X036/301

NATIONAL
QUALIFICATIONS
2007

FRIDAY, 1 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 6/3070

Marks

SECTION A

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

1. A warehouse security camera is controlled by a combinational logic system. The camera is activated when the warehouse door is opened at any time, or when a person is sensed near the door when it is dark.

The inputs and output of the control system are shown below.

INPUTS
Door sensor: D (= 1 when door is closed)
Person sensor: P (= 1 when person is sensed)
Light sensor: L (=1 when it is not dark)

OUTPUT
Camera: C (=1 when camera is activated)

For output C:

(*a*) write a Boolean expression in terms of the three inputs; **1**

(*b*) draw a combinational logic system using only AND, OR and NOT gates; **2**

(*c*) draw an equivalent logic system using only NAND gates. Simplify where possible. **3**

(6)

2. Figure Q2(*a*) shows a circuit designed to provide a warning when the temperature in a supermarket freezer is at or above –10 °C.

It was found that the lamp did not light.

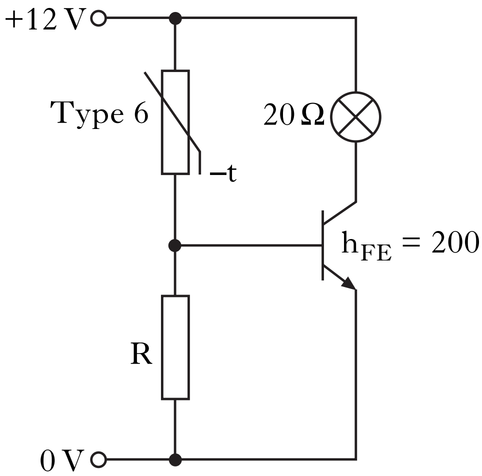

Figure Q2(*a*)

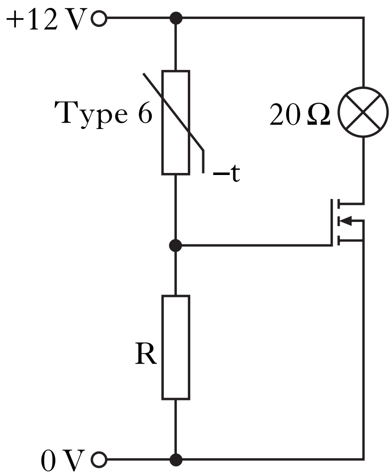

Figure Q2(*b*)

(*a*) State **one** reason for the circuit in Figure Q2(*a*) not functioning as required. **1**

The circuit in Figure Q2(*b*) was found to function correctly.

2. (continued)

The table in Figure Q2(*c*) shows the drain-source saturation current ($I_{DS\ [max]}$) for various gate voltages (V_{GS}), for the circuit shown in Figure Q2(*b*).

Gate Voltage (V_{GS})	Saturation Current ($I_{DS\ [max]}$)
2 V	0 mA
3 V	140 mA
4 V	260 mA
5 V	380 mA
6 V	490 mA
7 V	600 mA
8 V	710 mA

Figure Q2(*c*)

(*b*) Calculate the voltage drop across the lamp when the gate voltage is 3 V and the transistor is saturated. **1**

(*c*) Determine the minimum gate voltage necessary for the lamp to shine at maximum brightness. **1**

(*d*) Calculate the minimum value of resistor R in Figure Q2(*b*), so that the lamp shines at maximum brightness when the temperature is –10 °C. **2**

(5)

3. A microcontroller-based data-logging system is used to monitor the water temperature and the oil pressure of an engine at a remote pumping station. A temperature sensor and a pressure sensor each provide analogue signals to the system.

An 8-bit analogue-to-digital convertor (ADC) with a reference voltage of 2·55 V is used in the system. When the temperature and pressure signals are at their maximum values, the ADC output in each case must be 11111111. This is achieved by the use of two signal-conditioning systems.

(*a*) The maximum signal supplied by the temperature sensor is 0·34 V.

(i) Calculate the required voltage gain of the "temperature" signal-conditioning sub-system.

(ii) Design a signal-conditioning sub-system based on a **single** operational-amplifier (op-amp) to process the temperature signal. Show all calculations and resistor values. **2**

(*b*) The maximum signal supplied by the pressure sensor is 4·25 V.

(i) Calculate the required voltage gain of the "pressure" signal-conditioning sub-system.

(ii) Design a signal-conditioning sub-system based on op-amps to process the pressure signal. Show all calculations and resistor values. **3**

The temperature and pressure readings obtained are stored in non-volatile memory. Periodically this data is sent to a central office. The system memory is then reset ready to store a new set of readings.

(*c*) Draw a system diagram for this data-logging system, showing the main sub-systems. **3**

(8)

Marks

4. A garden centre has commissioned a design for the shade structure shown in Figure Q4. Titanium-alloy supporting cables hold the main columns in position.

