National
Qualifications
SPECIMEN ONLY

S823/77/11 Engineering Science

Date — Not applicable

Duration — 2 hours 30 minutes

Total marks — 75

You may refer to the Advanced Higher Engineering Science Data Booklet.

SECTION 1 — 35 marks

Attempt ALL questions.

SECTION 2 — 40 marks

Attempt ALL questions.

Write your answers clearly in the answer booklet provided. In the answer booklet you must clearly identify the question number you are attempting.

For questions 1 (a) and 6 (a), write your answers clearly in the worksheets provided in booklet S823/77/21.

Show all working and units where appropriate.

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.

Use **blue** or **black** ink. Sketches, diagrams and graphs may be drawn in pencil.

Before leaving the examination room you must give your answer booklet **and** worksheets to the Invigilator; if you do not, you may lose all the marks for this paper.

S8237711

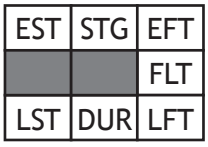
MARKS

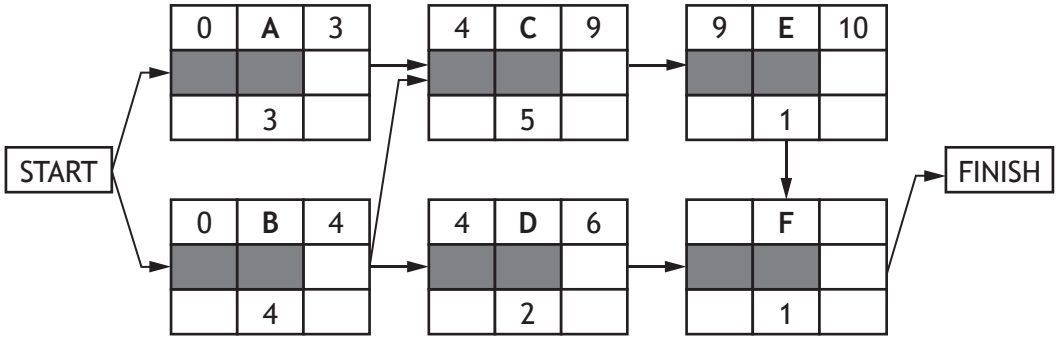
SECTION 1 — 35 marks

Attempt ALL questions

1. A partially complete activity network for an engineering project involving six stages, A–F, is shown below. Time for each stage is measured in weeks.

- STG – stage
- DUR – duration
- EST – earliest start time
- EFT – earliest finish time
- LST – latest start time
- LFT – latest finish time
- FLT – float





(a) On the **worksheet for question 1(a)**

(i) complete the activity network by adding

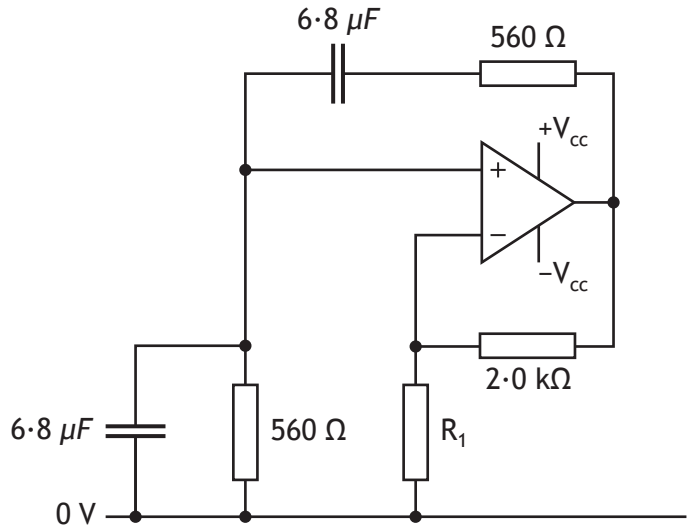
- the earliest start time and earliest finish time for activity F
- the latest finish time, the latest start time, and the float for each of activities A–F. **3**

(ii) use the activity network to identify the critical path. **1**

(b) Describe how the project manager would use information in the activity network to manage the project effectively. **2**

MARKS

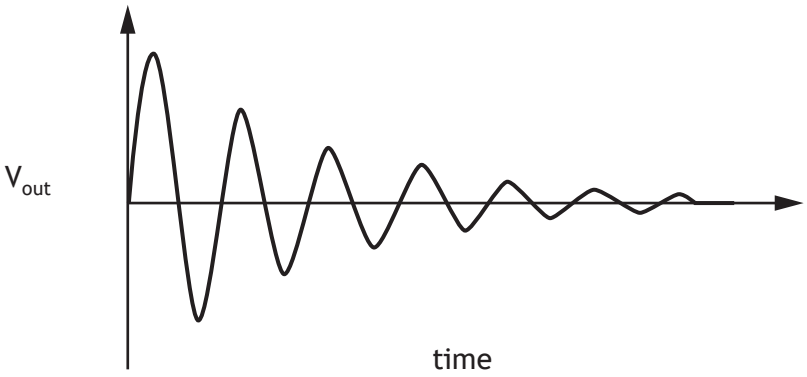
2. A Wien-bridge oscillator is being tested by a student.



The tolerance of the components used in the circuit is 5%.

(a) Calculate the range of frequencies the circuit will oscillate within. **2**

The student selects an incorrect resistor value for R_1 which produces the output waveform shown below.

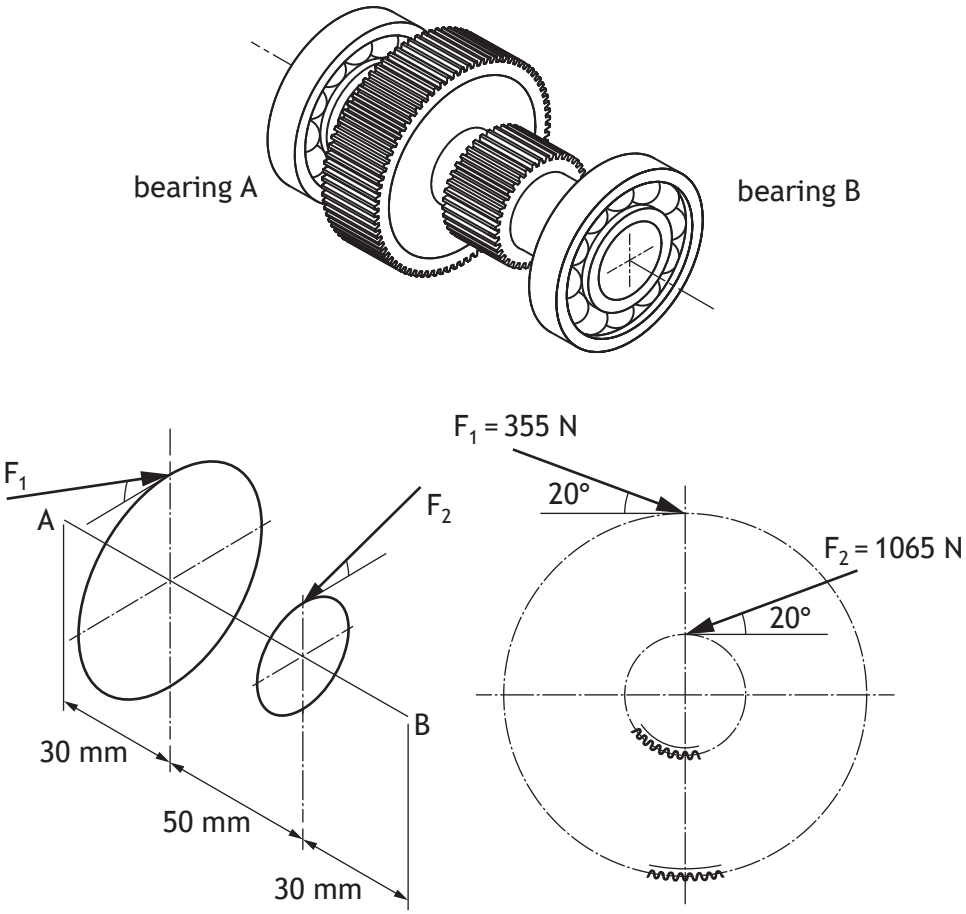


(b) State why the student's choice of resistance for R_1 has caused this output waveform and suggest a value for R_1 which would produce a constant amplitude sine-wave. **2**

[Turn over

MARKS

3. A shaft within a gearbox has loads applied due to the transmission of power, as shown below. Gear locations on the shaft are also shown.

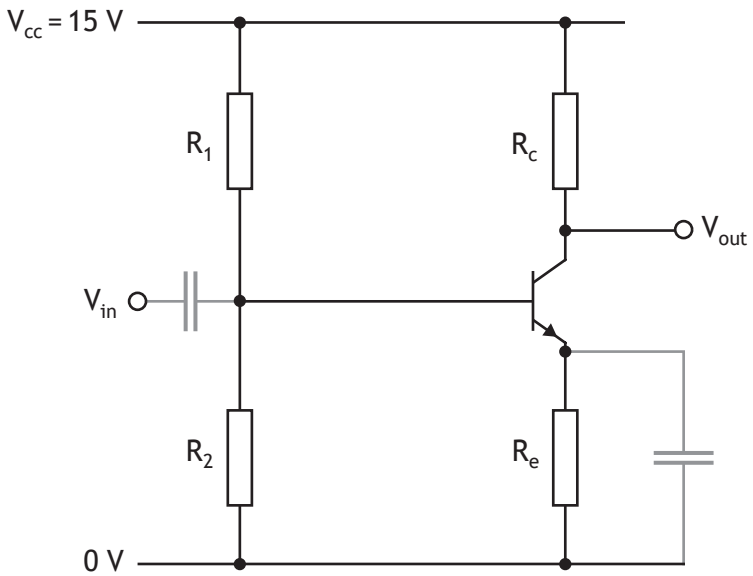


not drawn to scale

Calculate the magnitude and direction of the reaction at the bearing at A. **5**

MARKS

4. A student is designing an amplifier based on the circuit shown below.
For component calculations ignore the greyed-out capacitors.



