X036/301

NATIONAL QUALIFICATIONS 2009

MONDAY, 8 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.

Marks

SECTION A

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

1. A combinational logic system controls the air-conditioning system in a gym. A time clock (C), a temperature sensor (T) and an override switch (S) provide input signals to the combinational-logic system.

The completed truth table for the combinational-logic system is shown in Figure Q1.

Time Clock (C)	Temperature Sensor (T)	Override Switch (S)	Air Conditioner (Z)
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	0
1	0	0	1
1	0	1	1
1	1	0	0
1	1	1	0

Figure Q1

(*a*) Referring to the truth table in Figure Q1, write a Boolean expression for the air conditioner (Z) in terms of the three inputs C, T and S. **2**

(*b*) Draw the logic diagram for the air conditioner, using only AND, OR and NOT gates. **3**

(*c*) Draw an equivalent logic circuit using only NAND gates. Simplify where possible. **2**

The logic system is supplied by a 9V battery. TTL and CMOS integrated circuits (ICs) are available.

(*d*) (i) State which type of IC would be more suitable for this application. **1**

(ii) State **two** advantages of this type of IC. **1**

(9)

Marks

2. Figure Q2 shows a circuit for controlling a motor connected to a fan.

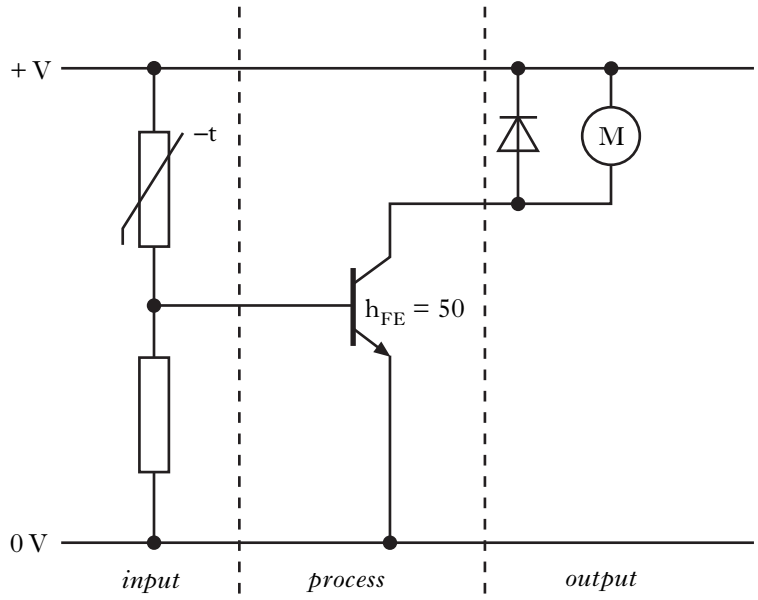

Figure Q2

(*a*) State the name of the protective component in the circuit and explain its function. **1**

(*b*) Explain the function of the circuit by describing how the *input* sub-system responds to increasing temperature, and how the resulting signal from the *input* sub-system affects the *process* and *output* sub-systems. **3**

It is found that a current gain of 1500 is necessary for the circuit to function satisfactorily. The required gain can be achieved by adding a second transistor to the circuit.

(*c*) (i) Redraw the circuit showing this new arrangement of two transistors.

(ii) State the name of this arrangement of two transistors.

(iii) Calculate the required current gain of the additional transistor. **3**

An alternative circuit that functions correctly uses a single MOSFET transistor.

(*d*) Describe the main difference in the operation of a MOSFET transistor compared with a bipolar transistor. **1**

(8)

[Turn over

Marks

3. A stepper motor rotates in steps of 7·5° and is controlled by pins 7, 6, 5 and 4 of a microcontroller. The program shown below controls the stepper motor.

```
init:       let dirs = %11110000
main:       for b0 = 1 to 12
               let pins = %10100000
               pause 20
               let pins =%10010000
               pause 20
               let pins = %01010000
               pause 20
               let pins = %01100000
               pause 20
            next b0
            end
```

When the program is run, the stepper motor rotates in a clockwise direction.

(*a*) (i) Calculate the number of degrees through which the stepper motor rotates.

(ii) Calculate the length of time for which the stepper motor rotates. **2**

(*b*) Write a program in PBASIC that will rotate the stepper motor **anticlockwise** through 720°, with a 5 ms time delay between steps. **2**

An alternative method of controlling a stepper motor involves the use of a stepper motor driver IC.

(*c*) State **two** advantages of using a stepper motor driver IC as compared with the system described above. **2**

(6)

