National Qualifications 2023

2023 Engineering Science

Advanced Higher

Finalised Marking Instructions

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General marking principles for Advanced 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 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.

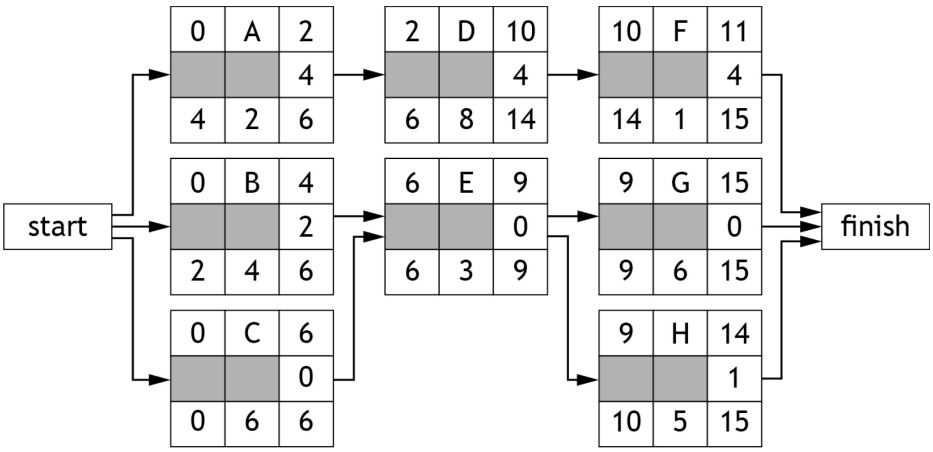
(i) Candidates can answer programming questions in any appropriate programming language. Award marks where the intention of the coding is clear, even where there are minor syntax errors.

(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.	(a)			**3**	**1 mark** Complete the earliest start and finish times for E, G and H. **1 mark** Complete the latest start and finish times for all stages A – H. **1 mark** Complete the float for all stages A – H.
					
	(b)		Critical Path is C, E, G.	**1**	
	(c)		Planning.	**1**	
	(d)		The project manager would hold review meetings to determine lessons to be learned from the project: any delays in the project would be analysed for cause and mitigation, so that similar delays could be avoided in future projects. The project manager would liaise with all project stakeholders and hand on all completion documentation to relevant parties, so that they can see that all work requiring certification has been fully certified. The project manager would ensure all stakeholders are satisfied that contractual obligations have been met, to avoid legal disputes arising after completion.	**2**	**1 mark** Activity that the project manager is likely to undertake. **1 mark** Explanation for the activity identified. Note: three possible responses are given but other responses may be valid.

Question			Expected response	Max mark	Additional guidance
2.	(a)		A step-up transformer is used to increase the voltage at which electrical power is transmitted on the grid. In doing so, this reduces the current required to transmit the electrical power from one point to the other. Reducing the current reduces the resistive power loss (I^2R) along the length of the transmission cable.	**2**	**1 mark** Describe the effect of using a step-up transformer on transmission voltage and current. **1 mark** Explain the efficiency benefit of reducing the transmission current.
	(b)		Base load is a power level that is required on the national grid continuously over the 24-hour cycle. This level does not vary greatly. A nuclear power station generates a large amount of power (typically 1.2 GW peak capacity) but the power station has a long start-up time, so cannot be switched on quickly to meet the demands of peak load, which is the maximum demand placed on the grid by consumers during the 24-hour cycle and is normally transient (short-lived, but significantly more than the normal base load).	**2**	**1 mark** Identify a method of generation by its large power generating capacity and long start-up time (tends to be heat cycles). **1 mark** Explain base load is continuous while peak load is transient, so the base load suits the long start-up time of the generating method.
	(c)		A- Full-wave Rectifier to convert variable frequency AC to DC. B- Inverter to convert DC to AC at controlled frequency.	**2**	**1 mark** Correct term for AC-DC converter (variable frequency not required). **1 mark** Correct term for DC-AC converter with controlled frequency. **1 mark (total)** A - converts AC to DC. B - converts DC to fixed-frequency AC. **1 mark (total)** A – rectifier. B – inverter.

