Candidate 1 evidence

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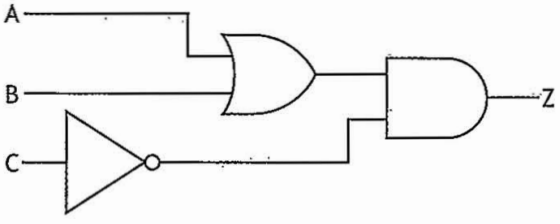
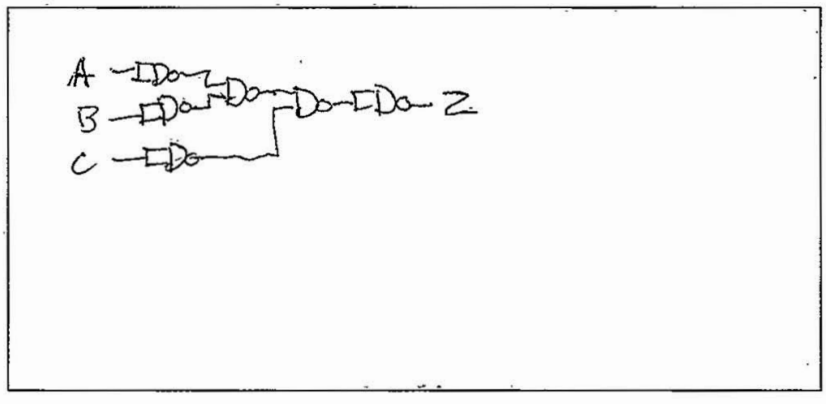
SECTION 1 — 20 marks

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 NAND equivalent circuit could be made using only one or two IC's, while the original would require three seperate ones, thus it is more cost effective to use NAND equivalents as less IC's are required.

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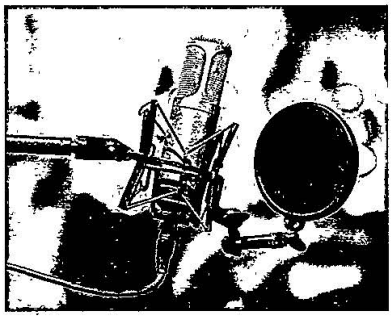
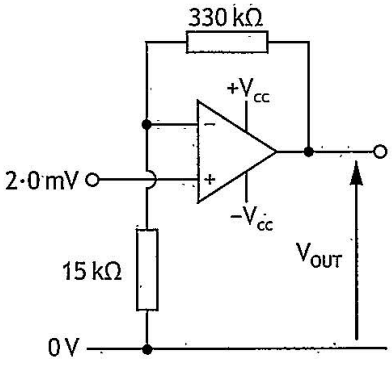
2. A microphone in a recording studio produces a maximum output signal of 2·0 mV.



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

$V_o = \left(1 + \frac{R_f}{R_1}\right) V_i$

$= 1 + \frac{330}{15} \times 2 \times 10^{-3}$

$= 0.046\ V$

$= 46\ mV$

MARKS | DO NOT WRITE IN THIS MARGIN

2. (continued)

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

The gain could be increased by either increasing the resistance of the feedback resistor, or decreasing the resistance of the input resistor (15kΩ).

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

Summing Amplifier.

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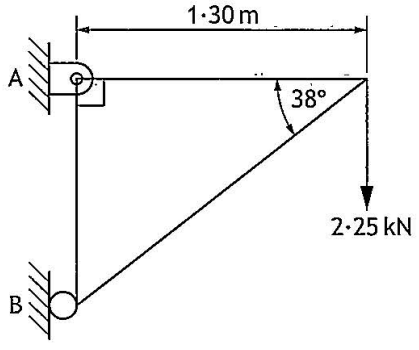
3. A frame structure is shown below.



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

$\tan\theta = \frac{O}{A}$

$\tan 38 = \frac{O}{1.3}$

$O = 1.016\ m$

$\Sigma M = 0$

$B \times 1.016 = 2.25 \times 1.3$

$B \times 1.016 = 2.925$

$B = 2.88\ kN \rightarrow$ (horizontal)

DO NOT WRITE IN THIS MARGIN

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

if (Pressure >= 100){

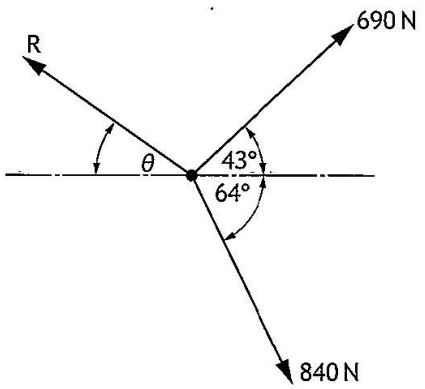
Correction 3

digitalWrite(Pump, LOW);

