X036/301

NATIONAL QUALIFICATIONS 2008

WEDNESDAY, 4 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 (2006 edition) which is provided.

SA X036/301 6/2670

SECTION A

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

1. The interior lamp of a car is controlled by a microcontroller. Figure Q1 shows the flowchart for the sub-procedure *dimlamp* which is used to dim the lamp gradually after the car doors are closed. The lamp is connected to pin 4 of the microcontroller.

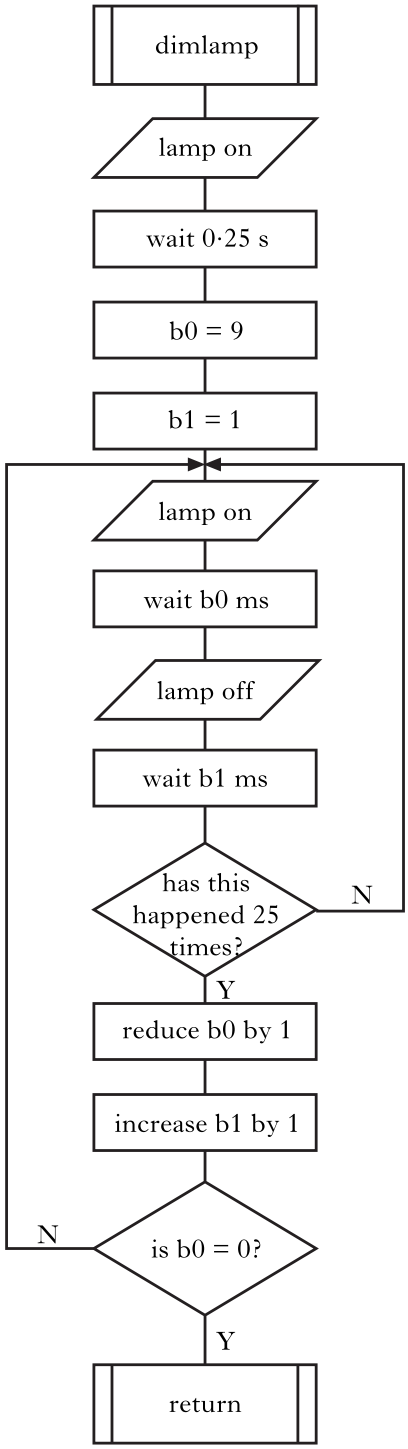

Figure Q1

(*a*) Write, in PBASIC, the sub-procedure *dimlamp*. **7**

(*b*) Calculate the time taken to execute the sub-procedure *dimlamp*. **1**

(8)

Marks

2. The stress-strain graphs for two different materials are shown in Figure Q2.

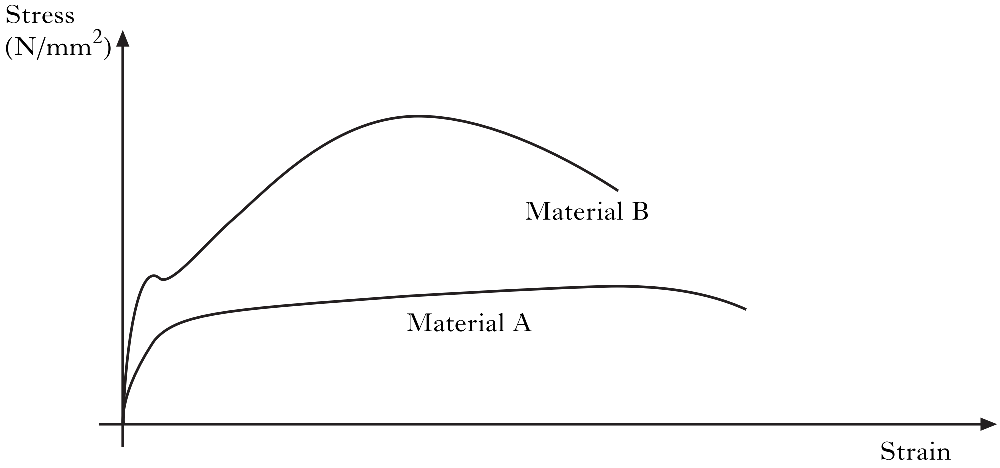

Figure Q2

(*a*) From the information given in Figure Q2, state **one** property of material A, giving a reason for your choice. **1**

(*b*) Describe the difference between elastic and plastic deformation. **2**

Another material with a gauge length of 120 mm and a cross-sectional area of 12 mm^2 was tested. It was found that at just below the yield point a force of 2·96 kN caused an increase in length of 0·185 mm.

(*c*) (i) Calculate the Modulus of Elasticity for this material.

(ii) State the name of the material.

(iii) State **one** reason why this material might be selected for a cable supporting an overhead lighting gantry. **3**

(6)

[Turn over

Marks

3. A stepper-motor is used to control the position of the pen in a plotter. The stepper-motor is controlled by a microcontroller. The connections to the microcontroller are shown in Figure Q3(*a*).

Pin	**Output**
7	Coil D
6	Coil C
5	Coil B
4	Coil A
3	
2	
1	
0	

Figure Q3(*a*)

When a pin of the microcontroller is set **high** the corresponding stepper-motor coil is connected to 12 V; when the pin is set **low** the coil is connected to 0 V. A timing diagram for clockwise rotation of the stepper-motor is shown in Figure Q3(*b*).

