National
Qualifications
2018

2018 Engineering Science

Advanced Higher

Finalised Marking Instructions

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General marking principles for Advanced Higher Engineering Science

This information is provided to help you understand the general principles you must apply when marking candidate responses to questions in this paper. These principles must be read in conjunction with the detailed marking instructions, which identify the key features required in candidate responses.

(a) Marks for each candidate response must **always** be assigned in line with these general marking principles and the detailed marking instructions for this assessment.

(b) Marking should always be positive. This means that, for each candidate response, marks are accumulated for the demonstration of relevant skills, knowledge and understanding: they are not deducted from a maximum on the basis of errors or omissions.

(c) 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.

(d) Where a candidate makes an error at an early stage in a multi-stage calculation, credit should normally be given for correct follow-on working in subsequent stages, unless the error significantly reduces the complexity of the remaining stages. The same principle should be applied in questions which require several stages of non-mathematical reasoning.

(e) All units of measurement will be presented in a consistent way, using negative indices where required (eg ms^{-1}). Candidates may respond using this format, or solidus format (m/s), or words (metres per second), or any combination of these (eg metres/second).

(f) Answers to numerical questions should normally be rounded to an appropriate number of significant figures. However, the mark can be awarded for answers which have up to two figures more or one figure less than the expected answer.

(g) Unless a numerical question specifically requires evidence of working to be shown, full marks should be awarded for a correct final answer (including unit) on its own.

(h) A mark can be awarded when a candidate writes down the relevant formula **and** substitutes correct values into the formula. No mark should be awarded for simply writing down a formula, without any values.

(i) Credit should be given where a labelled diagram or sketch conveys clearly and correctly the response required by the question.

(j) Marks should be awarded regardless of spelling as long as the meaning is unambiguous.

(k) Candidates may answer programming questions in any appropriate programming language. Marks should be awarded, regardless of minor syntax errors, as long as the intention of the coding is clear.

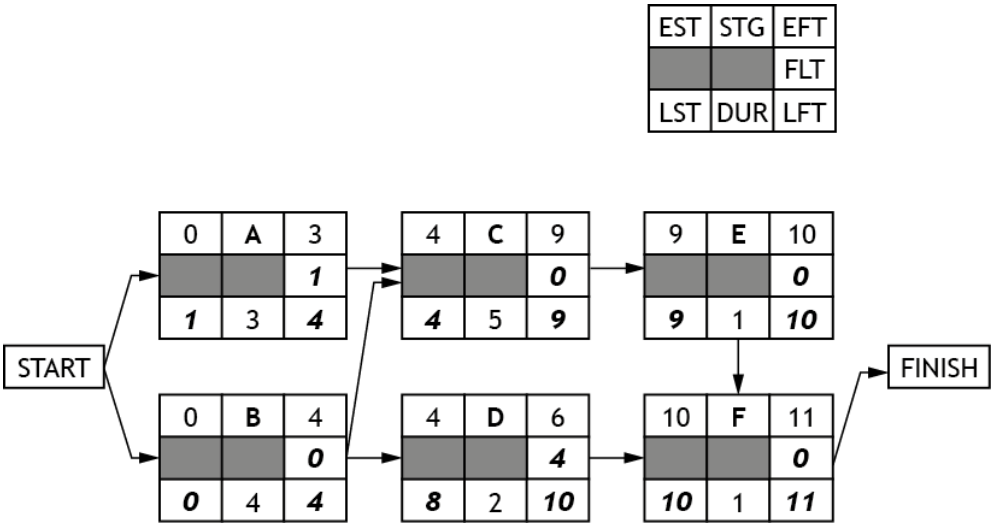
(l) Where a question asks the candidate to "explain", marks should only be awarded where the candidate goes beyond a description, for example by giving a reason, or relating cause to effect, or providing a relationship between two aspects.

(m) Where separate space is provided for rough working and a final answer, marks should normally only be awarded for the final answer, and all rough working ignored.