Circuit specifications

- I_c = 1 mA
- *A-Class* biased, with V_{out} = 50% of V_{cc}
- h_{fe} = 100
- V_e = 1 V
- V_{be} = 0·6 V
- V_{cc} = 15 V

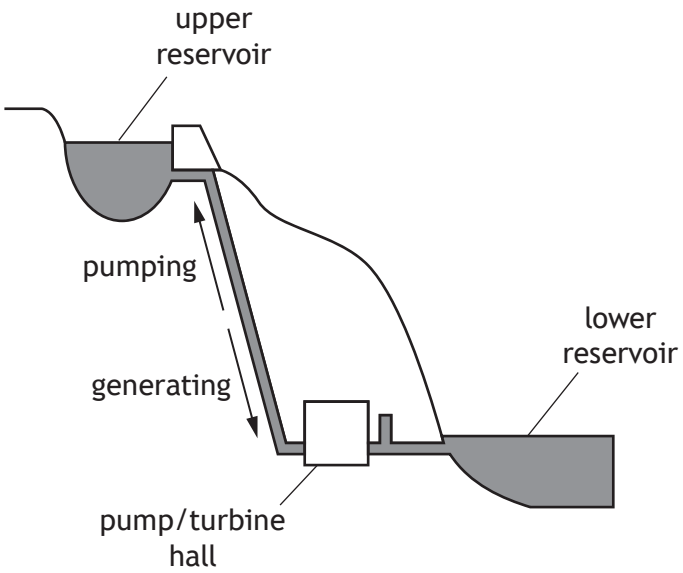
(a) Calculate values for R_c and R_e. **2**

(b) Calculate values for I_b and V_b. **1**

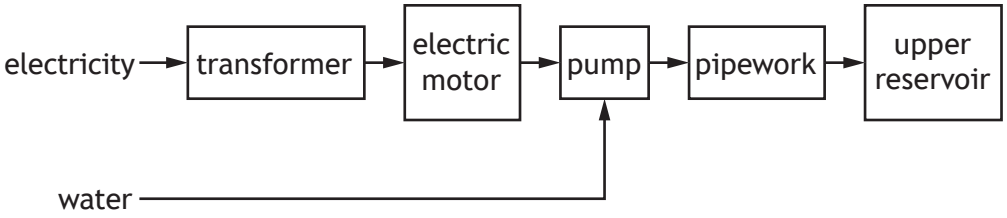
(c) Calculate values for R_1 and R_2 using the design rule $I_{R2} = 10I_b$. **2**

[Turn over

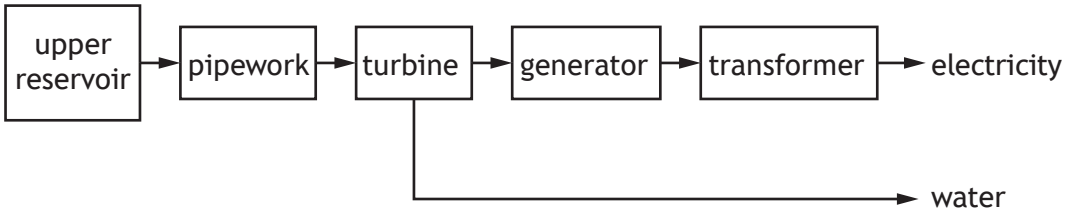
5. Two block diagrams for a hydropower pump-storage scheme similar to Cruachan in Scotland, are shown below.



PUMPING



GENERATING



The main system components have the following operating efficiencies.

	Overall efficiency (%)
Step-down transformer, electric motor driving pump and pump	87·0
Turbine, generator and step-up transformer	90·3

Energy loss in the water pipework between the pump and the upper reservoir amounts to 0·6% of the energy supplied to the water when pumping and 0·8% of the potential energy of the water in the upper reservoir when generating.

MARKS

5. (continued)

(a) Calculate the percentage of the electricity drawn from the National Grid to pump water that is returned to the National Grid as electricity by this system. Ignore evaporation from the reservoir. **2**

Cruachan pump-storage scheme can switch from pumping water to generating electricity in two minutes. It can generate up to 440 MW of electricity continuously for a maximum of 22 hours.

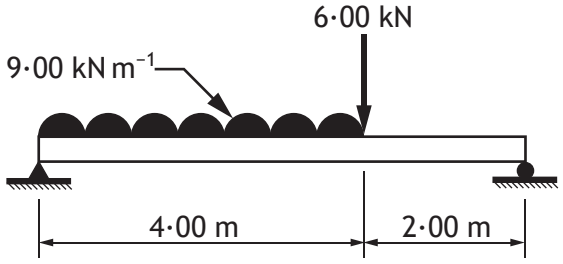
(b) Define the terms 'base load' and 'peak load' when used in relation to the National Grid and explain the role that pump storage generation capacity plays in maintaining electricity supply at all times. **3**

[Turn over

MARKS

6. A structural beam is used to support a balcony, external wall and the floor of a room in a modern house, as shown below.

The structural beam is loaded as shown below.



(a) Draw, on **worksheet for question 6(a)**, the shear force diagram for the beam. Indicate the important values of the shear force on the diagram. **4**

(b) Write an equation for the bending moment at a distance x from the left-hand end of the beam, for the region of the beam $0 < x < 4$. **2**

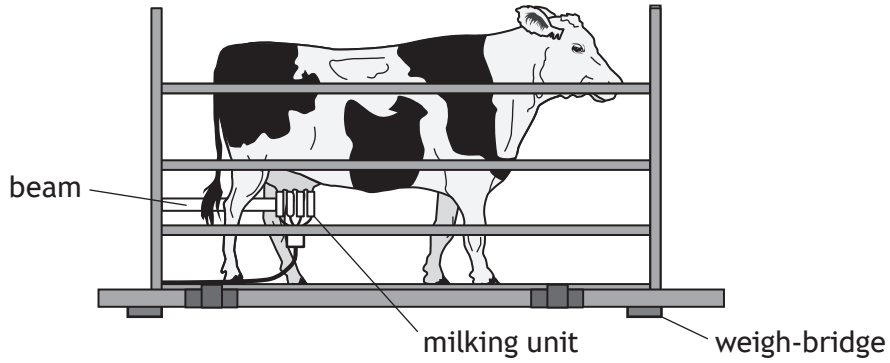
(c) Find the position and magnitude of the maximum bending moment. **2**

(d) Explain why it is important to find the position and magnitude of the maximum bending moment in a loaded beam which has a constant cross-section along its length. Make reference to the General Bending Equation. **2**

SECTION 2 — 40 marks

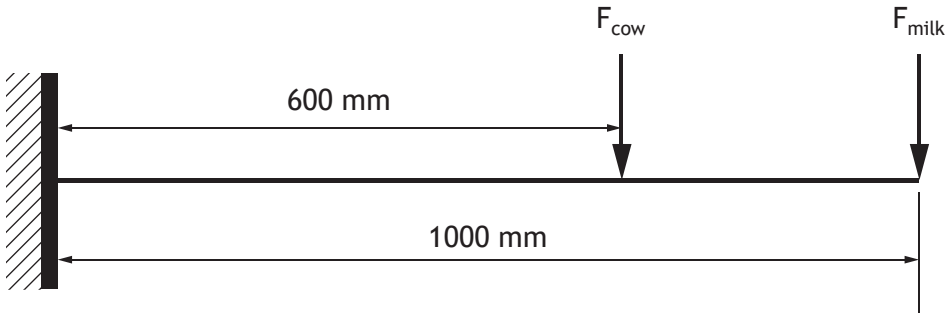
Attempt ALL questions

7. On a dairy farm, cows are milked and then weighed each day using an automated milking unit and weigh-bridge. A cow's weight is recorded in kilograms.



The structural support for the milking unit is considered to be a cantilever beam of length 1·00 m. The milking unit weighs 10 kg and is attached to the free end of the cantilever beam. The beam is made from aluminium alloy and has a hollow rectangular cross-section with external dimensions of width 30 mm and height 70 mm, and a wall thickness of 3·5 mm.

The beam has been designed to not only carry the load of the milking unit, but also to be strong enough to support 300 kg (a part of the weight of the cow, should it sit down on the device). The added load of the cow would act 600 mm from the wall.

