FOR OFFICIAL USE

National Qualifications 2026

Mark

X823/76/01 Engineering Science

FRIDAY, 24 APRIL
1:00 PM – 3:30 PM

X8237601

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.
Do not remove any exam materials. You must leave this booklet on your desk; if you do not, you could lose all the marks for this paper.

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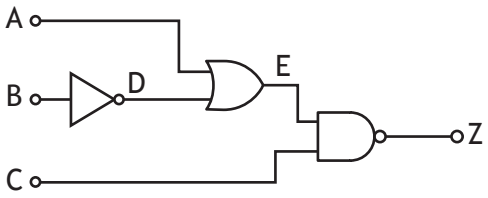
SECTION 1 — 20 marks

Attempt ALL questions

1. An electronic engineer uses the following logic diagram in the design of a gaming controller.



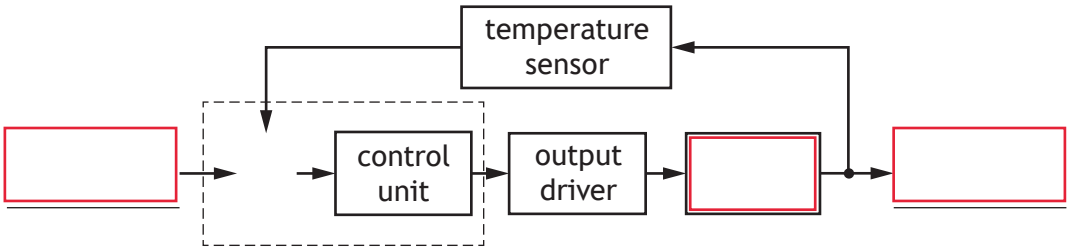
Complete the truth table for the logic diagram. **3**

A	B	C	D	E	Z
0	0	0			
0	0	1			
0	1	0			
0	1	1			
1	0	0			
1	0	1			
1	1	0			
1	1	1			

2. Incubators are used to provide a stable temperature level to hatch eggs.

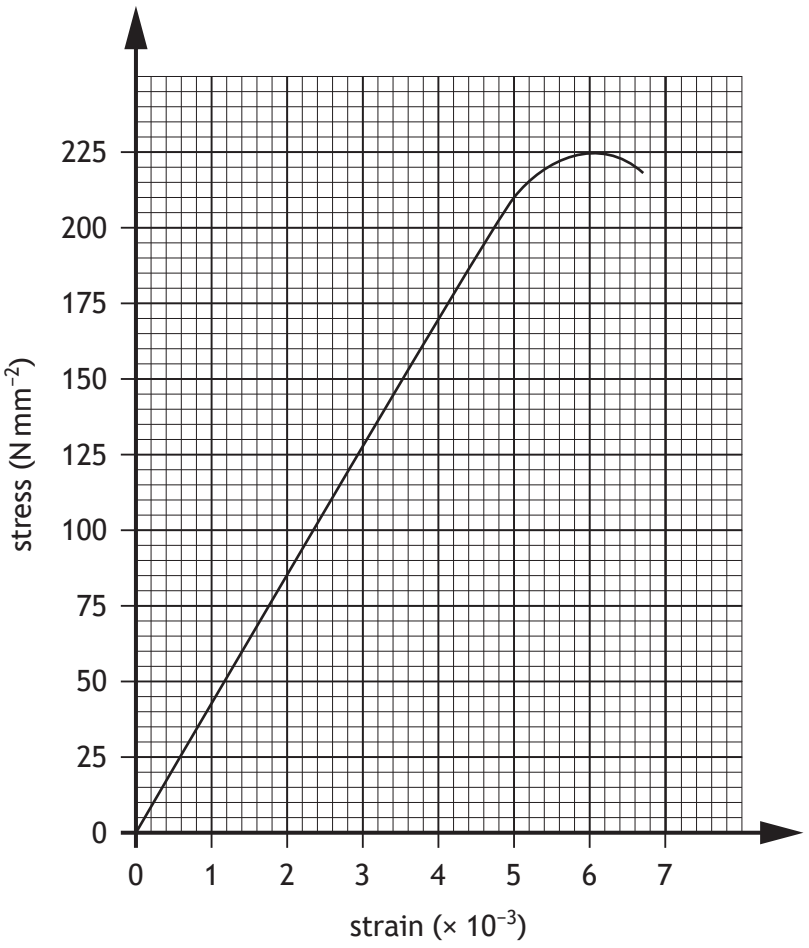
A heating system monitors the temperature inside the incubator and maintains the required temperature.

Complete the control diagram for the incubator's heating system. **3**



[Turn over

3. A material was subjected to a tensile test in a laboratory. The results are shown in the graph below.



(a) Describe the effect on the material of applying and then removing a load that produces a stress of 125 N mm^{-2}. **1**

(b) Annotate with an 'X', on the graph above, the yield point of the material. **1**

A **second** material was tested. It was found to have a lower value of Young's Modulus.

(c) Draw, on the graph above, a line that illustrates this property. **1**

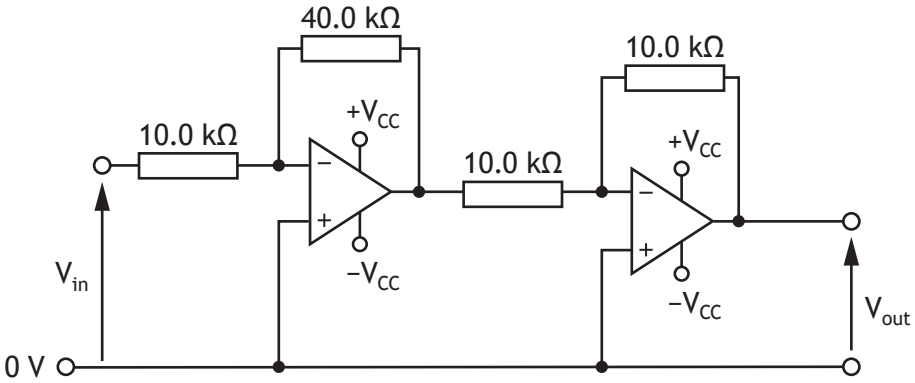
3. (continued)

A **third** material was found to experience an elastic strain of 3.64×10^{-3} while subjected to a stress of 175 N mm^{-2}.

