National Qualifications 2025

X823/77/11 Engineering Science

FRIDAY, 16 MAY

1:00 PM – 3:30 PM

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), 2, 4 (a), 10 (c) and 10 (d), write your answers clearly in the worksheets provided in the answer booklet.

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 to the Invigilator; if you do not, you may lose all the marks for this paper.

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B/SQA

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SECTION 1 — 35 marks **MARKS**

Attempt ALL questions

1. A capital project is divided into several phases, A to I. The precedents for each phase and the planned duration of each phase are detailed in the precedence table below.

Phase	Stage	Precedent	Duration (months)
Feasibility	A	--	4
Planning	B	A	4
Procurement	C	A	8
Recruitment	D	B, C	2
Groundwork	E	B, C	9
Utilities	F	D, E	7
Main build	G	E	5
Commissioning	H	G	3
Handover	I	F, H	1

(a) Using the precedence table and the **worksheet for question 1 (a)**:

(i) complete the activity network diagram by adding precedence arrows to stages D to G **1**

(ii) add the latest finish time, the latest start time, and the float for each of stages D to G **3**

(iii) identify the critical path. **1**

Project Management includes five main process groups, one of which is the Project **Planning** phase.

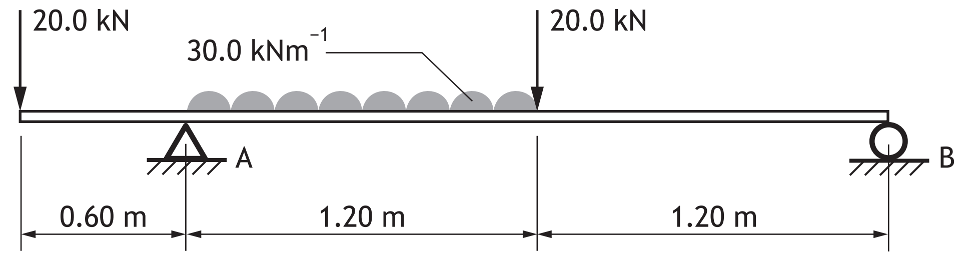
This may involve the following steps:

- estimate budget
- estimate resources required
- anticipate risks on time.

(b) Explain what a Project Manager would do in one of these steps. **2**

[Turn over

2. A simply supported beam is loaded with two point loads and a uniformly distributed load, as shown below.

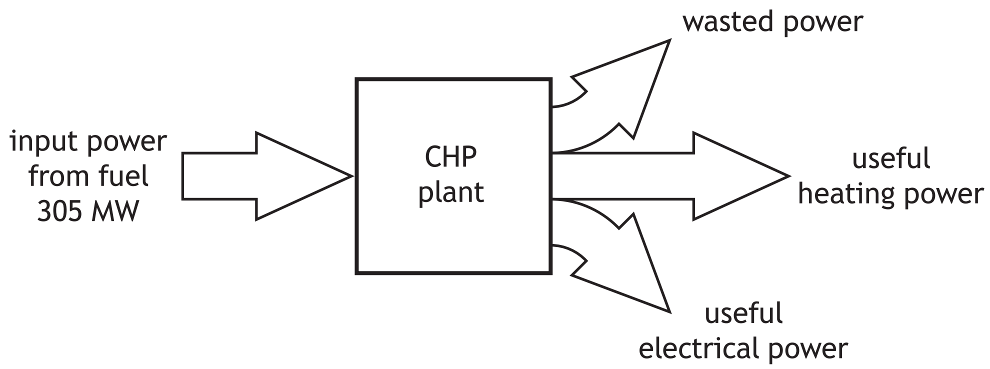


On the **worksheet for question 2**, draw the shear force diagram for the beam under the applied loads. **5**

3. Traditional power stations are designed solely to produce work (to generate electricity).

A Combined Heat and Power (CHP) plant is designed to provide useful work and heat.

