X036/12/01

NATIONAL QUALIFICATIONS 2012

FRIDAY, 18 MAY
1.00 PM – 4.00 PM

TECHNOLOGICAL STUDIES
HIGHER

200 marks are allocated to this paper.

Answer **all** questions in Section A (120 marks).

Answer **two** questions from Section B (40 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.

SECTION A

Marks

Attempt all the questions in this Section. (Total 120 marks)

1. Figure Q1 shows a production line for filling and capping bottles. A lid-fitting device (Z) operates when an ultrasound sensor (A) or a load cell (B) detects that the bottle is full, and a filling-nozzle sensor (C) detects that filling has stopped.

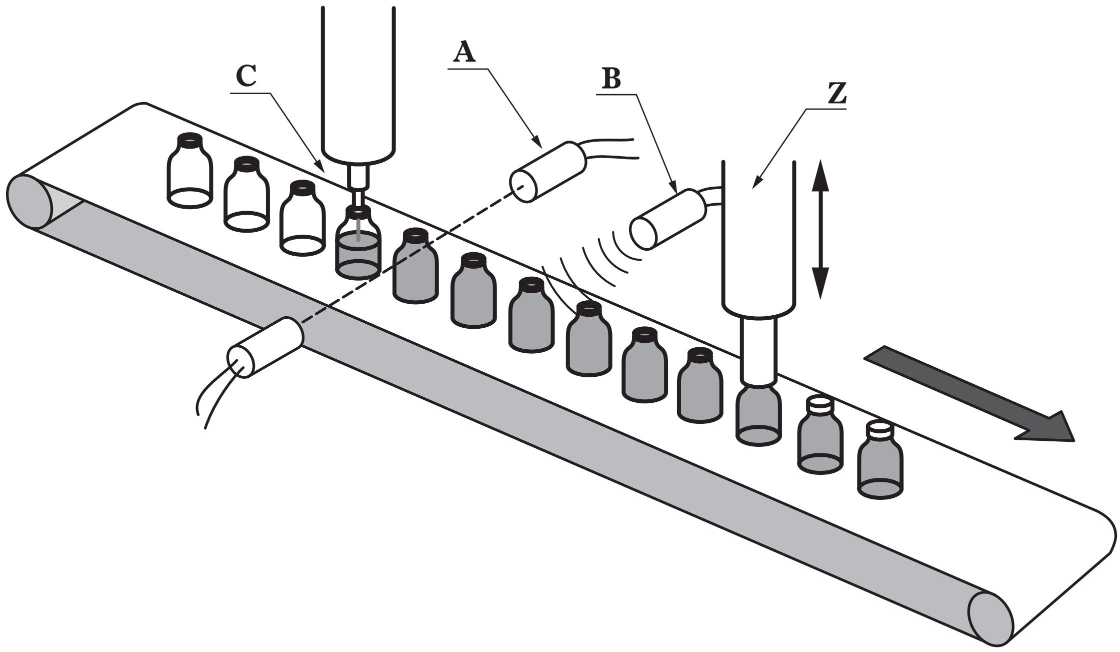

Figure Q1

Transducer	State
Ultrasound sensor (A)	1 = bottle full
Load cell (B)	1 = bottle full
Filling-nozzle sensor (C)	0 = filling stopped
Lid-fitting device (Z)	1 = fit lid

(*a*) Draw the truth table for inputs A, B, C and output Z. **3**

(*b*) Write a Boolean expression for the output Z in terms of the three inputs A, B and C. **4**

(*c*) Draw the logic diagram for the output Z using only NAND gates.

(2–input and 3–input NAND gates are available.)

Simplify where appropriate. **9**

(16)

Marks

2. A load-extension graph for a standard test specimen is shown in Figure Q2. The specimen is 200 mm long and 11·3 mm in diameter.

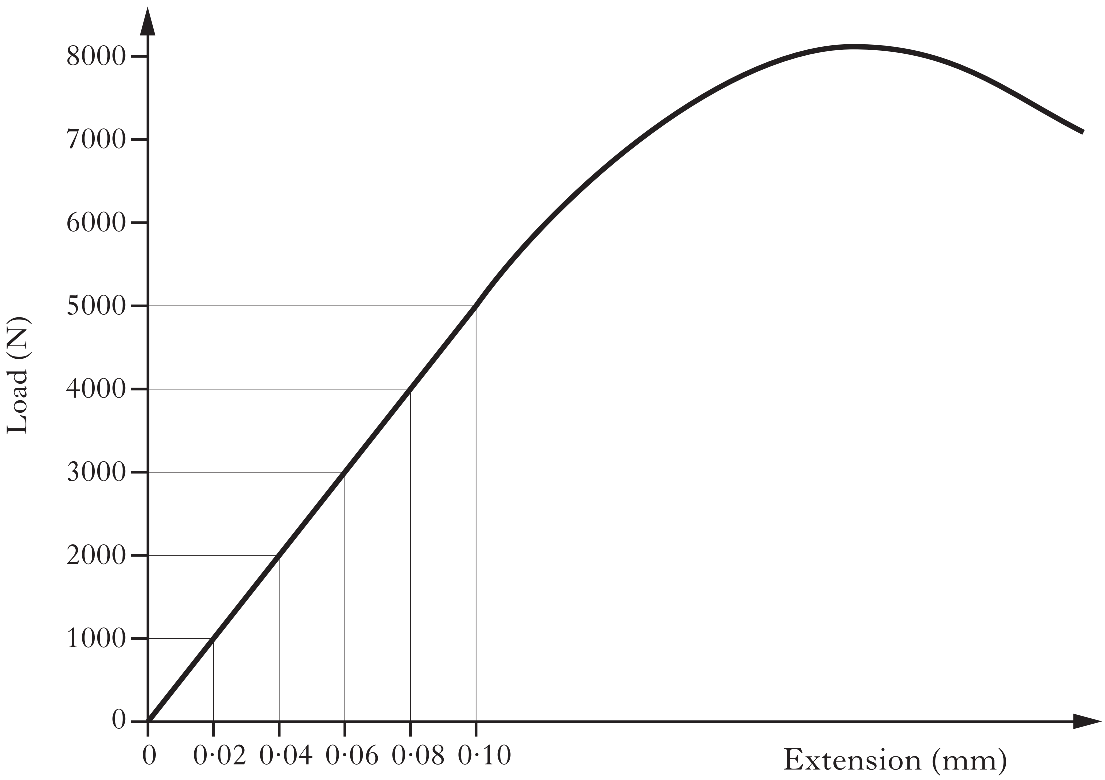

Figure Q2

(*a*) Calculate Young's Modulus for the test specimen. **5**

(*b*) State the name of the material from which the test specimen is made. **1**

(*c*) Sketch the graph shown in Figure Q2, and on it show the yield point, the ultimate load, the plastic range and the elastic range. **4**

Two further specimens were tensile tested. The dominant mechanical property of specimen A was brittleness, and that of B was ductility.