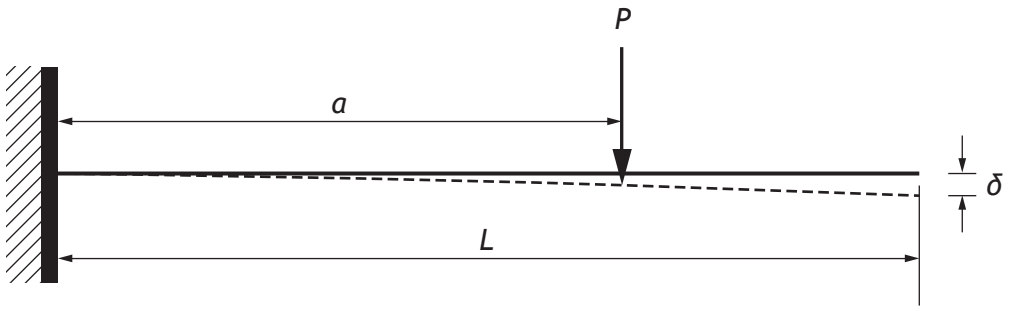


(a) Calculate the maximum stress in the beam at its support and determine if the beam would be permanently deformed if the cow sat down. **5**

[Turn over

7. (continued)

The end-point deflection, δ, of a cantilever beam due to a point load, P, applied between the wall and the end is calculated from



$$\delta = \frac{Pa^2}{6EI}(3L - a)$$

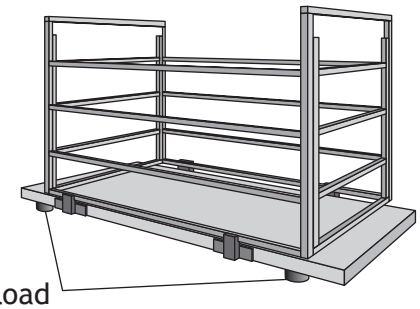
(b) Calculate the vertical deflection of the free end of the cantilever beam that the weight of the cow would produce. **2**

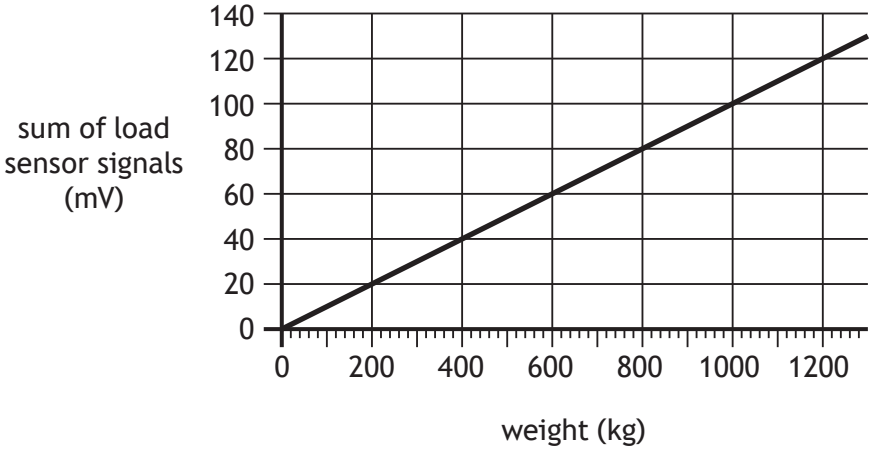
The automated milking unit has a total resistive power consumption of 21 kW and is supplied from a single-phase line 60 m long. The single-phase voltage at the machine is 230 V. The cable resistance is 0·524 $\Omega\,km^{-1}$.

(c) Calculate the power loss arising from the line resistance and hence the efficiency of the line. **2**

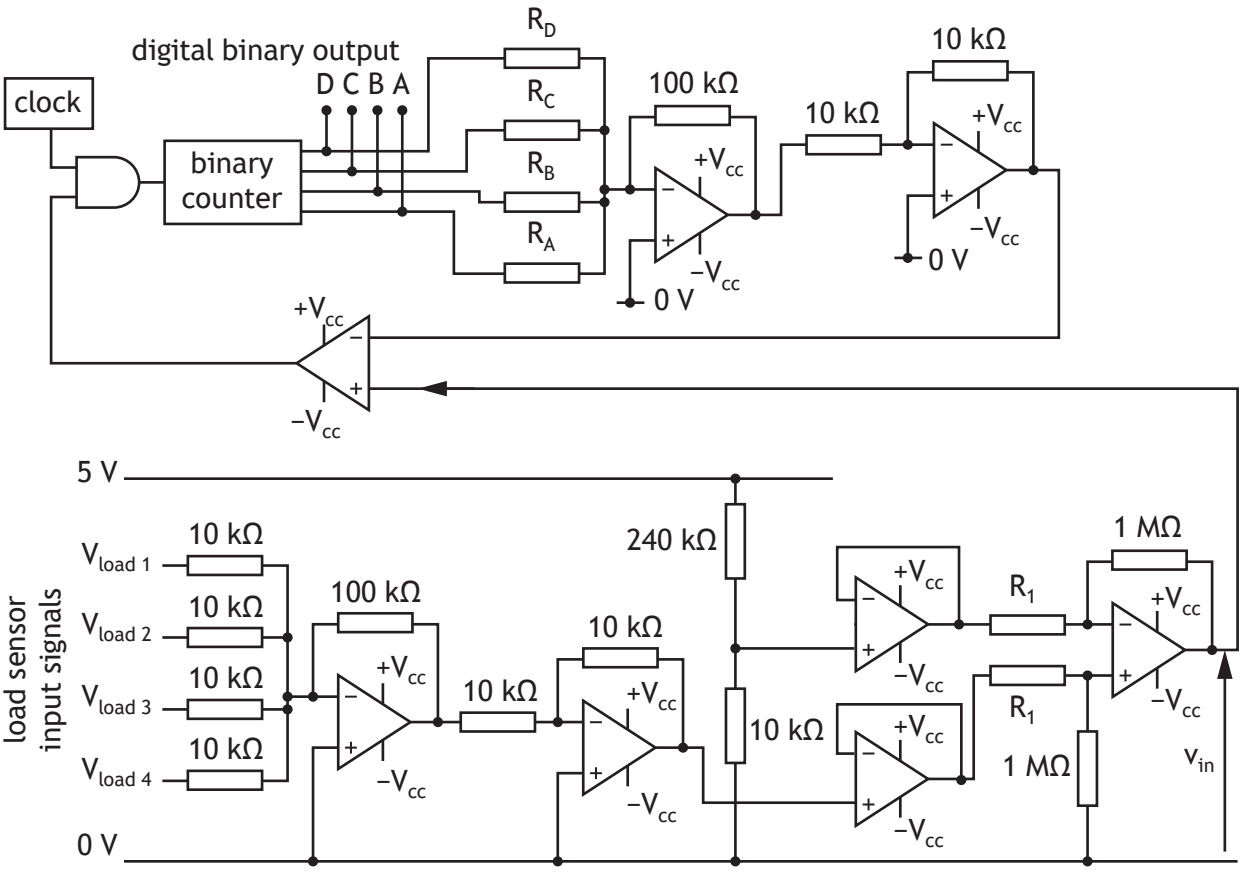
7. (continued)

Four identical load sensors measure the force at each corner of the weigh-bridge. Assume that the weight is evenly distributed between the four sensors. The graph below shows the combined output from the four load sensors for a given load.





The signals from the sensors are processed by the circuit shown below, to produce a 4-bit binary signal proportional to the weight of the cow.



[Turn over

7. (continued)

- The self-weight of the weigh-bridge is 200 kg.
- The maximum load, including self-weight, is 1200 kg.
- V_{in} should equal 0 V when the weigh-bridge is unloaded (self-weight only).
- V_{in} should equal 5 V at the maximum load.
- The digital value of 1111 is equivalent to an analogue voltage at V_{in} of 5 V.
- Output A is the LSB and Output D is the MSB.
- Binary counter outputs are each 5 V or 0 V.

(d) Calculate the values of R_1, R_A, R_B, R_C and R_D. **5**

A fault occurs in one of the load sensors giving a reading of −250 mV for V_{in} when the weigh-bridge is not loaded.

(e) Explain why this reading may have occurred. Include a calculation of the sum of the load voltages when V_{in} is −250 mV in your explanation. **2**

7. (continued)

The cow's temperature is measured during milking. A program is being tested which will read and display the cow's minimum and maximum temperature readings over a two minute period. The program is shown below.

ARDUINO

```
int temp = 0;                                   Section A
int mintemp = 0;
int maxtemp = 0;

void setup()
{
       Serial.begin(9600);
for(int counter=0; counter <= 120; counter ++)
 {
  temp = analogRead(0);
 if(maxtemp > temp)                             Section B
  {
   maxtemp = temp;
  }
  if(temp < mintemp)
  {
   mintemp = temp;
  }
delay (1000);
 }
 Serial.print("Max Temp: ");
 Serial.println(maxtemp);
 Serial.print("Min Temp: ");
 Serial.println(mintemp);

}
void loop() {
}
```

PBASIC

```
init:   symbol temp = b1
        symbol mintemp = b4
        symbol maxtemp = b5
        let temp = 0                            Section A
        let mintemp = 0
        let maxtemp = 0
temperature: for b2 = 1 to 120
             readadc 0, temp
                                                Section B
             if maxtemp > temp then
                  maxtemp = temp
             endif
             if temp < mintemp then
                  mintemp = temp
             endif
             pause 1000
        next b2

sertxd("Max Temp: ",#maxtemp,13,10)
sertxd("Min Temp: ",#mintemp,13,10)

end
```

During testing the following output was produced, indicating errors in the program.

