H

National
Qualifications
2024

2024 Engineering Science

Higher

Question Paper Finalised Marking Instructions

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 numerical questions, candidates should round their answers to an appropriate number of significant figures. However, award marks if their answer has up to two figures more or one figure less than the expected answer.

(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.

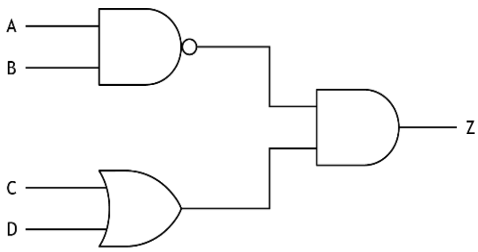
(i) Candidates can answer programming questions in any appropriate programming language. Award marks where the intention of the coding is clear, even where there are minor syntax errors.

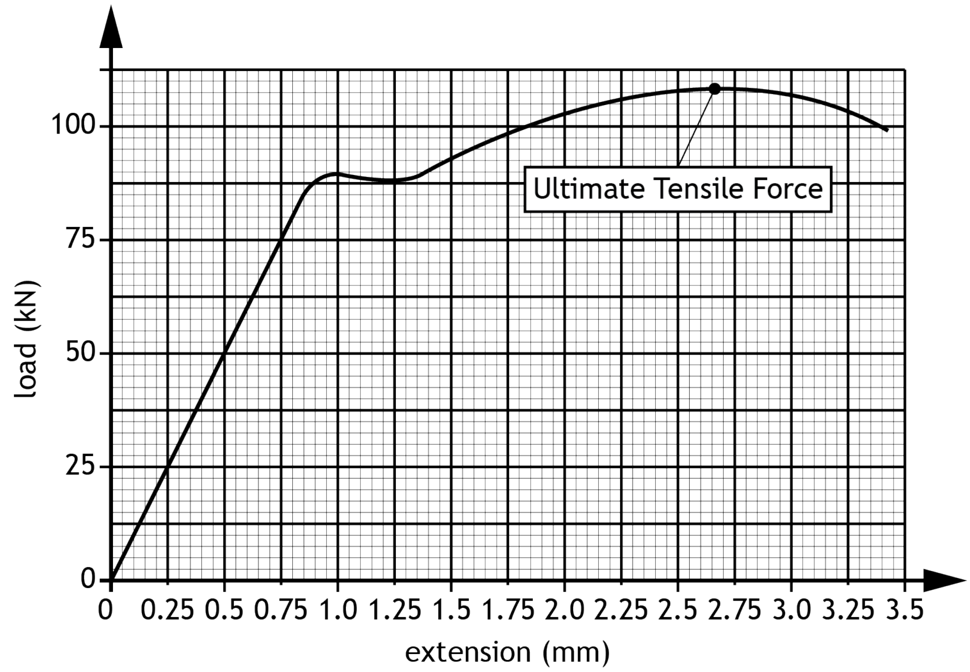
(j) For 'Explain' questions, only award marks where the candidate goes beyond a description, for example by giving a reason, or relating cause to effect, or providing a relationship between two aspects.