Marks

4. Figure Q4 shows a load-extension graph for a tensile test on a sample of a special type of steel.

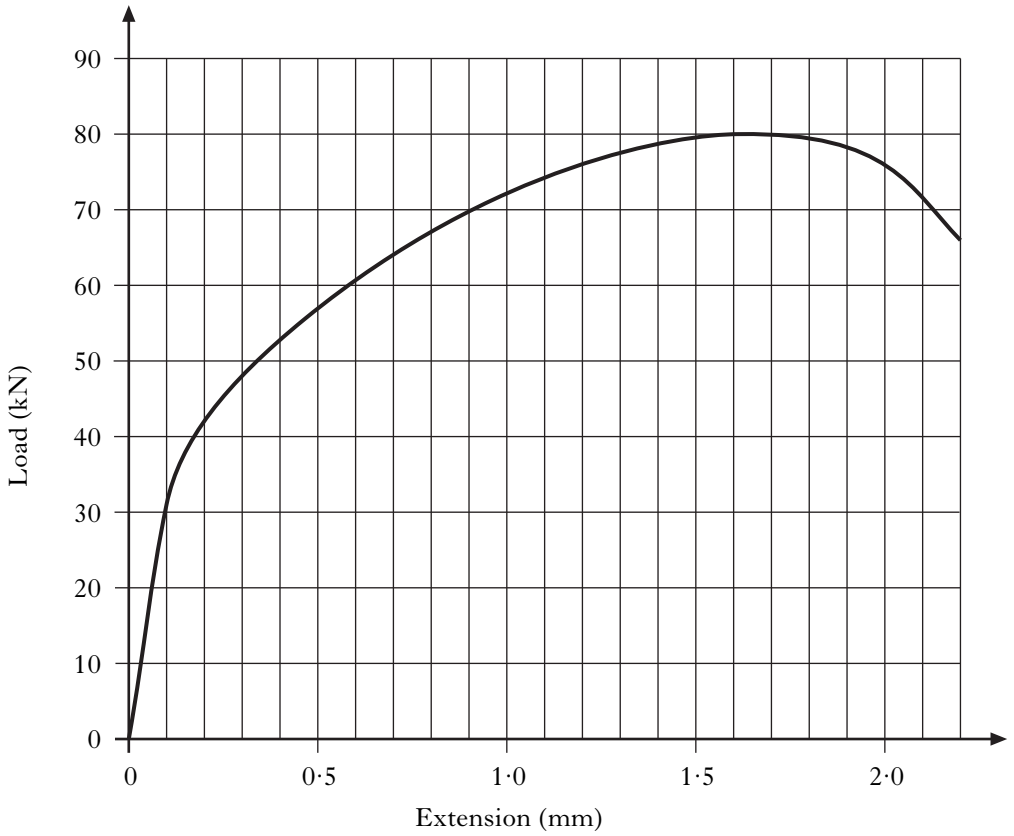

Figure Q4

(*a*) State whether this material is brittle or ductile. **1**

The test specimen was 50 mm long with a cross-sectional area of 80 mm^2.

(*b*) Calculate Young's Modulus for the material. **3**

(*c*) Calculate the **ultimate** tensile stress for the material. **1**

A bar with a rectangular cross-section of 30 mm × 10 mm is manufactured from the material. The bar is to be loaded in tension with a Factor of Safety of 6.

(*d*) (i) Calculate the safe working stress for the bar. **1**

(ii) Calculate the safe working load for the bar. **1**

(7)

[Turn over

Marks

5. A pharmaceutical manufacturing process requires accurate monitoring of temperatures. This is achieved by a system which includes two temperature sensors, a multiplexer, an analogue-to-digital converter and a microcontroller.

(*a*) Describe the function of a multiplexer. **1**

A PBASIC sub-procedure *tempmonitor* uses the pre-written sub-procedure *adcread* to take a reading, and the pre-written sub-procedure *eewrite* to store a reading in an EEPROM.

Tempmonitor takes a reading from sensor A and stores it in page 0 of the EEPROM. 1·8 seconds later *tempmonitor* takes a reading from sensor B and stores it in page 1 of the EEPROM.

(*b*) Draw a flowchart to represent the sub-procedure *tempmonitor*. **6**

(7)

Marks

6. An energy-saving system is installed in a new office block. If the natural light level in an office is high enough, the lights turn off automatically. The control circuit is shown in Figure Q6.

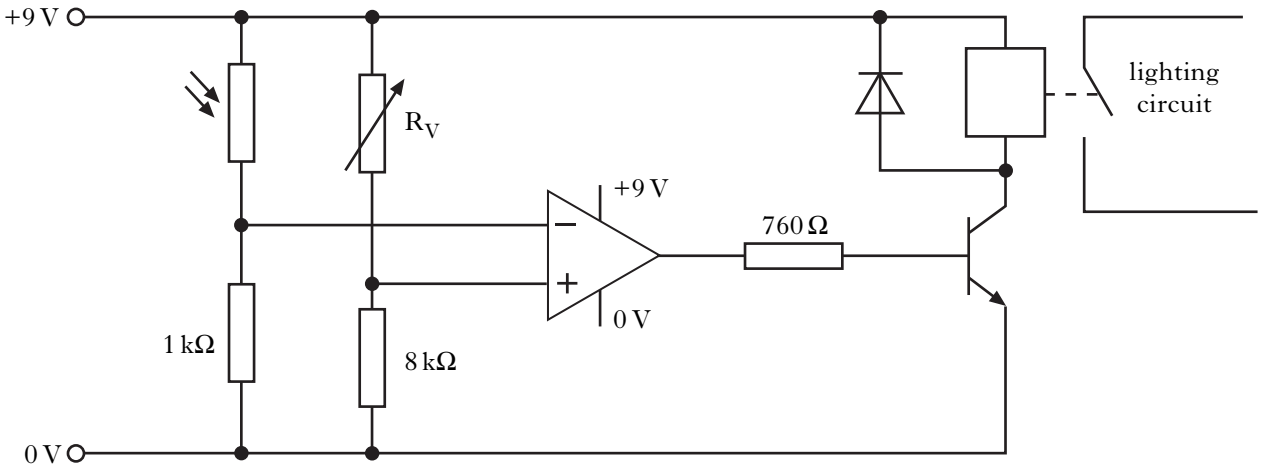

Figure Q6

(*a*) Calculate the value of R_V so that the light circuit switches off at 650 lux. **2**

(*b*) Calculate the base current when the op-amp output is high. **2**

The resistance of the relay is 15 Ω.