Max Temp: 0
Min Temp: 0

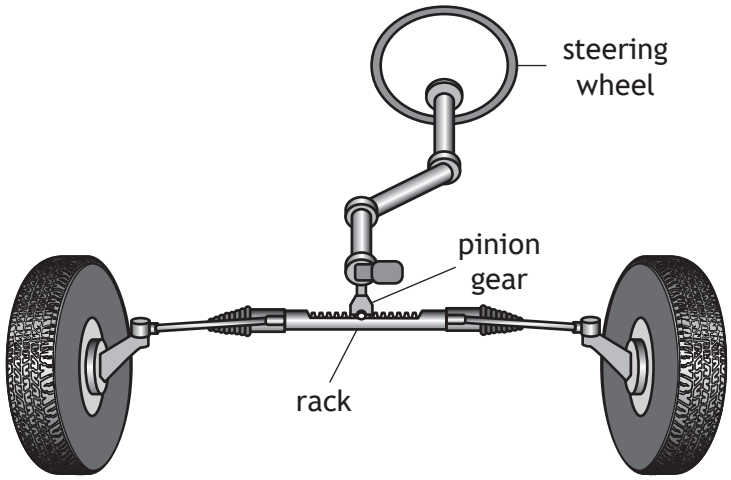
Note that the average temperature of a healthy cow is 38 °C, which would correspond to a recorded data value of 38.

The errors were narrowed down to the boxed sections A and B, highlighted above.

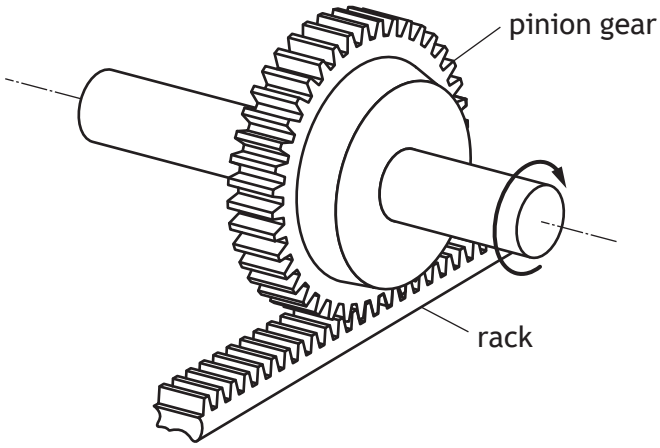
(f) Explain why the program does not produce the correct outputs and what changes should be made to rectify the errors. **4**

MARKS

8.



The steering mechanism for an electric car, shown above, comprises a steering wheel connected to a toothed bar, called a rack, via a pinion gear. The pinion gear is fixed in location and is free to rotate. The pinion gear and rack are shown below.

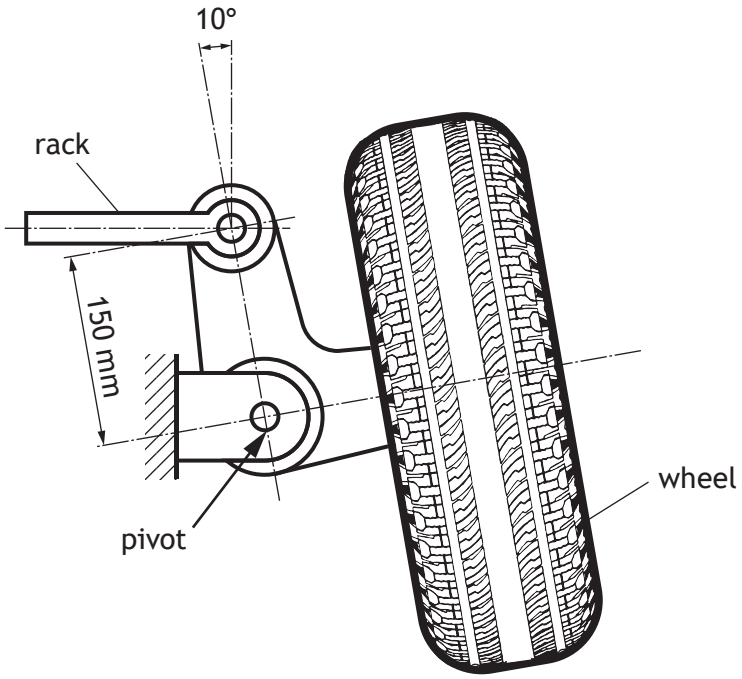


The pinion has a pitch circle diameter of 45 mm and a pressure angle of 25°. A torque of 10 Nm is required at the pinion for the car to turn a corner at a constant speed.

(a) Calculate the magnitude and direction of the tangential and radial components of force acting on the rack if the pinion is turned clockwise, as shown above. **3**

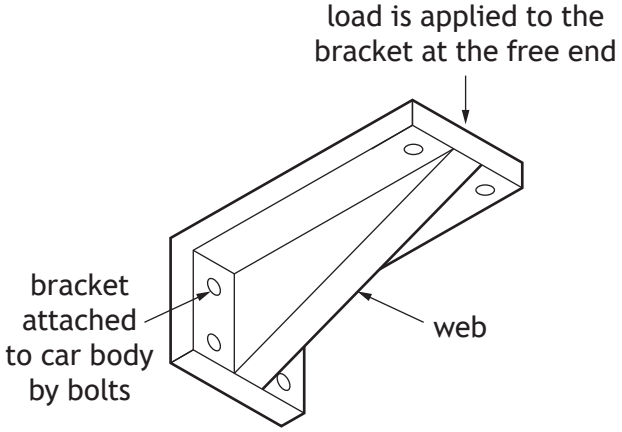
8. (continued)

The actual torque required to turn both wheels about their pivot is 100 Nm when the wheel is at an angle of 10°. A power steering system provides additional force to move the rack which causes the wheel to change angle about a pivot (changing the direction of the car). The arm connecting the rack to the pivot is 150 mm long. A simplified sketch of the plan view for the arrangement for one wheel is shown below.



(b) Calculate the required force in the rack to turn the wheels and hence the additional force supplied to the rack by the power steering system. **2**

In electric cars, the batteries are normally supported using webbed brackets. These cantilever webbed brackets are fixed securely to the car's chassis and the battery is attached to the free end of the bracket. A webbed bracket is shown below.

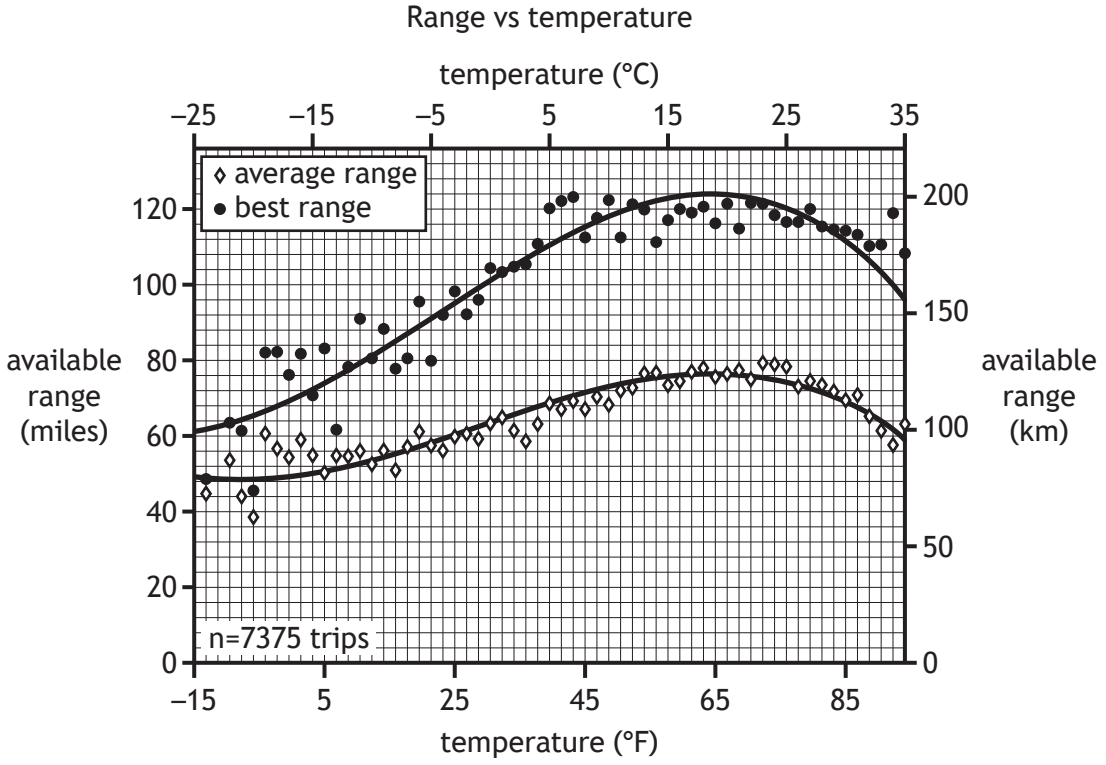


(c) Explain why this bracket is an efficient use of material for the function that it performs. **2**

8. (continued)

The range of a fully electric car is defined as the distance travelled by the vehicle on one full battery charge.

The graph below shows how the real-world range of the electric car varies depending on the ambient temperature.

