FOR OFFICIAL USE

H

National
Qualifications
2019

Mark

X823/76/01 Engineering Science

FRIDAY, 17 MAY

1:00 PM – 3:30 PM

X823760 1

Fill in these boxes and read what is printed below.

Full name of centre

Town

Forename(s)

Surname

Number of seat

Date of birth

Day Month Year

Scottish candidate number

Total marks — 110

SECTION 1 — 20 marks

Attempt ALL questions.

SECTION 2 — 90 marks

Attempt ALL questions.

Show all working and units where appropriate.

You should refer to the Higher Engineering Science Data Booklet which you have been given.

The number of significant figures expressed in a final answer should be equivalent to the least significant data value given in the question. Answers that have two more figures or one less figure than this will be accepted.

Write your answers clearly in the spaces provided in this booklet. Additional space for answers is provided at the end of this booklet. If you use this space you must clearly identify the question number you are attempting.

Use **blue** or **black** ink.

Before leaving the examination room you must give this booklet to the Invigilator; if you do not, you may lose all the marks for this paper.

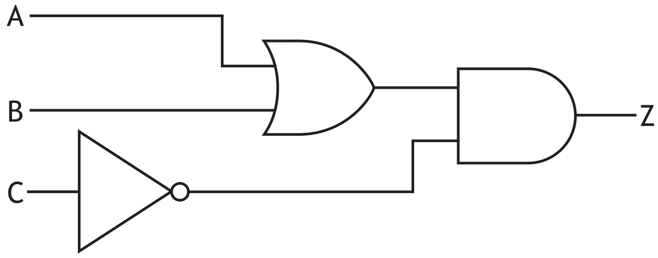
X82376 0101

B/PB

SECTION 1 — 20 marks

Attempt ALL questions

1. An electronic engineer requires the following circuit as part of a hand-held product. It is to be made using individual integrated circuits (ICs).

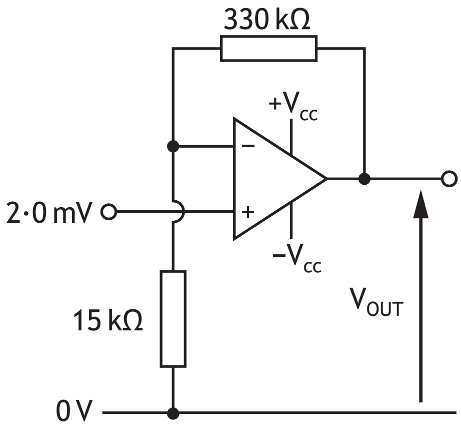


(a) Draw a NAND equivalent for the circuit shown above. **3**

(b) Explain why the engineer chose to use the NAND equivalent circuit in the product rather than the original circuit. **1**

2. A microphone in a recording studio produces a maximum output signal of 2·0 mV.

The following circuit is used to amplify the signal so that it can be recorded.



(a) Calculate the output voltage from the op-amp shown above. **1**

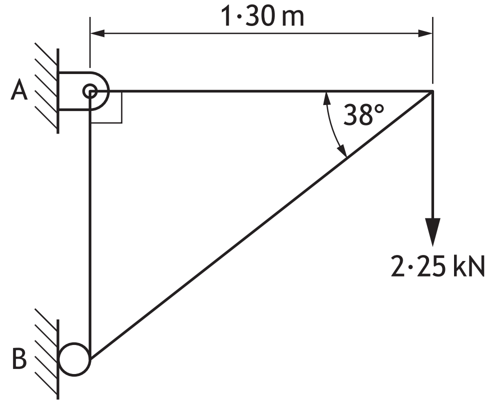
2. (continued)

(b) Describe how the gain of the op-amp circuit could be increased. **1**

The mixing desk in the studio needs to combine the signals from a number of microphones and instruments to produce one output signal for the speakers.

(c) State the op-amp configuration required to perform this task. **1**

3. A frame structure is shown below.



Calculate the magnitude and indicate the direction of the reaction at B. **4**

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4. An air pressure supply system in a car garage will be operated by programmable control. The system must meet the following specification.

- The system is activated when a user presses a start button
- The pumping system then switches on
- The air pressure is monitored by an analogue sensor
- When the air pressure rises above a set level (100), the pump switches off
- A light must flash five times to indicate that the air pressure has reached the set level
- The system then resets, ready for the next user

Input	Pin	Output
	7	Pump
	6	Light
Start button	1	
Pressure sensor	0	

Part of the same test program is shown below in **PBASIC** and **ARDUINO** code.

```
let dirs = %11110000
symbol pressure = b4

main: if pin1 = 1 then main

        high 7

check: readadc 0, pressure

if pressure ≤ 200 then check

        low 7

        for b3 = 0 to 5
                high 6
                pause 200
                low 6
                pause 200
        next b3

      goto main
```

```
int Pressure = 0;
int Pressuresensor = 0;
int Pump = 7;
int Light = 6;
int Startbutton = 1;

void setup(){
pinMode (Pressuresensor, INPUT);
pinMode (Startbutton, INPUT);
pinMode (Pump, OUTPUT);
pinMode (Light, OUTPUT);
}

void loop(){
  if (Startbutton == LOW) {
        digitalWrite(Pump, HIGH);
  } else {
        digitalWrite(Pump, LOW);
  }
  Pressure = analogRead (Pressuresensor);
  if (Pressure <= 200){
    digitalWrite (Pump, LOW);
  }
  for(int counter=0; counter<=5;
counter=counter+1)
         {digitalWrite(Light, HIGH);
         delay(200);
         digitalWrite(Light, LOW);
         delay(200);
}
}
```

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4. (continued)

There are three faults in the program shown opposite.