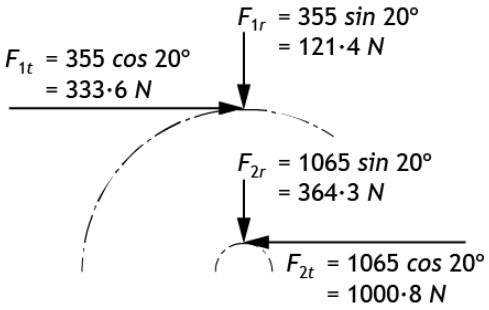
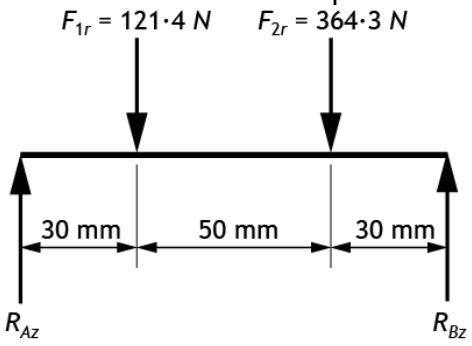
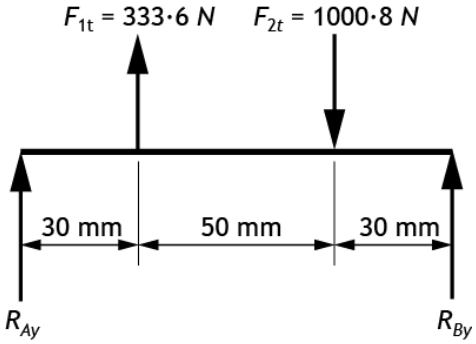
(n) The number of significant figures expressed in a final answer should be equivalent to the least significant data value given in the question. Answers that have two more or one less figure than this will be accepted.

Detailed marking instructions for each question

Section 1

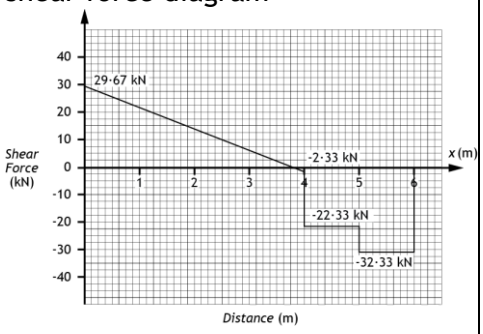
Question			Expected answer(s)	Max mark	Additional guidance
1.	(a)				
			Critical path: B,C,E,F	**3**	1 mark: Latest start time and latest finish times completed correctly 1 mark: Floats completed correctly 1 mark: Critical Path identified correctly
	(b)		Management of human resources (or material resources) required for stages on the critical path must be close and careful to ensure delays do not arise Any materials (or equipment or contracted labour) supplied on the critical path could have fixed-penalties for delays written into the delivery contract Human resources could be switched from stage A if stage B begins to lag and the skills base existed in the workforce Human resources could be switched from D to C or E or both if either begins to lag and the skills base existed in the workforce	**2**	1 mark: Recognise that resources must be most closely managed on the critical path 1 mark: Suggest a management technique that might be used to control the critical path

Question			Expected answer(s)	Max mark	Additional guidance
2.	(a)		Minimum frequency $f_{min} = \frac{1}{2\pi(560 \times 6.8 \times 10^{-6}) \times 1.05^2}$ $= 38\ Hz$ Maximum frequency $f_{max} = \frac{1}{2\pi(560 \times 6.8 \times 10^{-6}) \times 0.95^2}$ $= 46\ Hz$ The range of frequencies is 38 Hz to 46 Hz	**2**	1 mark: calculating lower limit of frequency correctly 1 mark: calculating the upper limit of frequency **OR** 1 mark: Calculating the frequency of the exact values $f = \frac{1}{2\pi(560 \times 6.8 \times 10^{-6})} = 42\ Hz$
	(b)		R_1 is too large causing a gain of < 3 meaning that the oscillation cannot be sustained. R_1 should be 1 kΩ in order to maintain a stable amplitude for the sine-wave with the gain = 3 $Gain = 1 + \frac{2k}{1k}$	**2**	1 mark: Cause: gain is < 3 due to R_1 too large, effect: oscillation decreases continuously 1 mark: Providing suitable value for R_1 to produce a gain of 3