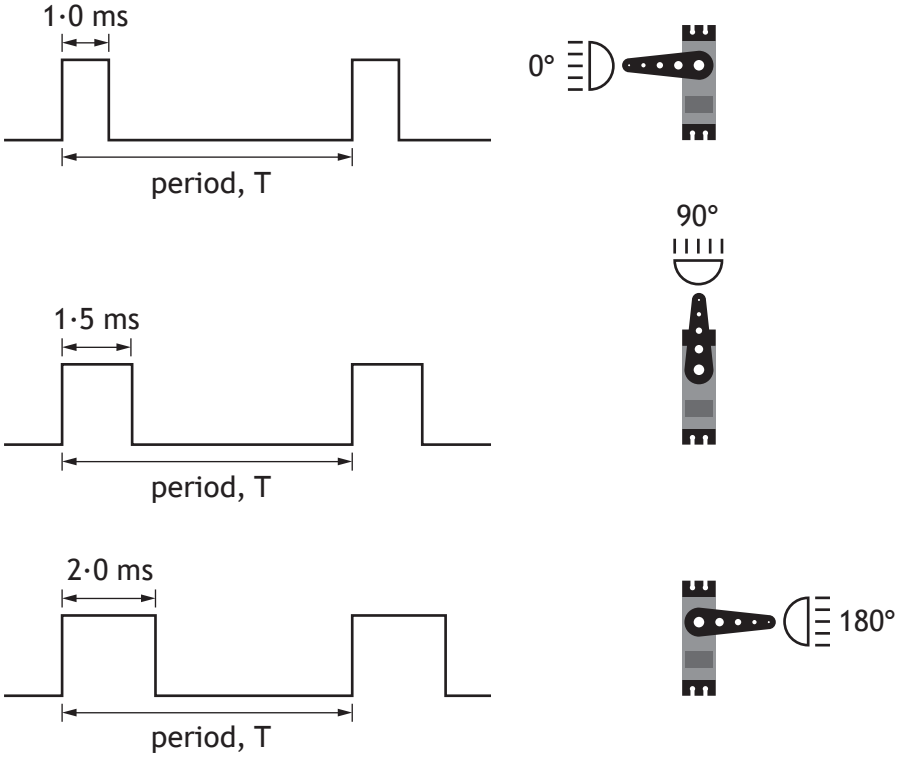


(d) Explain why this variation in range may have occurred. **3**

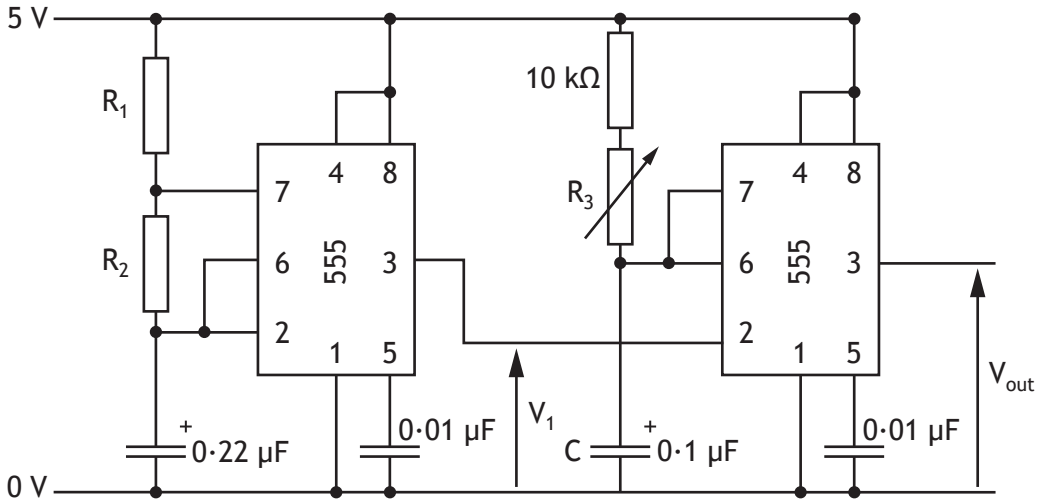
8. (continued)

A recent advance in car technology is to point the headlights in the direction that a car is turned.

A student uses a precision motor to adjust the angle of a car headlight as it corners. The angle is changed by applying a pulse of variable width to the motor, as shown in the waveform diagrams below.



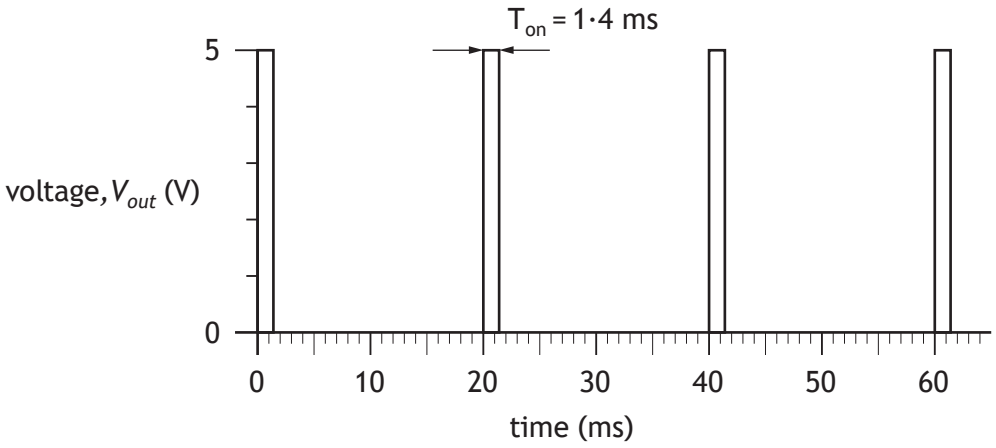
The motor waveforms are produced using the circuit shown below.



Note: V_1 has a duty cycle of 99%, ie mark : space ratio is 99:1

The second stage of the circuit produces the output signal V_{out}.

8. (continued)



The mark time is calculated using

$$T_{on}=1{\cdot}1RC$$

where R is the total resistance in series with the capacitor, C.

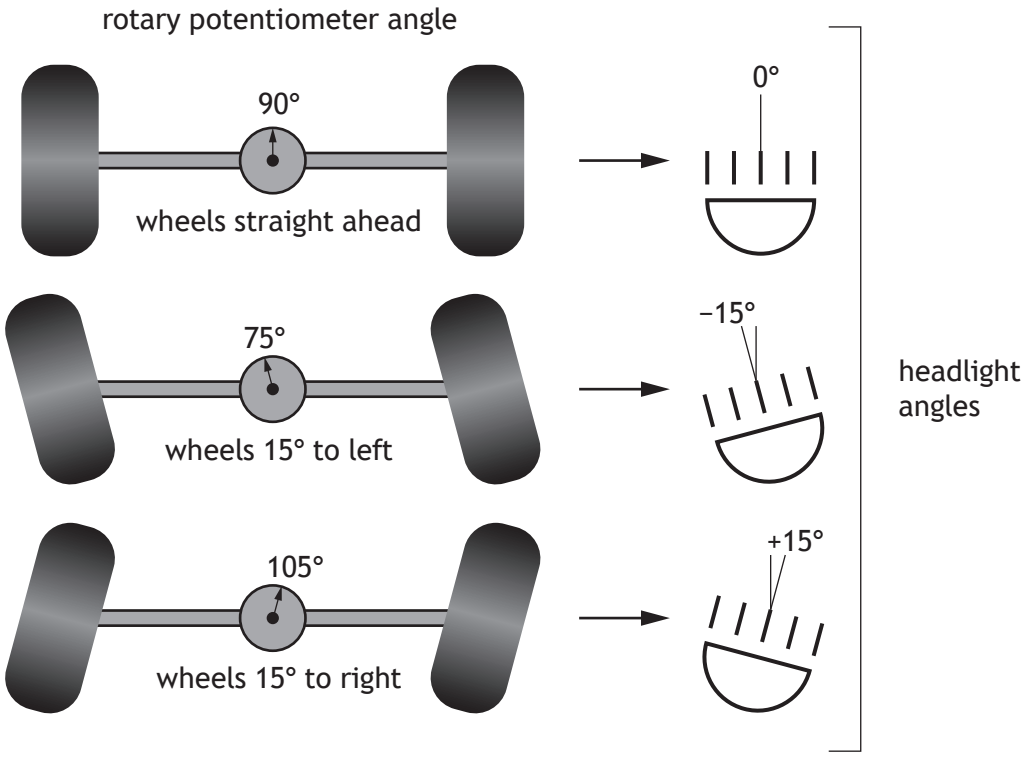
(e) Calculate the values of R_1, R_2, R_3 and the **angle** the precision motor will move to. **5**

8. (continued)

The student replaces the 555 circuit with a microcontroller. A program is written to process the angle of the wheels and produce a waveform to adjust the angle of the headlights.

The following information is included for reference.

- The range of movement of the headlight must be limited to −15° to +15°.
- The frequency of the output waveform must match the waveform in question 8 (e).
- The angular position of the front wheels is detected by a rotary potentiometer with a range of 0° to 180°.
- The voltage from the potentiometer is processed by the microcontroller's ADC producing a value stored in the integer variable *wheel_angle* in the range 0–255.
- Potentiometer rotation of 180° would produce a *wheel_angle* of 255.



