T Level Technical Qualification(s) in Engineering and Manufacturing (Level 3)

8730-031

Core: Exam paper 1

Sample mark scheme

Marker guidance

Unless otherwise stated in the marker guidance for a specific question, the following conventions apply:

- All marking, from start to finish must be consistent and in line with the mark scheme guidance. Continue to refer to the mark scheme throughout marking.
- Follow through errors: Where a candidate is required to use the result of a calculation for a subsequent part of the question and the initial calculation is incorrect, do not disallow the subsequent answer if the method is correct.
- For questions that ask for a specific method to be used, evidence of that method should be seen to award the mark.
- Where a method is not specified, full marks may be awarded for a correct answer using any appropriate method. The use of calculators may reduce the detail of working given, however marks for correct intermediate steps towards an incorrect answer should be given where there is sufficient evidence to do so.
- If the mark scheme gives a mark for the method and correct answer separately, the method mark can be given for correct method, but wrong answer, if it is clear the inaccuracy is through transferring the appropriate value incorrectly (eg through misreading) into the correct method.
- Unless specification of units is required by the question, marks are not lost for not including them if the intention is clear (eg as used in the question or the relevant SI unit). However, where accuracy of the calculation cannot be confirmed without the unit being specified, the mark is lost. Eg if the answer is to the wrong decimal place for the expected unit – ie the candidate's answer may be intended to be in Km rather than the expected m, but this cannot be inferred.
- For questions that ask for a specific number of points, accept the first answers given up to the number requested e.g. State three… only accept the first three answers listed, and disregard any additional answers provided.
- For questions requiring continuous prose answers, mark positively – all correct answers should receive the appropriate mark according to the mark scheme. Any wrong (**but neutral**) answers should be ignored, and no marks should be lost.
- In some circumstances, it is appropriate to disallow a candidate answer that initially appears to give the correct answer as given in the mark scheme, if it is undermined by the fact that it goes on to actively **contradict** its intention. Sometimes the minimal wording used in the mark scheme allows a match that in reality is trivial and it is clear the candidate is referring to the wrong knowledge/understanding. Only the part of the response to which the contradiction applies should be disallowed, not the whole response. Material that is irrelevant/neutral but not contradictory should be ignored and positive marking applied as above.
- Use the full range marks for a question as described by the mark scheme – e.g. for a 2 mark question, 0, 1 or 2 marks will always be available to award (never just 0 or 2). For levels marking, the full range of marks should be used freely as described by the mark scheme including 0 and full marks.
- Always award whole marks; half marks cannot be awarded.
- Allow phonetic misspellings as long as the meaning is clear, i.e. not so similar to another relevant but wrong term that you have to guess which was intended.
- Only allow 'it' as reference to the question topic if it is clear what 'it' refers to.
- Mark crossed out work UNLESS it has been replaced by another response.
- Where judgement is required, apply the guidance. Where the guidance does not sufficiently support for a particular candidate response/interpretation, contact your Team Lead.

- Accept alternative wording that reflects that given in the mark scheme.
- Contact your Team Lead if any additional correct answers arise which need to be added to the mark scheme.
- For level of response mark schemes:

  Note: indicative content has been provided to help orient the marking, providing a sense of the intentions of the question and expected parameters of the response. It is not exhaustive, and candidates do not need to cover all points referenced. Candidates may provide good quality responses while taking an approach which legitimately focuses either on breadth or depth given the time constraints. While the best responses are more likely to go to some depth across a broader range, there will be acceptable variation. Any pointers in the question towards coverage eg '…a range of…' should be kept in mind and balanced, though professional judgement, as to how much this affects the overall quality of the response when applying the marking instructions.

  - First, read the full candidate response and decide which band descriptor best fits the overall level of quality of the response in the context of the indicative content.
  - Then, to decide on a mark within the band, consider the ***degree to which*** **the response fits the criteria**, as indicated by the diagram below:

Comprehensively	Top of mark range for the band	5th	4th	3rd
Substantially	↑	4th	3rd	2nd
Generally		3rd 2nd	2nd	
Borderline	Positively mark and place on the bottom of the band	1st	1st	1st

The table below provides further detail on the descriptors used within each of the mark bands and what is expected at each level. Use the descriptors below alongside the mark scheme to support accurate and consistent judgment of candidate's response and allocation of marks.

AO2	AO3
Basic	
Limited understanding that is relevant to the context or question. Limited accuracy in interpretation through lack of application of relevant knowledge and understanding.	Limited accuracy in analysis through lack of application of relevant knowledge and understanding. Unsupported evaluation through lack of application of knowledge and understanding. Un-supported judgement through lack of application of knowledge and understanding.
Good	
Some understanding that is relevant to the context or question. Some accuracy in interpretation through the application of some relevant knowledge and understanding.	Some accuracy in analysis through the application of some relevant knowledge and understanding. Partially supported evaluation through the application of some relevant knowledge and understanding. Partially supported judgement through the application of some relevant knowledge and understanding.
Thorough	
A range of accurate understanding that is relevant to the context or question. Accurate interpretation through the application of relevant knowledge and understanding.	Accurate analysis through the application of relevant knowledge and understanding. Supported evaluation through the application of relevant knowledge and understanding. Supported judgement through the application of relevant knowledge and understanding.

