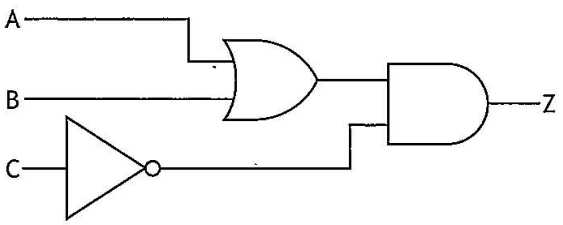
Candidate 2 evidence

MARKS | DO NOT WRITE IN THIS MARGIN

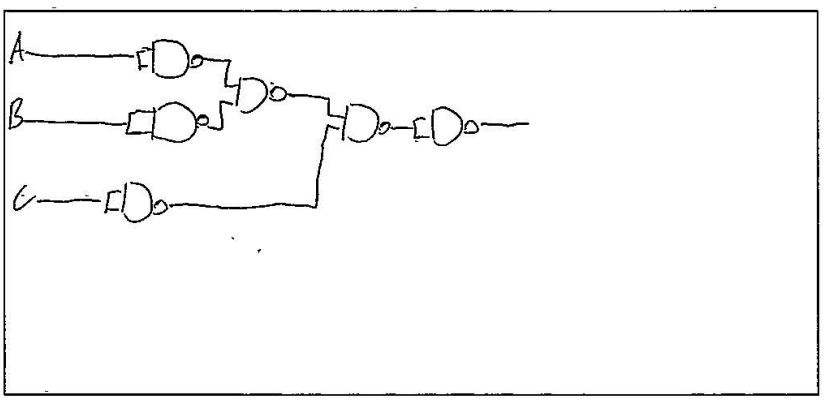
SECTION 1 — 20 marks

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

The use of the NAND Gate equivalent allows the engineer to use 1 or 2 NAND chips, whereas for the original circuit 3 chips would be required, therefore space is conserved and money is saved during production.

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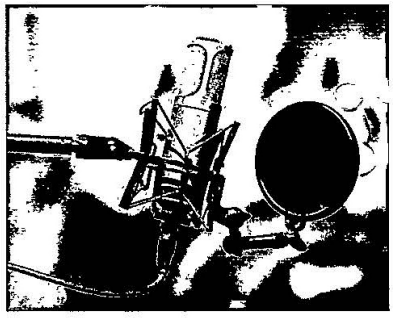
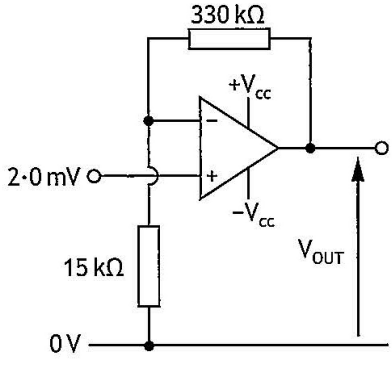
2. A microphone in a recording studio produces a maximum output signal of 2·0 mV.



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**

$V_o = \left(1 + \frac{R_f}{R_i}\right) \times V_i$

$V_o = \left(1 + \frac{330}{15}\right) \times 0.002$

$= 0.046\ V$

$= 46\ mV$

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2. (continued)

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

The gain could be increased by either making Ri a smaller resistance or Rf a larger resistance.

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

A summing amplifier.

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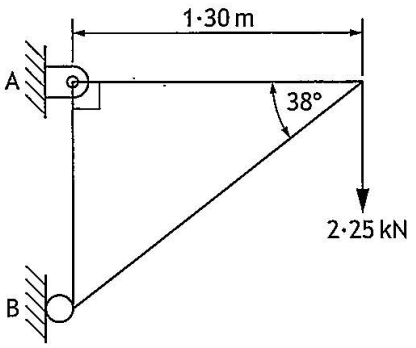
3. A frame structure is shown below.



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

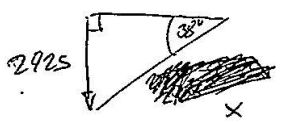
2.25×1.3

$= 2.925 kN$

$= 2925 N$

$\Sigma CWM = \Sigma ACWM$.

SOH CAH TOA



$\sin 38° = \frac{2925}{x}$

$x = \frac{2925}{\sin 38}$

$= 4750.987...$

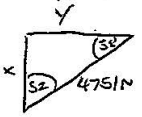
$\approx 4751 N$ (4sf)

$180 - (90 + 38)$

$= 52°$

SOH CAH TOA

$\sin 52 = \frac{Y}{4751}$



$Y = 3743.8...$

$= 3744 N$ to the right

SOH CAH TOA

$\cos 52 = \frac{x}{4751}$

$\cos 52 \times 4751 = 2925 N$ (4sf)

