AH National Qualifications 2018

X723/77/11 Engineering Science

THURSDAY, 24 MAY

1:00 PM – 3:00 PM

Total marks — 60

Reference may be made to the Advanced Higher Engineering Science Data Booklet.

SECTION 1 — 30 marks

Attempt ALL questions.

SECTION 2 — 30 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 X723/77/21.

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.

X723711

B/PB

MARKS

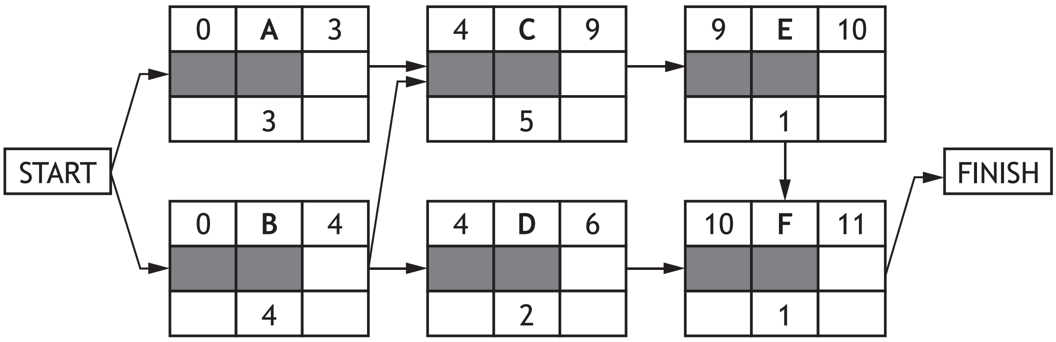
SECTION 1 — 30 marks

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

EST	STG	EFT
		FLT
LST	DUR	LFT

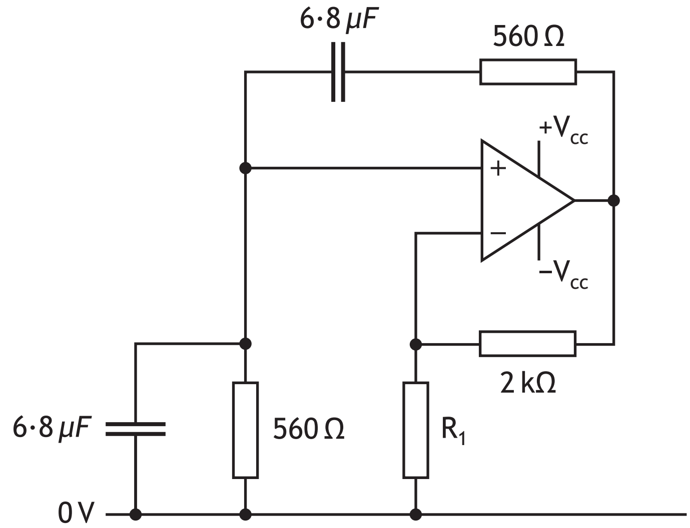


(a) Complete the activity network given on the **worksheet for question 1 (a)** by adding the latest finish time, the latest start time and the float for each of activities A–F, and hence identify the critical path. **3**

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

MARKS

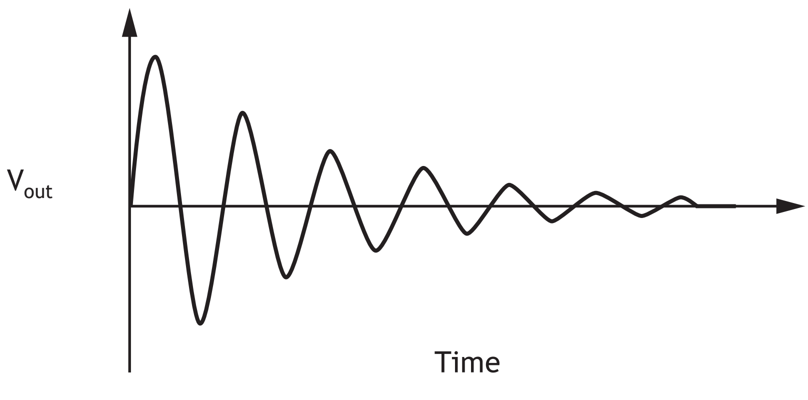
2. A Wien-bridge oscillator is being tested by a student.