[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

$\Sigma f_V = 0$

$R_V + 690\sin 43 = 840\sin 64$

$R_V + 470.5789 = 754.987$

$R_V = 284.41$

$\Sigma f_H = 0$

$R_H = 690\cos 63 + 840\cos 64$

$= 872.866$

$R = \sqrt{R_V^2 + R_H^2}$

$= \sqrt{284.4^2 + 872.9^2}$

$= 918.0326$

$= 918\ N$

$\tan\theta = \frac{o}{a}$

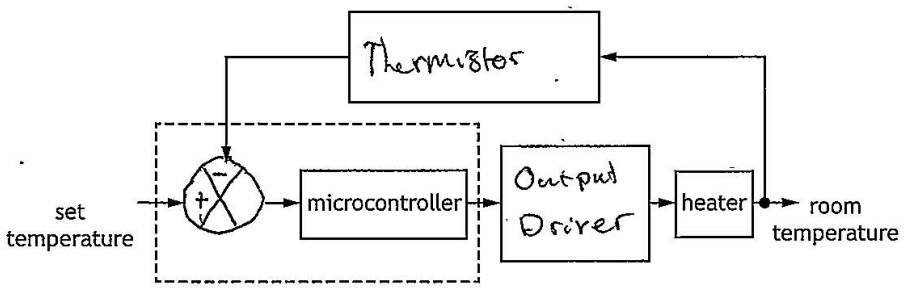
$\theta = \tan^{-1}\frac{284.41}{872.866} = 18.047 = 18°$

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



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SECTION 2 — 90 marks

Attempt ALL questions

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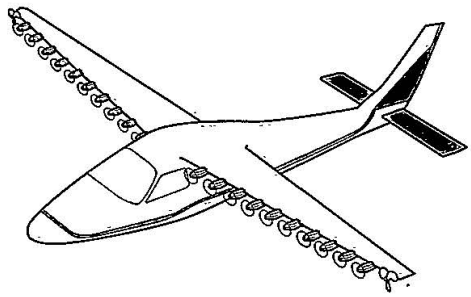
7. A prototype of an electrically powered aeroplane is being developed and tested by a team of engineers.



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

$P = 2\pi nT$

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

$n = 124.886 \text{ revs } s^{-1}$

$= 125 \text{ revs } s^{-1}$

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

$\eta = \frac{\text{out}}{\text{in}} \times 100$

$0.73 = \frac{18000 \times 22 \times t}{320 \times 10^6}$

$23360000 = 396000\,t$

$t = 989.899 \text{ s} = 989.9 \text{ s}$

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 By improving efficiency less energy will be required to power the plane, therefore less money will be spent on powering the plane. (supplying the energy)

Social People will feel happy and more inclined to use the plane, knowing that requires little energy so it helps towards the environment.

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**

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

$= \frac{1}{2} \times 4800 \times 95^2$

$= 21660000\ J$

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

$= \frac{1}{2} \times 4800 \times 25^2$

$= 1500000\ J$

$21660000 - 1500000$

$= 20160000\ J$

$\eta = \frac{out}{in} \times 100$

$0.64 = \frac{out}{20160000}$

$out = 12902400\ J$

$= 12.9\ MJ$

[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

By reducing friction in the bearings, the propellers will be made more energy efficient, as less energy will be lost due to heat and sound energy from friction. Friction also needs to be minimized to reduce the amount of wear on the bearings, so they have to be replaced less often, which is more cost effective.

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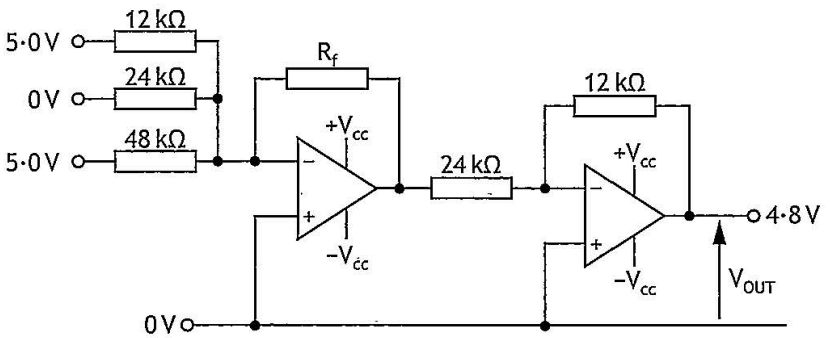
7. (continued)