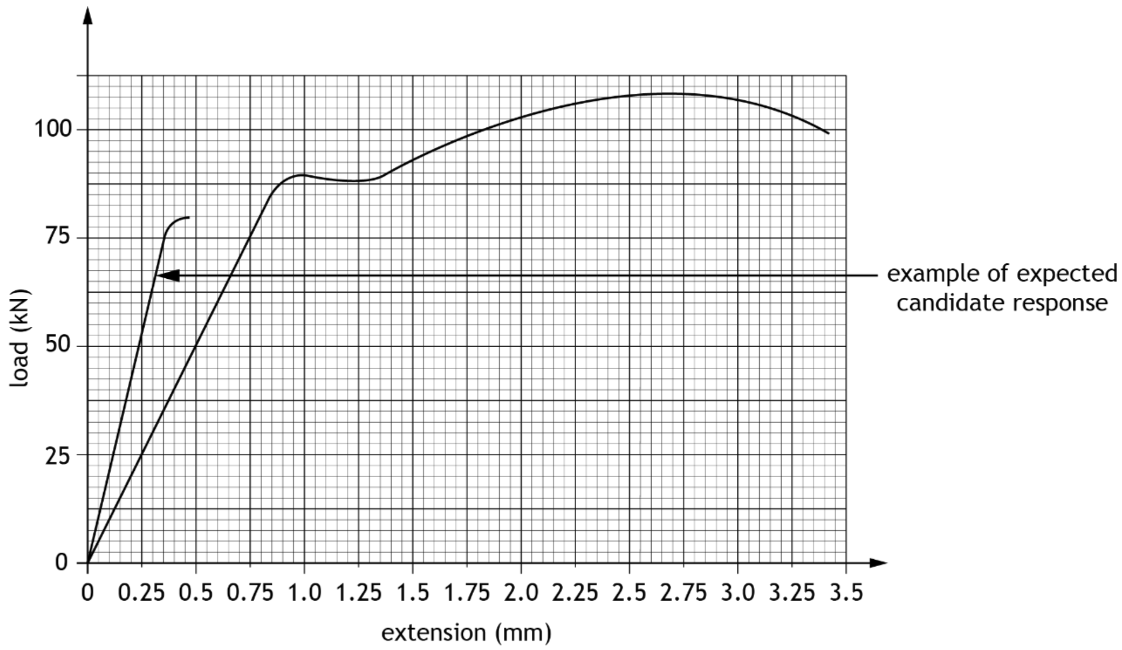
(k) Where separate space is provided for rough working and a final answer, only award marks for the final answer. Ignore all rough working.

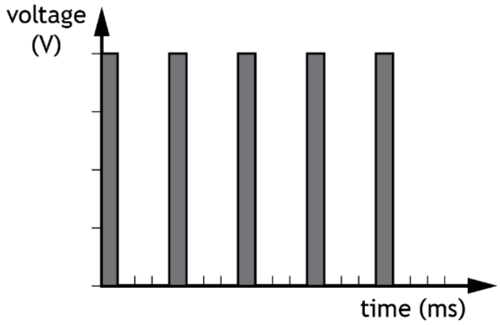
Marking instructions for each question

Section 1

Question			Expected response	Max mark	Additional guidance
1.				**3**	1 mark for NAND (AND and NOT) with connections. 1 mark for OR with connections. 1 mark for AND with connections. NAND equivalents also accepted.
2.			T = Fr T = ((76+95+18) × 9.8) × (0.84 / 2) T = 777.924 Nm **T = 780 Nm (2 sf)**	**2**	1 mark for correct substitution. 1 mark for correct answer (FTE).
3.			UDL point load = 1.8 × 8.3 = 14.94 kN @ 4.15m Take moments about A: (3.8 sin 62 × 5.8) + (14.94 × 4.15) = 8.3 R_B 81.46116495 = 8.3 R_B R_B = 9.814598187 kN **R_B = 9.8 kN (2 sf)**	**4**	1 mark for UDL value 14.94 (unit not required). 1 mark for 3.8sin62 (or 3.8cos28). 1 mark for correct substitution. 1 mark for R_B.
4.			Vo = -18 (5/54 + 5/36 + 5/18) Vo = -9.166666667 V **Vo = -9.2 V (2 sf)**	**2**	1 mark for correct substitution. 1 mark for correct answer.