Comprehensive	
A range of detailed and accurate understanding that is fully relevant to the context or question. Detailed and accurate interpretation through the application of relevant knowledge and understanding.	Detailed and accurate analysis through the application of relevant knowledge and understanding. Detailed and substantiated evaluation through the application of relevant knowledge and understanding. Detailed and substantiated judgement through the application of relevant knowledge and understanding.

This exam has been split into **two** sections.

Below details the types of questions and marks available for each section. Please allow time for each section accordingly.

Section A is made up of **67** marks and includes **18** short answer and medium answer questions.
Section B is made up of **33** marks and includes **3** extended response questions.

Assessment Objectives	Mark allocation
AO1a Demonstrate knowledge The ability to demonstrate basic recall of relevant knowledge in response to straightforward questioning – e.g. material properties.	**10%**
AO1b Demonstrate understanding The ability to explain principles and concepts beyond recall of definitions, but in a general way – i.e. out of a particular context in response to straight forward questioning e.g. simple concepts and terms of description in engineering contexts.	**22%**
AO2 Apply knowledge and understanding to different situations and contexts Using and applying knowledge and understanding, taking the understanding of generalities and applying them to specific situations. Questions are likely to ask for application in relation to a straightforward situation – e.g. assessing the application of a single concept and the application of essential mathematical concepts.	**46%**
AO3 Analyse or evaluate information & issues The ability to analyse the interrelated issues arising from a complex scenario and to evaluate these to propose a best solution or predict impacts etc – e.g. evaluating materials' properties and requirements for engineered products.	**22%**

Formula sheet

Candidates must note that they may not require every formula on this sheet to answer the questions, and that they may require additional formulae not presented here.

Pythagoras theorem	$a^2 + b^2 = c^2$	
Trigonometric functions	$sin\,\theta = \frac{opposite}{hypotenuse}$	
	$cos\,\theta = \frac{adjacent}{hypotenuse}$	
	$tan\,\theta = \frac{opposite}{adjacent}$	
Trigonometric identities	$tan\,\theta = \frac{sin\,\theta}{cos\,\theta}$	
	$cot\,\theta = \frac{1}{tan\,\theta}$	
	$sec\,\theta = \frac{1}{cos\,\theta}$	
	$cosec\,\theta = \frac{1}{sin\,\theta}$	
Sine rule	$\frac{a}{sin\,A} = \frac{b}{sin\,B} = \frac{c}{sin\,C}$	
Cosine rule	$a^2 = b^2 + c^2 - 2bc\cos A$	
	$b^2 = a^2 + c^2 - 2ac\cos B$	
	$c^2 = a^2 + b^2 - 2ab\cos C$	
Standard derivatives	ax^n	anx^{n-1}
	$\sin ax$	$a\cos ax$
	$\cos ax$	$-a\sin ax$
	$\tan x$	$sec^2 x$
Standard integrals	ax^n	$\frac{ax^{n+1}}{n+1} + c\ where\ n \neq 1$
	$\sin ax$	$\frac{-1}{a}\cos ax + c$
	$\cos ax$	$\frac{1}{a}\sin ax + c$
	$\tan x$	$-\ln\cos x + c$
Simple shapes	**Surface area**	**Volume**
Rectangular solid	$2lw + 2hw + 2lh$	lwh
Cylinder	$2\pi r^2 + 2\pi rh$	$\pi r^2 h$
Sphere	$4\pi r^2$	$\frac{4}{3}\pi r^3$
Cone	$\pi rs + \pi r^2$	$\frac{\pi r^2 h}{3}$

Quadratic equation		$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$
Graphs		$y = mx + c$
Arithmetic progression		$a_n = a + (n-1)d$
Geometric progression		$a_n = ar^{n-1}$
Statistics	**Mean value**	$\bar{x} = \frac{\sum(x)}{n}$
	Standard deviation	$\sigma = \sqrt{\frac{\sum(x-\bar{x})^2}{n}}$
Pressure		$P = \frac{F}{A}$
Hydrostatic thrust		$F = \rho g A x$
Bernoulli's equation		$P + \frac{1}{2}\rho v^2 + \rho g h = constant$
Specific heat		$Q = m\ c\ \Delta t$
Latent heat		$Q = mh$
Thermal expansion		$\Delta L = \alpha\ L\ \Delta t$
Polar to cartesian conversion		$x = r\ cos\theta$
		$y = r\ sin\theta$
Potential energy		$PE = mgh$
Kinetic energy		$KE = \frac{1}{2}mv^2$
Stress		$\sigma = \frac{F}{A}$
Strain		$\varepsilon = \frac{\Delta L}{L}$
Young's modulus		$E = \frac{\sigma}{\varepsilon}$
Gas laws	**Boyle's Law**	$P_1V_1 = P_2V_2$
	Charles' Law	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$
	General gas equation	$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
	Characteristic gas equation	$pV = mRT$
Resistance in series		$R_T = R_1 + R_2$
Resistance in parallel		$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$
Capacitance in series		$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$
Capacitance in parallel		$C_T = C_1 + C_2$
Electrical theory		Ohm's law $V = IR$
		$P = IV$