(*c*) (i) Calculate the collector current when the transistor saturates. **1**

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

(iii) State which of the transistors shown in the table below is most suitable for this circuit. **1**

(7)

Device	V_{CE}(max) (V)	I_c(max) mA	h_{FE}
2N3704	30	600	100
BC108	25	200	100
BC142	60	1000	20
BC182	50	100	120
BC548b	30	100	220
BFY51	30	1000	40

[Turn over

7. A cycle-carrier is fitted to a car as shown in Figure Q7(*a*).

Marks

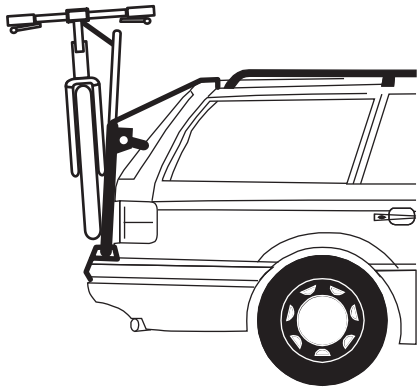

Figure Q7(*a*)

A simplified diagram of part of the cycle-carrier frame is shown in Figure Q7(*b*). To simplify calculations the frame has been rotated to the horizontal.

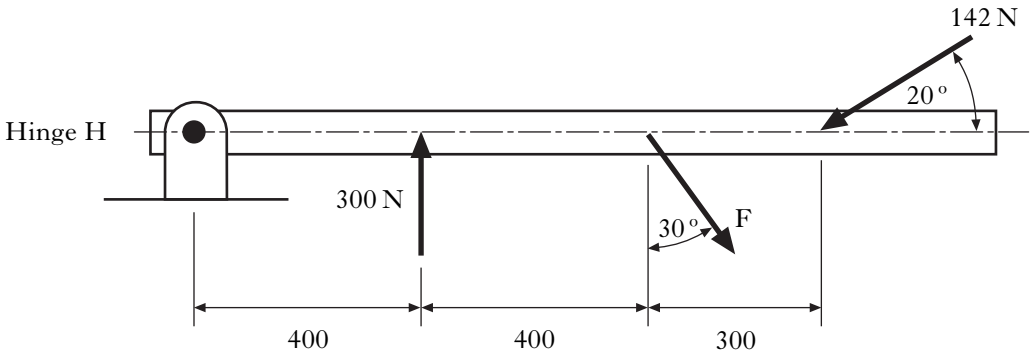

Figure Q7(*b*)

(*a*) Calculate the magnitude of the force F. Use the Principle of Moments. **3**

(*b*) Calculate the **magnitude** and **direction** of the reaction at hinge H. **6**

(9)

Marks

8. The circuit in Figure Q8(*a*) is used to control the speed of a motor, by varying the output voltage. It includes a processing sub-system, based on two op-amps, which processes four signals from a microcontroller.

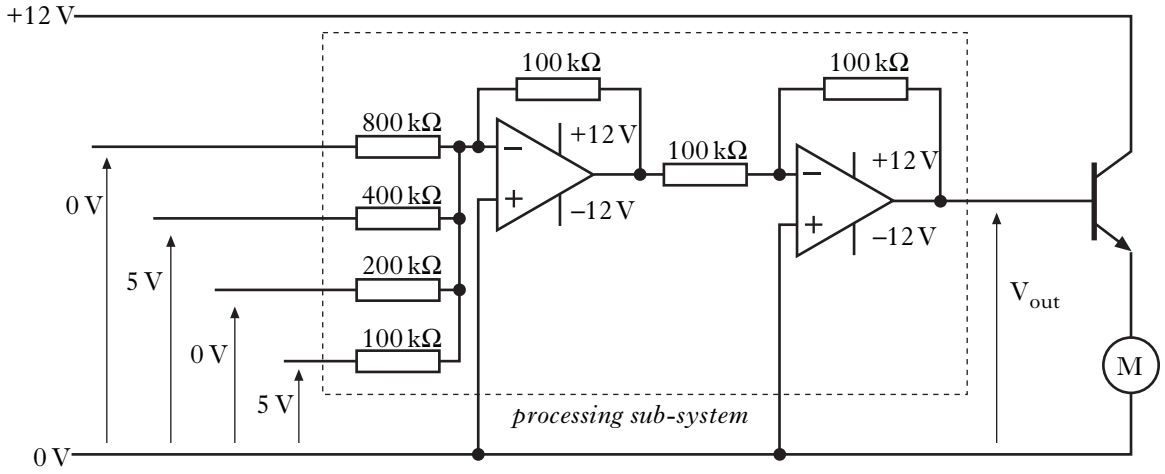

Figure Q8(*a*)

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

(*b*) Calculate the output voltage V_{out} for the input voltages shown in Figure Q8(*a*). **2**

An alternative method of controlling motor-speed involves switching a motor on and off rapidly, and adjusting the lengths of the "on" and "off" time periods.

(*c*) State the full name of this alternative method of controlling motor speed. **1**

Figure Q8(*b*) shows a typical graph of the voltage against time.

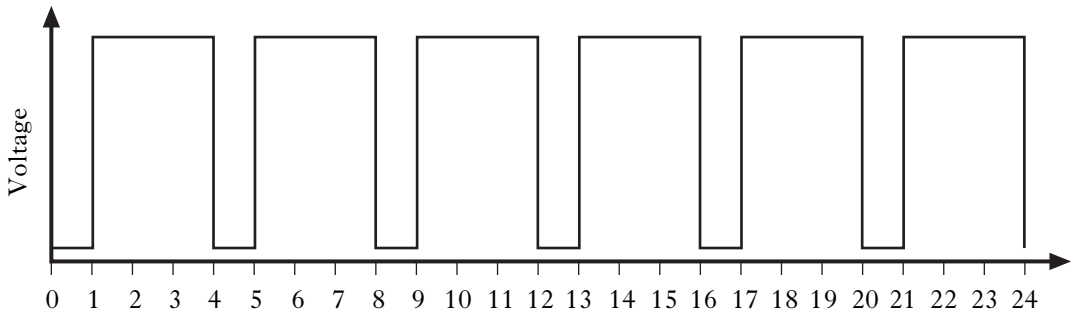

Figure Q8(*b*)

(*d*) State the mark:space ratio for this graph. **1**

In Figure Q8(*b*), the voltage is high for 75% of the time.