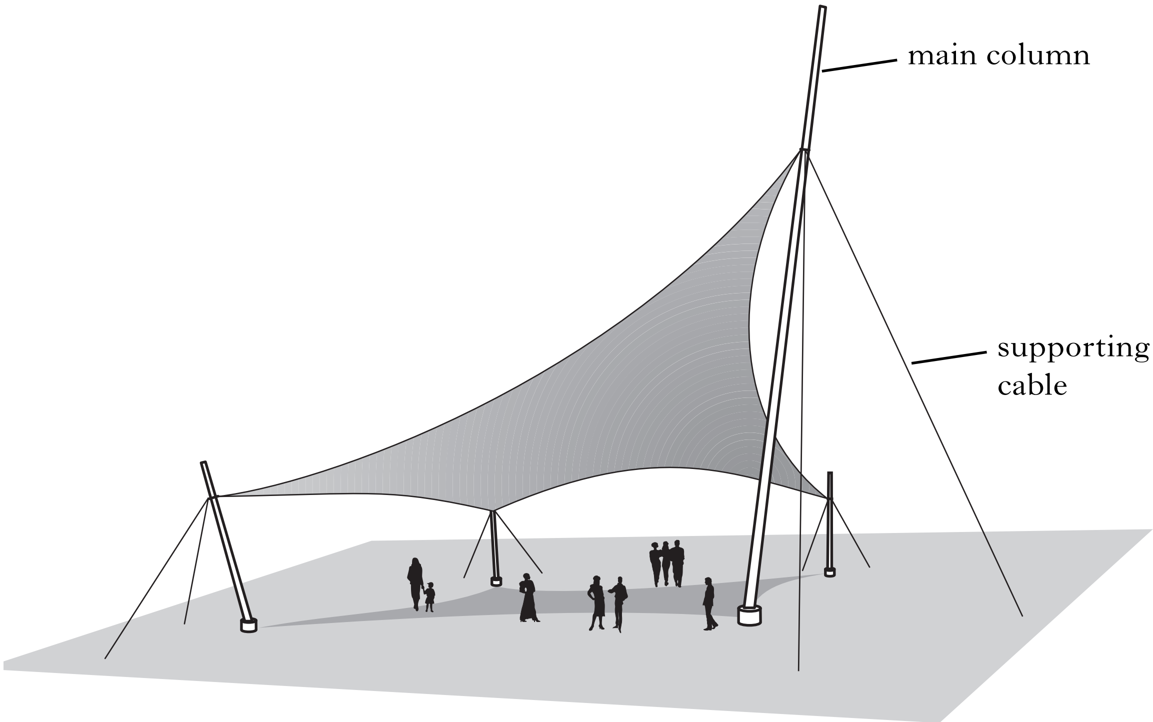

Figure Q4

The supporting cables have an effective diameter of 10 mm and the safe working strain is 0·0009.

(*a*) State why a high factor of safety would be appropriate for this design. **1**

(*b*) (i) Calculate the safe working stress.

(ii) Calculate the factor of safety. **3**

(*c*) Determine the maximum permissible load that can be applied to a supporting cable. **2**

(6)

Marks

5. Figure Q5 shows a processing system based on op-amps, which processes signals from a microcontroller.

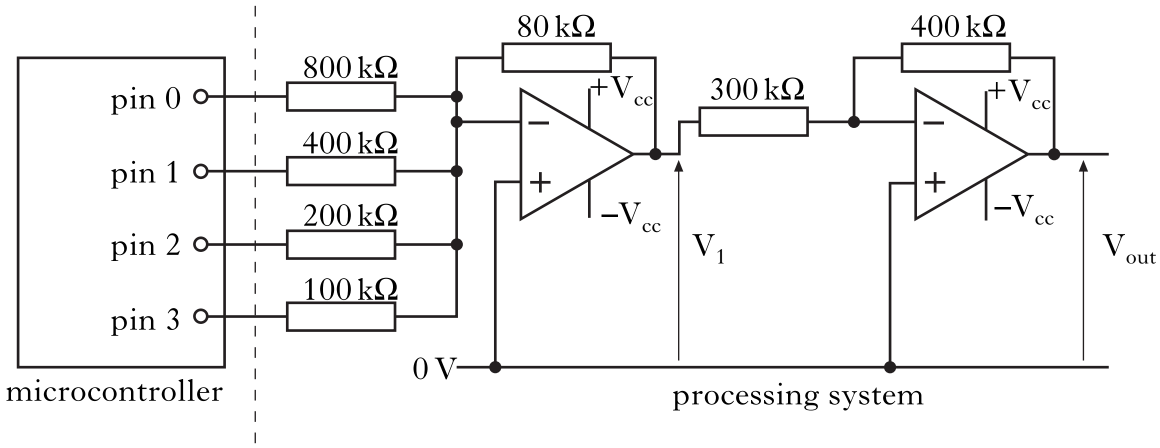

Figure Q5

(*a*) State the purpose of the **processing** system. **1**

The microcontroller is set up with pins 3, 2, 1 and 0 as outputs. When set high, the voltage on each output pin is 5 V.

(*b*) When the PBASIC command "let pins = %00000011" is executed, calculate:

(i) V_1; **2**

(ii) V_{out}. **1**

(*c*) Calculate the **maximum** possible value of V_{out}. **2**

The output signal from the processing system controls a motor.

(*d*) For the following section of PBASIC code:

```
for b0 = 3 to 14
        let pins = b0
        pause 400
next b0
let pins = 15
```

(i) sketch a graph showing V_{out} against time (values not required); **2**

(ii) explain the purpose of this section of code; **1**

(iii) state a reason for the lowest value of b0 being 3 rather than 1. **1**

(10)

[Turn over

Marks

6. A microcontroller-based system monitors the temperature in a conservatory. An analogue signal from a temperature sensor is sent to the microcontroller, which processes the signal and provides the temperature reading on a liquid crystal display (LCD), as shown in Figure Q6(*a*).

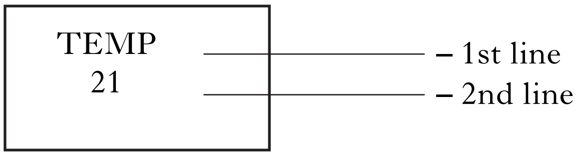

Figure Q6(*a*)

Part of the microcontroller program consists of a sub-procedure called "displaytemp". The flowchart for this sub-procedure is shown in Figure Q6(*b*).

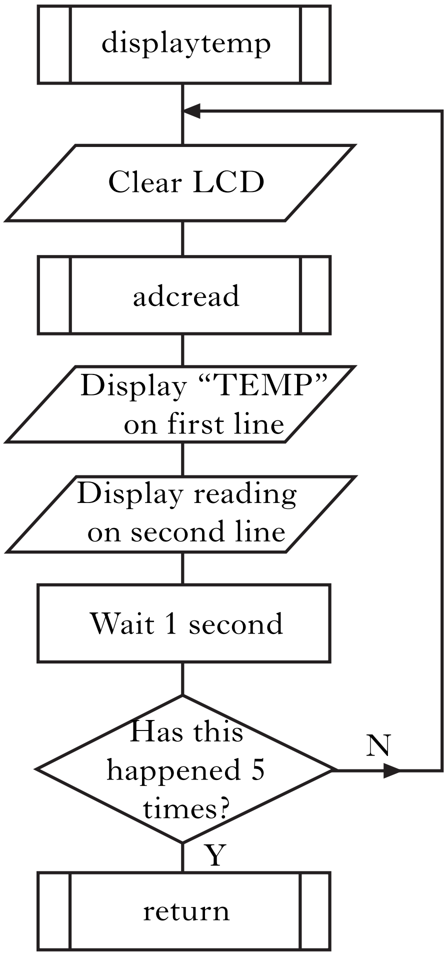

Figure Q6(*b*)

serout Instruction Structure

serout x, T2400,(254,n)
x – pin number
n – instruction number

n	Instruction
1	clear LCD
10	LCD screen off
12	hide cursor
14	LCD screen on
128	cursor to start of first line
192	cursor to start of second line

Figure Q6(*c*)

The prewritten sub-procedure "adcread" stores the temperature reading in a variable called *data*. The LCD display is connected to **pin 7** of the micro-controller.