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

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

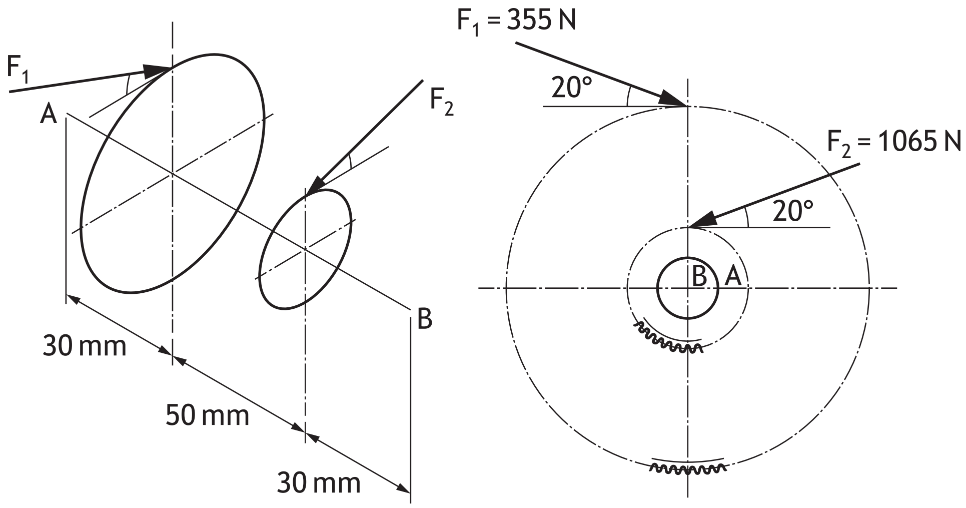
The student selects an incorrect resistor value for R_1 which produces the output waveform shown below.



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

[Turn over

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



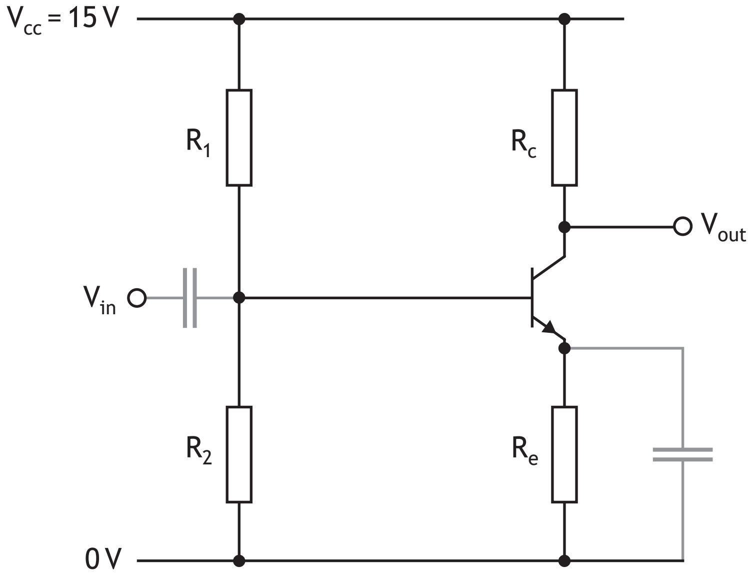
Not drawn to scale

Calculate the magnitude of the reaction at the bearing at A. **4**

MARKS

4. A student is designing an amplifier circuit based on the circuit shown below.

For component calculations, ignore the greyed-out components.



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

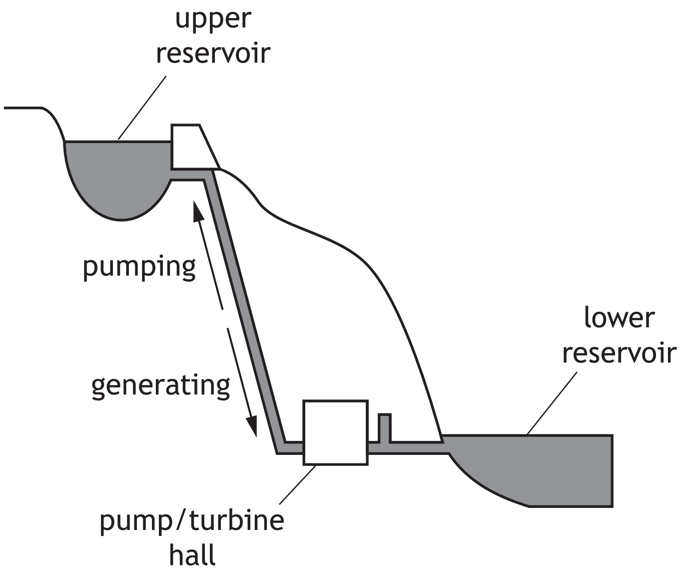
(a) Calculate values for R_c and R_e. **2**

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

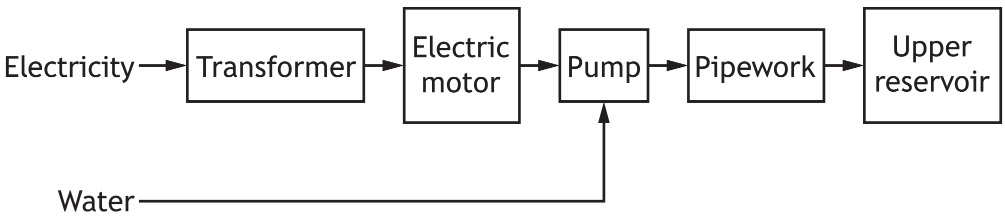
(c) Calculate values for R_1 and R_2 using the design rule $I_{R2} = 10I_b$. **2**