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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);
}
}
```

MARKS | DO NOT WRITE IN THIS MARGIN

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

Arduino : if(Pressure >=100){

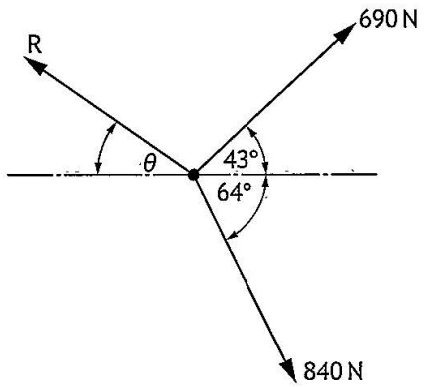
Correction 3

Arduin : for(int counter =1;

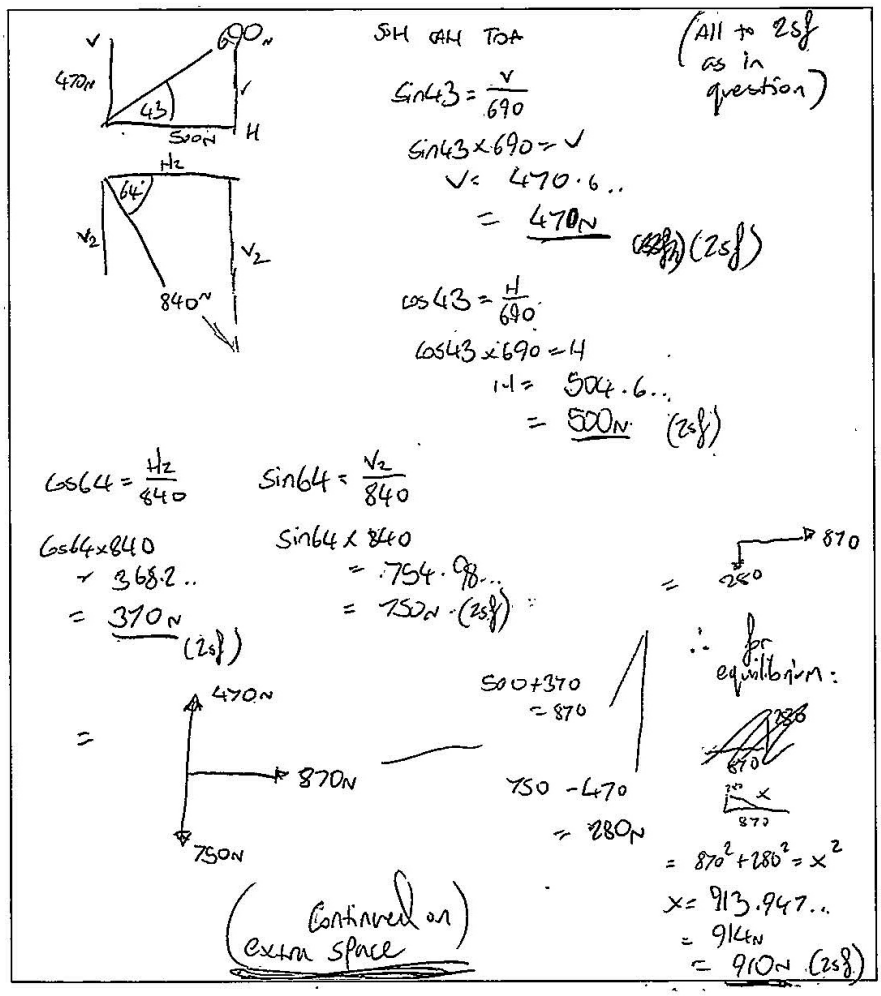
[Turn over

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

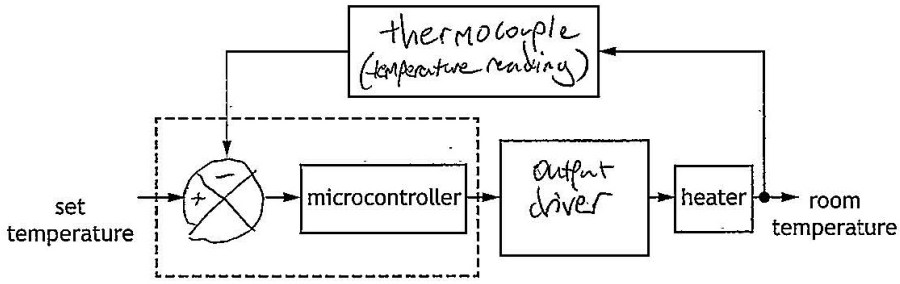


MARKS | DO NOT WRITE IN THIS MARGIN

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



[Turn over

SECTION 2 — 90 marks

Attempt ALL questions

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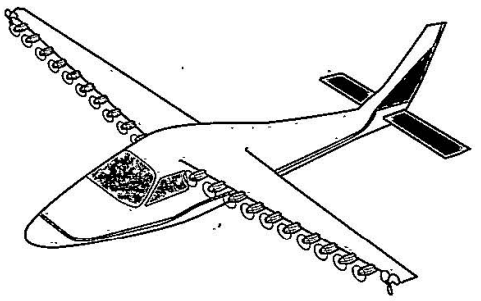
7. A prototype of an electrically powered aeroplane is being developed and tested by a team of engineers.



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**

~~$T = F \times r$~~

~~$P = FV$~~

$P = 2\pi n T$

$18000 = 2 \times \pi \times n \times 23$

$9000 = \pi n 23$, $\frac{9000}{23\pi} = n$, $n = 124.55...$

$= 125$ revs per second.

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**

~~320MJ = 100%~~

22×18000

$= 396000$ W

$P = \frac{E}{t}$ $t = \frac{E}{P}$, $\frac{320 \times 10^6}{396000}$

$= 808.08...$

$= 808$ s, $= 13$ mins 28 s

$808 = 100\%$

$1\% = 8.08$

$73\% = 589.8...$

$= 590$ s

$= 9$ mins 50 s

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 The plane can make longer journeys on a single charge, requiring it to overall be charged less, lowering the cost of running them, as less electricity is used.

Social If the plane can travel long distances people will be more inclined to use them, allowing more people to be able to travel longer distances to visit others.

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 m s^{-1} to 25 m s^{-1}. **3**

$m = 4800$

efficiency $= 64\%$

$95 - 25 = 70 ms^{-1}$

$E_k = \frac{1}{2}mv^2$

$E_k = \frac{1}{2} \times 4800 \times 70$