Write, in PBASIC, the sub-procedure "displaytemp". Refer to **Figure Q6(*c*)** for the appropriate *serout* instruction set. **(5)**

7. The temperature of a car's engine is displayed on the instrument panel by a bar-graph display. The lower four segments represent normal conditions and are lit by green and amber LEDs. The top segment indicates that the engine is too hot and is lit by a red LED. The arrangement of the circuit is shown in Figure Q7. The voltage divider has six identical resistors (R_2).

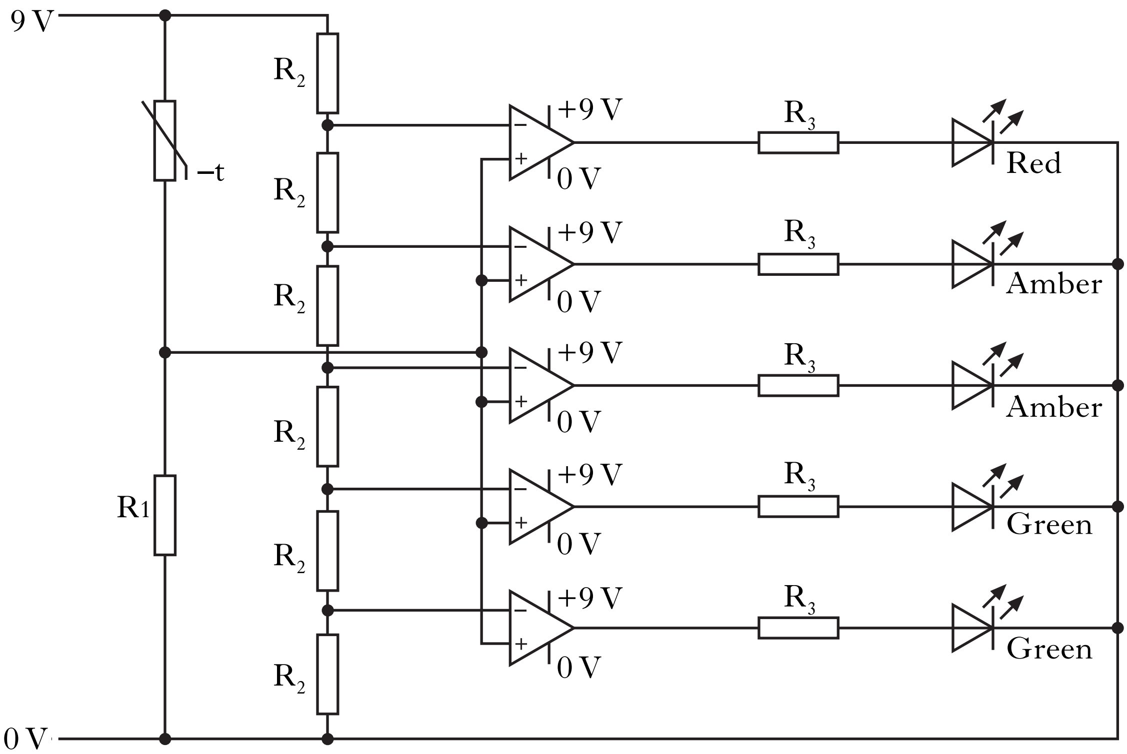

Figure Q7

(*a*) State the name of the op-amp configuration used in this circuit. **1**

(*b*) The red LED is required to illuminate at 125 °C. A type-6 thermistor is used.

(i) Calculate the value of resistor R_1 required to achieve the correct operation. **2**

(ii) Calculate the resistance of the thermistor when the lower green LED comes on. **1**

Each LED is rated at 1·5 V and 30 mA.

(*c*) Determine the required value of resistor R_3. **2**

(6)

[Turn over

8. A tree-harvesting operation transports cut logs with a system similar to that shown in Figure Q8(*a*). A free-body diagram showing the forces acting on the log is shown in Figure Q8(*b*). *Marks*

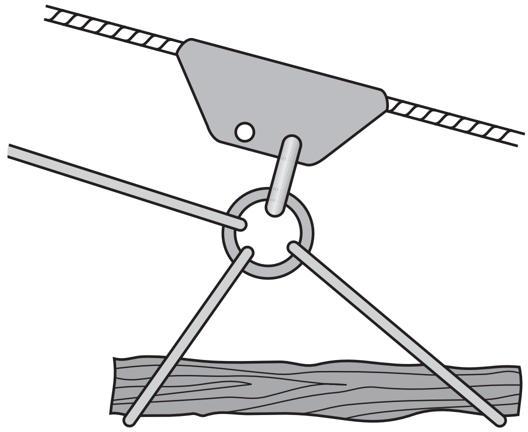

Figure Q8(*a*)

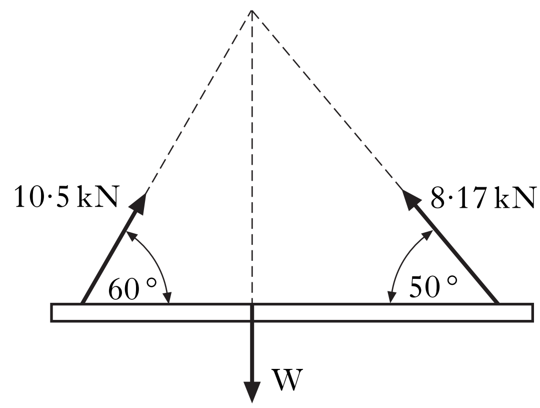

Figure Q8(*b*)

(*a*) Calculate the weight W of the log. **2**

The forces acting on the connecting ring are shown in Figure Q8(*c*). All forces act concurrently.