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**

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

$4.8 = -\frac{12}{24} \times V_i$

$V_i = -9.6\ V$

$V_o = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$

$-9.6 = -R_f\left(\frac{5}{12000} + \frac{0}{24000} + \frac{5}{168000}\right)$

$-9.6 = -R_f\left(5.21 \times 10^{-4}\right)$

$-18432 = -R_f$

$R_f = 18432\ \Omega$

$= 18000\ \Omega = 18\ k\Omega$

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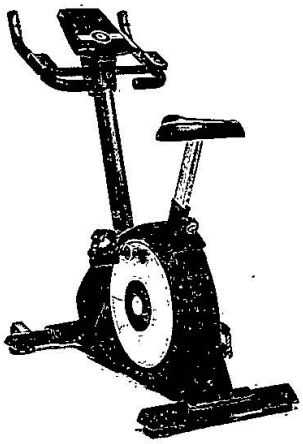
8. An exercise bike has an electronic monitoring system to tell users if they are pedalling within a set range of speeds.

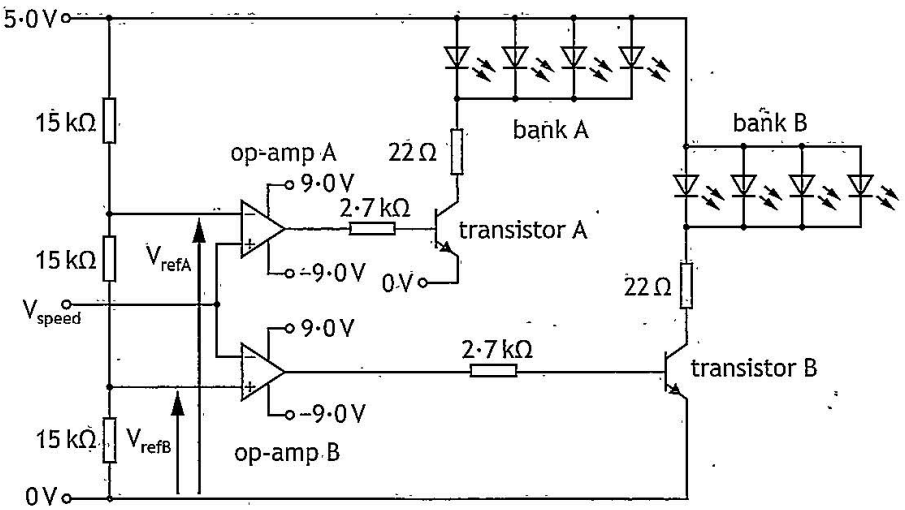


A speed sensor produces an output voltage, V_{speed}, in proportion to the speed of the pedals.

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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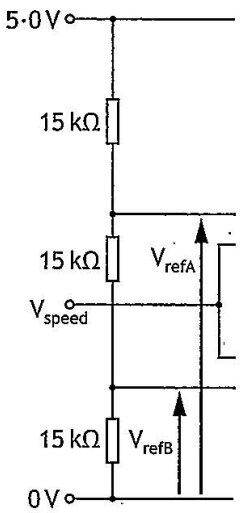
8. (continued)



A section of the circuit is shown above.

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

$V_{refA} = \frac{R_1}{R_1+R_2+R_3} \times V_S$

$= \frac{15+15}{15+15+15} \times 5$

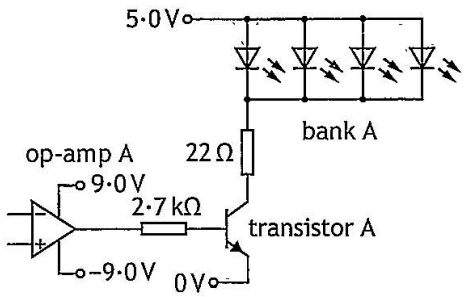
$= 3.33\,V$

[Turn over

MARKS | DO NOT WRITE IN THIS MARGIN

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

0.85x9 V = IR
= 7.65 V 6.95 = I x 2700
7.65 - 0.7 I = 2.574 x 10^{-3} A
= 6.95 V = 2.57 mA