A motor initially at rest receives a voltage which is high for 20% of the time. After 0·5 seconds the voltage is high for 30% of the time. Every 0·5 seconds this percentage rises by 10% until the voltage is continuously high.

(*e*) (i) State how the motor would respond to this changing signal.

(ii) State the purpose of controlling the motor this way. **2**

(7)

[*END OF SECTION A*]

[Turn over

SECTION B

Marks

Attempt any TWO questions in this Section.

Each question is worth 20 marks.

9. An airbag safety system for a vehicle is shown in Figure Q9(*a*).

During a collision, four sensors each produce an analogue signal proportional to the crash severity. The airbag control unit determines which of the four airbags, if any, is to be deployed.

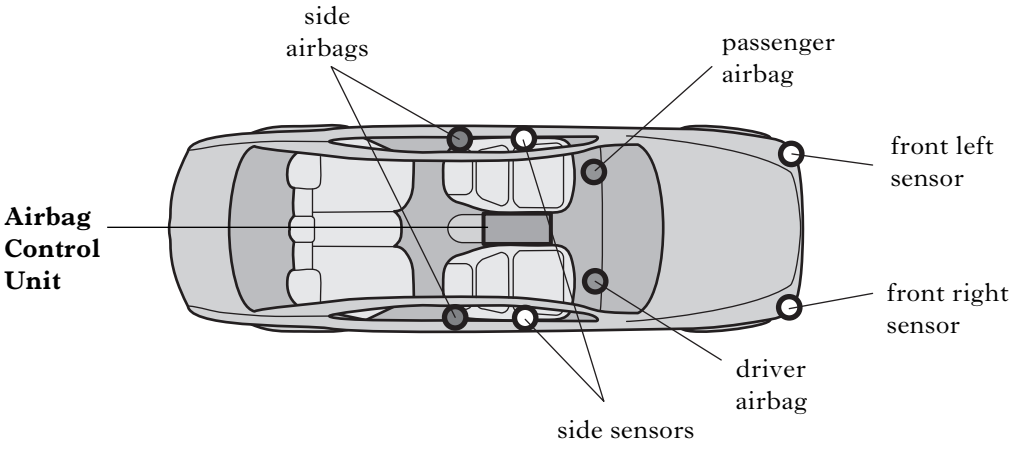

Figure Q9(*a*)

The airbag control unit conditions the four sensor signals before they are processed by an analogue-to-digital converter (ADC). A microcontroller uses the data from the ADC to control the airbags.

(*a*) Draw a block diagram showing the main sub-systems of the airbag safety system. **3**

The maximum output signal from one sensor is 6·8 V. The 8-bit ADC has a reference voltage of 5 V.

(*b*) Draw an appropriate circuit based on op-amps to condition the signal from the sensor. Show all calculations and appropriate resistor values. **3**

(*c*) Calculate the voltage produced by the **sensor** when the binary signal from the ADC is 10110111. **2**

9. (continued)

The sub-procedure *frontbags* controls the driver and passenger airbags. The flowchart for this sub-procedure is shown in Figure Q9(*b*).

