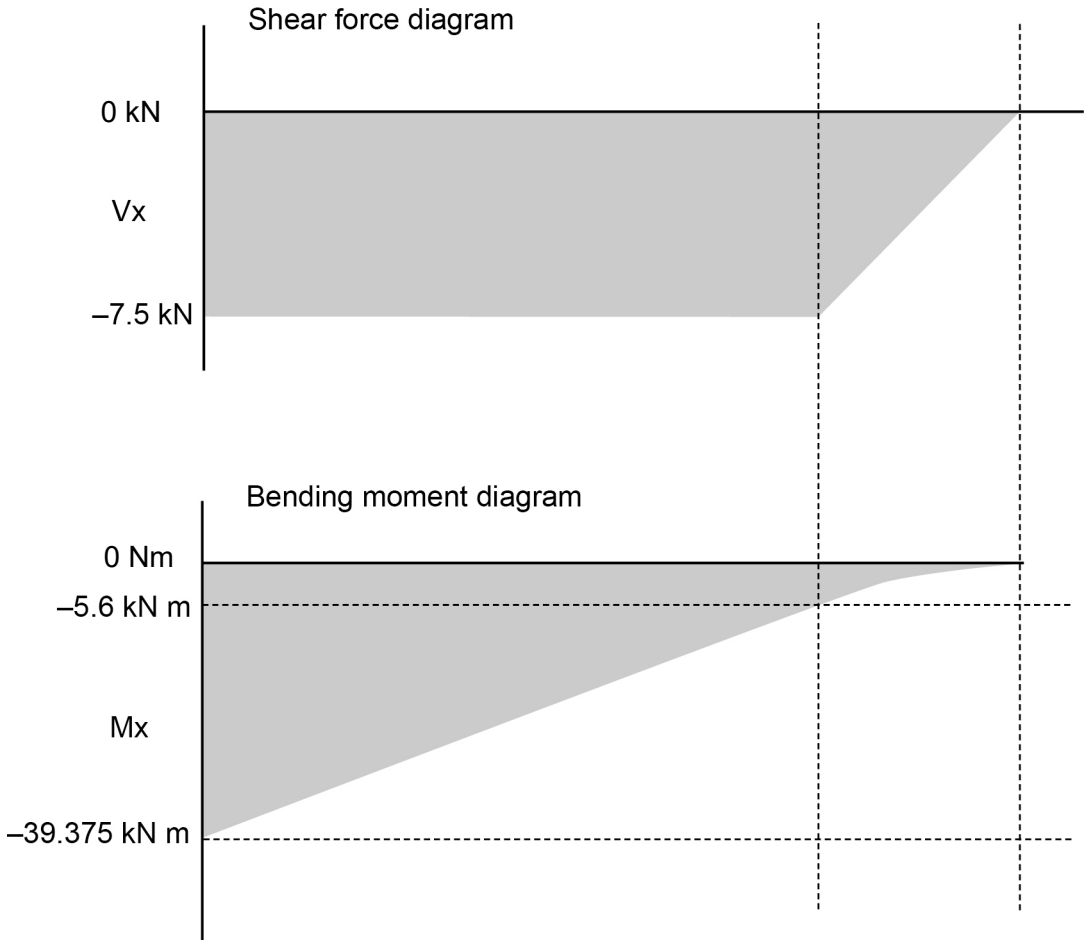
(b) Draw a shear force diagram for this beam on the graph paper provided on page 33. question. In the space below, show all calculations undertaken at reference points 1 and 2 on the beam diagram that are used to construct the shear force diagram. (7 marks)

Description	Marks
@1 ΣF_y = SF1 SF1 = Fr + Ry SF1 = –7.5 kN +7.5 kN SF1 = 0 kN Note: no working needs to be shown for full mark.	1
@2 ΣF_y = SF2 SF2 = Ry SF2 = 7.5 kN	1
SF2 = –7.5 kN	1
shear graph labels and units	1
shear graph alignments	1
shear force points found and plotted correctly	1–2
Total	**7**

(c) Draw a bending moment diagram for this beam on the graph paper provided on page 3 under the shear force diagram. In the space below, show all calculations undertaken at reference points A, B and C on the beam diagram that are used to construct the bending moment diagram. (12 marks)

