X036/301

NATIONAL QUALIFICATIONS 2010

MONDAY, 7 JUNE
1.00 PM – 4.00 PM

TECHNOLOGICAL STUDIES
HIGHER

100 marks are allocated to this paper.

Answer **all** questions in Section A (60 marks).

Answer **two** questions from Section B (20 marks each).

Where appropriate, you may use sketches to illustrate your answer.

Reference should be made to the Higher Data Booklet (2008 edition) which is provided.

SA X036/301 6/2410

SECTION A

Marks

Attempt all the questions in this Section. (Total 60 marks)

1. A logic circuit for the control of an industrial stamping machine is shown in Figure Q1.

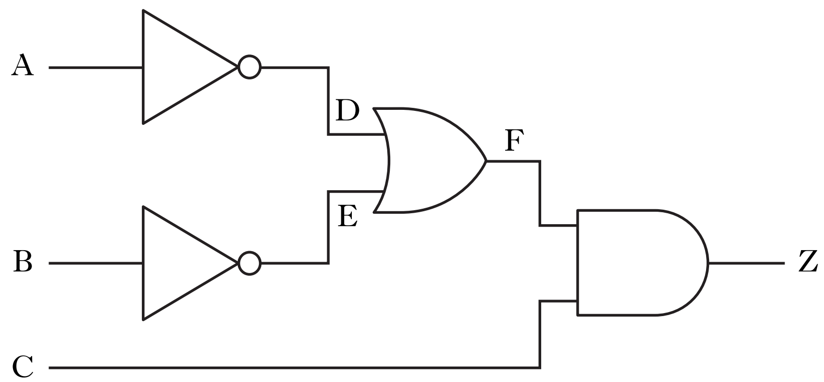

Figure Q1

(*a*) Write a Boolean expression for the output Z in terms of the inputs A, B and C. **1**

(*b*) Draw a truth table for the logic circuit.

Include in the table the intermediate logic values D, E and F. **2**

The logic circuit is constructed using TTL integrated circuits. At one stage during testing, all of the input pins were **unconnected**.

(*c*) State the logic values of the inputs A, B and C, and the output Z, for the conditions stated above. **1**

The circuit shown in Figure Q1 could be replaced by an equivalent logic circuit constructed entirely from NAND gates.

(*d*) Draw this equivalent logic circuit. Simplify where appropriate. **3**

(7)

Marks

2. The circuit shown in Figure Q2 represents a system for controlling a heater in a greenhouse.

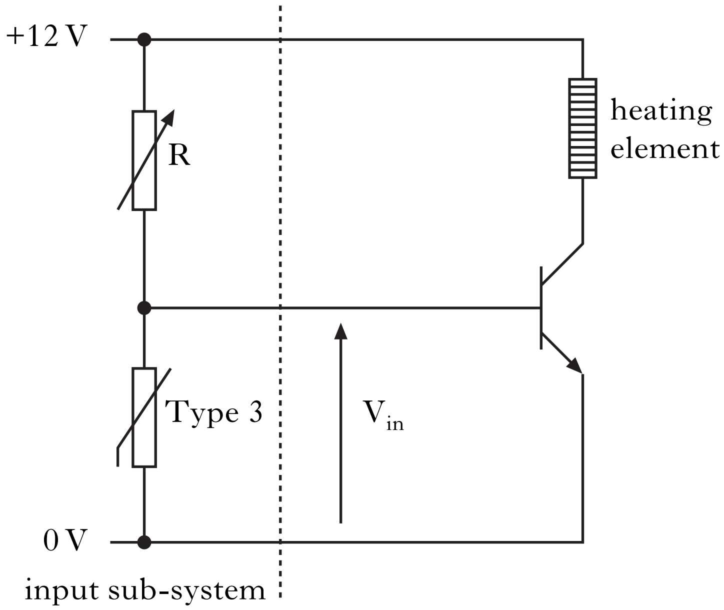

Figure Q2

(*a*) (i) State the name of component R and state its function in this circuit. **1**

(ii) Explain the operation of the input sub-system and the effect on V_{in} as the temperature in the greenhouse falls. **1**

The heating element is rated at 12 V, 100 W.

(*b*) Calculate the current flowing through the heating element when the transistor is saturated. **1**

The base current when the transistor is switched on and saturated is 4·7 mA.

(*c*) Calculate the minimum required current gain of the transistor. **1**

It was found that there was no single transistor available with the required current gain.

(*d*) (i) Draw a circuit based on two transistors to give the required current gain. Show all connections to the input sub-system, the heating element, and the power supplies. **2**

(ii) State the name of this configuration of two transistors. **1**

(*e*) Calculate the overall current gain of the circuit based on two transistors if the first transistor has a gain of 400 and the second transistor has a gain of 80. **1**

(*f*) Calculate the value of R if the two-transistor circuit saturates when the temperature is 10 °C. **2**

(10)

3. A pen plotter is a device which draws lines on paper. The pen is moved by two stepper motors, one to move the pen along the "X" axis, and one to move the pen along the "Y" axis, as shown in Figure Q3(*a*).

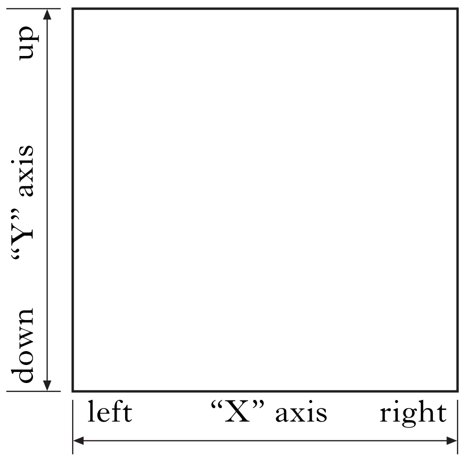

Figure Q3(*a*)

Each stepper motor is controlled by a separate stepper-motor-driver integrated circuit which receives pulses from a microcontroller. When the pen is in the lowered position, a line is drawn as the pen moves across the paper; when the pen is in the raised position, no line is drawn. The connections to the microcontroller are shown in Figure Q3(*b*).

