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

ENGINEERING STUDIES

ATAR course examination 2019

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.

2019/62857

Section One: Core content **40% (83 Marks)**

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

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

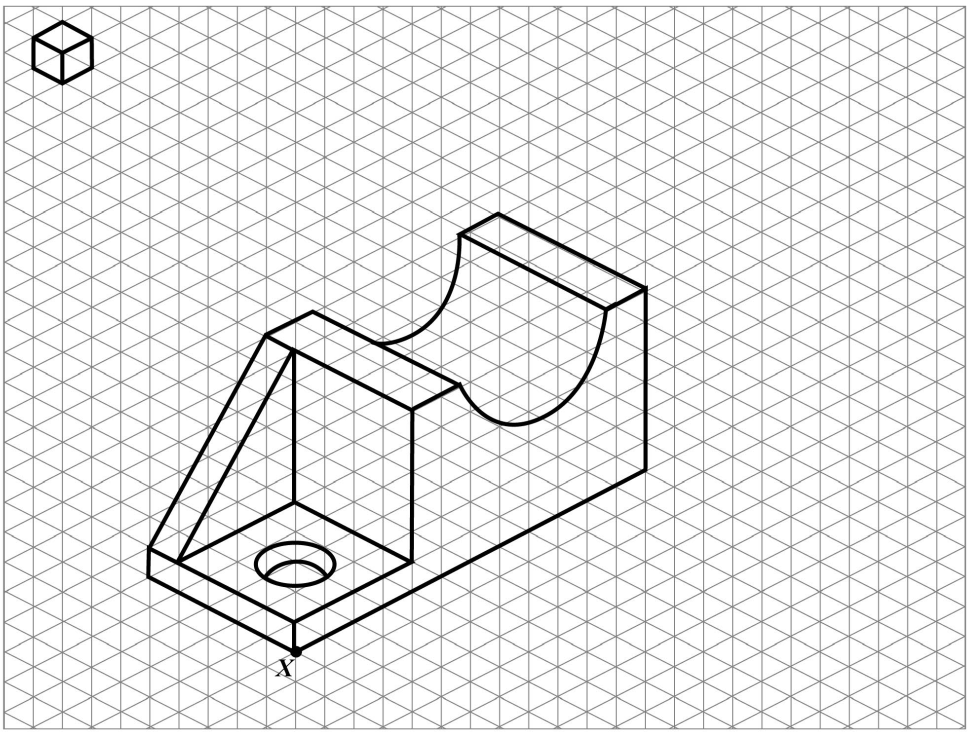
Part B: Extended response **30% (73 Marks)**

Question 11 **(17 marks)**

(a) Use the grid on the page 7 to produce a pictorial drawing of the bracket. This three-dimensional representation must be accurately proportioned. To assist with this, each grid represents 5 mm in each direction. (A 5 mm x 5 mm x 5 mm cube has been drawn in the top left-hand corner of the grid to illustrate how to use the grid). Use a ruler for straight lines and freehand for the circular and semi-circular features.

The corner *X*, indicated on the drawing above, is also marked on the grid with a small labelled dot to act as the starting point. No dimensioning is required. (8 marks)

Description	Marks
all three planes shown accurately proportioned	1–3
triangular web correctly located and correct size	1
full hole correctly positioned in proportion and elliptical	1–2
semicircular opening is correct location and correct shape	1–2
Total	**8**



(b) Calculate the volume of material in the bracket. Give your answer in units of mm^3.
(6 marks)

Description	Marks
hole $r^2 \times \pi \times h = 5^2 \times \pi \times 5 = 392.7$ mm^3	1
semicircular opening $0.5 \times r^2 \times \pi \times h = 0.5 \times 12.5^2 \times \pi \times 25 = 6135.9$ mm^3	1
triangular prism $0.5 \times 20 \times 25 \times 5 = 1250$ mm^3	1
small rectangular prism $20 \times 25 \times 5 = 2500$ mm^3	1
large rectangular prism $40 \times 30 \times 25 = 30\,000$ mm^3	1
total volume = 1250 + 2500 + 30 000 – 392.7 – 6135.9 = 27221.4 mm^3 or = 45000 – 392.7 – 6135.9 – 1250 – 10000 = 27221.4 mm^3	1
Total	**6**

(c) With reference to information in the Data Book, calculate the mass of the bracket.
(3 marks)

Description	Marks
conversion 27 221.4 mm^3 = 0.000 027 2214 m^3	1
mass = density × volume = 0.000 027 2214 × 8740 = 0.238 kg	1–2
Total	**3**

Question 12 **(16 marks)**

Name **four** important physical properties that the construction material (aluminium alloy) must exhibit if it is to be suitable for a bicycle frame. The focus must be on fitness for purpose and **not** how the frame is manufactured. Define each property and justify why each is a requirement of the material used in a bicycle frame.

Description		Marks
Property	stiffness	1
Definition	ability of a material to resist deformation under load	1
Justification	The frame must retain its shape when under load otherwise mechanical elements may not remain aligned and the bicycle will not function, or it may become unsafe to ride or steer due to misalignment of parts.	1–2
	Subtotal	**4**
Property	density	1
Definition	mass per unit volume of a material	1
Justification	A low-density material will reduce mass of the frame and thus the rider is required to do less work when riding to a destination.	1–2
	Subtotal	**4**
Property	strength	1
Definition	the ability of a material to withstand stress without failure	1
Justification	The mass of the rider and dynamic forces will place stress on the frame and it must resist this without breaking or failure of the frame and/or injury to the rider will occur.	1–2
	Subtotal	**4**
Property	corrosion resistance	1
Definition	ability of a material to resist destruction by chemical or electrochemical attack	1
Justification	The frame will be exposed to the elements and this includes rain and dampness. If the material is not corrosion resistant, then it will weaken, and this will lead to failure of the frame and/or injury to the rider.	1–2
	Subtotal	**4**
Properties from the syllabus that would be unacceptable are: plasticity, ductility and conductivity – thermal and electrical.		
Accept other reasonable properties and/or definitions and/or justifications		
	Total	**16**
Other properties from the syllabus that would be acceptable are: Elasticity – ability of a material to return to its original dimensions after being subjected to stress that caused it to deform. Provided this is not excessive, then some ‘flex’ of the frame will result in a cushioning of road shock and this will lead to a more comfortable journey for the rider. Toughness – ability of a material to absorb energy when being deformed and thus resist deformation and failure. It is likely that the frame will have forces transmitted to it when riding across rough or uneven terrain. The frame must be able to absorb the energy of impacts that occur without failure otherwise damage to the frame may occur.		