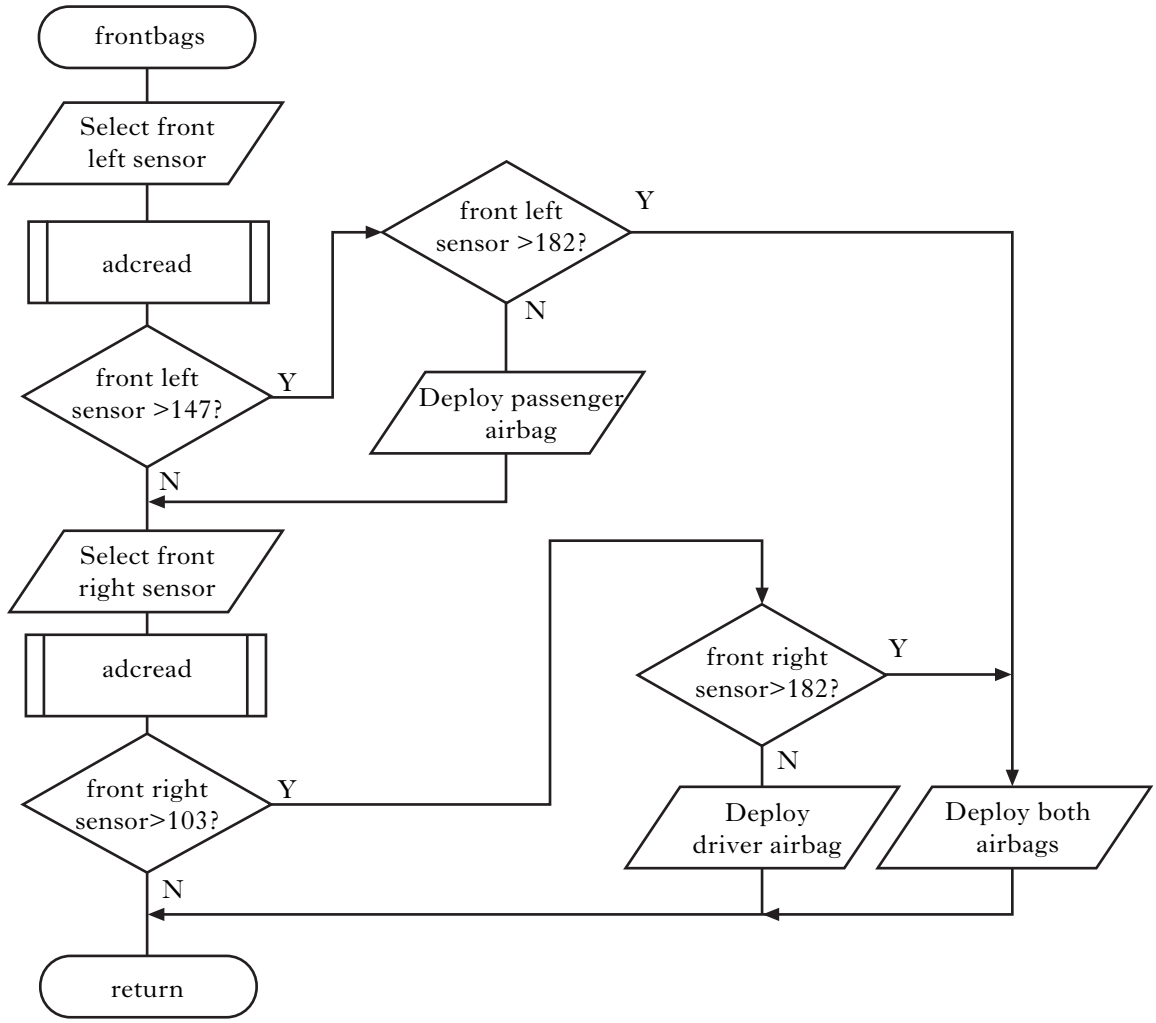

Figure Q9(*b*)

The front left sensor is selected when pin0 = 0.
The front right sensor is selected when pin0 = 1.
The passenger airbag is deployed when pin6 = 1.
The driver airbag is deployed when pin7 = 1

The pre-written sub-procedure *adcread* reads a value from the ADC and stores it in the variable DATA.

(*d*) Write, in PBASIC, the sub-procedure *frontbags*. **9**

[Turn over

9. (continued)

When the ignition is turned on the system performs a check of the sensors. If a fault is detected a warning lamp is illuminated. The op-amp-based system shown in Figure Q9(*c*) performs this check.

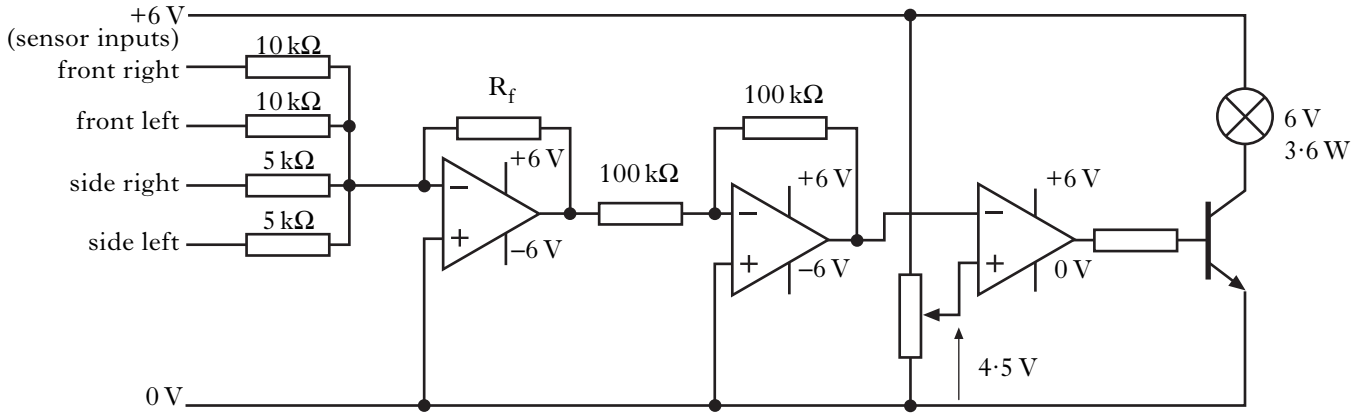

Figure Q9(*c*)

When the car is stationary a front sensor should have an output voltage of 1·2 V and a side sensor should have an output of 0·6 V.

(*e*) Calculate an appropriate value for R_f so that the warning lamp will light if any of the sensors produce a test voltage output below the correct value. **2**

A bipolar transistor-based driver circuit controls the lamp.

When a fault exists, the base current is 15·5 mA and the voltage across the lamp is 6 V.

(*f*) Calculate the minimum current gain for the driver circuit. **1**

(20)

Marks

10. A diagram of a lighting gantry above a stage is shown in Figure Q10(*a*).

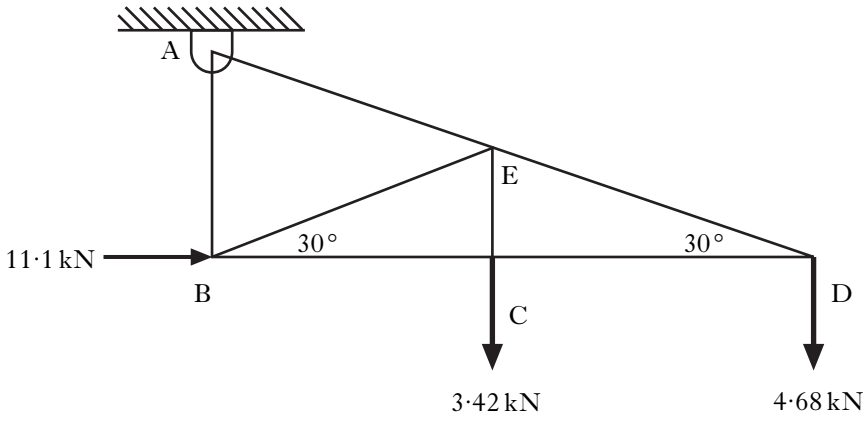

Figure Q10(*a*)

(*a*) Using *nodal analysis* for the conditions shown in figure Q10(*a*), calculate the **magnitude** and **nature** of the forces in frame members DE, CD, BC and BE. **6**

Spotlights are supported by a bracket at C as shown in Figure Q10(*b*). **Four** mild steel bolts support the bracket and are under tension.