Description	Marks
@A $\Sigma M_A = MA$ $MA = -39.375$ kN m	1
@B $\Sigma M_B = MB$ $MB = 7.5 \times 4.5 - 39.375$ kN m	1
$MB = -5.625$ kN m	1
@C $\Sigma M_C = MC$ $MC = 7.5 \times 6 - 39.375 - 7.5 \times 0.75$	1–2
$MC = 0$ kN m	1
bending moment graph labels and units	1
bending moment graph alignments	1
bending moment points found and plotted correctly	1–3
bending moment graph has curve shape	1
Total	**12**

Diagrams for Question 28 parts (b) and (c).



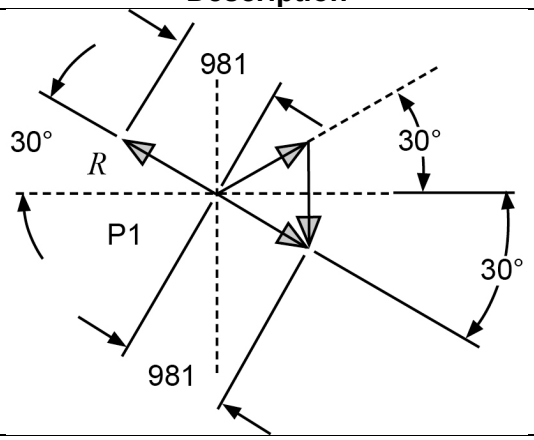
Note: If both graphs are mirror-imaged along the X-axis award full marks.

Question 29 **(11 marks)**

(a) Calculate the tensile forces in the two wire segments P1 to P2 and P2 to C. (2 marks)

Description	Marks
$F_m = mg$ F_m = 980 N	1
F_m = P1 – P2 = P2 – C = 980 N	1
Total	**2**

(b) Graphically solve the resultant force acting on the axis of the pulley P1 and draw in the reaction force R on the axis pin including its angle. (6 marks)

Description	Marks
	
magnitude	1
angle	1
drawing vectors tip to tail	1–2
clear diagram including axes and P1 as origin	1
reaction (R)	1
Total	**6**

(c) If the pulleys at points P1 and P2 are increased to a diameter of 100 mm and remain frictionless, explain what effect this will have on the resultant force at the axis. Justify your answer. (3 marks)

Description	Marks
no change	1
The acting forces are still the same and are still opposed by an equal and opposite force at the pin.	1–2
Total	**3**

Question 30 **(19 marks)**

(a) Calculate the mass m (kg) required. (3 marks)

Description	Marks
F = 1500 + 1000 = 2500 N	1
2500/9.8 N kg^{-1}	1
255 kg	1
Total	**3**

(b) What is the total unloaded wire length? (4 marks)

Description	Marks
Total = 2400 + 5000/cos(30) + 4000/cos(10)	1–3
= 12235 mm	1
Total	**4**

(c) Which of the following three materials would you select for this tension wire considering the design requirements? Circle and then justify your selection. (3 marks)

Description	Marks
mild steel	1
Mild steel because it has the highest yield strength and would therefore allow for the thinnest wire to be used in the design.	1–2
Total	**3**
NOTE: maximum of 1 mark to be awarded if material selection does not consider designer requirements in cable thickness, but has a sound justification (at markers discretion).	

(d) Calculate the diameter of the material you selected for the wire. If you were unable to calculate a value for part (b), use 12 m. With reference to the Data Book comment on the suitability of this wire. (9 marks)

Description	Marks
E = from data book 200 000 N mm^{-2}	1
d = unknown	1
L = 12.2 m ΔL = 0.35 m F = 1000 N	1
$A = F.L/E.\Delta L$ This is the area of steel that would cause the required elongation over this length.	1
= 0.174285714 mm^2	1
$A = \pi \times d^2/4$	1
d = 0.471071 mm	1
The question here is if a 0.5 mm diameter wire can hold 1000 N safely. Stress = F/A = 1000/0.174285714 = 5738 N mm^{-2} This greatly exceeds yield and so is not viable.	1–2
Total	**9**

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

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

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

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

Question 41 **(24 marks)**

(a) Calculate V_{R2}, the voltage across R2. (4 marks)