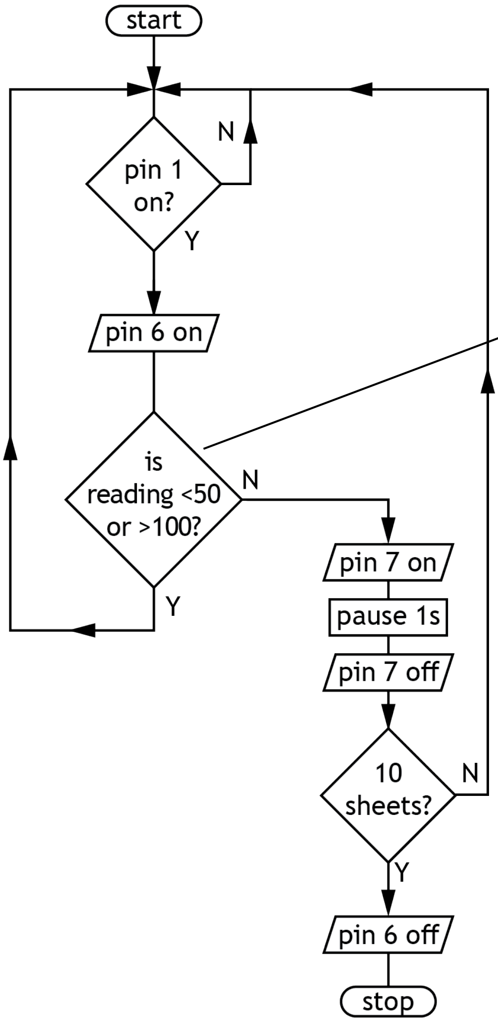
Question			Expected resonse	Max mark	Additional guidance
5.	(a)				
				1	1 mark for correct annotation on graph.
	(b)		$E_s = ½ Fx$ $E_s = 0.5 \times 75x10^3 \times 0.00075$ $E_s = 28.125$ J **E_s = 28 J (2 sf)**	**2**	1 mark for correct substitution. 1 mark for correct answer.
	(c)		The material stretches and then returns to its original length.	**1**	

Question			Expected resonse	Max mark	Additional guidance
5.	(d)		A graph that shows very little extension beyond yield point.	**1**	Further guidance on acceptable responses: Graph may be similar to classic trace for cast iron. Graph may have straight line gradient (gradient and E value not important) with no or little plastic region prior to failure.
			eg: 		

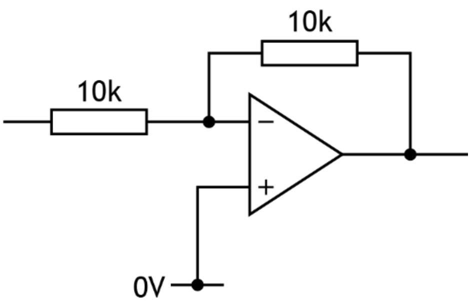
Question			Expected response	Max mark	Additional guidance
6.	(a)		Correction 1 PBASIC: if pin 1 = 0 then main ARDUINO: if digitalRead(pin1)==LOW){ loop();} Correction 2 PBASIC: pause 45 ARDUINO: delay(45);	**2**	1 mark for Correction 1. Also accept: if pin 1 = 1 then pwm (must be followed by ‘goto main’) OR: if digitalRead(pin1)==HIGH){ pwm();} (must be followed by ‘return’) 1 mark for Correction 2. The same correction may not be given for two different codes.
	(b)			**2**	1 mark for marks with same voltage. 1 mark for all three correct mark:space ratio. Response must include minimum of three marks and two spaces to establish correct duty cycle.

Section 2

Question			Expected response	Max mark	Additional guidance
7.	(a)		Fault: Pilot actuator on V_1. Correction: Replace with diaphragm actuator. Fault: No delay between C_A outstroking and C_B & C_C outstroking (V_1 and V_2). Correction: Connect UDR and reservoir in series between V_1 and V_2. Fault: Time delay not connected correctly. Correction: UDR and reservoir to be swapped around.	**6**	1 mark for identifying each fault. 1 mark for each correct solution.
	(b)	(i)	Components are hard wearing/more reliable, so fewer waste products. Components are hard wearing/more reliable, so fewer materials need to be mined for manufacture. The exhaust air causes no pollution. System is more energy efficient when supplied from stored air. Less oil is used, so there is a reduction in environmentally harmful waste products.	**2**	
		(ii)	Using equations to calculate the forces/pressures/areas of cylinders. Using equations to calculate mechanical power. Using equations to calculate reservoir volume/time delay.	**1**	

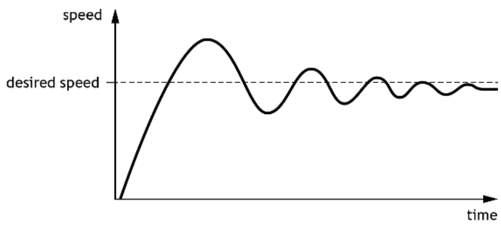
Question			Expected response	Max mark	Additional guidance
7.	(c)		I_{DS} = (6-5.2)/2.9 = 0.275862069 A **V_{GS} = 4.2 V (2 sf)**	**3**	1 mark for calculating voltage across solenoid. 1 mark for calculating I_{DS}. 1 mark for identifying V_{GS}.
	(d)			**5**	Choosing correct conditions for pneumatic action – 1 mark. Loop to start after checking analogue sensor – 1 mark. Pneumatic control (pin 7 on/pause 1s/pin 7 off) – 1 mark. ‘10 sheets?’ decision with correct loop and stop – 1 mark. Pin 6 off and on – 1 mark.