Question 13 **(22 marks)**

(a) Name a renewable energy source that is not mentioned in the text above. (1 mark)

Description	Marks
Tidal, biomass	1
Total	**1**

(b) Name the energy generation system mentioned in the text you would consider has the **least** environmental impact during its construction, operation and demolition? Explain the reason for your choice. (2 marks)

Description	Marks
Energy system geothermal	1
Explanation No negative effect on the atmosphere as there is nothing added to the environment in the electrical production process. Minimal during construction, compact manufacture, production and recycling of materials at demolition.	1
Total	**2**

(c) Name the energy generation system mentioned in the text you would consider has the **greatest** atmospheric environmental impact during its operation? Explain the reason for your choice. (3 marks)

Description	Marks
Energy system fossil fuels	1
Explanation Atmospheric global warming issues, public health issues due to combustion products including large quantities of the oxides of carbon, nitrogen, methane, water vapour (all of which are greenhouse gases), as well as microscopic pollutant particles and radioactive oxides.	1–2
Total	**3**

Question 13 (continued)

(d) Circle **one** of the following forms of energy generation and outline briefly **two** advantages and **two** disadvantages of this method. (4 marks)

Hydroelectric Windfarm Nuclear

Description	Marks
Hydroelectric	
Advantage one: Large quantities of energy are produced and can be delivered on demand.	1
Advantage two: It is renewable – driven by the water cycle which is solar energy derived.	1
Disadvantage one: Major disruption to the environment due to flooding upstream and much smaller outflow downstream.	1
Disadvantage two: Evidence that the production of greenhouse gases is large scale and significant.	1
Subtotal	**4**
or	
Windfarm	
Advantage one: No atmospheric pollutants are directly produced through the production of energy.	1
Advantage two: available at all times provided wind present.	1
Disadvantage one: Energy can only be produced when wind is present at acceptable velocity/strength.	1
Disadvantage two: Windfarm towers are very large (e.g. The widely used GE 1.5-megawatt model, for example, consists of 35 m blades atop a 65 m tower for a total height of 100 m.) and require a large amount of land for installation.	1
Subtotal	**4**
or	
Nuclear	
Advantage one: During energy production the only by-product released to the atmosphere is water vapour/steam.	1
Advantage two: Energy can be supplied in large quantities and is available on demand.	1
Disadvantage one: Spent fuel rods are radioactive and remain so for a very long time.	1
Disadvantage two: Disasters, human error or natural, could cause an accident where hazardous nuclear radiation is released to the environment.	1
Subtotal	**4**
Total	**4**
Accept other relevant advantages and disadvantages.	

(e) (i) Explain why this project requires the coupling of the photovoltaic panels to battery storage? (3 marks)

Description	Marks
Photovoltaic (PV) panels only function in daylight above a certain intensity so no solar irradiance means no output power.	1–3
The panels may produce more power than is being drawn for usage during periods of operation. Excess output can be used to charge the batteries.	
Batteries are able to deliver their stored energy when the panels stop functioning or to cover a period of excess load.	
Total	**3**

(ii) In units of kilojoules (kJ), calculate the energy available from the energy storage system when it is fully charged. (2 marks)

Description	Marks
120 000 000 x 3600 = 432 000 000 000 J	1
432 000 000 000/1000 = 432 000 000 kJ	1
Total	**2**
Accept other valid methods of calculation.	

(iii) Given each panel in the solar farm has an area of 1.94 m^2 and an efficiency of 20%, calculate the total power being produced at a time when the solar irradiance is 0.88 kW m^{-2}. Answer in units of megawatts (MW). (4 marks)

Description	Marks
Area = 628 000 x 1.94 = 1218 320 m^2	1
Power = 1218 320 x 0.88 x 0.2 = 214 424 kW	1–2
= 214.4 MW	1
Total	**4**
Accept other valid methods of calculation.	

(iv) On a particular evening, after the solar panels had stopped functioning, the battery storage went from fully charged to quarter charged in a five-hour period. Calculate the power being supplied by the storage system if it was constant over this five-hour period. Answer in units of megawatts (MW). (3 marks)

Description	Marks
Energy used = 0.75 x 120 = 90 MWh	1–2
Power delivered = 90/5 = 18 MW	1
Total	**3**
Accept other valid methods of calculation.	

Question 14 **(18 marks)**

(a) (i) For the propulsion of the ship and working and living quarters of the crew, identify the form of energy required and describe the relevant energy conversions. (6 marks)

Description	Marks
Form of energy (propulsion): fossil fuels (diesel, fuel oil)	1
Description: The fuel is a source of chemical energy that undergoes combustion in the engines of the ship to be converted into kinetic energy to move the ship.	1–2
Form of energy (working and living quarters): electrical	1
Description (two examples): To provide the power for cooking (electrical into thermal), ventilation (electrical into kinetic (e.g. fans)), heating/cooling (electrical into kinetic and thermal), lighting (electrical into light), communications (electrical into electromagnetic, then into sound), etc.	1–2
Total	**6**
Accept other relevant answers	

(ii) Name **two** types of environmental impact that are likely to occur during this transport phase. For each impact, provide a brief description that includes **two** specific examples. (6 marks)

Description	Marks
Environmental impact one: atmospheric/air pollution	1
Combustion by products in the engine exhaust will contain greenhouse gases such as CO_2 that will affect global warming.	1
Examples: other atmospheric pollutants like sulphur dioxide, nitrogen oxides and particulates (at least one of these needs to be mentioned for the mark to be awarded).	1
Environmental impact two: Water pollution	1
Examples: pollution of the ocean from rubbish and human waste dumped into them from the ship.	1
Possibility of oil and fuel spills.	1
Total	**6**
Accept other relevant answers	

(b) Name **two** environmental impacts that result directly from the delivery truck in transit, and **one** indirect environmental impact associated with the infrastructure required for the truck to get from the port to the point of sale. Outline each of these environmental impacts. (6 marks)