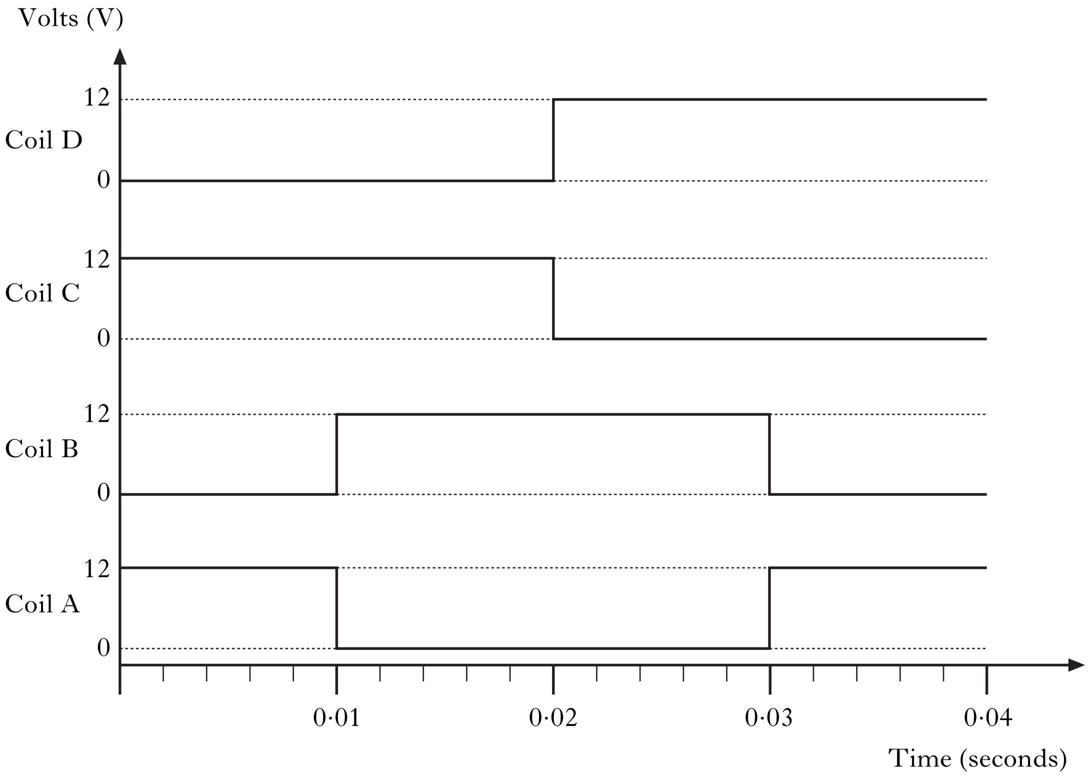

Figure Q3(*b*)

(*a*) Write, in PBASIC, a sub-procedure *cw* which will rotate the stepper-motor clockwise through the **four** steps of the sequence shown in Figure Q3(*b*). **3**

(*b*) Describe the changes that would need to be made to the sub-procedure to rotate the stepper-motor **anticlockwise**. **1**

Marks

3. (continued)

An alternative control system for the stepper-motor uses a stepper-motor-driver integrated circuit. The connections to the microcontroller for this control system are shown in Figure Q3(*c*).

Pin	**Output**
7	
6	
5	
4	
3	Direction (= 0 for clockwise) (= 1 for anticlockwise)
2	Pulse
1	
0	

Figure Q3(*c*)

(*c*) Write, in PBASIC, a new sub-procedure *cw* which will rotate the stepper-motor **clockwise** through **four** steps, at the **same speed** as the sub-procedure in part (*a*). **3**

(*d*) State the change that would need to be made to this sub-procedure to rotate the stepper-motor **anticlockwise**. **1**

(*e*) State **one** advantage of using the stepper-motor-driver integrated circuit. **1**

(9)

[Turn over

Marks

4. A coin-sorting machine separates coins into two groups – copper coins and silver coins. It then determines the monetary value of the coins by weighing the two groups, using separate analogue weighing devices.

The signals from the two weighing devices are processed using the circuit shown in Figure Q4(*a*).

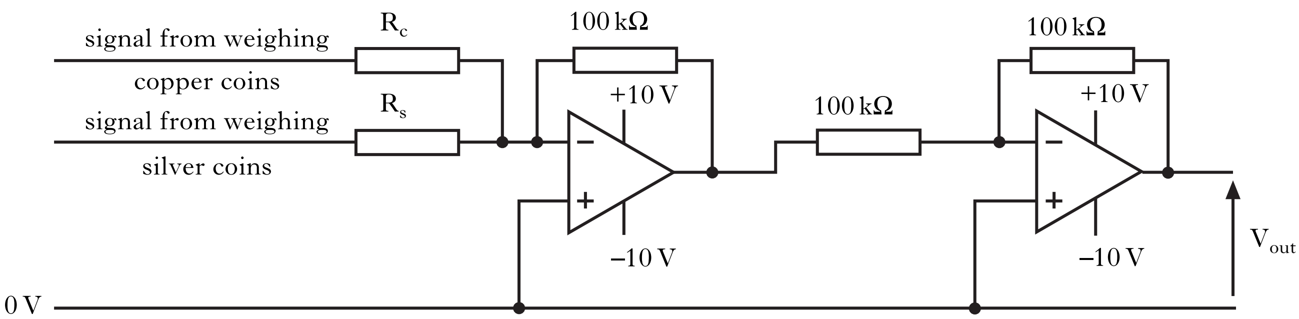

Figure Q4(*a*)

The signals from the weighing devices representing a monetary value of £1·00 for each group are shown in Figure Q4(*b*).

Group	**Output**
copper coins	4·45 V per £1·00
silver coins	1·63 V per £1·00

Figure Q4(*b*)

(*a*) (i) Calculate the value of resistor R_c so that when £1·00 of copper coins **only** is weighed, V_{out} = 1·00 V.

(ii) Calculate the value of resistor R_s so that when £1·00 of silver coins **only** is weighed, V_{out} = 1·00 V. **3**

(*b*) Calculate V_{out} when a batch consisting of all the coins in the table below is weighed.

Group	Coin	Number in Batch
copper coins	1p	135
	2p	92
silver coins	5p	27
	10p	32

2

(*c*) Determine the maximum monetary value of coins that can be weighed without saturating the op-amps. **1**

(6)

Marks

5. An engine hoist is shown in Figure Q5(*a*). A hydraulic piston raises the lifting arm which pivots about point P. The engine shown weighs 800 N.

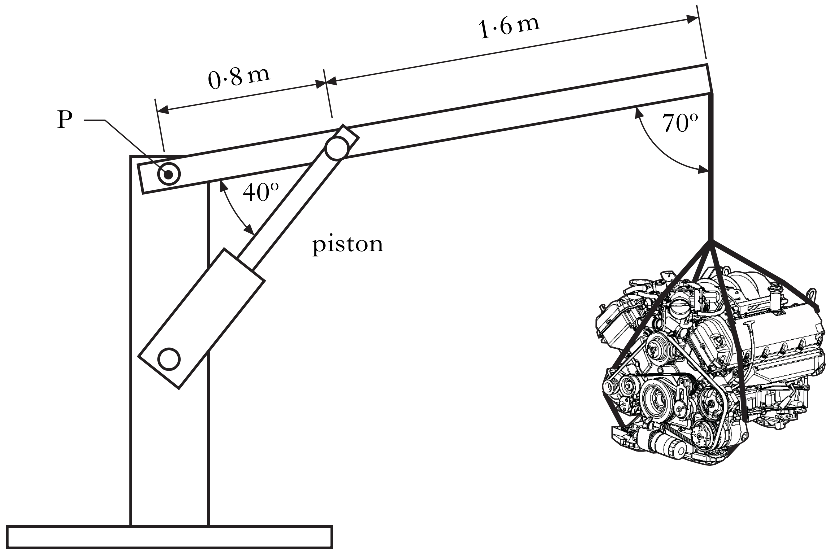

Figure Q5(*a*)

To simplify calculations the lifting arm has been rotated to the horizontal as shown in Figure Q5(*b*).