Question			Expected answer(s)	Max mark	Additional guidance
3.			 'vertical forces' on x – z plane  Take moments about B (right-hand end of shaft) $\sum M_B = 0$ $\boldsymbol{R_{Az} \times 110 - 121 \cdot 4 \times 80 - 364 \cdot 3 \times 30 = 0}$ $\boldsymbol{R_{Az} = 187 \cdot 6\ N}$ 'horizontal forces' on x – y plane  Take moments about B (right-hand end of shaft) $\sum M_B = 0$ $\boldsymbol{R_{Ay} \times 0 \cdot 11 + 333 \cdot 6 \times 0 \cdot 08 - 1000 \cdot 8 \times 0 \cdot 03 = 0}$ $\boldsymbol{R_{Ay} = 30 \cdot 3\ N}$ Calculate the magnitude of the reaction at bearing A $\boldsymbol{\lvert R_A \rvert = \sqrt{187 \cdot 6^2 + 30 \cdot 3^2}}$ $\lvert \boldsymbol{R_A} \rvert = 190\ N\ (3sf)$	**4**	1 mark: Resolve applied forces into components 1 mark: Calculate component of bearing reaction in a plane 1 mark: Calculate a second perpendicular component of bearing reaction in a perpendicular plane 1 mark: Answer and unit

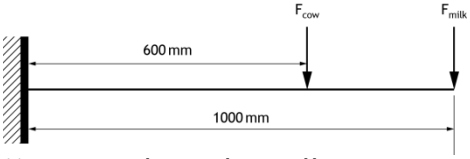
Question			Expected answer(s)	Max mark	Additional guidance
4.	(a)		$R_c = \frac{7.5}{1 \times 10^{-3}} = 7.5\ k\Omega$ $R_e = \frac{1}{1.01 \times 1 \times 10^{-3}} = 990\Omega$ accept $R_e = \frac{1}{1 \times 10^{-3}} = 1\ k\Omega$	**2**	**1 mark:** calculate R_c correctly **1 mark:** calculate R_e correctly Emitter current is the sum of base and collector currents, but the high transistor gain means that the emitter current is only 1% greater than the collector current, so using the collector current value for the second calculation gives a very small error
	(b)		$V_b = 1 + 0.6 = 1.6V$ $I_b = \frac{1 \times 10^{-3}}{100} = 10\mu A$	**1**	**1 mark:** calculate V_b and I_b
	(c)		$I_{R2} = 100\mu A$ $R_2 = \frac{1.6}{100 \times 10^{-6}} = 16\ k\Omega$ $I_{R1} = 100\mu A + 10\mu A$ $R_1 = \frac{13.4}{110 \times 10^{-6}} = 122\ k\Omega$	**2**	**1 mark:** calculate R_2 correctly **1 mark:** calculate R_1 correctly

Question			Expected answer(s)	Max mark	Additional guidance
5.	(a)		$Energy\ transfer\ efficiency\ through\ pipework\ is\ (100-0.60)\%\ and\ (100-0.8)\%$ $99.4\%\ and\ 99.2\%$ $Efficiency = 0.870 \times 0.994 \times 0.992 \times 0.903 = 0.775$ 77·5% of the electricity used to pump water is returned to the grid as electricity.	**2**	1 mark: Find an energy efficiency for the water flow to and from the upper reservoir 1 mark: Calculate the overall system efficiency
	(b)		Base load is the amount of electricity required to meet minimum demand on the grid at any point in the 24 hour cycle, while peak demand is the maximum demand for electricity in any 24 hour cycle Generally, large power generators, such as nuclear reactors cannot vary their output rapidly (they will start up and shut down over many hours), but supply large amounts of power continuously to meet base load Pump storage can only run for a limited time, but can turn on to generate electricity rapidly, so can be used to supply during peak periods of demand, which will only be for a small number of hours each day	**3**	1 mark: Define base load and peak load correctly 1 mark: Explain the problem of generating for the varying demand 1 mark: Explain how pump-storage can be used as a solution for the problem

Question			Expected answer(s)	Max mark	Additional guidance
6.	(a)		Determine the forces at the reactions, let A be the left hand end and B the right hand end. There are only vertical forces. $$\sum M_A = 0$$ $$8 \times 4 \times \frac{4}{2} + 20 \times 4 + 10 \times 5 - R_B \times 6 = 0$$ $$R_B = \frac{194}{6}$$ $$R_B = 32.\dot{3}\ kN$$ $$\sum F_V = 0$$ $$R_A - 8 \times 4 - 20 - 10 + R_B = 0$$ $$R_A = 29.\dot{6}\ kN$$ shear force diagram  	**3**	Candidates may use an alternative convention for force and moment 'direction' as used here Reaction forces should be opposite in direction to the applied forces 1 mark: calculate both reaction forces 1 mark: UDL represented correctly on diagram 1 mark: Reactions and two point loads shown correctly on diagram