$= 168\,000$ J

$100\% = 168$ kJ

$1\% = 1.68$ kJ

$64\% = 107.52$ kJ

[Turn over

MARKS | DO NOT WRITE IN THIS MARGIN

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

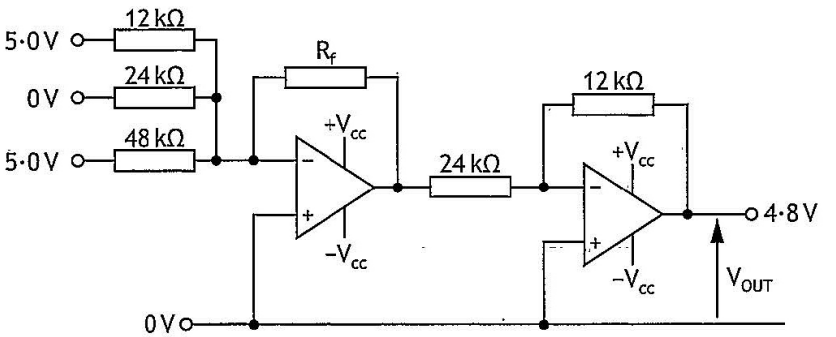
The more friction there is in the propellor, the more force that is required to overcome the friction, causing wasted energy for the motors. Also, with more friction more heat is generated, meaning energy is lost as heat and the efficiency is made worse.

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

$V_{out} = -\frac{R_f}{R_i} \times V_i$

$V_{out} = 4{\cdot}8\text{v}$

$V_o = -\frac{R_f}{R_i} \times V_i$

$\frac{V_o}{V_i} = -\frac{R_f}{R_i}$

$\frac{4{\cdot}8}{V_i} = -\frac{R}{24}$

$\frac{4{\cdot}8}{V_i} = -\frac{1}{2}$

$V_i = \frac{4{\cdot}8}{-0{\cdot}5}$

$V_i = -9{\cdot}6\text{v}$

$\therefore$ V_{out} of first op amp = (−9·6v)

$V_{out} = -\frac{R_f}{R_i} \times 5\text{v}$

$-9{\cdot}6 = -\frac{R_f}{R_i} \times 5\text{v}$

$\frac{1}{R_i} = \frac{1}{12} + \frac{1}{48}$

$R_i = 9{\cdot}6\text{k}\Omega$

$-9{\cdot}6 = -\frac{R_f}{9{\cdot}6} \times 5$

$\frac{-9{\cdot}6}{5} = -\frac{R_f}{9{\cdot}6}$

$\frac{9{\cdot}6}{5} = \frac{R_f}{9{\cdot}6}$, $R_f = 18{\cdot}4\text{k}\Omega$ (1dp)

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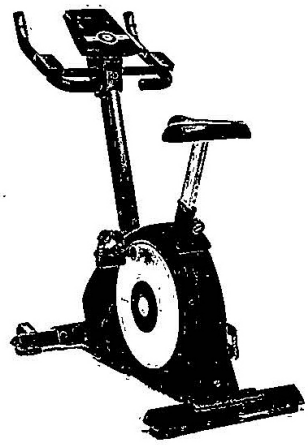
8. An exercise bike has an electronic monitoring system to tell users if they are pedalling within a set range of speeds.

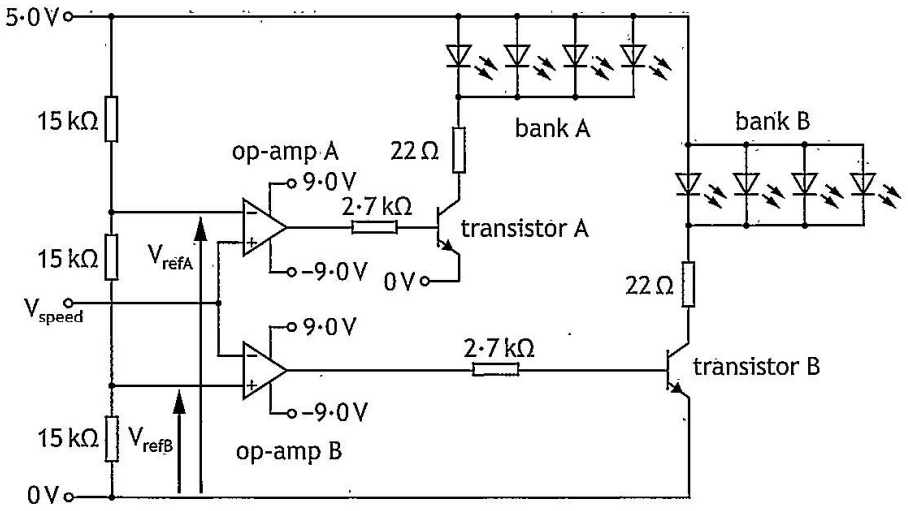


A speed sensor produces an output voltage, V_{speed}, in proportion to the speed of the pedals.

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.



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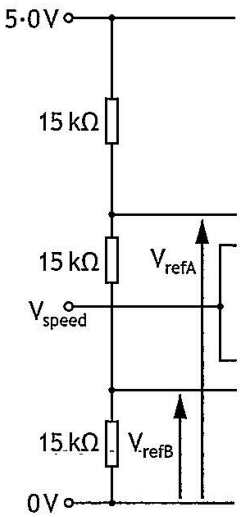
8. (continued)



A section of the circuit is shown above.

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

$V_1 = \frac{R_1}{R_T} \times V_S$

$R_1 = 15k + 15k$