Description	Marks
$\sum\Delta V = 0$ $= V_{S2} - V_{R2} - V_{R3} - V_{R4}$	
V_{R2} $= 6 - (R_3 \times 0.0075) - (R_4 \times 0.0075)$ $(I_{R3} = I_{R4})$	
$= 6 - (330 \times 0.0075) - (270 \times 0.0075)$	
$= 6 - 2.475 - 2.025$	1–3
$= 1.5$ V	1
or	
$\sum\Delta V = 0$ $= V_{S2} - V_{R2} - (V_{R3} + V_{R4})$	
V_{R2} $= 6 - (R_3 + R_4) \times 0.0075$ $(I_{R3} = I_{R4})$	
$= 6 - (600 \times 0.0075)$	
$= 6 - 4.5$	1–3
$= 1.5$ V	1
Total	**4**

(b) Calculate R_2, the resistance of R2. (4 marks)

Description	Marks
$\sum I = 0$ $= I_{R1} + I_{R3} - I_{R2}$ $(I_{R1} = I_{S1}$ and $I_{R3} = I_{R4})$	
I_{R2} $= 0.0075 + 0.0075$	1
$= 0.015$ A	1
$R_2 = \frac{V_{R2}}{I_{R2}}$	
$= \frac{1.5}{0.015}$	1
$= 100\ \Omega$	1
Total	**4**

(c) Calculate P_{S1}, the power supplied by S1. (4 marks)

Description	Marks
$\Sigma\Delta V = 0$ $= V_{S1} - V_{R1} - V_{R2}$	
V_{S1} $= (1000 \times 0.0075) + 1.5$	
$= 7.5 + 1.5$	1
$= 9$ V	1
P_{S1} $= 9 \times 0.0075$	1
$= 0.0675$ W	1
Total	**4**
Accept other valid methods of calculation.	

(d) A voltmeter is connected to the circuit as shown in the above diagram. Using calculations, determine its reading. (3 marks)

Description	Marks
$\Sigma\Delta V = 0 \quad = V_{S2} - V_{R4} - V_{METER}$ $V_{METER} \quad = V_{S2} - V_{R4}$ $= 6 - (270 \times 0.0075)$ $= 6 - 2.025$	1–2
$= 3.975$ V	1
Alternatively	
$\Sigma\Delta V = 0 \quad = V_{METER} - V_{R2} - V_{R3}$ $V_{METER} \quad = V_{R2} + V_{R3}$ $= 1.5 + (330 \times 0.0075)$ $= 1.5 + 2.475$	1–2
$= 3.975$ V	1
Total	**3**
Accept other valid methods of calculation.	

(e) Using calculations, determine I_{WIRE}, the current that flows through the wire. If you were unable to obtain a value for part (a), use 90 Ω. If you were unable to obtain a value in part (c), use 10 V. (9 marks)

Description	Marks
$I_{R4} = \dfrac{0.6416}{330}$	1
$= 0.022$ A	1
$R_2 = R_3 = \dfrac{100 \times 330}{100 + 330}$	
$= \dfrac{100 \times 33\,000}{430}$	1
$= 76.744\ \Omega$	1
$V_{R2} = V_{R3} = \dfrac{9 \times 76.744}{1000 + 76.744}$	
$= \dfrac{690.7}{1076.744}$	1
$= 0.6415$ V	1
$I_{R3} = \dfrac{0.6416}{330}$	
$= 0.001944$ A	1
$\sum I = 0 = I_{R3} + I_{R4} - I_{WIRE}$	
$I_{WIRE} = 0.022 + 0.00194$	1
$= 0.02394$ A	1
Total	**9**
Accept other valid methods of calculation.	