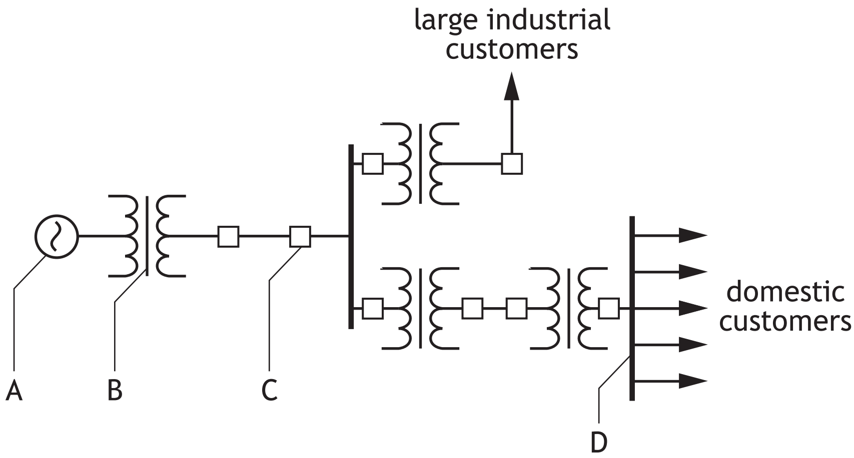
The energy audit for a CHP plant is shown below. The overall efficiency of the plant is 82%, and the ratio of useful heating power to useful electrical power is 5:3.



Calculate the efficiency of the CHP plant for electricity generation. **3**

MARKS

4. A simplified electricity supply line diagram is shown below.



(a) Identify the electricity supply line components that symbols A, B, C and D represent by placing each letter next to the correct component in the table on the **worksheet for question 4 (a)**. **2**

(b) Describe the function of:

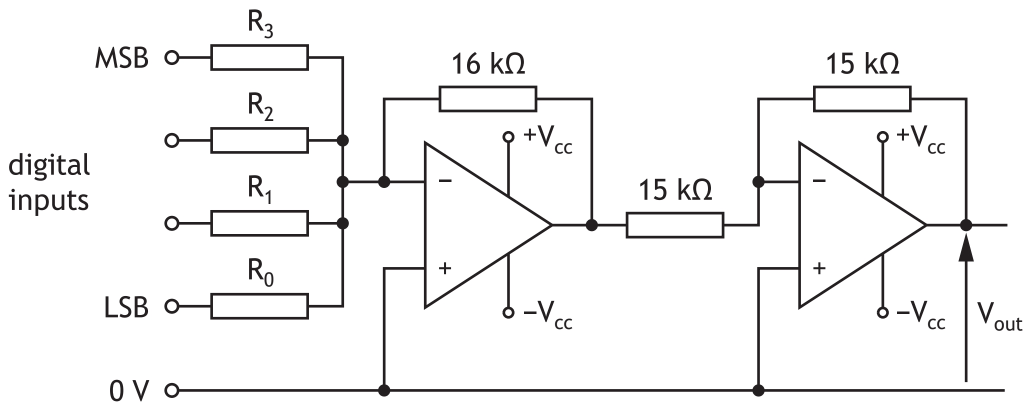
(i) a busbar **1**

(ii) a circuit breaker. **1**

[Turn over

MARKS

5. A student builds a 4-bit digital to analogue convertor (DAC). The circuit is shown below.



Circuit specifications:

Logic 1 = 5.0 V

Logic 0 = 0 V

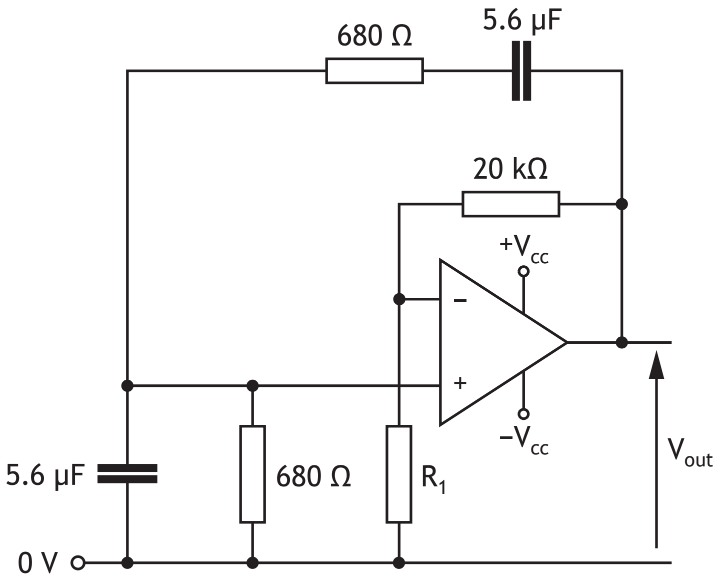
V_{out} = +10.0 V when digital input is 1111_{LSB}

(a) State the purpose of the inverting amplifier within the DAC circuit. **1**

(b) State the number of different digital input combinations that this configuration of DAC will accept. **1**