(d) Calculate Young's Modulus for this material. **1**

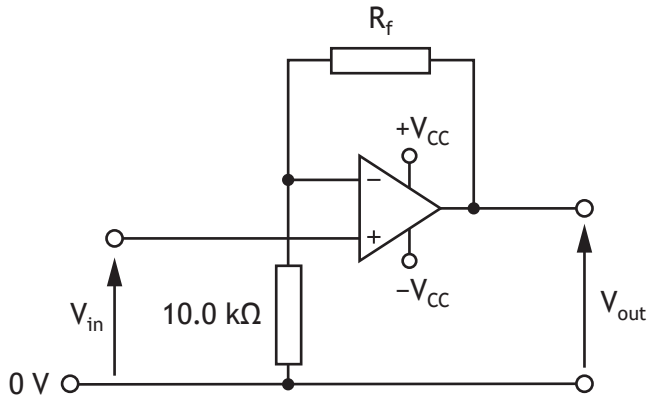
[Turn over

4. Part of an electronic control circuit for a washing machine is shown below.



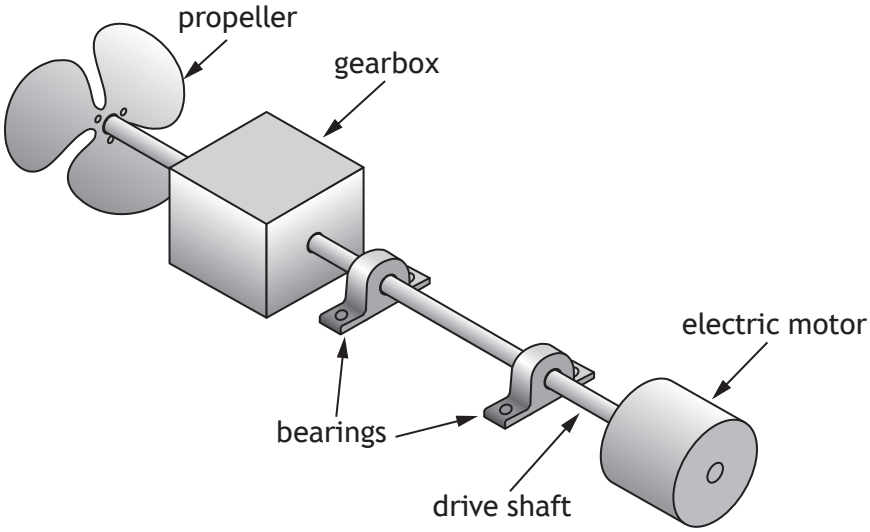
(a) Calculate the voltage gain of the circuit. **2**

An alternative design, shown below, using just one op-amp is proposed. It must have a voltage gain of 19.

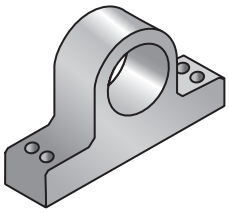


(b) Calculate a suitable value for R_f. **1**

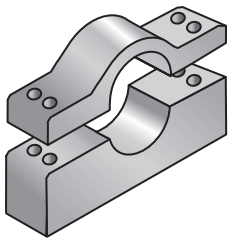
5. A mechanical engineer has designed a drive system for a ship's propeller that allows the drive shaft to be connected to a gearbox.



(a) Describe the purpose of a bearing in a drive system. **1**



original bearing



split bearing

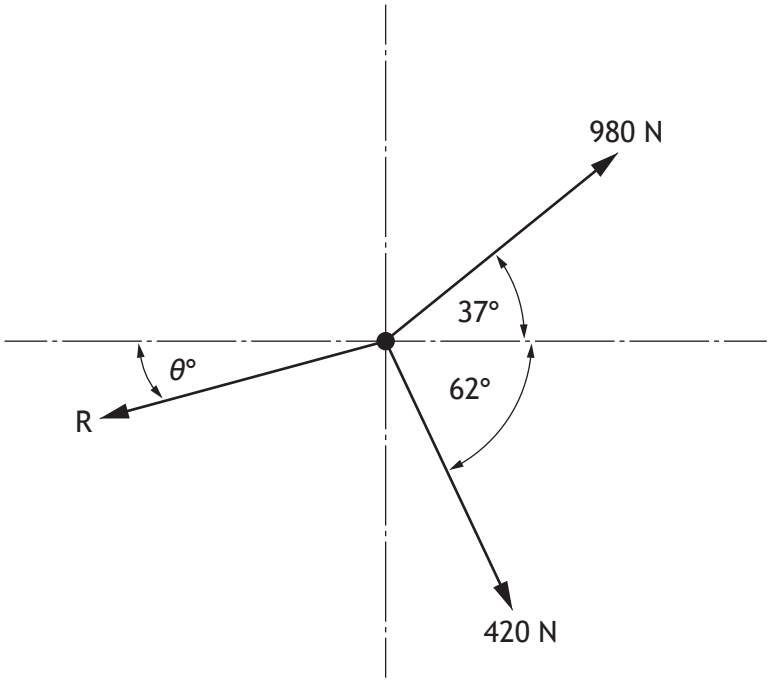
The engineer decides to replace the original bearings with split bearings, as shown above.

(b) State one advantage the split bearing has in this situation. **1**

A mechanism is required that will temporarily disconnect the drive between the motor and the gear box while the gear ratios are changed.

(c) State the name of a suitable mechanism. **1**

6. A concurrent force system in equilibrium is shown below.



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

[Turn over for next question

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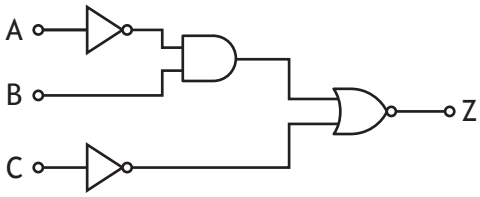
SECTION 2 — 90 marks

Attempt ALL questions

7. An airport operator is upgrading their fleet of luggage carrying trucks to automated trucks.

Once in position, the trucks will automatically load luggage onto a conveyor belt.

An initial design for part of the trucks' electronic control system is shown in the logic diagram below.