(*d*) Sketch, on the same axes, typical stress-strain graphs for specimen A and specimen B. Clearly label the axes and identify each graph. **4**

(14)

[Turn over

3. A motorised control valve in a refinery has to close at a controlled speed for safety reasons. The flowchart for the sub-procedure *close*, used to achieve this, is shown in Figure Q3. Assume that the variable TIME has been defined in the main program.

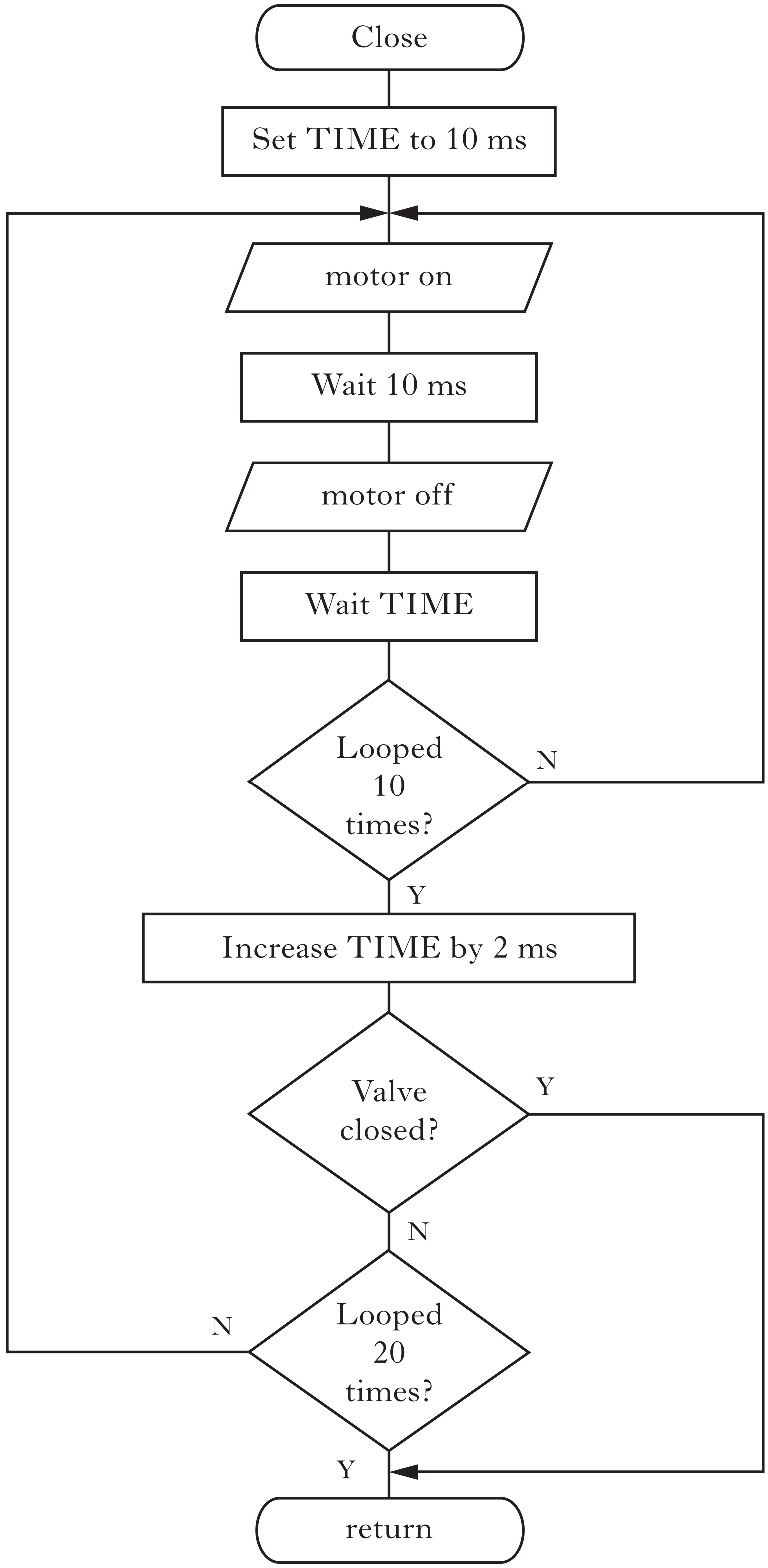

Figure Q3

3. (continued) *Marks*

The motor is connected to pin 4 of a microcontroller, and a microswitch indicates that the valve is fully closed when pin 2 = 1.

(*a*) Write, in PBASIC, the sub-procedure *close*. **11**

(*b*) (i) State the name of this type of speed control. **1**

(ii) Describe how the valve behaves as sub-procedure *close* runs. **2**

(*c*) Determine the mark-space ratio when the motor runs at its slowest possible speed. **2**

(16)

[Turn over

Marks

4. The motorised pump shown in Figure Q4(*a*) is to be tested against a specification by a maintenance engineer.

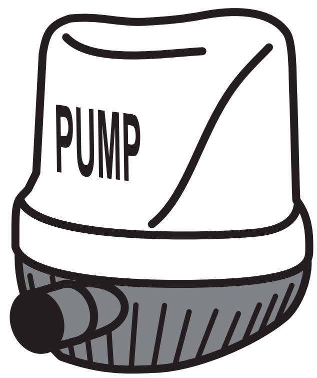

Figure Q4(*a*)

Part of the pump circuit is shown in Figure Q4(*b*).

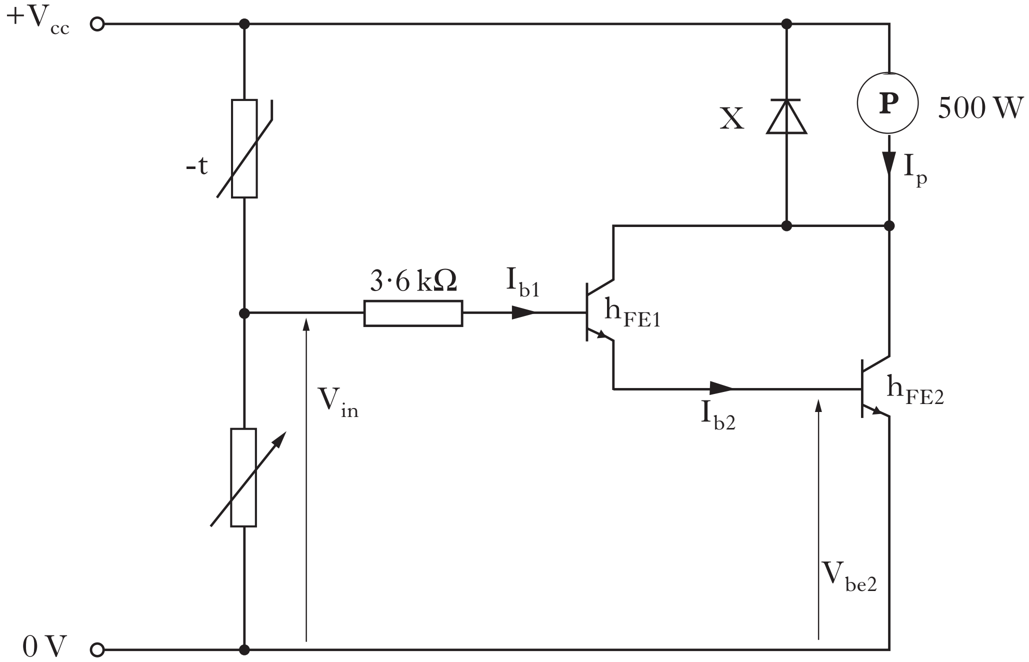

Figure Q4(*b*)