Description	Marks
Direct impact one: atmospheric pollution	1
Description: Production of greenhouse gasses such as CO_2 from fuel combustion.	1
Direct impact two: noise	1
Description: Road and engine noise of large vehicles will disturb homes and businesses near the route taken by the trucks.	1
Indirect impact: road building and/or maintenance	1
Description: Land needs to be set aside for building roads and/or large quantities of materials and energy are required to build roads and/or materials and energy are required to make repairs to roads.	1
Total	**6**
Accept other relevant answers	

Section Two: Specialised field – Mechanical **60% (113 Marks)**

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

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

Part B: Extended answer **50% (103 Marks)**

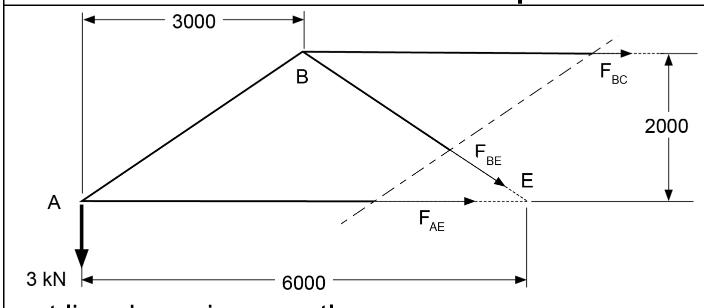
Note: Carry through marks apply to all questions in Part B Mechanical unless noted otherwise.

Question 25 **(21 marks)**

(a) Find the reaction forces at the two supports. (4 marks)

Description	Marks
Sum Forces Y $R1y + R2y = 15$ kN	1
Sum Moments About Reaction Point 2 $R1y \times 3 = 3 \times 9$ $R1y = 9$ kN	1–2
Substitute in Sum of Forces Y Equation $R2y = 15 - 9$ $R2y = 6$ kN	1
Total	**4**

(b) Apply the method of sections and draw a free body diagram of the remaining part of the truss that can be used to determine the forces through members AE, BC and BE. Include the cut line and label the forces F_{AE}, F_{BC} and F_{BE} on the diagram on page 19. (5 marks)

Description	Marks
 cut line drawn in correctly one mark for each of the three forces drawn in correctly (with arrow heads) includes the 3 kN *dimensions carry no marks and can be omitted	1–5
Total	**5**

(c) Use the method of sections to determine the force in members AE, BC and BE. Circle to show whether each member is in tension or compression. (12 marks)

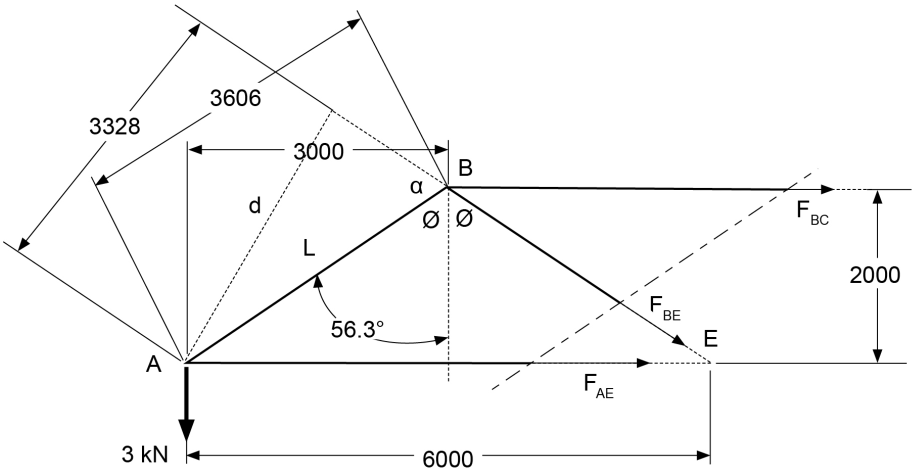
(i) Member AE

Description	Marks
Selecting appropriate point to take moments about to work out F_{AE} (at B) $3 \times 3 + F_{AE} \times 2 = 0$ $F_{AE} = -4.5$ kN AE – compression	1–3
Total	**3**

(ii) Member BC

Description	Marks
Selecting appropriate point to take moments about to work out F_{BC} (at E) $3 \times 6 - F_{BC} \times 2 = 0$ $F_{BC} = 9$ kN BC – tension	1–3
Total	**3**

(iii) Member BE

Description	Marks
Selecting appropriate point to take moments about to work out F_{BE} (at A)  L = SQRT(3000^2 + 2000^2) L = SQRT(13 000 000)mm $\theta = \tan\theta = \dfrac{3000}{2000}$ θ = 56.3° α = 180°– (2 x 56.3°) α = 67.4° d = L x sin(α) d = 3328 mm 9 x 2 + F_{BE} x d = 0 F_{BE} = –5.4 kN BE – compression	1–6
Total	**6**

Question 26 **(13 marks)**

(a) Calculate the second moment of area I_{xx} for the cross-section. (2 marks)

Description	Marks
D = 25 $I_{xx} = \pi D^4/64$ I_{xx} = 19 175 mm^4	1–2
Total	**2**

(b) Calculate the dimension of a solid square steel bar with the same I_{xx} as the round, solid steel beam, but still have the same resistance to deflection under equivalent forces. (4 marks)

Description	Marks
$I_{xx} = bh^3/12$	1
I_{xx} square bar = I_{xx} of round bar = 19 175 mm^4	1
$I_{xx} = bh^3/12$ 19175 mm^4 = b^4/12	1
$b = \sqrt[4]{12\ x\ 19\ 175}$ b = 21.9 mm	1
Total	**4**

(c) Calculate $Y1$, the deflection of the round beam at its centre due to self-weight only. (3 marks)