Question 42 **(12 marks)**

(a) Calculate the total capacitance of the arrangement of C1 and C2 only. Answer in units of nanofarads (nF). (3 marks)

Description	Marks
C_1 = 100 000 pF = 100 nF	1
C_2 = 100 µF = 100 000 nF	1
C_T = 100 + 100 000	
= 100 100 nF	1
Total	**3**

(b) What is the purpose of the capacitors in this circuit? Describe how these components perform the required function and explain why this is necessary, given that the voltage regulator circuit will supply power to a microcontroller. (5 marks)

Description	Marks
The purpose of the capacitors is to 'smooth' the supply voltage/current.	1
When there is 'ripple' i.e. spikes and falls of the supply power the capacitors will absorb and release electric charge thereby smoothing the supply.	1–2
Microcontrollers are prone to malfunction when there is 'electrical noise' i.e. ripple on the supply is likely to be sensed as false signals and cause problems with the operation of the microcontroller.	1–2
Total	**5**

(c) Although the diode is not always included in voltage regulator circuits it is a very useful addition. What is its purpose and how does it perform its function? (4 marks)

Description	Marks
The purpose of the diode is to protect the circuit from incorrect polarity connection of the input supply.	1
Reverse polarity can lead to damage or failure of delicate components. (e.g. polarized capacitors will explode!)	1
The diode will only pass a current if it is correctly biased i.e. its anode is connected to positive of the supply and the cathode toward a pathway that leads to negative (0 V or Ground).	1
Reverse polarity connection of the supply will cause the diode to block the current and therefore protect the circuit.	1
Total	**4**

Question 43 **(20 marks)**

(a) Explain the behaviour of the digital input when the switch is operated. (6 marks)

Description	Marks
When the switch is not being pressed it is in closed circuit and a current will flow through the (pull-up) resistor and the switch. Since the switch can be assumed to have negligible or no resistance then no voltage will be dropped across it (Ohm's law).	1
All voltage will be held across the resistor (Kirchhoff's voltage law).	1
The digital signal being detected by the microcontroller is the voltage across the switch and will therefore be *low* (0 V).	1
When the switch is being pressed it is in open circuit and current cannot flow through the (pull-up) resistor and the switch. No voltage will be held across the resistor (Ohm's law).	1
All voltage will be held across the switch (Kirchhoff's voltage law).	1
The digital signal being detected by the microcontroller is the voltage across the switch and will therefore be *high* (5 V).	1
Total	**6**
Accept descriptions that refer to relevant formulae rather than electrical laws since this indicates knowledge and understanding of the correct concepts.	

(b) Explain why the output of the sensor that incorporates an LDR will increase when conditions become brighter. (4 marks)

Description	Marks
The resistance of the LDR will decrease when it detects an increase in light intensity.	1
Since its relative resistance value will be less so too will be the voltage held across it (Ohm's law and/or behavior of a voltage divider)	1
Therefore, the voltage across the variable resistor must increase (Kirchhoff's voltage law and/or behavior of a voltage divider).	1
The analog signal being detected by the microcontroller is the voltage across the variable resistor and will therefore increase.	1
Total	**4**
Accept descriptions that refer to relevant formulae rather than electrical laws since this indicates knowledge and understanding of the correct concepts.	

(c) Calculate the resistance of the LDR. (4 marks)

Description	Marks
ADC value of $153 = \frac{153}{255} \times 5$ $= 3$ V	1
$\Sigma\Delta V = 0 = 5 - V_{LDR} - V_{RV}$ $V_{LDR} = 5 - 3 = 2$ V	1
$R_{LDR} = \frac{2}{0.0003}$ 300 µA = 0.0003 A	1
= 6667 Ω	1
Total	**4**
Accept other valid methods of calculation	

(d) When the microcontroller pin is connected to *low* and the LED glows, or *high* and the LED stops glowing. Explain why this occurs. (6 marks)

Description	Marks
When the microcontroller output pin is 'low' it allows a pathway to ground (current will sink into microcontroller pin).	1
This results in the LED and series current limiting resistor having 5 V held across it in forward-bias.	1
The LED will allow a current to flow (controlled by the resistor) and therefore it glows.	1
When the microcontroller output pin is 'high' its voltage will be 5 V.	1
Since this is the same as V_{CC} the voltage across the LED and series current limiting resistor will be 0 V.	1
Thus, the LED is not forward-biased and therefore no current is passed to cause the LED to glow.	1
Total	**6**

Question 44 **(17 marks)**

(a) (i) Calculate I_C, the collector current of the transistor. (5 marks)