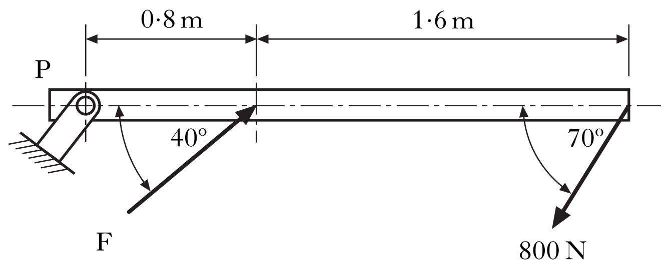

Figure Q5(*b*)

Calculate:

(*a*) the **magnitude** of the force F exerted by the piston; **2**

(*b*) the **magnitude** of the reaction force at the pivot P. **4**

(6)

[Turn over

6. A wind turbine used for generating electricity is fitted with a safety system to prevent the turbine rotating too quickly in strong winds. If the speed of the turbine shaft rises above the maximum safe level, an actuator is switched on to apply brakes on the turbine shaft. The greater the excess shaft speed above the maximum safe speed, the more the brakes are applied. *Marks*

(*a*) State the full name of the type of control used. **1**

(*b*) Draw a control diagram for the safety system. **3**

The electronic circuit used to control the braking system is shown in Figure Q6. A tachogenerator generates a signal which varies with the shaft speed.

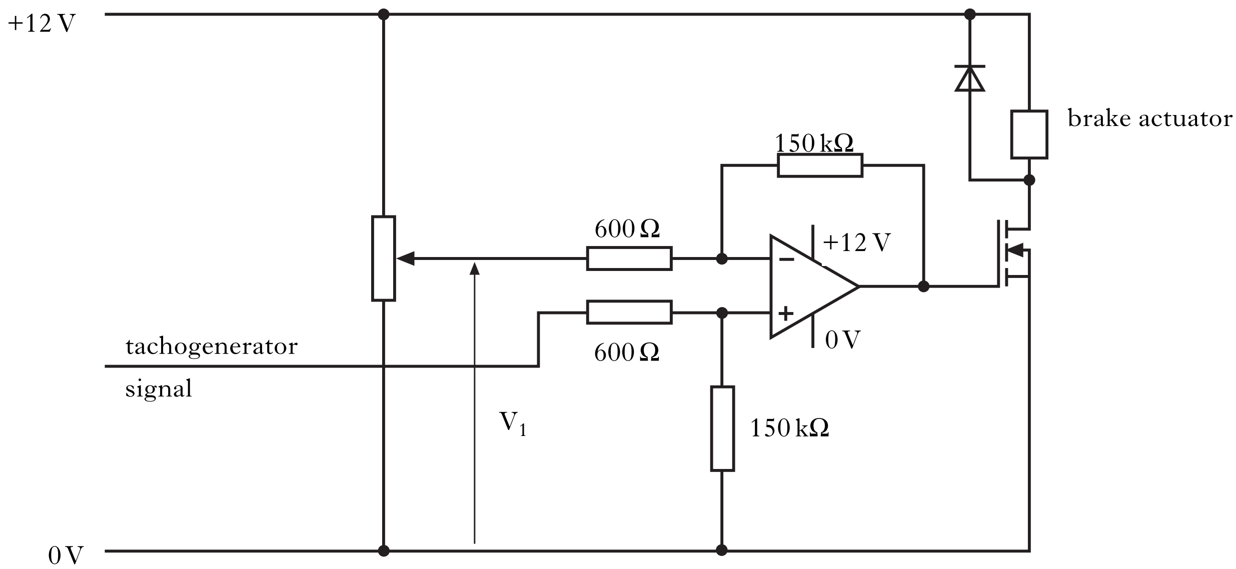

Figure Q6

The potentiometer is adjusted so that V_1 = 4 V. The brakes are first applied when the voltage on the gate of the MOSFET is 2 V.

(*c*) Calculate the voltage generated by the tachogenerator when the brakes are first applied, correct to 3 decimal places. **2**

(6)

7. A safety system is installed just before the entrance to a warehouse to provide an audible warning to a driver if his vehicle is too high. The system is shown in Figure Q7(*a*).

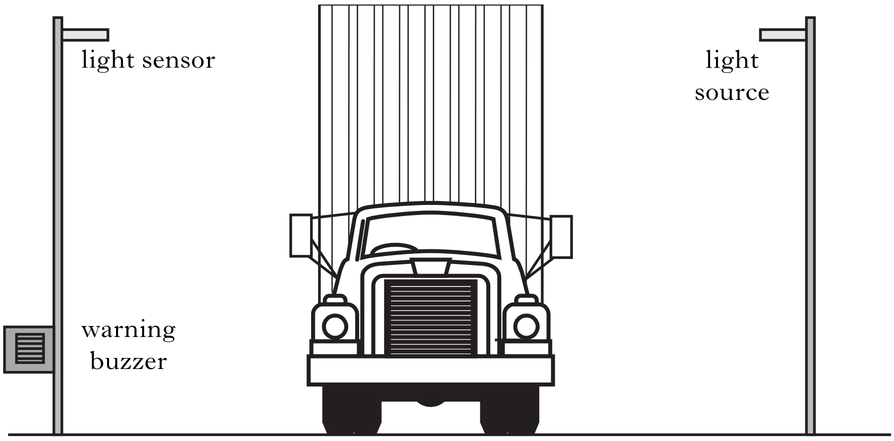

Figure Q7(*a*)

The electronic circuit for the safety system is shown in Figure Q7(*b*).

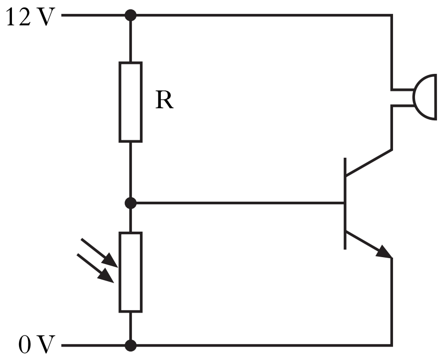

Figure Q7(*b*)

At a light level of 200 lux the voltage across the LDR is 0·6 V.