(*a*) For the circuit shown in Figure Q4(*b*):

(i) state the name of the transistor configuration; **1**

(ii) describe the purpose of component X. **2**

4. (continued) *Marks*

The maintenance engineer completes the table shown in Figure Q4(c) for comparison to the test specification.

Quantity	**Value**
V_{in}	2·3 V
V_{be2}	
I_{b1}	
I_{b2}	
I_p	2·13 A
Pump resistance	
h_{FE1}	80
h_{FE2}	
Overall current gain	

Figure Q4(c)

(b) Copy and complete the table shown in Figure Q4(c). (Show all working.) **12**

(15)

[Turn over

Marks

5. A soldering machine passes printed circuit boards (PCBs) over a fluxer and then over a solder wave as shown in Figure Q5(*a*). As each PCB passes through the machine, a microcontroller records the temperature of the flux and the solder.

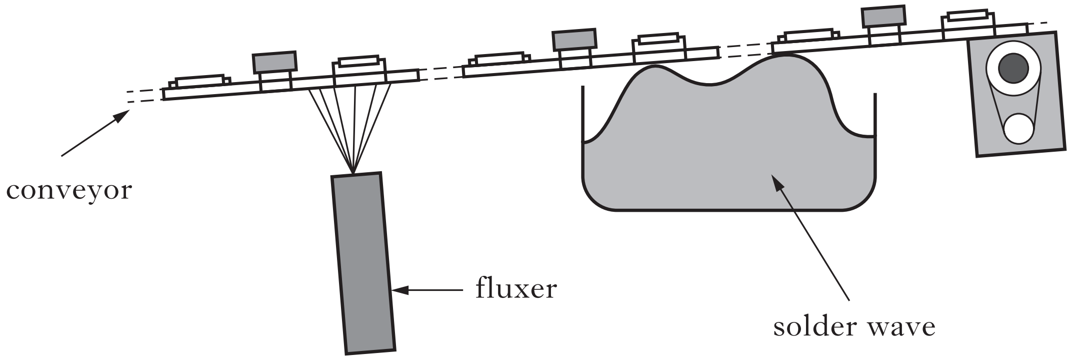

Figure Q5(*a*)

Figure Q5(*b*) shows a block diagram of the temperature monitoring and recording system.

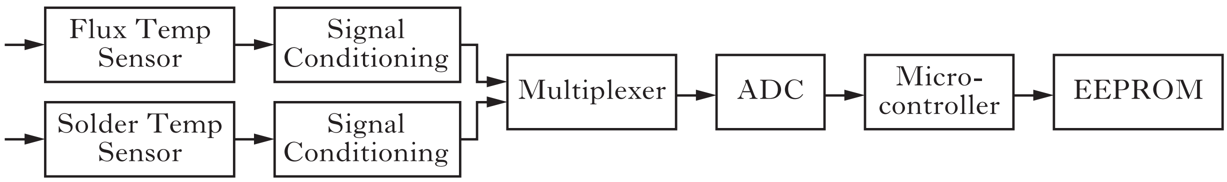

Figure Q5(*b*)

(*a*) State the purpose of the signal-conditioning sub-systems. **1**

(*b*) State **two** reasons for using an EEPROM in a data logger. **2**

(*c*) State the **two** factors that determine the choice of sampling frequency in a data-logging system. **2**

A sub-procedure *tempmonitor* makes use of two pre-written sub-procedures *adcread* and *eewrite* to monitor and record one reading from each of the temperature sensors.

The flux temperature readings are recorded on page 0 of the EEPROM.
The solder temperature readings are recorded on page 1 of the EEPROM.

The flux temperature is recorded first, and the solder temperature is recorded 3·8 seconds later.

(*d*) Develop a flowchart to represent the sub-procedure *tempmonitor*. **10**

(15)

6. The mast of a racing yacht has three main supporting cables: the forestay, the backstay and the shrouds, as shown in Figure Q6(*a*). An overload-sensing system monitors the cable tensions using strain gauges fitted to each cable type.

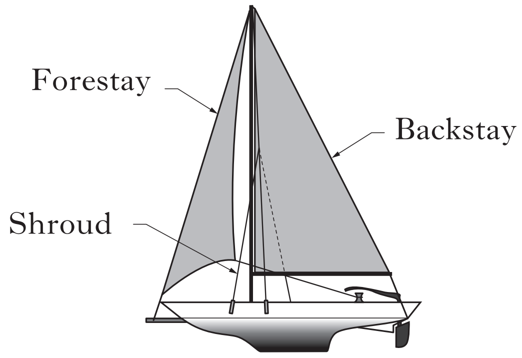

Figure Q6(*a*)

Part of the overload circuit is shown in Figure Q6(*b*) below.