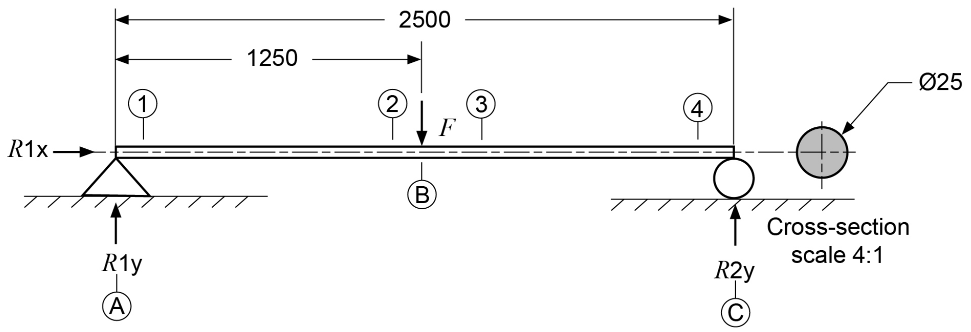
Description	Marks
F_{UDL} = 37.55 x 2.5 = 93.88N	1
look up E = 200 000 N/mm^2	1
$Y1$ = 5 x $F_{UDL}\ L^3/384EI$ = 4.98 mm	1
Total	**3**

(d) Calculate the new total deflection due to both the self-weight and the applied force F in the middle of the beam. (4 marks)

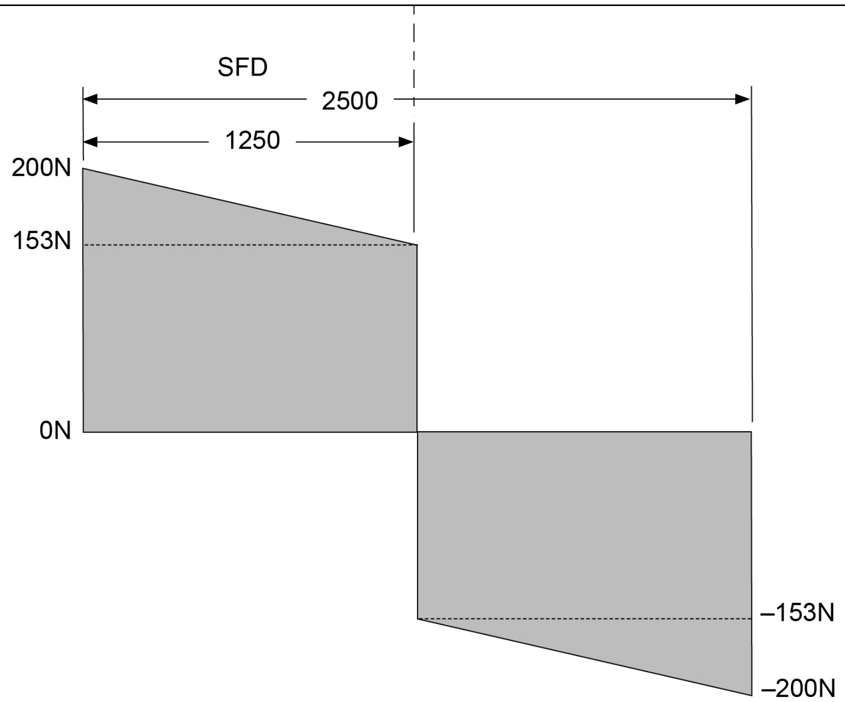
Description	Marks
deflection form distributed load (self-weight) is used $Y1$ = 4.98 mm	1
deflection from centrally acting force $Y2 = FL^3/48EI$ $Y2$ = 306.125 x (2500)^3 / 48 x 200 000 x 19 175 $Y2$ = 25.98 mm	1–2
total deflection $Y1 + Y2$ = 30.96 mm	1
Total	**4**

Question 27 **(20 marks)**

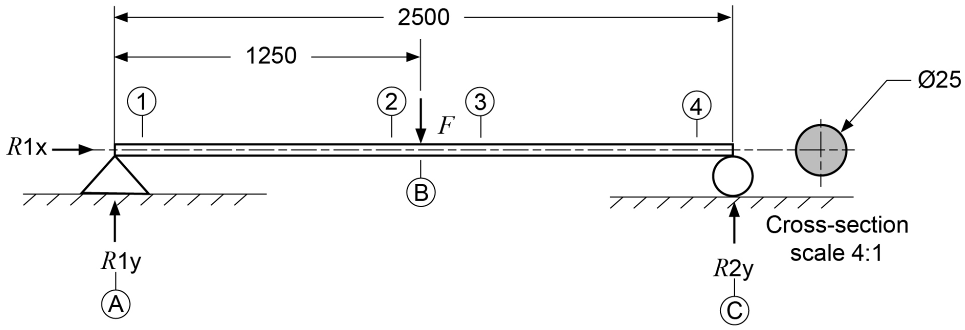
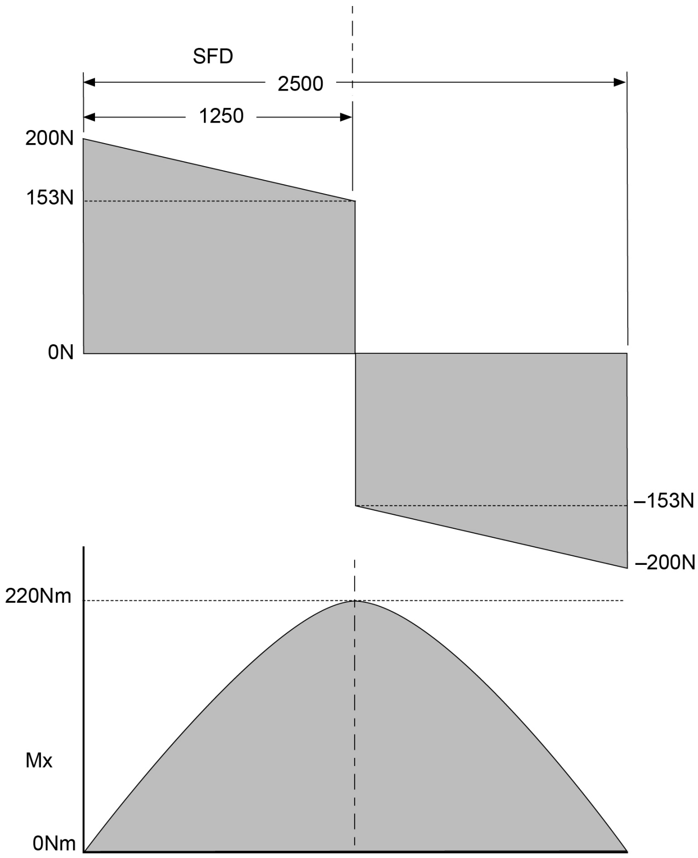
(a) Using points 1, 2, 3 and 4 labelled in the diagram above, construct a shear force diagram on the axes on the top half of the grid provided on page 26. In the space below, show all calculations undertaken to construct this diagram. (12 marks)