$= 30k$

$V_1 = \frac{30}{45} \times 5$

$= 3.33V$ (calc)

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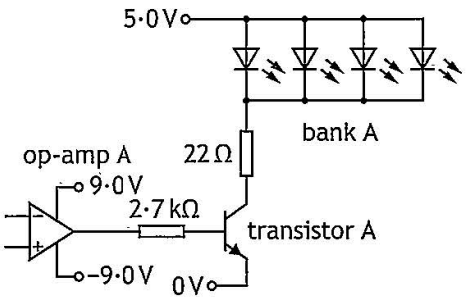
8. (continued)

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

$I = \frac{V}{R}$

$V = 0.7$

$R = 2700$

$I = \frac{0.7}{2700}$

$I = 0.26\text{mA}$ (2dp)

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

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

0.26×140

$= 36.4\text{mA}$

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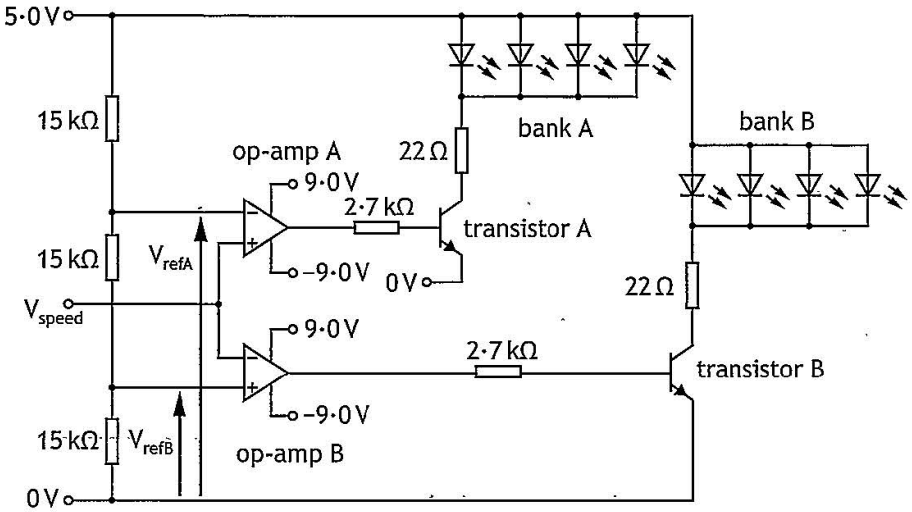
8. (continued)



(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**

As the voltage from the speed sensor rises, op-amp A uses the voltage as a reference voltage, and op-amp B uses it as the input voltage. Once the speed voltage is greater than the 3.33v of VrefA, op-amp A saturates positively which activates the transistor allowing current to flow and turning bank A on. VrefB is 1.66v, so when ~~op-amp~~ Vspeed is greater than 1.06v the op-amp saturates negatively turning off transistor B. So as Vspeed rises from zero, first op-amp B saturates negatively and bank B turns off, and once Vspeed has increased further op-amp A saturates positively and bank A turns on when transistor A changes.

MARKS | DO NOT WRITE IN THIS MARGIN

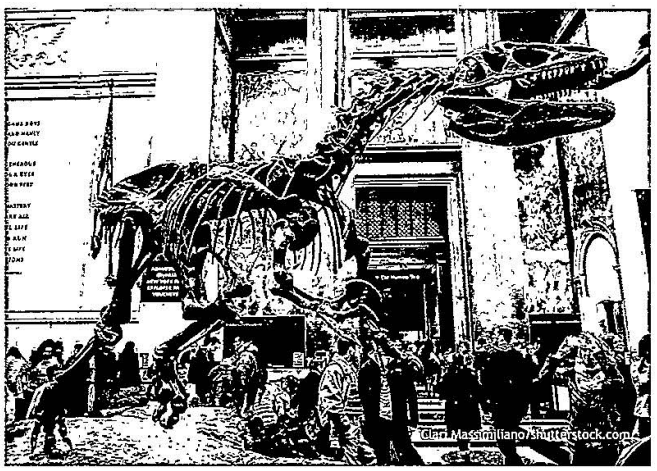
8. (continued)

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

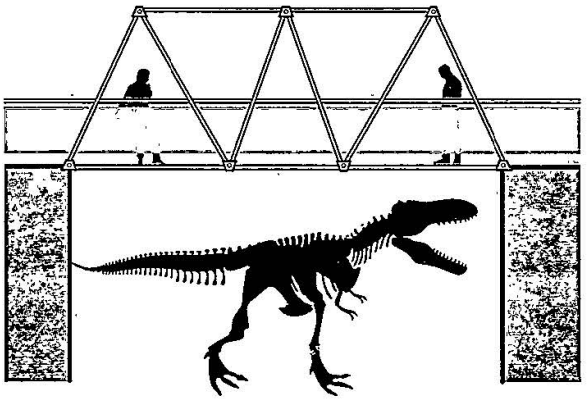
The control circuit could replace the top 15kΩ resistor with a variable resistor. This would allow the voltages for op-amp A & B to be adjusted, changing the V_{speed} at which they saturate negatively and positively. ~~This will also allow the pattern of switching to remain the same~~ Alternatively, the two 2.7kΩ resistors leading to the transistors could be replaced with variable resistors, allowing people to adjust the current flowing into them.

DO NOT WRITE IN THIS MARGIN