INPUTS	PIN	OUTPUTS
	0	
	1	
	2	"**X**" stepper-motor driver: direction (0 = left, 1= right)
	3	"**X**" stepper-motor driver: pulse
	4	"**Y**" stepper-motor driver: direction (0 = down, 1= up)
	5	"**Y**" stepper-motor driver: pulse
	6	pen positioner (0 = pen raised, 1 = pen lowered)
	7	

Figure Q3(*b*)

The pen moves 0·5 mm for every step of the stepper motor. There is a time delay of 0·02 s between steps.

(*a*) Write, in PBASIC, a program for the following sequence:

- the pen is lowered
- a horizontal line 120 mm long is drawn from left to right across the paper
- the pen is raised.

Assume that initialisation has been carried out. **3**

(*b*) Calculate the time taken to draw the line. **1**

3. (continued)

Figure Q3(*c*) shows an "L" shape drawn by the plotter.

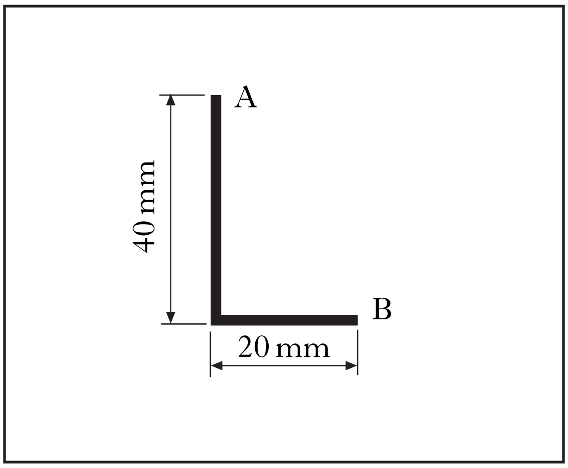

Figure Q3(*c*)

The pen starts in the raised position above point A.

- The pen is lowered.
- It moves vertically and then horizontally to draw the 'L' shape.
- When the pen reaches point B it is raised.

The pen moves 0·5 mm for every step of the stepper motor, with a time delay of 0·02 s between steps.

(*c*) Draw a flowchart for the control of the pen and the stepper motors, to draw the "L" shape shown in Figure Q3(*c*). **5**

(9)

4. A solid rod of diameter 27 mm has a length of 1·4 m when unloaded. The length increases by 1·5 mm when supporting a tensile load of 43 kN.

(*a*) (i) Calculate the Modulus of Elasticity and identify this material. **4**

(ii) Calculate the load at which the rod begins to yield. **1**

(*b*) State **two** factors that should be considered when determining the Factor of Safety applied in a particular situation. **1**

(6)

[Turn over

5. A digital-to-analogue converter (DAC) is shown in Figure Q5. A microcontroller provides the input signals to the DAC. The output voltage, V_{out}, from the DAC controls the speed of a motor.

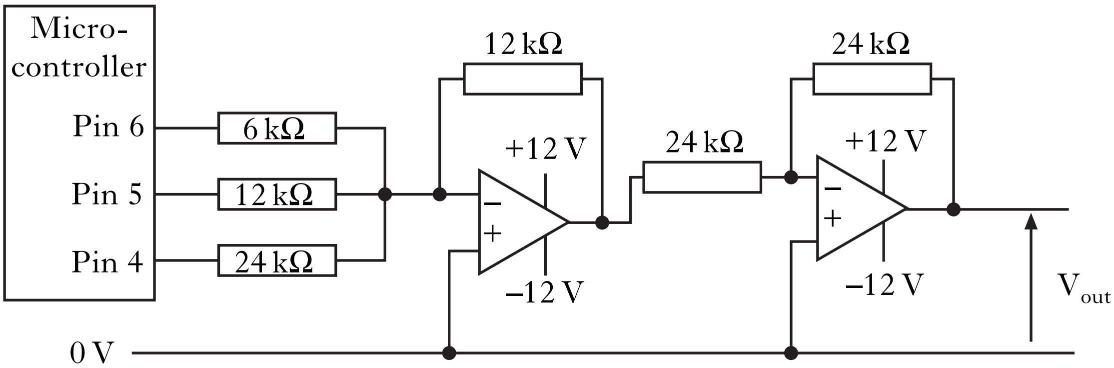

Figure Q5

Each microcontroller output pin provides a voltage of 5V when high.

(*a*) Calculate V_{out} when pin 4 and pin 6 are high and pin 5 is low. **2**

(*b*) Complete the table shown below for this circuit.

Pin 6	Pin 5	Pin 4	V_{out} (volts)
0	0	0	
0	0	1	
0	1	0	
0	1	1	
1	0	0	

2

The program shown below was downloaded to the microcontroller.

```
main:  pins = %00010000
       pause 200
       pins = %00100000
       pause 200
       pins = %00110000
       pause 200
       pins = %01000000
       pause 200
       pins = %01010000
       end
```

(*c*) (i) Describe the effect this program would have on a motor controlled by V_{out}. **1**

(ii) State the purpose of controlling a motor in this way. **1**

An alternative method of speed control is PWM (pulse width modulation).

(*d*) State two advantages of PWM. Justify your answers. **2**

(8)

Marks

6. A frame structure is shown in Figure Q6.

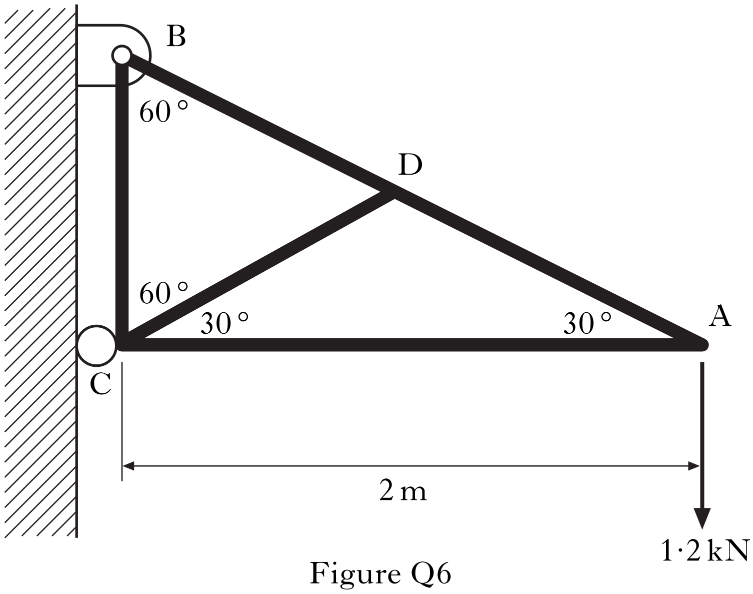

Figure Q6

(*a*) Calculate the **magnitude** of:

(i) the reaction force at C, using the Principle of Moments; **2**

(ii) the reaction force at B. **1**

CD is a redundant member.