Description	Marks
$\Sigma\Delta V = 0 = 9 - V_R - V_{LED,ON} - V_{CE}$ $V_R = 9 - 2.1 - 1.85$	1–2
$= 5.05$ V	1
$I_C = I_R = \frac{5.05}{470}$	1
$= 0.010745$ A or 10.75 mA or 10.8×10^{-3} A	1
Total	**5**
Accept other relevant answers	

(ii) Calculate the resistance of R2. If you were unable to obtain a value for part (i), use 0.01 A. (5 marks)

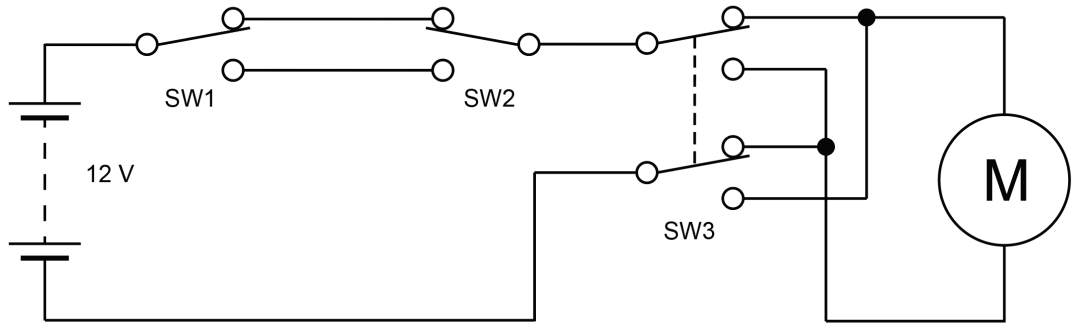
Description	Marks
$I_C = I_B \times \beta$ $I_B = \frac{0.010745}{25}$	1
$= 0.000\ 43$ A	1
$R_2 = \frac{(5 - 0.7)}{0.000\ 43}$ $= \frac{4.3}{0.000\ 43}$	1–2
$= 10\ 000\ \Omega$ (accept a value within 50 Ω)	1
If using $I_C = 0.01$ A then the answer will be 10 750 Ω	
Total	**5**

(b) Suppose R2 is replaced with a 2k2 Ω resistor. When the microcontroller output pin is *high* will the transistor operate in its forward-active or saturation region? Explain your answer by providing supporting calculations. (7 marks)

Description	Marks
$I_{C,SATURATION} = \frac{9 - V_{CE,SAT} - 2.1}{470}$	
$= \frac{6.9}{470}$	1
$= 0.01468$ A	1
$I_B = \frac{5 - 0.7}{2200}$	
$= \frac{4.3}{2200}$	1
$= 0.00195$ A	1
If forward-active then I_C = 0.00195 × 25 = 0.04886 A and this is not possible since maximum I_C = 0.01468 A	1
Check for saturation $\frac{I_C}{I_B} = \frac{0.014568}{00.00195} = 7.53$	
$7.53 < 25$ (β)	1
Transistor is operating in saturation region	1
Total	**7**

Question 45 **(13 marks)**

(a) In the space below, use appropriate circuit symbols to draw a neat, labelled circuit diagram that meets the needs of the system described above. (10 marks)



Description	Marks
12 V battery symbol correct, labelled and in sensible location	1
SW1 can connect and disconnect power without having to adjust SW2	1–2
SW2 can connect and disconnect power without having to adjust SW1	1–2
SW3 can cause the motor to be + at one connection and – at the other	1–2
SW3 can reverse the polarity of the connections	1–2
Motor symbol correct, labelled and in sensible location	1
Total	**10**
Accept other variations of the model circuit provided it will still function correctly.	

