X036/301

NATIONAL QUALIFICATIONS 2011

FRIDAY, 27 MAY
9.00 AM – 12.00 NOON

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.

A Worksheet has been provided for Question 10.

SECTION A

Marks

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

1. A logic system controls warning lights at the approach to the bridge shown in Figure Q1.

Figure Q1

The input signals to the logic system are as follows:

A weight sensor (W) = 0 if a vehicle is too heavy for the bridge;
A height sensor (H) = 0 if a vehicle is too high for the bridge.

If a vehicle is either too heavy or too high, then the warning lights illuminate (L = 1).

(*a*) Draw a truth table including the inputs W and H, and the output L. **1**

(*b*) State the name of the single logic gate which could provide the required logic function. **1**

The system is modified by the addition of an override button (B):

B = 1 when the override button is pressed.

The output (L) from the redesigned logic system = 1 if the override button is pressed, or if a vehicle is either too heavy or too high.

(*c*) Write a Boolean expression for the redesigned logic system, in terms of W, H, B and L. **2**

(*d*) Draw a logic diagram for the redesigned logic system using NOT gates, AND gates and OR gates as appropriate. **2**

(*e*) Redraw the logic diagram in part (*d*) using only NAND gates. Simplify where appropriate. **2**

(8)

2. A control system which regulates the heating in a large open-plan office space uses three temperature sensors located in different areas.

The circuit for each sensor is shown in Figure Q2.

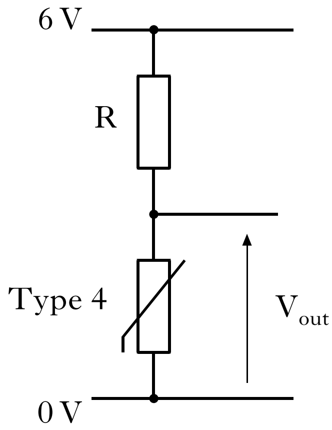

Figure Q2

(*a*) Calculate a suitable value for R so that V_{out} = 1·2 V at 16 °C. **2**

The three sensor signals are combined by a processing circuit based on a single operational amplifier (op-amp) which is connected to +12 V and –12 V supply rails. The feedback resistor is 40 kΩ and the input resistors are each 20 kΩ.

(*b*) Draw the processing circuit described above. Show all component values and supply rail connections. **1**

(*c*) Calculate the output from the op-amp when two sensors are at 10 °C and the third sensor is at 16 °C. **3**

The output voltage calculated in part (*c*) is further processed to produce an output of +5 V.

(*d*) Draw the circuit required for this further processing. Show all calculations and resistor values. **2**

(8)

[Turn over

3. Two boats are tied to a mooring post by polypropylene ropes.

The forces acting concurrently on the mooring post are shown in Figure Q3.

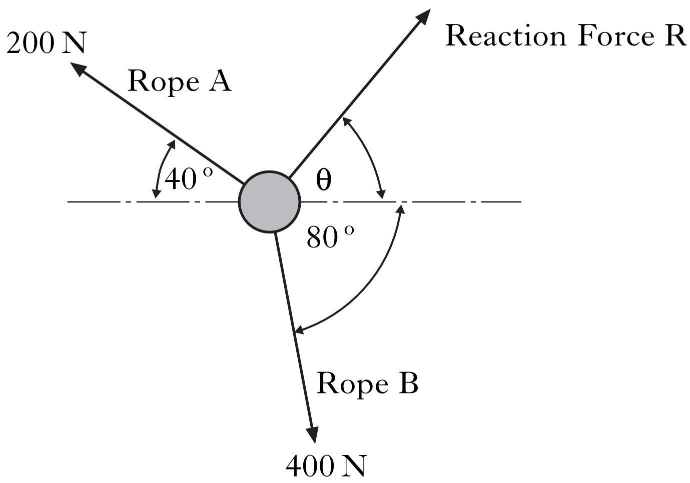

Figure Q3

(*a*) Calculate the magnitude of the reaction force R, and the angle θ. **5**

Each polypropylene rope has a diameter of 20 mm and a length of 20 m when unloaded.

(*b*) Calculate the change in length of rope B when loaded as shown in Figure Q3. **3**

(8)

Marks

4. A signal from a logic circuit controls the operation of a 12 V lamp by means of the transistor driver shown in Figure Q4.