Question			Expected answer(s)	Max mark	Additional guidance
6.	(b)		Bending moment equation $For\ 0 < x < 4$ $$R_A x - 8x\frac{x}{2} - M_B = 0$$ $$M_B = 29.\dot{6}x - 4x^2$$ Bending moment is potentially a maximum value when $$\frac{dM_B}{dx} = 0$$ $$\frac{dM_B}{dx} = 29.\dot{6} - 8x$$ $$29.\dot{6} - 8x = 0$$ $$x = 3.708\dot{3}$$ $$M_B = 29.\dot{6}(3.708\dot{3}) - 4(3.708\dot{3})^2$$ $$M_B = 55.0\ kNm$$	**3**	1 mark: correct equation (need not be simplified) Accept a statement of form "max bending moment occurs where graph of shear force crosses *x*-axis" **OR** "max bending moment occurs when shear force = 0" 1 mark: correct position of maximum bending moment (units not required) (a proportional method using values on the graph may be used, but it is not sufficient to read an approximate value from the graph) 1 mark: correct magnitude of maximum bending moment (units required)
	(c)		"The maximum bending moment can be used to determine the correct selection of material and beam geometry to ensure that the beam is strong enough to resist the applied loading." **OR** "If the beam is constant cross-section this position of maximum bending moment is the location at which the beam is most likely to fail because the bending stress will be greatest."	**1**	1 mark: Candidate must indicate that they are aware the maximum bending moment affects maximum stress in the beam Do not accept "this is the weakest point of the beam". The beam is constant cross-section, so its resistance to bending stress is the same along its length

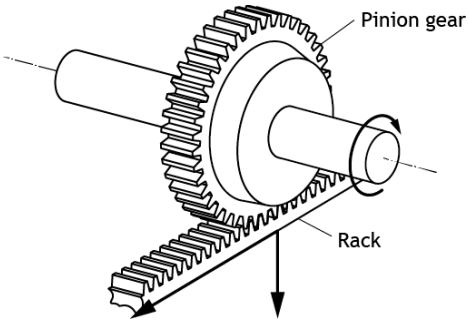
Section 2

Question			Expected answer(s)	Max mark	Additional guidance
7.	(a)		Stress is found from: $$\sigma = \frac{My}{I}$$ Cantilever, so maximum moment arises at the wall.  Moments about the wall $M_w = F_{cow} \times 600 + F_{milk} \times 1000$ $M_w = 300 \times 9 \cdot 8 \times 600 + 10 \times 9 \cdot 8 \times 1000$ $M_w = 1 \cdot 862 \times 10^6 Nmm$ $$y = \frac{70}{2} = 35mm$$ $$Ixx = \frac{BD^3}{12} - \frac{bd^3}{12}$$ $$Ixx = \frac{30 \times 70^3}{12} - \frac{23 \times 63^3}{12}$$ $$Ixx = 378 \cdot 24325 \times 10^3 mm^4$$ $$\sigma = \frac{1 \cdot 862 \times 10^6 \times 35}{378 \cdot 24325 \times 10^3}$$ $\sigma = 172 \cdot 29 \ldots Nmm^{-2}$ $\sigma = 172 \ldots Nmm^{-2} (3\ s \cdot f \cdot)$ From data booklet; Aluminium Alloy has a yield stress of 250 Nmm^{-2}: as the calculated stress is less than this value, the beam is in the elastic region under the applied loads and will not be permanently deformed under the worst-case scenario.	**5**	1 mark: Correct value for maximum moment 1 mark: correct equation and substitutions for second moment of area, I 1 mark: correct result for second moment of area, I Note: $$Ixx = \frac{30 \times 70^3}{12}$$ $Ixx = 857 \cdot 5 \times 10^3 mm^4$ Would gain the first mark for second moment of area, but not the second 1 mark: correct value of maximum stress with unit 1 mark: decision based on calculated stress and value extracted from the tables