(c) Calculate required resistor values R_0, R_1, R_2 and R_3. **3**

6. A student is testing a Wien bridge oscillator. The circuit is shown below.

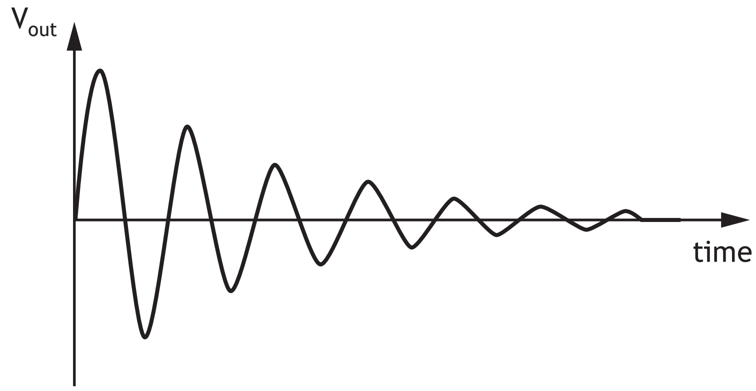


The 680 Ω resistors have a 1% tolerance and the 5.6 μF capacitors have a 5% tolerance.

(a) Calculate the **highest** possible frequency at which this circuit would be expected to oscillate when tested. **2**

(b) State the value of R_1 that will produce and maintain a stable amplitude sine wave. **1**

The student tested their circuit but selected an incorrect value for R_1. The output waveform the circuit produced is shown below.



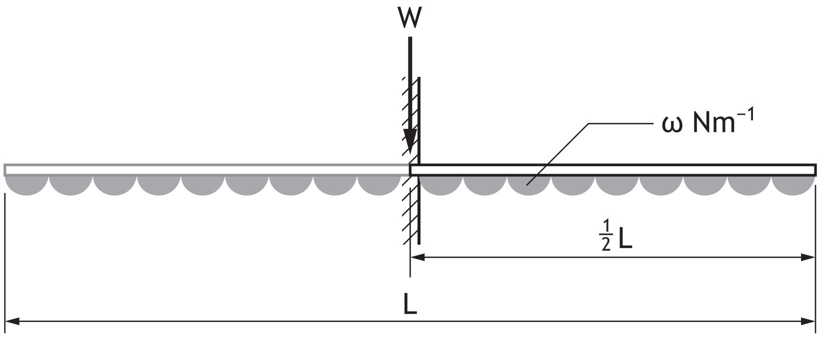
(c) State whether too large or too small a value of R_1 has been used. **1**

[Turn over

MARKS

7. A 102 kg person stands in the middle of a paddleboard. The board is 2.5 m long and is made from polystyrene, with a Young's Modulus of 3.25 $GN\,m^{-2}$.

To determine deflection, the board can be modelled as two rectangular cross-section cantilever beams with a uniformly distributed load (UDL) applied due to the water buoyancy force, acting symmetrically about a central point load to balance the person's weight.



(a) Calculate the magnitude of the UDL, ω Nm^{-1}, required to balance the weight, W, of the person. **1**

The board is assumed to have a constant rectangular cross-section of breadth 690 mm and thickness 75 mm.

(b) Calculate the deflection of the free end of the board in relation to its centre. **3**

MARKS

8. A stair lift carries a person between two floors (floor 1 and floor 2) of a house.

During the design of a microcontroller-based control system for this stair lift, a student needs to produce an 8-bit variable, called ‘flag’, containing the logical state of the five input switches connected to pins 2–6 of the data port.

Pins 7, 1 and 0 are used as outputs and should be set to zero in the variable ‘flag’.

INPUT	PORT	OUTPUT
	7	
Emergency	6	
Call floor 1	5	
Call floor 2	4	
Floor 1 limit switch	3	
Floor 2 limit switch	2	
	1	
	0	

The student sets the PORT register to the binary value 11111111, so that the required value of ‘flag’ becomes binary value 01111100.

The student tests three commands that perform bitwise logic between two registers:

PBASIC

(1) flag = PORTB | %01111100 (bitwise OR)

(2) flag = PORTB & %01111100 (bitwise AND)

(3) flag = PORTB ^ %01111100 (bitwise XOR)

ARDUINO

(1) flag = PORTD | 0b01111100 (bitwise OR)

(2) flag = PORTD & 0b01111100 (bitwise AND)

(3) flag = PORTD ^ 0b01111100 (bitwise XOR)

Note that 00110000 | 01010000 gives the result 01110000, where numbers are binary.