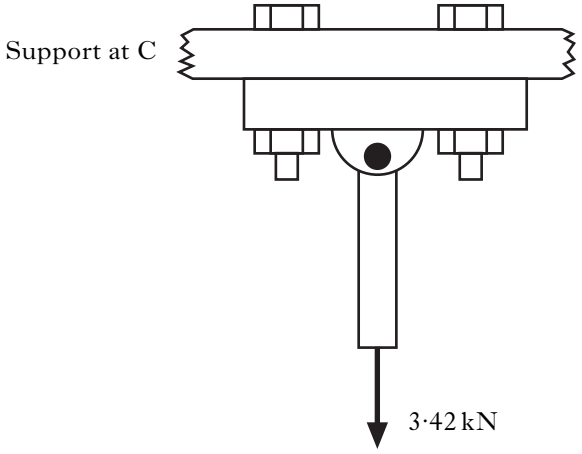

Figure Q10(*b*)

The tensile force in each of the four bolts due to tightening is 80 N, and the applied loading on the bracket is 3·42 kN. A Factor of Safety of 8 is applied.

(*b*) Calculate the minimum diameter of each bolt. **5**

[Turn over

10. (continued)

A motor in each spotlight moves a lens backwards or forwards to adjust the focus of the light. The motor is controlled by the circuit shown in Figure Q10(*c*).

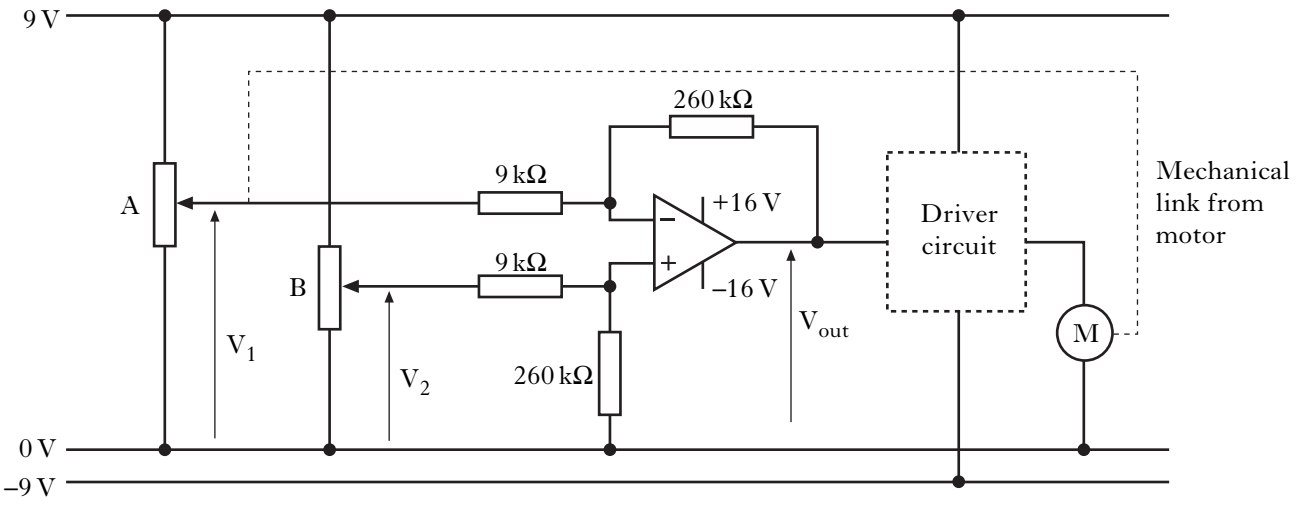

Figure Q10(*c*)

(*c*) Sketch an appropriate transistor-based driver circuit that will control the motor.

Show **all** connections. **2**

(*d*) For the circuit shown in Figure Q10(*c*):

(i) calculate V_1 when V_2 is 4·08 V and V_{out} is 9·68 V; **2**

(ii) calculate the maximum difference between V_1 and V_2 before the op-amp saturates. **1**

When the motor is stationary, the setting of potentiometer B is altered.

(*e*) Explain the operation of the control system after the setting of potentiometer B is altered. **2**

It was found that the motor stopped before the spotlight reached the desired position.

(*f*) Suggest a modification to the circuit that will enable the spotlight to reach the required position. **1**

It was suggested that the op-amp configuration shown in Figure Q10(*c*) could be replaced by a comparator.

(*g*) Describe **one** effect this would have on the motor. **1**

(20)

Marks

11. A security system has a digital keypad as shown in Figure Q11(*a*). A correct code must be entered on the keypad to open a door. The logic system shown in Figure Q11(*b*) processes the signals from the keys 0–9. When a key is pressed a **high** signal is placed on an input line to the logic system, otherwise the signal on the input line is **low**.