Question			Expected response	Max mark	Additional guidance
3.	(a)		$R_c = \frac{12 - 7 \cdot 2}{2.4 \times 10^{-3}} = 2000$ **Use a 2.0 kΩ resistor.** $R_e = \frac{1.25}{2.4 \times 10^{-3} \times (1 + \frac{1}{210})} = 518.3...$ **Use a 510 Ω resistor.**	**2**	**1 mark** Value for R_C. **1 mark** Value for R_E. Bracket including consideration of DC voltage gain not required on denominator for second mark- the approximation $I_E=I_C$ does not affect resistor selection.
	(b)		$\frac{12 - V_B}{82 \times 10^3} - \frac{V_B}{16 \times 10^3} - 11.1 \times 10^{-6} = 0$ $V_B = 1.81057...$ **V_B = 1.8 V (2 sf)** **OR** $I_C = h_{FE(\min)} \times I_B$ $I_E = \left(1 + h_{FE(\min)}\right) \times I_B$ $I_E = (1 + 210) \times 11.1 \times 10^{-6}$ $I_E = 2.3421 \times 10^{-3}$ $V_B = V_E + V_{BE}$ $V_B = I_E \times R_E + V_{BE}$ $V_B = 2.3421 \times 10^{-3} \times 510 + 0.62$ **V_B = 1.8 V (2 sf)**	**2**	**1 mark** Correct use of Kirchhoff's current law at node between resistors. It should be clear that the candidate attempts to calculate the current through the upper resistor and lower resistor and that there is a recognition that the net current flow at the node is zero. **1 mark** Answer and unit. **OR** **1 mark (total because nodal analysis requirement ignored)** Calculate V_E via I_E. Approximation $I_E=I_C$ may be made in second line without affecting answer. Add the specified value of V_{BE}. **Do not award marks for a voltage divider calculation involving R_1 and R_2. (1.96 V).**
	(c)		$P = \left(V_c - V_e\right) \times I_c$ $= \left(7.2 - 1.25\right) \times 2.4 \times 10^{-3}$ $= 14.28 \times 10^{-3}$ **= 14 mW (2 sf)**	**1**	**1 mark** Answer and unit.

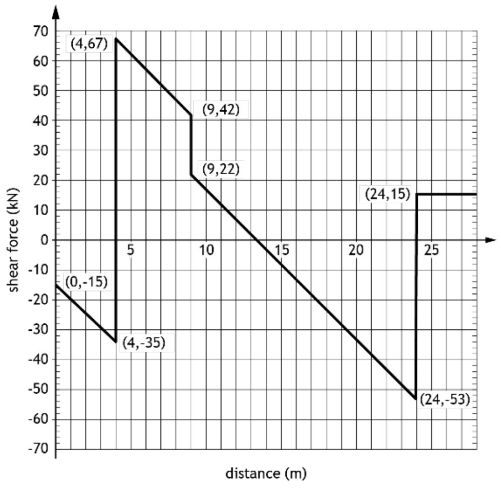
Question			Expected response	Max mark	Additional guidance
4.	(a)		$V_{out} = -\frac{1}{RC}\int V_{in}dt$ $V_{out} = -\frac{3.3 \times t}{15 \times 10^3 \times 2.2 \times 10^{-6}} + k$ When $t = 0,\ V_{out} = 9,$ so $k = 9$ $V_{out} = 9 - 100t$	**2**	**1 mark** $9\ldots$ **1 mark** $\ldots -100t$
	(b)		$V_{out} = 9 - 100t$ $-9 = 9 - 100t$ $t = \frac{18}{100}$ **t = 180 ms (2 sf)** **OR** $\Delta V_{out} = -100t$ $-18 = -100t$ $t = \frac{18}{100}$ **t = 180 ms (2 sf)**	**2**	**1 mark** $18 = 100t$ **1 mark** $t = 180$ ms (2 sf) **OR** **1 mark** $-18 = -100t$ **1 mark** $t = 180$ ms (2 sf) **1 mark(total)** $18 = -100t$ $t = 0.18s$
	(c)		The rate at which the voltage varies is reduced. Increasing the capacitor value by a factor of 10 reduces the rate at which the output voltage varies by a factor of 10. The amplitude of the triangular wave would reduce.	**1**	The first statement is sufficient. The final statement is sufficient.

