National
Qualifications
2023

2023 Engineering Science

Higher

Finalised Marking Instructions

These marking instructions have been prepared by examination teams for use by SQA appointed markers when marking external course assessments.

General marking principles for Higher Engineering Science

Always apply these general principles. Use them in conjunction with the detailed marking instructions, which identify the key features required in candidates' responses.

(a) Always use positive marking. This means candidates accumulate marks for the demonstration of relevant skills, knowledge and understanding; marks are not deducted for errors or omissions.

(b) If a specific candidate response does not seem to be covered by either the principles or detailed marking instructions, and you are uncertain how to assess it, you must seek guidance from your team leader.

(c) Where a candidate makes an error at an early stage in a multi-stage calculation, award marks for correct follow-on working in subsequent stages. Do not award marks if the error significantly reduces the complexity of the remaining stages. Apply the same principle in questions which require several stages of non-mathematical reasoning.

(d) SQA presents all units of measurement in a consistent way, using negative indices where required (for example ms^{-1}). Candidates can respond using this format, or solidus format (m/s), or words (metres per second), or any combination of these (for example metres/second).

(e) For calculations, the number of significant figures expressed in a final answer should be equivalent to the least significant data value given in the question. Answers that have two more figures or one less figure than this will be accepted.

(f) Unless a numerical question specifically requires candidates to show evidence of their working, award full marks for a correct final answer (including unit) on its own.

(g) Award marks where a labelled diagram or sketch conveys clearly and correctly the response required by the question.

(h) Award marks regardless of spelling if the meaning is unambiguous.

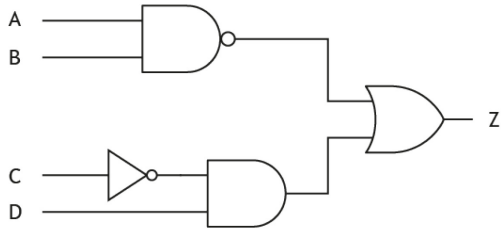
(i) Candidates can answer programming questions in any appropriate programming language. Award marks where the intention of the coding is clear, even where there are minor syntax errors.

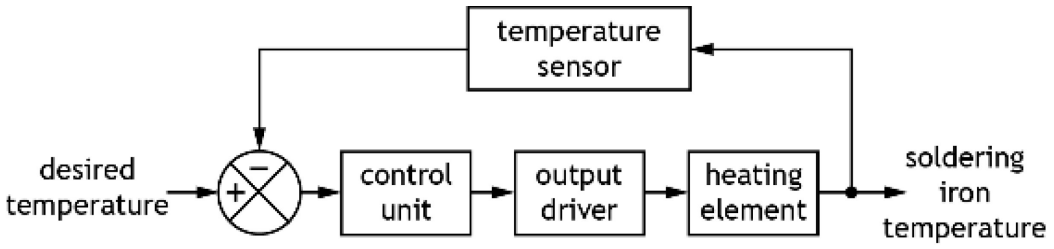
(j) For 'Explain' questions, only award marks where the candidate goes beyond a description, for example by giving a reason, or relating cause to effect, or providing a relationship between two aspects.

(k) Where separate space is provided for rough working and a final answer, only award marks for the final answer. Ignore all rough working.

Marking instructions for each question

Section 1

Question			Expected response	Max mark	Additional guidance
1.				**3**	1 mark for NAND with inputs A and B (also accept AND and NOT in series). 1 mark for NOT and AND for inputs C and D. 1 mark for OR.
2.	(a)		$A_v = V_o / V_i$ $A_v = 7.59 / 0.11$ **A_v = 69 (2 sf)**	**1**	1 mark for final answer with correct unit.
	(b)		$A_v = 1 + (R_f / R_i)$ $69 = 1 + (R_f / R_i)$ $R_f / R_i = 68$ **R_f = 68 kΩ (2 sf)** **R_i = 1.0 kΩ (2 sf)**	**2**	1 mark substitution. 1 mark for proportionally correct values for R_f and R_i with correct units. (Any two values with correct ratio).
3.	(a)		r = 0.84 + 0.34 r = 1.18 m F = T/r F = 295 / 1.18 **F = 250 N (2 sf)**	**2**	1 mark for r. 1 mark for F.
	(b)		x = 21 mm (from graph) $E_s = ½ Fx$ $E_s = 0.5 \times 150 \times 0.021$ $E_s = 1.575$ **E_s = 1.6 J (2 sf)**	**2**	1 mark for x. 1 mark for E_s with correct unit (accept Nm as alternative unit).