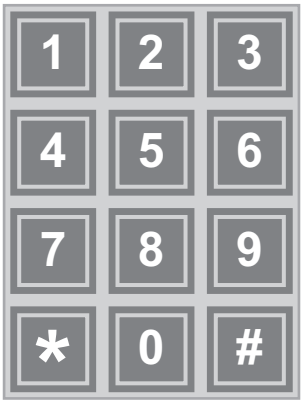

Figure Q11(*a*)

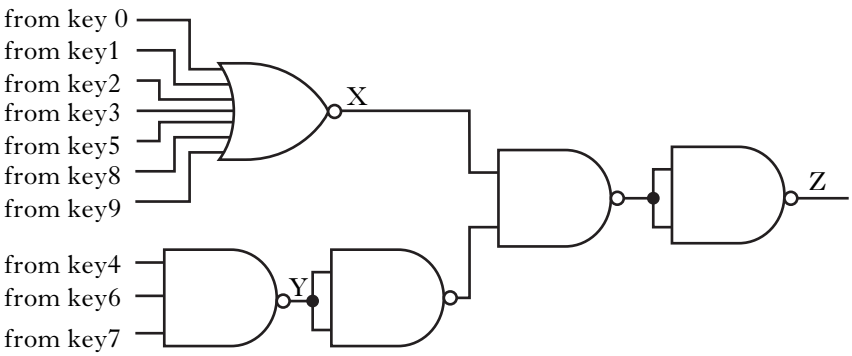

Figure Q11(*b*)

(*a*) (i) Draw a truth table with signals X and Y as inputs, and signal Z as the output. **1**

(ii) **From the truth table**, write a Boolean expression for the output Z in terms of X and Y. **1**

(*b*) Explain what a user must do, in order to cause a high signal at Z. **1**

A high signal at Z opens the door; a low signal at Z closes the door.

(*c*) State **two** disadvantages of this security system. **2**

The logic system is to be replaced by a microcontroller-based system to process the signals from the keypad. Figure Q11(*c*) shows the connections to the microcontroller, enabling the twelve keys of the keypad to be monitored by a microcontroller with only eight I/O pins.

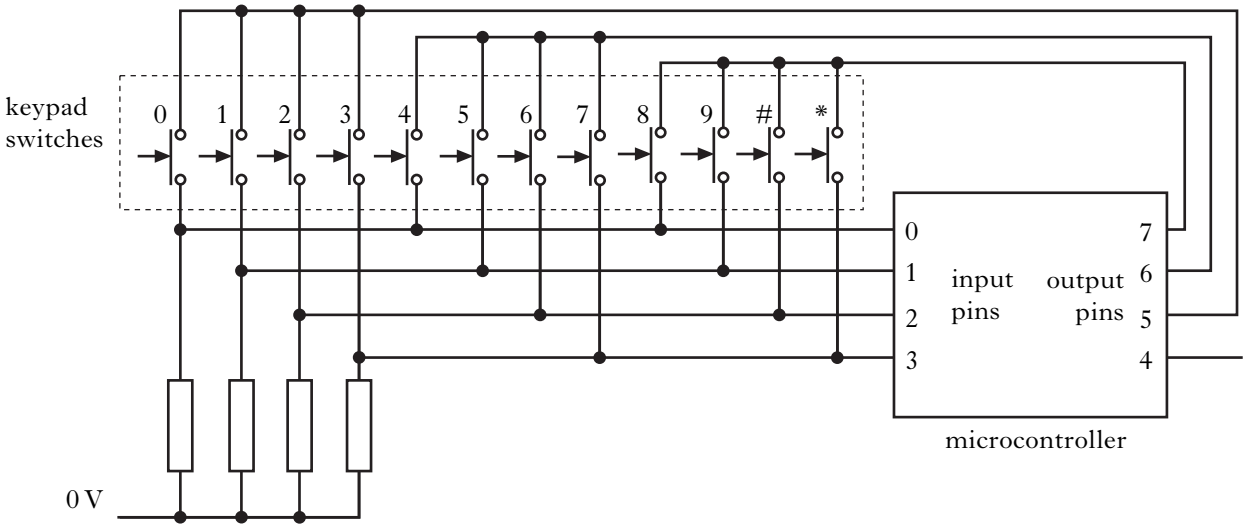

Figure Q11(*c*)

(*d*) Referring to Figure Q11(*c*):

(i) state which keys are monitored when output pin 6 of the microcontroller is high; **1**

(ii) state which input pin will go high if the # key is pressed when output pin 7 is high. **1**

11. (continued)

The control program is represented by the flowchart shown in Figure Q11(*d*).