Description	Marks
 $F_{UDL\ TOTAL}$ $=37.55 * 2.5$ $=93.875$ N ΣF to find $R1y$ $0 = -306.125 - 93.875 + R1y + 200$ $R1y = 200$ N Point 1 ΣF $200N - V_{x1} = 0$ $V_{x1} = 200$ N Point 2 $F_{UDL} = 37.55 \times 1.25$ $F_{UDL} = 46.94$ N ΣF $= 200 - 46.94 - V_{x2} = 0$ $V_{x2} = 153.06$ N Point 3 ΣF $200 - 46.94 - 306.125 - V_{x3} = 0$ $V_{x3} = -153.06$ N Point 4 $F_{UDL} = 37.55 \times 2.5$ (Even though same as $F_{UDL\ TOTAL}$ above it deserves separate mark as this is different context) $F_{UDL} = 93.875$ N ΣF $200N - 93.875 - 306.125 - V_{x4} = 0$ $V_{x4} = -200$ N	1–8
Subtotal	**8**

Question 27 (continued)

 axes drawn correctly points found plotted correctly points connected with lines graph labels and units	1–4
Subtotal	**4**
Total	**12**

(b) Using points A, B and C labelled on the diagram on page 24, construct a bending moment diagram on the axes on the bottom half of the grid provided on page 26. Make sure you show clearly the maximum bending moment and its location. In the space below, show all calculations undertaken to construct this diagram. (8 marks)

Description	Marks
 Point A M_A =0 Nm Point B F_{UDL} = 37.55 x 1.25 = F_{UDL} = 46.94 N 200 N x 1.25 – 46.94 x 0.625 – M_B = 0 M_B = 220 Nm Point C M_C = 0 Nm	1–4
Subtotal	**4**
	1–4

Question 27 (continued)

Shape of BMD lines connected between points must be shown as parabolic (Note it is in reality almost linear due to the relatively small influence of the self-weight.) max BM aligns with 0 SF and ends of diagrams are aligned points found plotted correctly graph labels and units	
Subtotal	**4**
Total	**8**

Question 28 **(20 marks)**

(a) Calculate the acceleration (a) of the mass (m) going up. (4 marks)

Description	Marks
Fm = 30 x 9.81 = 294.3 N	1
ΣF = 500 – 294.3 = 205.7 N	1
a = 205.7/30 = 6.86 m s^{-2}	1–2
Total	**4**

(b) Calculate the final velocity of the mass (m) just before the piston hits its limit going up. (3 marks)

Description	Marks
$v^2 = u^2 + 2as$	1
$u^2 = 0$ s = 0.1 m $v = sqrt$(2 x 6.86 x 0.1) = 1.17 m s^{-1}	1–2
Total	**3**

(c) Calculate the displacement of the mass (m) after 0.1 seconds going up from rest. (3 marks)

Description	Marks
$s = ut + 0.5at^2$	1
$u = 0$ s = 0 + 0.5 x 6.86 x (0.1)^2 = 0.034 m or 34 mm	1–2
Total	**3**

(d) Calculate the time taken for the piston to reach full extension. (2 marks)

Description	Marks
$0.1 = 0 + 0.5 \times 6.86 \times t^2$ $t = sqrt(0.1/(0.5 \times 6.86))$ $= 0.17$ s	1–2
Total	**2**

(e) Calculate the power used by the piston in one full extension. (2 marks)

Description	Marks
$P = F\,s/t$	1
$= 294.3 \times 0.1/0.17$ $= 173.1$ W	1
Total	**2**

(f) Calculate the energy required for the piston to lift the securely-fixed mass (m) in line with the ledge. (2 marks)

Description	Marks
$E = mgh$ or $F\,s$	1
$E = 30 \times 9.81 \times 0.1$ $= 29.43$ J	1
Total	**2**

(g) Explain the relationship between conservation of energy and gravity during the mass's journey described above. (Ignore air resistance). (3 marks)

Description	Marks
Initially it takes energy from the pressure of the fluid in the piston to gain potential energy, the 29.43 J calculated in part (f).	1
Constant gravitational acceleration brings the mass to a stop on its upward journey where $E_k = E_p$. On its downward journey E_p becomes E_k as it is accelerated under gravity.	1–2
Total	**3**

(h) State what happens to the E_k when the ball hits the top of the piston on its downward journey. (1 mark)

Description	Marks
Converted to sound, heat less E_k on bounce.	1
Total	**1**
Accept any reasonable answer.	

Question 29 **(20 marks)**

(a) Name the material that is toughest and state why. (2 marks)

Description	Marks
Material X	
Is toughest as has largest area under graph X = ~80 x 2.9 = 232 Y = ~400 x 0.35 = 140 Z = ~0.5 x 200 x 0.6 = 60	1 – 2
Total	**2**

(b) Name the material that has the highest resilience and state why. (2 marks)

Description	Marks
Material Y	
Highest resilience because has highest area under linear portion of graph X = ~0.5 x 32.8 x 0.02 = 0.33 Y = ~0.5 x 295 x 0.003 = 0.44 Z = ~0.5 x 33 x 0.02 = 0.33	1 – 2
Total	**2**

(c) Circle which of these is Material Y and justify your selection. (2 marks)

Description	Marks
Y – mild steel	1
steel has highest tensile strength	1
Total	**2**
Accept any reasonable justification	

(d) Circle which of these materials you believe would be best suited for this application as safety cable and justify your selection. (2 marks)

Description	Marks
polypropylene	1
Most important reason it is best in this situation as it strongly elongates before failure but does not weaken providing maximum warning.	1
Total	**2**

(e) Derive Young's modulus for the selected material in part (d) using the stress-strain curves and testing data provided. (3 marks)

Description	Marks
Read from table: Stress = 32.8 N/mm^2	1
Read from table: Strain = 0.02439	1
E = y/x = 1345 N/mm^2 (acceptable range 1300 - 1500 N/mm^2)	1
Total	**3**