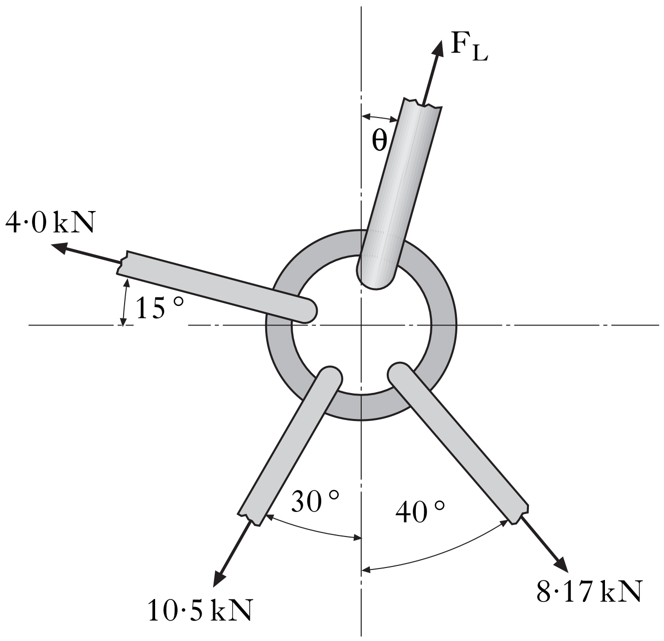

Figure Q8(*c*)

For the forces shown:

(*b*) calculate the magnitude and direction of force F_L in the link. **6**

(8)

9. A strain-gauge system is part of an accurate weighing device used in a laboratory. Figure Q9(*a*) shows the arrangement of the strain gauges on the beam of the weighing device.

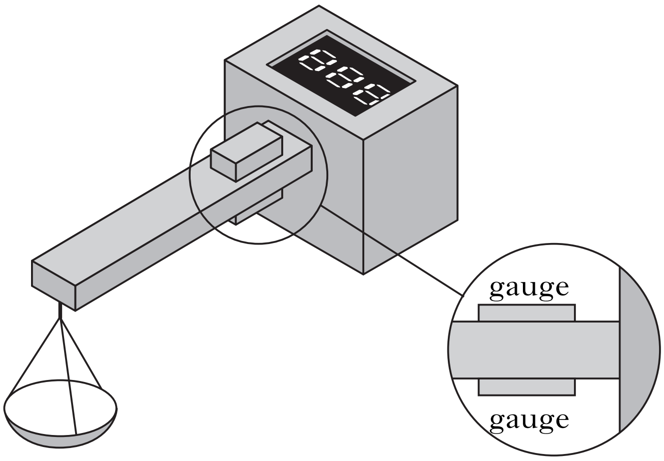

Figure Q9(*a*)

The electronic circuit used is shown in Figure Q9(*b*).

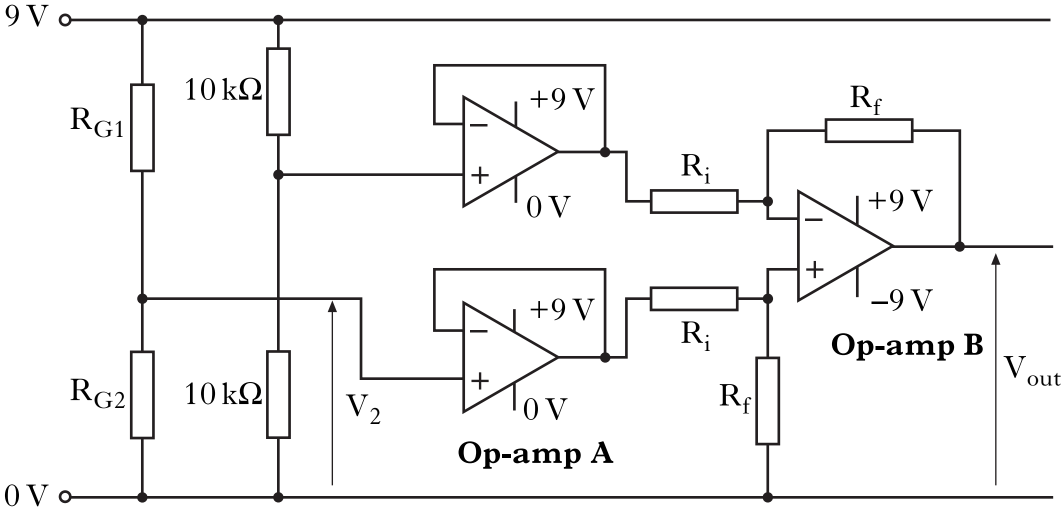

Figure Q9(*b*)

(*a*) State the name of the configuration of **op-amp A** and of **op-amp B** in this circuit. **1**

(*b*) State **one** reason for placing one strain gauge above the cantilever beam and a second strain gauge below the beam. **1**

The unloaded resistance of the strain gauges = 120 Ω.

For a particular loading R_{G1} = 119·85 Ω and R_{G2} = 120·15 Ω and V_{out} = 6 V.

(*c*) State which strain gauge is placed on top of the beam. Justify your selection. **1**

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

(*e*) Calculate appropriate values for resistors R_f and R_i to produce the required output voltage V_{out}. **2**

(6)

[*END OF SECTION A*]

SECTION B

Attempt any TWO questions in this Section.

Each question is worth 20 marks.

10. A lift operates between 3 floors of a building, and is controlled by a microcontroller. Request buttons on the three floors are used to call the lift. The flowcharts in Figure 10(*a*) show the control sequence for the movement of the lift to the appropriate floor.