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

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

$h_{FE} = \frac{I_c}{I_b}$

$140 = \frac{I_c}{2.574 \times 10^{-3}}$

$I_c = 0.36$ A

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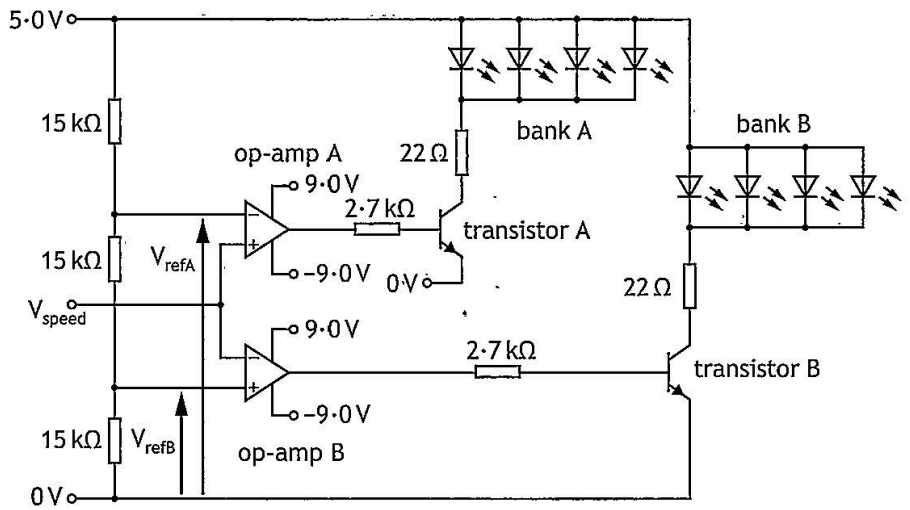
8. (continued)



(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**

When the voltage V_{speed} rises above 1.67 V, op-amp B saturates negatively, thus switching off transistor B, and the LEDs of bank B switch off. Then, when V_{speed} rises above 3.33 V, op-amp A saturates positively, which switches on transistor A, and the LEDs of bank A switch on.

Between 0 - 1.67 V bank B is on, between 1.67 - 3.33 V neither bank of LEDs are on, and between 3.33 - 5 V bank A is on.

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

Replace the fixed resistors (of 15kΩ) with potentiometers (or variable resistors), thus allowing users to adjust the reference voltages so the LEDs switch on at different speeds.

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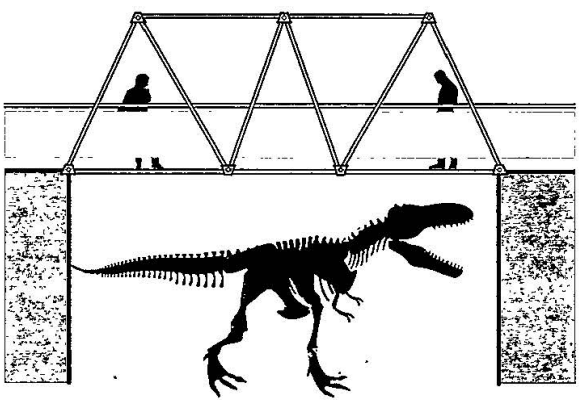
9. A team of engineers is asked to design a walkway over a dinosaur exhibit for a natural history museum.

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



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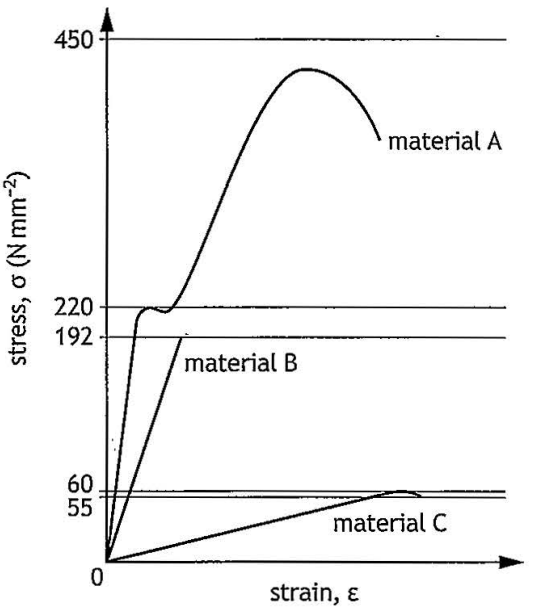
9. (continued)

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 very brittle compared to A, as once it's yield point has been surpassed, it breaks, while material A will act in a plastic manner, deforming before breaking. Material A also has a higher yield point, so it will act plastic under greater stress than B, while B has more toughness than C, as its yield point is higher.

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

Material A Mild Steel.

Material C Plastic, ABC polycarbonate.