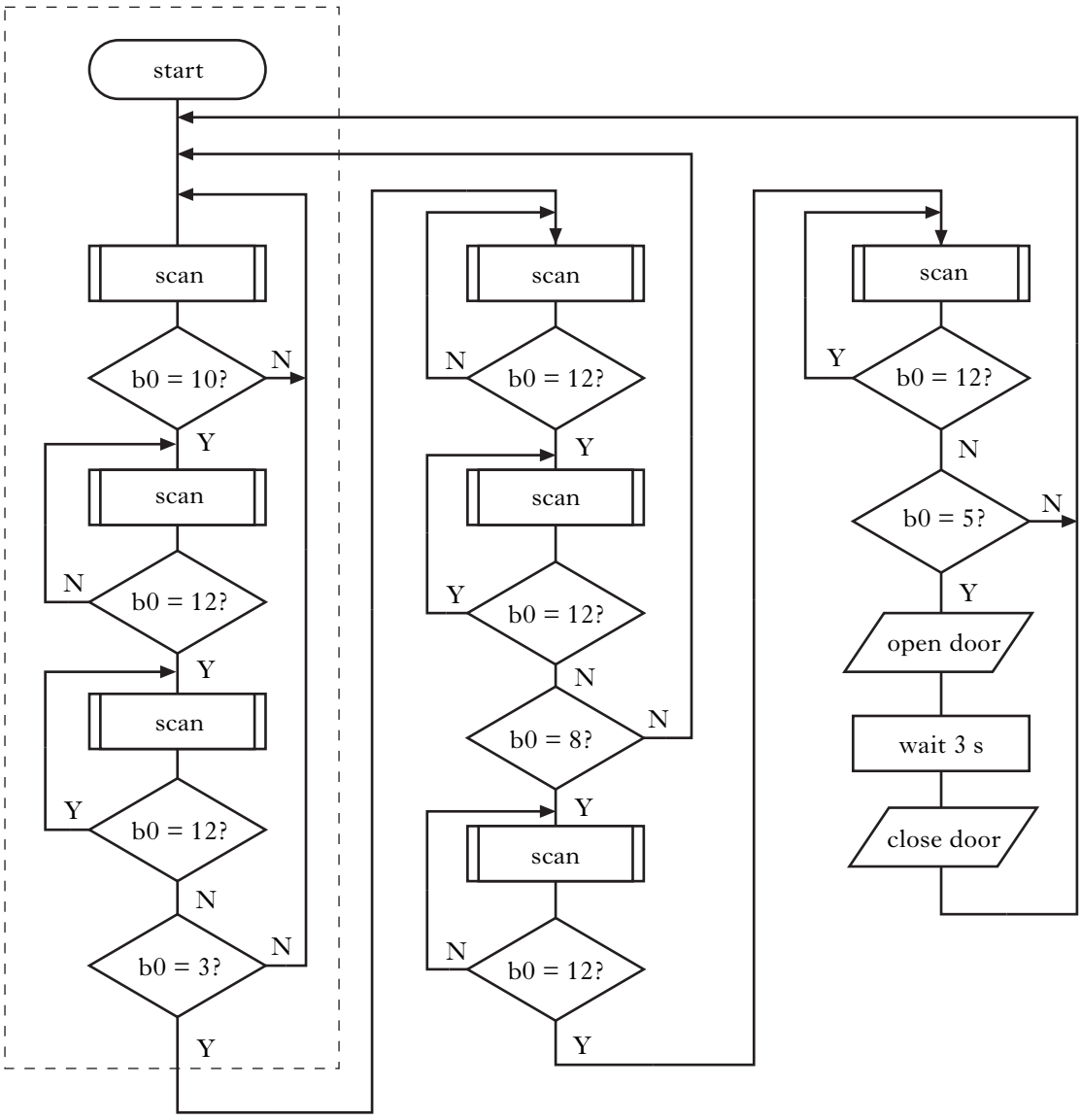

Figure Q11(*d*)

(*e*) Write, in PBASIC, the section of control program represented by the portion of flowchart **within the dashed box**. Assume that the I/O port has been initialised. **6**

The value of the key pressed during the sub-procedure *scan* is stored in the variable b0.

When the # key is pressed, b0 = 10.
If no key is pressed, b0 = 12.

(*f*) State the user inputs required at keys 0–9 and the # key, in order to open the door. **2**

11. (continued)

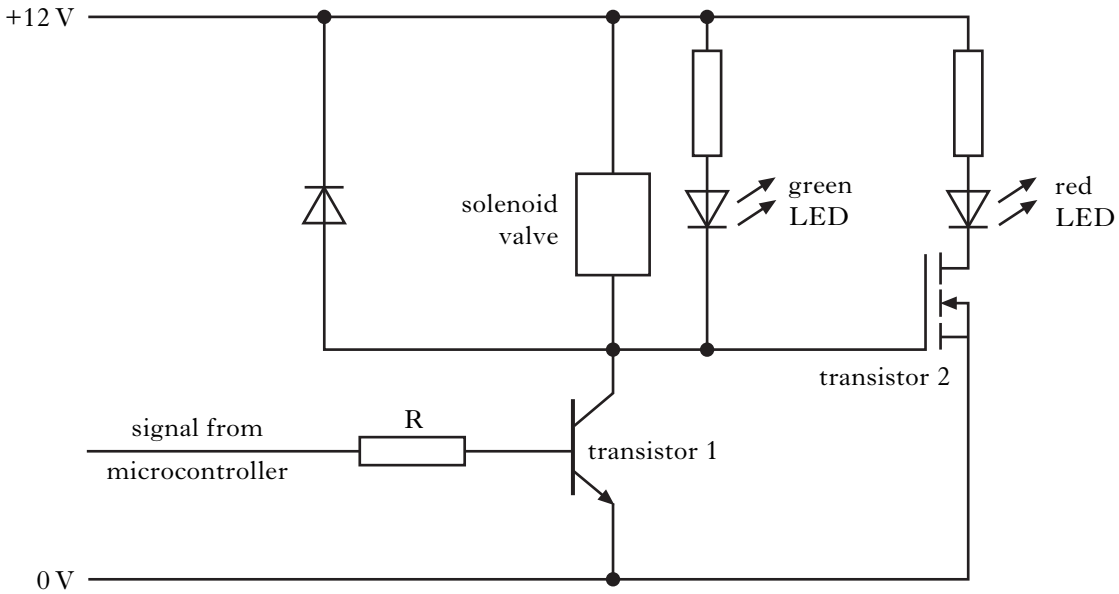

Figure Q11(*e*)

The output-driver circuit for the security system is shown in Figure Q11(*e*). When the solenoid valve is activated, a hydraulic cylinder outstrokes, opening the door. A high signal from the microcontroller is at 5 V, and causes 0·8 mA of current to flow from the microcontroller to the output-driver circuit.

(*g*) Calculate the required value of resistor R. **1**

(*h*) State whether the microcontroller output signal is high or low when the red LED is on. Justify your answer. **2**

The solenoid has a resistance of 50 Ω. Each LED draws 20 mA when it is switched on. When transistor 1 is switched on and saturated, $V_{CE} = 0{\cdot}2$ V.

(*i*) Calculate the minimum current gain of transistor 1. **2**

(20)

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