(b) The electric motor draws a current of 2.5 A and is operated for three hours and 45 minutes. Calculate the quantity of energy transferred from the battery to the motor. Answer in units of kilojoules. Note: 1 W = 1 J s^{-1}. (3 marks)

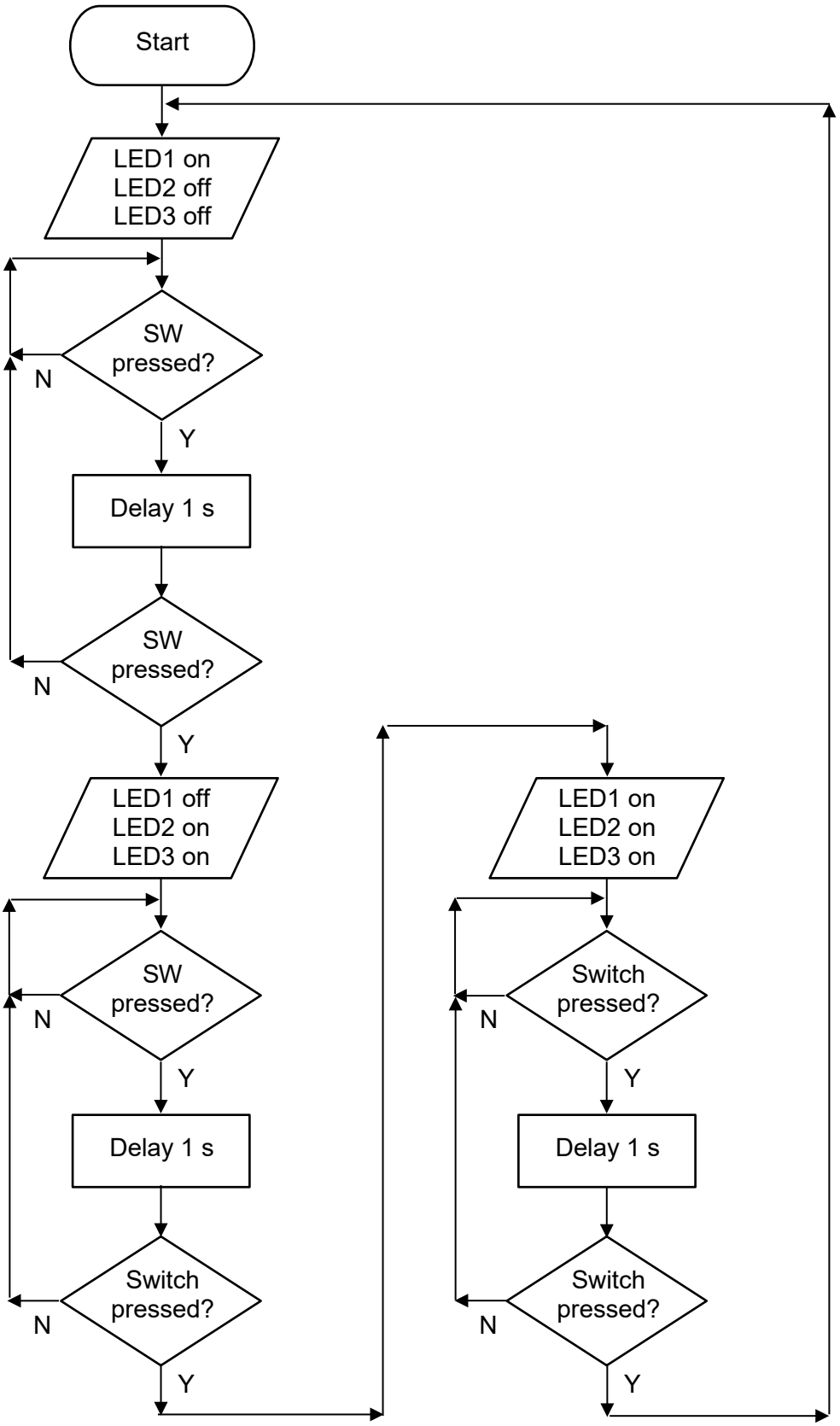
Description	Marks
$E = P \times t$ $= (2.5 \times 12) \times (3.75 \times 60 \times 60)$	
$= 30 \times 13\,500 = 405\,000$ J	1–2
= 405 kJ	1
Total	**3**
Accept other valid methods of calculation	

Question 46 **(14 marks)**

(a) On page 53, use labelled flowchart symbols to design a system to control the headlamp to meet the specifications below: (8 marks)

- There are three lighting combinations. In order, these are:
  Combination 1 - LED1 on LED2 off LED3 off
  Combination 2 - LED1 off LED2 on LED3 on
  Combination 3 - LED1 on LED2 on LED3 on
  Then loop back to Combination1.
- When the headlamp is powered up, Combination 1 is activated.
- To progress one combination at a time, it is necessary to hold SW down for at least one second. If SW is pressed for less than one second, then the program does not progress to the next combination (i.e. it remains on its current combination).
- Once the program has advanced to the next combination, SW must be released within one second or else the program will continue to progress to each successive lighting combination until released.