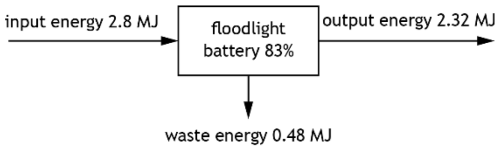
Question			Expected response	Max mark	Additional guidance
4.	(a)		Can be used where shafts intersect at a slight angle. Dampens vibrations or reduces shocks that shafts are subjected to.	**2**	1 mark for each described advantage.
	(b)		Clutch. Universal joint. Specified type of coupling (do not accept rigid or flexible)	**1**	Any drive system that can be used to join to shafts through engagement, eg worm & wheel. Simply stating coupling no mark.
	(c)		It supports the weight of the shaft while allowing the shaft to rotate. Reduces contact surface area and therefore energy loss. Reduces contact surface area so reduces friction. Reduces friction and therefore saves wear on the shaft. Replace the worn bearing instead of the parent part. To enable a shaft to smoothly rotate. To assist with smooth rotation of moving components	**1**	
5.				**3**	1 mark for error detector, negative feedback configuration. 1 mark for output driver (or driver/ transistor/MOSFET/Transducer Driver/TD). 1 mark for heating element (or element).
					

Question			Expected response	Max mark	Additional guidance
6.			Difference amplifier: • provides proportional control • ouput varies proportionally with error in inputs • output signal reduces as desired output is approached, and is able to remain consistent at the desired output. Comparator: • provides two-state control • output is either fully on or fully off depending on the feedback signal • output will continually overshoot and undershoot (hunting), and the output never remains consistent at desired level.	**3**	Up to two correct descriptive comments for each.

Section 2

Question			Expected response	Max mark	Additional guidance
7.	(a)	(i)	UDL = 2.4 × 1.4 UDL = 3.36 kN Moments @ A CWM = ACWM (3.36 × 0.7) + (3.5sin65 × 1.1) = B × 1.4 B (vertical) = 4.172346414 **= 4.2 kN (2 sf)**	**3**	1 mark for UDL point load equivalent (no unit required). 1 mark for substitution. 1 mark for calculating B with correct unit.
		(ii)	$\Sigma F_v = 0$ $V_A + 4.2 = 3.5\sin65 + 3.36$ $V_A = 2.332077255$ kN $\Sigma F_H = 0$ $3.5\cos65 = H_A = 1.479163916$ $H_A = 1.479163916$ kN $R_A = \sqrt{(2.332077255^2 + 1.479163916^2)}$ $R_A = 2.761613697$ **R_A = 2.8 kN (2 sf)** $\theta = \tan^{-1}(2.332077255 / 1.479163916)$ $\theta = 57.61431725$ **θ = 58° (2 sf)**	**4**	1 mark for calculating V_A (no unit required). 1 mark for calculating H_A (no unit required). 1 mark for calculating R_A, with correct unit. 1 mark for calculating direction with correct unit.
	(b)	(i)	Choosing of manufacturing methods that are eco-friendly to reduce the environmental impact. Choosing of materials that are eco-friendly, eg sustainable. Specifying waste management procedures/protocols for the construction. Researching low carbon technologies to reduce carbon footprint. Adapting the design to limit the impact on the environment eg soil/ water/wildlife/plants etc.	**2**	Must be related to being environmentally friendly.

Question			Expected response	Max mark	Additional guidance
7.	(b)	(ii)	Positive impact: • less waste disposal costs during construction • will be more attractive to environmentally conscious stakeholders who will use the academy and increase revenue • energy costs lowered • benefit from government incentives, eg tax savings, grants. Negative impact: • initial capital costs to meet legislation • more energy efficient building methods are more costly • sustainable materials are more expensive • energy efficient materials are more costly.	**2**	All answers must be descriptive and not statements. Must have an economic aspect. Must be related to the being environmentally friendly. Simply writing initial cost, as a negative impact, is not enough. The response must give indication of what areas the initial cost will cover. eg insulation, water reclamation systems, heat recycling etc.
	(c)		Calculate reaction forces using the sum of moments. Calculate the magnitude and nature of forces in members using nodal analysis. Determine if a member is in compression or tension using nodal analysis. Calculate the cross-sectional area of materials using factor of safety. Calculate the cross-sectional area of materials using stress and strain. Use trigonometry to find missing forces and angles. Calculate factor of safety to determine material section. Calculation of loads due to impact of weather, eg snow loads, wind loads.	**2**	1 mark for each response. Must be a descriptive response relating a mathematical process to a specific purpose. Each application must be different. Any other suitable application will be accepted. No mark for just calculating factor of safety.