[Turn over

8. (continued)

Programming commands to produce time delays

ARDUINO	**PBASIC**

Syntax
 	
`delayMicroseconds(us)`
 	
Parameters
us — is a variable/constant (0–16383) which specifies the number of microseconds to pause
 	
Example
delayMicroseconds(50);//Wait 50 µs
	Syntax
	
	`PAUSEMICRO microseconds`
	
	Parameters
	Microseconds — is a variable/constant (0–16383) which specifies the number of microseconds to pause
	
	Example
	PAUSEMICRO 50 'Wait 50 µs

Syntax
 	
`delay(ms)`
 	
Parameters
ms — is a variable/constant which specifies the number of milliseconds to pause
 	
Example
delay(5000); //Wait 5000 ms
	Syntax
	
	`PAUSE ms`
	
	Parameters
	ms — is a variable/constant which specifies the number of milliseconds to pause
	
	Example
	PAUSE 5000 'Wait 5000 ms

Program variables	
ARDUINO	**PBASIC**
wheel_angle **mark** **space** All variables are integers in the range (–32768 to 32767)	**wheel_angle** **mark** **space** All variables are word integers in the range (0–65535)

8. (continued)

ARDUINO

```
void sub_procedure_B()
{

wheel_angle = analogRead(14)/4;          // get wheel angle and
                                         // scale to 0–255 range
```

`if(wheel_angle < 106)`
`{`
`  wheel_angle = 106;`
`}`
 	
`if(wheel_angle > 149)`
`{`
`  wheel_angle = 149;`
`}`
	block 1

`mark = wheel_angle*1000/255+1000;`
`space = 20000 – mark;`
 	
`digitalWrite(3, HIGH);`
`delayMicroseconds(mark);`
`digitalWrite(3, LOW);`
`delayMicroseconds(space);`
 	
`}`
	block 2

PBASIC

```
sub_procedure_B:
                                         ‘ get wheel angle
readadc 0, wheel_angle
```

`IF wheel_angle < 106 then`
 	
`  let wheel_angle = 106`
 	
`ELSEIF wheel_angle > 149 then`
 	
`  let wheel_angle = 149`
 	
`ENDIF`
	block 1

`LET mark = wheel_angle*1000/255+1000`
`LET space = 20000 – mark`
 	
`HIGH 3`
`PAUSEMICRO mark`
`LOW 3`
`PAUSEMICRO space`
 	
`return`
	block 2

8. (continued)

(f) Explain the purpose of the program lines in block 1, and show how the numbers 106 and 149 are calculated. **2**

After testing the program and finding faults, block 2 was modified as shown below.

ARDUINO

```
mark=wheel_angle*100/255+100;
mark=mark*10;
space=2000–mark;

digitalWrite(3,HIGH);
delayMicroseconds(mark);
digitalWrite(3,LOW);

delay(18)

delayMicroseconds(space);

}
```

PBASIC

```
LET mark=wheel_angle*100/255+100
LET mark=mark*10
LET space=2000–mark

HIGH 3
PAUSEMICRO mark
LOW 3

PAUSE 18

PAUSEMICRO space;

return
```

(g) Explain why the boxed lines were altered. **3**

[END OF SPECIMEN QUESTION PAPER]

FOR OFFICIAL USE

National Qualifications
SPECIMEN ONLY

Mark

S823/77/21

Engineering Science Worksheets

Date — Not applicable

Duration — 2 hours 30 minutes

* S 8 2 3 7 7 2 1 *

Fill in these boxes and read what is printed below.

Full name of centre

Town

Forename(s)

Surname

Number of seat

Date of birth

Day Month Year

Scottish candidate number

Worksheets for questions 1 (a) and 6 (a).

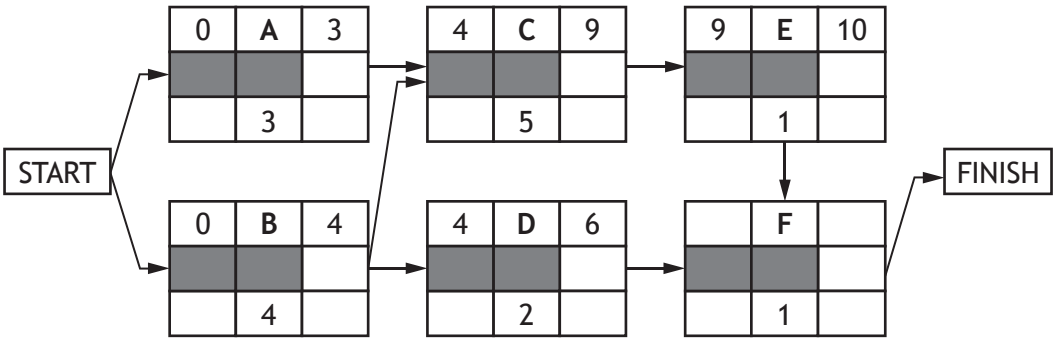
Write your answers clearly in the spaces provided in this booklet.

Use **blue** or **black** ink. Sketches, diagrams and graphs may be drawn in pencil.

Before leaving the examination room you must give your answer booklet **and** worksheets to the Invigilator; if you do not, you may lose all the marks for this paper.

DO NOT WRITE IN THIS MARGIN

Worksheet for question 1 (a)

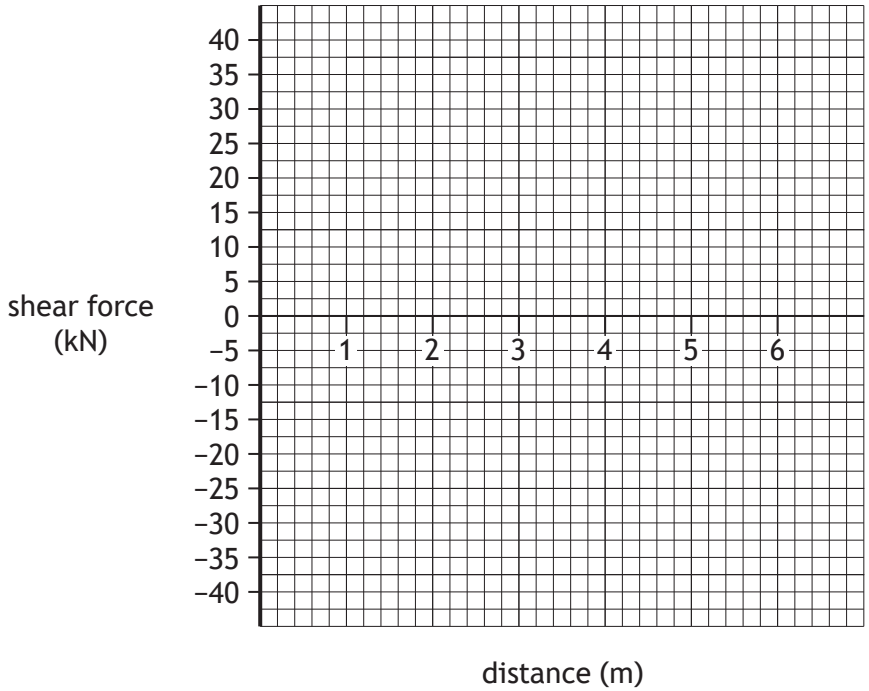


Critical path _____

DO NOT WRITE IN THIS MARGIN

Worksheet for question 6 (a)

Space for working



[END OF SPECIMEN WORKSHEETS]

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Qualifications
SPECIMEN ONLY

S823/77/11 Engineering Science

Marking Instructions

These marking instructions have been provided to show how SQA would mark this specimen question paper.

SQA
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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.

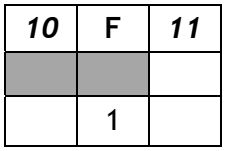
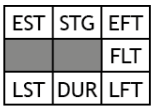
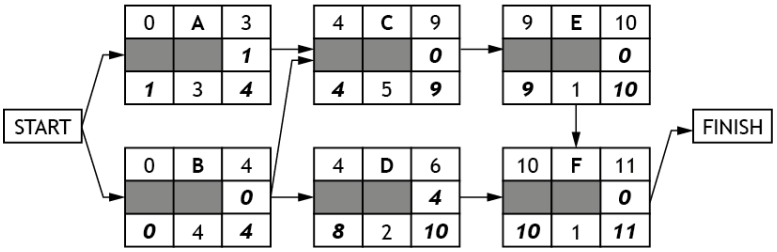
(i) Candidates can answer programming questions in any appropriate programming language. Award marks where the intention of the coding is clear, even where there are minor syntax errors.

(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.

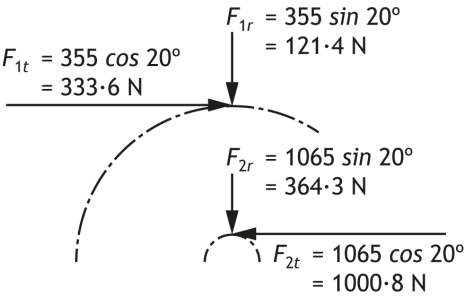
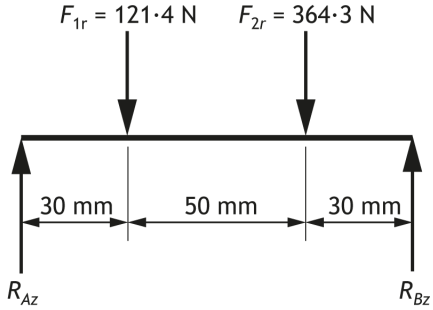
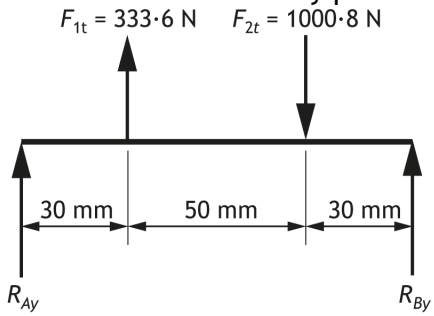
(k) Where separate space is provided for rough working and a final answer, only award marks for the final answer. Ignore all rough working.