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.



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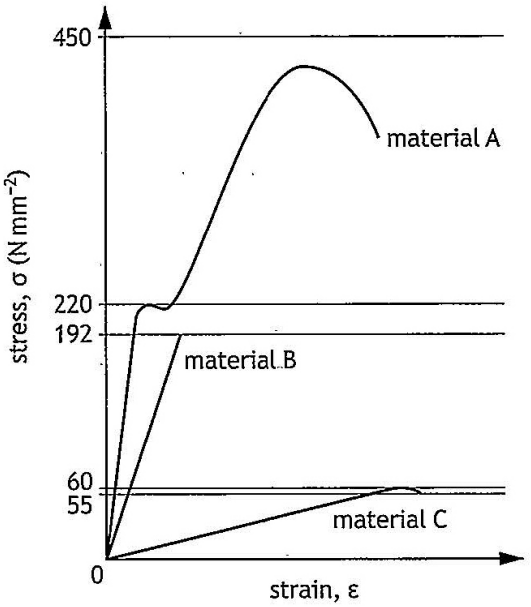
9. (continued)

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

Material B is less ductile than both material A and C. Material B is ~~more elastic than Ma~~ less elastic than material C, but it can withstand more pressure. Material B is also more brittle than both Material C & A.

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

Material A Mild Steel

Material C Plastic, ABS polycarbonate

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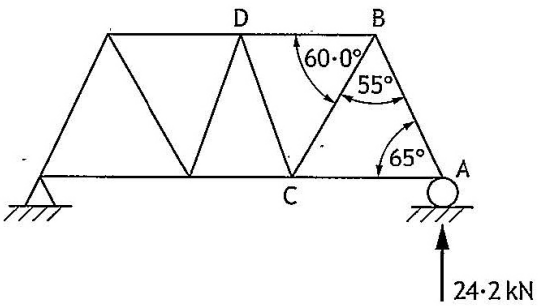
9. (continued)

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. 7

Complete the table below.

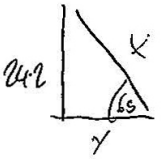
Show all working and final units on the page opposite.

Member	Magnitude	Nature
AB	26.7 kN	STRUT
AC	11·3kN	TIE
BC	27·9kN	STRUT
BD	11·3kN	STRUT

DO NOT WRITE IN THIS MARGIN

9. (b) (continued)

Space for working



SOH CAH TOA

$\sin 65 = \frac{24.2}{x}$

$\frac{24.2}{\sin 65} = x$

$x = 26.7$ KN

$\therefore AB = 26.7$KN

$\cos 65 = \frac{y}{26.7}$

$\cos 65 \times 26.7 = y$

$y = 11.283...$

$= 11.3$kN (1dp)

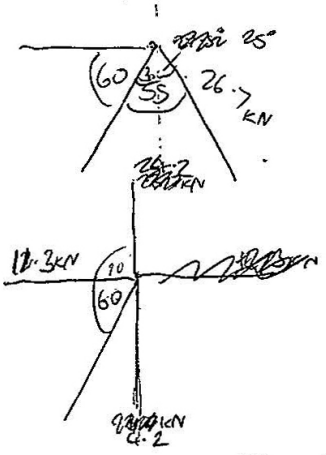
$\therefore AC = 11.3$kN

AB = STRUT

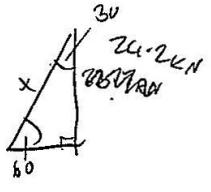
AC = TIE

BC = STRUT

BD = STRUT



$60 + 90 = 150°$

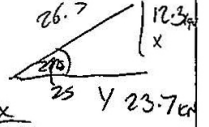


SOH CAH TOA

$\sin 60 = \frac{24.2}{x}$

$\frac{24.2}{\sin 60} = x$

$x = 27.94... = 27.9$kN $= BC$



SOH CAH TOA

$\sin 27.5 = \frac{x}{26.7}$

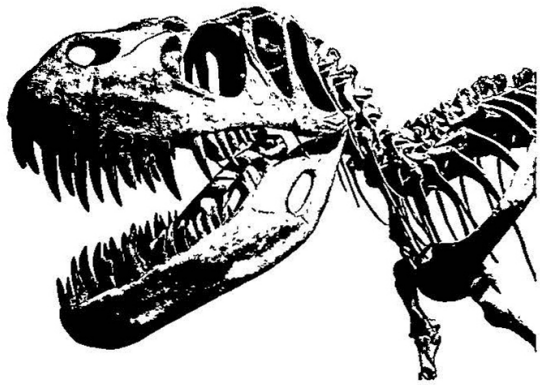
$- 11.3$kN $= BD$

$\cos 27.5 = \frac{y}{26.7}$

$= 24.2$kN

MARKS | DO NOT WRITE IN THIS MARGIN

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

Aluminium alloy = 70 kN mm^{-2} Youngs Modulus

$E = \frac{\sigma}{\epsilon}$

$\sigma = \frac{F}{A}$ $\sigma =$

Ultimate load = 300 N mm^{-2} $FOS = \frac{\text{Ultimate}}{\text{Safe}}$