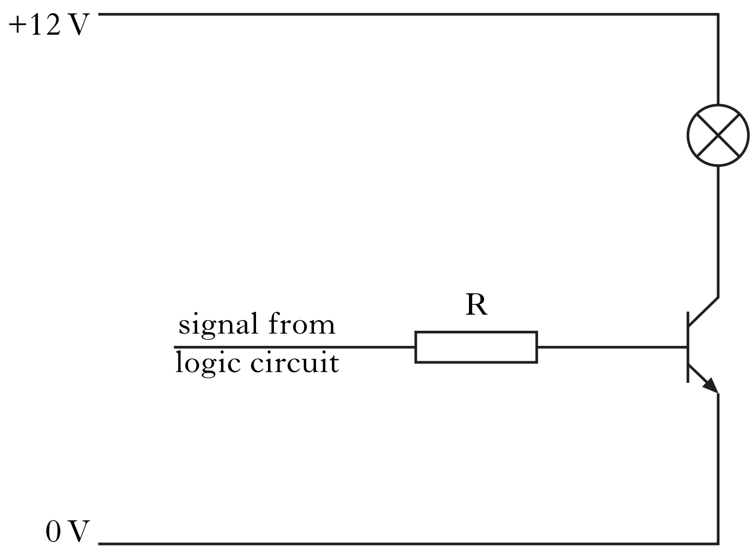

Figure Q4

When the signal from the logic circuit is high, the voltage is 12 V and the current is 3 mA.

(*a*) Calculate the value of resistor R. **1**

The lamp is rated at 20 W at its normal operating temperature. However, when the lamp is cold it draws a much higher current and so the transistor must be capable of handling 5 times the normal operating current of the lamp.

(*b*) Calculate the minimum required current gain of the transistor. **2**

No single transistor has a sufficiently high current gain for this circuit. A Darlington Pair could be used to provide the required current gain.

(*c*) (i) Draw a circuit diagram showing a Darlington Pair replacing the single transistor. **1**

(ii) Calculate the required value of resistor R in the new circuit, that will limit the current from the logic circuit to 3 mA. **1**

(*d*) Draw a circuit diagram showing how a MOSFET transistor could be used to replace the Darlington Pair. **1**

(*e*) State two advantages of a MOSFET-based driver compared with a bipolar-transistor-based driver. **1**

(7)

[Turn over

5. A microcontroller-based system controls the temperature in a greenhouse by opening and closing a window. Figure Q5(*a*) shows the flowchart for the sub-procedure *open*. A motor rotates clockwise to open the greenhouse window.

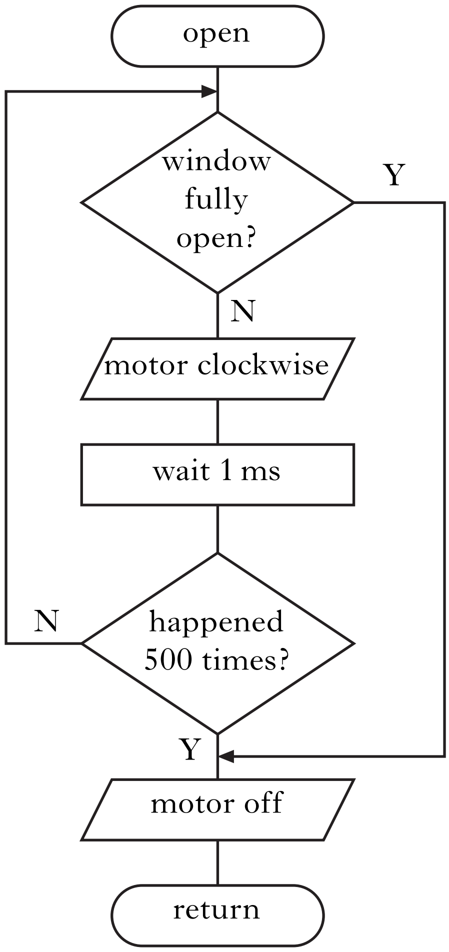

Figure Q5(*a*)

(*a*) Explain how the sub-procedure *open* controls the movement of the window. **2**

The relevant connections to the microcontroller are shown in Figure Q5(*b*).

INPUTS	PIN	OUTPUTS
“open” limit switch (= 1 when window fully open)	0	
“closed” limit switch (= 1 when window fully closed)	1	
	4	fan
	5	heater

Figure Q5(*b*)

5. (continued)

The main control program is shown in Figure Q5(*c*). The sub-procedure *adcread* takes a reading from an analogue temperature sensor, converts it into a digital value, and stores the result in a variable called DATA.