(*b*) Explain what is meant by the term "redundant member". **1**

(*c*) Calculate, using *nodal analysis*, the **magnitude** and **nature** of the forces in members AD and AC. **3**

(7)

[Turn over

Marks

7. A solar panel is moved on a motorised support to make best use of the available light, as shown in Figure Q7(*a*). The system uses two light sensors, an analogue-to-digital converter (ADC), a multiplexer (MPX), and a microcontroller to control a motor that rotates the solar panel.

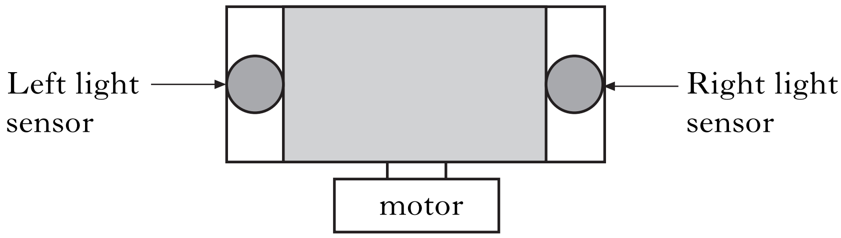

Figure Q7(*a*)

Figure Q7(*b*) shows the output connections from the microcontroller.

PIN	OUTPUTS
7	Motor FWD (1 = motor forwards)
6	Motor BCK (1 = motor backwards)
5	
4	
3	MPX (= 0 to select right sensor, 1 to select left sensor)
2	
1	
0	

Figure Q7(*b*)

A prewritten sub-procedure *adcread* converts the analogue signal from each light sensor in turn, and stores the value in the variable b4.

The control sequence is as follows:

a reading is taken from the right light sensor;
this reading is transferred from b4 to b5;
a reading is taken from the left light sensor;
if the right light sensor has the higher reading the motor moves forwards;
if the left light sensor has the higher reading the motor moves backwards;
if both light readings are the same, the motor remains stationary;
the control sequence repeats indefinitely.

Write, in PBASIC, the program for the control sequence.

Assume that the microcontroller has already been initialised. **(7)**

8. A variable-speed fan can rotate in one direction to remove stale air from a room or rotate in the opposite direction to bring fresh air into the room. The fan speed and direction are controlled by a dial as shown in Figure Q8(*a*).

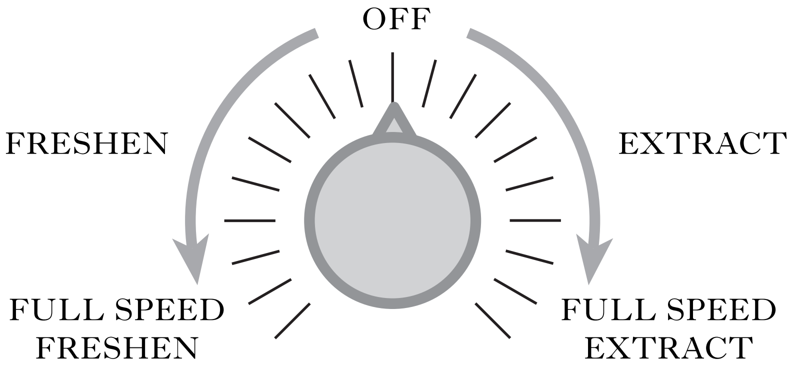

Figure Q8(*a*)

The dial is connected to a potentiometer in a control system, as shown in Figure Q8(*b*).

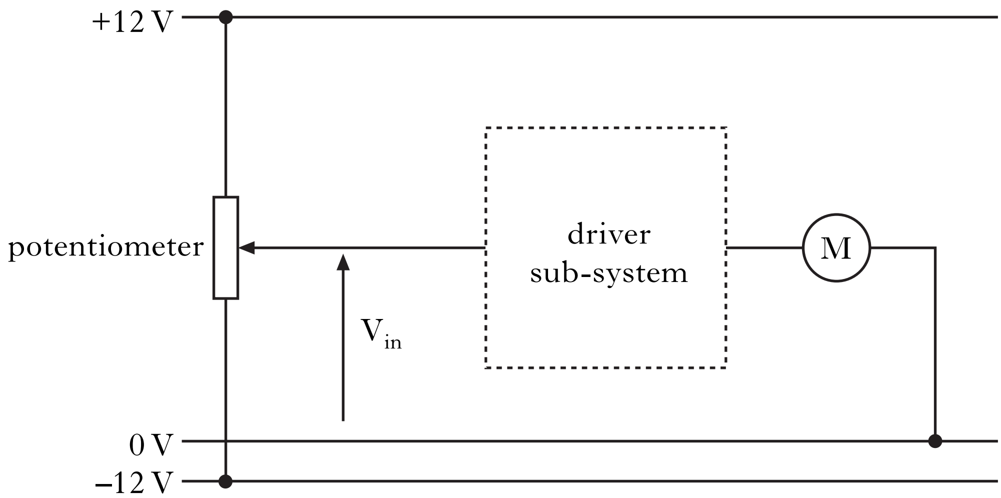

Figure Q8(*b*)

(*a*) State the name of the driver sub-system. **1**

(*b*) Draw a circuit diagram for the driver sub-system. Label connections to the potentiometer, the motor and the power supply rails. **3**

(*c*) State the value of V_{in} when the dial is in the "off" position. **1**

As the dial is turned clockwise from the "off" position, V_{in} becomes more positive.

(*d*) Describe how the motor responds when the dial is turned clockwise from the "off" position to the "full speed extract" position. **1**

(6)

[*END OF SECTION A*]

SECTION B

Attempt any TWO questions in this Section.