Identify the lines where the faults are and write the corrected code.

Complete for **either** PBASIC **or** ARDUINO. **2**

The first fault is shown below.

Correction 1 PBASIC *main: if pin1 = 0 then main*

Correction 1 ARDUINO *if (Startbutton == HIGH) {*

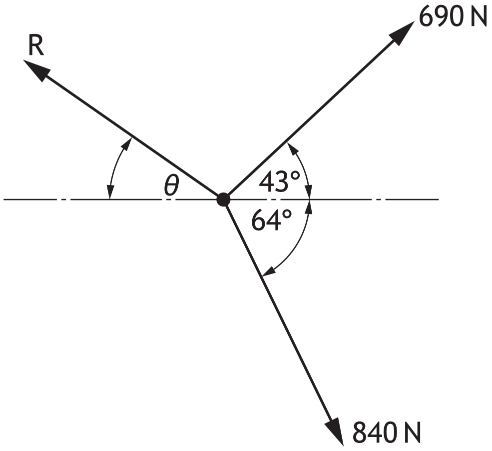
Correction 2

Correction 3

[Turn over

MARKS DO NOT WRITE IN THIS MARGIN

5. A concurrent force system is shown below.



Calculate the magnitude and angle of the force R required to maintain equilibrium. 4

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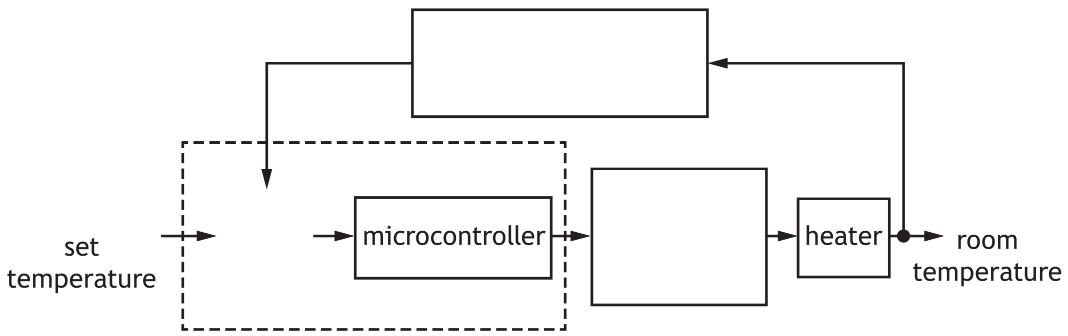
6. The temperature in a room can be set by a signal from a mobile phone or directly using a control panel.

A heating system monitors the temperature of the room and maintains the set temperature.

Complete the control diagram below for the heating of the room. 3



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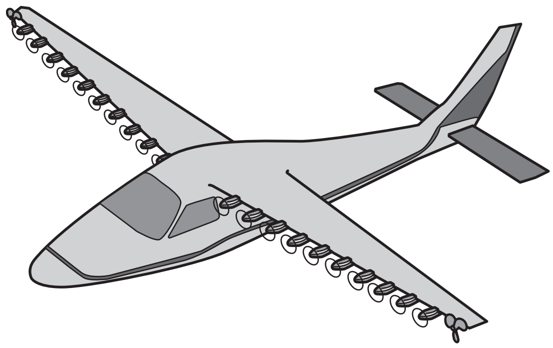
SECTION 2 — 90 marks

Attempt ALL questions

MARKS | DO NOT WRITE IN THIS MARGIN

7. A prototype of an electrically powered aeroplane is being developed and tested by a team of engineers.



The aeroplane is powered by 22 motor-driven propellers that each supply 18 kW.

(a) Calculate the rotational speed of each motor if it produces 23 N m of torque. **1**

When operating at full power the aeroplane is 73% efficient. The aeroplane's battery stores 320 MJ when fully charged.

(b) Calculate how much time the aeroplane can run at full power before the battery runs out. **2**

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7. **(continued)** **MARKS** DO NOT WRITE IN THIS MARGIN

Improving efficiency is a key task for the engineers who design the aeroplane.

(c) Explain **one** economic and **one** social impact of improving the efficiency of the aeroplane. **2**

Economic ____________________

____

____

Social ____________________

____

____

When the aeroplane lands, the propellers are used to transform its kinetic energy back into electrical energy to recharge the batteries as part of a regenerative braking system.