[Turn over

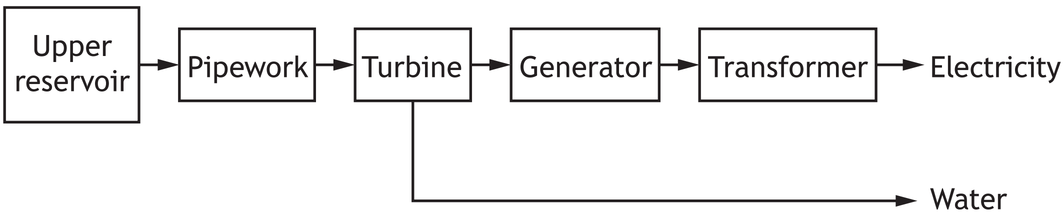
5. Two block diagrams for a hydropower pump-storage scheme similar to Cruachan in Scotland, are shown below.



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.

5. **(continued)** **MARKS**

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

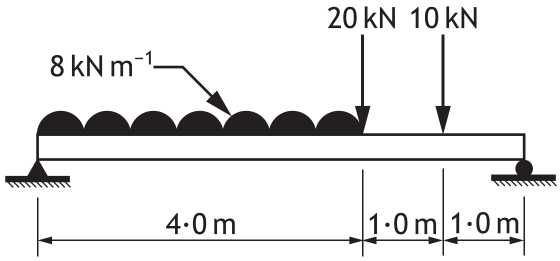
Cruachan pump-storage scheme can switch from pumping water to generating electricity in two minutes. It can generate up to 440 MW of electricity continuously for a maximum of 22 hours.

(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 static 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. **3**

(b) By considering the section of the beam $0 \leq x \leq 4$ from the left-hand end, find the position and magnitude of the maximum bending moment. **3**

(c) Give a reason 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. **1**

[Turn over for SECTION 2

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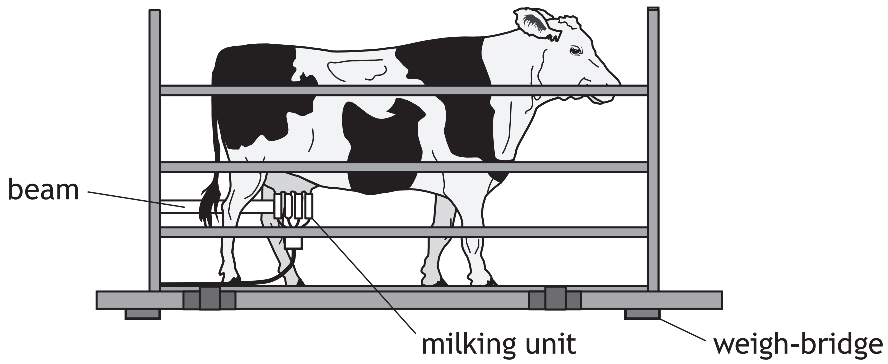
SECTION 2 — 30 marks

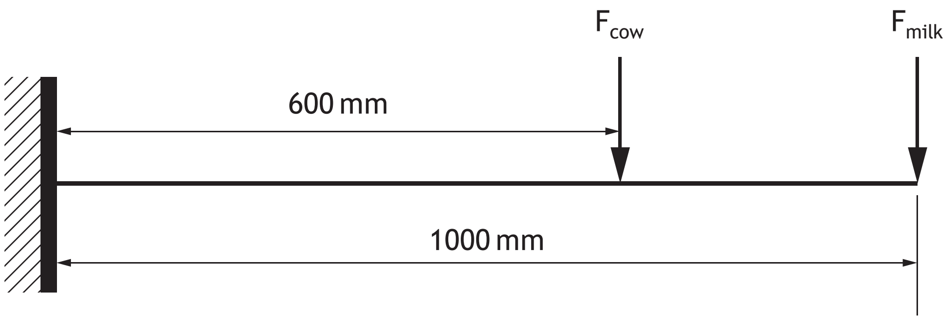
Attempt ALL questions

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.