Question			Expected response	Max mark	Additional guidance
8.	(a)		$R_A/R_B = R_1/R_2$ $119/120 = R_1/1000$ $R_1 = (119 \times 1000)/120$ $= 991.6666667\ \Omega$ $=$ **990 Ω (2 sf)**	**2**	1 mark for recognising the relationship between the two input voltages. 1 mark for correct answer with unit.
	(b)		It counteracts the impact of expansion/contraction due to temperature changes in the system. Passive strain gauge B serves to enhance the accuracy and reliability of strain measurements. Strain gauge B acts as a reference for the active strain gauge.	**1**	
	(c)		$5 \times 0.85 = 4.25$ V $I_b = (4.25\text{-}0.7)\ /\ 1200$ $= 0.00295833$ A $I_c = 0.00295833 \times 320$ $= 0.94666667$ A $=$ **0.95 A (2 sf)**	**4**	1 mark for output from op-amp. 1 mark for voltage across resistor. 1 mark for I_b. 1 mark for I_c.
	(d)		**Range = 1.1 V to 3.9 V** Motor will turn when both op-amps are on. V_{in} must be greater than $V_{ref}B$ and less than $V_{ref}A$. $V_{ref}B = 5 \times 1.2/(1.2 + 3.3 + 1.2)$ $= 1.052631579$ V $=$ **1.1 V (2 sf)** $V_{ref}A = 5 \times 4.5/(1.2 + 3.3 + 1.2)$ $= 3.947368421$ V $=$ **3.9 V (2 sf)** Alternative method: $V_{CC}\ /\ R_1 = V_{ref}A\ /\ R_A$ $5\ /\ 5700 = V_{ref}A\ /\ 4500$ $V_{ref}A =$ **3.95 V (2 sf)** $V_{CC}\ /\ R_t = V_{ref}B\ /\ R_B$ $5\ /\ 5700 = V_{ref}B\ /\ 1200$ $V_{ref}B =$ **1.1 V (2 sf)**	**3**	1 mark for identifying the range (units not required, FTE applies). 1 mark for calculating $V_{ref}B$. 1 mark for calculating $V_{ref}A$.

Question			Expected response	Max mark	Additional guidance
8.	(e)		When V_{in} is 0V, op-amp B is off and op-amp A is on, therefore MOSFET B is switched off and MOSFET A is switched on, so the motor is off. When V_{in} is more than V_{ref}B but less than V_{ref}A, both op-amps are on, so both MOSFETs are switched on and the motor is on. When V_{in} is greater than V_{ref}A, op-amp B is on and op-amp A is off, therefore MOSFET B is on and MOSFET A is off, so the motor is off.	**3**	1 mark for: description of op-amp B off, MOSFET B off, motor off, under the correct conditions. 1 mark for: description of all components on, under the correct conditions. 1 mark for: description of op-amp A off, MOSFET A off, motor off, under the correct conditions.
	(f)	(i)	$-2.7 = -R_f \times ((0.012/33000) + (0.017/33000) + (0.026/33000) + (0.024/33000))$ $R_f = 1127848.101\ \Omega$ = **1.1 MΩ (2 sf)**	**2**	1 mark for correct substitution. 1 mark for correct answer from given working.
		(ii)		**2**	1 mark for inverting op-amp with all connections. 1 mark for R_f and R_i being the same value. Units required.