The combined mass of the aeroplane and passengers is 4800 kg and the regenerative braking system is 64% efficient.

(d) Calculate the energy recovered if the aeroplane's velocity changes from $95\,\mathrm{m\,s^{-1}}$ to $25\,\mathrm{m\,s^{-1}}$. **3**

[Turn over

7. (continued)

Bearings are required on the propellers to ensure that they can spin and transfer kinetic energy to make the aeroplane move.

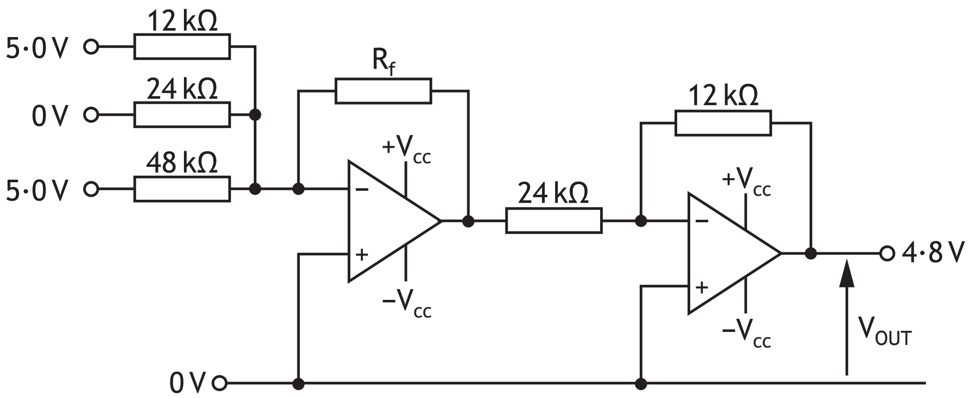
(e) Explain, giving two reasons, why friction needs to be minimised in the bearings. **2**

MARKS | DO NOT WRITE IN THIS MARGIN

7. (continued)

The pilot controls the speed of the aeroplane by moving an accelerator lever. A signal is sent from the lever to a microcontroller which, in turn, sends a signal to an op-amp circuit and the motors' drive systems.

The op-amp circuit is shown below. Each pin from the microcontroller gives a 5·0 V signal when on.



(f) Calculate the value of the feedback resistor, R_f, when V_{OUT} is 4·8 V. **3**

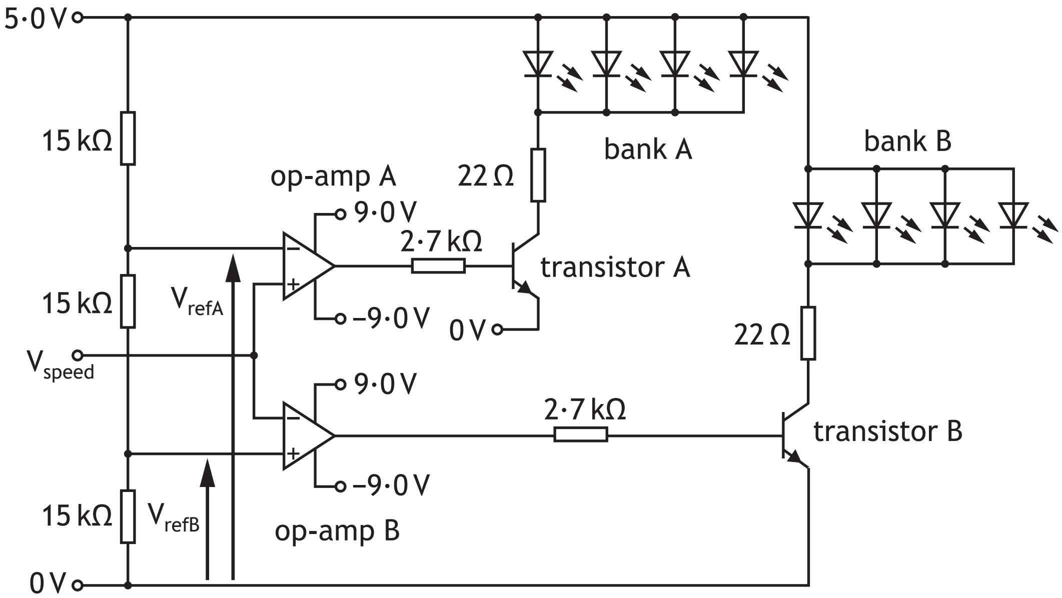
8. An exercise bike has an electronic monitoring system to tell users if they are pedalling within a set range of speeds.

A speed sensor produces an output voltage, V_{speed}, in proportion to the speed of the pedals.

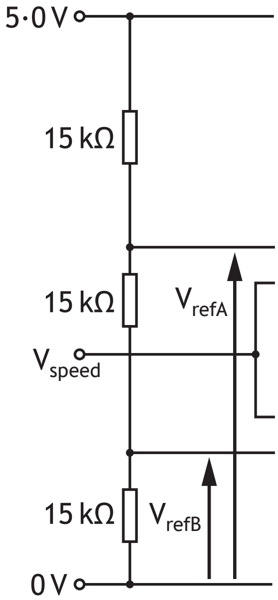
If the voltage is below the lower limit, a bank of LEDs lights to say, ‘SPEED UP’.