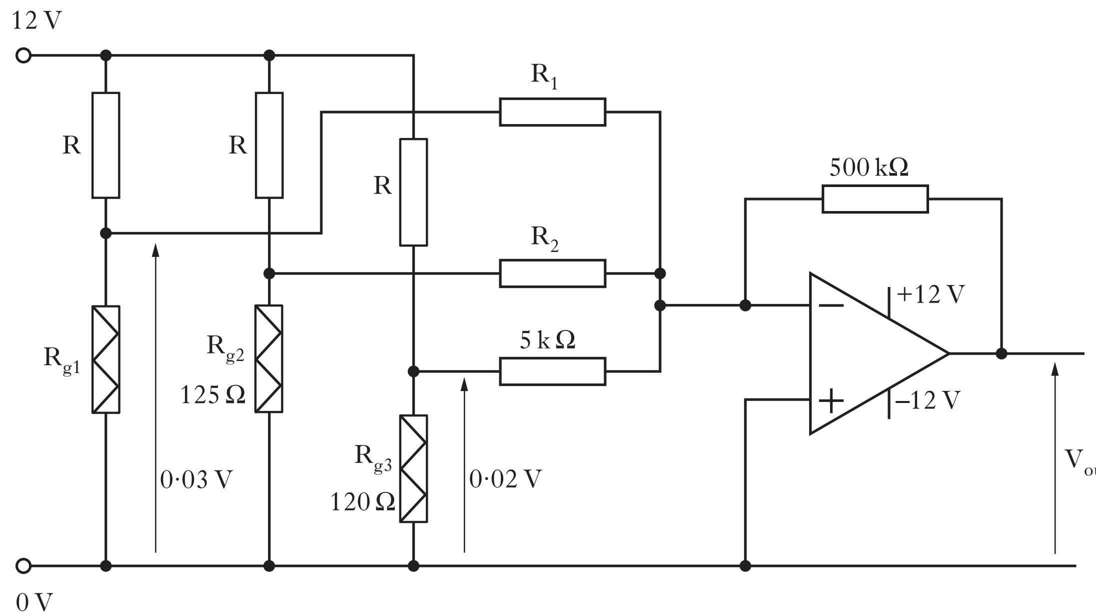

Figure Q6(*b*)

(*a*) State the name of the operational amplifier configuration. **1**

Due to different loadings in the support cables, different gains are applied to each of the strain-gauge signals. The signal from R_{g1} is amplified by −40, from R_{g2} by −50, and from R_{g3} by −100.

(*b*) For the loading condition shown in Figure Q6(*b*), calculate the values of:

(i) R; **2**

(ii) R_{g1}; **2**

(iii) R_1 and R_2. **2**

(*c*) Calculate the output voltage (V_{out}). **7**

(14)

7. Tests are to be carried out on the supports of one of the seating units of the fairground swing shown in Figure Q7(*a*). *Marks*

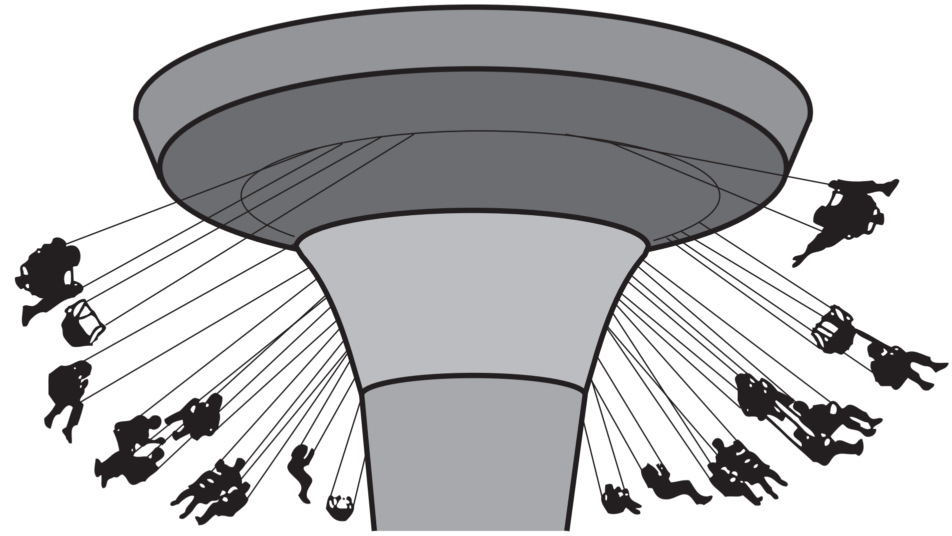

Figure Q7(*a*)

A simplified free body diagram of the supporting unit, for a particular loading condition, is shown in Figure Q7(*b*).

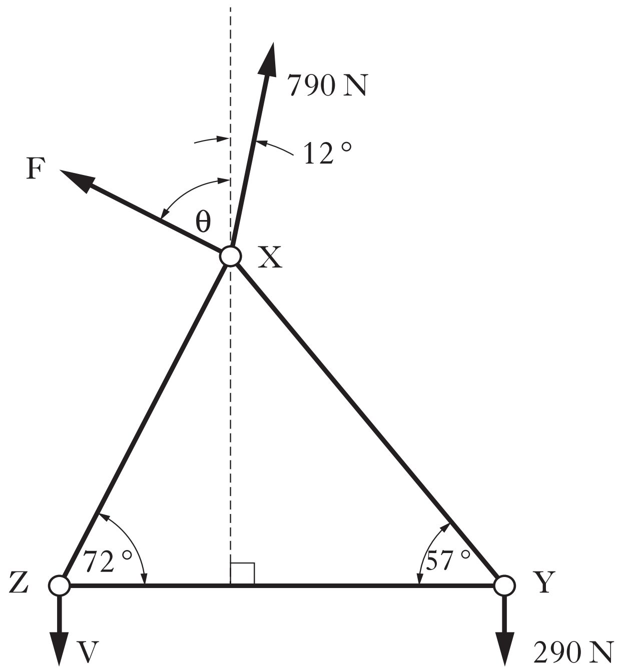

Figure Q7(*b*)

(*a*) Calculate:

(i) the magnitude of the forces in members XY, YZ and XZ; **6**

(ii) the magnitude of the forces in V and F; **6**

(iii) the angle θ. **2**

(14)

Marks

8. An electronic system controls a spotlight in an art gallery. As the natural light level varies, the spotlight brightens or dims as required, in order to keep the overall light level constant. The light level at which the spotlight is triggered can be adjusted.

(*a*) Draw a control diagram for the system. **7**

The op-amp-based circuit for the system is shown in Figure Q8.

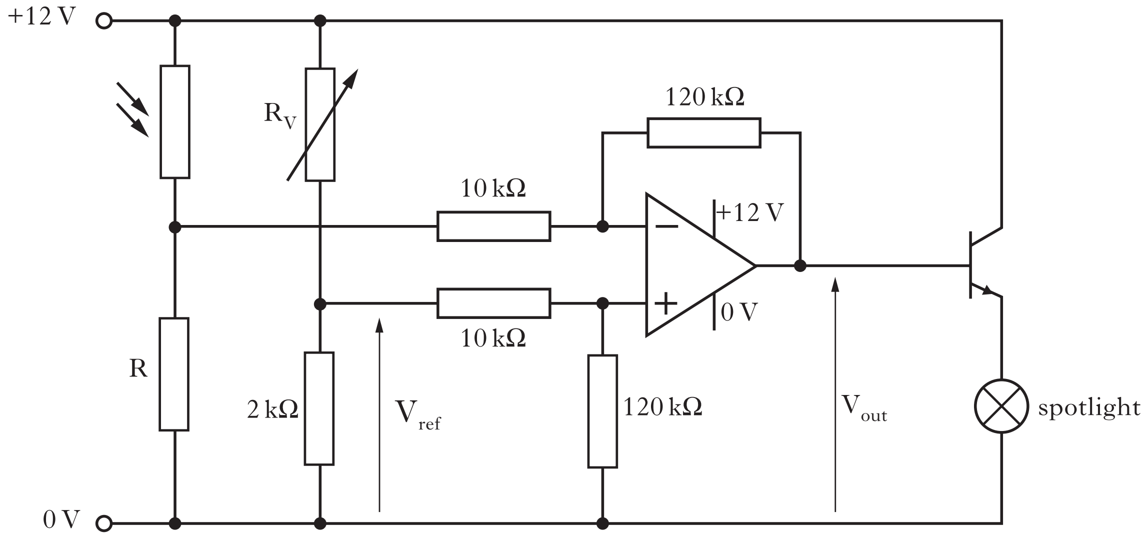

Figure Q8

When the variable resistor $R_v = 4{\cdot}8\,k\Omega$:

(*b*) calculate the voltage V_{ref}. **2**

When the light level is 400 lux and $V_{out} = 8\,V$:

(*c*) calculate the resistance R. **7**

(16)

[*END OF SECTION A*]

[Turn over

SECTION B

Marks

Attempt any TWO questions in this Section.

Each question is worth 40 marks.

9. A gantry carrying an overhead road sign is loaded as shown in Figure Q9(*a*).

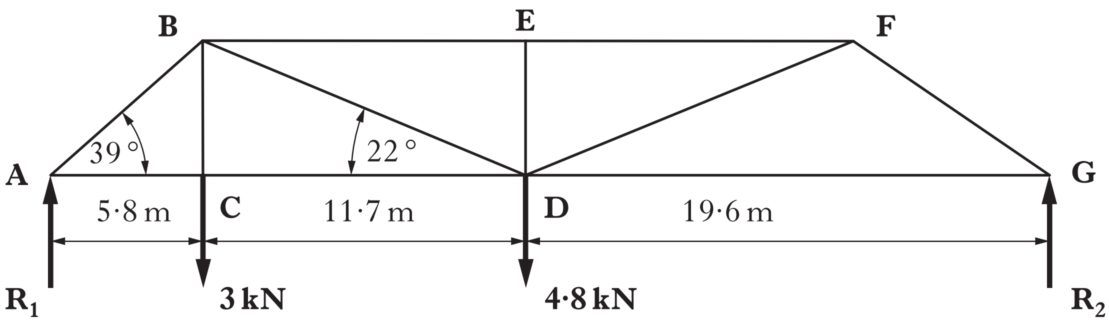

Figure Q9(*a*)

For the loading conditions shown in Figure Q9(*a*):

(*a*) calculate the reaction force R_1 acting at A; **2**

(*b*) calculate the **magnitude** and **nature** of the forces in members AB, AC and BD. **14**

A force of 8·0 kN acts on member DF, which is an aluminium-alloy tube 13·7 m long and 75 mm outside diameter. The maximum allowed extension is 2·5 mm.

(*c*) Calculate the minimum required wall thickness for member DF. **11**

The gantry carries a dot-matrix display. Part of the display is shown in Figure Q9(*b*). A microcontroller switches on each **row** of lights in a rapid sequence with a 5 ms delay to display a symbol. Each light requires a **row** pin and a **column** pin to be high.

The sub-procedure *display_arrow* is used to display the symbol "↙", shown in Figure Q9(*b*).

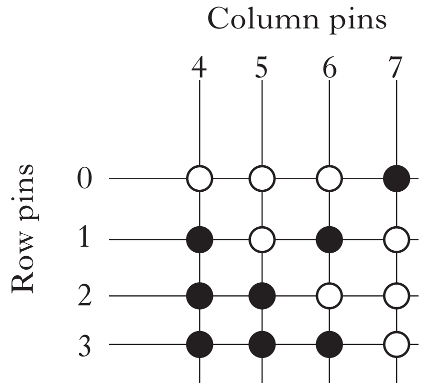

Figure Q9(*b*)

9. (continued) *Marks*

The sub-procedure *display_arrow* begins as shown below:

```
display_arrow:      for b0 = 1 to 50
                    pins = %10000001
                    pause 5
```

(*d*) Complete the sub-procedure *display_arrow*. **6**

Each of the lights on the matrix display consists of an array of five LEDs. The circuit shown in Figure Q9(*c*) controls one array of LEDs.

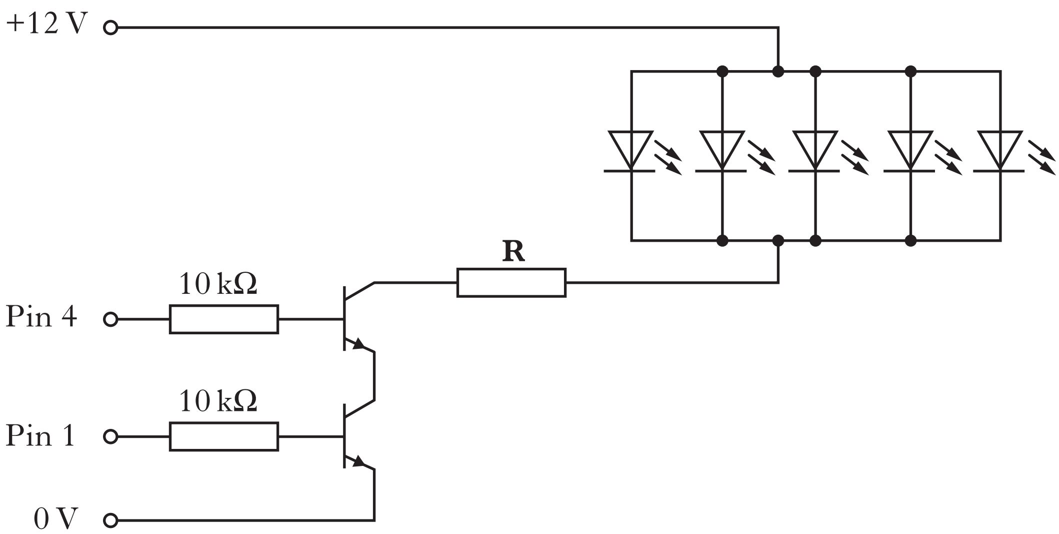

Figure Q9(*c*)

The circuit uses identical transistors, each of which has a voltage drop, V_{CE}, of 0·2 V when saturated. The voltage drop across the LED array is 1·8 V and the current flow through each LED is 20 mA.

(*e*) Calculate the required value of resistor R. **3**

The microcontroller outputs are 6 V when high.

(*f*) Calculate the minimum current gain required for the transistor connected to pin 1. **4**

(40)

[Turn over

10. Automated pickers are used in a warehousing depot to find and retrieve stock, as shown in Figure Q10(*a*). Each picker is controlled by an on-board microcontroller. Movement is provided by two stepper motors controlled by stepper-motor-driver Integrated Circuits.