(f) Calculate the elongation in the cable made of your selected material in part (d) above after it is loaded with 2000 N if prior to loading it was 1 m long with a cross sectional area of 78.5 mm^2. If you were unable to obtain a value for part (e), use 1700 N mm^2. (2 marks)

Description	Marks
$dL = FL/AE$ =2000 x 1000/78.5 x 1345 =18.9 mm	1–2
Total	**2**

(g) This cable will need to safely hold 120 kg. If a factor of safety of 2 is required, calculate the smallest cable diameter allowable. (7 marks)

Description	Marks
$F = mg$ F = 120 x 9.81 = 1177.2 N	1
σ_{UTS} successfully attained from graph =80 N/mm^2 (78–82 N/mm^2 Acceptable)	1
σ_{DESIGN} = σ_{UTS} / 2 =40 N/mm^2	1
$A = \pi D^2/4$ $\sigma_{DESIGN} = F/A$ $\sigma_{DESIGN} = F/(\pi D^2/4)$	1–2
40 = 1177.2/(πD^2/4) D = $Sqrt$(4708.8/(π x 40)) D = 6.12 mm	1–2
Total	**7**

Question 30 **(9 marks)**

(a) Calculate the magnitude and angle to the horizontal of the resultant force. (5 marks)

Description	Marks
Sum Forces y F_y = –35 – 200 = –235 kN	1
Sum of Forces x F_x = 80 kN	1
Magnitude of resultant R = $sqrt(-235^2 + 80^2)$ R = 248 kN	1–2
Angle of resultant to horizontal $\alpha = \tan\alpha = \frac{235}{80}$ = 71.2°	1
Total	**5**

(b) Calculate the turning moment about the centre of the base of the retaining wall due to the soil pressure. (2 marks)

Description	Marks
Sum of moment taken at weight line of action and base ΣM = 80 x 0.33 = 26.4 kN m	1–2
Total	**2**

(c) Calculate the perpendicular distance from the resultant to the centre of the retaining wall base. If you were unable to obtain a value for part (a), use 250 kN acting at an angle of 70° to the horizontal. If you were unable to obtain a value for part (b), use 30 kN m. (2 marks)

Description	Marks
Normal distance of resultant from midpoint $\Sigma M = Fd$ d = 26.4/248 = 0.106 m	1–2
Total	**2**

Section Two: Specialised field – Mechatronics **60% (113 Marks)**

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

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

Part B: Extended answer **50% (103 Marks)**

Question 41 **(20 marks)**

(a) Calculate the current through R_2. (3 marks)

Description	Marks
I_{R2} = V/R	
= 9/1200	1–2
= 0.0075 A	1
Total	**3**

(b) Calculate the current being supplied to the circuit by the battery. (6 marks)

Description	Marks
R_{TOTAL} = 680 || 1200 || 647	
= (1/680) + (1/1200) + (1/647)	1–3
= 259.8 Ω (accept 260 Ω)	1
I = V/R	
= 9/259.8 or 9/260	1
= 0.0346 A	1
Total	**6**
Accept other valid methods of calculation.	
Alternatively:	
R_{TOTAL} = 680 || 1200 || 647	
= ((680 × 1200)/1880)) || 647 = 434 || 647	
= (434 × 647)/1081 = 280 798/1081	
= 259.8 Ω (accept 260 Ω)	

Question 41 (continued)

(c) Calculate the voltage held across R_4. (7 marks)

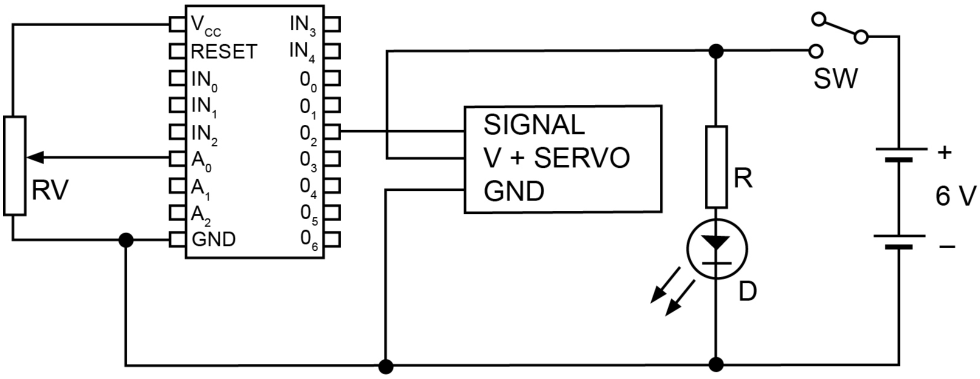
Description		Marks
I	$= I_{R3} = I_{R4} = I_{R5}$	1
	= 9/(330 + 270 + 47) or 9/647	1–2
	= 0.0139 A	1
V	$= IR$	
V_{R4}	= 0.01391 x 270	1
	= 3.756 V	1
	= 3.76 V accept 3.75 V or 3.76 V	1
	Total	**7**
Accept other valid methods of calculation e.g. Kirchhoff's voltage law.		

(d) If its tolerance band is gold, calculate the maximum possible power R_1 will dissipate. (4 marks)

Description		Marks
R	= 680 – (680 × 0.05) = 680 – 34	1–2
	= 646 Ω	
P	$= V^2/R$	
	$= 9^2/646 = 81/646$	1–2
	= 0.1254 W accept 0.125 W	
	Total	**4**
Accept other valid methods of calculation.		

Question 42 **(17 marks)**

(a) Using labelled circuit symbols, complete the circuit diagram described above, i.e. add the potentiometer, servo, 6 V battery, switch, LED and resistor. (11 marks)



Description	Marks
RV connection to V_{CC}	1
RV output to A_0 or A_1 or A_2	1
RV connection to GND of microcontroller	1
servo signal connected to any one of O_0 – O_6 Note: students may include a resistor	1
servo connected to GND of microcontroller	1
servo positive connection made and broken by SW Note: students may include a capacitor across positive and GND	1–2
negative of battery connects to GND of microcontroller	1
resistor and LED in series (positions may be swapped from that shown on marking key diagram) and positioned after SW	1–2
LED correct polarity	1
Total	**11**

(b) (i) Calculate the current that flows through the LED. (3 marks)

Description	Marks
$I_{LED} = I_R$	
$I_R = (6\text{ V} - V_{LED})/330$	1
$= 3.9/330$	1
$= 0.0118$A (accept 0.012 A)	1
Total	**3**
Accept other valid methods of calculation.	