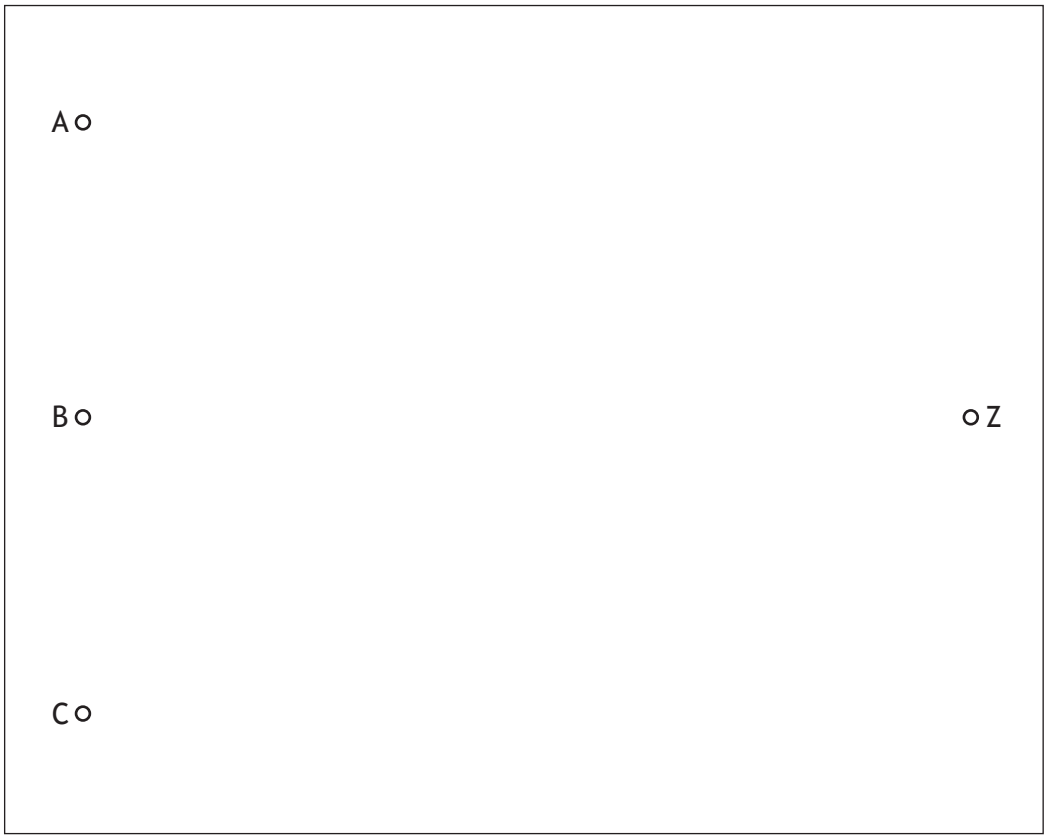


(a) Complete a Boolean equation for this logic diagram. **3**

Z =

7. (continued)

(b) Draw a NAND equivalent circuit for this logic diagram. Your solution does not need to be simplified. **3**



[Turn over

7. (continued)

Luggage can be damaged when being manually loaded onto the conveyor belt.

A key priority for the engineers is to design the automated system to handle luggage with care.

(c) Describe one economic and one social impact of a system which handles the luggage with care. **2**

Economic

Social

The conveyor belt requires a drive system.

(d) Describe two examples of how a mechanical engineer may apply mathematics in the design of the drive system. **2**

Example 1

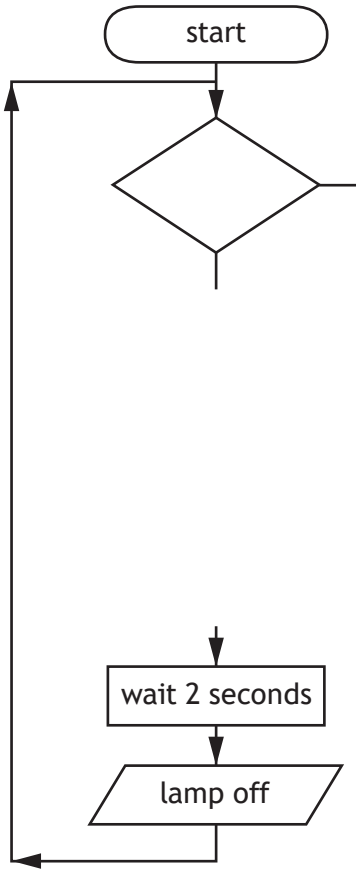
Example 2

7. (continued)

A warning lamp (L) on the conveyor belt is switched on for 2 seconds under the conditions given by the following Boolean equation.

$$L = \overline{A} + B$$

(e) Complete the following flowchart to perform the function described above. **3**

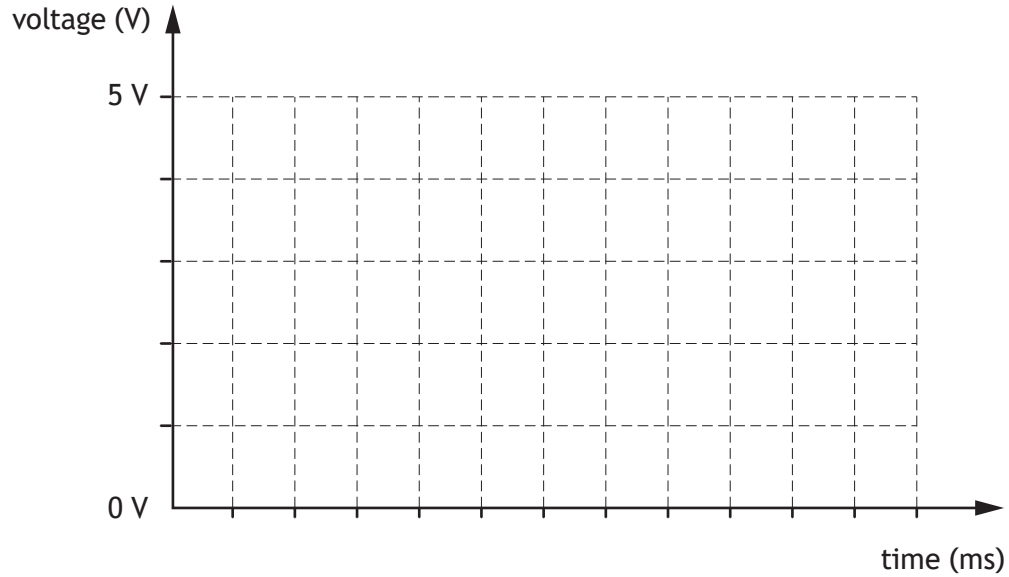


7. (continued)

Pulse-width modulation (PWM) is used to control the speed of a conveyor belt motor.