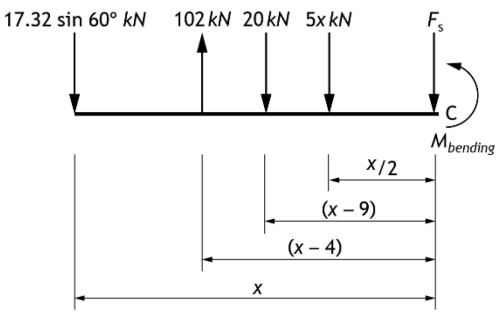
Question			Expected response	Max mark	Additional guidance
5.			$\eta_{PV+element} = \eta_{PV} \times \eta_{element}$ $= 0.22 \times 0.98$ $= 0.2156$ **$= 0.22$ (2 *sf*)** $\eta_{\text{flat plate collector}} = \frac{\dot{m} \times c_p \times \Delta T}{\text{power supplied by radiation + system power losses}}$ $= \frac{0.025 \times 3730 \times 4}{1100 \times 0.505 + 25}$ **$= 0.64$ (2 *sf*)** Under these conditions the flat-plate collector is more efficient at converting solar energy to warm water.	**4**	**1 mark** Efficiency of heating the water by PV + heating element (0.22). **1 mark** Rate of energy transfer to water ($mc_p\Delta T$)(373J). **1 mark** Efficiency of heating water by water and antifreeze combination (0.64). **1 mark** Choice between the two options based on a **calculated** value for both.

Question			Expected response	Max mark	Additional guidance
6.	(a)		Depth of hole, d = 40 x 2 = 80 mm	**1**	
	(b)		From table, 2nd moment of area for I-beam with depth 200 mm: 15980000 mm^4 From table, thickness of web: 5 mm 2nd moment of area for subtracted rectangular section: $I = \frac{BD^3}{12} = \frac{5 \times 80^3}{12}$ $I = 15980000 - \frac{5 \times 80^3}{12}$ $I = 15.77 \times 10^6$ mm^4 **$I = 20 \times 10^6$ mm^4 (1 sf)**	**3**	**1 mark** Correct value for the second moment of area of the beam with depth of 200mm where no hole exists at the centreline. **1 mark** Calculation of the 2nd moment of area of the material missing from the centre of the I-beam. **1 mark** Calculation of the 2nd moment of area of the cross-section as a difference, giving final answer and units. Follow-through error possible from part (a) and from first mark for second and third marks.

Question			Expected response	Max mark	Additional guidance
7.	(a)		$\sigma_{max} = \frac{7.2}{3} = 2.4 \text{ Nmm}^{-2}$ $y_{max} = \frac{54}{2} = 27 \text{ mm}$ $M_{max} = \frac{\sigma_{max} \times I}{y}$ $= \frac{2.4 \times 101 \times 10^3}{27}$ $= 8.9\dot{7} \times 10^3$ $\mathbf{= 9.0 \times 10^3 \text{ Nmm (2 sf)}}$	**2**	**1 mark** Correct values for maximum working stress and maximum distance from neutral axis of cross section. **1 mark** Final answer and unit. Note: 9×10^3 Nmm $= 9$ Nm
	(b)		Simply supported, with UDL $M = \frac{\omega L^2}{8}$ $L = \sqrt{\frac{8 \times M}{\omega}}$ $= \sqrt{\frac{8 \times 8.5 \times 10^3}{(6.5 + 19.6) \times 10^{-3}}}$ $= 1614.1...$ $\mathbf{L = 1.6 \text{ m (2 sf)}}$	**2**	**1 mark** Correct formulae and substitutions. **1 mark** Final answer and unit. Note: accept L=1.7 m Note: if UDL is substituted as 26.1 candidate gains first mark but not second mark. If an incorrect formula is selected for the supports stated, then second mark may be awarded if all values are substituted correctly, and the answer is subsequently correct. Note: 1.6m = 1600mm

Section 2

Question			Expected response	Max mark	Additional guidance
8.	(a)		$\sum M_A = 0$ $-(17.32\sin 60^\circ \times 4) + (20 \times 5)$ $+\left(5 \times 24 \times \left(\frac{24}{2} - 4\right)\right)$ $-R_B \times 20 + 17.32\sin 60^\circ \times 24 = 0$ $20R_B = -60 + 100 + 960 + 360$ $R_B = 68\ kN$ $\sum F_y = 0$ $-17.32\sin 60^\circ + R_A - 20 - 5 \times 24$ $+R_B - 17.32\sin 60^\circ = 0$ $R_A = 102\ kN$  	**4**	**1 mark** Calculate reactions R_A and R_B. Diagram features: **1 mark** Point loads at x=0,9,28 m. (The two reactions are also point loads arising at x=4 and 24m; they do not need to appear correctly for this mark) **1 mark** Unchanging shear force for 24<x<28 m. **1 mark** UDL correct slope for range 0<x<24 m.