(ii) Calculate the power dissipated by the resistor. (3 marks)

Description	Marks
$P_R = I_R V_R$	
$P_R = 0.0118 \times 3.9$	1–2
$= 0.0461$ W	1
Total	**3**
Accept other valid methods of calculation.	
Alternatively	
$P_R = 3.9^2/330$	1–2
$= 15.21/330$	
$= 0.0461$ W	1

Question 43 **(16 marks)**

(a) If SW is left in open circuit will the input detected by the microcontroller be *high* (5 V) or *low* (0 V)? Support your answer with relevant calculations. (4 marks)

Description		Marks
The input will be high (5 V). Accept either high and/or 5 V		1
$\Sigma\Delta V = 0$	$= 5 - V_R - V_{SW}$	
V_{SW}	$= 5 - V_R$	
	$= 5 - (R \times I_R)$	
	$= 5 - (22\,000 \times 0)$	1–2
	$= 5$ V	1
	Total	**4**
Accept other valid methods of calculation		

(b) If the temperature detected by NTC rises, then will the voltage detected by the microcontroller increase or decrease? Explain your reasoning. (4 marks)

Description	Marks
The voltage detected by the microcontroller will increase.	1
As temperature rises the resistance of NTC will decrease.	1
Since NTC and R_V form a voltage divider then as the resistance of NTC becomes smaller relative to the resistance of R_V so too does the voltage across NTC.	1
Therefore, the voltage across R_V must increase (KVL).	1
Total	**4**

(c) Calculate the value of the resistance R_V needed so that the voltage being detected by the microcontroller is 3.25 V. (4 marks)

Description		Marks
3.25	$= 5 \times R_V/(R_V + R_{NTC})$	
$5R_V$	$= 3.25\,(R_V + 12\,500)$	
$5R_V$	$= 3.25R_V + 40\,625$	
$1.75R_V$	$= 40\,625$	
R_V	$= 40\,625/1.75$	1–3
	$= 23\,214\ \Omega$	1
	Total	**4**
Accept other valid methods of calculation		
Alternatively		
1.75	$= 5 \times R_{NTC}/(R_V + R_{NTC})$	
1.75	$= 62\,500/(R_V + 12\,500)$	1–2
$R_V + 12\,500$	$= 62\,500/1.75$	
R_V	$= 35\,714 - 12\,500$	1
	$= 23\,214\ \Omega$	1

(d) What does ADC mean and, if its resolution is 10-bit, what will be its value when the voltage being detected is 3.25 V? Present a calculation to show how you determined the 10-bit value. (4 marks)

Description	Marks
ADC means analogue (accept analog) to digital conversion.	1
10-bit value = (3.25/5.0) × 1023 or 10 bits = Resolution = $\frac{5V}{2^{10}}$ = 4.883 mV $= \frac{3.25}{4.883 \times 10^{-3}}$	1–2
= 665	1
Total	**4**

Question 44 **(21 marks)**

(a) Describe the purposes of the resistor R and the diode D. (4 marks)

Description	Marks
The resistor is used to control the current that flows into the base of the transistor when the output pin of the microcontroller is *high*. This will determine whether the transistor operates in its forward-active or saturation region.	1–2
The diode protects sensitive components from back e.m.f. when the electromagnet is switched off by the transistor.	1–2
Total	**4**
Accept other relevant answers	

(b) (i) Calculate I_B the base current of the transistor. (3 marks)

Description	Marks
I_B = (5 – $V_{BE,ON}$)/1200	
= (5 – 0.7)/1200	
= 4.3/1200	1–2
= 0.00358 A	1
Total	**3**
Accept other relevant answers	

(ii) Calculate I_C the collector current of the transistor. If you could not obtain a value for part (b) (i), use 0.006 A. (3 marks)

Description	Marks
I_C = $I_B \times \beta = I_B \times 55$	
= 0.00358 × 55	1–2
= 0.197 A (0.247 A)	1
Total	**3**

(iii) Calculate V_{CE} the voltage across the collector-emitter voltage of the transistor. If you could not obtain a value for part (b) (ii), use 0.22 A. (3 marks)

Description	Marks
V_{CE} = 12 – (0.197 × 48)	
= 12 – 9.456	1–2
= 2.544 V accept 2.54 V (1.44 V)	1
Total	**3**

(c) (i) At the transition point between forward-active and saturation, the transistor will still operate in forward-active but V_{CE} = 0 V. Calculate R, the ideal value for the resistor, so that this condition is achieved. (6 marks)

Description	Marks
At this point $I_C = I_B \times \beta$ and V_{CE} = 0 V	
I_C = 12/48 = 0.25 A	1–2
I_B = 0.25/β = 0.25/55 = 0.004545 A	1–2
R = 4.3/0.004545 = 946 Ω	1–2
Total	**6**
Accept other valid methods of calculation.	

(ii) Specify the **maximum** E12 preferred value resistor that would be used for a practical circuit such that the transistor will be forced into saturation and, assuming a tolerance of ±5%, list its 4-band colour code. (2 marks)

Description	Marks
E12 value 820 Ω	1
Colour code Grey red brown gold	1
Total	**2**