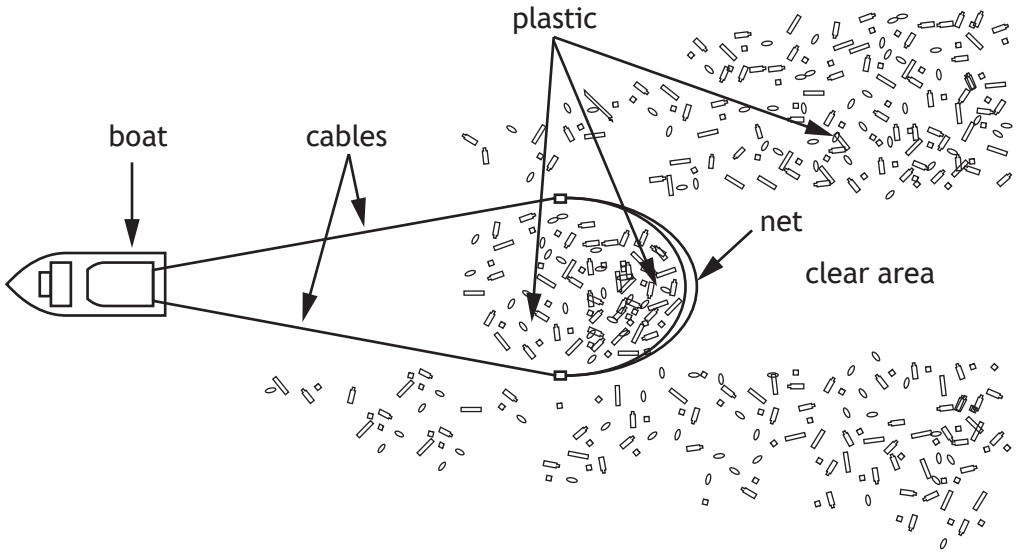
(f) Complete the graph below to show how PWM could be used to make the motor rotate at a mark to space ratio of 2:1.

You must include at least three pulses. **2**

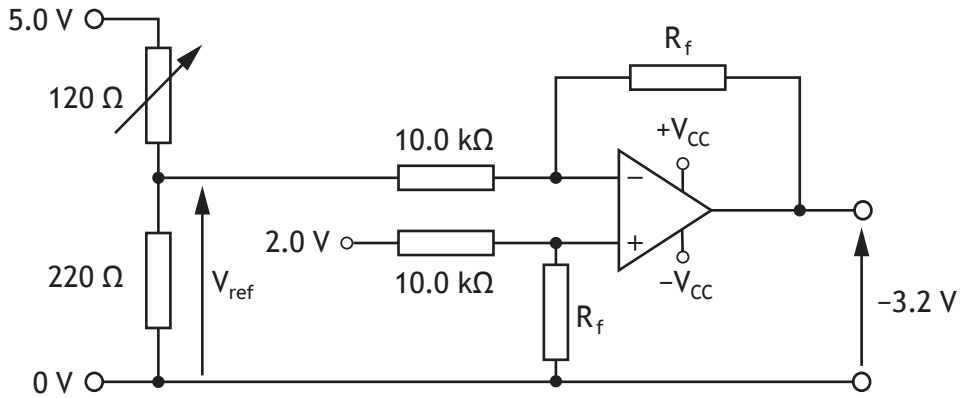


(g) Describe, with reference to both mark and space, how the speed of the motor could be increased using PWM. **1**

8. A boat collects plastic waste floating in the ocean. A shallow net is dragged behind the boat and then wound in using a winching system to bring the waste onto the boat for processing.



The following prototype circuit is used to control the speed of the motors driving the winching system.



(a) Calculate the value of R_f. **3**

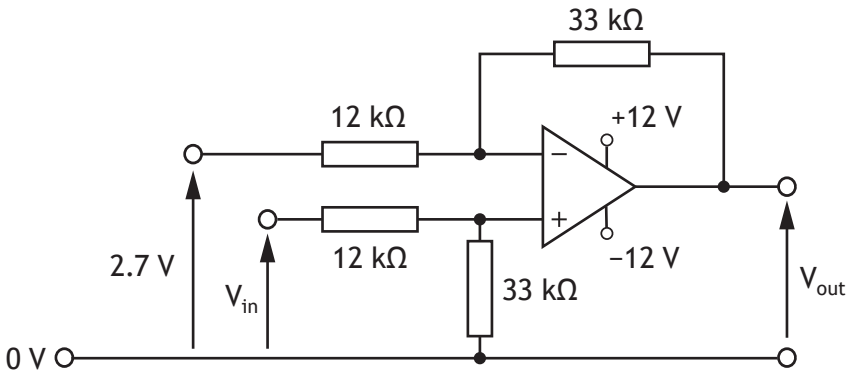
8. (continued)

(b) Describe two adaptations that could be applied to the circuit shown on the previous page that would produce a positive output, given the same input conditions. **2**

Adaptation 1

Adaptation 2

An alternative design for the circuit is shown below. In this case, V_{in} is a signal from a sensor that monitors how much net has been wound in.



The op-amp saturates at 87% of its supply voltage.

(c) Calculate the maximum positive value of V_{in} that could be applied before the op-amp saturates. **2**

8. (continued)

After testing, the op-amp is replaced with one that saturates when V_{in} is 7.5 V.

The sensor supplying the V_{in} signal monitors how much net has been wound onto the winching system. It produces a voltage in the range 10 V (when the net is fully out) to 2.7 V (when the net is fully wound in).

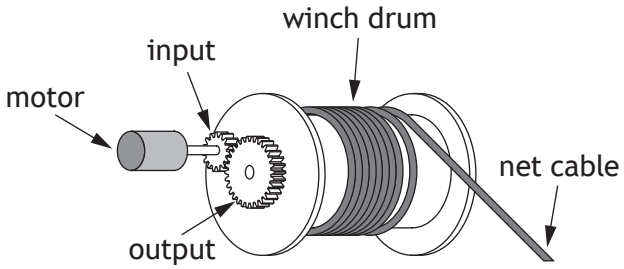
The speed of the motors is proportional to the output of the circuit.

(d) Describe the speed of the motors as V_{in} drops from 10 V to 2.7 V. **3**

[Turn over

8. (continued)

The winch drum that winds in the net is driven by a motor and gear train. The motor spins at 60.0 revs min^{-1} and supplies 21 kW of power.



(e) Calculate the torque supplied by the motor. **2**

8. (continued)

The winch drum has a diameter of 4.6 m and under different loading conditions provides 2.6 kN m of torque.