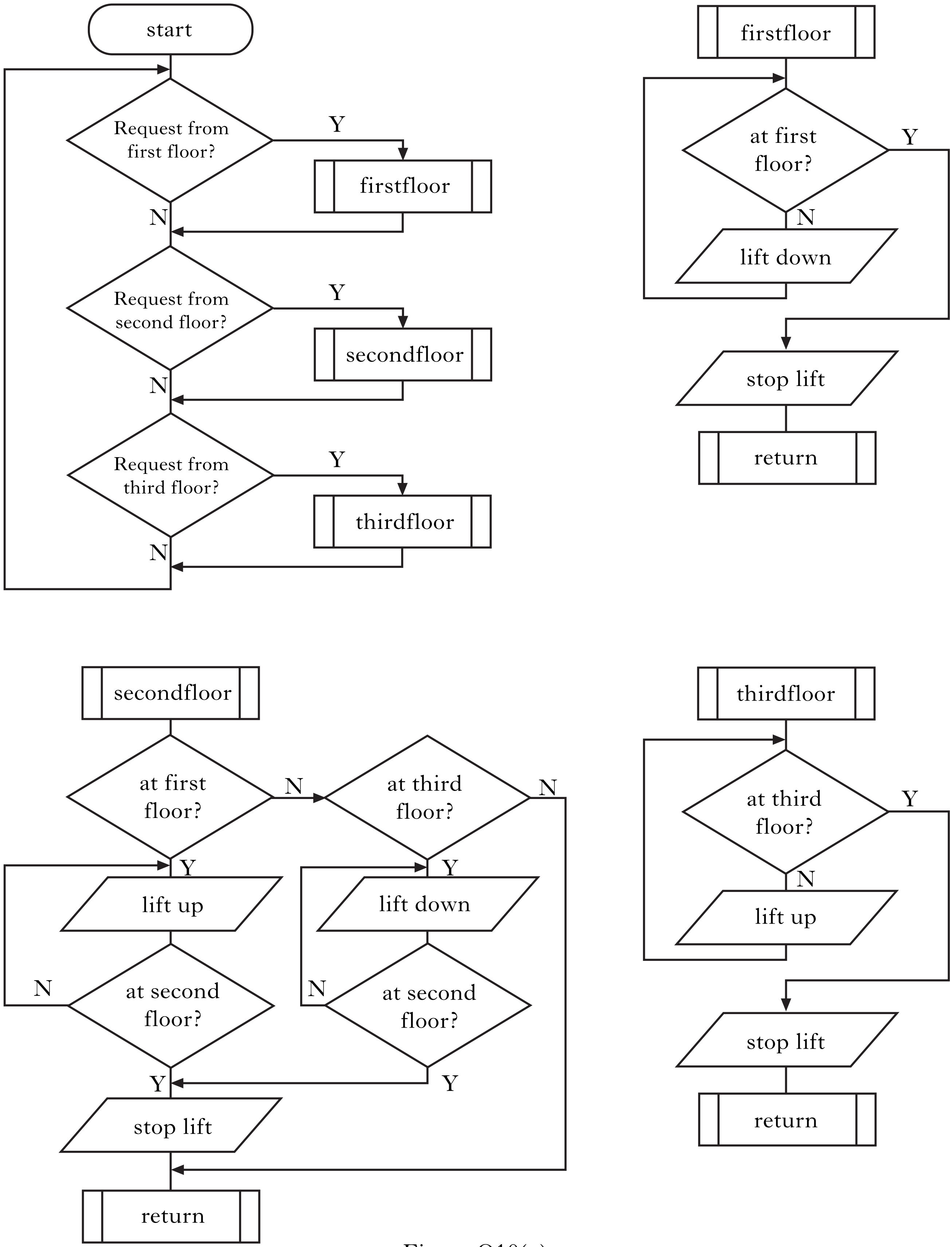

Figure Q10(*a*)

Marks

10. (continued)

(*a*) (i) State the circumstances under which the lift will move upwards. **1**

(ii) State the condition for which the lift will not move if a request is received for the second floor. **1**

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

Input	Pin	Output
	7	
	6	Motor controller (= 1 to make lift go up)
	5	Motor controller (= 1 to make lift go down)
	4	
Third floor limit switch (= 1 when lift is at third floor)	3	
Second floor limit switch (= 1 when lift is at second floor)	2	
First floor limit switch (= 1 when lift is at first floor)	1	
	0	

Figure Q10(*b*)

(*b*) Write, in PBASIC, the sub-procedure "secondfloor". **7**

A safety system, which protects lift users from injury when the lift door closes, operates as follows. A light beam shining onto a light sensor is interrupted if an obstacle blocks the doorway, and a pressure switch on the edge of the door closes if the door strikes an obstacle. If an obstacle is detected, the electronic sub-system shown in Figure Q10(*c*) sends a **high** signal to a control system to immediately open the door.

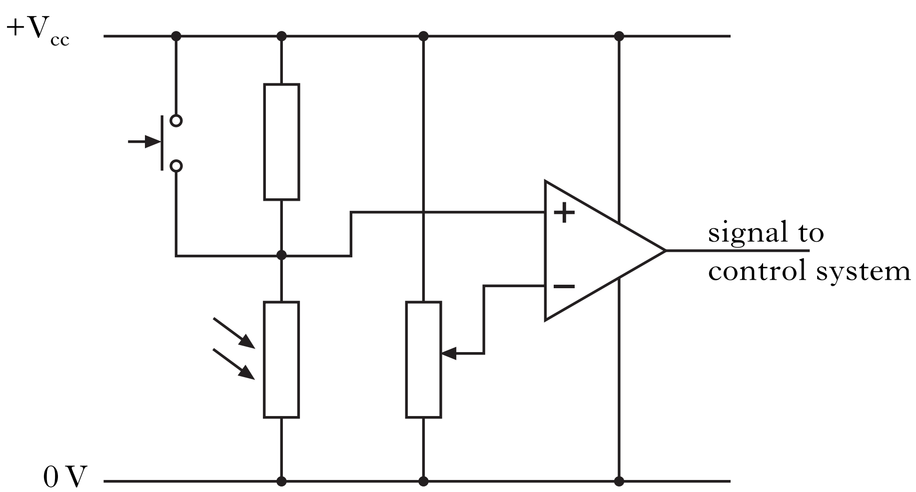

Figure Q10(*c*)

(*c*) Explain the operation of this electronic sub-system. **3**

10. (continued) *Marks*

Figure Q10(*d*) shows the structure used to support the lift motor and cable drum.

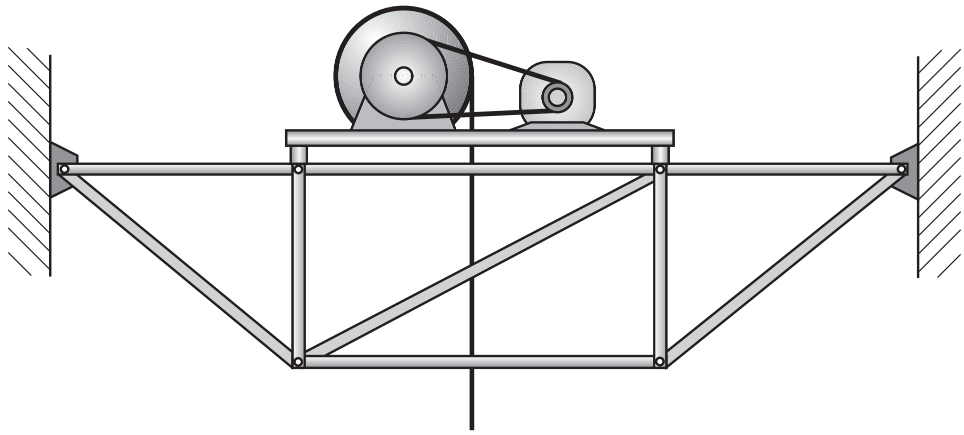

Figure Q10(*d*)

The free-body diagram in Figure Q10(*e*) shows the forces acting on one truss of the structure at a particular instant.