Each question is worth 20 marks.

9. A domestic hot-water system receives heat from the sun through a solar panel. A pump circulates water from the solar panel to heat the water in the storage tank, as shown in Figure Q9(*a*).

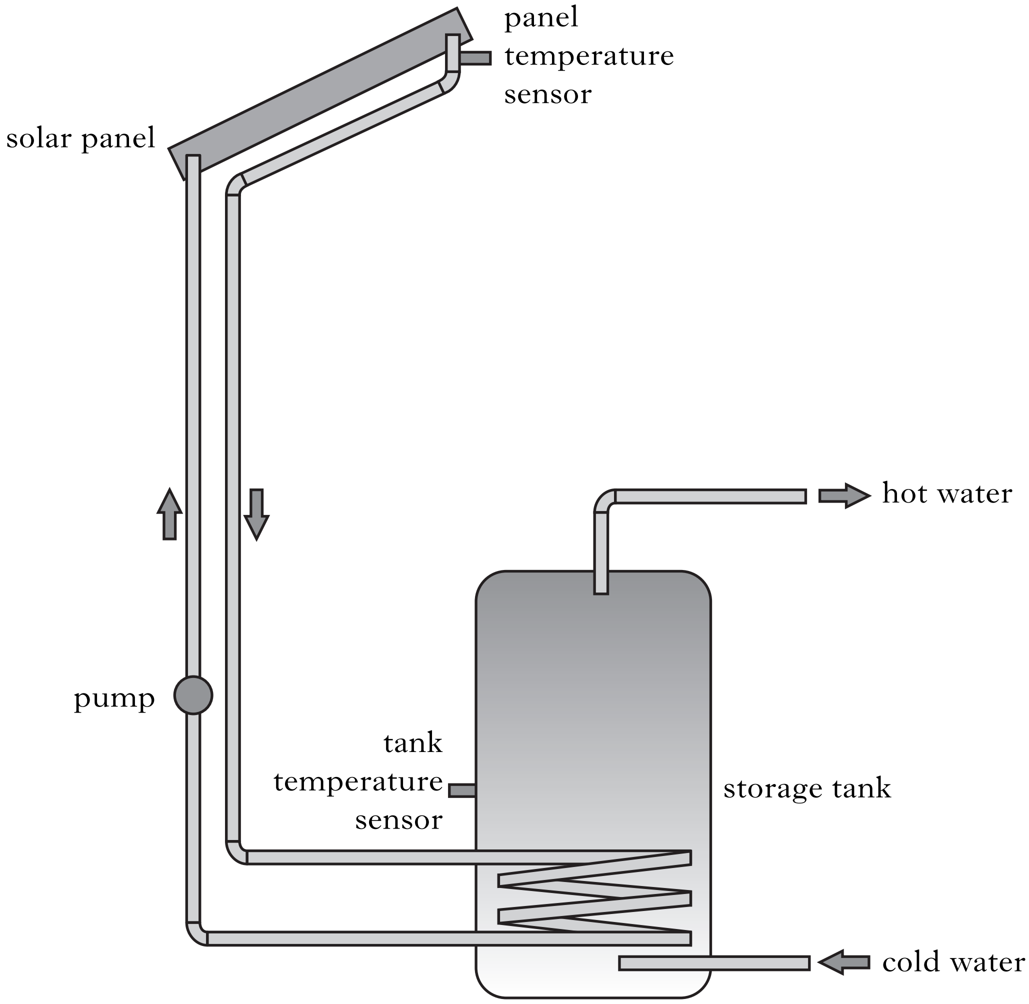

Figure Q9(*a*)

9. (continued)

The control system for the pump is shown in Figure Q9(*b*).

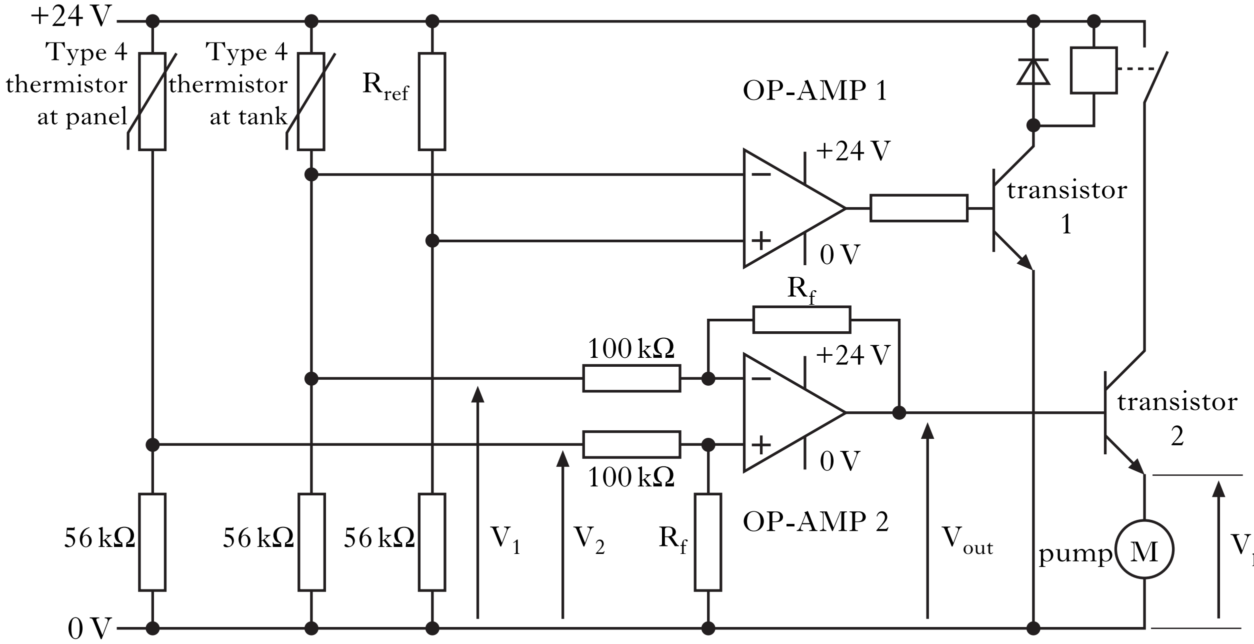

Figure Q9(*b*)

The output of op-amp1 changes state when the tank temperature reaches 90 °C.