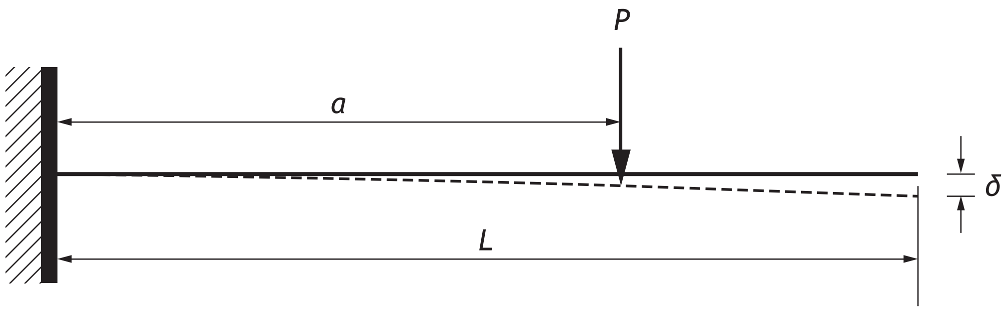
The beam has been designed to not only carry the load of the milking unit, but also to be strong enough to support 300 kg, a part of the weight of the cow should it sit down on the device. The added load of the cow would act 600 mm from the wall.



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

7. (continued) **MARKS**

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**

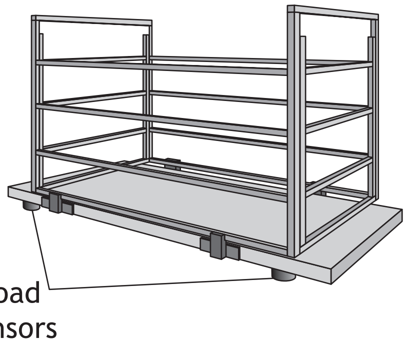
The automated milking unit has a total resistive power consumption of 21 kW and is supplied from a single-phase line 60 m long. The cable resistance is 0·524 Ω/km. The single-phase voltage at the machine is 230 V.

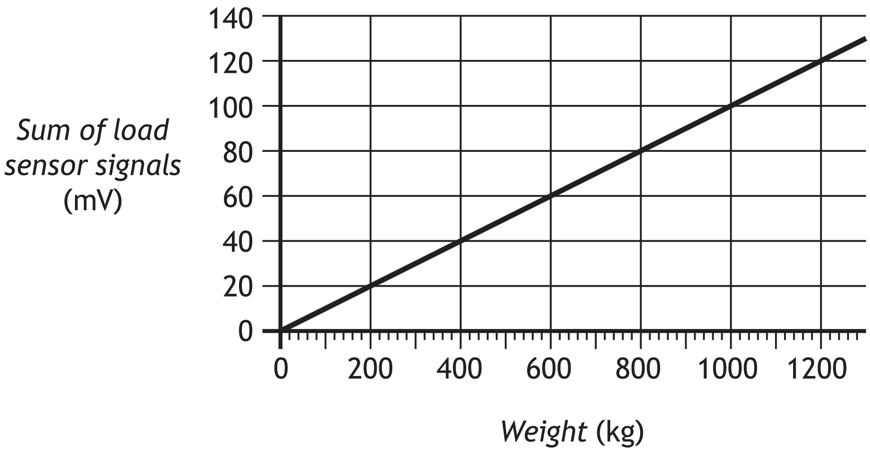
(c) Calculate the power loss arising from the line resistance and hence the efficiency of the line. **2**

[Turn over

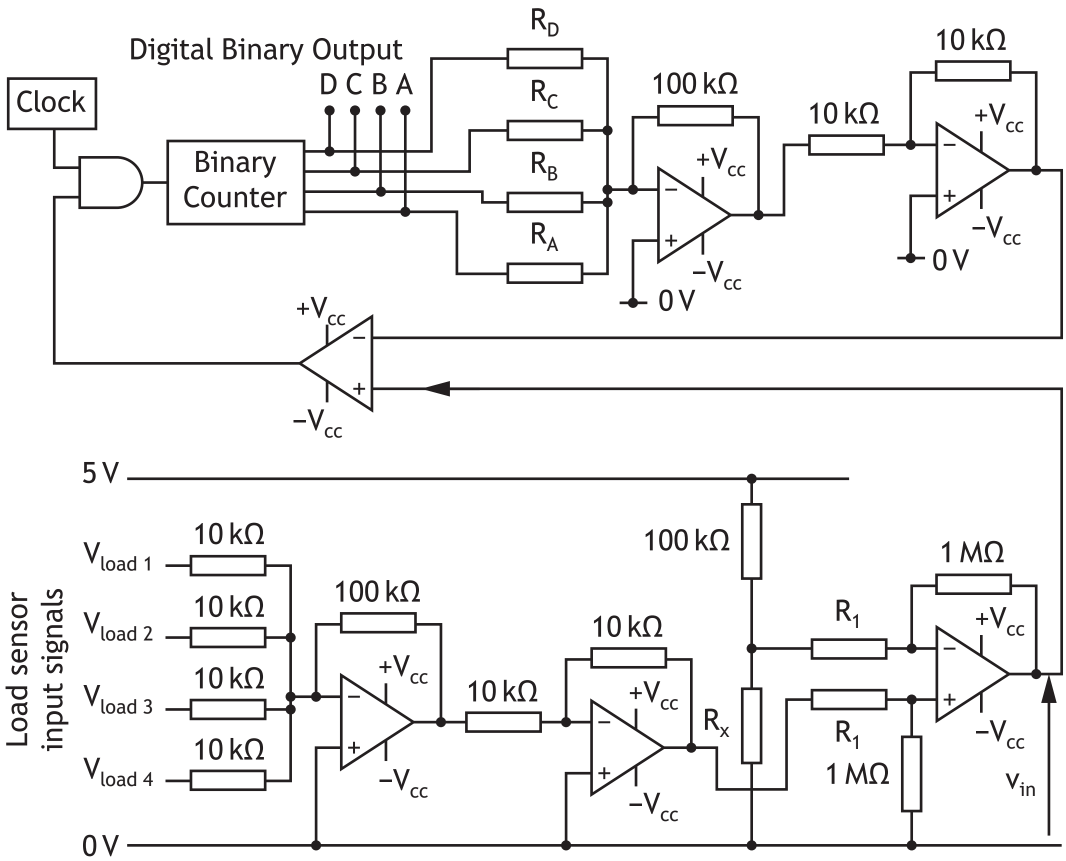
7. (continued)