Section A

Q1	Describe what is meant by fan in and fan out in signal processing. (2 marks)	
Mark Scheme	Fan in refers to the number of signals to a single input gate [1] Fan out describes the number of gate inputs to other logic gates that can be driven by the output of a single logic gate [1].	**Marking guidance** 1 mark per correct description, up to a maximum of 2 marks.
Total marks	2	
AO	AO1a = 2	
Qual spec reference	8.1.4.5 – fan in and fan out	

Q2	Name **two** different types of smart material and for each give a typical application. (4 marks)	
Mark Scheme	Types of smart materials: • Thermochromic pigment [1] – Food packaging which requires a change of colour with temperature [1] • Photochromic pigment [1] – Sunglasses which require a change of colour with light [1] • Piezoelectric [1] – An element of speaker or headphone which requires a change of shape through electrical energy [1] • Shape memory alloy [1] – Sprinkler system where the sensor changes shape due to heat [1] • Quantum tunnelling composite [1] – ATM keypads where an electrical signal is allowed to pass through when pressure is applied [1]	**Marking guidance** 1 mark for each smart material and a further mark for a typical application, up to a maximum of 4 marks. Accept other suitable materials and applications.
Total marks	4	
AO	AO1a = 4	
Qual spec reference	6.2.1.9 – smart materials	

Q3	Define the following terms used in engineering: a) Reliability (1 mark) b) Accuracy (1 mark) c) Precision (1 mark)	
Mark Scheme	a) The degree of consistency of measurement / the ability to get similar results when an activity is repeated [1] b) How close a measurement is to the accepted or true value [1] c) How close measurements of the same feature are to each other [1]	**Marking guidance** 1 mark for each correct definition, up to a maximum of 3 marks.
Total marks	3	
AO	AO1a = 3	
Qual spec reference	5.3 – scientific methods and approaches to scientific inquiry and research	

Q4	A robotic delivery vehicle of mass 500 kg is being used to move wagons containing materials around a factory. The wagon and materials have a combined mass of 125 kg. The robotic delivery vehicle, which is initially travelling at 2.4 m s^{-1}, collides with the stationary wagon and the two become fixed together and move as a single mass. Calculate the common velocity after the collision. (4 marks)
Mark Scheme	$m_1 = 500\ kg, m_2 = 125\ kg$ $u_1 = 2.4\ m\ s^{-1}, u_2 = 0\ m\ s^{-1}$ Initial momentum $= m_1 u_1 + m_2 u_2$ [1, AO1a] $= (500 \times 2.4) + (125 \times 0) = 1200\ kg\ m\ s^{-1}$ [1, AO1b] Final momentum $=$ Initial momentum $= 1200\ kg\ m\ s^{-1} = (m_1 + m_2) \times u_3$ [1, AO1b] Rearranging $u_3 = \frac{1200}{500+125} = 1.92\ m\ s^{-1}$ [1, AO1b]
Total marks	4
AO	AO1a = 1 AO1b = 3
Qual spec reference	7.2.1 – principle of conservation of momentum

Q5

Complete the table below, stating a different item of equipment to carry out each measurement. (3 marks)

Measurement	Equipment used
Checking that the diameter of a hole is 8±0.1 mm	
Checking that the separation between two metal parts is 1.5±0.1 mm	
Deviation from concentricity of a shaft	

Mark Scheme

Measurement	Equipment used
Checking that the diameter of a hole is 8±0.1 mm	Vernier callipers *or* inside micrometer [1] – *do not accept engineer's rule*
Checking that the separation between two metal parts is 1.5±0.1 mm	Slip gauge [1] – *do not accept Vernier callipers*
Deviation from concentricity of a shaft	Dial test indicator (DTI) *or* CMM *or* roundness gauge [1] – *do not accept go/no-go, micrometer*

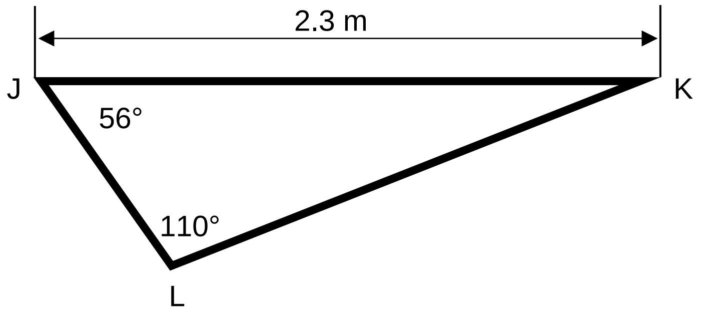
Marking guidance

1 mark for each cell completed with correct information, up to a maximum of 3 marks.