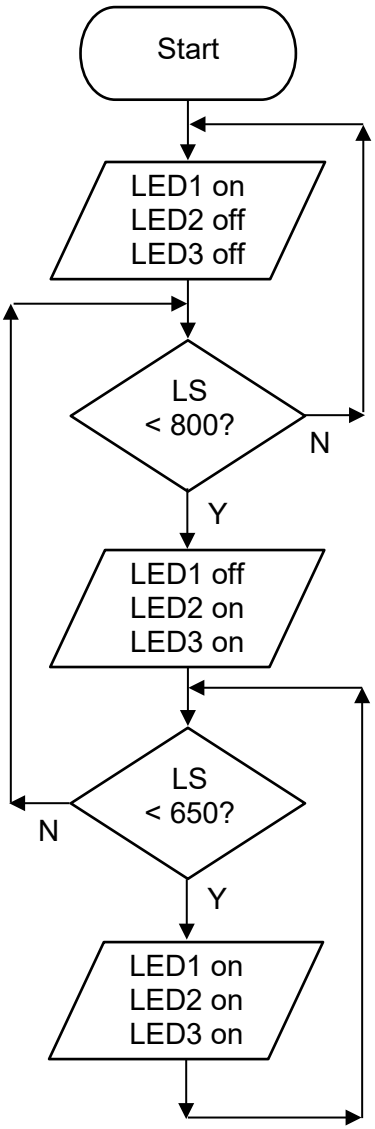
Description	Marks
When the headlamp is powered up LED1 turns on.	1
If SW is pressed for a minimum of one second, then LED1 turns off and LEDs 2 and 3 turn on.	1
However, if SW is pressed for less than one second, then only LED1 will glow.	1
If the program has progressed to where LED1 is off and LEDs 2 and 3 are on and SW is again pressed for a minimum of one second, then all 3 LEDs will be on.	1
However, if SW is again pressed for less than one second, then only LEDs 2 and 3 will glow.	1
If the program has progressed to where all three LEDs are on and SW is again pressed for a minimum of one second, then the program loops to the beginning where only LED1 is on.	1
However, as in previous steps, if SW is again pressed for less than one second, then all three LEDs continue to glow.	1
Continually holding SW down will cause the program to loop from combination to combination until SW is released.	1
Total	**8**
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.	


Start
LED1 on
LED2 off
LED3 off
SW
pressed?
N
Y
Delay 1 s
SW
pressed?
N
Y
LED1 off
LED2 on
LED3 on
SW
pressed?
N
Y
Delay 1 s
Switch
pressed?
N
Y
LED1 on
LED2 on
LED3 on
Switch
pressed?
N
Y
Delay 1 s
Switch
pressed?
N
Y

Question 46 continued

(b) In the space below, use labelled flowchart symbols to design a new system to control the headlamp that meets the following specifications: (6 marks)

- When the headlamp is powered up, LED1 only turns on.
- If LS detects a light level for the surroundings that produces a 10-bit value greater than or equal to 800 then LED1 only will remain on.
- However, if the 10-bit value being produced is less than 800, then LED1 turns off and LEDs 2 and 3 turn on.
- Should the 10-bit value fall below 650, then all three LEDs will be on.
- The program must constantly monitor conditions and ensure that the correct number of LEDs is on at the specified light levels.



Description	Marks
When the headlamp is powered up LED1 only turns on.	1
If LS detects a light level for the surroundings that produces a 10-bit value greater than 800 then only LED1 will turn on.	1
However, if the 10-bit value being produced is less than 800 then LED1 turns off and LEDs 2 and 3 turn on.	1
Should the 10-bit value fall below 650 then all 3 LEDs will be on.	1
The program must constantly monitor conditions and ensure that the correct number of LEDs are on at the specified light levels.	1–2
Total	**6**
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.	

ACKNOWLEDGEMENTS

An *Acknowledgements variation* document is available on the Authority website.

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