Determine which of the three commands should be used, stating the binary value of ‘flag’ that results in each case. **3**

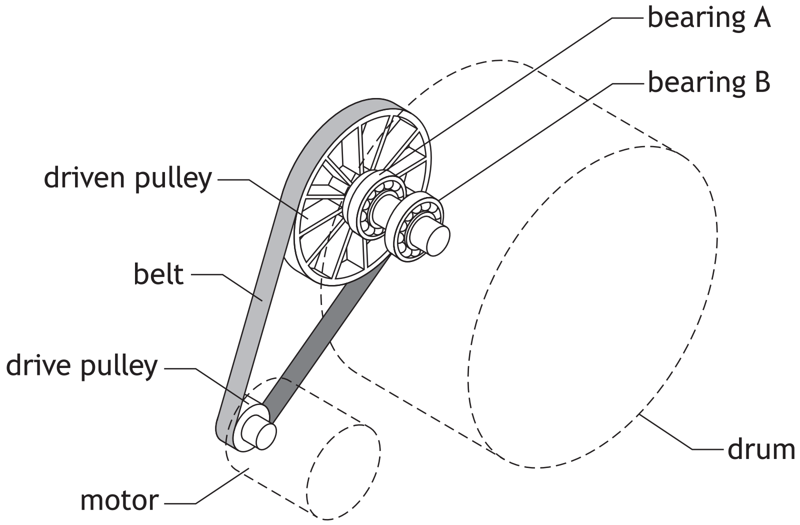
[Turn over

SECTION 2 — 40 marks

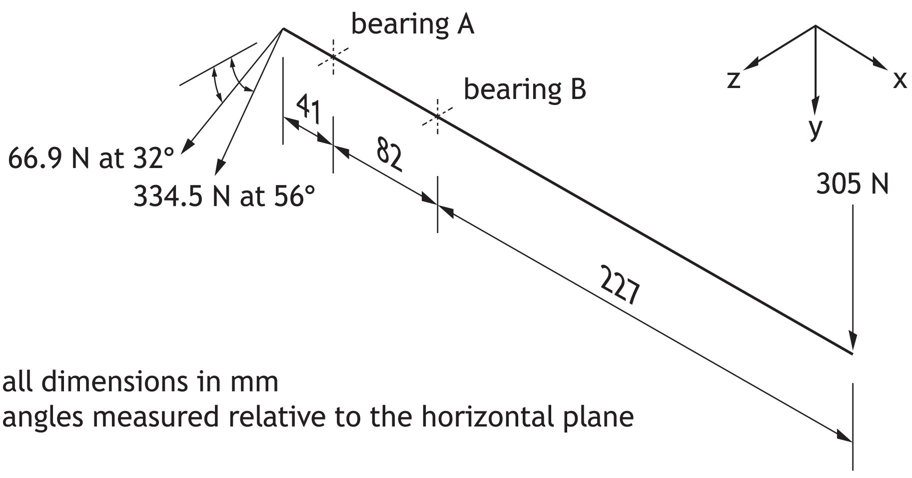
Attempt ALL questions

9. An image of an industrial tumble dryer is shown below.

An electric motor rotates the drum in either direction via a belt drive, as shown below.



The diagram below shows the external forces acting on the shaft that connects the driven pulley to the drum. The two forces at the left-hand end represent the tensions in the belt when running and the vertical force at the right-hand end represents the weight of the drum when fully-loaded.

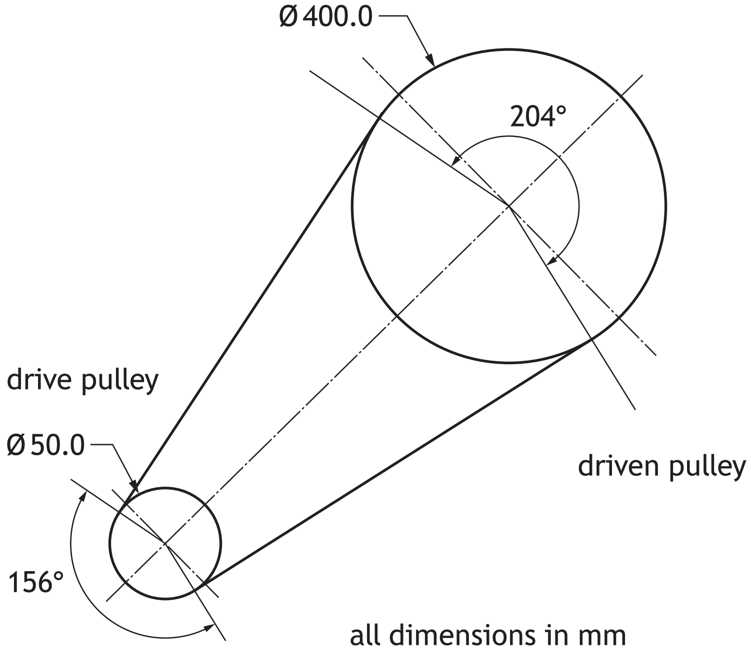


MARKS

9. (continued)

(a) Calculate the magnitude of the reaction at bearing B, shown opposite. **5**

A diagram of the belt drive geometry is shown below. The pulley diameter and the belt contact angle for each pulley are given.