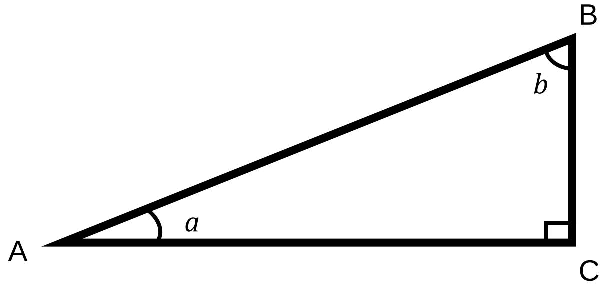
Accept appropriate alternative equipment.

Total marks	3
AO	AO1b = 3
Qual spec reference	5.4.1 – [measurement] equipment

Q6	The input into a gearbox is 300 revolutions per minute (rpm). The output from the gearbox is 2700 rpm. The gearbox contains two gears.
	The output gear has 18 teeth. How many teeth does the input gear have? (2 marks)
Mark Scheme	Teeth on input = gear ratio × teeth on output $= \frac{2700}{300} \times 18$ [1] $= 162$ teeth [1]
Total marks	2
AO	AO1b = 2
Qual spec reference	4.1.1.7 – ratios

Q7	The shape in Figure 1 must be accurately measured before manufacturing. Calculate the length of side KL. (3 marks)  Figure 1 – Not to scale
Mark Scheme	Rearranging the sine rule $KL = \frac{KJ \sin J}{\sin L}$ [1] $= \frac{2.3 \sin 56°}{\sin 110°}$ [1] $= 2.03\ m$ [1]
Total marks	3
AO	AO1b = 3
Qual spec reference	4.1.5.5 – sine and cosine rules

Q8	A pneumatic cylinder with a movable piston contains 0.9 m^3 of air at a pressure of 6 MPa. Calculate the volume of the air if the pressure exerted within the cylinder is reduced to 1.2 MPa. Assume that the temperature remains constant. (2 marks)
Mark Scheme	(From Boyle's Law) $P_1V_1 = P_2V_2$ Rearranging $V_2 = \frac{P_1\,V_1}{P_2} = \frac{6 \times 0.9}{1.2}$ [1] $V_2 = 4.5\,m^3$ [1]
Total marks	2
AO	AO1b = 2
Qual spec reference	5.8.8.6 – Boyle's Law

Q9	The triangle in Figure 2 is a structural part that needs to be manufactured. The designer of the part has specified that cot $a = 1.73$  Figure 2 – Not to scale
Q9 a)	Determine the angles a and b. (3 marks)
Q9 b)	Show that the ratio of lengths BC to AB is approximately 0.5 (2 marks)
Mark Scheme	a) Rearranging the trigonometric identity $cot\ a = \frac{1}{tan\ a}$: $tan\ a = \frac{1}{cot\ a}$ [1] $= \frac{1}{1.73} = 0.578; tan^{-1}\ 0.578 = 30°$ [1] $b = 180 - 90 - 30 = 60°$ [1] b) $\frac{Length\ BC}{Length\ AB} = \sin\theta$ [1] $= \sin 30° = 0.5\ QED$ [1]
Total marks	5
AO	AO1b = 3 + 2
Qual spec reference	4.1.5.6 – common trigonometric identities and values

Q10	A company wants to chemically etch stainless steel labels with its logo and product details, such as the ones shown in Figure 3. Describe how the etching process would be carried out. (4 marks)  Figure 3 *Source: www.brunelengraving.co.uk*	
Mark Scheme	E.g. Using a photosensitive film etching process • Laminate the metal labels with a photosensitive coating [1] • Expose the areas to be etched to ultraviolet (UV) light, masking the required details [1] • Place the labels into hydrochloric acid etchant solution for a specified period of time [1] • Remove the steel labels from the acid and thoroughly clean [1]	**Marking guidance** 1 mark for each step described, up to a maximum of 4 marks. Accept other appropriate chemical etching processes and their relevant steps.
Total marks	4	
AO	AO1b = 4	
Qual spec reference	5.5.2.3 – reactions of metals and alloys with weak and strong acids and alkalis	