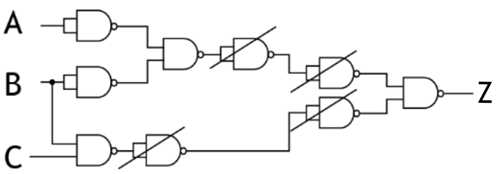
Question			Expected response	Max mark	Additional guidance
9.	(a)		$T = Fr$ $T = 240 \times 0.30$ $T = 72$ Nm $P = VI$ $P = 220 \times 6.6$ $P = 1452$ W $P = 2 \times \pi \times n \times T$ $1452 = 2 \times \pi \times n \times 72$ $n = 1452 / (2 \times \pi \times 72)$ $n = 3.209624686$ revs sec^{-1} **n = 3.2 revs sec^{-1} (2 sf)**	**4**	1 mark for calculating torque. 1 mark for calculating power. 1 mark for substitution. 1 mark for calculating n, unit required.
	(b)		Total working stress on bolt = (UTS/FOS) = (430/3.0) = 143.3333333 Nmm^{-2} Safe working stress on bolt = 143.3333333 – 5.5 = 137.8333333 Nmm^{-2} Cross-sectional area of bolt $A = F/\sigma$ = 5000/137.8333333 = 36.27569529 mm^2 Diameter of bolt $d = \sqrt{(4A/\pi)}$ $d = \sqrt{((4 \times 36.27569529)/\pi)}$ $d = 6.796149628$ mm **d = 6.8 mm (2.sf)**	**4**	1 mark for SWS. 1 mark for subtracting 5.5. 1 mark for area, apply FTE if 143.3333333 used. 1 mark for required diameter, unit required.
	(c)		2500 litres = 2500 kg $E_w = Fd$ $E_w = (2500 \times 9.8) \times 2.9$ $E_w = 71050$ J $E_{ff} = E_{out} / E_{in}$ $E_{in} = 71050 / 0.87$ $E_{in} = 81666.66667$ J $E_e = VIt$ $81666.66667 = 230 \times 5 \times t$ $t = 71.01449275$ s **t = 71 s (2 sf)**	**4**	1 mark for E_w (E_{out}). 1 mark for E_{in} (E_e). 1 mark for substitution. 1 mark for t, unit required.

Question			Expected response	Max mark	Additional guidance
9.	(d)		$A = F / \sigma$ $A = 625 / 3.4$ $A_{effective} = 183.8235294\ mm^2$ $A_{effective} = A_{outer} - A_{inner}$ $183.8235294 = A_{outer} - (\pi \times 37^2 / 4)$ $183.8235294 = A_{outer} - 1075.210086$ $A_{outer} = 183.8235294 + 1075.210086$ $A_{outer} = 1259.033615\ mm^2$ $A = \pi \times d^2 / 4$ $d = \sqrt{(1259.033615 \times 4 / \pi)}$ $d = 40.03812417\ mm$ thickness = (40.03812417 – 37) / 2 thickness = 1.519062084 mm **thickness = 1.5mm (2 sf)**	**5**	 1 mark for effective area. 1 mark for A_{inner}. 1 mark for outer area. 1 mark for outer diameter. 1 mark for thickness, unit required.

Question			Expected response	Max mark	Additional guidance
10.	(a)	(i)	Thermistor resistance = 2.0 kΩ I_{therm} = (5-0.70)/2000 =0.00215 A =0.0022 A (2 sf) **= 2.2 mA (2 sf)**	**3**	1 mark for correct reading of resistance from graph. 1 mark for voltage over thermistor. 1 mark for calculating I_{therm}.
		(ii)	I_r = 0.70/680 = 0.001029412 A I_b = I_{therm} - I_r = 0.0022 - 0.001029412 = 0.001170588 **= 1.2 mA (2 sf)**	**2**	1 mark for calculating I_r. 1 mark for calculating I_b. (FTE applies – 1.1 mA if 2.15 mA given from 10(a)(i)).
	(b)		The power/motor would either be on or off **meaning** there would not be a smooth motion. **OR** The power/motor would either be on or off **meaning** there would be a significant overshoot that would cause over tightening.	**2**	1 mark for cause (motor on or off/ too fast or too slow). 1 mark for effect (smooth motion/ overshoot/not steady speed).
	(c)		8.0 = (48/12) × (3.2 - $V_{feedback}$) **$V_{feedback}$ = 1.2 V (2 sf)**	**2**	1 mark for substitution. 1 mark for feedback voltage.
	(d)		• Initial response would be quicker/steeper. • The error reduces over time. • Eventually, it would settle.  	**3**	1 for each correct comment or illustration. 3 marks awarded for correctly drawn graph to illustrate each bullet point.