If the voltage is above the higher limit, a second bank of LEDs lights to say, ‘TAKE IT EASY’.

The control circuit is shown below.



8. (continued)



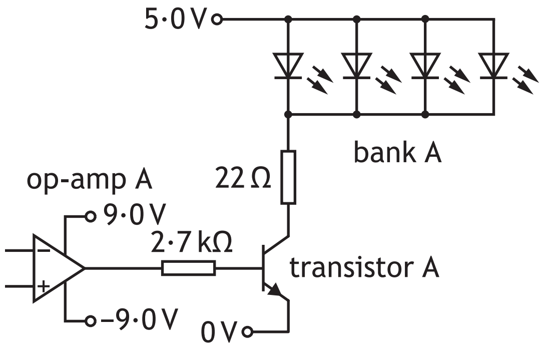
A section of the circuit is shown above.

(a) Calculate the reference voltage V_{refA}. **2**

[Turn over

8. (continued)

A section of the circuit is shown.

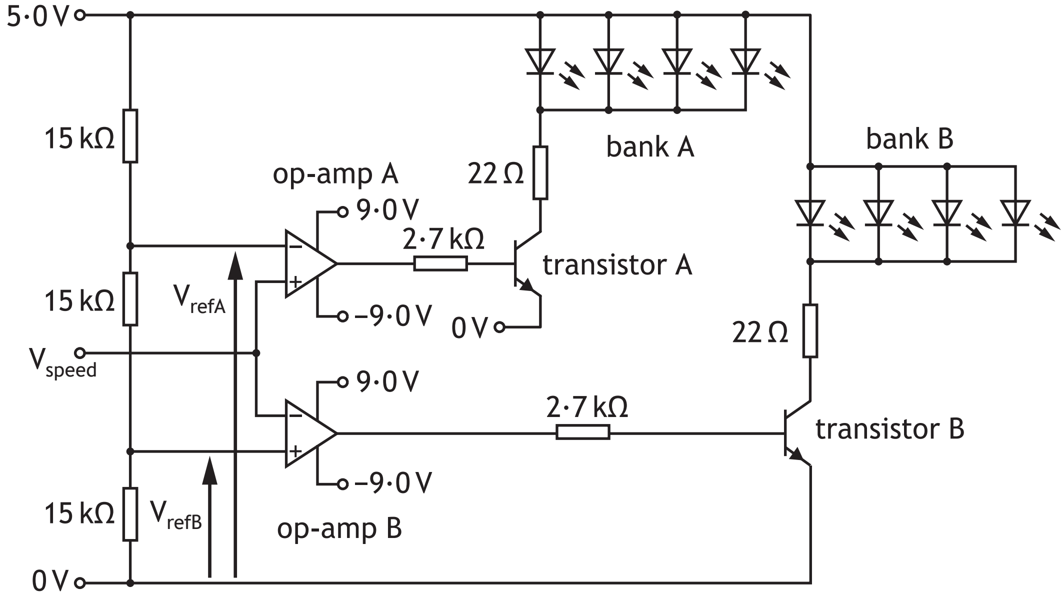


(b) (i) Calculate the base current for transistor A when op-amp A is saturated positive. (Assume V_{be} is 0·70 V). **3**

Transistor A has a gain (h_{FE}) of 140.

(ii) Calculate the collector current when op-amp A is saturated. **1**

8. (continued)



(c) Describe, with reference to the circuit diagram, what happens to the LEDs as the voltage from the speed sensor (V_{speed}) rises from 0 V to 5·0 V.

The complete circuit diagram is shown above again for reference. **6**

8. (continued)

(d) Describe how the control circuit should be adapted to allow users to change the speeds that switch on the LED banks. **2**