(f) (i) Calculate the force pulling in the net cable. **1**

(ii) Calculate the linear speed at which the net cable is wound in when the winch drum rotates at 65 revs min^{-1}. **2**

[Turn over

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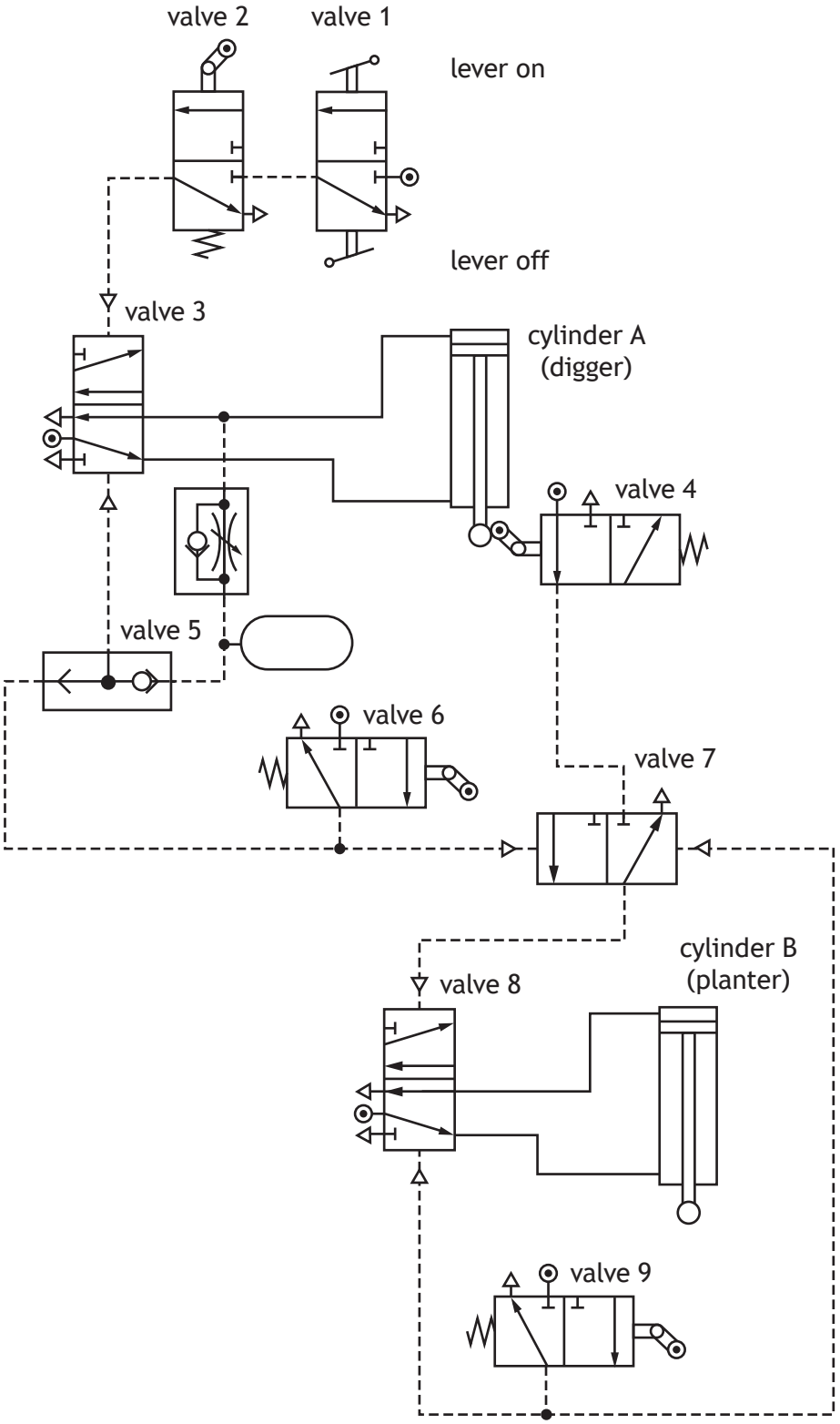
9. A system is needed to plant trees as part of a large-scale environmental project.

A team of engineers have built a pneumatically-controlled machine that meets the following specification:

- A lever must be actuated to activate the system.
- A roller is triggered each time a wheel completes a revolution.
- A cylinder then outstrokes to dig a hole then immediately instrokes.
- When the first cylinder has instroked, a second cylinder outstrokes to plant a tree.
- If the first cylinder hits ground that is too hard and the cylinder is unable to outstroke fully, it must instroke after a short delay, and no tree is to be planted.

The complete circuit is shown on the following page.

9. (continued)



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9. (continued)

MARKS

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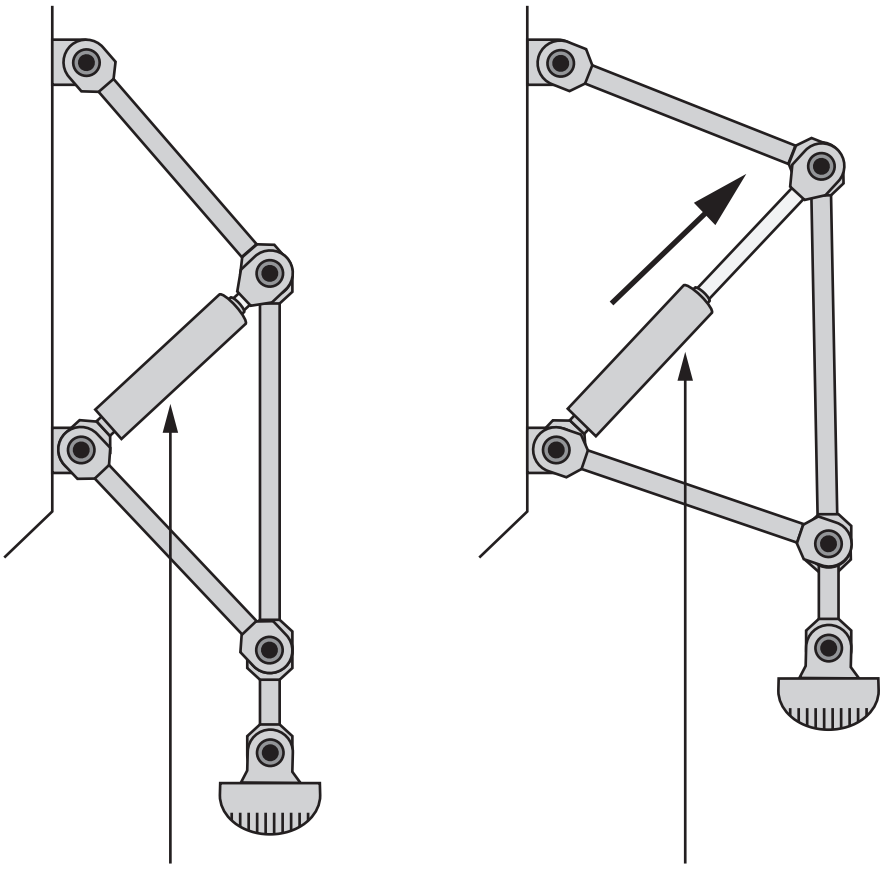
Describe, with reference to all the components, the operation of the system. **8**

10. A team of engineers is designing a lunar landing module for an international space agency's next mission to the moon. The final design for the lunar landing module is shown below.