(*a*) Calculate the value of resistor R. **2**

When a vehicle blocks the light beam a base current of 0·8 mA flows. The buzzer is rated at 12 V, 1 W.

(*b*) Calculate the minimum gain of the transistor necessary to cause saturation when a vehicle blocks the light beam. Assume that the voltage across the buzzer is 12 V when the transistor saturates. **1**

It was found that the sound from the buzzer was not loud enough. It was decided to use a 230 V siren instead.

(*c*) Draw a modified circuit diagram showing how the 230 V siren would be controlled. (The same buzzer symbol may be used to represent the siren.) **2**

(5)

[Turn over

8. An automatic factory vehicle follows a white line painted onto a dark floor. The vehicle is fitted with two light-dependent resistors (LDRs), as shown in Figure Q8(*a*). If either LDR moves away from the line, the system reacts to direct the vehicle back towards the line.

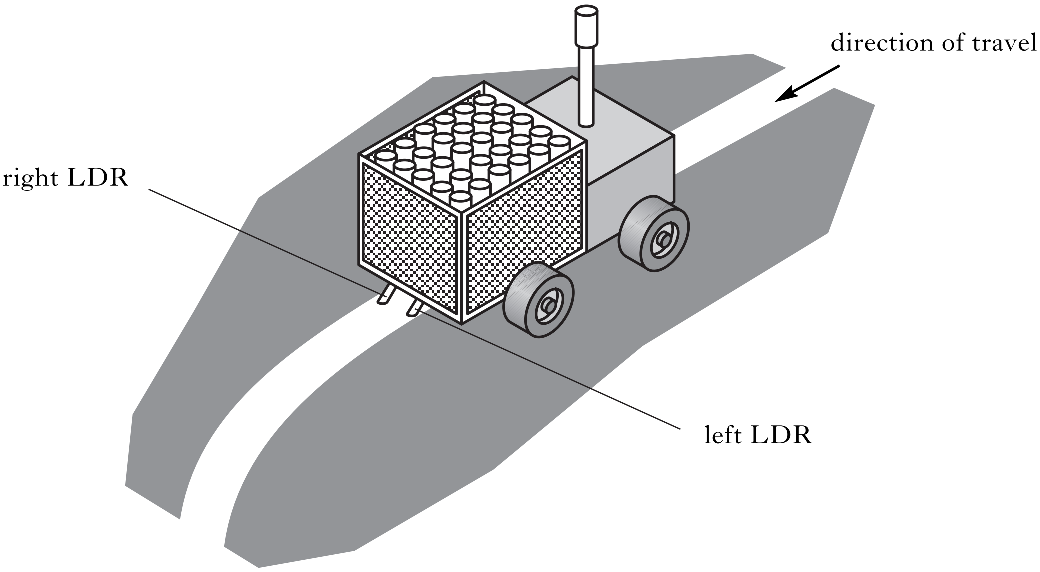

Figure Q8(*a*)

The circuit shown in Figure Q8(*b*) controls the vehicle's motors.

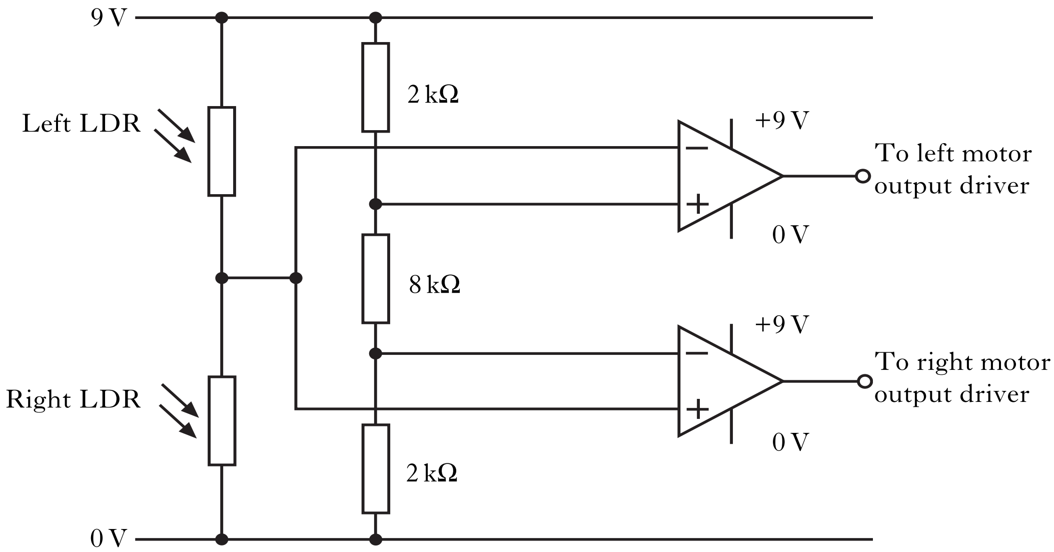

Figure Q8(*b*)

(*a*) State the name of the configuration of the op-amps shown. **1**

(*b*) State the full name of the type of control this system uses. **1**

When an LDR is over the white line, it receives a light level of 650 lux. When the vehicle arrives at the bend shown in Figure Q8(*a*), the right LDR moves over the dark area outside the white line. This causes the left motor to stop, and the vehicle turns back towards the line.

(*c*) Determine the darker light level required to stop the left motor. **3**

(5)

Marks

9. A gas-fired boiler provides room-heating or hot water, but not both simultaneously. The boiler is controlled by a combinational logic system. The inputs and outputs of the logic system are shown below.

INPUTS
Timer T (= 1 when room heating is required)
Overheat sensor S (= 1 if boiler overheats)
Flow sensor F (= 1 when a hot tap is open)

OUTPUTS
Pump P (= 1 to turn pump on)
Gas valve G (= 1 to open gas valve)

The pump is always switched off when a hot tap is open.

If all hot taps are closed, the pump turns on when room heating is required, or if the boiler overheats.

An incomplete truth table for the logic system is shown in Figure Q9.