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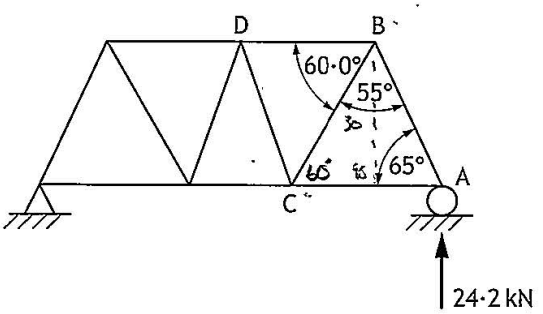
9. (continued)

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	11.28 kN	TIE
BC	27.94 kN	TIE
BD	23.25 kN	STRUT

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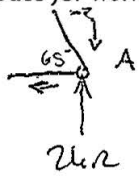
9. (b) (continued)

Space for working



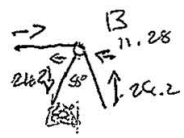
$AB = \frac{24.2}{\sin 65}$

$= 26.7017$ kN

$= 26.7$ kN strut

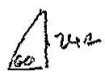
$AC = \frac{24.2}{\tan 65}$

$= 11.28$ kN tie



$BC = \frac{24.2}{\sin 66}$

$= 27.94$ kN tie



$\frac{24.2}{\tan 66} = 13.97$

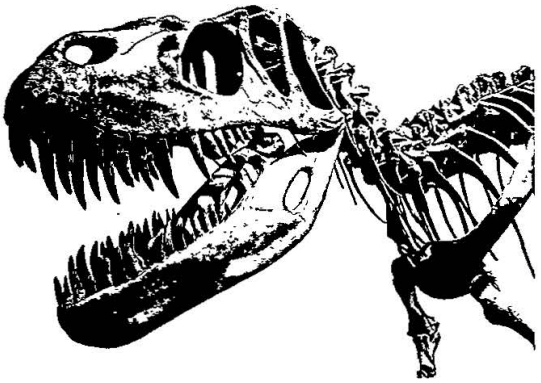
$13.97 + 11.28$

$= 25.25$ kN

$\therefore BD = 25.25$ kN strut

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

$A = \pi r^2$

$= \pi \times 4^2$

$= 50.27 \text{ mm}^2$

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

$= \frac{33200}{50.27}$

$= 660.49 \text{ Nmm}^{-2}$

$FoS = \frac{\text{ultimate}}{\text{safe}}$

$= \frac{300}{660.49}$

$= 0.454$

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

The factor of safety is dangerously low, meaning the rod will most likely break under these conditions, This is bad as it can put humans at risk of injury.