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.



MARKS

7. **(continued)**

- The self-weight of the weigh-bridge is 200 kg.
- The maximum load 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.

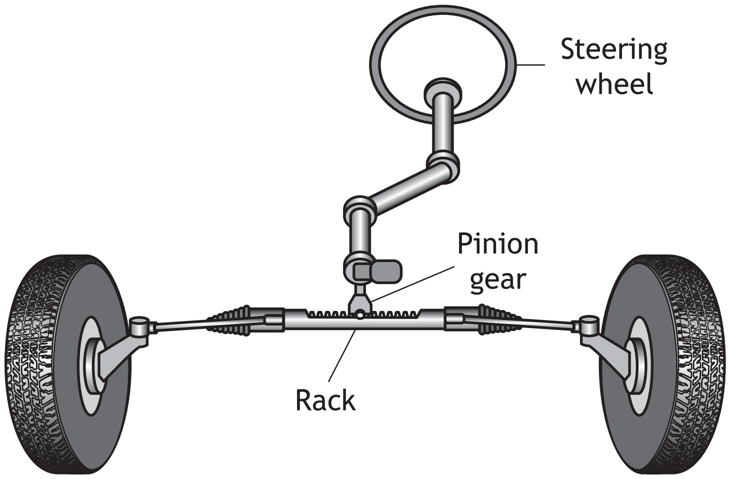
(d) Calculate the values of R_x, R_1, R_A, R_B, R_C and R_D. **4**

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.

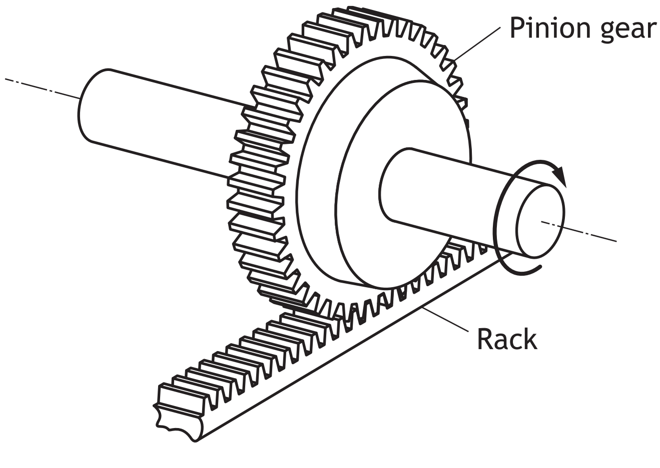
(e) Calculate the sum of the load voltages for this value of V_{in} and then explain how this reading may have occurred. **2**

[Turn over

8.