Question			Expected response	Max mark	Additional guidance
10.	(e)		$\sum F_v = 0$ 753sin64 + 877sin59 = Fv +940sin47 676.7919169 + 751.7357227 = F_v + 687.4724795 F_v = 741.0551601 N $\sum F_H = 0$ 877cos59 + 940cos47 = F_H + 753cos64 451.6883917 + 641.0784585 = F_H + 330.0934735 F_H = 762.6733766 N F = √ (741.0551601^2 + 762.6733766^2) F = 1063.406521 N **F = 1100 N (2 sf)** θ = tan^{-1} (741.0551601/762.6733766) θ = 44.17634918 ° **θ = 44° (2 sf)**	**6**	1 mark for substitution. 1 mark for calculating F_v. 1 mark for substitution. 1 mark for calculating F_H. 1 mark for calculating F, unit required. 1 mark for calculating θ, unit required.

Question			Expected response	Max mark	Additional guidance
11.	(a)		| Member | AB | AE | BE | BC | | Force | 54kN | 27kN | 2.3kN | 28kN | | Nature | strut | tie | tie | strut |		
			Node A sin60 = 47/AB AB = 54.27092530 kN **AB = 54kN (2 sf)** cos60 = AE/54 **AE = 27 kN (2 sf)** Node B $\Sigma F_v = 0$ $F_{vAB} = 45 + F_{vBE}$ 47 = 45 + BEsin60 BE = 2.309401077 kN **BE = 2.3 kN (2 sf)** (tie) $\Sigma F_H = 0$ $BC = F_{HAB} + F_{HBE}$ BC = 54cos60 + 2.3cos60 BC = 28.15 kN **BC = 28kN (2 sf)** (strut)	6	1 mark for calculating AB. 1 mark for calculating AE. 1 mark for calculating BE (accept use of F_{vAB} = 54sin60). 1 mark for the nature of BE. 1 mark for calculating BC. 1 mark for the nature of BC.

<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>(b)</td><td>(i)</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>1</td></tr><tr><td>0</td><td>0</td><td>1</td><td>1</td><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>0</td><td>1</td><td>1</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td><td>1</td><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>0</td><td>1</td><td>1</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td><td>1</td><td>0</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>0</td><td>0</td><td>1</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>1</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 (FTE available).
1 mark for column Z (FTE available).</td></tr>
<tr><td></td><td></td><td>(ii)</td><td>$Z = \overline{(A+B)} + (B \cdot C)$</td><td>3</td><td>1 mark for NOT A+B (with brackets).
1 mark for OR.
1 mark for B·C.</td></tr>
<tr><td></td><td></td><td>(iii)</td><td></td><td>4</td><td>1 mark for NOR NAND with connections.

1 mark for AND NAND with connections.

1 mark for OR NAND with connections.

1 mark for simplification.</td></tr>
<tr><td></td><td>(c)</td><td></td><td>Use knowledge of logic gates and their operation to design circuits.

Use knowledge of Boolean algebra to simplify logic circuit design.

Use knowledge of truth tables to test logic circuit designs.

Use knowledge of NAND conversion to simplify circuit construction.

Use knowledge of digital sensing control circuits to design voltage divider circuits.

Use knowledge of op amp configurations and their operations to design circuits.

Use knowledge of control systems using microcontrollers.

Use knowledge of programming language.

Use knowledge of interfacing with output circuits.</td><td>2</td><td>Responses must be descriptive.

1 mark for each valid response.</td></tr>
</table>

Question			Expected response	Max mark	Additional guidance
11.	(d)		Improved physical health through promotion of walking/running/ cycling as mode of transport. Improved social relationships as improved infrastructure means it is easier to meet up with and visit friends/family. Improved mental health as opportunities to go out and socialise are increased. Improved physical health as less pollution in the city. Any other reasonable response.	**2**	Responses must be descriptive. 1 mark for each valid response.

[END OF MARKING INSTRUCTIONS]