Timer (T)	Overheat Sensor (S)	Flow Sensor (F)	Pump (P)	Warning Light (W)	Gas Valve (G)
0	0	0		0	0
0	0	1		0	1
0	1	0		1	0
0	1	1		1	0
1	0	0		0	1
1	0	1		0	1
1	1	0		1	0
1	1	1		1	0

Figure Q9

(*a*) Write down the values for pump P as they should appear in the truth table shown in Figure Q9. **1**

(*b*) Write a Boolean expression for output G in terms of inputs T, S and F. **1**

(*c*) Draw a logic diagram for output G using AND, OR and NOT gates. **3**

(*d*) Draw a NAND-equivalent circuit for output G. Simplify where appropriate. **2**

The controller circuit-board has a supply voltage of 12 V.

(*e*) State whether TTL or CMOS integrated circuits are more suitable for this application. Justify your answer. **1**

(*f*) State **two** disadvantages of CMOS logic devices compared with TTL devices. **1**

(9)

[*END OF SECTION A*]

[Turn over

SECTION B

Attempt any TWO questions in this Section.

Each question is worth 20 marks.

10. An electric shower unit has a microcontroller-based control system. The user controls the operation of the shower using four switches to select "cold", "economy", "high" or "stop" settings. The flowchart for the control of the shower is shown in Figure Q10(*a*).

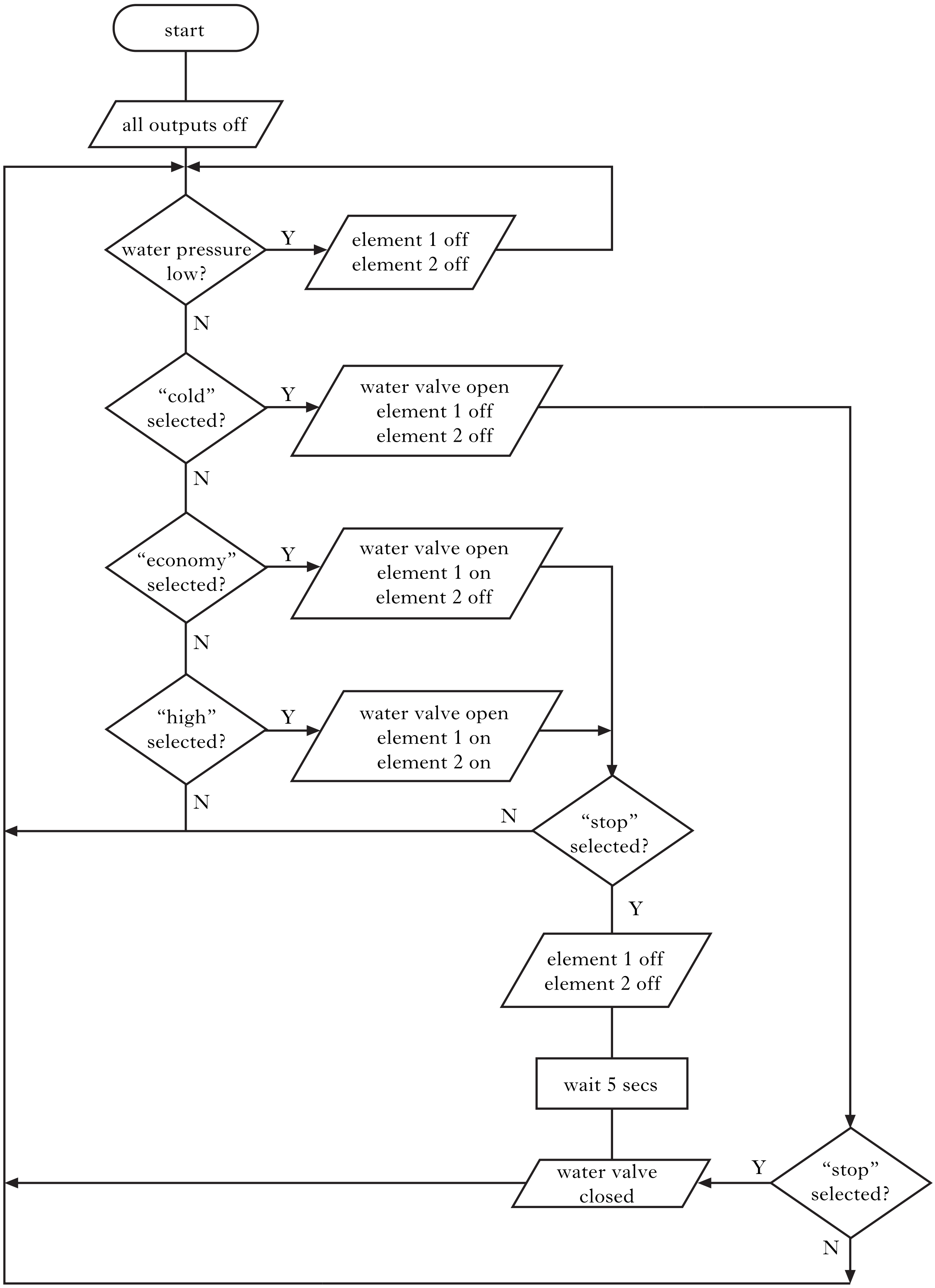

Figure Q10(*a*)

Marks

10. (continued)

(*a*) Describe the effect of operating the "stop" switch after "cold", "economy" or "high" has been selected. **1**

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

Input		Pin	Output	
		7	Water valve	(1 = open)
		6	Heating element 1	(1 = on)
		5	Heating element 2	(1 = on)
"High" switch	(=1 when selected)	4		
"Economy" switch	(=1 when selected)	3		
"Cold" switch	(=1 when selected)	2		
"Stop" switch	(=1 when selected)	1		
Water pressure sensor	(=1 when pressure low)	0		

Figure Q10(*b*)

The PBASIC code for the start of the control program is shown below:

```
init:       dirs = %11100000
main:       pins = 0
pressure:
```

(*b*) Write, in PBASIC, the control program, from the label "pressure" onwards. **8**

[Turn over

The water is heated by two heating elements placed inside a heating vessel. A safety system interrupts the power supply to one or both heating elements if the temperature in the heating vessel itself is too high, or if the temperature at the vessel outlet is too high. The electronic circuit for this safety system is shown in Figure Q10(*c*).