Question			Expected response	Max mark	Additional guidance
8.	(a)		$Z = A \bullet \overline{B} \bullet (C \oplus D)$	**3**	1 mark for A AND. 1 mark for NOT B AND. 1 mark for C XOR/EOR D.
	(b)		$E_{in} = 15 \times 13 \times (4 \times 60 \times 60) =$ 2808000 J **= 2.8 MJ (2 sf)** Waste energy = 2800000 – 2320000 = **480000 J (2 sf)** Efficiency = 2320000 / 2800000 = 0.8285714286 **= 83% (2 sf)**  	**3**	1 mark for calculating input and waste energy (no unit required). 1 mark for calculating efficiency (unit as appropriate). 1 mark for completing diagram correctly.
	(c)		<table><tr><th>Member</th><th>Magnitude</th><th>Nature</th></tr><tr><td>AB</td><td>910 N</td><td>Tie</td></tr><tr><td>AE</td><td>790 N</td><td>Strut</td></tr><tr><td>BD</td><td>1800 N</td><td>Strut</td></tr><tr><td>BC</td><td>2300 N</td><td>Tie</td></tr></table> Node A $\Sigma F_v = 0$ ABsin30 = 455 **AB = 910 N (2 sf)** $\Sigma F_H = 0$ AE = 910cos30 = 788.0831174 N **AE = 790 N (2 sf)** Node B $\Sigma F_v = 0$ BDsin30 = 910sin30 + 450 BD = 1810 N **BD = 1800 N (2 sf)** BD is a strut $\Sigma F_H = 0$ BC = 1800cos30 + 910cos30 BC = 2346.928844 **BC = 2300N (2 sf)** BC is a tie	**8**	1 mark for AB. 1 mark for AE. 1 mark for substitution. 1 mark for BD. 1 mark for nature. 1 mark for substitution. 1 mark for BC. 1 mark for nature.

Question			Expected response	Max mark	Additional guidance
9.	(a)		R_{ldr} = 600 Ω R_{ldr} values between 600 Ω and 630 Ω acceptable. $R_v/R_{ldr} = R_1/R_f$ 5000/600 = R1/1000 **R1 = 8.3 kΩ (2 sf)** **Alternative solution** V_{+ve} = (600/5600) × 6 = 0.64285714 V 0.64285714 = 6 × (1000/(R_1+1000) 0.64285714 × (R_1 + 1000) = 6000 R_1 × 0.64285714= 6000 - 642.85714 **R_1 = 8.3 kΩ (2 sf)**	**3**	1 mark for correct resistance of LDR. 1 mark for substitution. 1 mark for final answer with units.
	(b)		Max output from op-amp = 9 × 0.78 = 7.02 V I_b = 55/220 = 0.25 mA R_b = (7.02 – 0.70)/ 0.00025 R_b = 25280 R_b **= 25 kΩ (2 sf)**	**4**	1 mark for op-amp output (no unit required). 1 mark for base current (no unit required). 1 mark for voltage over the base resistor (no unit required). 1 mark for final answer with correct unit.
	(c)		$R_{motor} = V^2/P$ = 36/0.4 = 90 Ω I = 6/(90 + 2.3) = 0.06500542 = **65 mA (2 sf)**	**3**	1 mark for resistance of motor (no unit required). 1 mark for total resistance (no unit required). 1 mark for final answer with correct unit.
	(d)		Switching on output 7 activates the top MOSFET and allows current to flow to the motor causing it to spin. Output 6 will control the relay which will change the direction of rotation of the motor.	**2**	1 mark for indicating the effect of each output pin. Cause and effect required for each statement.
	(e)		Inverting	**1**	

Question			Expected response	Max mark	Additional guidance
9.	(f)		Gain = -0.8/0.2 = **-4 (1 sf)**	**1**	Any suitable point on the t-axis can be used to calculate the answer. Clearly identifiable values from peaks and troughs must be used.
	(g)		The op-amp is saturating/clipping.	**1**	1 mark for suitable reason.