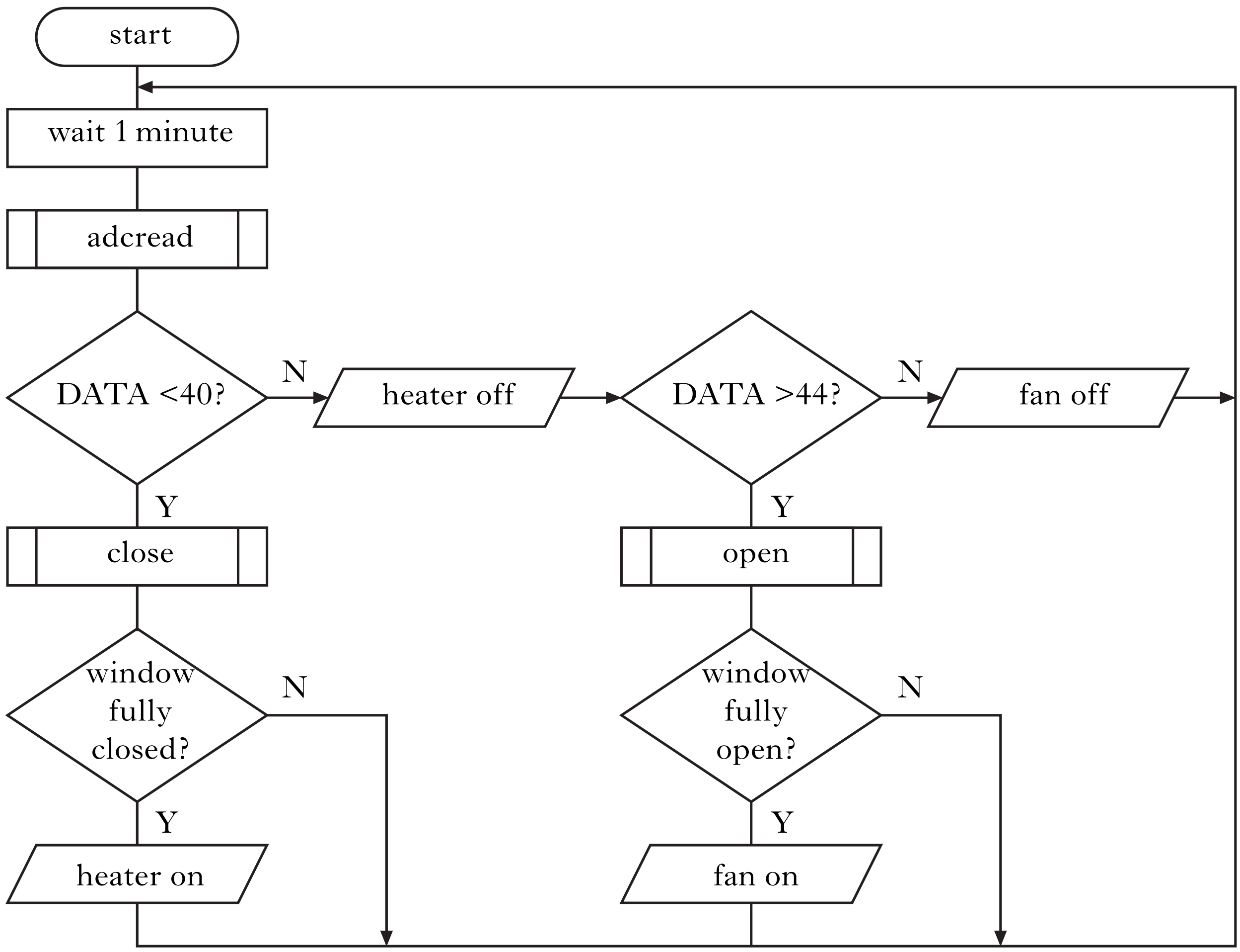

Figure Q5(*c*)

(*b*) Write, in PBASIC, the main control program described in Figure Q5(*c*). **8**

(10)

[Turn over

6. Two hanging baskets, each weighing 150 N, are attached to a support arm which is fixed to a lamppost, as shown in Figure Q6.