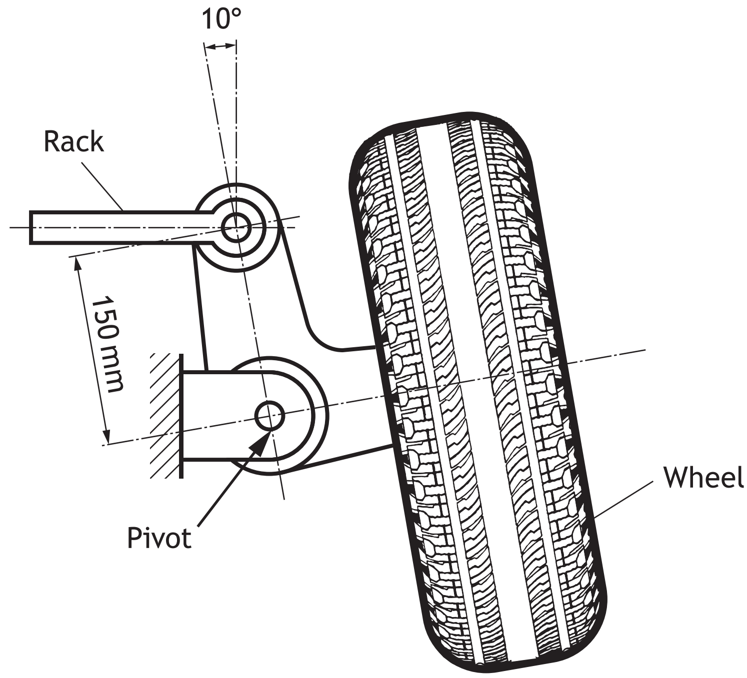
The steering mechanism for a car, shown above, comprises a steering wheel connected to a toothed bar called a 'rack' via a 'pinion' gear. The pinion gear is fixed in location and is free to rotate. The rack moves to the left or to the right depending on the direction of rotation of the pinion gear. The 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. **3**

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 sketch of the plan view for the arrangement for one wheel is shown below.



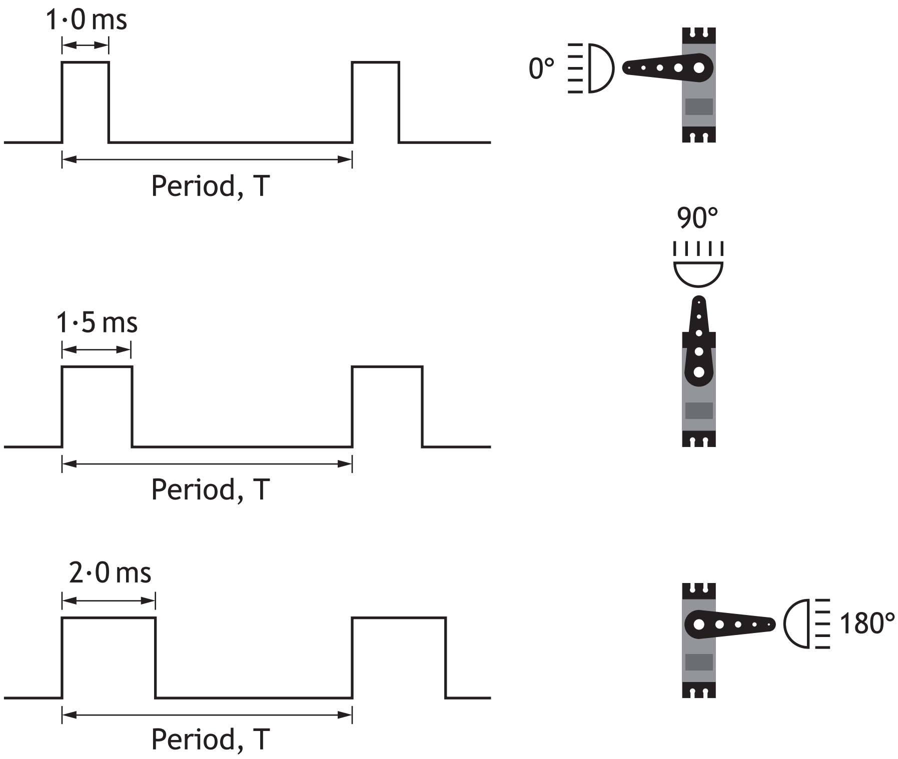
(b) Calculate the required force in the rack to turn the wheels and hence the additional force supplied to the rack by the power steering system. **2**

[Turn over

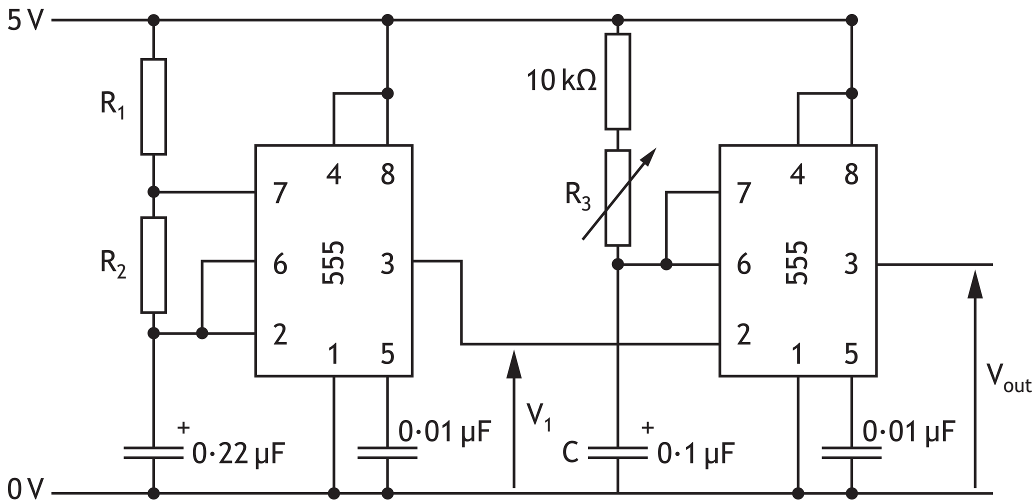
8. (continued)

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.