Question			Expected response	Max mark	Additional guidance
10.	(a)		V_B lets air through when pressed. V_B has no exhaust. V_C is connected to the output of V_D. The restrictor and reservoir are connected in the wrong sequence. There is no restrictor to slow the instroke of the cylinder. The ball and valve in the UDR are upside down.	**4**	1 mark for each correctly described fault.
	(b)		Fault: the testing for pin 1 does not match specification. When pin 1 is high it should go to main. Fault: The cylinder does not instroke as there is no command to stop the outstroking. Pin 7 must be switched off before "high 6"/ "digitalWrite(6,HIGH);" Fault: The last line of the program does not return to the start of the code to monitor the switches.	**3**	1 mark for each correctly described fault. Candidates should describe three different faults. The same fault in both languages cannot receive 2 marks.
	(c)		When V_1 is actuated a pilot signal actuates V_2 causing C_A to outstroke. As C_A outstrokes there is a delay then V_4 is actuated. V_4 causes C_B to outstroke and actuates V_3. **V_3 cutting off the pilot signal.** After a delay V_4 and V_2 are actuated causing both cylinders to instroke. Both cylinders will instroke anytime V_5 is actuated.	**5**	1 mark for each clearly stated point up to 4 marks. One mark reserved for identifying the function of V_3. Identifying that V_5 acts as a reset is an acceptable alternative to final example.

Question			Expected response	Max mark	Additional guidance
11.	(a)	(i)	Mild steel UCS = 430 Nmm^{-2} (from data booklet) σ = UCS/FoS = 430/15 = 28.66666667 Nmm^{-2} A = F/σ = 49000/28.66666667 = 1709.302326 mm^2 d = $\sqrt{}$(4 × 1709.302326/π) = 46.65138063 **= 47mm (2 sf)**	**4**	1 mark for UCS from data book (no unit required). 1 mark for stress (no unit required). 1 mark for area (no unit required). 1 mark for final answer with correct unit.
		(ii)	ε = σ/E = 86/196000 = 0.000438776 Δl = εl = 0.000438776 × 320 = 0.140408320 **= 0.14 mm (2 sf)**	**3**	1 mark for E from data book (no unit required). 1 mark for ε. 1 mark for Δl with correct unit.
	(b)		Designing the drive system to reduce friction. Designing the drive system to increase efficiency. Calculating the speeds of drive systems to ensure appropriate speeds can be achieved. Using simulation software to model/ design/test mechanical aspects of the drive system. Selection of appropriate materials based on their properties. Calculating maximum force transmitted by pneumatic cylinders to ensure they are strong enough.	**2**	1 mark for each valid description of a different skill.

<table>
<tr><th colspan="3">Question</th><th>Expected response</th><th>Max mark</th><th>Additional guidance</th></tr>
<tr><td>11.</td><td>(c)</td><td>(i)</td><td>$\Sigma F_v = 0$
$F_1\sin45\uparrow = 15\sin30\downarrow + F_2\sin60\downarrow$
$F_1\sin45 - F_2\sin60 = 15\sin30$</td><td>1</td><td>Any form of presentation of equation shown is acceptable.

1 mark for equation based on vertical force components.</td></tr>
<tr><td></td><td></td><td>(ii)</td><td>$\Sigma F_h = 0$
$F_1\cos45\rightarrow + F_2\cos60\rightarrow = 15\cos30\leftarrow$
$F_1\cos45 + F_2\cos60 = 15\cos30$</td><td>1</td><td>Any form of presentation of equation shown is acceptable.

1 mark for equation based on horizontal force components.</td></tr>
<tr><td></td><td></td><td>(iii)</td><td>Vertical components:
$F_1\sin45 - F_2\sin60 = 15\sin30$

Horizontal components:
$F_1\cos45 + F_2\cos60 = 15\cos30$

Vertical forces – Horizontal forces
F_2 (-sin60 – cos60) =
15sin30 – 15cos30
F_2 = (15sin30 – 15cos30) / (-sin60 – cos60)
$F_2 = 4.019237886$
F_2 = 4.0 kN (2 sf)

F_1 sin45 – 4.0sin60 = 15sin30
$F_1 = 15.5055812$
F_1 = 16kN (2 sf)</td><td>3</td><td>1 mark for appropriate substitution (other correct methods are acceptable).

1 mark for F_2 with correct unit.