Question			Expected response	Max mark	Additional guidance
8.	(b)		 $\sum M_C = 0$ $-(17.32\sin 60^\circ \times x) - 5x\left(\frac{x}{2}\right) - \left(20 \times (x-9)\right)$ $+R_A \times (x-4) - M_{bending} = 0$ $M_{bending} = -15x - 2.5x^2 - 20x + 180 + 102x - 40$ $M_{bending} = -2.5x^2 + 67x - 228$	**2**	**1 mark** Accounts for point loads correctly. **1 mark** Accounts for UDL correctly. First equation of equilibrium including the internal bending moment would be awarded both marks.
	(c)		$\frac{dM_{bending}}{dx} = -5x + 67$ When bending moment is a maximum $\frac{dM_{bending}}{dx} = 0$ $-5x + 67 = 0$ $x = 13.4\ m$ Maximum bending moment is given by: $M_{bending} = -2.5(13.4)^2 + 67(13.4) - 228$ $\boldsymbol{M_{bending} = 221\ kNm\ (3\ sf)}$	**3**	**1 mark** Determines equation for shear force in the region.F (Follow through available if equation for bending moment from part (b) is not correct.) **1 mark** Equates equation for shear force to zero and determines point at which maximum bending moment arises. (Award this mark if the value calculated is correct for the bending moment equation used, and it lies in the range 9<x<24) **1 mark** Calculates the maximum bending moment.

<table>
<tr><th colspan="3">Question</th><th>Expected response</th><th>Max mark</th><th>Additional guidance</th></tr>
<tr><td>8.</td><td>(d)</td><td></td><td>The shear force diagram indicates that shear force would be zero at these points as well as at x=13.4 m. This means that there are local maximum values of bending moment at these points.

It turns out that both values are less in magnitude than that calculated at x=13.4 m, but they should be checked in case the magnitude of either bending moment is larger. The greatest magnitude will lead to the greatest bending stress and the greatest likelihood of failure in a uniform cross-section beam.</td><td>2</td><td>1 mark
Identify that the three points are all indicated as points at which the shear force function becomes zero and that the bending moment magnitude reaches a localised maximum value.

1 mark
The three points should be checked to find an overall maximum bending moment. This is most likely to lead to failure of the beam under load.</td></tr>
<tr><td></td><td>(e)</td><td></td><td><table><tr><th>Strain Gauge</th><th>Location</th><th>Alternative</th><th>LOAD</th></tr><tr><td>R_{G1}</td><td>A</td><td>C</td><td>Compression</td></tr><tr><td>R_{G2}</td><td>B</td><td>D</td><td>Tension</td></tr><tr><td>R_{G3}</td><td>D</td><td>B</td><td>Tension</td></tr><tr><td>R_{G4}</td><td>C</td><td>A</td><td>Compression</td></tr></table></td><td>2</td><td>1 mark
R_{G1} on the upper half of the beam and R_{G2} on the lower.

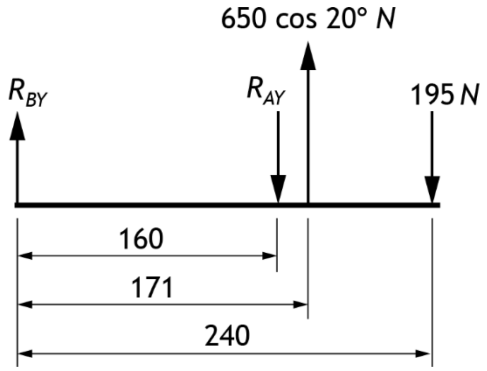
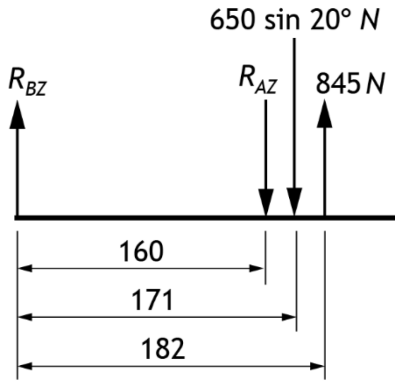
1 mark
R_{G4} on the upper half of the beam and R_{G3} on the lower.</td></tr>
</table>