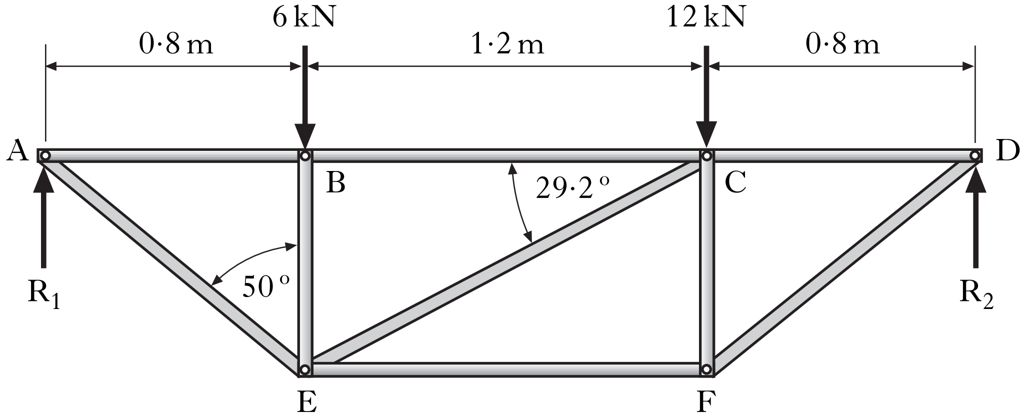

Figure Q10(*e*)

(*d*) For the loading conditions shown in Figure Q10(*e*):

(i) determine the magnitude of R_1; **2**

(ii) use *nodal analysis* to calculate the magnitude and nature of the forces in members AE, AB, BE and CE. **6**

(20)

11. Figure Q11(a) shows a control system for a satellite dish. The user selects the desired position for the dish by turning a knob connected to the shaft of potentiometer A. Potentiometer B is attached to the shaft of the satellite dish. The control system rotates the satellite dish to the desired position. *Marks*

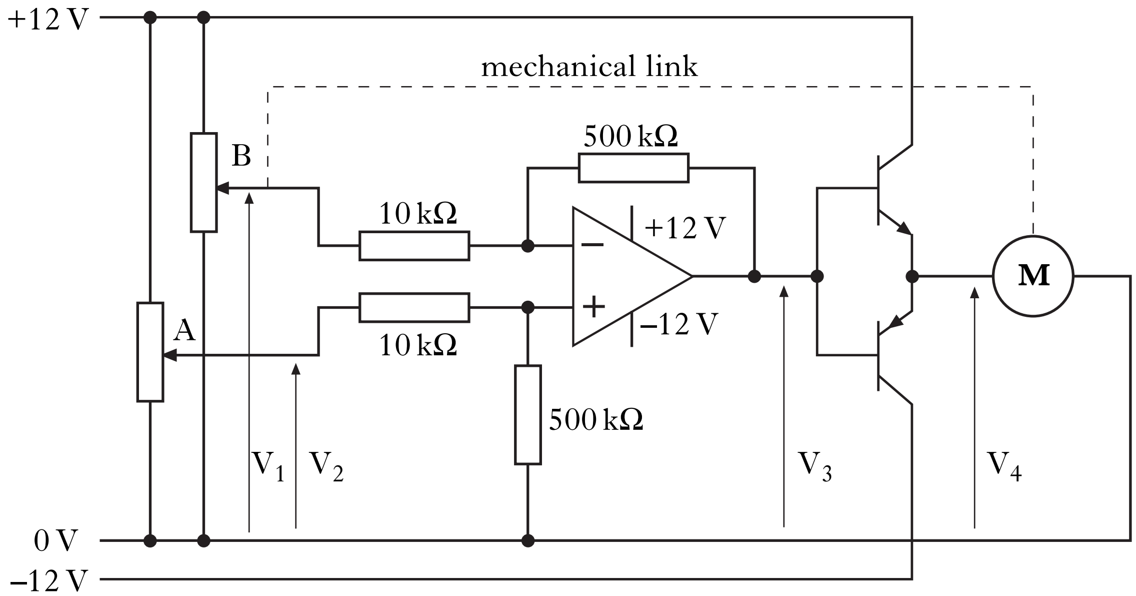

Figure Q11(a)

(a) Draw a *control diagram* for the satellite-dish controller. Clearly label each sub-system. **3**

The op-amp in Figure Q11(a) saturates at 85% of the supply voltage.

(b) Calculate the minimum voltage difference required between inputs in order to saturate the op-amp. **1**

Each potentiometer provides an output voltage of 0 V when rotated fully anticlockwise, and 12 V when rotated fully clockwise through 360°. The relationship between the output voltage and the angle of rotation is linear.

When the satellite dish is **stationary** at a particular position, V_1 = 1·72 V, V_2 = 1·72 V, and V_3 = 0 V.

(c) For the instant that potentiometer A is rotated 2·7° clockwise to select a new position, calculate the value of:

(i) V_2; **2**

(ii) V_3; **1**

(iii) V_4. **1**

(d) Describe the operation of the control system and the behaviour of the motor as the dish rotates towards the new position. **2**

11. (continued)

In an **alternative** system the dish is rotated by a stepper motor, which is controlled by a microcontroller. Four switches allow four separate preset positions to be selected. When a switch is pressed the stepper motor rotates the correct number of steps in the appropriate direction to bring the dish to the required position.

The op-amp-based control system shown in Figure Q11(*a*) and the microcontroller-based system use two different types of control.

(*e*) (i) For each of the two control systems, state the type of control used. **1**

(ii) Explain one advantage of the op-amp-based control system compared with the microcontroller-based system. **1**

A flowchart describing the control of the stepper motor is shown in Figure Q11(*b*).