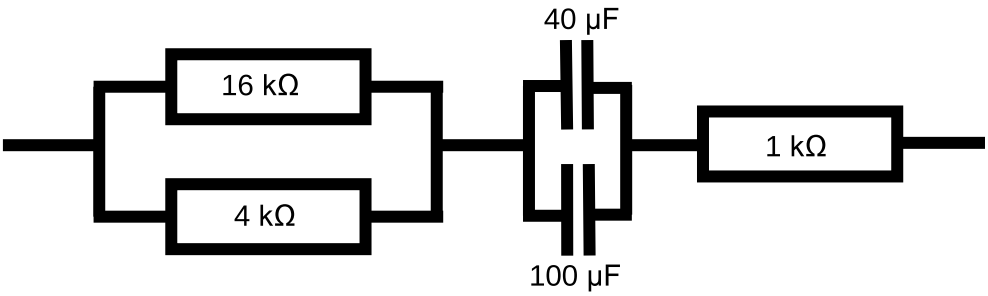
Q11	When a sample selected at random from a batch of products was inspected, it was found that: • 89% of the products contained no defect and were satisfactory, • 9% of the total quantity of products contained crack defects, • 6% of the total quantity of products contained porosity defects. Some of the products contained both types of defect. Calculate the probability that a product selected at random contains only one defect. (3 marks)
Mark Scheme	Probability of a defect $= 100 - 89 = 11\%$ [1] the proportion of products with 2 defects must equal total quantity of defects $-11 = (9 + 6) - 11 = 4\%$ [1] Thus, the probability of a product containing only a single defect is $11 - 4 = 7\%$ [1]
Total marks	3
AO	AO2 = 3
Qual spec reference	4.1.6.1 – analysis of data and calculation of probabilities in engineering contexts

Q12	A test was carried out to evaluate the usable life of a machine tool. This involved recording the number of defective parts produced by the machine each hour. The first defective part was produced in hour 5. The number of defects in subsequent hours increased geometrically. The number of defects produced in the hour 8 was 64. Calculate the common ratio that multiplies the number of defects in each successive batch. (3 marks)
Mark Scheme	Taking the first batch with a defective product as $a = 1$ $(n = t - 4)$ [1 for correct value of n] In hour 8, the total number of defects $= 64 = ar^{n-1} = 1\,r^{((8-4)-1)}$ [1 for correct value of a] Rearranging $r = \sqrt[3]{\frac{64}{1}} = 4$ [1]
Total marks	3
AO	AO2 = 3
Qual spec reference	4.1.1 – standard arithmetic

Q13	In a circuit, three components each change the amplitude of the output, D, in sequence by different values: • Component 1 causes the amplitude to increase by the cube of its value (D^3). • Component 2 causes the amplitude to be divided by the square of its value (D^2). • Component 3 multiplies the resultant output by its square root ($D^{\frac{1}{2}}$). Determine the simplest form of the equation to represent how the output signal is affected by the three components. (3 marks)
Mark Scheme	$\frac{D^3}{D^2} \times D^{\frac{1}{2}} \equiv D^{3-2} \times D^{\frac{1}{2}}$ [1] $\equiv D^{1+\frac{1}{2}}$ [1] $\equiv D^{\frac{3}{2}}$ [1]
Total marks	3
AO	AO2 = 3
Qual spec reference	4.1.2.2 – solving quadratics using indices and logarithms

Q14	A tool moves in a straight line in a machine. At time t seconds, its position relative to a fixed point in the machine, x mm, is given by the function $$x = 2t^3 + 2\cos(3t)$$ Determine the difference in the velocity of the tool between t=1.0 and t=2.5 seconds, to two decimal places. (5 marks)
Mark Scheme	$x = 2t^3 + 2\cos(3t)$ $\rightarrow v = \frac{dx}{dt} = 6t^2$[1] $- 6\sin(3t)$[1] $v_1 = 6 - 6\sin 3 = 6 - 0.314 = 5.69$ [1] $v_{2.5} = 37.5 - 6\sin 7.5 = 36.7$ [1] $\rightarrow v_{2.5} - v_1 = 36.7 - 5.69 = 31.01$ [1]
Total marks	5
AO	AO2 = 5
Qual spec reference	4.1.4 – calculus

Q15	A steel bar is being used to provide rigidity inside an industrial oven. It was fixed in position at both ends inside the oven when the temperature was 20°C. When in use, the oven operates at 130°C and any expansion or contraction of the steel bar is prevented. Calculate the maximum stress experienced by the bar as a result of the change in temperature. Additional information: For steel, $\alpha = 12 \times 10^{-6}$ $°C^{-1}$ and E = 205 GN m^{-2} (6 marks)
Mark Scheme	The maximum stress will be experienced at the highest temperature difference of $130 - 20 = 110°C$ [1] Rearranging $E = \frac{\sigma}{\varepsilon}, \sigma = \varepsilon \times E$ [1] Substituting in $\varepsilon = \frac{\Delta L}{L}, \sigma = \frac{\Delta L}{L} \times E$ [1] Substituting in $\Delta L = \alpha L \Delta t, \sigma = \frac{\alpha L \Delta t}{L} \times E$ [1] Cancelling out L therefore $\sigma = \alpha t E$ [1] $\sigma = 12 \times 10^{-6} \times 110 \times 205\ GN\ m^{-2} = 271\ MN\ m^{-2}$ [1]
Total marks	6
AO	AO2 = 6
Qual spec reference	5.8.6 – expansivity (3 marks) 6.6.2.2.5 – calculation of stress (3 marks)