[Turn over for next question

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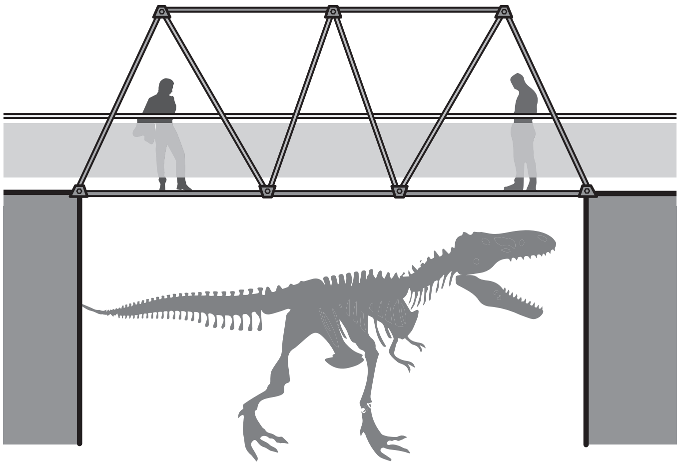
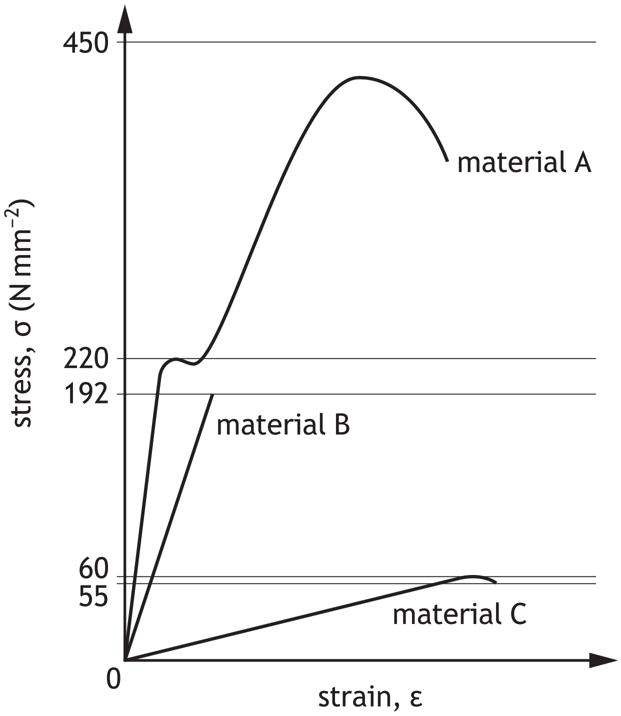
9. A team of engineers is asked to design a walkway over a dinosaur exhibit for a natural history museum.

An initial design for a walkway over the top of the exhibit is shown below.



9. (continued)

Tensile test results for three materials considered for use in the walkway are shown in the stress-strain graph below.



(a) (i) Describe, with reference to the stress-strain graph, three **different** properties of material B in relation to material A or material C. **3**

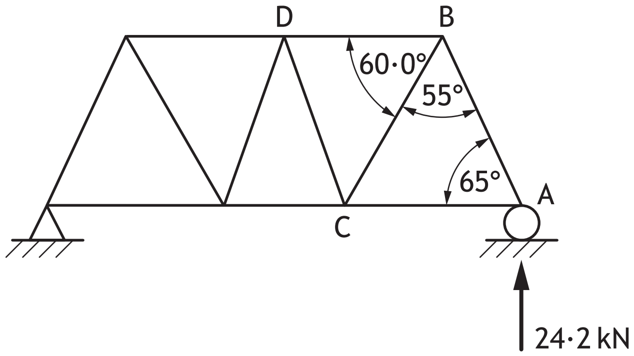
(ii) Identify, with reference to the Data Booklet, material A and material C. **2**

Material A ______________________

Material C ______________________

9. (continued)

A partially completed free body diagram of the design for the walkway is shown.



(b) Calculate, using nodal analysis, the magnitude and nature of the forces in members AB, AC, BC and BD.

Complete the table below. **7**

Show all working and final units on the page opposite.

Member	Magnitude	Nature
AB		STRUT
AC		TIE
BC		
BD		

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9. (b) (continued)

Space for working

* X 8 2 3 7 6 0 1 2 3 *

[Turn over

10. A mechanical engineer produced a preliminary design for a pneumatic system to open and close a dinosaur skeleton's jaw.

The pneumatic cylinder used to move the jaw has an 8·0 mm diameter **aluminium alloy** piston rod to support a load of 33·2 kN.

(a) (i) Calculate the factor of safety applied to the design of the piston rod. **4**

10. (a) (continued)

(ii) Comment on the appropriateness of the factor of safety of the piston rod. **1**

The mechanical engineer decides to use a different pneumatic cylinder to support the 33·2 kN load.

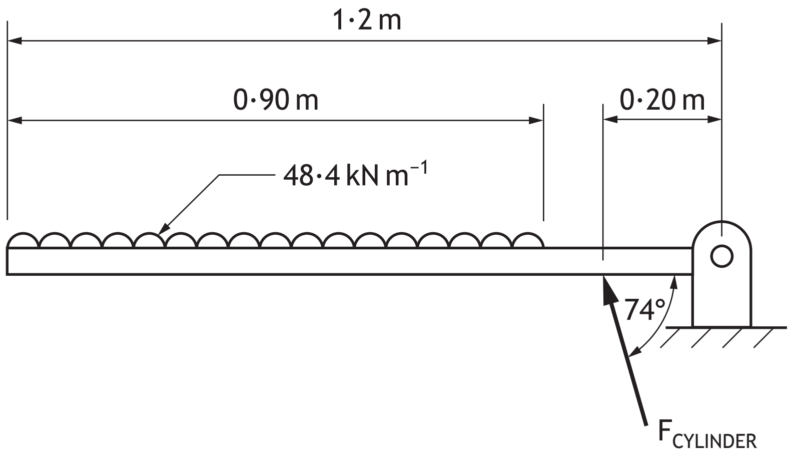
The piston rod area is 491 mm^2 and is made from **titanium alloy** with a length of 0·78 m.