Question			Expected answer(s)	Max mark	Additional guidance
7.	(b)		$L = 1000mm, a = 600\ mm$ $P = 300\ \times\ 9 \cdot 8 = 2940\ N$ $E = 70 \times 10^3 Nmm^{-2}$ $I = 378 \cdot 24325 \times 10^3 mm^4$ $\delta = \frac{Pa^2}{6EI}(3L - a) = 16.0mm\ (3\ s.f)$	**2**	1 mark: Substitution of correct values into formula 1 mark: Answer and unit
	(c)		Resistance: $\frac{60}{1000} \times 0 \cdot 524 = 0 \cdot 03144\ \Omega$ Current: $\frac{21000}{230} = 91 \cdot 3\ A$ Power loss = I^2R $91 \cdot 3^2 \times 0 \cdot 03144 = 262W$ Efficiency = $\frac{21000}{21000 + 262} \times 100\% = 98 \cdot 8\%$	**2**	1 mark: Calculate power loss 1 mark: Calculate efficiency

Question			Expected answer(s)	Max mark	Additional guidance
7.	(d)		$V_{in} = 5$ V at maximum load $V_{signal} = 120$ mV V_+ $= (120 \times 10^{-3})\left(-\frac{100k}{10k}\right)\left(-\frac{10k}{10k}\right)$ $= 120 \times 10^{-3} \times 10$ $= 1 \cdot 2$ V To remove self − weight, $V_x = 20 \times 10^{-3} \times 10 = 0 \cdot 2$ V $R_x = \frac{100k \times 0 \cdot 2}{4 \cdot 8} = 4.17\ k\Omega$ $5 = \frac{1 \times 10^6}{R_1}(1 \cdot 2 - 0 \cdot 2)$ $R_1 = \frac{1 \times 10^6}{5} = 200\ k\Omega$ When digital input $= 0001$ $V_{out} = \frac{5}{(2^4 - 1)} = 0 \cdot \dot{3}$ V $0 \cdot \dot{3} = \frac{R_f}{R_A} \times 5$ $R_B = \frac{R_A}{2} = 750\ k\Omega$ $R_C = \frac{R_A}{4} = 375\ k\Omega$ $R_D = \frac{R_A}{8} = 187 \cdot 5\ k\Omega$	**4**	1 mark Calculate R_x 1 mark Calculate R_1 1 mark: Calculating R_A for 0001 1 mark: Calculating R_B, R_C and R_D

Question			Expected answer(s)	Max mark	Additional guidance
7.	(e)		At self-weight, each sensor should read 5 mV (20 mV / 4) For V_{in} = -250 mV $-250 \times 10^{-3} = 5\left((10 \times \Sigma V_{load}) - 0 \cdot 2\right)$ $-50 \times 10^{-3} = 10 \times \Sigma V_{load} - 200 \times 10^{-3}$ $\Sigma V_{load} = \frac{150 \times 10^{-3}}{10}$ $\Sigma V_{load} = 15\ \text{mV}$ One sensor has short circuited to ground giving a signal input of 0 V from this sensor	**2**	1 mark: Calculating ΣV_{load} 1 mark: Recognising that the fault could be due to a short circuit to ground Note: this mark is available if a sensible fault is identified for an incorrect value calculated for the first mark

Question			Expected answer(s)	Max mark	Additional guidance
8.	(a)		Tangential force from Torque applied and radius of gear; $$T = F \times r$$ $$10 = F_t \times \frac{0 \cdot 045}{2}$$ $$F_t = 444 \cdot \dot{4}\ N$$ $$F_t = 440\ N\ (3\ s \cdot f\ \cdot)$$ Radial force due to gear geometry; $$F_r = F_t \tan\theta$$ $$F_r = 444.\dot{4} \times \tan 25°$$ $$F_r = 207\ N\ (3\ s.f.)$$  If the pinion is turning clockwise then the force on the gear on the rack is acting to the left and the radial force acts vertically down w.r.t. the diagram in the question	**3**	**1 mark:** tangential component of force **1 mark:** radial component of force $$F_t = F\cos\theta$$ $$F_r = F\sin\theta$$ $$F_r = \frac{F_t}{\cos\theta}\sin\theta = F_t\tan\theta$$ **1 mark:** explanation of force direction (pinion gear forces are equal and opposite)