Q16	A designer requires a circuit to have a time constant (T = RC) of 0.5 ± 0.05 seconds. Determine if the time constant of the arrangement shown in Figure 4 would be acceptable. (5 marks)  Figure 4
Mark Scheme	Method is to calculate resistance in parallel, then resistance in series; capacitance in series; finally time constant For the resistors in parallel $\frac{1}{R_{TP}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{16} + \frac{1}{4} = \frac{5}{16} k\Omega$ rearranging $R_{TP} = \frac{16}{5} = 3.2\ k\Omega$ [1] The total resistance $R_T = R_{TP} + R_3 = 3.2 + 1 = 4.2\ k\Omega$ [1] The total capacitance $C_T = C_1 + C_2 = 40 + 100 = 140\ \mu F$ [1] Time constant $\mathrm{T} = \mathrm{RC} = 4200 \times 140 \times 10^{-6} = 0.588\ \mathrm{seconds}$ [1] The time constant is outside the acceptable range of 0.45 to 0.55 and therefore this arrangement is not acceptable. [1] *Do not accept an answer that has not been justified appropriately.*
Total marks	5
AO	AO2 = 5
Qual spec reference	8.1.3 – DC circuit networks

<table>
<tr><td>Q17</td><td colspan="2">A company manufactures hard hats from a metal alloy, such as the one shown in Figure 5. The design specifies that the metal should have a crystalline structure. Due to a manufacturing issue, the metal has been produced with an amorphous non-crystalline structure.
Explain how this will affect the performance of the hard hat when it is subjected to an impact.
(4 marks)

Figure 5
Source: www.forestry-suppliers.com</td></tr>
<tr><td>Mark Scheme</td><td>• In the amorphous metal, the stress cannot be relieved by slippage of planes of atoms [1], as the atoms will be randomly distributed rather than in crystal planes, reducing potential deformation of the hat which means it will absorb less energy [1].
• This will also result in the toughness of the hard hat being lower [1] increasing the risk that the hard hat will break when subjected to an impact [1]
• The hard hat could be subject to high levels of impact damage [1], therefore it would be unsuitable for use [1].</td><td>Marking guidance
1 mark for each explanation with a further mark for an appropriate expansion of the explanation, up to a maximum of 4 marks.

Accept other appropriate answers.</td></tr>
<tr><td>Total marks</td><td colspan="2">4</td></tr>
<tr><td>AO</td><td colspan="2">AO2 = 4</td></tr>
<tr><td>Qual spec reference</td><td colspan="2">6.2 – Types of material and their structures</td></tr>
</table>

<table>
<tr><td>Q18</td><td>A company is planning to build a new factory to mass produce electronic circuit boards for phones. Each of the assembly operations will be carried out by dedicated robotic arms. The factory will work seven days a week, 24 hours a day in order to meet demand. New phone designs will be manufactured each year.

Explain why programmable logic controllers (PLCs) would be used to control the robotic arms, rather than dedicated integrated circuits. (6 marks)</td></tr>
<tr><td>Levels of response</td><td>
<table>
<tr><th>Band</th><th>Marks</th><th>Descriptor</th></tr>
<tr><td>3</td><td>5-6</td><td>Demonstrates comprehensive knowledge and understanding through the application of PLCs and integrated circuits to the specific situation in the question.

Explores one or more reasons extensively or multiple reasons to a lesser detail.</td></tr>
<tr><td>2</td><td>3-4</td><td>Demonstrates good knowledge and understanding through the application of PLCs and integrated circuits to the specific situation in the question.

Explores one reason to some depth or a few reasons in limited detail.</td></tr>
<tr><td>1</td><td>1-2</td><td>Demonstrates limited knowledge and understanding through the application of PLCs and integrated circuits and mostly describes the function of these concepts.

Explores one or two reasons in their answer with limited detail.</td></tr>
<tr><td></td><td>0</td><td>No relevant material</td></tr>
</table>

Indicative content

Programming would replace hardware as a PLC could be used in place of several other integrated circuits, so this reduces the size of the robot arm system.
The cost of the robot arm system is therefore reduced as there are fewer components and materials needed.
Unlike dedicated integrated circuits, PLCs can be reprogrammed to facilitate the required design changes in the circuits faster and at lower cost.
Unlike PLCs, dedicated integrated circuits may also require hardware changes to accommodate new circuit designs.
This application requires continuous operation. PLCs are more robust than dedicated integrated circuits and therefore more suited to control the robotic arms.
As PLCs are less likely to fail, this reduces the risk of unplanned downtime, which results in the prevention of lost productivity.