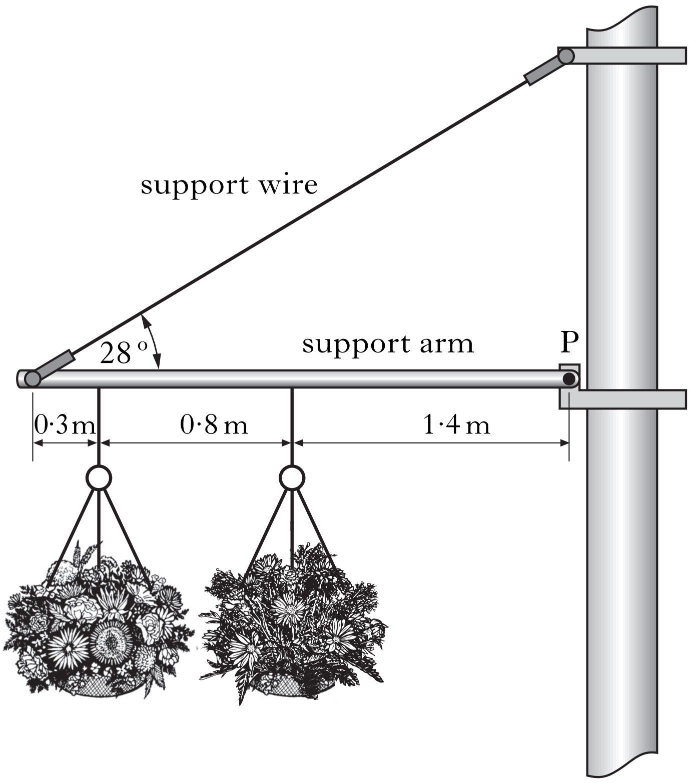

Figure Q6

(*a*) Draw a free-body diagram for the support arm, showing all the forces acting on it. **2**

(*b*) Calculate the tension in the support wire. **3**

(*c*) Calculate the **magnitude** and **direction** of the reaction force at the pivot, P. **3**

(8)

7. An electronic control system keeps the wind turbine shown in Figure Q7 facing into the wind.

The wind direction is sensed by a wind vane connected to a potentiometer.

The signal from the potentiometer is compared with a reference voltage, and the turbine head is rotated by a motor to face the wind.

As the turbine head moves closer to the wind direction the motor slows and then comes to rest.

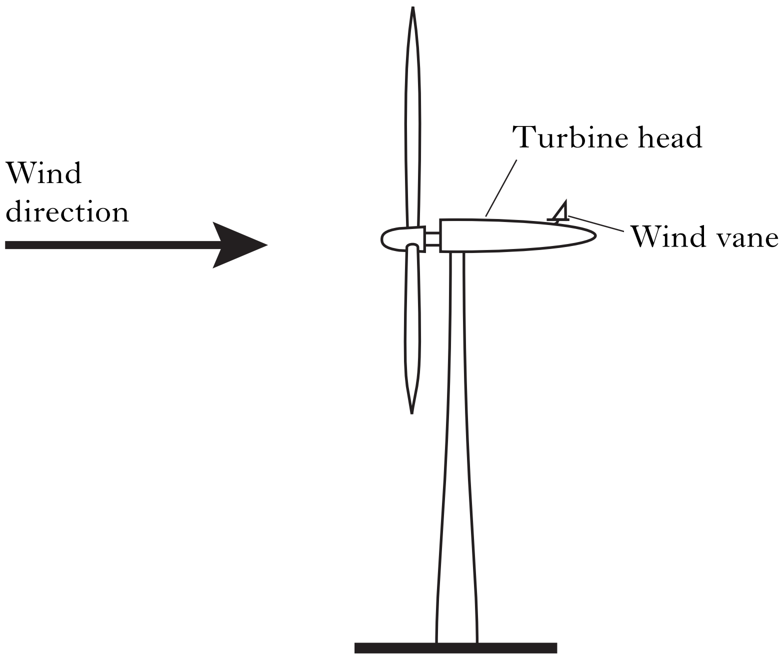

Figure Q7

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

(*b*) Draw a control diagram for the direction-control system of the wind turbine. **3**

(*c*) State which configuration of operational amplifier would be used in this electronic control system. **1**

(*d*) (i) Draw a circuit diagram for the electronic control system, including the motor driver. Show all components and connections. **3**

(ii) Describe how the electronic system controls the movement of the turbine head when the wind direction changes. **3**

(11)

[*END OF SECTION A*]

[Turn over

SECTION B

Marks

Attempt any TWO questions in this Section.

Each question is worth 20 marks.

8. A car park barrier is shown in Figure Q8(*a*).

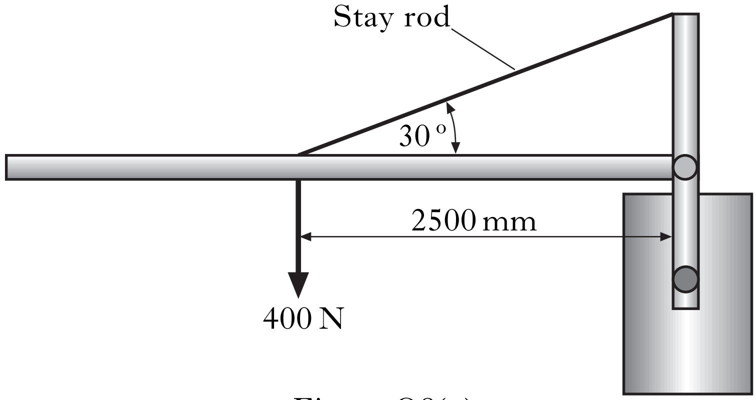

Figure Q8(*a*)

The maximum allowable extension of the stainless-steel stay rod is 3 mm.