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

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

$= \frac{33200}{491}$

$= 67.62 \text{ Nmm}^{-2}$

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

$110,000 = \frac{67.62}{\varepsilon}$

$\varepsilon = 6.147 \times 10^{-4}$

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

$6.147 \times 10^{-4} = \frac{\Delta L}{0.78}$

$\Delta L = 4.79 \times 10^{-4}$ m

$= 0.479$ mm

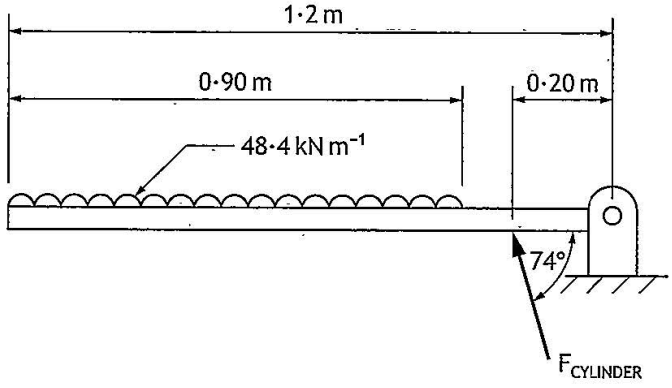
$= 0.48$ mm

MARKS | DO NOT WRITE IN THIS MARGIN

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

$\Sigma M = 0$

$F_c \sin 74 \times 0.2 = 48.4 \times 0.9 \times (0.45 + 0.3)$

$0.2 F \sin 74 = 32.67$

$F \sin 74 = 163.35$

$F = 169.93\ kN = 170\ kN$

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

$\Sigma f_v = 0$

$48.4 \times 0.9 + R_v = 169.93 \times \sin 74$

$43.56 + R_v = 163.35$

$R_v = 119.79\ kN \downarrow$

$\tan\theta = \frac{o}{A}$

$\theta = \tan^{-1} \frac{119.79}{46.84}$

$= 68.64°$

$= 68.6°$

$\Sigma f_h = 0$

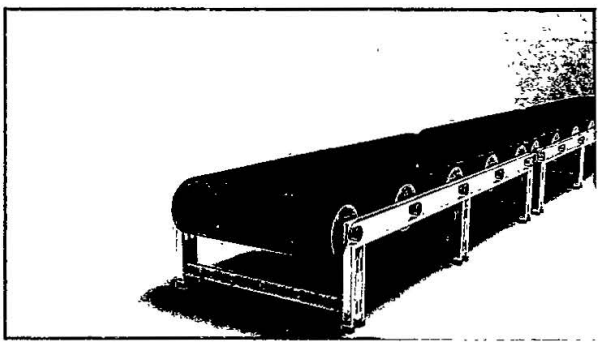
$R_h = 169.93 \cos 74$

$= 46.84\ kN \rightarrow$

$R = \sqrt{R_v^2 + R_h^2}$

$= 128.62\ kN @ 68.6°$

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

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

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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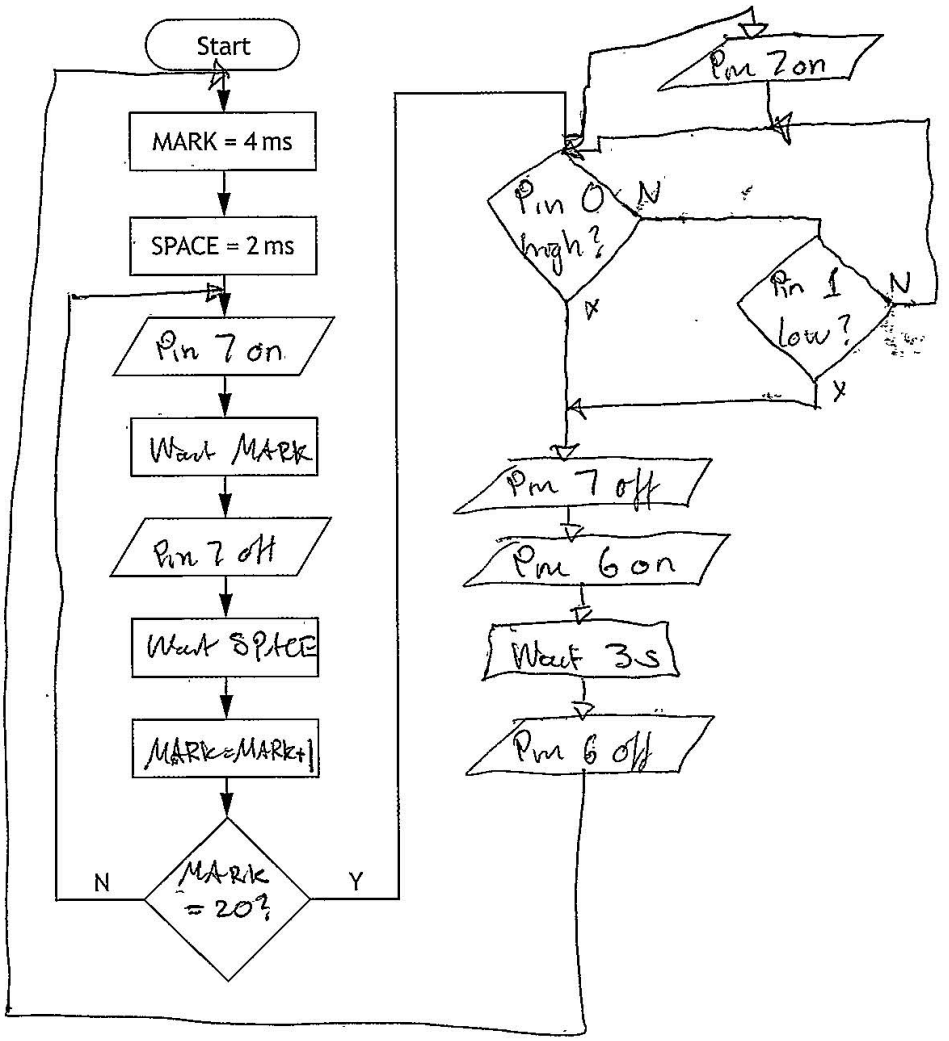
11. (continued)