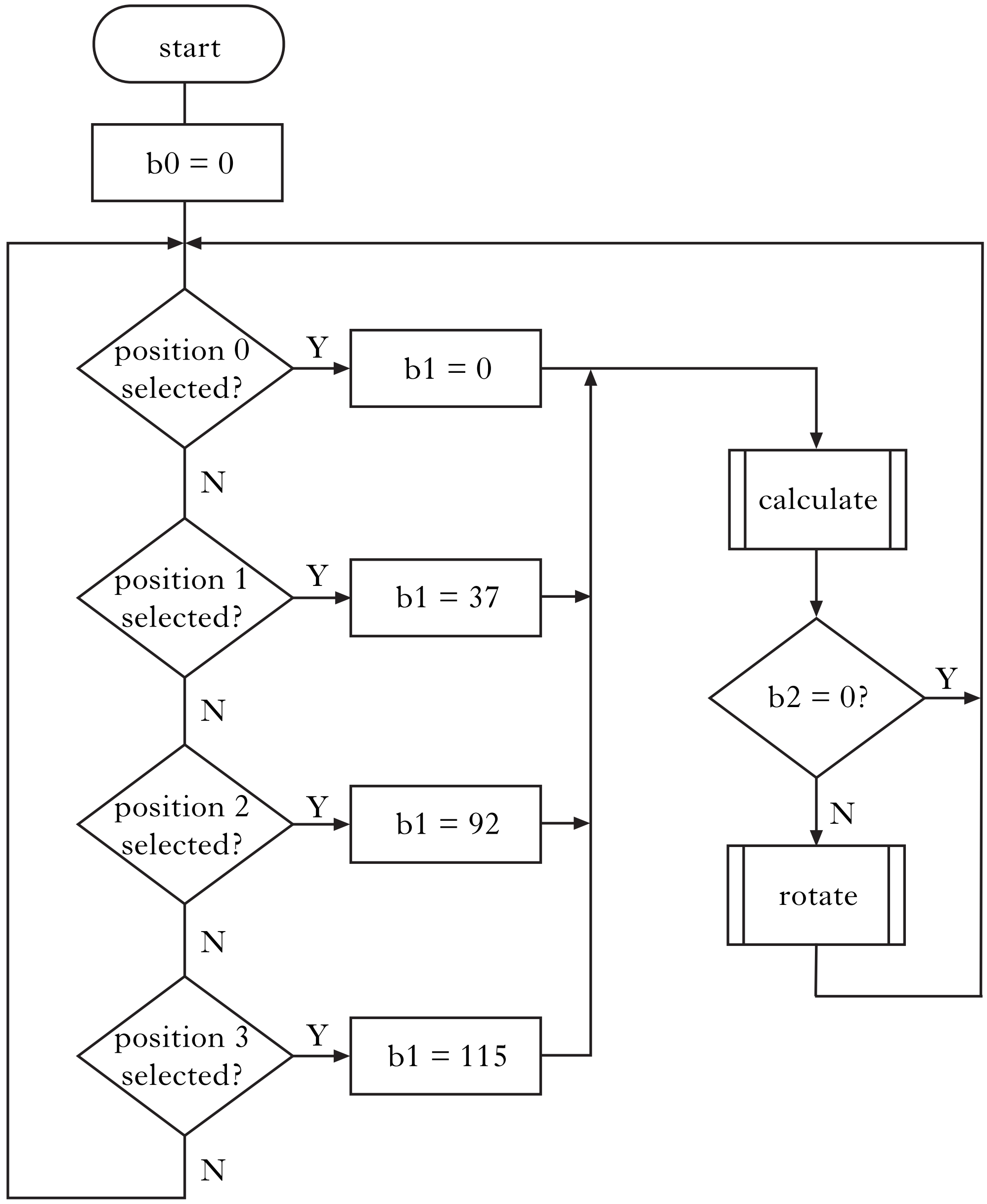

Figure Q11(*b*)

Marks

11. (continued)

The input connections to the microcontroller and the output connections to a stepper-motor driver IC are shown in Figure Q11(*c*).

Input	**Pin**	**Output**
	7	
	6	
	5	Stepper motor pulse
	4	Stepper motor direction
Switch 3 (for position 3)	3	
Switch 2 (for position 2)	2	
Switch 1 (for position 1)	1	
Switch 0 (for position 0)	0	

Figure Q11(*c*)

The variables used in the program are shown in Figure Q11(*d*). The satellite dish starts at position 0. The sub-procedure "calculate" is shown below.

```
calculate:   if b1 > b0 then clock
             if b1 < b0 then anticlock
             b2 = 0
             goto end
clock:       b2 = b1 – b0
             low 4
             goto reset
anticlock:   b2 = b0 – b1
             high 4
reset:       b0 = b1        'Line 10
finish:      return
```

Variable	Value stored
b0	Actual position in ° clockwise from start
b1	Desired position in ° clockwise from start
b2	Number of degrees dish must rotate

Figure Q11(*d*)

(*f*) Explain the purpose of the command "b0 = b1", on line 10 of the sub-procedure. **1**

When the stepper motor is in position 3, Switch 1 is pressed.

(*g*) Referring to the sub-procedure "calculate" and to Figure Q11(*b*):

(i) calculate the value stored in b2 after the sub-procedure "calculate" has been executed; **1**

(ii) state the logic condition of pin 4 after the sub-procedure "calculate" has been executed. **1**

The sub-procedure "rotate" rotates the satellite dish to the desired position. The microcontroller sends 100 pulses per second to the stepper-motor driver IC.

Due to the use of a speed-reduction gearbox, **four** pulses are required to turn the satellite dish **through 1°**. The variable b2 stores the number of degrees the dish must rotate.

(*h*) Write, in PBASIC, the sub-procedure "rotate". Refer to the information in Figures Q11(*c*) and (*d*). **4**

(*i*) Calculate the speed of rotation of the satellite dish in r/min. **1**

(20)

12. An industrial guillotine is fitted with two push-switches and a light-sensing circuit to sense if material is in position ready for cutting. The guillotine control circuit is shown in Figure Q12(*a*). *Marks*