$A = \pi r^2$ $\frac{660}{300} = 2.2$

$8/2 = 4 = r$

$A = \pi \times 4^2$

$= 50.265...$

$= 50.3 \text{ mm}^2$

$\sigma = \frac{F}{A}$

$\sigma = \frac{33200}{50.3} =$ 660 N mm^{-2}

MARKS | DO NOT WRITE IN THIS MARGIN

10. (a) (continued)

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

This factor of safety is quite low, especially if this is a design to be used around the public.

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

$E = \frac{\sigma}{\varepsilon}$

$E = 110\ kNmm^{-2}$

$\sigma = \frac{F}{A}, \quad \sigma = \frac{33200}{491}$

$= 67.62\ Nmm^{-2}$

$= 68\ Nmm^{-2}$ (2sf)

$110000 = \frac{68}{\varepsilon}$

$\frac{68}{110000} = \varepsilon$

$\varepsilon = 0.000618...$

$= 6.2 \times 10^{-4}$

$\varepsilon = \frac{\Delta L}{L}$

$0.00062 = \frac{\Delta L}{0.78}$

$0.00062 \times 0.78 = \Delta L$

$\Delta L = 0.00048...\ m$

$= 0.48\ mm$

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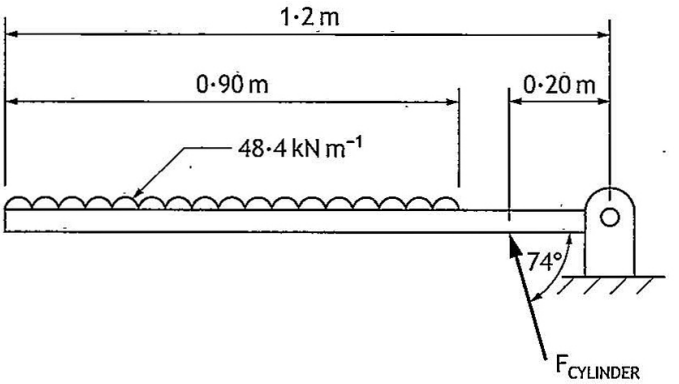
10. (continued)

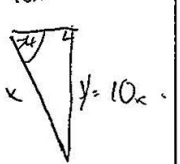
After testing, the pneumatic cylinder is repositioned to move a hinged beam in the jaw of the dinosaur as shown below.

The uniformly distributed load of the jaw is 48·4 kN m^{-1}.



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

SOH CAH TOA



$\sin 74 = \frac{y}{x}$

$\frac{48.4\ m}{0.9} = 53.8\ kN$ @ $\left(\frac{1}{2} \times 0.9\right) + 0.3$

$E_{cwm} = E_{acwm}$ $= 0.45\ m$

$(53.8 \times 0.75) = \Sigma (F_C \sin 74 \times 0.2)$

$\frac{40.35_{kN}}{0.2} = F_C \times \sin 74$

$= \frac{201.75}{\sin 74} = F_C$, $F_C = 209.9_{kN}$

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

53.8_{kN} @ 0.75_m $= \Sigma (53.8 \times 0.75) = 40.35_{kN}$

209.9_{kN} @ $0.2m$ $= (209.9 \times 0.2) = 41.98$

$41.98_{kN} - 40.35_{kN} = 1.63_{kN}$

$E_{acwm} - E_{cwm}$

$= 1.63_{kN}$ anticlockwise / downwards

11.

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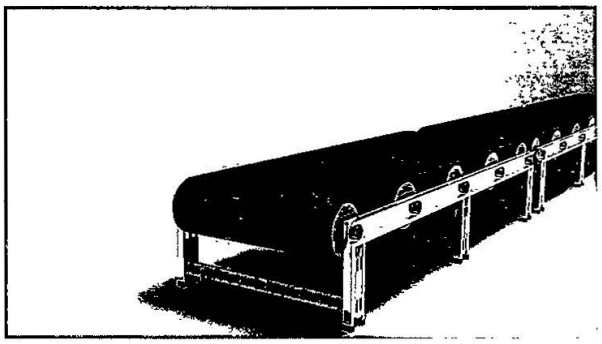