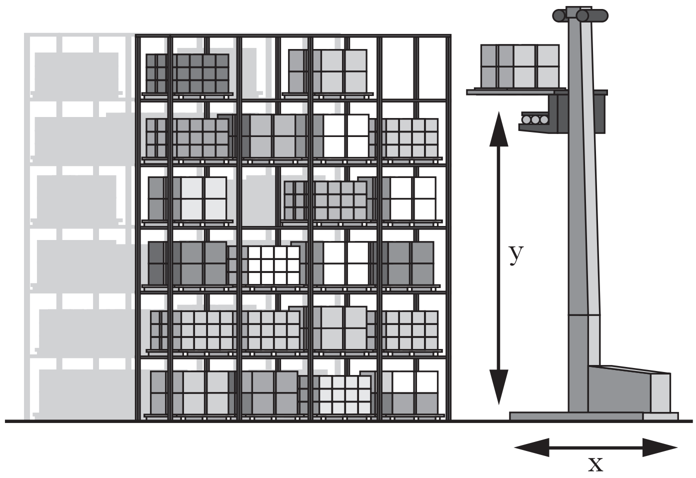

Figure Q10(*a*)

(*a*) State **two** reasons for using stepper motors in this application. **2**

The sub-procedure *locate*, shown in Figure Q10(*b*) opposite, controls the movement of the picker to the required component. Values for the distance the picker is to move along the aisle (x-direction), and how far up the stack (y-direction), are sent from the main warehouse program as a number of pulses required by the stepper motors.

A pre-written sub-procedure *pulsedata* reads the number of pulses from the main warehouse program and stores the number in a variable called DATA. To ensure reliability, the required number of pulses is sent twice.

The sub-procedure *x-move*, shown in Figure Q10(*c*) opposite, controls the stepper motor in the x-direction via the stepper-motor-driver IC. A similar sub-procedure, *y-move,* controls movement in the y-direction. Pin connections are shown in Figure Q10(*d*).

(*b*) (i) Write, in PBASIC, the sub-procedure *locate*. **18**

(ii) Write, in PBASIC, the sub-procedure *x-move*. **5**

10. (continued)

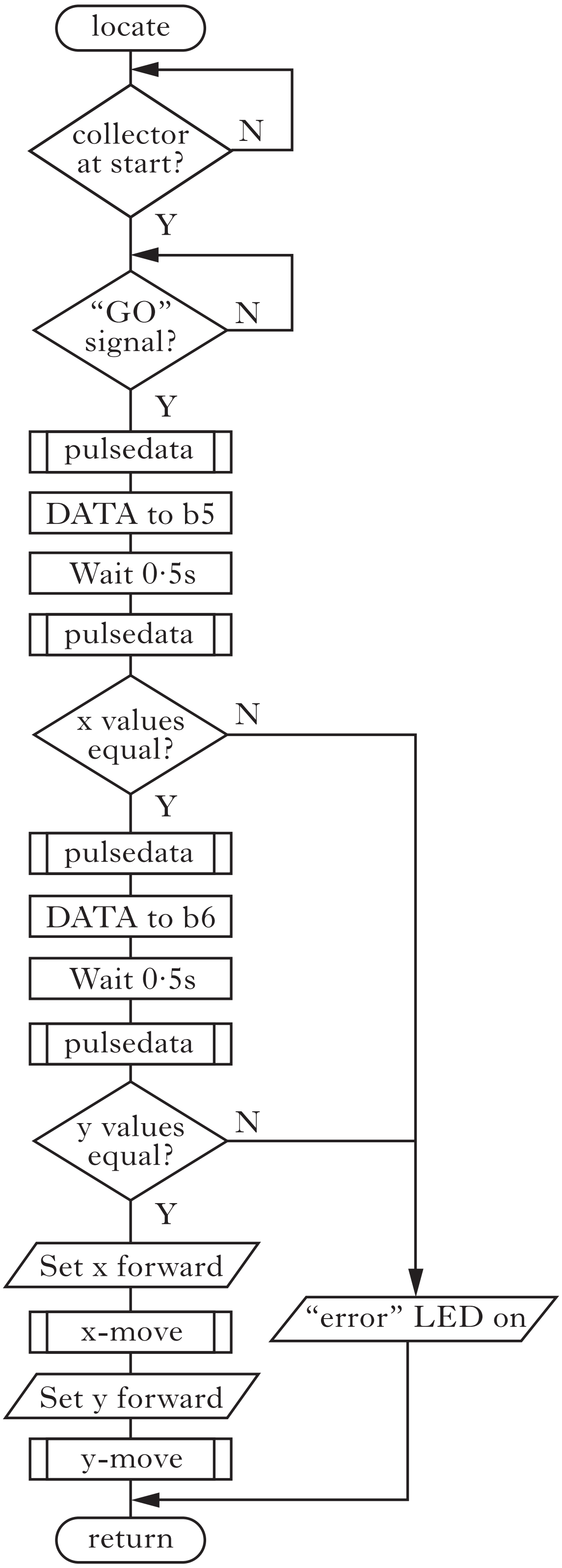

Figure Q10(*b*)

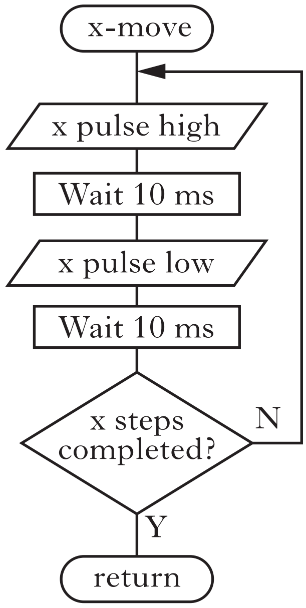

Figure Q10(*c*)

Input	Pin	Output
	7	y pulse
	6	y direction (1=FWD)
	5	x pulse
	4	x direction (1=FWD)
	3	
	2	"Error" LED
Start sensor (1=at start)	1	
"GO" (1=go)	0	

Figure Q10(*d*)

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10. (continued) *Marks*

The picker breaks a light beam at the start position, using the sensing circuit shown in Figure Q10(*e*).