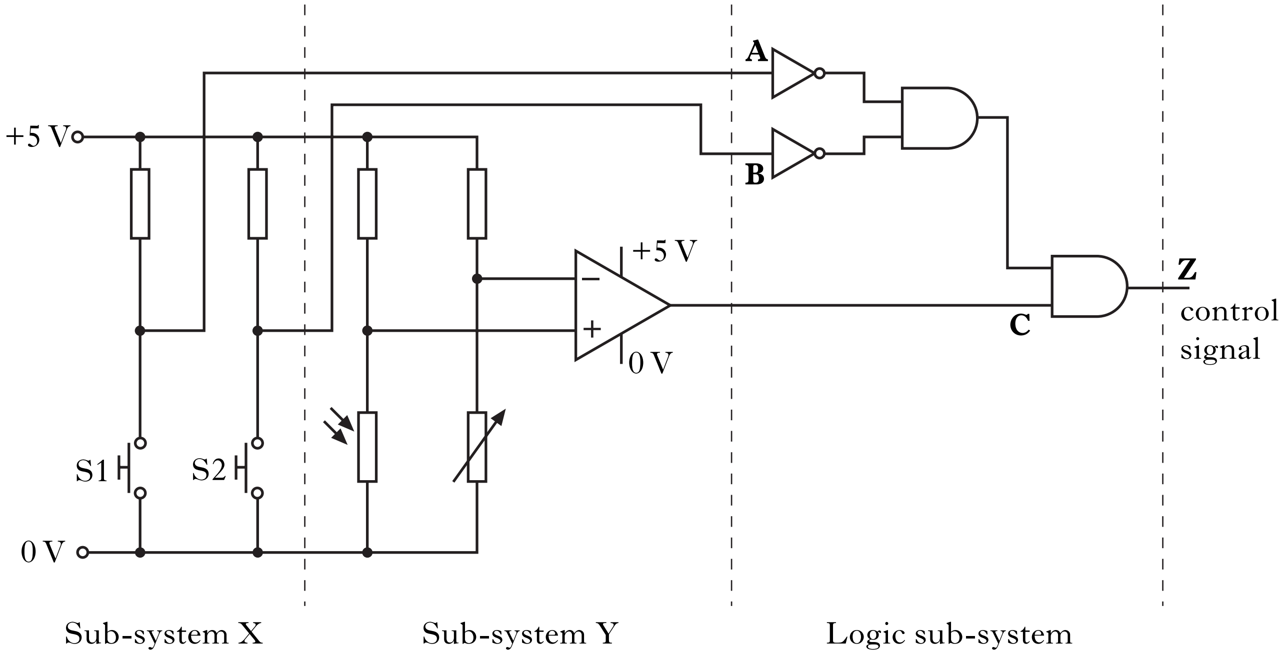

Figure Q12(*a*)

(*a*) Describe the operation of the electronic control circuit shown in Figure Q12(*a*). Refer to each of the three sub-systems shown. **4**

(*b*) For the logic sub-system shown in Figure Q12(*a*), draw a truth table for the output Z in terms of the three inputs A, B and C. **1**

An electronics engineer suggests that the logic sub-system shown in Figure Q12(*b*) would provide a simpler solution than the original sub-system.

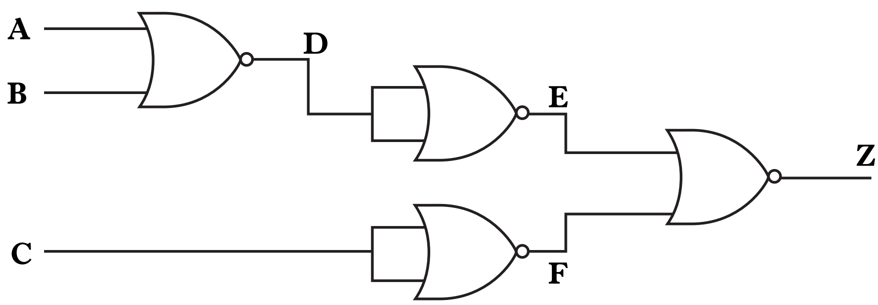

Figure Q12(*b*)

(*c*) Demonstrate whether the logic sub-system shown in Figure Q12(*b*) is equivalent to the logic sub-system shown in Figure Q12(*a*). **3**

12. (continued)

When the control signal from the logic sub-system is **high** (5 V), a driver sub-system supplies current to a solenoid valve. The driver sub-system is shown in Figure Q12(*c*).

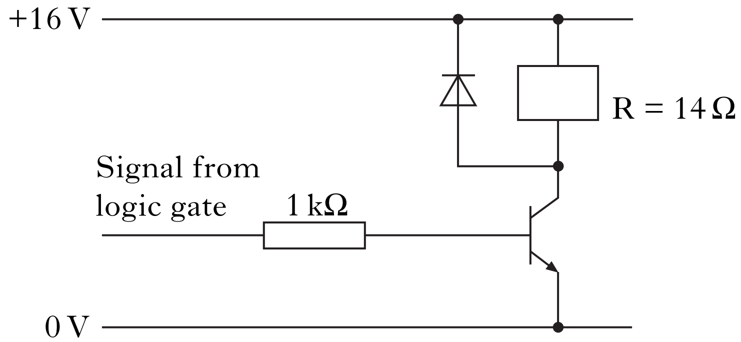

Figure Q12(*c*)

(*d*) Calculate the current flowing into the base of the transistor when the control signal is **high**. **1**

The transistor should saturate when the control signal is **high**. At saturation V_{CE} is 0·2 V.

(*e*) Calculate the minimum current gain required to operate the solenoid under these conditions. **2**

The circuit was modified in order to reduce the current flowing from the logic sub-system. The current gain of the driver sub-sytem was then 800.

Figure Q12(*d*) shows the operating characteristics of the available transistors.

Device	Case style	IC (max) mA	h_{FE}
BC108	T0-18	200	100
BFY51	T0-39	1000	40
TIP31A	T0-220	3000	10
BC142	T0-39	1000	20

Figure Q12(*d*)

(*f*) Draw a modified circuit diagram for a driver sub-system with the required current gain. Use the information given in Figure Q12(*d*), and clearly label every device used. **2**

[Turn over

12. (continued)

Figure Q12(*e*) shows the forces acting on the guillotine blade at one instant when cutting a component.

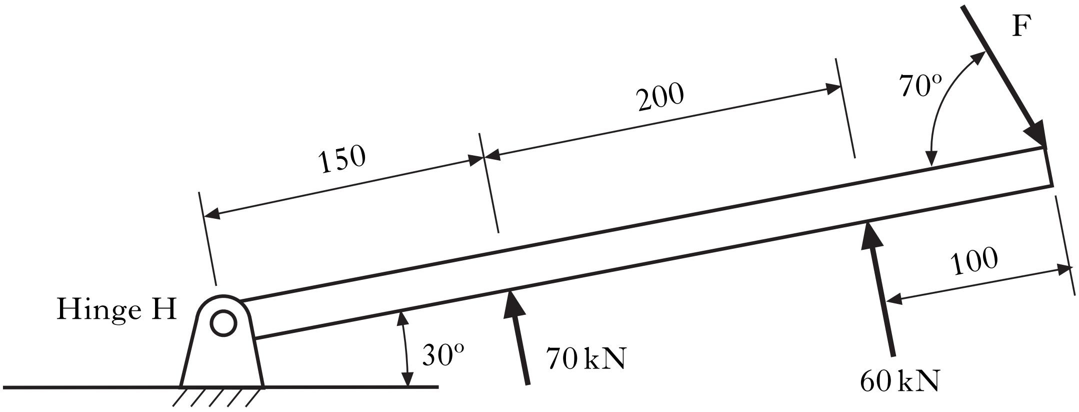

Figure Q12(*e*)

(*g*) For the condition shown:

(i) calculate the force F; **2**

(ii) calculate the **magnitude** and **direction** of the reaction at the hinge H. **5**

(20)

[*END OF QUESTION PAPER*]

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