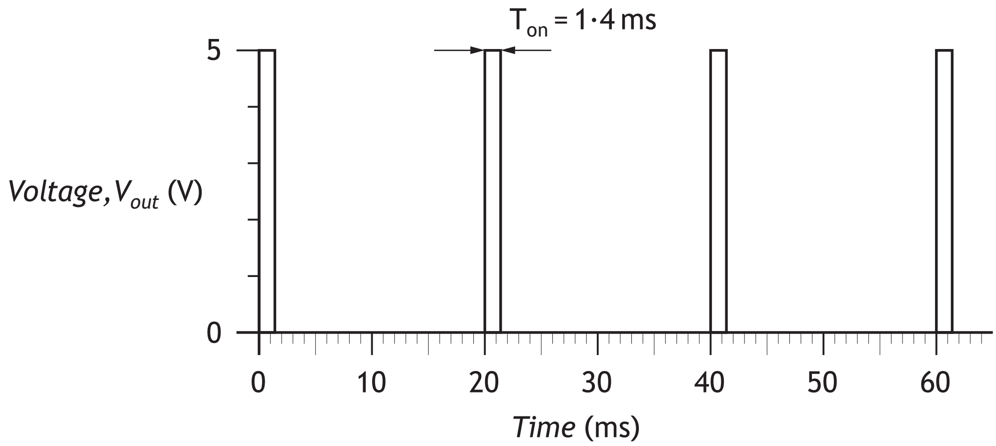


The motor waveforms are produced using the circuit shown below.



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}.



The mark time is calculated using:

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

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

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

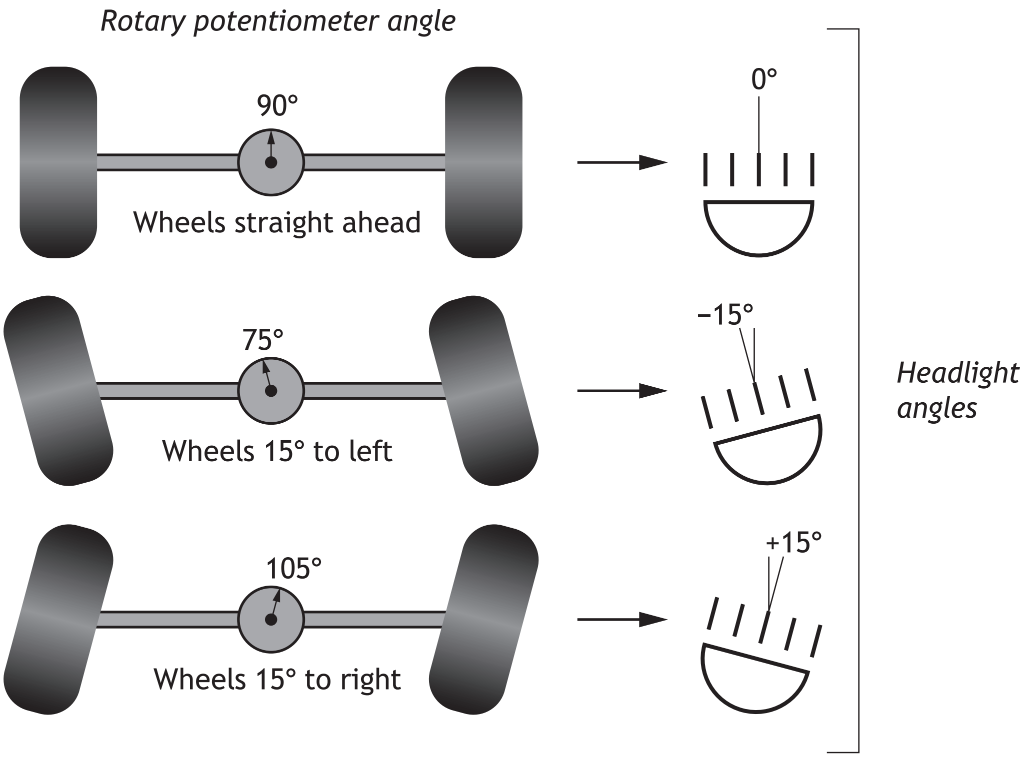
[Turn over

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 part (c).
- 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.