(*a*) Determine the value of resistor R_{ref}. **1**

(*b*) For a tank temperature of 25 °C:

(i) calculate the panel temperature when $V_p = 6$ V, if $R_f = 460$ kΩ; **4**

(ii) calculate the value of R_f necessary so that the difference amplifier saturates at a panel temperature of 40 °C. **3**

(*c*) Explain the operation of the pump control system for the conditions described below. Refer to Figure Q9(*b*), and include details of the state of the relay and the output of op-amp2.

(i) At the start of the day, when the tank temperature is 25 °C and the panel temperature is 25 °C. **1**

(ii) During the morning when the tank temperature is 30 °C and the panel temperature is 70 °C. **1**

(iii) In the middle of the day when the tank temperature has reached 90 °C and the panel temperature is 95 °C. **1**

[Turn over

9. (continued)

Figure Q9(*c*) shows the crane which was used to lift the solar panel onto the roof of the house. The boom weighs 1500 N, acting 6 m from the pivot.

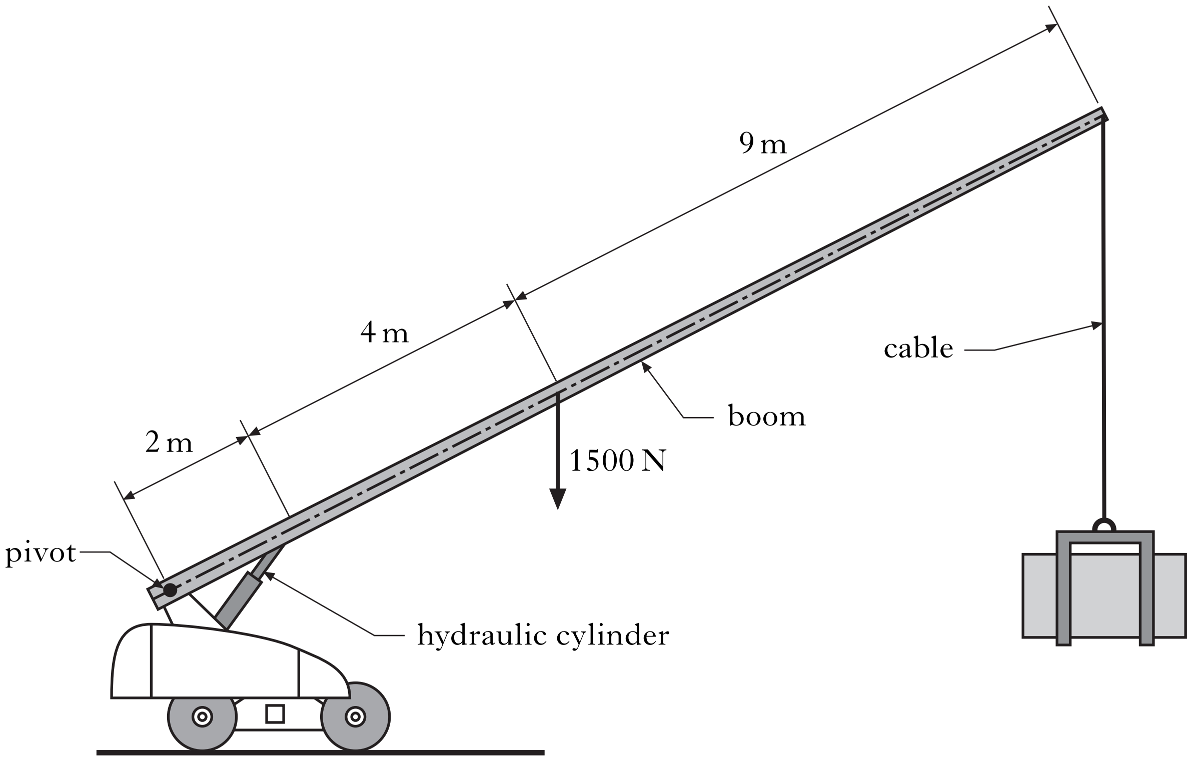

Figure Q9(*c*)

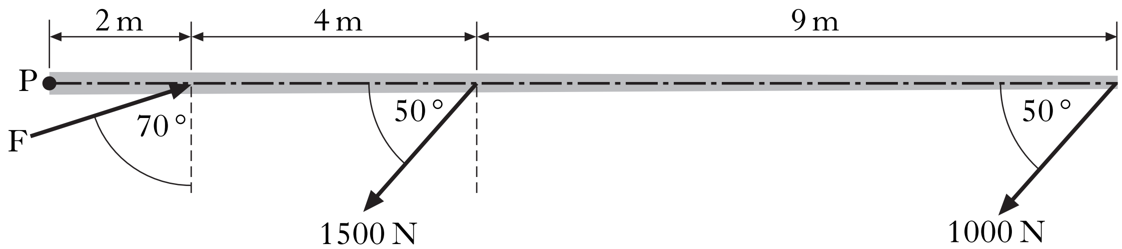

Figure Q9(*d*)

Figure Q9(*d*) shows the boom rotated to the horizontal position to simplify calculations.

(*d*) For a load at the end of the boom of one solar panel weighing 1000 N:

(i) calculate the **magnitude** of the force F exerted by the hydraulic cylinder on the boom; **3**

(ii) calculate the **magnitude** of the reaction force at the pivot P. **3**

The crane is capable of lifting 6 kN, and uses a cable manufactured from low-alloy steel, with a Factor of Safety of 12.

(e) Calculate the minimum effective diameter of the cable required for a load of 6 kN. **3**

(20)

10. The baby-bottle steriliser shown in Figure Q10(*a*) uses steam to sterilise bottles for 10 minutes. After sterilisation, the bottles remain sterile for up to 3 hours.