The slack side of the belt has a tension of 66.9 N, the tight side of the belt has a tension of 334.5 N and the driven pulley turns at a constant speed of 175 revs min^{-1}.

(b) Calculate the power delivered by the motor to the drive pulley. **2**

The ratio of tensions of the belt such that there is no slip, is given by the equation

$$\frac{F_{max}}{F_{min}} \leq e^{\mu\theta}$$

where: F is tension (N)

μ is the coefficient of friction between the belt and the pulley

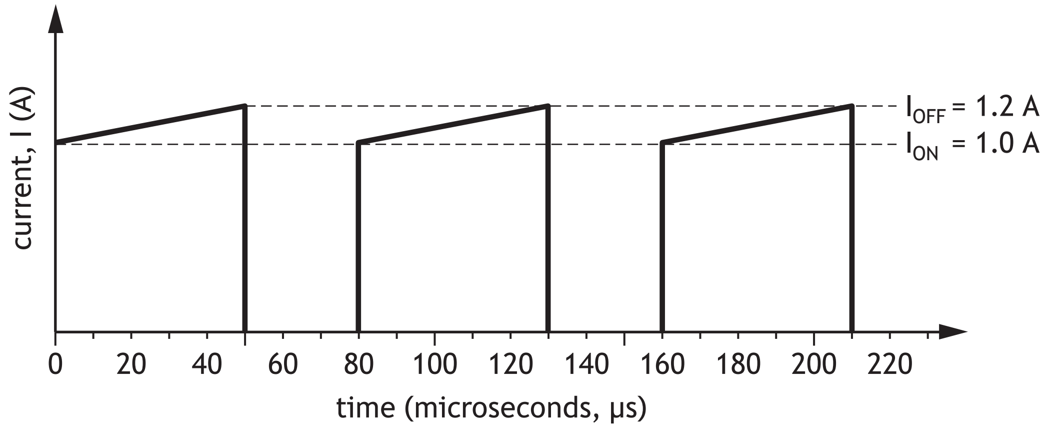
θ is the contact angle between the belt and the pulley, in radians (2π radians = 360°).

(c) Show that the belt does not slip when the coefficient of friction is 0.80. **2**

[Turn over

9. (continued)

The diagram below shows a pulse-width modulation (PWM) signal used to test the MOSFET-based drive circuitry for the drum motor. The current through the MOSFET increases slightly between it turning on and turning off. Both the frequency and duty cycle (the ratio of the 'on' time to the period of each pulse) are constant.



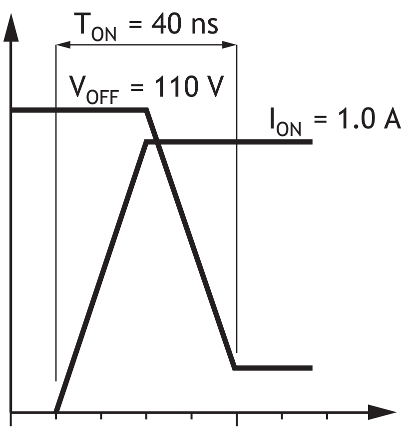
The power dissipated by the signal when the MOSFET is conducting is given by the formula

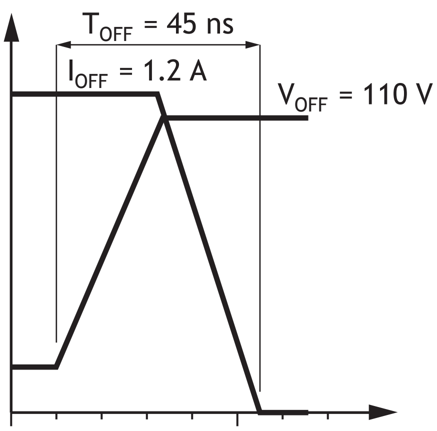
$$P_C = \frac{1}{3} \times D \times R_{DS(on)} \times (I_{ON}^2 + I_{ON} \times I_{OFF} + I_{OFF}^2)$$

where: D is the duty cycle

$R_{DS(on)} = 0.15\ \Omega$ for the MOSFET.

Data for the MOSFET switching characteristics are shown in the diagram below.