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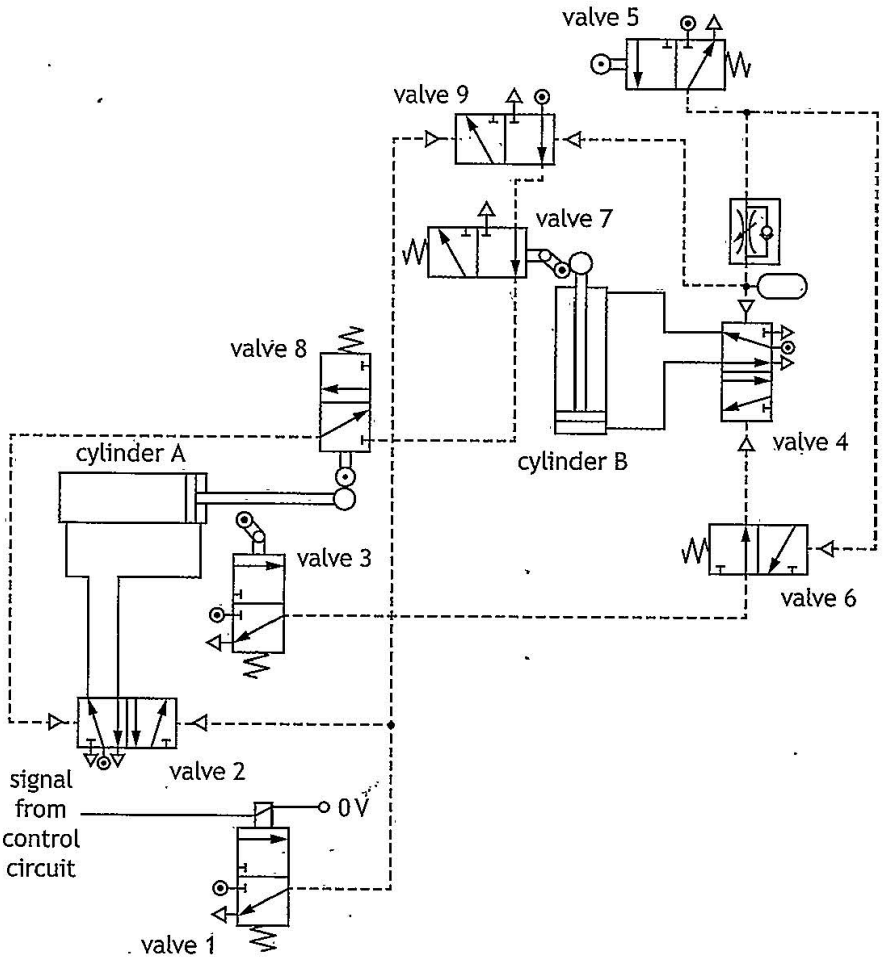
12. A pneumatic system will be used in a manufacturing process for holding material in place and then moving it along the production line. The system diagram is shown below.



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

When valve 1 is actuated,

pilot air is sent to valve 2 and valve 9 - valve 2 changes state causing cylinder A to outstroke, which actuates the roller trip on valve 3; valve 9 changes state, which stops the pilot air being sent to valve 7's

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12. (a) (continued)

main air (cylinder A's outstroke also stops actuating valve 8, which opens air flow to valve 2, however this does nothing for now as valve 9 stopped air flow). Valve 3 then sends pilot-air through valve 6 to valve 4, which changes state and outstrokes cylinder B. This actuates valve 5 (and stops actuating valve 7), valve 5 then sending air to a reservoir and valve 6 (also stops air flow from valve 3, making it possible for valve 4 to change state again). Once the reservoir is full (it acted as a time delay due to the unidirectional restrictor slowed air flow), both valve 4 and 9 change state again - valve 4 causes cylinder B to outstroke, which actuates valve 7 again; valve 9 allows air flow through to now open valve 7 and valve 8 to valve 2, which changes state and cylinder A outstrokes (this actuates valve 8, stopping air flow to valve 2 so it can change state again) and the system resets.

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12. (continued)