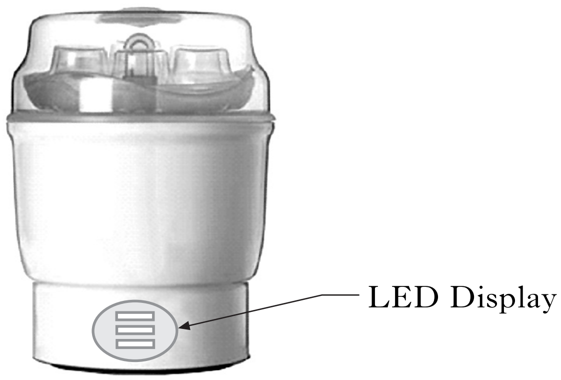

Figure Q10(*a*)

A temperature sensor senses when the water is boiling and a microcontroller controls a heating element and an LED display. A block diagram of the system is shown in Figure Q10(*b*).

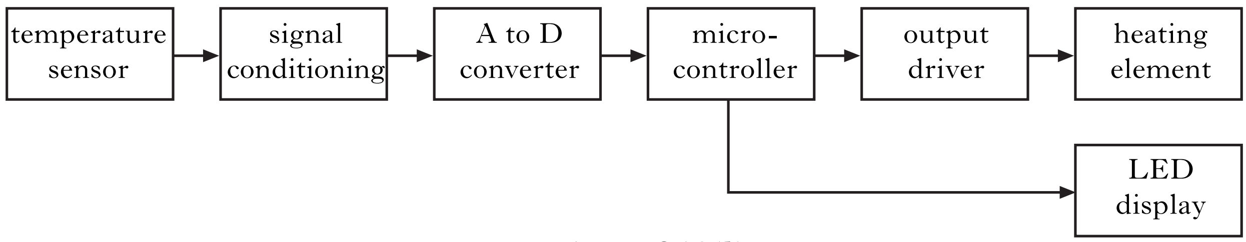

Figure Q10(*b*)

(*a*) With reference to Figure Q10(*b*), explain the function of the two sub-systems listed below:

(i) signal conditioning; **2**

(ii) microcontroller. **1**

When the signal from the temperature sensor sub-system is 5 V, the output from the signal-conditioning sub-system is 2·71 V.

(*b*) Design a suitable signal-conditioning system based on operational amplifiers, showing all resistor values. **3**

The analogue-to-digital converter (ADC) has a reference voltage of 3·8 V.

(*c*) Determine the input voltage to the ADC when the binary output is 10011010. **1**

[Turn over

The relevant connections to the microcontroller are shown in Figure Q10(*c*).

INPUTS	PIN	OUTPUTS
	7	Heater
	6	LED 1
	5	LED 2
	4	LED 3
	3	
	2	
	1	
Start Switch (1 = start)	0	

Figure Q10(*c*)

The flowchart for the control of the steriliser is shown in Figure Q10(*d*). A pre-written sub-procedure *timer* produces a delay of 1 minute and adds 1 to the value stored in the variable MINUTE. The pre-written sub-procedure *adcread* reads data from the ADC and stores it in the variable DATA.

At 100 °C, DATA = 182.

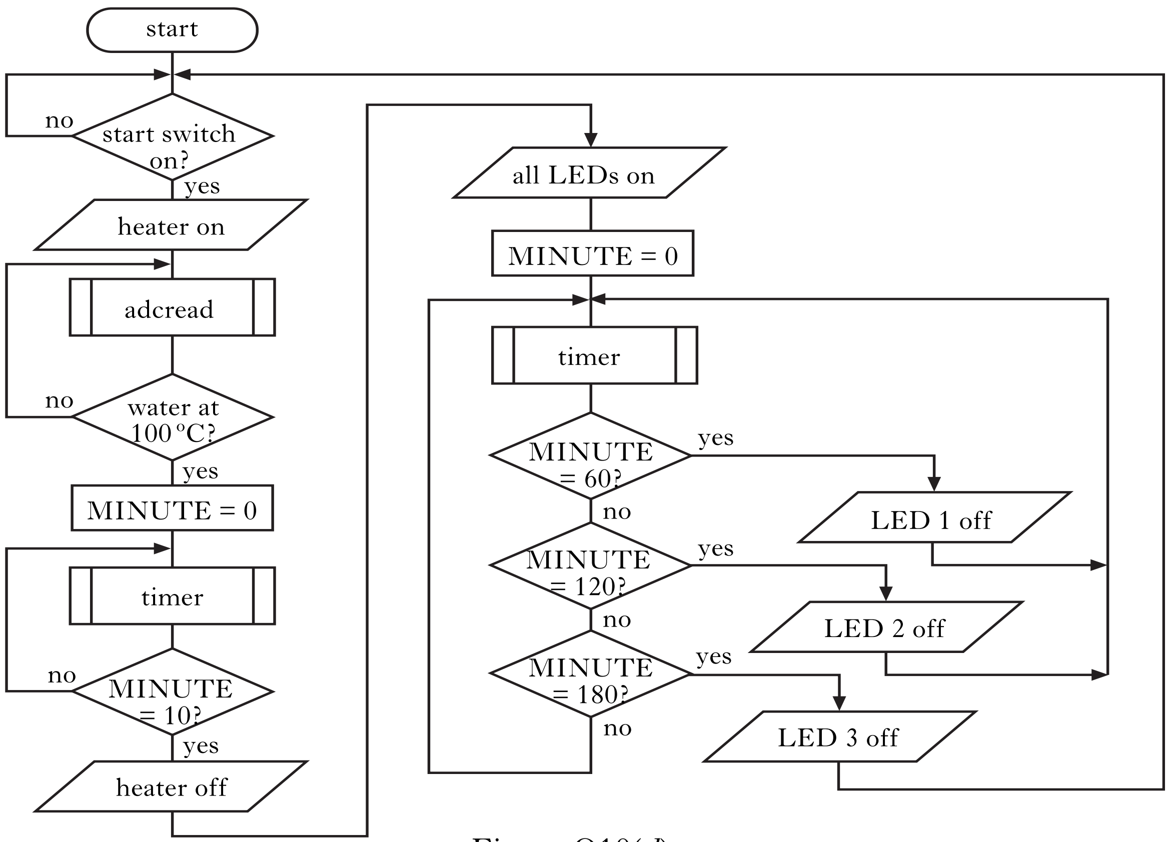

Figure Q10(*d*)

(*d*) Write, in PBASIC, the program represented by the flowchart shown in Figure Q10(d).