A proposed design for the operation of a conveyor belt motor has the following specification.

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

$M = \overline{A} \cdot (B \cdot \overline{C})$ + D

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	

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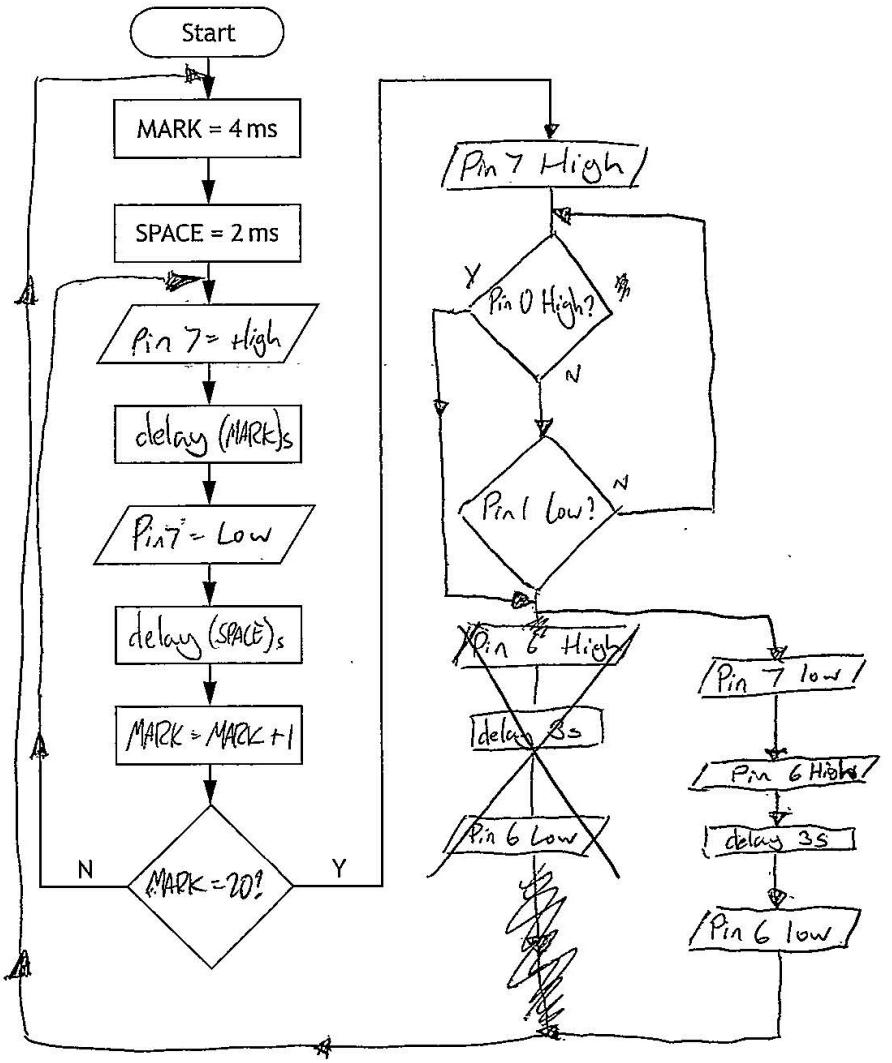
11. (continued)

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



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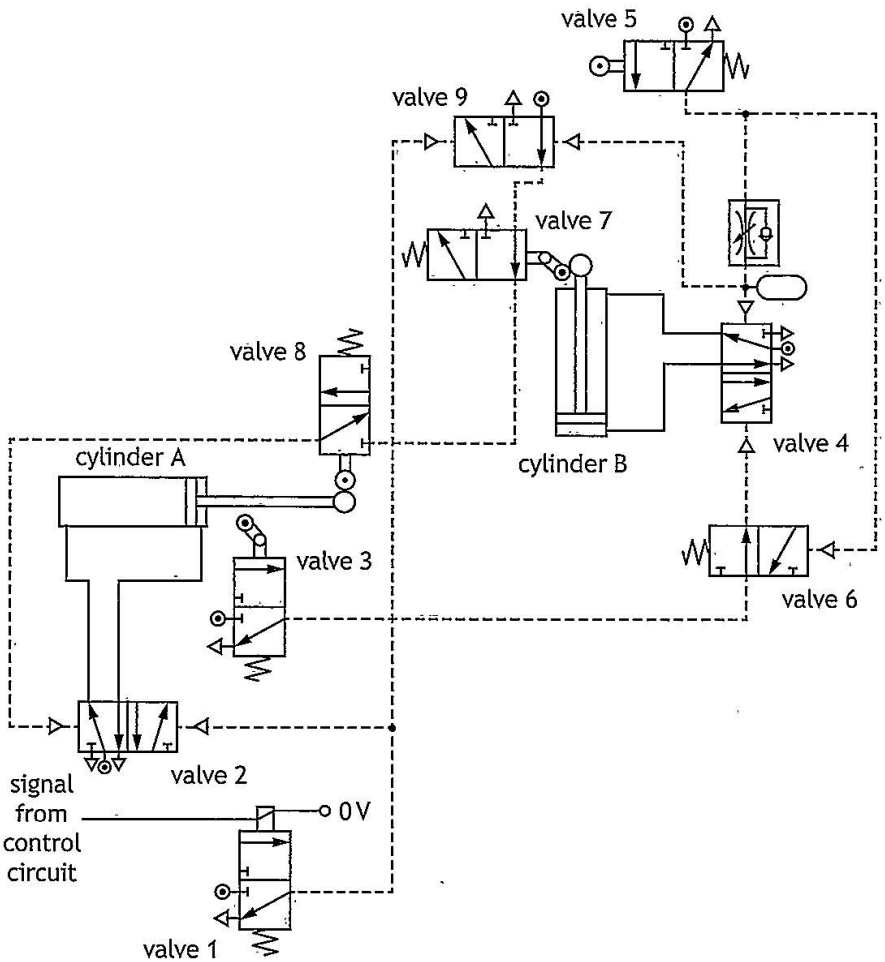
12. A pneumatic system will be used in a manufacturing process for holding material in place and then moving it along the production line. The system diagram is shown below.



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

When valve 1 is actuated,

Pilot air flows to valve 2 and valve 9. Valve 9 changes state, stopping pilot air flow to valves 7 and 8. Valve 2 changes state, causing cylinder A to instroke. It actuates valve 3, which

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12. (a) (continued)

sends pilot air to valve 6, actuating valve 4 causing cylinder B to outstroke. cylinder B actuates valve 5, which sends pilot air through a uni-directional restrictor into a reservoir, and to valve 6. valve 6 then changes state, stopping pilot air flow to valve 4. The time delay created with the reservoir then actuates valves 4 and 9. 4 changes state causing cylinder B to instroke, and 9 changes state restoring pilot air flow to valves 7 and 8. Cylinder B actuates valve 7 as it instrokes, sending pilot air through valve 8 to valve 2, which changes state causing cylinder A to outstroke again. This then actuates valve 8, and the whole circuit is reset and ready to be used again.

[Turn over

12. (continued)

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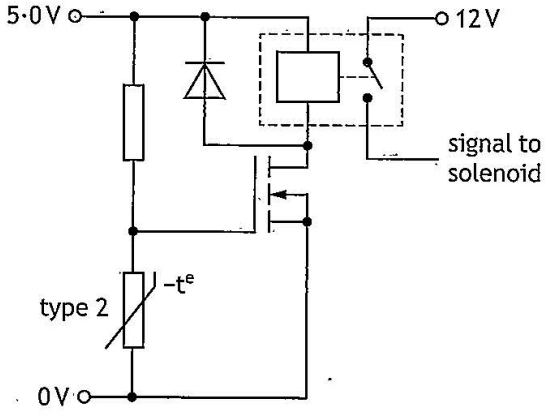
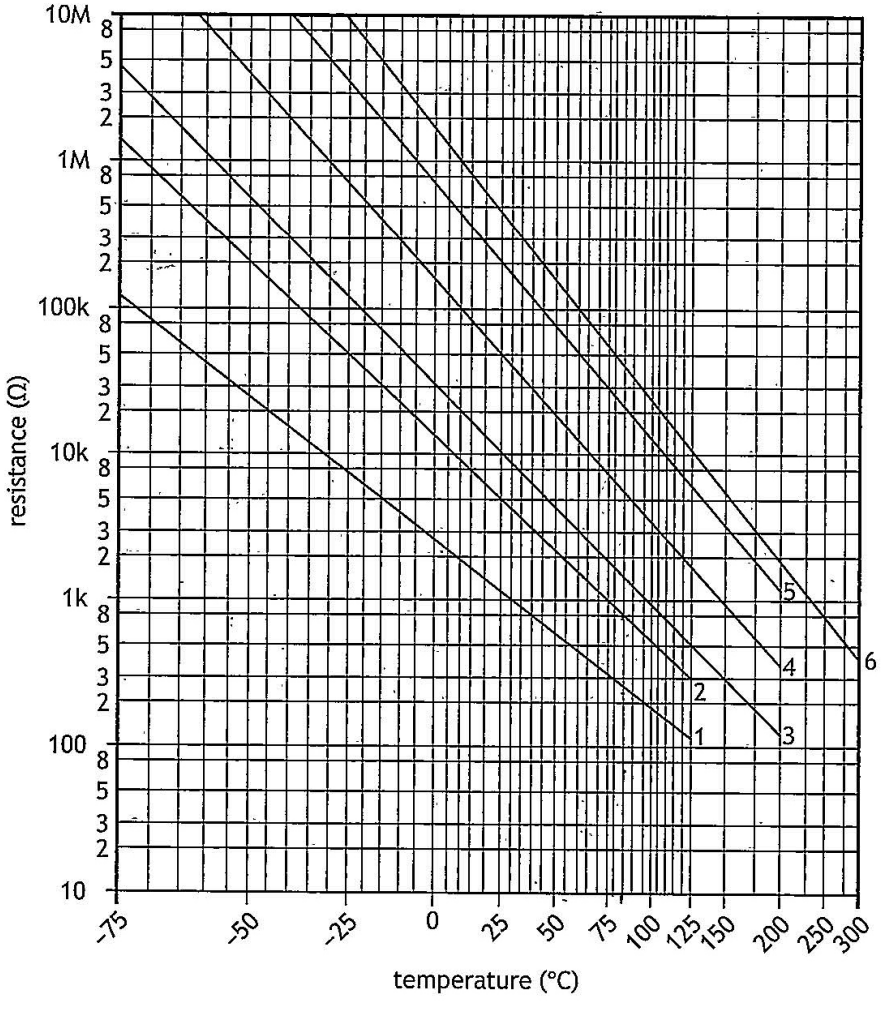