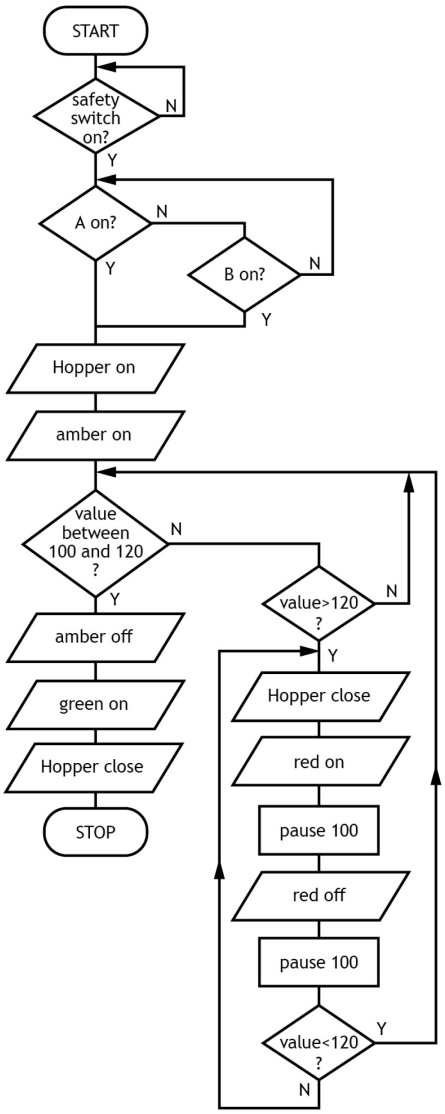
1 mark for F_1, with correct unit.</td></tr>
<tr><td></td><td>(d)</td><td></td><td>
<table>
<tr><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th><th>F</th><th>Z</th></tr>
<tr><td>0</td><td>0</td><td>0</td><td>1</td><td>1</td><td>1</td><td>0</td></tr>
<tr><td>0</td><td>0</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>0</td><td>1</td><td>1</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>0</td><td>1</td><td>0</td><td>0</td></tr>
<tr><td>1</td><td>0</td><td>1</td><td>0</td><td>1</td><td>0</td><td>0</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>1</td><td>1</td><td>1</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
</table>
</td><td>4</td><td>1 mark for column D.

1 mark for column E.

1 mark for column F.

1 mark for column Z.</td></tr>
</table>

Question			Expected response	Max mark	Additional guidance
12.	(a)		V @ inverting input = 5 × (120/241.5) = 2.48447205 V V @ non-inverting input = 5 × (1/2) = 2.5 V V_{out} = (2.5- 2.48447205) × (330/12) = 0.42701863 V = **0.43 V (2 sf)**	**3**	1 mark $V_{inverting}$ (no unit required). 1 mark $V_{non\text{-}inverting}$ (no unit required). 1 mark for V_{out} with correct unit.
	(b)		Summing amp output = -2.3 V $-2.3 = -(R_f/33) \times (0.32+0.53+0.47)$ R_f = 57.5 kΩ **R_f = 58 kΩ (2 sf)**	**2**	1 mark for output of summing amp (no unit required). 1 mark for R_f with correct unit
	(c)		Initially both op-amps will be saturated low. The AND gate will be off and NOT gate B will be on. This will make the amber LED light only. As the voltage rises, op-amp B will saturate high causing NOT gate B, and the amber LED, to switch off and this will cause the AND gate to switch on (causing the green LED to light). As the voltage rises further, op-amp A will saturate high causing the AND gate to switch off. This will cause the green LED to switch off and the red LED to light.	**3**	1 mark for identifying that a lower voltage will cause the amber LED to light. 1 mark for identifying that when the voltage rises op-amp B goes on and op-amp A remains off it will cause the green LED to light and the amber light to switch off. 1 mark for identifying that a high voltage will cause both op-amps to be on and will cause only the red LED to light.

Question			Expected response	Max mark	Additional guidance
12.	(d)			**10**	1 mark for checking both A and B. 1 mark for correct OR connections. 1 mark for hopper open and amber on. 1 mark for checking analogue value in correct range, including correct connections. 1 mark for amber off, green on and hopper closing. 1 mark for 'value>120' decision and loops. 1 mark for hopper closing. 1 mark for red on and off. 1 mark for correct pauses. 1 mark for 'value<120' decision and loops. No marks awarded for 'Stop' or alternative loop back to the start of the flow chart.

[END OF MARKING INSTRUCTIONS]