(iii) Calculate the change of length in the piston rod under these conditions. **4**

10. (continued)

After testing, the pneumatic cylinder is repositioned to move a hinged beam in the jaw of the dinosaur as shown below.

The uniformly distributed load of the jaw is $48 \cdot 4\ \text{kN m}^{-1}$.



(b) (i) Calculate the magnitude of force $F_{CYLINDER}$. **3**

(ii) Calculate the magnitude and direction of the reaction at the hinge. **4**

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11.

MARKS DO NOT WRITE IN THIS MARGIN

A proposed design for the operation of a conveyor belt motor has the following specification.

1. The motor will not run if emergency stop(A) is high
2. The motor will run if a pressure sensor(B) is high and a light sensor(C) is low
3. The motor will run if a test switch(D) is high

(a) Complete the Boolean equation for when the motor switches on. **4**

M =

When the conveyor belt motor starts it uses pulse width modulation to accelerate to a set speed.

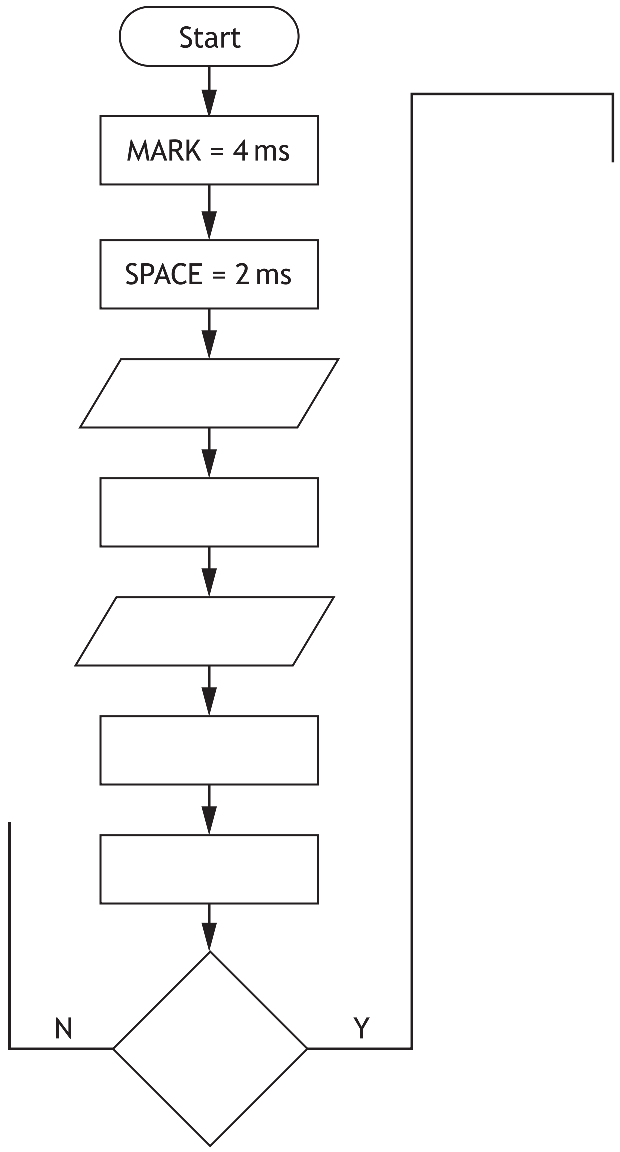
The control sequence for the acceleration of the conveyor belt motor has the following steps.

- Initially the MARK = 4 and the SPACE = 2
- Each new pulse increases the MARK by 1
- The acceleration continues until the MARK reaches 20
- The motor turns on
- The motor will then stop when the emergency stop is high or the override switch is low
- A brake engages for 3 seconds
- The sequence repeats