8. (continued)

Programming commands to produce time delays

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

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

[Turn over

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;
}
	SECTION A

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

BASIC

```
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
	SECTION A

LET mark = wheel_angle*1000/255+1000 LET space = 20000 – mark HIGH 3 PAUSEMICRO mark LOW 3 PAUSEMICRO space return	**SECTION B**

8. (continued) **MARKS**

(d) Explain the purpose of the program lines in section A, and show how the numbers 106 and 149 have been calculated. **2**

After testing the program and finding faults, section B was modified as shown below.

ARDUINO	BASIC

mark=wheel_angle * 100/255 + 100;
mark = mark * 10;
space = 2000 – mark;
 	
digitalWrite(3,HIGH);
delayMicroseconds (mark);
digitalWrite(3,LOW);
delay(18);
delayMicroseconds(space);
 	
}
	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

(e) Explain why the lines highlighted were altered. **3**

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National Qualifications 2018

Mark

X723/77/21

Engineering Science Worksheets

THURSDAY, 24 MAY

1:00 PM – 3:00 PM

* X 7 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.

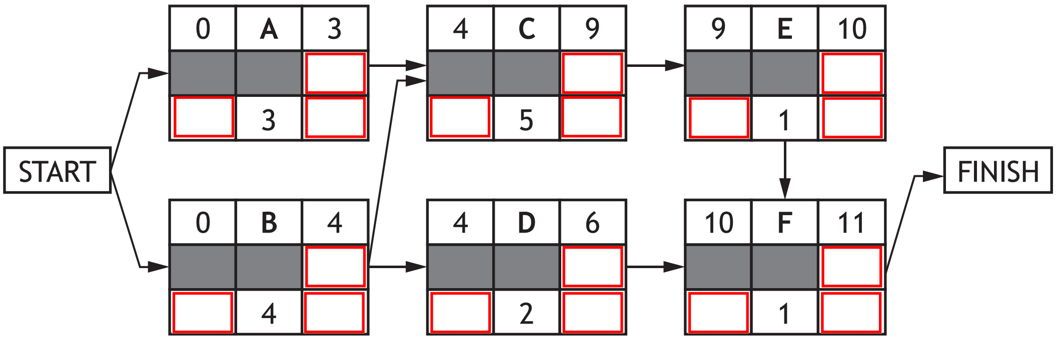
Use **blue** or **black** ink. Sketches, diagrams and graphs may be drawn in pencil.

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.

* X 7 2 3 7 7 2 1 0 1 *

A/PB

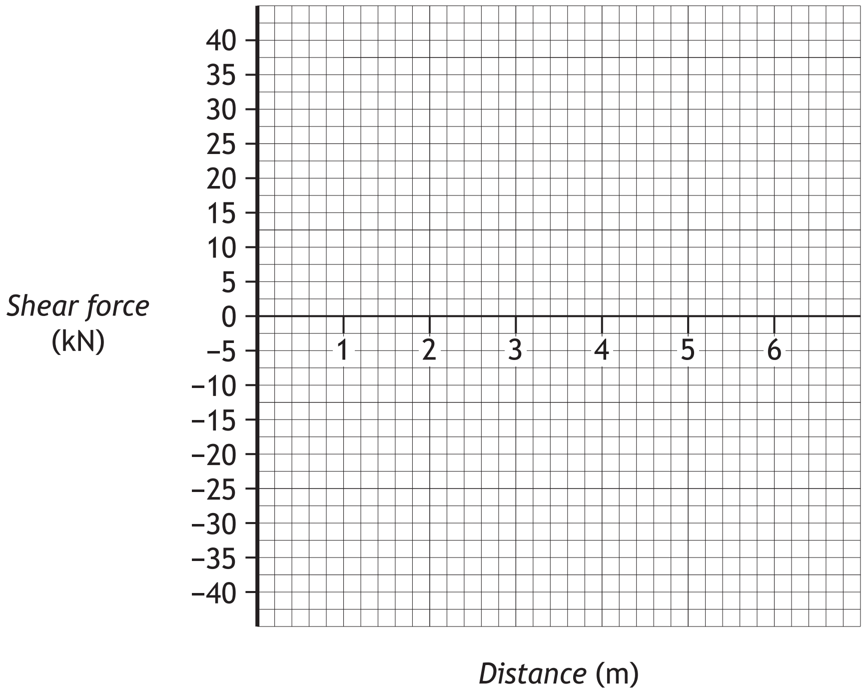
Worksheet for question 1 (a)



Critical path

Worksheet for question 6 (a)

Space for working



[END OF WORKSHEETS]

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X723/77/01

Engineering Science Answer Booklet

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

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For marker's use	
Question	Marks