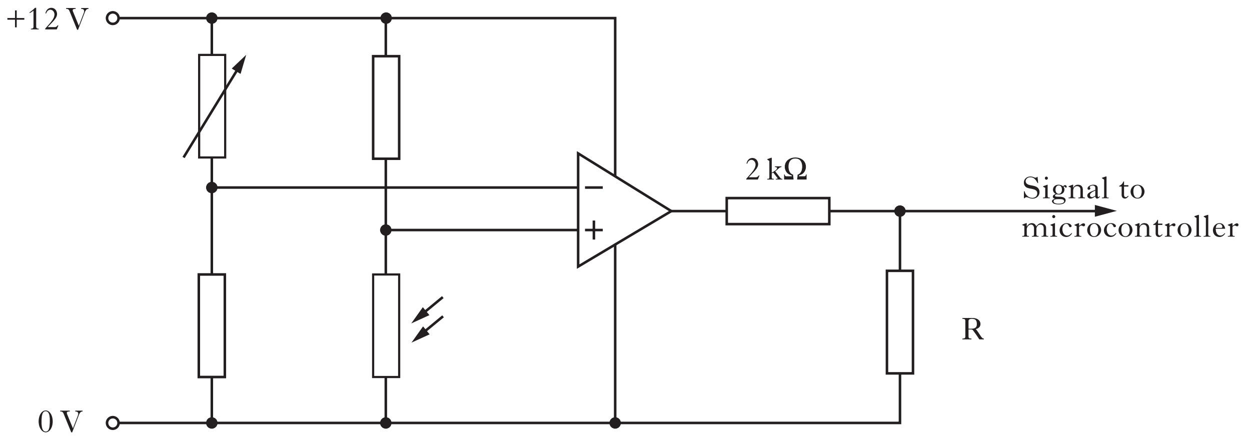

Figure Q10(*e*)

(*c*) Explain, in terms of input, process and output, the operation of this circuit. **4**

The signal to the microcontroller is 5 V when the picker is sensed at the start position.

(*d*) Calculate the required value of resistor R. **3**

The system was found to be prone to giving false readings due to dirt on the LDR, which could cause the output from the op-amp to go high. The alternative system shown in Figure Q10(*f*) was developed. Two comparators were used to provide an upper and a lower threshold.

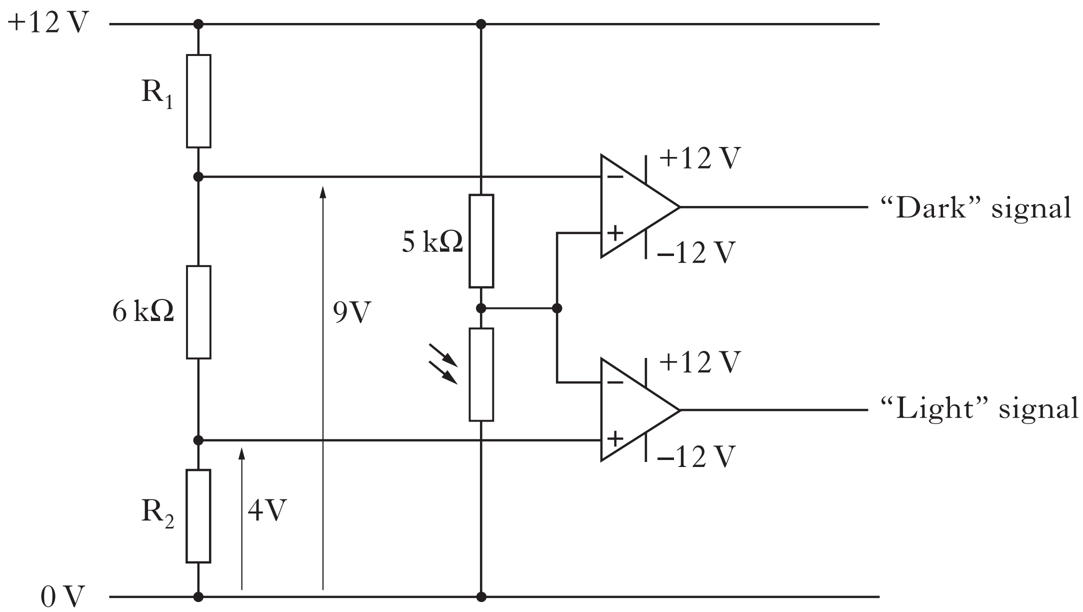

Figure Q10(*f*)

(*e*) (i) Calculate the required values of R_1 and R_2. **4**

(ii) Calculate the threshold light level on the LDR at which the "dark" signal changes state. **4**

11. The temperatures of the coolant in a nuclear reactor are monitored using two thermocouples positioned as shown in Figure Q11(*a*). *Marks*

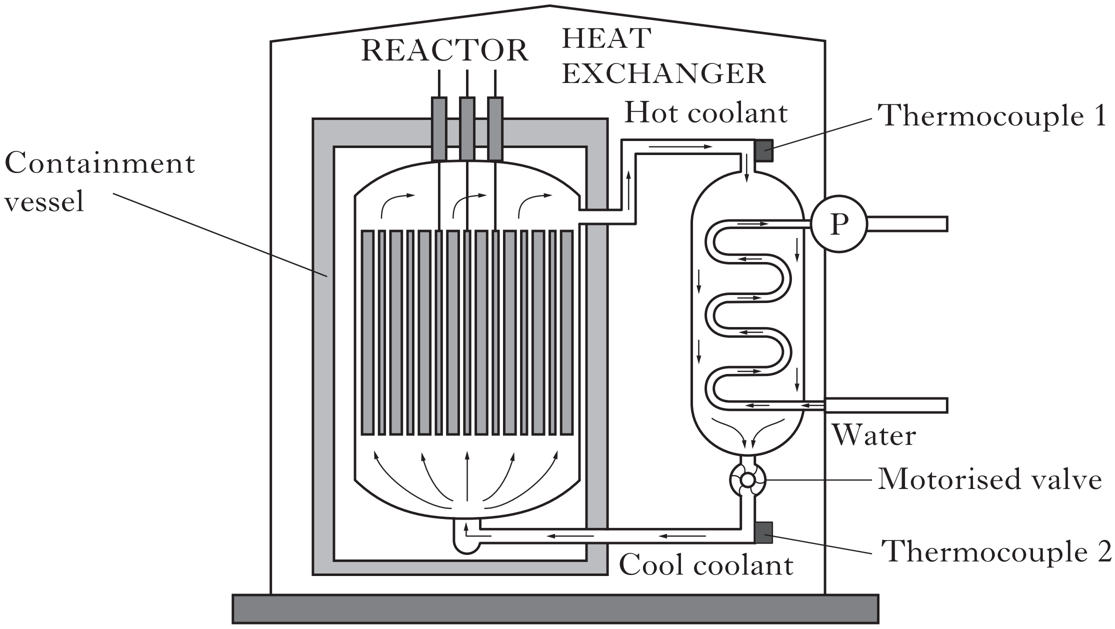

Figure Q11(*a*)

The signals from the two thermocouples are conditioned and processed by the electronic circuit shown in Figure Q11(*b*).