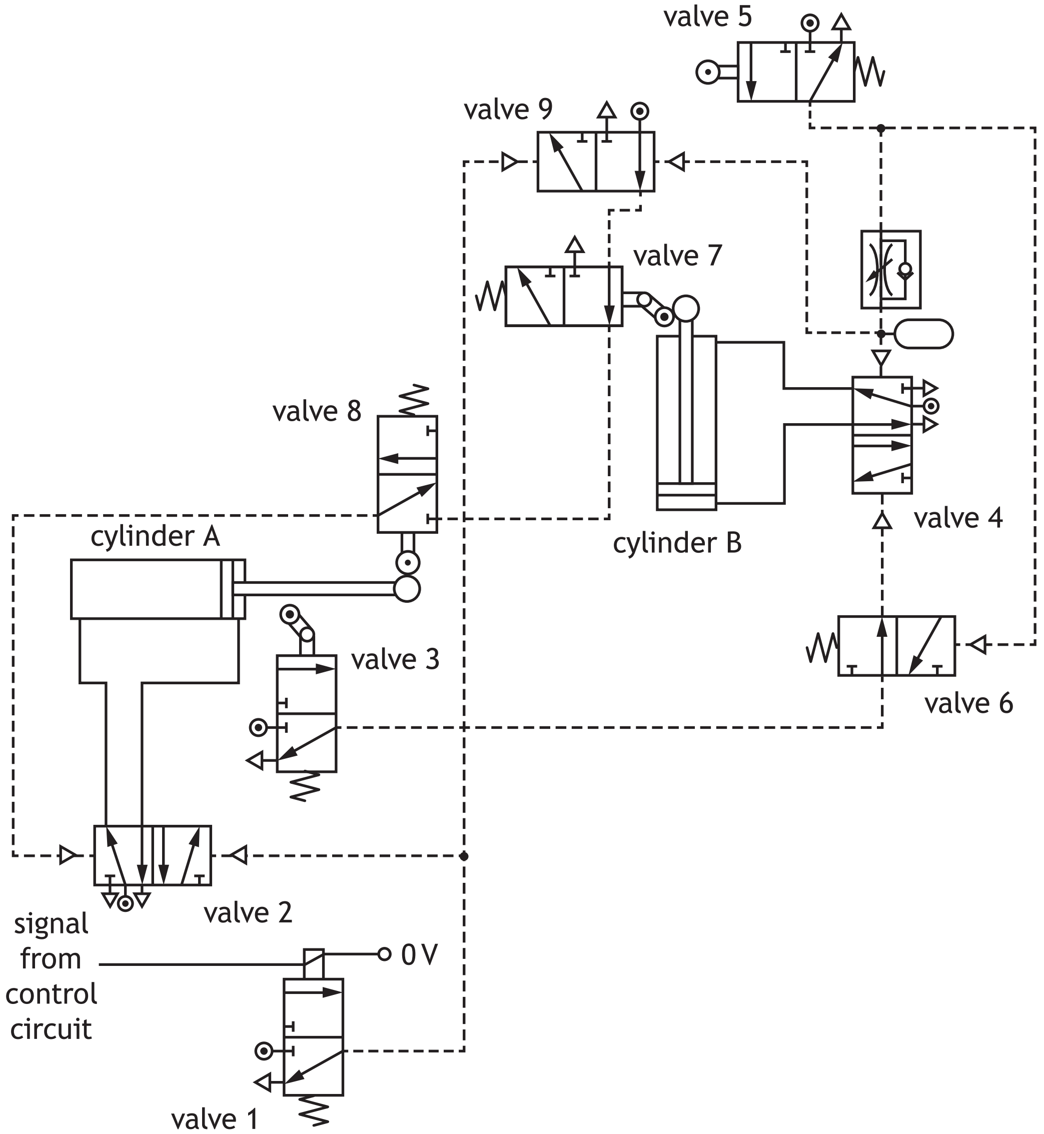
INPUT	PIN	OUTPUT
	7	motor
	6	brake
override switch (released = 0)	1	
emergency stop (pressed = 1)	0	

11. (continued)

(b) Complete, with reference to the specification and input/output table shown opposite, the flowchart for the control of the motor. **13**



12. A pneumatic system will be used in a manufacturing process for holding material in place and then moving it along the production line. The system diagram is shown below.



(a) Describe, making reference to the diagram above, the operation of the pneumatic circuit. **7**

When valve 1 is actuated,

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12. (a) (continued)