Question			Expected answer(s)	Max mark	Additional guidance
8.	(b)		Tangential force is the force that is applied to the steering arms; torque supplied by the driver. Resistance to turning is 100 Nm $T_{turn} = F_{rack} \times r$ $100 = F_{rack} \times 0 \cdot 15 \cos 10°$ $F_{rack} = \frac{100}{0 \cdot 15 \cos 10°} = 676 \cdot 95\ N$ Difference in rack force $= 676 \cdot 95 - 444 \cdot 44$ $= 232 \cdot 51\ N$ $= 233\ N\ (3\ s \cdot f \cdot)$	**2**	1 mark: Correct rack force, noting that the radius is less than 150mm due to angle Rack force applies to both wheels 1 mark: Correct difference
	(c)		From the graph of V_{out}, Period = 20ms T_1 =0·99 x 20 ms = 19·8 ms T_2 = 20 ms – 19·8 ms = 0.2 ms $T_2 = 0 \cdot 7 \times R_2 C$ $R_2 = \frac{0 \cdot 2 \times 10^{-3}}{0 \cdot 7 \times 0 \cdot 22 \times 10^{-6}} = 1.3\ k\Omega$ $T_1 = 0 \cdot 7(R_1 + R_2)C$ $R_1 = \frac{19 \cdot 8 \times 10^{-3}}{0 \cdot 7 \times 0 \cdot 22 \times 10^{-6}} - 1300$ $R_1 = 127\ k\Omega$ $T_{on} = 1.1RC$ $R_{series} = \frac{1 \cdot 4 \times 10^{-3}}{1 \cdot 1 \times 0 \cdot 1 \times 10^{-6}}$ $= 12{,}727\ \Omega$ $R_3 = 12{,}727 - 10{,}000 = 2{,}727\ \Omega$ Precision motor angle $= \frac{0 \cdot 4}{0 \cdot 5} \times 90$ $= 72°$	**5**	1 mark: Extract period from the graph and calculate T_1 and T_2 1 mark: Calculate R2 1 mark: Calculate R1 Note: $f = \frac{1 \cdot 44}{(R_1 + 2R_2)C}$ $(R_1 + 2R_2) = \frac{1 \cdot 44}{50 \times 0 \cdot 22 \times 10^{-6}}$ $(R_1 + 2R_2) = 130\ k\Omega$ Award mark for R2 but not R1 if this working is shown, but individual values are not subsequently found 1 mark: Calculate R3 1 mark: Calculate precision motor angle

Question			Expected answer(s)	Max mark	Additional guidance
8.	(d)		The 106 and 149 were calculated using the potentiometer angles given in the question. -15 degrees = 75 degrees on rotary potentiometer +15 degrees = 105 degrees on rotary potentiometer $\frac{75}{180} \times 255 = 106$ $\frac{105}{180} \times 255 = 149$ The lines in section A check to see if the wheel angle is outside the limits of 106 and 149, if so then the wheel_angle variable is set to the minimum or maximum value	**2**	1 mark: Show how to calculate ADC values corresponding to -15 and + 15 degrees 1 mark: check that the wheel angle is not outside limits: if so, then set wheel_angle to max/min value

Question			Expected answer(s)	Max mark	Additional guidance

8.	(e)		`mark = wheel_angle * 100 / 255+100;`
			`mark = mark * 10;`
			
			Max wheel_angle = 149, which when multiplied by 1000 in the original program would produce an overflow as it exceeds 32767 (Arduino) & 65535 (BASIC). Taking two steps to calculate it prevents this from happening as maximum value is now 14900
			
			`digitalWrite(9, HIGH);`
			`delayMicroseconds (mark);`
			`digitalWrite(9, LOW);`
			`delay(18);`
			`delayMicroseconds(space);`
			
			`HIGH 3`
			`PAUSEMICRO mark`
			`LOW 3`
			`PAUSE 18`
			`PAUSEMICRO space`
			
			The maximum value of microseconds for delayMicroseconds/pausemicro is 16383. This value is exceeded in the original program for the *space* at all times, even when *mark* is at the maximum value of 1584, *space* = 18416. The delay(18)/pause 18 produces a delay of 18000 microseconds. This ensures that the maximum value for delayMicroseconds/ pausemicro is always <16383
				3	1 mark:
					explain that the mark calculation would exceed the maximum value permitted for the integer variable and that this is prevented by the 2-step calculation
					
					1 mark:
					identify the problem with the space value exceeding the maximum value for delayMicroseconds/pausemicro
					
					1 mark:
					outline the solution using delay(ms)/pause ms and delayMicroseconds(us)/ pausemicro(us) combined

[END OF MARKING INSTRUCTIONS]