Question			Expected response	Max mark	Additional guidance
8.	(f)		$V_2 = \frac{R_{G2}}{R_{G2}+R_{G1}} \times 12$ $= \frac{120+0.024}{(120+0.024)+(120-0.024)} \times 12$ $= 6.0012$ $V_1 = \frac{R_{G4}}{R_{G4}+R_{G3}} \times 12$ $= \frac{120-0.024}{(120-0.024)+(120+0.024)} \times 12$ $= 5.9988$ $V_2 - V_1 = \frac{120+0.024-(120-0.024)}{(120+0.024)+(120-0.024)} \times 12$ $V_2 - V_1 = \frac{0.048}{240} \times 12$ $V_2 - V_1 = 2.4 \times 10^{-3}\ V$ $\boldsymbol{V_2 - V_1 = 2.4\ mV\ (2\ sf)}$	**2**	**1 mark** Establish expressions to calculate the value of each voltage V_2 and V_1. **1 mark** Final answer and unit.
	(g)		$A_V = \left(1+\frac{2R_1}{R_2}\right)\frac{R_4}{R_3}$ $R_2 \to \infty$ $A_V = (1+0)\frac{R_4}{R_3} = \frac{R_4}{R_3}$ $\frac{R_4}{R_3} = 1$ $999 = \left(1+\frac{2R_1}{R_2}\right)\frac{R_4}{R_3}$ $999 = \left(1+\frac{2R_1}{R_2}\right)$ $R_2 = \frac{2R_1}{998}$ $R_2 = \frac{2 \times 25.2 \times 10^3}{998}$ $\boldsymbol{R_2 = 50.5\ \Omega\ (3\ sf)}$	**2**	**1 mark** Establish that R_3 and R_4 have the same resistance. **1 mark** Calculate the required value for R_2.

Question			Expected response	Max mark	Additional guidance
8.	(h)	(i)	$resolution = \frac{2.5\ V}{2^8 - 1} = \mathbf{9.8\ mV (2\ sf)}$	**1**	
		(ii)	$\frac{2.4}{2.5} = \frac{x}{2^8 - 1}$ $x = 244.8$ $x = \%11110100$ $x = \%11110101$	**2**	

Question			Expected response	Max mark	Additional guidance
9.	(a)		$P = 2\pi \times \frac{n}{60} \times T$ $= 2\pi \times \frac{42}{60} \times F_t \times \frac{PCD_{54tooth}}{2}$ $F_t = \frac{P}{2\pi \times \frac{42}{60} \times \frac{PCD_{54tooth}}{2}}$ $F_t = \frac{235}{2\pi \times \frac{42}{60} \times \frac{0.135}{2}}$ **= 790 *N* (2 sf)** $F_r = F_t \times \tan 20^\circ$ **= 290 *N* (2 sf)** **OR** $P = 2\pi \times \frac{n}{60} \times T$ $T = \frac{P}{2\pi \times \frac{42}{60}}$ $T = 53.43....$ $T = F_t \times \frac{PCD_{54tooth}}{2}$ $53.43... = F_t \times \frac{0.135}{2}$ **= 790 *N* (2 sf)** $F_r = F_t \times \tan 20^\circ$ **= 290 *N* (2 sf)**	**3**	**1 mark** Re-arrangement of formula and correct substitutions for running speed and radius of tangential force. **1 mark** Final answer and unit for tangential force at mesh. **1 mark** Final answer and unit for radial force at mesh. **OR** **1 mark** Calculate torque on gear **1 mark** Final answer and unit for tangential force at mesh. **1 mark** Final answer and unit for radial force at mesh.

Question			Expected response	Max mark	Additional guidance
9.	(b)		$T_{chain} = \left(T_m + T_p\right)$ $= \frac{P_m}{2\pi \times \frac{42}{60}} + F_p \times r_p \times \cos 45^\circ$ $= \frac{235}{2\pi \times \frac{42}{60}} + 225 \times 0.18 \times \cos 45^\circ$ $= 82.0684 \ldots$ $T_{chain} = F_{chain} \times r_c$ $F_{chain} = \frac{T_{chain}}{r_c}$ $= \frac{82.0684 \ldots}{0.078}$ $= 1052.159 \ldots$ **= 1.1 kN (2 sf)**	**3**	**1 mark** Torque balance between drivers and driven identified correctly. Torque produced by tensile force in chain balances the torque produced by the foot pedal and the torque produced by the motor. **1 mark** Torque produced by the pedal is calculated as: $T_p = F_p \times r_p \times \cos 45^\circ$ $T_p = 225 \times 0.18 \times \cos 45^\circ$ **1 mark** Final answer and unit. Note: in the second line: $\frac{P_m}{2\pi \times \frac{42}{60}} = F_t \times \frac{PCD_{54tooth}}{2}$