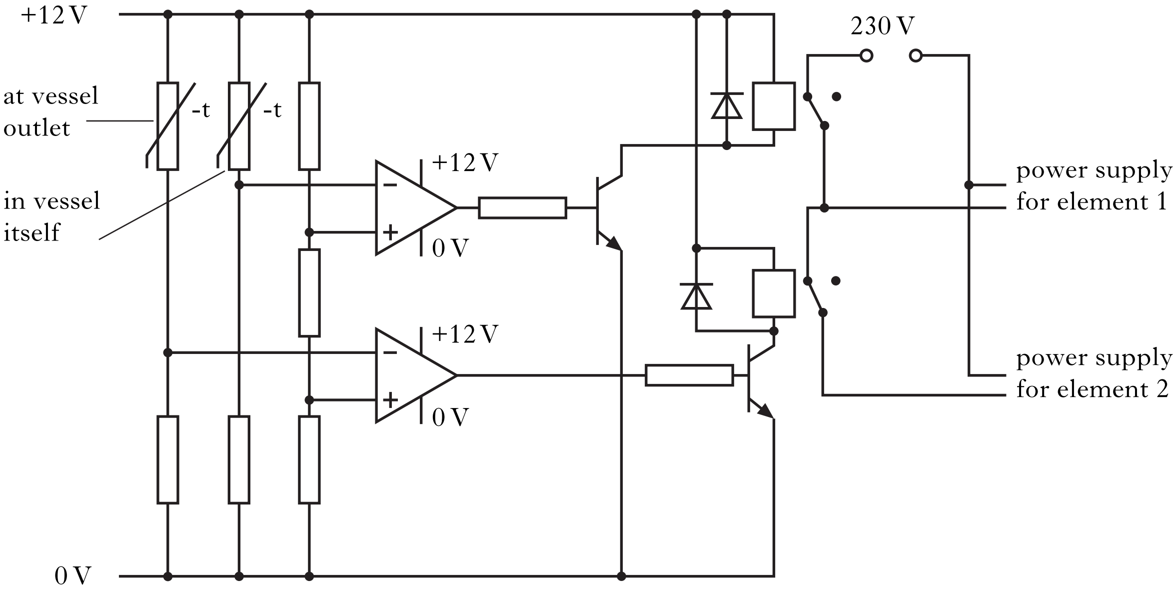

Figure Q10(*c*)

Marks

(*c*) (i) Explain clearly the operation of the circuit if the temperature in the vessel itself is **not** too high, but the temperature at the outlet **is** too high. **4**

(ii) Explain clearly the change in the operation of the circuit if the temperature **in the vessel itself** is too high. **2**

The water valve is operated by a solenoid, which is controlled by the circuit shown in Figure Q10(*d*). When the transistors are switched on and saturated, V_{CE} = 0·8 V. The maximum current that can be drawn from the microcontroller is 0·12 mA.

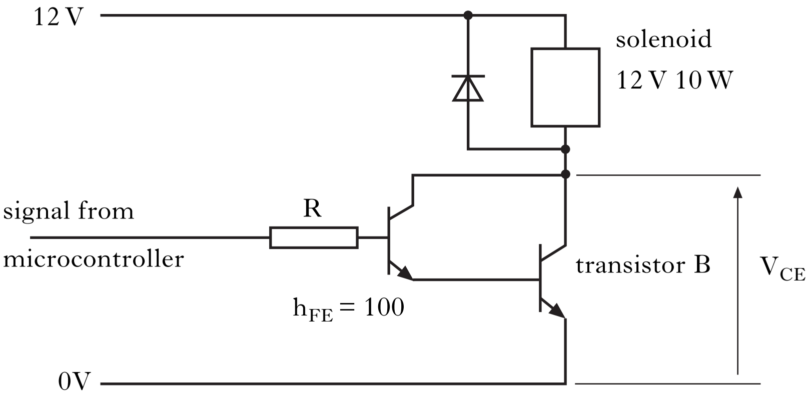

Figure Q10(*d*)

(*d*) Calculate the minimum current gain for transistor B to ensure saturation. **3**

A transistor with a current gain of 80 is chosen for transistor B.

(*e*) Calculate the minimum base current necessary to cause saturation. **1**

The signal from the microcontroller is 5 V when the solenoid is activated.

(*f*) Calculate the value of base resistor R necessary to limit the base current to 0·12 mA. **1**

(20)

11. Figure Q11(*a*) shows a structure supporting a hopper used for filling lorries with concrete. *Marks*

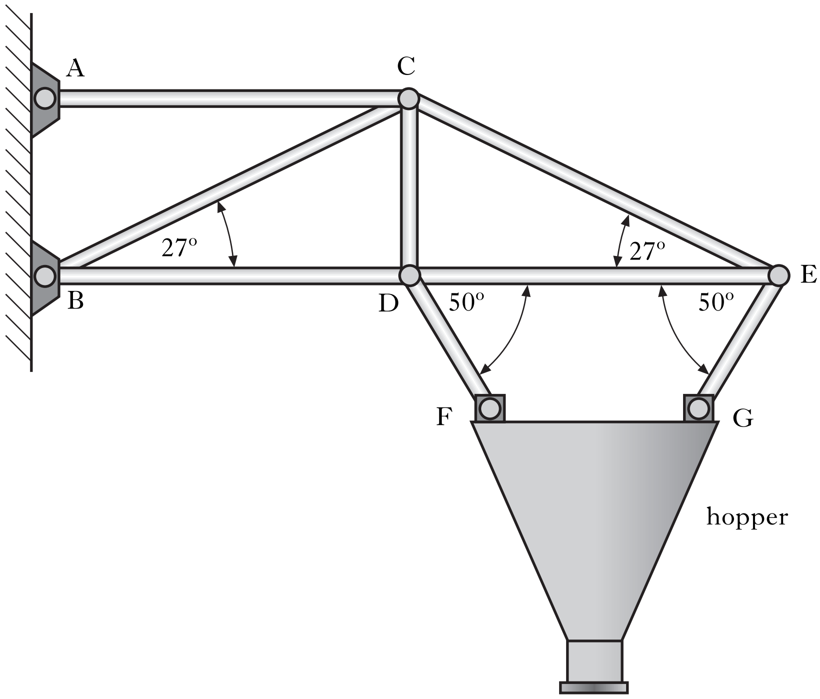

Figure Q11(*a*)

For a particular load, members DF and EG are each subjected to a tensile force of 78 kN.

(*a*) Using *nodal analysis*, calculate the **magnitude** and **nature** of the forces in members CE, DE, CD, BD and BC. **9**

Two strain gauges attached to member AC, as shown in Figure Q11(*b*), indirectly monitor the weight of concrete in the hopper.