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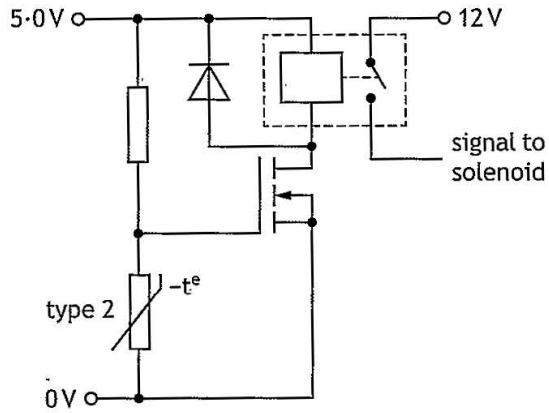
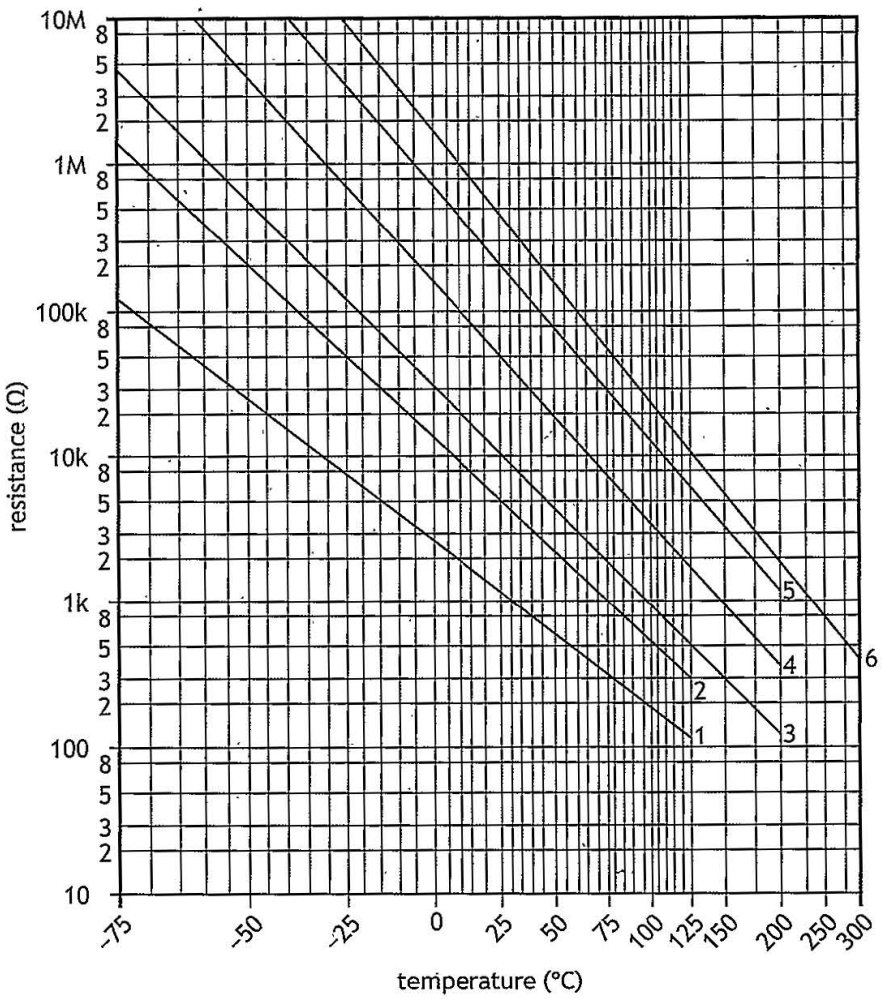
A diagram of the control circuit for the solenoid is shown below. The MOSFET switches on when the gate voltage reaches 3·2 V. This happens when the thermistor is at 85 °C.





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

thermistor R = 800Ω

$V_2 = \frac{R_2}{R_1+R_2} V_S$

$3.2 = \frac{800}{R_1+800} \times 5$

$0.64 = \frac{800}{R_1+800}$

$0.64R_1 + 512 = 800$

$0.64R_1 = 288$

$R_1 = 450\Omega$

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 Being able to construct a prototype and evaluate its performance against the specification of the drive system, thus looking for ways to improve its efficiency.

Knowledge The function of bearing and couplings, and how to use them for mechanisms such as the pistons, or motors

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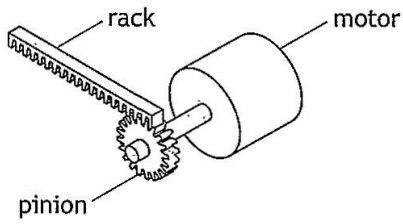
12. (continued)

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

$24 \times 3 \times 10^{-3}$

$= 0.072$ m per rev

$\frac{2.75}{0.072} = 38.19$ revs

$\frac{38.19}{3} = 12.73$ revs s^{-1}

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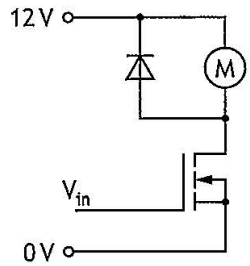
12. (continued)

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**

$P = \frac{V^2}{R}$

$8.5 = \frac{12^2}{R}$

$R = 16.94\ \Omega$

$16.94 + 0.65 = 17.59\ \Omega$

$V = IR$

$12 = I \times 17.59$

$I = 0.68\ A$

[END OF QUESTION PAPER]