Assume the microcontroller has been initialised. **8**

10. (continued)

The output-driver circuit for the heater is shown in Figure Q10(*e*).

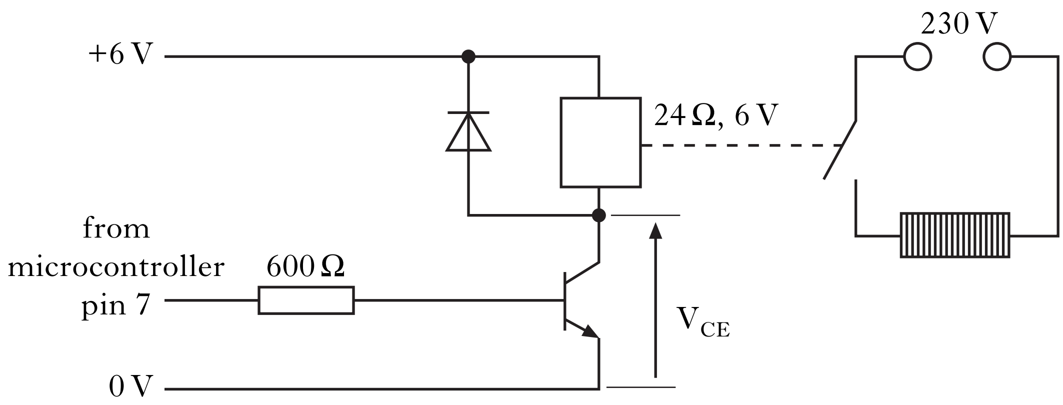

Figure Q10(*e*)

Pin7 of the microcontroller is at 5 V when it is high. When the transistor is switched on and saturated $V_{CE} = 0{\cdot}2$ V.

(*e*) Calculate the minimum current gain required to close the relay contacts when microcontroller pin7 is high. **3**

An alternative MOSFET-based circuit is shown in Figure Q10(*f*).

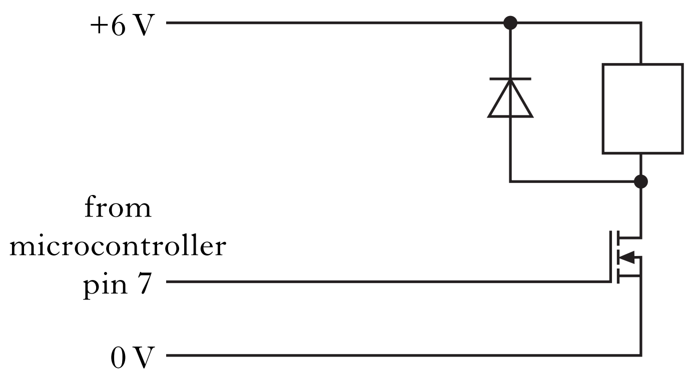

Figure Q10(*f*)

The gate threshold of the MOSFET is 2 V.

(*f*) Sketch a graph of Drain-Source current (I_{DS}) against Gate voltage (V_G). **2**

(20)

[Turn over

11. A revolving door at a hotel entrance is turned by an electric motor. If the door hits an obstruction there is an increase in the tension force in a support bar connected to the motor, as shown in Figure Q11(*a*). A microcontroller-based control system senses this increased tension, and stops the motor.

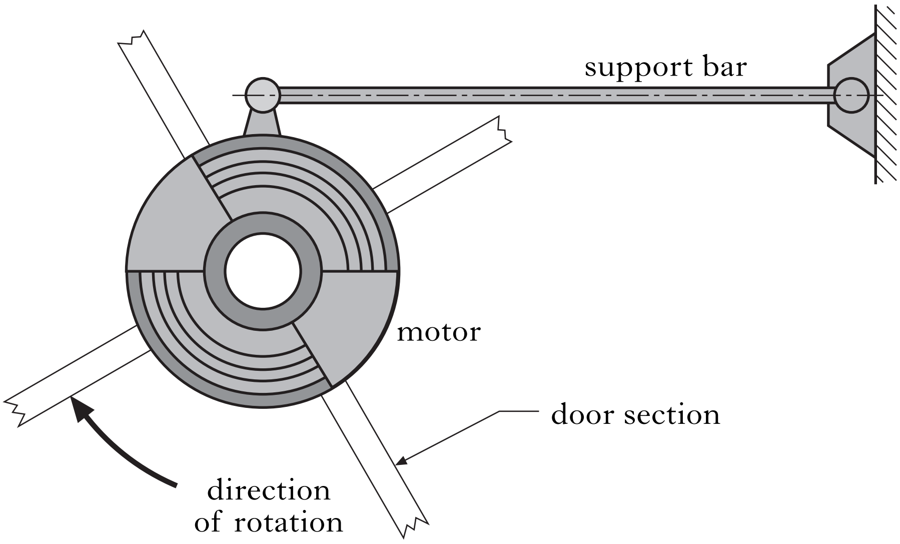

Figure Q11(*a*)

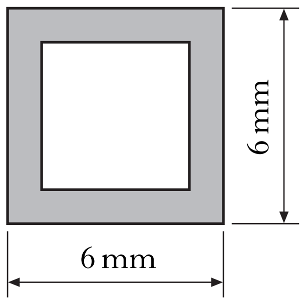

Figure Q11(*b*)

The mild-steel support bar is of hollow square-section tube, as shown in Figure Q11(*b*).