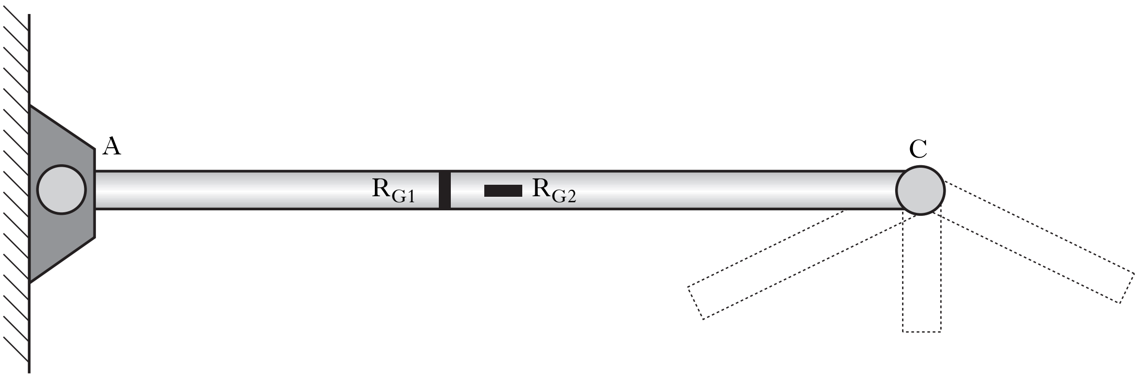

Figure Q11(*b*)

(*b*) Explain why the resistance of strain gauge R_{G2} **increases** as the load in the hopper increases, whereas the resistance of strain gauge R_{G1} does **not** change as the load increases. **1**

[Turn over

11. (continued)

As the hopper is filled by an operator, the electronic circuit shown in Figure Q11(*c*) gives the operator a visual indication of whether there is too little or too much concrete in the hopper.

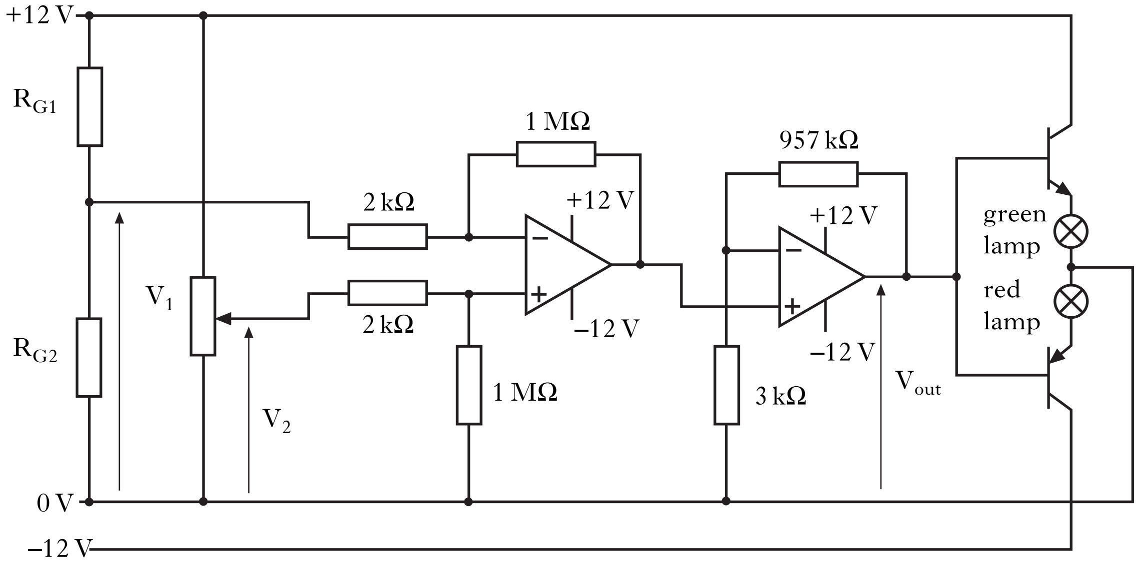

Figure Q11(*c*)

V_2 is preset so that when the required amount of concrete is in the hopper, $V_{out} = 0\,V$.

(*c*) Explain the operation of the electronic circuit as concrete is loaded into the hopper. Include in your answer details for part load, correct load and overload conditions. **3**

The unloaded resistance of the strain gauges is 120 Ω. When the weight of the concrete in the hopper is exactly correct, the combined weight of the hopper and concrete is 140 kN and $R_{G2} = 120{\cdot}02\,\Omega$. The potentiometer is adjusted so that $V_{out} = 0\,V$.

(*d*) Calculate V_2 correct to **4 decimal places**. **1**

The red lamp is visibly lit when $V_{out} = -4\,V$.

(*e*) (i) Calculate V_1 under these circumstances, correct to **6 decimal places**. **3**

(ii) Calculate R_{G2} correct to **3 decimal places**. **1**

There is a linear relationship between change in resistance of the strain gauges and the applied load.

(*f*) Calculate the combined weight of the hopper and concrete when $V_{out} = -4\,V$ and the red lamp is visibly lit. **2**

(20)

12. A microcontroller-based control system ensures that fuel is delivered at a constant rate when an aircraft is being refuelled. The required rate is set by a potentiometer. As the fuel is pumped, a tachogenerator generates a voltage proportional to the rate of flow of the fuel.

A block diagram of part of the fuel delivery system is shown in Figure Q12(*a*).

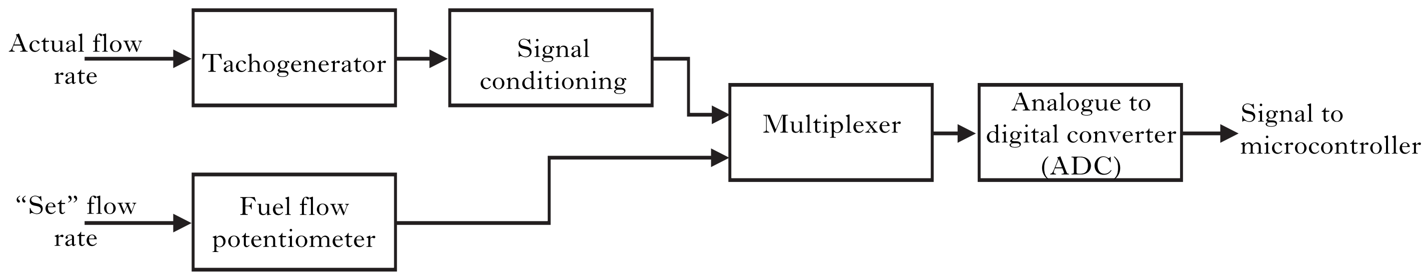

Figure Q12(*a*)

Figure Q12(*b*) shows the relationship between the output voltage of the tachogenerator and the fuel flow-rate.