The power dissipated as the MOSFET switches on and as it switches off is given by the formula

$$P_{SW} = \frac{1}{2} \times f \times V_{OFF} \times (T_{ON} \times I_{ON} + T_{OFF} \times I_{OFF})$$

where: f is the PWM frequency.

(d) Determine the total power dissipation in the MOSFET. **3**

MARKS

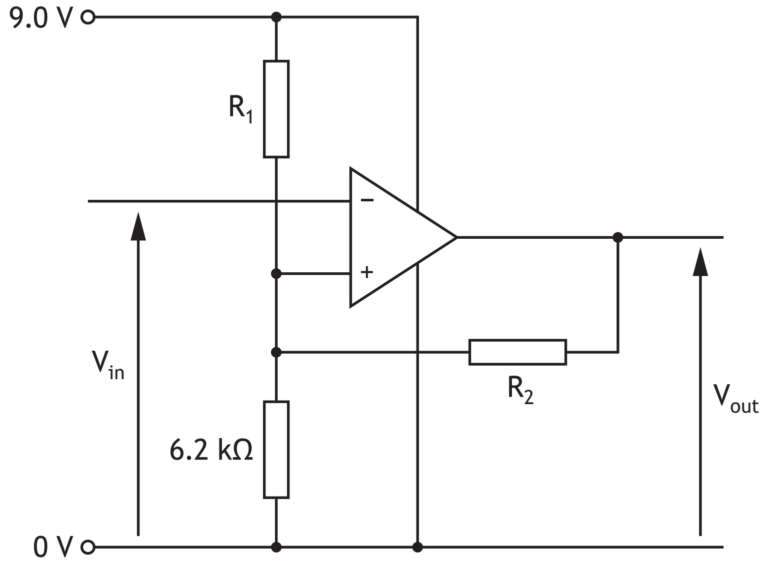
9. **(continued)**

The electronic control circuitry in the tumble dryer is designed to work from a 9 V DC supply derived from a 230 V AC supply.

(e) (i) Identify two electrical devices specified by the design engineer in order to produce the AC to DC conversion. **1**

(ii) Describe the function of each device. **2**

A sensor produces a pattern of electrical pulses which are counted to determine the drum motor speed. The noise on the pulses is removed using the Schmitt trigger circuit shown below.

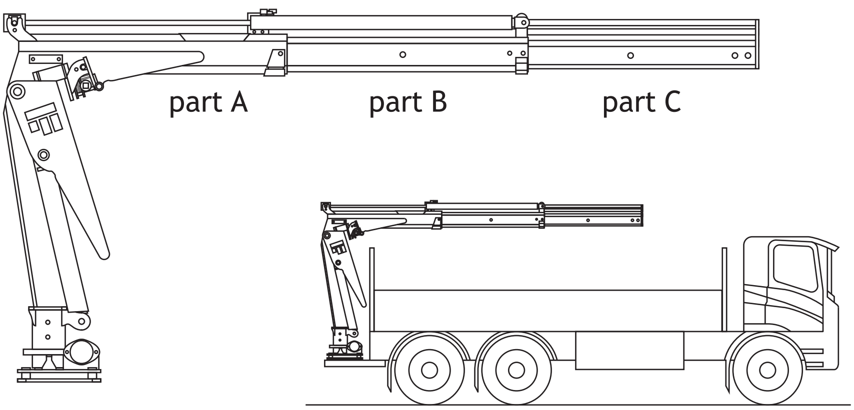


The op-amp output saturates at 7.5 V and 0 V. The required upper threshold voltage is 5.2 V, and the lower threshold voltage is 2.7 V.

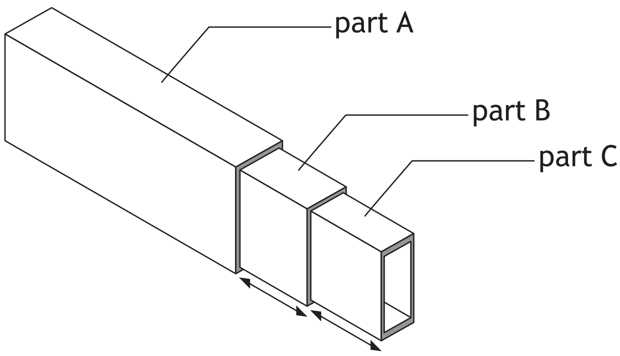
(f) Calculate, using nodal analysis, the required values for R_1 and R_2. **5**