Marking instructions for each question

Section 1

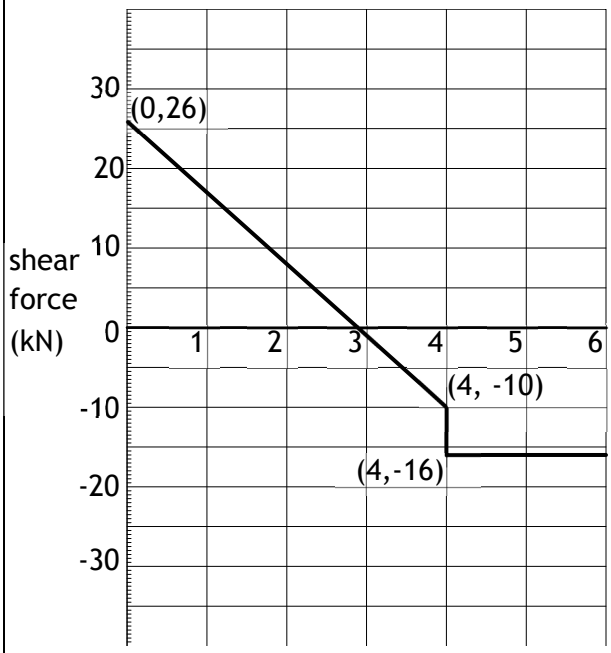
Question			Expected response	Max mark	Additional guidance
1.	(a)	(i)	  	**3**	**1 mark** Earliest start time for activity F from consideration of earliest finish times of activities D and E and earliest finish time for activity F completed correctly. **1 mark** Latest start time and latest finish times completed correctly. **1 mark** Floats completed correctly.
		(ii)	Critical path: B,C,E,F	**1**	**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/run late and if the skills base existed in the workforce to be able to undertake the various stages in the work schedules/activities. Human resources could be switched from D to B or C or if either begins to lag/run late and if the skills base existed in the workforce to be able to undertake the various stages in the work schedules/activities.	**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 response	Max mark	Additional guidance
2.	(a)		Minimum frequency $f_{min} = \frac{1}{2\pi\left(560 \times 6{\cdot}8 \times 10^{-6}\right) \times 1{\cdot}05^2}$ =38 Hz Maximum frequency $f_{max} = \frac{1}{2\pi\left(560 \times 6{\cdot}8 \times 10^{-6}\right) \times 0{\cdot}95^2}$ =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 $f = \frac{1}{2\pi\left(560 \times 6{\cdot}8 \times 10^{-6}\right) \times 1{\cdot}00^2}$ = 42Hz
	(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 response	Max mark	Additional guidance
3.	 'vertical forces' on x – z plane  Take moments about B (right-hand end of shaft) $\Sigma M_B = 0$ $(R_{Az} \times 110) - (121{\cdot}4 \times 80) - (364{\cdot}3 \times 30)$ $= 0$ $\boldsymbol{R_{Az} = 187{\cdot}6\ \text{N}}$ 'horizontal forces' on x – y plane  Take moments about B (right-hand end of shaft) $\Sigma M_B = 0$ $(R_{Ay} \times 0{\cdot}11) + (333{\cdot}6 \times 0{\cdot}08$ $-(1000{\cdot}8 \times 0{\cdot}03) = 0$ $\boldsymbol{R_{Ay} = 30{\cdot}3\ \text{N}}$ Calculate the magnitude of the reaction at bearing A $\lvert R_A \rvert = \sqrt{187{\cdot}6^2 + 30{\cdot}3^2}$ $\boldsymbol{\lvert R_A \rvert = 190\ \text{N} (3\ \text{s.f.})}$ $\theta = \tan^{-1}\left(\frac{187{\cdot}6}{30{\cdot}3}\right) = 80{\cdot}8°$	**5**	**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 for magnitude. **1 mark** Answer for angle. Note: sense of angle must be clear.

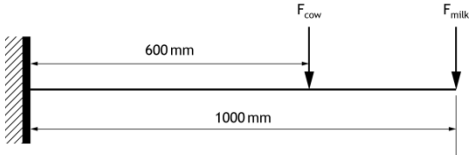
Question			Expected response	Max mark	Additional guidance
4.	(a)		$R_c = \frac{7{\cdot}5}{1\times10^{-3}} = 7{\cdot}5\ \text{k}\Omega$ $R_e = \frac{1}{1{\cdot}01\times1\times10^{-3}} = 990\ \Omega$ accept $R_e = \frac{1}{1\times10^{-3}} = 1\ \text{k}\Omega$	**2**	**1 mark** Calculate R_c correctly. **1 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)		$V_b = 1 + 0{\cdot}6 = 1{\cdot}6\ \text{V}$ $I_b = \frac{1\times10^{-3}}{100} = 10\ \mu\text{A}$	**1**	**1 mark** Calculate V_b and I_b.
	(c)		$I_{R2} = 100\ \mu\text{A}$ $R_2 = \frac{1{\cdot}6}{100\times10^{-6}} = 16\ \text{k}\Omega$ $I_{R1} = 100\ \mu\text{A} + 10\ \mu\text{A}$ $R_1 = \frac{13{\cdot}4}{110\times10^{-6}} = 122\ \text{k}\Omega$	**2**	**1 mark** Calculate R_2 correctly. **1 mark** Calculate R_1 correctly.

Question			Expected response	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 × 0·994 × 0·992 × 0·903 = 0·775 77·5% of the electricity used to pump water is returned to the National 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. **OR** **1 mark** Calculate combined efficiency of the pumping and generating process, but not accounting for flow loses correctly. *Efficiency* = 0·870 × 0·903 = 0·786
	(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. Accept Renewable energy sources may generate surplus power but at unpredictable times; any surplus should be stored if possible for use when demand is higher or generation is insufficient to meet demand.

Question			Expected response	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. $\Sigma M_A = 0$ $\left(9 \times 4 \times \frac{4}{2}\right) + (6 \times 4) - (R_B \times 6) = 0$ $R_B = \frac{96}{6}$ $R_B = 16 \text{ kN}$ $\Sigma F_V = 0$ $R_A - (9 \times 4) - 6 + R_B = 0$ $R_A = 26 \text{ kN}$ shear force diagram  	**4**	Candidates may use an alternative convention for force and moment 'direction' from that 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 (sloping line) $0 < x < 4$. **1 mark** Point load represented correctly on the diagram at $x = 4$. **1 mark** Constant shear force shown on diagram for $4 < x < 6$.
	(b)		Bending moment equation *For* $0 < x < 4$ $R_A x - 9x\left(\frac{x}{2}\right) - M_B = 0$ $M_B = 26x - \frac{9}{2}x^2$	**2**	**1 mark** Correct term for moment due to reaction at left-hand end (need not be simplified). **1 mark** Correct term for moment due to UDL (need not be simplified).

Question			Expected response	Max mark	Additional guidance
6.	(c)		Bending moment is potentially a maximum value when $\frac{dM_B}{dx} = 0$ $\frac{dM_B}{dx} = 26 - 9x$ $26 - 9x = 0$ $x = 2{\cdot}8888\ldots$ $x = 2{\cdot}89\ \text{m}(3\ \text{s.f.})$ $M_B = 26(2{\cdot}8888\ldots) - \frac{9}{2}(2{\cdot}8888\ldots)^2$ $M_B = 37{\cdot}5555\ldots$ $M_B = 37{\cdot}6\ \text{kNm}(3\ \text{s.f.})$ OR graphically, $(0,26),(4,-10)$ $m = \frac{y_2 - y_1}{x_2 - x_1}$ $m = \frac{26-(-10)}{0-4} = -9$ $y = mx + c$ $(0,26) \Rightarrow c = 26$ $y = -9x + 26$ When $y = 0$ $0 = -9x + 26$ as above.	**2**	**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). Note that the magnitude of the gradient is the magnitude of the UDL, so working not required.
	(d)		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 because material stress determines failure; it is proportional to bending moment and to y/I, which relates to beam cross section and so is constant. **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 according to My/I and y/I is constant. y/I should be small enough to ensure an adequate factor of safety at this point.	**2**	**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. **1 mark** Candidate must make a link to elastic beam bending equation in the explanation.

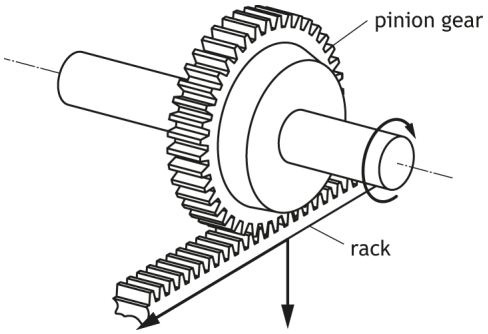
Section 2

Question			Expected response	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 $y = \frac{70}{2} = 35$ mm $I_{xx} = \frac{BD^3}{12} - \frac{bd^3}{12}$ $I_{xx} = \frac{30 \times 70^3}{12} - \frac{23 \times 63^3}{12}$ $I_{xx} = 378{\cdot}24325 \times 10^3$ 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.f.) 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 $I_{xx} = \frac{30 \times 70^3}{12}$ $I_{xx} = 857{\cdot}5 \times 10^3$ 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 (note potential for two follow-through errors). **1 mark** Decision based on calculated stress and value extracted from the tables.