(*a*) Calculate the diameter of the stay rod. **4**

(*b*) State **two** reasons why a high Factor of Safety is not required in this situation. **1**

The barrier is raised by a stepper motor controlled by a microcontroller. The stepper motor operates in the **four-step** sequence shown in Figure Q8(*b*). Each step rotates the barrier by 3·2°.

Step	**Coil 4**	**Coil 3**	**Coil 2**	**Coil 1**
1	on	off	on	off
2	on	off	off	on
3	off	on	off	on
4	off	on	on	off

Figure Q8(*b*)

In the fully raised position, the barrier is inclined at 80° above the horizontal.

(*c*) (i) Calculate the number of steps required by the stepper motor to fully raise the barrier from the horizontal position. **1**

(ii) Draw the flowchart of the microcontroller program required to fully raise the barrier in four seconds. **3**

8. (continued) *Marks*

Figure Q8(c) shows the mechanism for issuing car-parking tickets. When the ticket-request switch is pressed, a ticket is fed out by the mechanism.

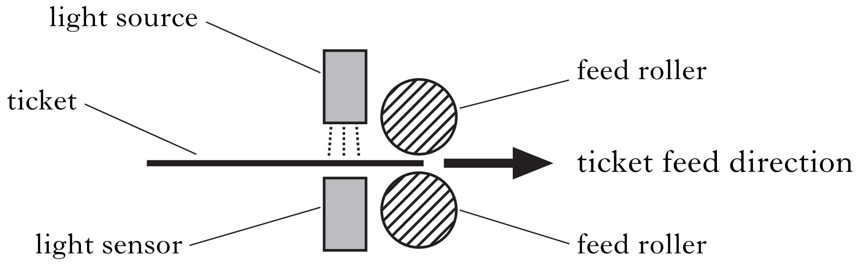

Figure Q8(c)

The electronic control sytem for the ticket-issuing mechanism is shown in Figure Q8(d).

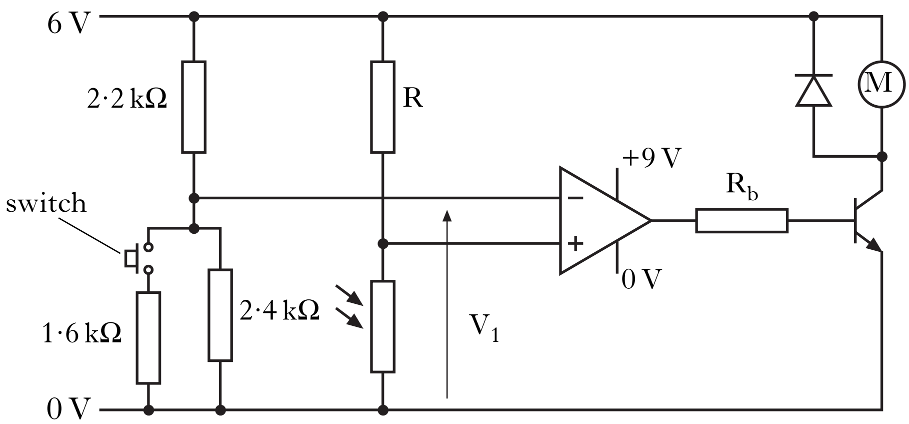

Figure Q8(d)

(d) Calculate the two possible voltages V_1 at the inverting input of the op-amp. **2**

When the ticket-request switch is pressed, the motor (M) drives the feed rollers until the light sensor is uncovered.

(e) Describe how the op-amp input voltages compare as a ticket is dispensed. Begin with the ticket-request switch not pressed, as shown in Figure Q8(d). **4**

The light level on the light sensor is 10 lux when covered by a ticket.

(f) When the light sensor is covered, determine the minimum value for R so that the motor remains **off** when the ticket-request switch is not pressed. **2**

The transistor shown in Figure Q8(d) has a minimum gain of 15 when it provides the required current of 1 A to operate the motor.

For these conditions:

(g) calculate the maximum allowable value for the base resistor R_b. **3**

(20)