[Turn over

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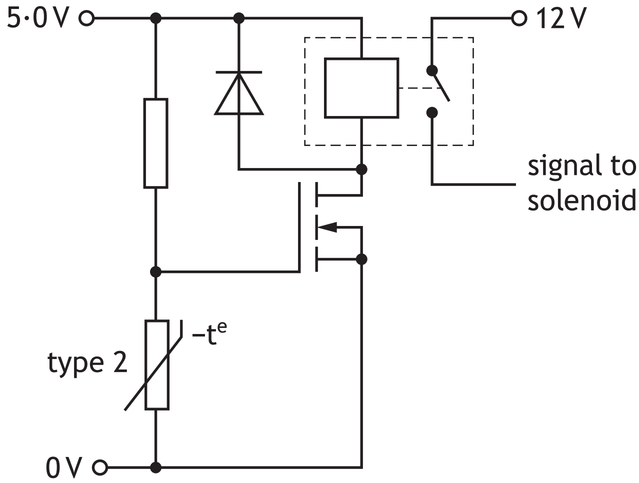
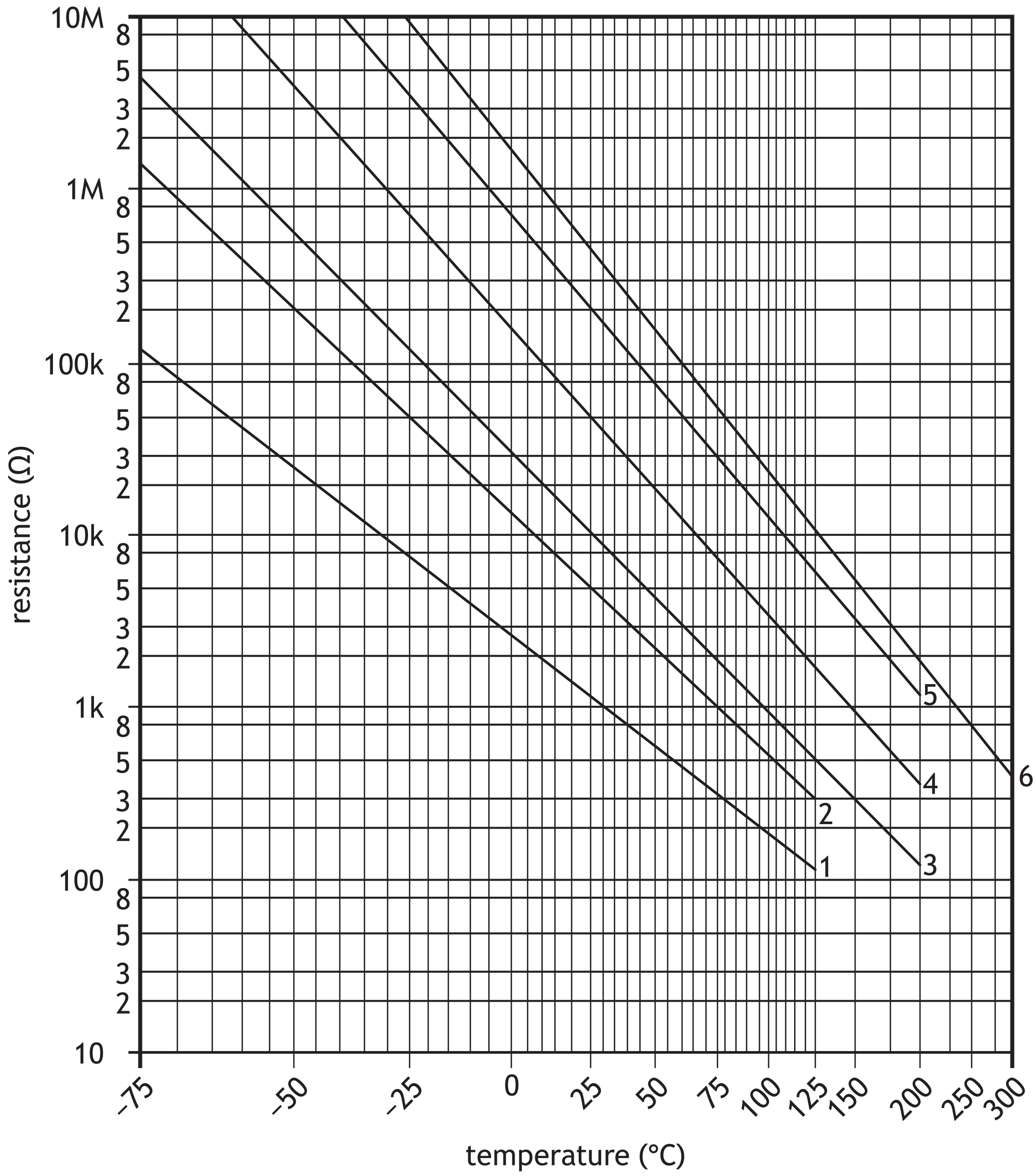
12. (continued)

A diagram of the control circuit for the solenoid is shown below. The MOSFET switches on when the gate voltage reaches 3·2 V. This happens when the thermistor is at 85 °C.





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(b) Calculate, with reference to the graph opposite, the resistance of the fixed resistor to produce a gate voltage of 3·2 V. **3**

The next stage of the manufacturing process requires a drive system.

(c) Describe one skill and one piece of knowledge a **mechanical engineer** requires to design the drive system. **2**

Skill ______________________________

____

____

____

Knowledge ______________________________

____

____

____

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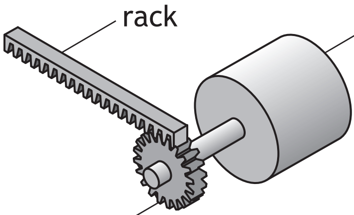
12. (continued)

Part of the design involves rotary motion, from a motor, transforming into linear motion.



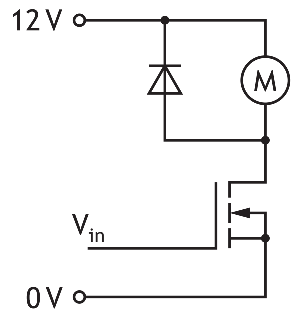
The pinion gear has 24 teeth and the pitch of the teeth on the rack is 3·0 mm.

The rack is required to move 2·75 m in three seconds.

(d) Calculate the required speed of the motor. **3**

12. (continued)

Part of the circuit controlling the motor is shown below.



The motor has a **rating** of 12 V and 8·5 W.

When the motor is switched on the MOSFET has a resistance of 0·65 Ω.

(e) Calculate the MOSFET drain current. **3**

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ADDITIONAL SPACE FOR ANSWERS

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