</td></tr>
<tr><td>Total marks</td><td>6</td></tr>
<tr><td>AO</td><td>AO2 = 6</td></tr>
<tr><td>Qual spec reference</td><td>9.2 – the operation, function and applications of programmable logic controllers (PLC) in mechatronic systems</td></tr>
</table>

Section B

Q19	A company is making a chain for a ship's anchor that a ship will use when at sea. They are using a ferrous metal. The company has three potential processing techniques that could be used to make the links in the chain: • Casting • Forging • Welding bent pieces together. The chain also needs to be protected from corrosion. Suggest which of the three processing techniques would be suitable for the chain and a method to improve its corrosion resistance, justifying your suggestions compared to the alternatives. (9 marks)
Mark Scheme	(see below)

Band	**Marks**	**Descriptor**
3	**7-9**	Demonstrates comprehensive justification of the suggested method for both processing and surface treatment, with detailed reference to the alternatives. Demonstrates comprehensive application of knowledge and understanding of the use of methods relative to the manufacturing needs of the chain. Demonstrates comprehensive evaluative skills and comprehensive reasoning for which method and treatment would be most suitable.
2	**4-6**	Demonstrates a good justification of the suggested method for both processing and surface treatment, with some reference to the alternatives. Demonstrates good application of knowledge and understanding of the use of different methods relative to the manufacturing needs of the chain. Demonstrates good evaluative skills with clear reasoning to which method and treatment would be most suitable.
1	**1-3**	Demonstrates basic justification of the suggested method for either processing or surface treatment, with limited reference to the alternatives. Demonstrates basic application of knowledge and understanding of the use of different methods relative to the manufacturing needs of the chain. Demonstrates basic evaluative skills with limited reasoning to which method or treatment would be most suitable.
	0	**No relevant material**

Indicative content

Processing technique

- Casting and forging would produce chain links as solid single parts.
- Welded links would not be homogenous.

	• Non-homogenous links would result in property variations in the heat-affected zone, such as reduced tensile strength and increased likelihood of corrosion. • Casting would give a coarser grain structure than forging, resulting in slightly lower tensile strength so the links may need to be thicker/heavier. • Forging can give anisotropic properties allowing greater strength in the direction that the force is applied to the links. • Forging would result in a better surface finish/lower surface porosity than casting, reducing defect/corrosion initiation sites giving more consistent performance by each link. **Corrosion protection** • Galvanic protection requires contact with an electrolyte which would be ineffective, as part of the chain is outside of the water. • Painting and galvanising would provide a barrier to the water at relatively low cost. • Galvanising typically has a higher initial cost. • The effectiveness of galvanising will reduce over time and cannot easily be repeated. • Painting can be reapplied as frequently as necessary, potentially increasing the period over which the anchor chain can be protected. • Painting and galvanising could be prone to local damage from the friction of the links. • Painting could cause rapid corrosion in locally damaged areas leading to premature failure of the chain. • Galvanising would still provide some corrosion resistance to damaged links as the zinc could corrode in preference to the ferrous metal.
Total marks	9
AO	AO2 = 3 AO3 = 6
Qual spec reference	6.3, 6.4, 6.5

<table>
<tr><td>Q20</td><td>A manufacturing company is considering using a renewable source of power for a new factory. The factory will have a number of electrically-powered machining processes which are expected to operate continuously. The factory is in a high altitude rural location with no nearby river and limited access by road.
Evaluate the different power sources available and suggest the most suitable for the needs of this company. (12 marks)</td></tr>
<tr><td>Mark Scheme</td><td>
<table>
<tr><th>Band</th><th>Marks</th><th>Descriptor</th></tr>
<tr><td>4</td><td>10-12</td><td>Demonstrates comprehensive use of analysis of the different types of power sources.
Demonstrates comprehensive application of knowledge and understanding of different power sources relevant to the specific requirements of the company.
Demonstrates comprehensive evaluative skills, comprehensive reasoning and justifications to which power source would be most suitable.
The response is fully coherent and is articulated using a logical structure that maximises understanding.</td></tr>
<tr><td>3</td><td>7-9</td><td>Demonstrates a thorough use of analysis of the different types of power sources.
Demonstrates thorough application of knowledge and understanding of different power sources relevant to the specific company.
Demonstrates thorough evaluative skills with thorough reasoning and justifications to which power source would be most suitable.
The response is clearly expressed and is well-structured.</td></tr>
<tr><td>2</td><td>4-6</td><td>Demonstrates a good use of analysis of the different types of power sources.
Demonstrates good application of knowledge and understanding of the use of different power sources relevant to the specific company.
Demonstrates good evaluative skills with clear reasoning to which power source would be most suitable.
The response is generally clearly expressed, with some consideration given to how it is structured.</td></tr>
<tr><td>1</td><td>1-3</td><td>Demonstrates a basic use of analysis of the different types of power sources.
Demonstrates basic application of knowledge and understanding of the use of different power sources relevant to the specific company.
Demonstrates basic evaluative skills with limited reasoning to which power source would be most suitable.
The response lacks some clarity and is generally poorly structured.</td></tr>
<tr><td></td><td>0</td><td>No relevant material</td></tr>
</table>