[Turn over

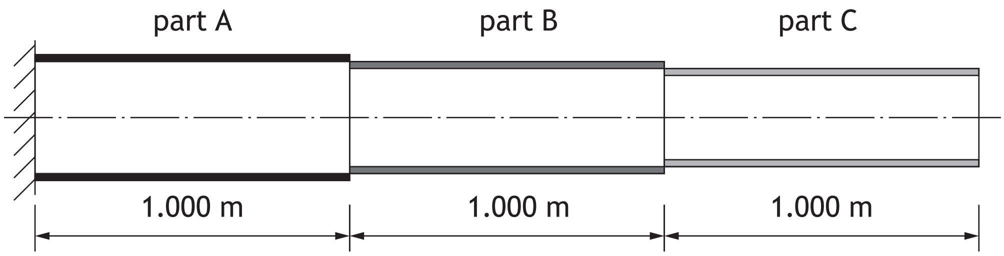
10. A telescopic boom arm crane is shown below. Two hydraulic cylinders move part B relative to part A and part C relative to part B.

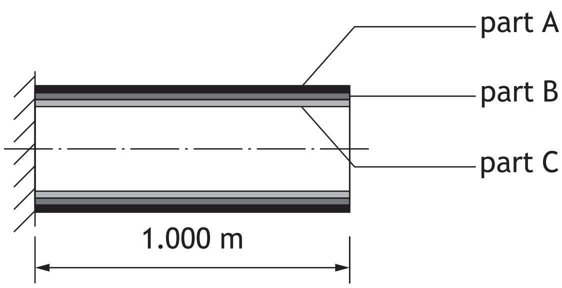


A simplified model for the arm comprises three parts of equal length, each being hollow rectangular box-section, and where the part on the right fits inside the part to its immediate left. This means that the arm can fully retract or extend by a factor of three.

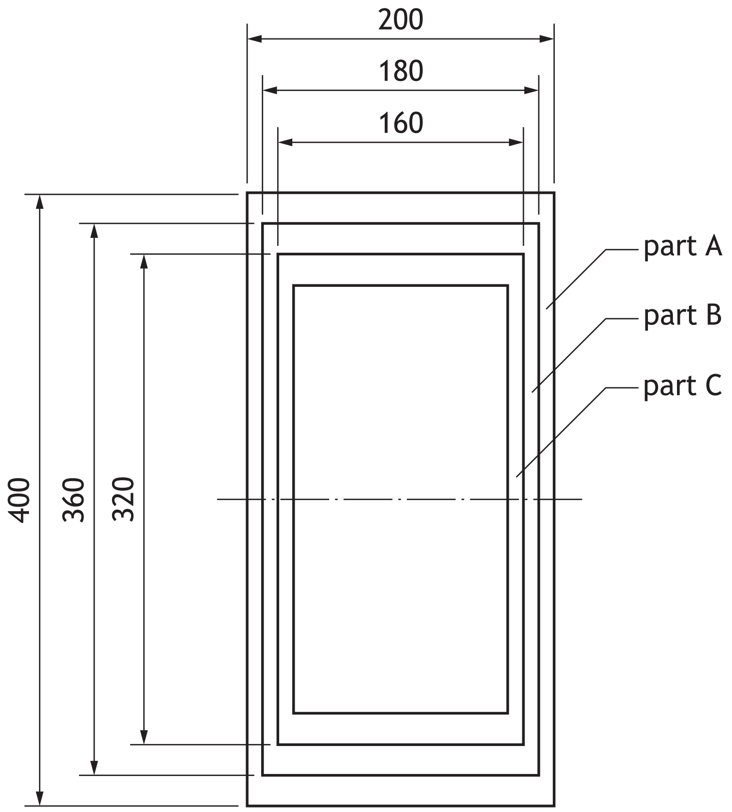


Sectional diagrams of fully extended and fully retracted positions for the simplified model are shown below.





10. (continued)



end elevation of simplified model

The table shown below summarises the data for each arm part. All dimensions are accurate to the nearest mm.

	Part A	Part B	Part C	Units
Height	400	360	320	mm
Breadth	200	180	160	mm
Length	1.000	1.000	1.000	m
I_{xx}		262.9	180.8	$\times 10^6$ mm^4
Mass	121.6	108.8	96.0	kg

The arm is a cantilever, built-in at the left-hand end of part A.