9. A frame for supporting a maintenance platform suspended from the top of a building is shown in Figure Q9(*a*).

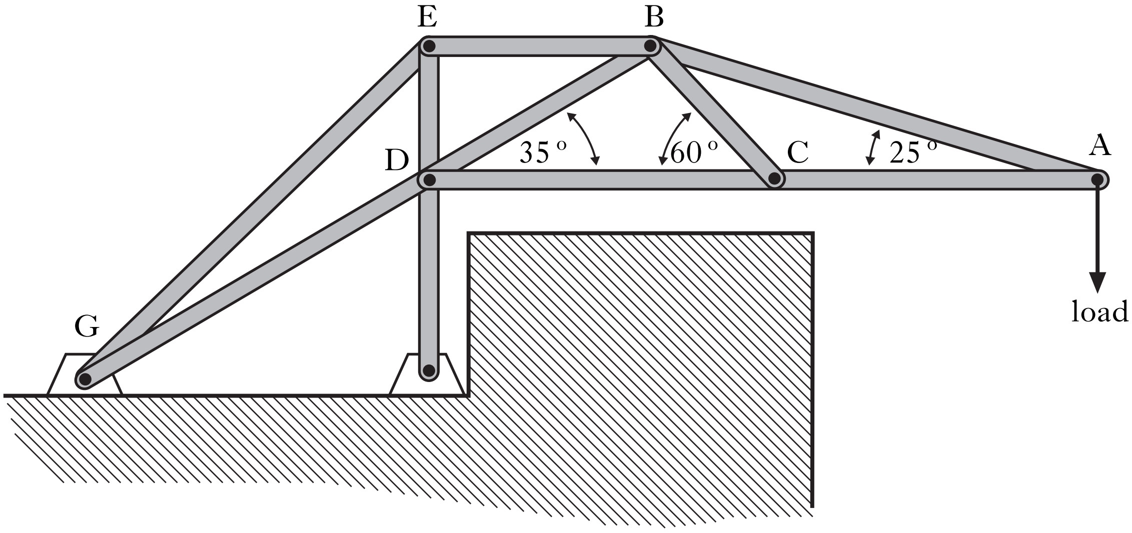

Figure Q9(*a*)

(*a*) Calculate, using *Nodal Analysis*, the magnitude and nature of the forces in members AB, AC, BC, CD and BD, for a load of 5 kN acting on the support frame. **6**

The members of the support frame are made from mild-steel tube with an outside diameter of 80 mm and wall thickness of 4 mm. A Factor of Safety of 9 is applied to the design.

(*b*) Calculate the maximum safe tensile load for the members of the frame. **3**

Member EG experiences the greatest loading. The electronic circuit shown in Figure Q9(*b*) incorporates strain gauges to monitor the load in member EG.

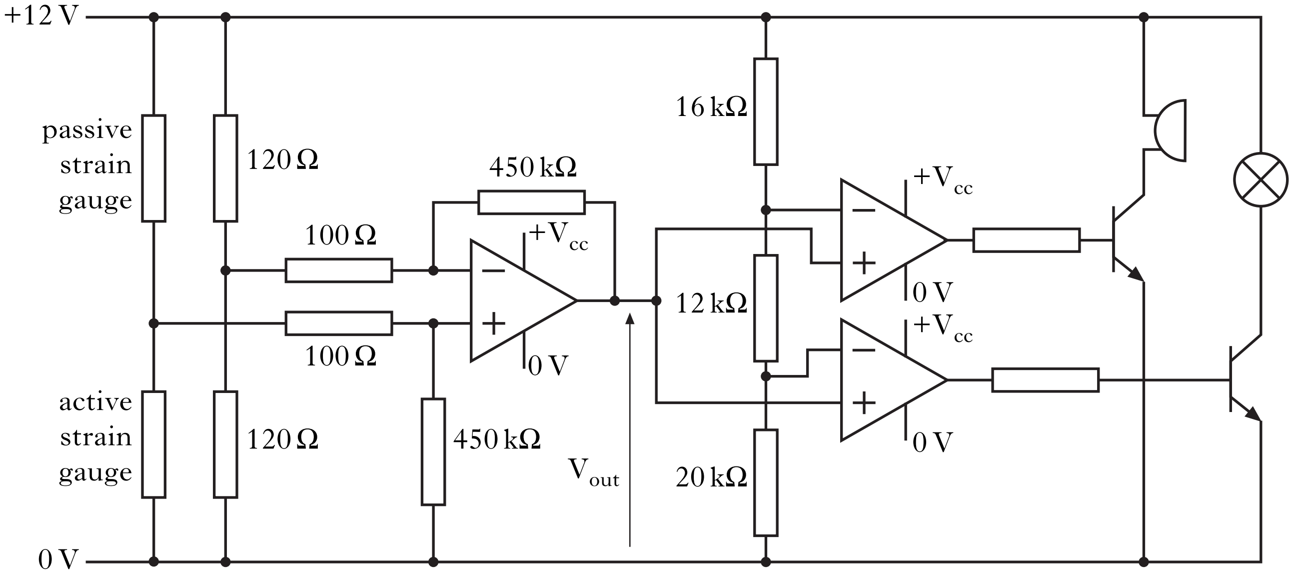

Figure Q9(*b*)

(*c*) Explain the operation of the monitoring sytem as the tension in member EG increases from zero to a dangerous level. Refer to the input signals to the difference amplifier, the input signals to the comparators, the input signals to the transistors, and the states of the buzzer and the lamp. **3**

Marks

9. (continued)

The unloaded resistance of each strain gauge is 120 Ω.