A diagram of the control circuit for the solenoid is shown below. The MOSFET switches on when the gate voltage reaches 3·2 V. This happens when the thermistor is at 85 °C.





12. (continued)

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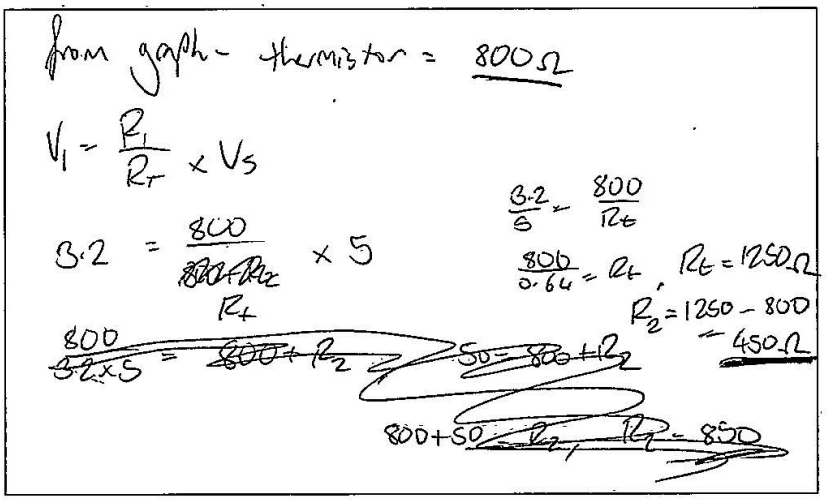
(b) Calculate, with reference to the graph opposite, the resistance of the fixed resistor to produce a gate voltage of 3·2 V. **3**



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 The skill to be able to calculate the required capabilities of the drive system to allow for the selection of parts.

Knowledge To have knowledge of the different available drive systems and parts to be able to select those that will produce the required output.

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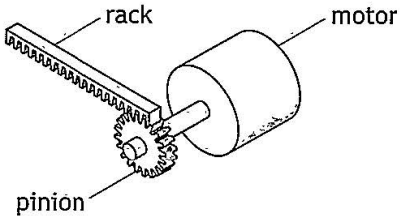
12. (continued)

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

3mm × 24
= 72mm
= 7.2cm per rotation

$\frac{275}{7.2}$ = 38.2 (1dp) rotations total required

$\frac{38.2}{3}$ = 12.73 rotations per second.
= 13 rotations per second (2sf)

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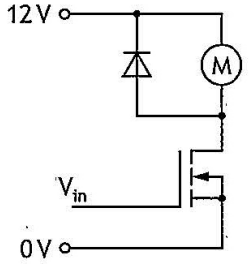
12. (continued)

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

$P = IV$

$8.5 = I \times 12$

$\frac{8.5}{12} = I$

$I = 0.7083...$

$= 0.71\,A$ (2dp)

$I = \frac{V}{R}$

$I = \frac{12}{0.65}$

$R_m = \frac{V}{I}$

$R_m = \frac{12}{0.71}$

$R_m = 16.9\,\Omega$

$16.9 + 0.65$

$= 17.55\,\Omega$

$I = \frac{V}{R}$

$I = \frac{12}{17.55}$

$I = 0.683...$

$= 0.68\,A$ (2sf)

[END OF QUESTION PAPER]

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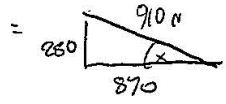
ADDITIONAL SPACE FOR ANSWERS

5)



SOH CAH TOA

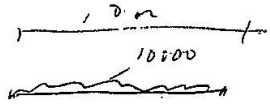
$\sin x^\circ = \frac{280}{910}$

$x^\circ = \sin^{-1}\left(\frac{280}{910}\right)$

$x^\circ = 17.92...$

$= 18^\circ$ (2sf)

= 910 N, at 18°



1, 8, 9, 10a