The landing gear for the lunar landing module is designed to be able to fold. The engineers decided to use a pneumatic cylinder to achieve this.

A simplified diagram of the landing gear is shown below.



pneumatic cylinder instroked (folded)

pneumatic cylinder outstroked (unfolded)

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10. (continued)

(a) The pneumatic cylinder used in the design has a 76 mm diameter aluminium alloy piston rod to support a load of 36.9 kN.

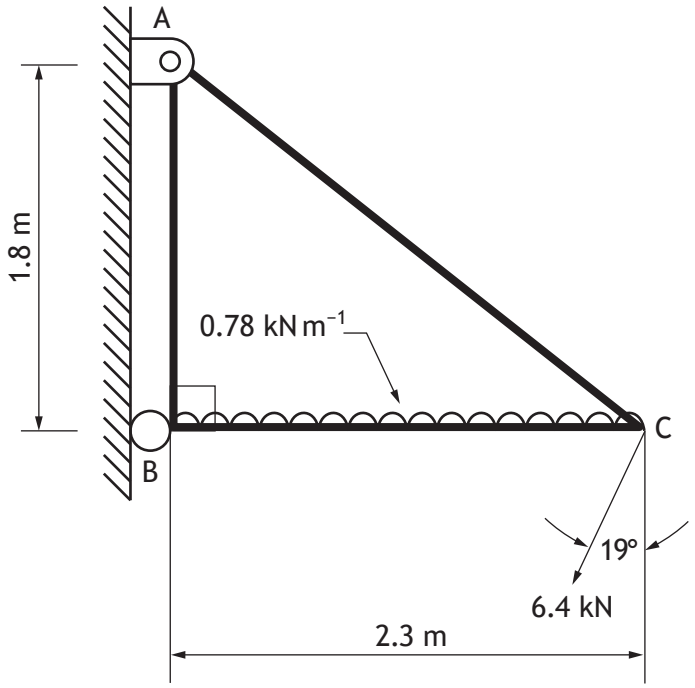
(i) Calculate the factor of safety applied to the design of the piston rod. **4**

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

[Turn over

10. (continued)

The engineers used the frame shown below to enable strength testing of component parts from another part of the landing gear structure.



(b) Calculate the magnitude of the reaction at B. **5**

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11. A manufacturer uses forklift trucks to lift, lower and transport materials in a warehouse.

The speed at which materials are lifted is controlled by a microcontroller using pulse-width modulation (PWM). An engineer must design a program to control the speed of a motor that moves the lifting mechanism.

If the speed is too fast or too slow, the microcontroller will adjust the speed of the motor.

The desired speed is represented by the analogue value 125.

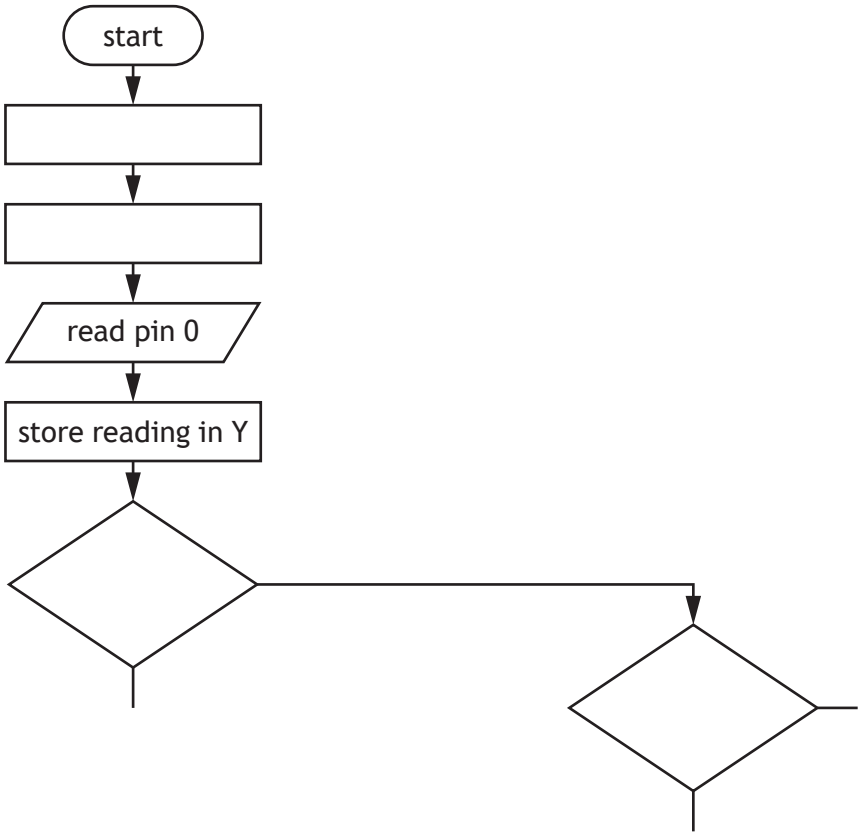
The proposed program must meet the following criteria:

- Values for *mark* and *space* need to be initially set at 50.
- A reading must be taken from the speed sensor and stored in a variable Y.
- If the value of Y is greater than 125 then the *mark* decreases by 1 and the *space* increases by 1.
- If the value of Y is less than 125 then the *mark* increases by 1 and the *space* decreases by 3.
- If the value of Y is 125 then *mark* and *space* do not change.
- The motor must be switched on and off for the times specified by *mark* and *space*.
- The process must loop back to take the next reading.

Input connection	Pin	Output connection
	7	motor
speed sensor (analogue)	0	

11. (continued)

(a) Complete, with reference to the specification and the input/output connection table shown opposite, the flowchart for the control of the system. **10**



11. (continued)

An alternative design uses a braking system containing a brake disc to control the speed that materials are lowered.

A load of 765 kg was lowered from a height of 23 m to 0 m.

The brake disc's temperature changed by 168 °C during braking.

The disc material has a specific heat capacity of 310 $J\,kg^{-1}\,K^{-1}$.

(b) Calculate the mass of the brake disc.

Assume all potential energy is converted to heat energy in the disc. **2**

The forklift trucks are battery powered.

The battery is rated at 48 V and provides 110 A for 8.0 hours. During this time, it produces 36 MJ of waste energy.