(*d*) Calculate the minimum resistance of the active strain gauge that will cause the lamp to light. **3**

The change in resistance of the strain gauges is proportional to the strain in the member. For a strain of 1×10^{-4}, the change in resistance is 0·02 Ω. Member EG is made from mild steel.

(*e*) Calculate the minimum stress in member EG that will cause the lamp to light. **2**

An alternative safety and warning system for the maintenance platform uses a microcontroller. The relevant connections to the microcontroller are shown in Figure Q9(*c*).

INPUTS	PIN	OUTPUTS
limit switch (= 1 if maintenance platform reaches the ground)	0	
	2	warning light
	3	buzzer
	7	motor (to lower platform)

Figure Q9(*c*)

The signal proportional to the strain in member EG, (V_{out}), shown in Figure Q9(*b*), is processed by an ADC. The sub-procedure *adcread* takes the binary value from the ADC and stores it in the variable DATA. The microcontroller program is shown below:

```
main: gosub adcread
      if DATA > 200 then a
      low 2
      low 3
      goto main
a:    high 2
      if DATA > 220 then b
      low 3
      goto main
b:    high 3
      if DATA > 240 then c
      goto main
c:    high 7
d:    if pin0 = 0 then d
      low 7
      goto main
```

(*f*) Explain the operation of the program, stating clearly how the warning light, buzzer and motor respond to changing values of strain in member EG. **3**

(20)

[Turn over

Marks

10. A microcontroller-based reversing aid emits an audible warning as a car reverses towards an obstruction. Figure Q10(*a*) shows a block diagram of the reversing aid.

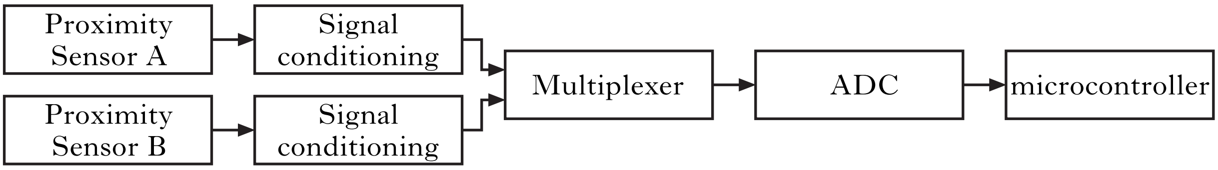

Figure Q10(*a*)

The signal from each proximity sensor is processed by an ADC.

(*a*) Draw a signal-conditioning circuit based on a single op-amp that will produce an output of 5 V when a sensor is producing its maximum output of 4·6 mV. Show all calculations and resistor values. **2**

The sensor signal is processed by an 8-bit ADC with a reference voltage of 5 V.

(*b*) Calculate the output of the ADC as a binary value when the voltage from the sensor is 1·48 mV. **2**

The flowchart for the sub-procedure *reverse* is shown in Figure Q10(*b*).