Question			Expected response	Max mark	Additional guidance
7.	(b)		$L = 1000$ mm, $a = 600$ 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 $\delta = \frac{Pa^2}{6EI}(3L - a) = 16{\cdot}0$ mm$(3$ 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 $91{\cdot}3^2 \times 0{\cdot}03144 = 262$ W Efficiency = $\frac{21000}{21000 + 262} \times 100\% = 98{\cdot}8\%$	**2**	**1 mark** Calculate power loss. **1 mark** Calculate efficiency.

Question			Expected response	Max mark	Additional guidance
7.	(d)		At maximum load $V_{in} = 5\text{ V}$, $V_{signal} = 120\text{ mV}$ $V^+ = 0{\cdot}12 \times \left(-\frac{100k}{10k}\right)\left(-\frac{10k}{10k}\right) \times 1$ $= 0{\cdot}12 \times 10 = 1{\cdot}2\text{ V}$ $V^- = \frac{\left(10 \times 10^3\right)}{\left(250 \times 10^3\right)} \times 5 \times 1$ $= 0{\cdot}2\text{ V}$ $V_{in} = \frac{R_2}{R_1}\left(V^+ - V^-\right)$ $5 = \frac{1 \times 10^6}{R_1}\left(1{\cdot}2 - 0{\cdot}2\right)$ $R_1 = \frac{1 \times 10^6}{5} = 200\text{ k}\Omega$ When digital input = 0001 $V_{out} = \frac{5}{\left(2^4 - 1\right)} = 0{\cdot}\dot{3}\text{ V}$ $0{\cdot}\dot{3} = \frac{R_f}{R_A} \times 5$ $R_A = \frac{100 \times 10^3}{0{\cdot}\dot{3}} \times 5 = 1{\cdot}5\text{ M}\Omega$ $R_B = 750\text{ k}\Omega$ $R_C = 375\text{ k}\Omega$ $R_D = 182{\cdot}5\text{ k}\Omega$	**5**	**1 mark** Calculate voltage at output of follower attached to non-inverting terminal of difference amplifier. Calculate voltage at output of follower attached to inverting terminal of difference amplifier. **1 mark** Calculate R_1. **2 marks** Calculating R_A for 0001 (Value of V_{out}, corresponding value of R_A). OR calculating R_D $V_{out} = R_f\left(\frac{V_D}{R_D} + \frac{V_C}{2R_D} + \frac{V_B}{4R_D} + \frac{V_A}{8R_D}\right)$ $5 = \frac{100 \times 10^3}{R_D}\left(\frac{15}{8}\right)(5)$ $R_D = 182{\cdot}5\text{k}\Omega$ (Value of resistors as multiples of R_D, corresponding value of R_D). **1 mark** Calculating R_B, R_C and R_D.
7.	(e)		At self-weight, each sensor should read $5\text{ mV}\left(20\text{ mV}/4\right)$ For $V_{in} = -250\text{ mV}$ $-250 \times 10^{-3} = 5\left(\left(10 \times \Sigma V_{load}\right) - 0{\cdot}2\right)$ $-50 \times 10^{-3} = 10\left(\Sigma V_{load}\right) - 200 \times 10^{-3}$ $\Sigma V_{load} = \frac{150 \times 10^{-3}}{10}$ $\Sigma V_{load} = 15\text{ mV}$ One sensor has short circuited to ground giving a signal input of 0 V from this sensor.	**2**	**1 mark** Calculating ΣV_{load} 20 mV is the combined sensor output arising from self-weight of the weigh-bridge. **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 response	Max mark	Additional guidance
7.	(f)		ARDUINO **int mintemp = 0** Setting the minimum temperature to 0 prevents the minimum temperature from being set properly. When the condition if(temp < mintemp) is tested, since the actual temperature can never be below 0 degrees, the mintemp will not be changed. The line needs to be updated to a value higher than any expected temperature, int mintemp = 255; **if(maxtemp > temp)** This test is inverted and will result in no change to maxtemp as it will never exceed temp. The line needs to be modified to if(maxtemp < temp) or if(temp >maxtemp). PBASIC **let mintemp = 0** Setting the minimum temperature to 0 prevents the minimum temperature from being set properly. When the condition if temp < mintemp is tested, since the actual temperature can never be below 0 degrees, the mintemp will not be changed. The line needs to be updated to a value higher than any expected temperature, let mintemp = 255. **if maxtemp > temp then** This test is inverted and will result in no change to maxtemp as it will never exceed temp. The line needs to be modified to if maxtemp < temp or if temp >maxtemp.	**4**	**1 mark** Identify the line with an error in it and explain why it prevents the mintemp being updated. **1 mark** Describe a change to the initial value of mintemp in excess of the average temperature. **1 mark** Identify the line with the error in it and explain why it prevents the maxtemp being updated. **1 mark** Describe the correct change to the line.

Question			Expected response	Max mark	Additional guidance
8.	(a)		Tangential force from torque applied and radius of gear $T = F \times r$ $10 = F_t \times \frac{0{\cdot}045}{2}$ $F_t = 444{\cdot}4 \text{ N}$ $F_t = 440 \text{ N} (3 \text{ s.f.})$ Radial force due to gear geometry $F_r = F_t tan\theta$ $F_r = 444{\cdot}4 \times tan25°$ $F_r = 207 \text{ N} (3 \text{ s.f.})$  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 with reference to the diagram in the question.	**3**	**1 mark** Tangential component of force. **1 mark** Radial component of force $F_t = Fcos\theta$ $F_r = Fsin\theta$ $F_r = \frac{F_t}{cos\theta} sin\theta = F_t tan\theta$ **1 mark** Explanation of force direction (pinion gear forces are equal and opposite).
	(b)		Tangential force is the force that is applied to the steering arms; torque supplied by the driver. Resistance to turning is 100 Nm $T_{turn} = F_{rack} \times r$ $100 = F_{rack} \times 0{\cdot}15cos10°$ $F_{rack} = \frac{100}{0{\cdot}15cos10°} = 676{\cdot}95 \text{ N}$ Difference in rack force $= 676{\cdot}95 - 444{\cdot}44$ $= 232{\cdot}51 \text{ N}$ $= 233 \text{ N} (3 \text{ s.f.})$	**2**	**1 mark** Correct rack force, noting that the radius is less than 150 mm due to angle. Rack force applies to both wheels. **1 mark** Correct difference.

Question			Expected response	Max mark	Additional guidance
8.	(c)		For a webbed bracket, the cantilever beam cross sectional properties *I* and *y* change along the length of the beam and are largest at the wall where the maximum bending moment occurs. This means that the bracket can be lighter as there is less material at sections of the cantilever beam that have less applied bending moment.	**2**	**1 mark** Identifying that section properties *I* and *y* change along the length of the cantilevered element of the webbed bracket. **1 mark** Indication that the changing section properties allow the bracket to be optimised in terms of weight.
	(d)		During colder ambient temperatures the driver will use the car's electric heater more than normal to heat the cabin which will drain the battery and reduce range. Cold temperatures increase the internal resistance of the battery which lowers its capacity. Cold temperatures are likely to occur at times of year when there is less daylight and so the car headlights will be used more, draining the battery and reducing range. During warmer ambient temperatures, the driver will use the car's air conditioning more to cool the cabin which will drain the battery and reduce range.	**3**	**2 marks** Cause and effect of low temperatures on range (any two). **1 mark** Cause and effect of high temperatures on range.

Question			Expected response	Max mark	Additional guidance
8.	(e)		From the graph of V_{out}, period = 20 ms $T_1 = 0{\cdot}99 \times 20 \text{ ms} = 19{\cdot}8 \text{ ms}$ $T_2 = 20 \text{ ms} - 19{\cdot}8 \text{ ms} = 0{\cdot}2 \text{ ms}$ $T_2 = 0{\cdot}7 \times R_2 C$ $R_2 = \frac{0{\cdot}2 \times 10^{-3}}{0{\cdot}7 \times 0{\cdot}22 \times 10^{-6}} = 1{\cdot}3 \text{ k}\Omega$ $T_1 = 0{\cdot}7(R_1 + R_2)C$ $R_1 = \frac{19{\cdot}8 \times 10^{-3}}{0{\cdot}7 \times 0{\cdot}22 \times 10^{-6}} - 1300$ $R_1 = 127 \text{ k}\Omega$ $T_{on} = 1{\cdot}1RC$ $R_{series} = \frac{1{\cdot}4 \times 10^{-3}}{1{\cdot}1 \times 0{\cdot}1 \times 10^{-6}} = 12{,}727 \ \Omega$ $R_3 = 12{,}727 - 10{,}000 = 2{,}727 \ \Omega$ Precision motor angle $= \frac{0{\cdot}4}{0{\cdot}5} \times 90$ $= 72^\circ$	**5**	**1 mark** Extract period from the graph and calculate T_1 and T_2. **1 mark** Calculate R_2. **1 mark** Calculate R_1. Note $f = \frac{1{\cdot}44}{(R_1 + 2R_2)C}$ $(R_1 + 2R_2) = \frac{1{\cdot}44}{50 \times 0{\cdot}22 \times 10^{-6}}$ $(R_1 + 2R_2) = 130 \text{ k}\Omega$ Award mark for R_2 but not R_1 if this working is shown, but individual values are not subsequently found. **1 mark** Calculate R_3. **1 mark** Calculate precision motor angle.
	(f)		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 response	Max mark	Additional guidance

8.	(g)		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) and 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 SPECIMEN MARKING INSTRUCTIONS]