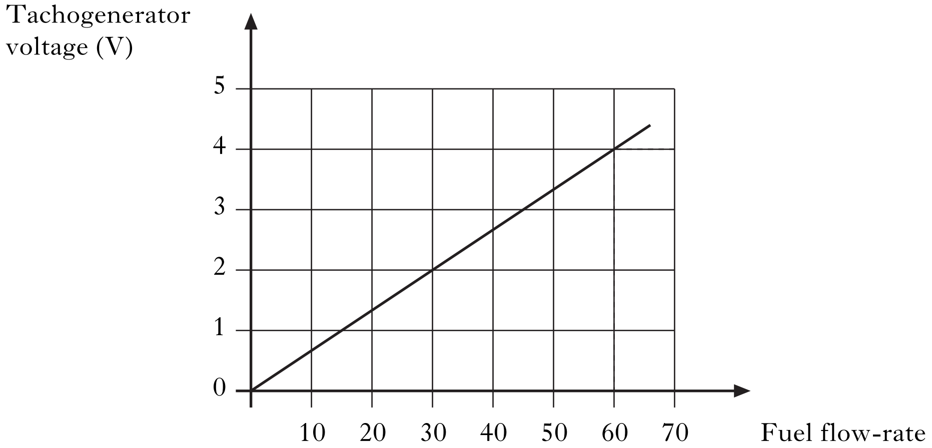

Figure Q12(*b*)

The tachogenerator signal is conditioned before being sent to an ADC with a reference voltage of 4·8 V. When the flow-rate is 60 litres/second, a binary value of 10110100 is sent to the microcontroller.

(*a*) (i) Design a signal conditioning system based on operational amplifiers, showing all resistor values. **4**

(ii) Calculate the binary value sent to the microcontroller for a flow-rate of 48 litres/second. **2**

[Turn over

12. (continued)

The microcontroller outputs are processed by the summing amplifier shown in Figure Q12(*c*). This acts as a digital-analogue converter, which controls the pump speed.

The microcontroller output pins are at 5 V when switched on.

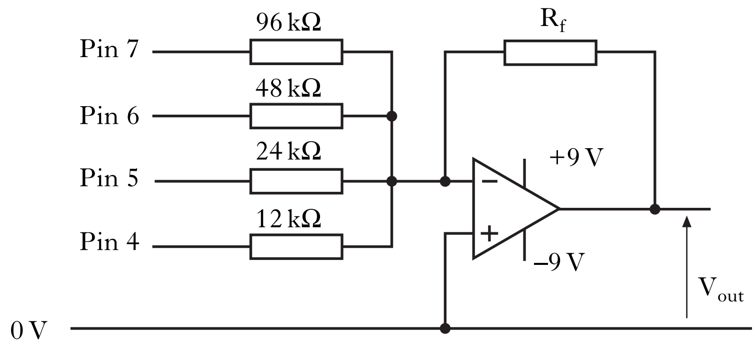

Figure Q12(*c*)

(*b*) For the summing amplifier shown in Figure Q12(*c*):

(i) calculate the value of resistor R_f so that the maximum output voltage V_{out} is –6·8 V; **2**

(ii) calculate the output voltage V_{out} when the command "pins = %01100000" is executed. **1**

The fuel-delivery system is controlled by a PBASIC program, part of which is shown below. A pre-written sub-procedure *adcread* takes a reading from the ADC and stores the value in a variable called DATA.

```
            let dirs = %11111101
            let b8 = 0
main:       low ADC_MPX
            gosub adcread
            let b5 = DATA
            high ADC_MPX
            gosub adcread
            if DATA > b5 then slow
            if DATA < b5 then fast
            goto main
slow:       if b8 = 0 then main
            let b8 = b8 –1
            let pins = b8*16
            goto main
fast:       let b8 = b8 + 1
            if b8 = 16 then main
            let pins = b8*16
            goto main
```

(*c*) (i) State which microcontroller pin receives data from the ADC. **1**

(ii) Explain the purpose of the command "high ADC_MPX". **1**

(iii) State the purpose of the variable b5. **1**

(iv) Explain why b8 is multiplied by 16. **1**

12. (continued)

The fuel hose is supported by the frame shown in Figure Q12(*d*).

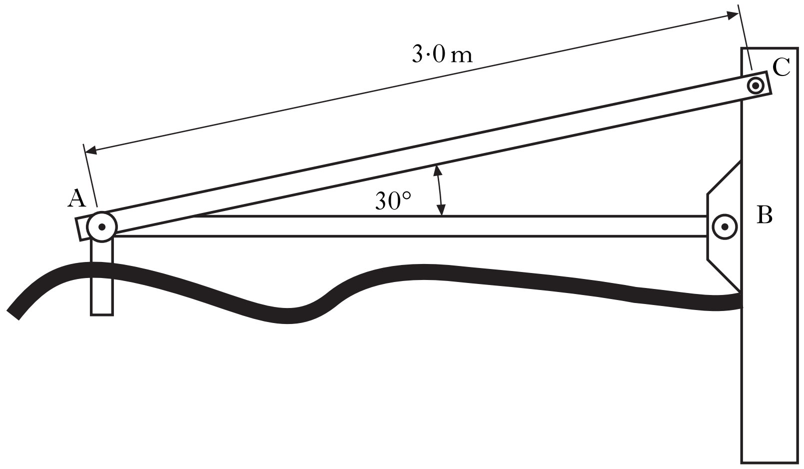

Figure Q12(*d*)

Member AC is a hollow square-section aluminium-alloy tube, as shown in Figure Q12 (*e*).

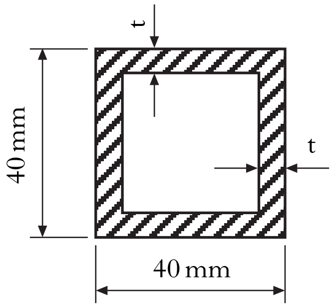

Figure Q12(*e*)

The hose exerts a vertical force of 1·2 kN on node A, and this causes a change of length in member AC of 0·91 mm.

(*d*) For member AC, calculate:

(i) the stress; **2**

(ii) the Factor of Safety; **1**

(iii) the material thickness (t). **4**

(20)

[*END OF QUESTION PAPER*]