Question			Expected response	Max mark	Additional guidance
9.	(c)		 $\sum M_B = 0$ $(R_{AY} \times 160)$ $-(650\cos 20^\circ \times 171) + (195 \times 240) = 0$ $R_{AY} = 360.29\ldots$	**4**	**1 mark** Moment equilibrium in XY plane.
			 $\sum M_B = 0$ $(R_{AZ} \times 160)$ $+(650\sin 20^\circ \times 171) - (845 \times 182) = 0$ $R_{AY} = 723.59\ldots$		**1 mark** Moment equilibrium in XZ plane. **1 mark** Correct magnitudes of horizontal and vertical components of reaction at bearing A.
			$\|R_A\| = \sqrt{R_{AY}{}^2 + R_{AZ}{}^2}$ $= \sqrt{360.29\ldots{}^2 + 723.59\ldots{}^2}$ $= 808.3\ldots$ $\|R_A\| = \mathbf{810\ N\ (2\ sf)}$		**1 mark** Magnitude of reaction at bearing A.

Question			Expected response	Max mark	Additional guidance
9.	(d)		$F = \frac{\delta d^4 G}{8D^3 N}$ $d = \frac{63.5 - 47.5}{2} = 8.0$ $D = \frac{63.5 + 47.5}{2} = 55.5$ $F = \frac{18 \times 8.0^4 \times 77.2 \times 10^3}{8 \times 55.5^3 \times 4}$ $= 1040.4\ldots$ **$F = 1.0$ kN (2 sf)**	**3**	**1 mark** Calculation of coil cross-section diameter, d. Calculation of mean coil diameter, D. **1 mark** Change subject of formula and substitute all parameter values with consistent units (77.2 GNm^{-2}=77.2 $kNmm^{-2}$). **1 mark** Final answer and unit.

Question			Expected response	Max mark	Additional guidance
9.	(e)	(i)	**ARDUINO** At 1 rev s^{-1}, the time for ½ a rev would be 0.5 s which is 500000 µs. Dividing this value by the measured duration of time returned by the function **pulseIn** for ½ rev, measured in µs, will give the running speed of the motor in revs s^{-1}. Speed range of motor is 60-540 rev min^{-1}, which is 1 rev s^{-1} to 9 rev s^{-1}. At 1 rev s^{-1} 'length' would be 500000, so 'speed' would be 500000/500000 = 1. At 9 rev s^{-1} 'length' would be 55555, so speed would be 500000/55555 = 9.	**5**	**1 mark** Relate the ½ rev for a pulse to its duration at 1 rev s^{-1} in microseconds (or 10 microsecond intervals for PBASIC). **1 mark** Note that the division then renders the number of revs per second that the motor is making. **1 mark** Establish the maximum and minimum running speeds of the motor. **1 mark** Establish values for the two variables at minimum speed. **1 mark** Establish values for the two variables at maximum speed.
			PBASIC At 1 rev s^{-1}, the time for ½ a rev would be 0.5 s which is 50000 10µs intervals. Dividing this value by the measured duration of time returned by the function **pulsin** for ½ rev, measured in 10µs intervals, will give the running speed of the motor in revs s^{-1}. Speed range of motor is 60-540 rev min^{-1}, which is 1 rev s^{-1} to 9 rev s^{-1}. At 1 rev s^{-1} 'length' would be 50000, so 'speed' would be 1. At 9 rev s^{-1} 'length' would be 5555, so speed would be 9.		**Note** For final mark, 'length' must be an integer and 'speed' must be an integer.

Question			Expected response	Max mark	Additional guidance
9.	(e)	(ii)	**ARDUINO** If speed decreases the duration of the pulse increases so 'length' becomes greater than 'interval'. 'speed' is an integer, so if the calculation produces a fraction, its value will become the integer part of the result, 0 (zero). **PBASIC** If speed decreases, the duration of the pulse increases, so 'length' becomes greater than 'interval'. The microcontroller only performs integer arithmetic. A division of a number by a larger number is fractional, so the result of the division is zero, the integer part of the result.	**2**	**1 mark** Recognise that the value of 'length' will increase to become greater than 'interval' to produce a fractional result in the division. **1 mark** Only the integer part of the result will be assigned to 'speed', which is zero.

[END OF MARKING INSTRUCTIONS]