(a) Calculate the second moment of area (I_{xx}) value for part A. **2**

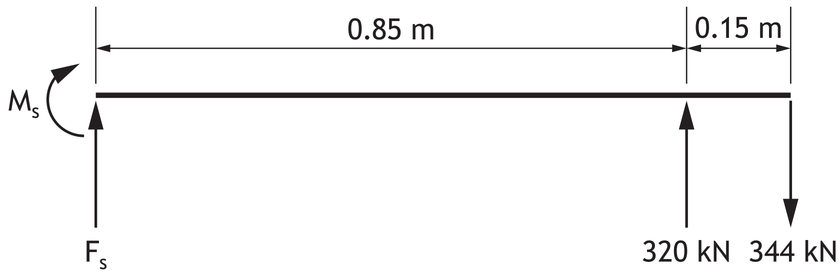
(b) Determine the ratio of the maximum stresses in the arm **due to self-weight** when the arm is in its fully extended position and when it is in its fully retracted position. **6**

[Turn over

10. (continued)

The following free-body diagram is used to analyse bending moments in part A when the crane arm is fully extended and bearing its maximum load.

F_s and M_s represent the shear force and bending moment at the built-in support point for part A.

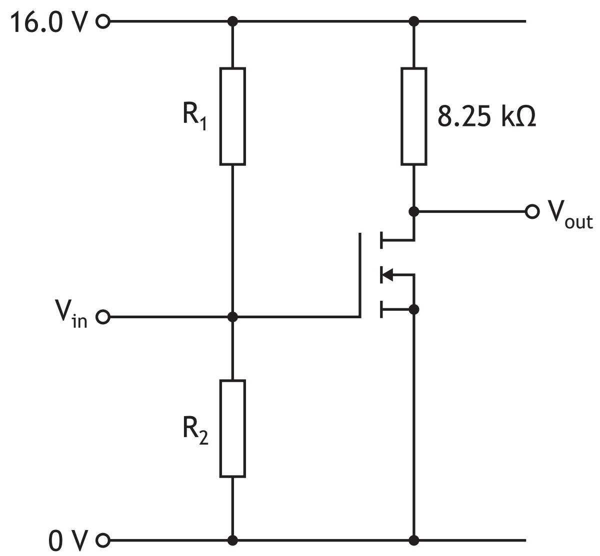


(c) Draw the bending moment diagram for this free-body diagram on the **worksheet for question 10 (c)**. 3

10. (continued)

The crane has an audible alarm to warn when loads being lifted are too heavy.

A student is developing a stage for an audio amplifier circuit. The circuit diagram is shown below.



The quiescent point (Q-point) is selected to give a drain-source voltage value (V_{DS}) of 9.00 V.

(d) Draw the load line for the circuit on the **worksheet for question 10 (d)** and hence, or otherwise, identify the value of the drain current, I_D, and gate-source voltage, V_{GS}, at the quiescent point (Q-point). **2**

Design rule: The combined resistance of R_1 in parallel with R_2 is 85.0 kΩ.

All resistors in the circuit have a tolerance of 1%, so their values have 3 significant figures.

(e) Calculate suitable values for R_1 and R_2. **3**

[Turn over

10. (continued)

The following extract from a program is used to generate pulses to a servomotor within the control system for the telescopic boom arm actuators. A rotational potentiometer supplies a voltage input to an analogue port of the microcontroller.

ARDUINO	PBASIC

void setup()
{
PinMode(6,OUTPUT);
}
 	
unsigned int pos = 0;
 	
void loop() {
	symbol pos = w1
	
	let pos = 0
	
	main:

pos=analogRead(A0);	readadc10 C.1, pos

pos = pos + 750;
 	
digitalWrite(6,HIGH);
delayMicroseconds(pos);
digitalWrite(6,LOW);
 	
pos = 2000 – pos;
delayMicroseconds (pos);
 	
delay(18);
 	
}
	pos = pos + 750
	
	high B.6
	pausemicro (pos)
	low B.6
	
	pos = 2000 – pos
	pausemicro (pos)
	
	pause(18)
	
	goto main

In either language, the analogue to digital conversion has 10-bit resolution when an analogue input is sampled.

(f) State the maximum and minimum values that the variable 'pos' could hold immediately after the line highlighted in the program executes. **1**

MARKS

10. (continued)

For a 40 ms time interval, the input voltage is a constant 1.225 V. The analogue to digital converter (ADC) produces its maximum value when the input voltage reaches 5.0 V.

(g) Calculate the frequency and duty cycle of the pulses produced at pin 6 during this 40 ms time interval. **3**

(Duty cycle is the ratio of the 'on' time to the period of each pulse, normally expressed as a percentage.)

ARDUINO	PBASIC
Syntax	**Syntax**
delayMicroseconds (*microseconds*)	PAUSEMICRO (*microseconds*)
Parameters *microseconds* — is a variable/ constant (0–65535) which specifies the number of microseconds to pause.	**Parameters** *microseconds* — is a variable/constant (0–65535) which specifies the number of microseconds to pause.
Example delayMicroseconds(500) //Wait 500 μs	**Example** pausemicro(500) 'Wait 500 μs

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