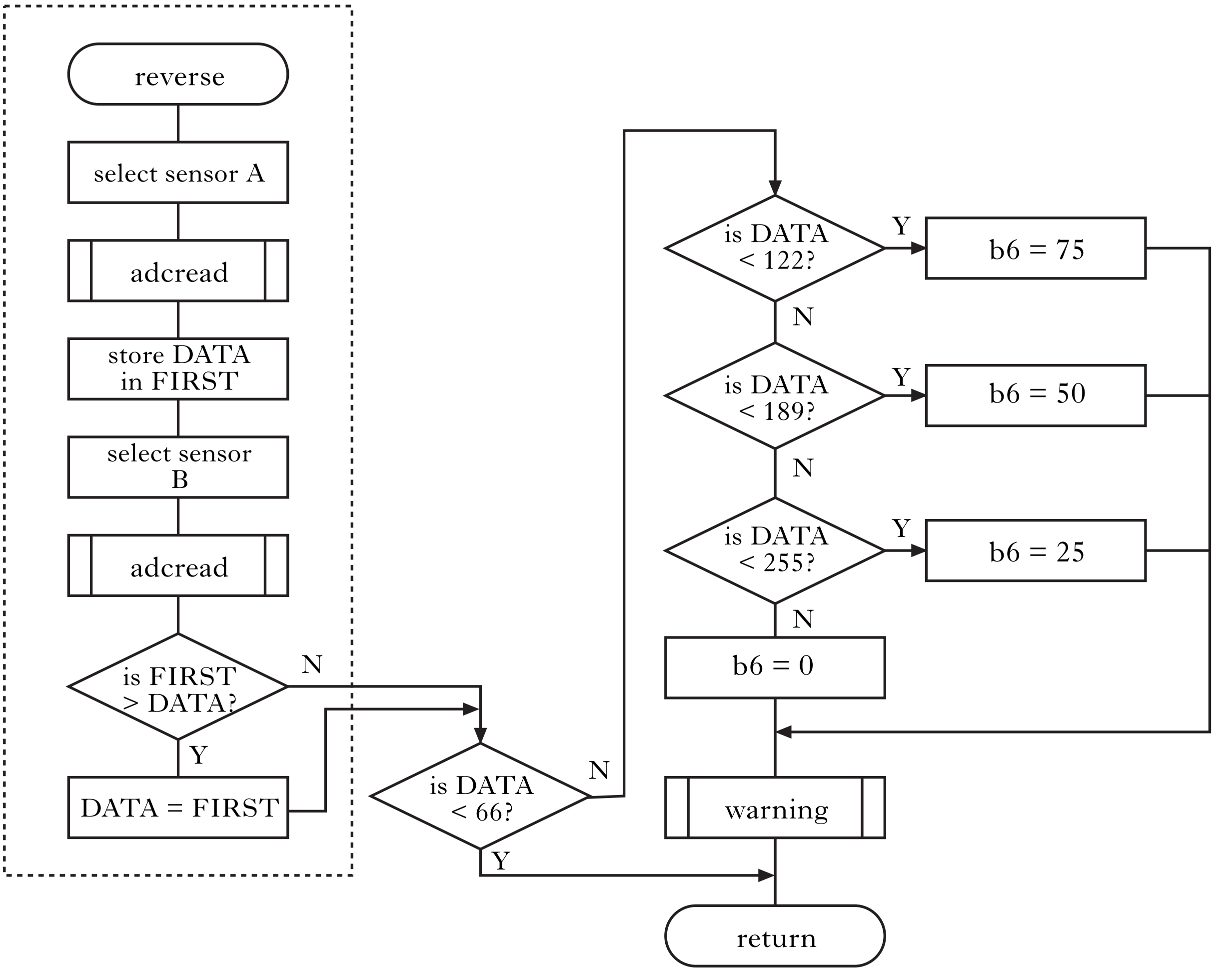

Figure Q10(*b*)

10. (continued)

The multiplexer selects sensor A when pin 3 is set low and sensor B when pin 3 is set high. The pre-written sub-procedure *adcread* reads a value from the ADC and stores it in the variable DATA.

(*c*) Explain the function of the portion of the flowchart within the dashed box. **2**

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

For each value of b6 the sub-procedure *warning* switches a sounder on and off. The flowchart for *warning* is shown in Figure Q10(*c*).

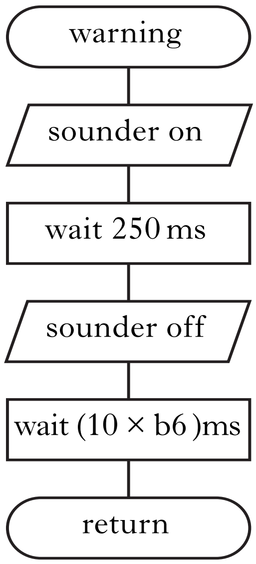

Figure Q10(*c*)

As the car moves closer to an obstruction the value in b6 reduces. A set of values for b6 is shown in Table Q10 on **Worksheet Q10**.

(*e*) On **Worksheet Q10** draw a graph of sounder voltage against time for the b6 values shown in Table Q10. The sounder operates from a 12 V supply. **2**

A bipolar-transistor-based driver circuit operates the sounder.

The microcontroller output is 5 V when high. The base resistor is 1 kΩ and the collector-emitter voltage V_{CE} is 0·22 V when the transistor is on and saturated.

The sounder has a resistance of 56 Ω and operates from a 12 V supply.

(*f*) Calculate the minimum required transistor gain. **3**

(20)

[*END OF QUESTION PAPER*]

FOR OFFICIAL USE

Marks

X036/302

NATIONAL QUALIFICATIONS 2011

FRIDAY, 27 MAY
9.00 AM – 12.00 NOON

TECHNOLOGICAL STUDIES
HIGHER
Worksheet for Q10

Fill in these boxes and read what is printed below.

Full name of centre

Town

Forename(s)

Surname

Date of birth
Day Month Year

Scottish candidate number

Number of seat

To be inserted inside the front cover of the candidate's answer book and returned with it.

WORKSHEET Q10

Warning cycle	b6 value
1	75
2	75
3	50
4	50
5	50
6	25
7	25
8	0
9	0

Table Q10