(c) Calculate the efficiency of the battery. **3**

11. (continued)

The manufacturer that owns the warehouse wants to become more environmentally friendly.

(d) Describe an economic impact for the company of becoming more environmentally friendly. **1**

An electronic engineer is asked to design the control system for an automated robotic vacuum cleaner to help clean the warehouse floor.

(e) Describe one skill and one piece of knowledge the electronic engineer would use when developing the control system. **2**

Skill

Knowledge

[Turn over

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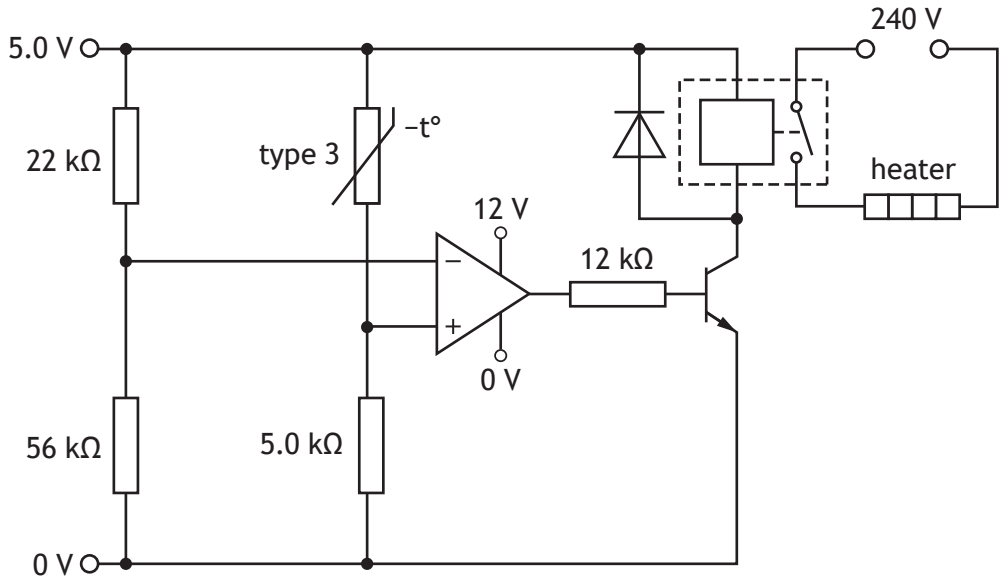
12. An electric shower needs a control system for its water heater.

A prototype control circuit, shown below, has been designed by an electronic engineer.



MARKS

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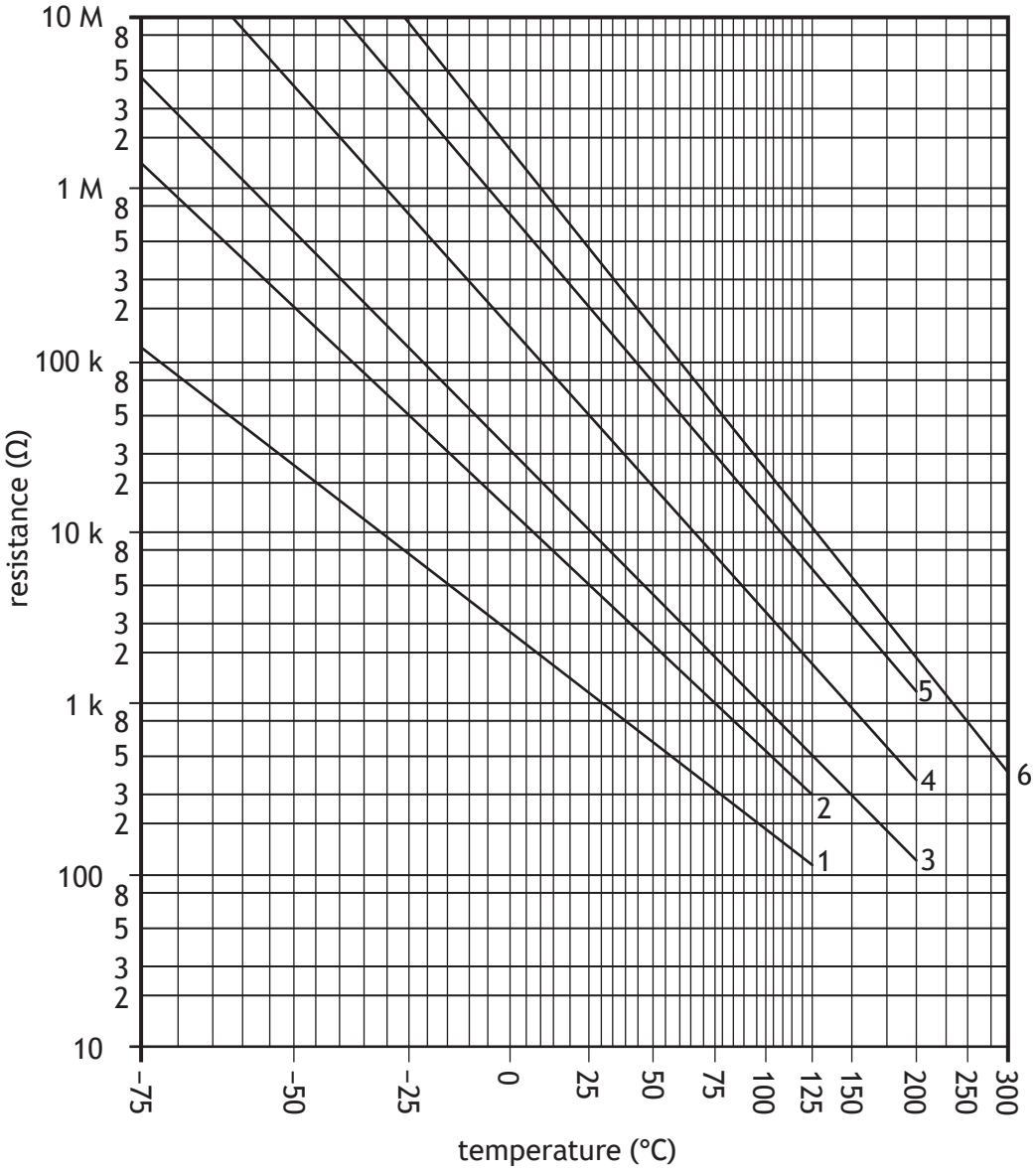
The circuit uses a type 3 thermistor.



(a) Calculate, with reference to the graph shown above, the temperature that will cause the comparator to saturate positively. **2**

12. (continued)

The comparator will saturate at 78% of its supply voltage.