(*a*) For a tension force of 900 N in the support bar:

(i) calculate the stress in the bar; **2**

(ii) calculate the strain in the bar. **1**

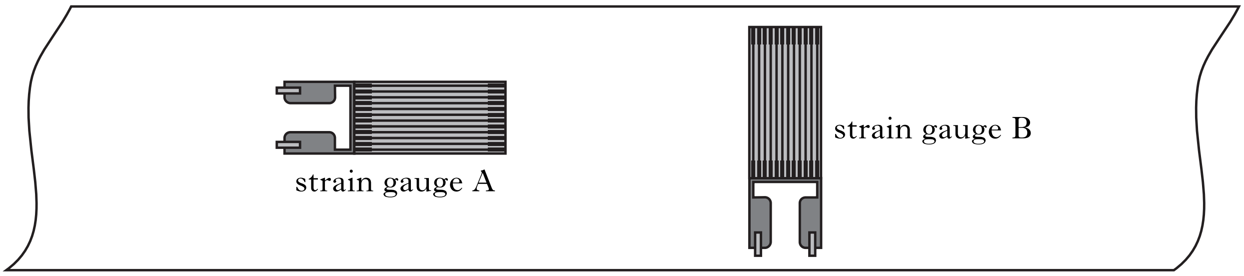

Figure Q11(*c*)

A pair of strain gauges is attached to the bar, as shown in Figure Q11(*c*). The resistance of strain gauge B does not change due to changing tension in the support bar.

(*b*) State the reason for the inclusion of strain gauge B in the system. **1**

11. (continued)

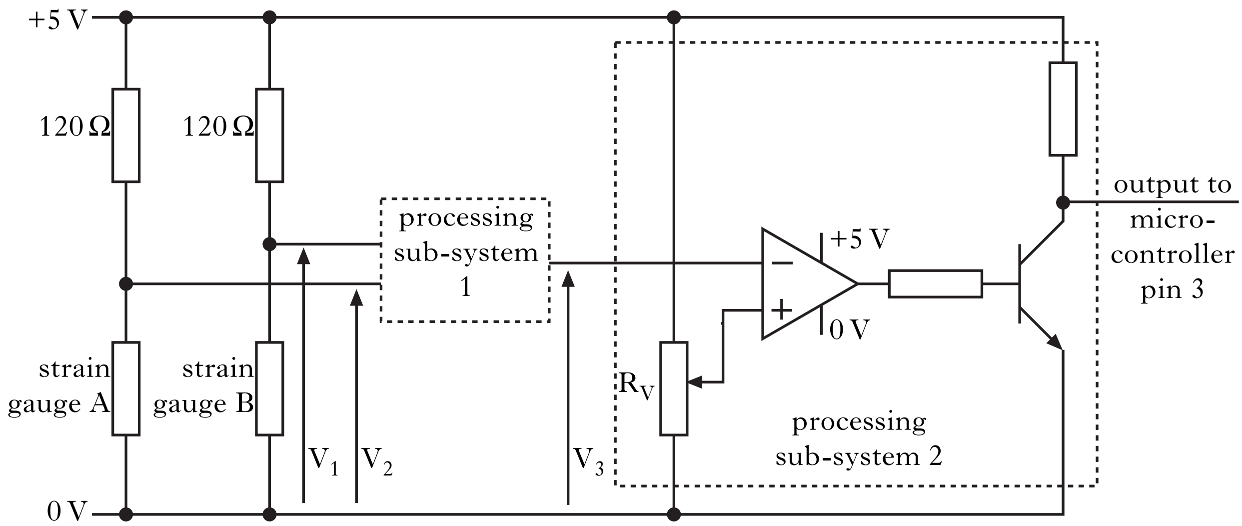

Figure Q11(*d*)

The strain gauges form part of the obstruction-sensor circuit shown in Figure Q11(*d*). The unloaded resistance of each strain gauge is 120 Ω.

The change in strain-gauge resistance is proportional to the strain, ε, and is given by the equation

$\Delta R = 2R\varepsilon$ where ΔR = change in resistance
R = unloaded resistance

When the tensile strain in the bar is $5{\cdot}00 \times 10^{-4}$, voltage $V_3 = 2{\cdot}50$ V.

(*c*) (i) Calculate V_2 correct to 5 decimal places. **2**

(ii) Draw a circuit diagram for processing sub-system 1.

Show all connections, calculations and resistor values. **3**

V_3 rises as the strain in the support bar rises.

(*d*) Explain how the output from processing sub-system 2 is affected by an increasing strain in the support bar. Include details of the function of R_V, the operational amplifier, and the transistor in processing sub-system 2. **2**

[Turn over

11. (continued)

The microcontroller controls the motor in response to signals from the obstruction sensor shown in Figure Q11(*d*) on *Page seventeen* and from a zone sensor. The microcontroller connections are shown in Figure Q11(*e*).

INPUTS	PIN	OUTPUTS
	0	
zone sensor (= 1 if a person enters a zone in or near door)	1	
	2	
obstruction sensor (= 1 if obstruction sensed)	3	
	4	motor (= 1 to turn on motor)
	5	
	6	
	7	

Figure Q11(*e*)

The control program shown below includes a sub-procedure *motorpower* which controls the speed of the motor. Before the sub-procedure is called, the speed value, between 0 and 100, is stored in the variable b4. The duration of the sub-procedure is 10 milliseconds.

CONTROL PROGRAM

```
main:         low 4
              if pin1 = 1 then startmotor
              goto main
startmotor:   for b4 = 21 to 100
                 gosub motorpower
                 if pin3 = 1 then stop
              next b4
motor:        high 4
              if pin1 = 0 then stop
              if pin3 = 1 then stop
              goto motor
stop:         low 4
              pause 3000
              goto main
```

The motor runs at full speed when the speed value is 100.

(*e*) Calculate the time taken for the motor to reach full speed from rest, if no obstruction is sensed. **1**

Marks

11. (continued)

The program is run. After five seconds a person is detected in the zone; six seconds later the door is obstructed for two seconds; after a further eight seconds a person is no longer detected in the zone.

(*f*) Describe in detail how the system behaves for this sequence of events. Refer to the control program shown on *Page eighteen*. **3**

It was found that the obstruction sensor was too sensitive. It stopped the motor at a very low value of tension force in the support bar.

(*g*) Describe the adjustment that should be made to processing sub-system 2 to improve the operation of the system. Refer to Figure Q11(*d*) on *Page seventeen*. **1**

It was decided to make adjustments to the sensitivity of the system in software instead. Processing sub-system 2 was replaced by a sub-system which processed values of voltage V_3 for storage in the microcontroller.

(*h*) State the name of this processing sub-system, and its function. **1**

(*i*) Describe the changes that would need to be made in the software. **2**

(*j*) State why changes to software are usually preferred to changes to hardware. **1**

(20)

[*END OF QUESTION PAPER*]

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