Indicative content</td></tr>
</table>

	• Solar and wind power are the main options. The limited access and rural location may inhibit the use of biofuels. • The factory requires continuous operation - solar cells only produce electricity during the day, whereas wind produces energy at night as well. • Despite recent developments in the storage of solar power, less energy storage may be needed for wind power resulting in lower hardware cost compared to solar energy. • Space needed – solar power would require significant coverage area facing towards the direction of the sun, whereas with wind power it may be possible to use a single large wind turbine. • Using a single wind turbine could result in interruption of supply if there are maintenance issues, therefore it may be preferrable to use multiple smaller turbines. • Solar panels could be installed on the factory's roof, offsetting the space requirement. • Utilising roof space would reduce impact on local ecosystems. • Wind power generates more power per unit area than solar power so less land area would be needed. • High altitude of the factory would contribute to increased wind power. • The high altitude of the factory would make the use of geothermal power more challenging as greater drilling depths will be required. • No river near the company excludes the use of hydroelectric power and the rural location excludes the use of wave power, unless extensive cabling was available, which would greatly increase the cost. • The rural location may mean that animal produced biofuels could be considered, however this would need a substantial quantity in order to be feasible. • The rural location could mean difficulties in transportation by potential biofuel elements, such as cooking oil, from residential areas. • Solar power produces DC electricity, whereas the generator in a wind turbine produces AC electricity. Therefore, solar energy would require a DC to AC conversion system to provide mains voltages for the equipment.
Total marks	12
AO	AO2 = 4 AO3 = 8
Qual spec reference	7.2.9.3 – renewable energy Synoptic

Q21	A company has been asked to develop a wheelchair that will be used by an athlete in the Paralympics. The wheelchair needs to be manually powered and will be used for long distance racing on roads and track, and must be manufactured as a one-off. Discuss the factors that are most important when selecting the materials to make the wheelchair and recommend a suitable main material for the frame, justifying your choice. (12 marks)

Mark Scheme

Band	Marks	Descriptor
4	**10-12**	Demonstrates comprehensive understanding of a wide variety of considerations for selecting the material. Demonstrates comprehensive application of knowledge and understanding of a wide variety of materials suitable for the wheelchair and their properties. Demonstrates comprehensive evaluative skills, comprehensive reasoning and justifications to which material would be most suitable. The response is fully coherent and is articulated using a logical structure that maximises understanding.
3	**7-9**	Demonstrates a thorough understanding of a wide variety of considerations for selecting the material. Demonstrates thorough application of knowledge and understanding of a variety of materials suitable for the wheelchair and their properties. Demonstrates thorough evaluative skills with thorough reasoning and justifications to which material would be most suitable. The response is clearly expressed and is well-structured.
2	**4-6**	Demonstrates a good use of analysis of some considerations for selecting the material. Demonstrates good application of knowledge and understanding of materials suitable for the wheelchair and their properties. Demonstrates good evaluative skills with clear reasoning to which material would be most suitable. The response is generally clearly expressed, with some consideration given to how it is structured.
1	**1-3**	Explains a few considerations for selecting the material. Demonstrates basic application of knowledge and understanding of materials and their properties. Demonstrates basic evaluative skills with limited reasoning to which power source would be most suitable. A material is recommended which may not be fully appropriate. The response lacks some clarity and is generally poorly structured.
	0	**No relevant material**

Indicative content

Quality of responses should be judged on engineering knowledge. Misunderstandings around the context of the Paralympics or disabilities should be disregarded.

	• The main consideration would be the performance requirements, such as speed, stability, overall weight of the chair. • Long distance racing would require the materials to be wear resistant for at least the duration of the race. • Road racing means that the surface could be uneven, so a more robust frame would be needed in order to handle things such as potholes or kerbs. • Road racing could result to minor knocks and bumps, so consideration should be given to the elasticity and toughness of the material and how minor damage can be repaired. • Considerations would be individual characteristics of the user, such as height, weight and specific physical limitations, which would affect the chair's structure, its maximum weight and influence the required density and strength to weight ratio. • Use in the Paralympics means that the chair has to be manually powered, without the use of motorised assistance, considering aspects such as the weight, density and potentially the conductivity of the frame. • Suitable types of material would include as composites, aluminium alloys, titanium alloys. • Form of available materials, such as fibre sheet, metal tubes, as appropriate to the material types, as this influences the required manufacturing processes, and hence the complexity of designs that can be achieved. • The potential effects of processing on the material (including heat treatment and surface finish such as painting, if applicable). • The existence of Paralympics regulations and rules for specific sports should be taken into consideration.
Total marks	12
AO	AO2 = 4 AO3 = 8
Qual spec reference	Synoptic 5.6, 6.1, 6.2, 6.3, 6.4, 6.5, 7.2 Could also draw from 5.1, 5.4, 6.6, 7.1. 8.1