Question 45 **(16 marks)**

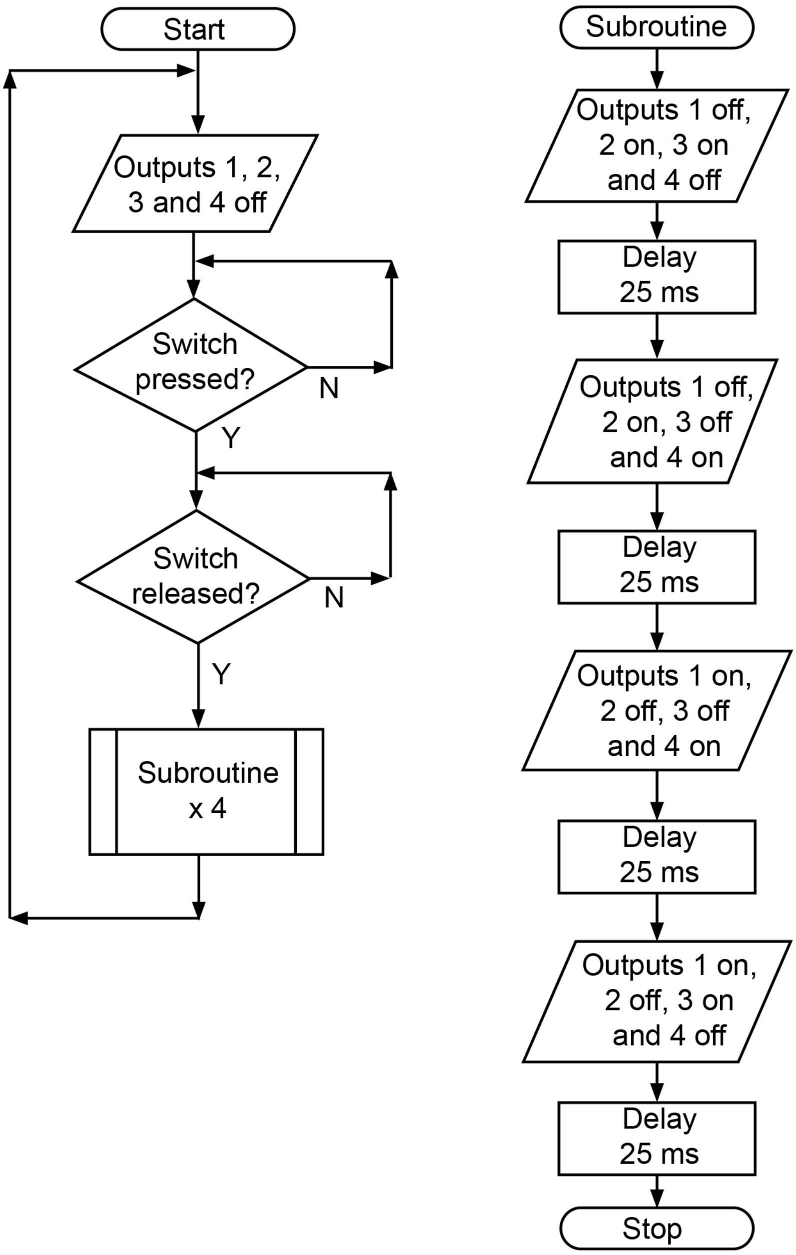
(a) Calculate the period of time that each step needs to be activated so that the speed of rotation is 50 revolutions per minute. Answer in milliseconds. (3 marks)

Description		Marks
48 steps	= 1 rotation	
Steps required in 60 seconds	= 48 × 50 = 2 400	1
Delay between steps	= 60/2400 = 0.025 s	1
	= 25 ms	1
	Total	**3**
Accept other valid methods of calculation.		

(b) On page 47, use labelled flow chart symbols to design a system to control the stepper motor that meets the following specifications: (13 marks)

- when the program is started, all coils of the stepper motor are low
- the condition of a switch, SW, is checked
- if SW is not pressed, then all coils of the stepper motor remain low
- if SW is pressed and then released, the stepper motor rotates anticlockwise at 50 rpm through an angle of 120°
- the stepper motor will then switch off (all coils low)
- a subroutine must be included in the flow chart to control the sequence of the four steps
- the system must loop.

Description	Marks
When the program is started all outputs are low.	1
SW is checked. If it is not pressed the stepper motor coils remain low.	1
When SW is **pressed** it must then be **released** to proceed through the loop.	1–2
A **subroutine** causes the stepper motor to **rotate anticlockwise** in increments of **four steps** at **50 rpm**. 1 mark for each step with correct outputs for a maximum of 4 marks. 1 mark for including delay (or pause) with answer from part (a) as label.	1–5
The subroutine is repeated **four times** i.e. 4 × 4 steps × 7.5° = 120°.	1–2
The system then loops, and all coils switched off.	1
SW is rechecked and, if pressed and released the stepper rotates as specified and the routine repeats.	1
Total	**13**
The flow chart can look different to the one in the marking key but must perform the specified functions to be awarded full marks.	


Start
Outputs 1, 2, 3 and 4 off
Switch pressed?
N
Y
Switch released?
N
Y
Subroutine x 4
Subroutine
Outputs 1 off, 2 on, 3 on and 4 off
Delay 25 ms
Outputs 1 off, 2 on, 3 off and 4 on
Delay 25 ms
Outputs 1 on, 2 off, 3 off and 4 on
Delay 25 ms
Outputs 1 on, 2 off, 3 on and 4 off
Delay 25 ms
Stop

Question 46 **(13 marks)**

(a) Calculate VR, the velocity ratio of the compound gear drive. (3 mark)

Description	Marks
VR = product of followers/product of drivers	
= (60 × 60 × 60)/ (15 × 20 × 20)	
= 216 000/6000	1–2
= 36 or 36:1	1
Total	**3**
Alternatively:	
VR = (60/15) × (60/20) × (60/20)	
= 4 × 3 × 3	1–2
= 36 or 36:1	1

(b) The input speed of the motor that is connected to the driver gear of the compound gear drive, is 500 rpm. Calculate the output speed of the worm wheel. Assume 100% efficiency. If you were unable to obtain a value for part (a), use 42. (4 marks)

Description	Marks
$VR_{\text{WORM DRIVE}}$ = # teeth worm wheel/1	
= 360/1 = 360	1
VR_{TOTAL} = 36 × 360	
= 12 960	1
Output speed = *Input speed*/*VR*	
= 500/12 960	1
= 0.03858 rpm	1
Total	**4**
Accept other valid methods of calculation.	

(c) Calculate the time it takes for the telescope to rotate through 180°. If you were unable to obtain a value for part (b), use 0.06 rpm. Give your answer in seconds. (4 marks)

Description	Marks
Time to rotate 180° = 0.5 × (1/0.03858) × 60	
= 0.5 × 25.92 × 60	1–3
= 777.6 s (750 s)	1
Total	**4**
Accept other valid methods of calculation.	

(d) Can the worm wheel be used to rotate the worm gear? Explain your reasoning. (2 marks)

Description	Marks
No, the worm wheel cannot be used to rotate the worm gear.	1
Because a torque applied by the worm wheel to the worm will be self-locking.	1
Total	**2**
Accept other valid explanations.	

ACKNOWLEDGEMENTS

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