(b) (i) Calculate the base current when the comparator switches on. Assume V_{be} is 0.7 V. **3**

The current gain (h_{FE}) of the transistor is known to be 54.

(ii) Calculate the collector current. **1**

The relay is known to have a resistance of 85 Ω.

(iii) Calculate the power dissipated between the collector and emitter in the transistor. **3**

12. (continued)

The inclusion of the comparator means the shower is operated using two-state control.

(c) State which op-amp configuration would provide proportional control. **1**

[Turn over

13. A space rocket takes off from a launch pad. The structure on the launch pad helps to support the rocket prior to launch.

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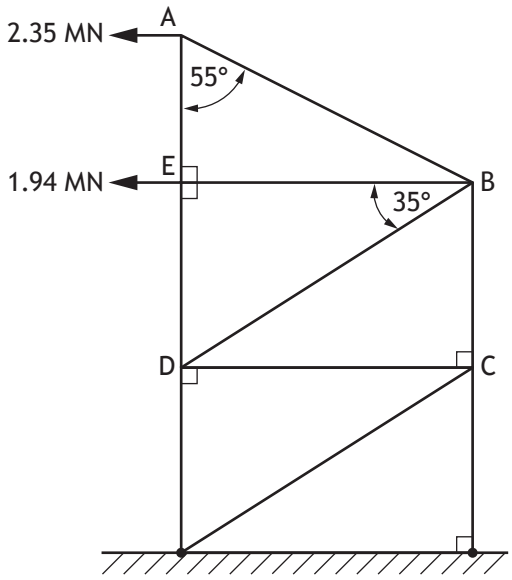
A diagram of part of the launch pad structure is shown below.



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

Show all answers in the table provided.

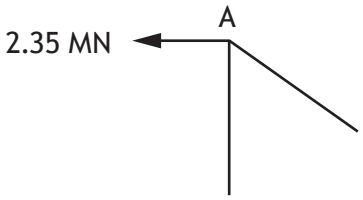
Show all working and final units on the page opposite. **6**

Member	Magnitude	Nature
AB		
AE	1.6 MN	strut
BC		
BD		
BE	1.94 MN	tie

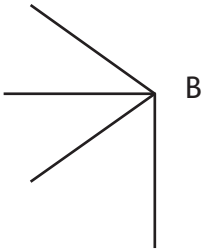
13. (a) (continued)

Space for calculations

node A

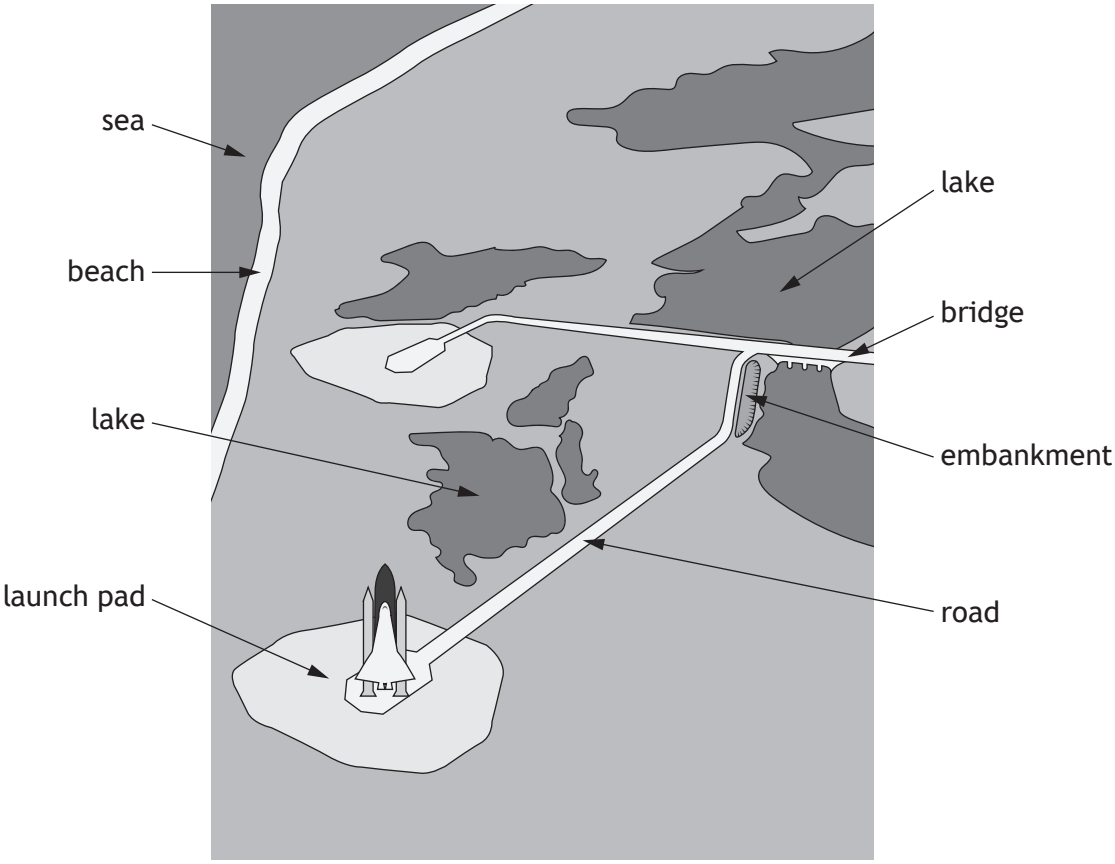


node B



13. (continued)

A map containing the launch pad site is shown below.



Civil engineers had a key role when developing the infrastructure of the launch pad site.

(b) Describe two roles a civil engineer would have to perform in the development phase of the launch pad site. **2**

Role 1

Role 2

13. (continued)

A nearby museum displays space rockets.

The rockets are supported by cables which are subject to tensile loading and fixed to the ground.

One cable used to support a rocket stores 0.7645 J of strain energy and changes length by 0.087 mm.

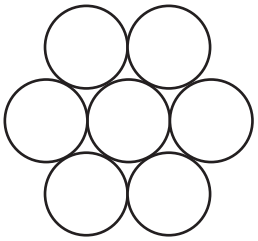
(c) Calculate the force in the cable under these conditions. **1**

13. (continued)

Another rocket is supported by a 33 m long cable which is subject to tensile loading of 2.25 kN and fixed to the ground.

Young's Modulus for the cable material is 216 kN mm^{-2}.

The cable is made up of seven circular strands as shown below.



Under these loading conditions, the cable changes length by 0.055 mm.

(d) Calculate the cross-sectional area of **one** strand of the cable. **4**

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