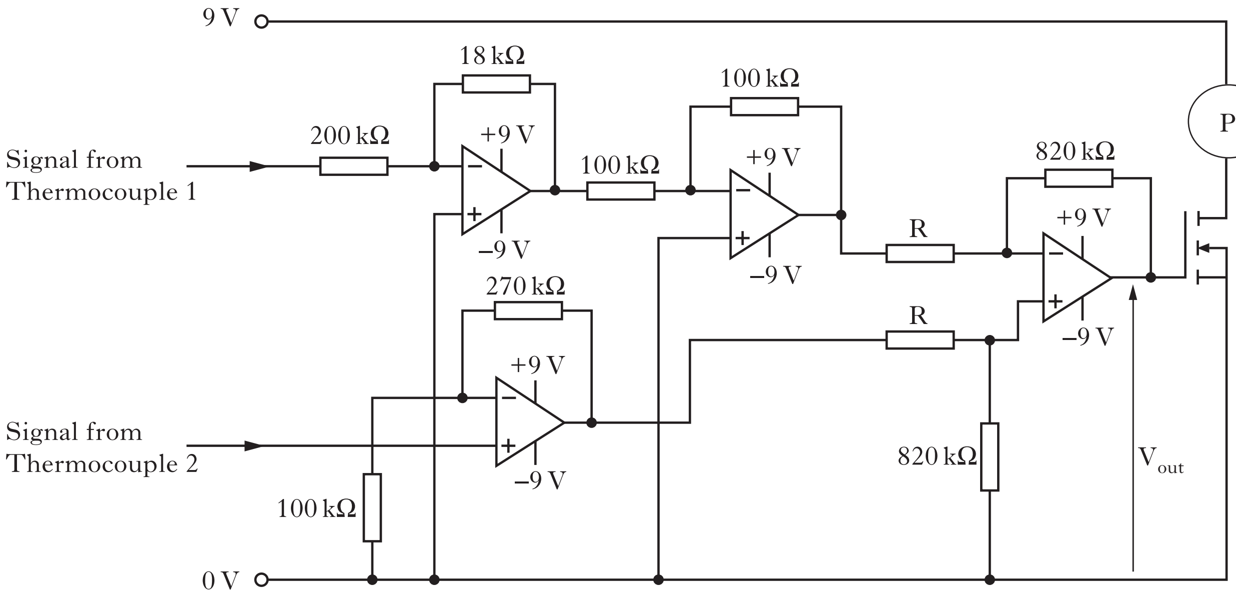

Figure Q11(*b*)

(*a*) State the main difference between a thermocouple and a thermistor in terms of their operation in a circuit. **2**

The temperature measured by Thermocouple 1 is 400 °C. When the temperature measured by Thermocouple 2 is 100 °C, the voltage V_{out} is 3·84 V.

(*b*) Calculate the required value of the resistors R. **10**

11. (continued) *Marks*

The table in Figure Q11(*c*) shows drain currents (I_D) for increasing gate/source voltages (V_{GS}) for the MOSFET in Figure Q11(*b*).

V_{GS} (V)	I_D (mA)
3·80	0
3·82	0·2
3·86	10·2
3·90	20·4
3·94	30·6
3·98	40·8
5·00	40·8

Figure Q11(*c*)

(*c*) For this MOSFET:

(i) state the threshold voltage V_T, and the saturation current; **2**

(ii) sketch the graph of I_D against V_{GS} (label the axes); **4**

(iii) calculate the transconductance value, (g_m). **2**

The rate of flow of the coolant is controlled by a motorised valve which can be opened and closed by reversing the direction of the motor. This is achieved by means of a bi-polar transistor push/pull driver circuit.

(*d*) Sketch an appropriate circuit, showing the required transistors, motor and power rails. **4**

11. (continued) *Marks*

During reactor maintenance, the control rods are lifted from the containment vessel using the pick-and-place robot arm shown in Figure Q11(*d*). The forearm of the robot consists of a single member, as shown in Figure Q11(*e*) where it is rotated to the horizontal position.

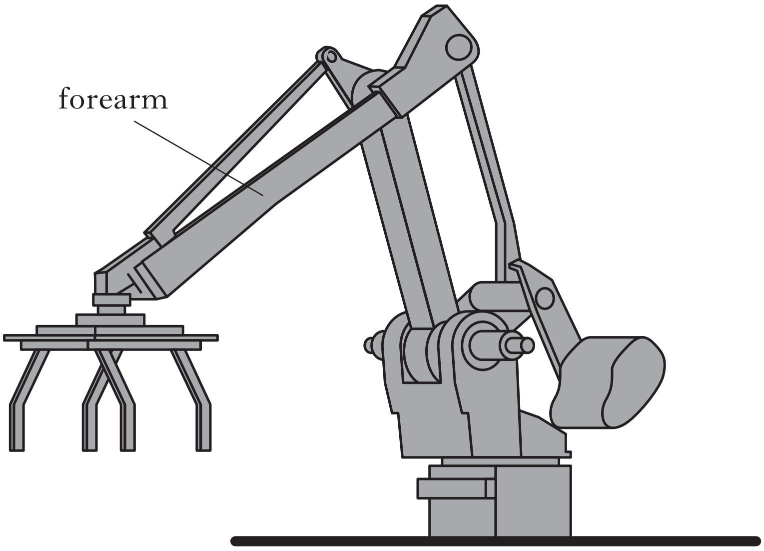

Figure Q11(*d*)

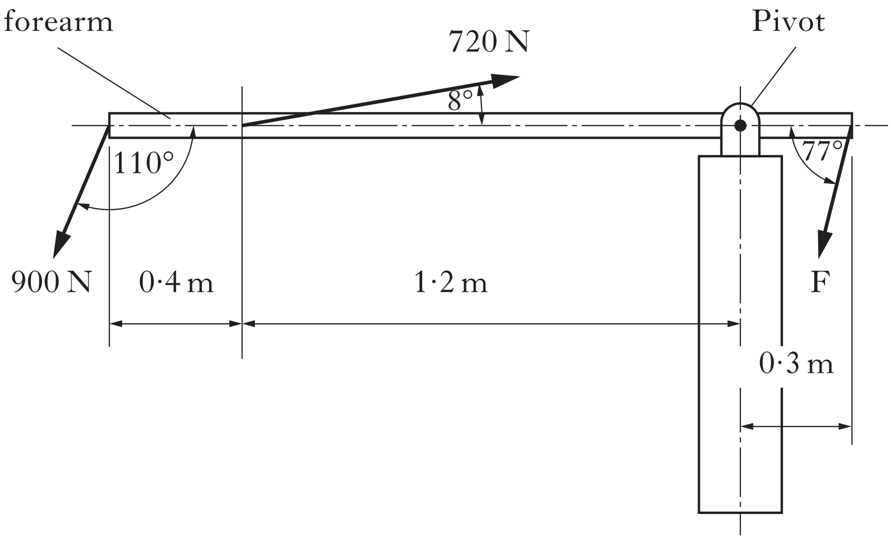

Figure Q11(*e*)

(*e*) Calculate, using the Principle of Moments, the force F. **5**

(*f*) Calculate the **magnitude** and **direction** of the reaction at the pivot. **11**

(40)

[*END OF QUESTION PAPER*]

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