Government of **Western Australia**
School Curriculum and Standards Authority

ATAR course examination, 2024

Question/Answer booklet

ENGINEERING STUDIES

Please place your student identification label in this box

WA student number: In figures | | | | | | | | | |

In words _____

_____

Place a tick (✓) in one of the following boxes to indicate your specialist field.

Mechanical ☐

Mechatronics ☐

Number of additional answer booklets used (if applicable): ☐

Time allowed for this paper

Reading time before commencing work: ten minutes
Working time: three hours

Materials required/recommended for this paper

To be provided by the supervisor

This Question/Answer booklet
Multiple-choice answer sheet
Data Book

To be provided by the candidate

Standard items: pens (blue/black preferred), pencils (including coloured), sharpener, correction fluid/tape, eraser, ruler, highlighters

Special items: up to three calculators, which do not have the capacity to create or store programmes or text, are permitted in this ATAR course examination

Important note to candidates

No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised material. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of examination
Section One **Core content**			70		
Part A: Multiple-choice	10	10		10	10
Part B: Extended answer	3	3		65	30
Section Two **Mechanical**			110		
Part A: Multiple-choice	10	10		10	10
Part B: Extended answer	6	6		100	50
Section Two **Mechatronics**			110		
Part A: Multiple-choice	10	10		10	10
Part B: Extended answer	6	6		100	50
				Total	100

Instructions to candidates

1. The rules for the conduct of the Western Australian external examinations are detailed in the *Year 12 Information Handbook 2024: Part II Examinations*. Sitting this examination implies that you agree to abide by these rules.

2. Section One: You must answer all questions.

   Section Two: You must choose to answer only one of the specialist fields. In the specialist field you have chosen, answer all questions.

   In both Section One and Section Two, answer the questions according to the following instructions.

   Part A: Multiple-choice
   Answer all questions on the separate Multiple-choice answer sheet provided. For each question, shade the box to indicate your answer. Use only a blue or black pen to shade the boxes. Do not use erasable or gel pens. If you make a mistake, place a cross through that square, then shade your new answer. Do not erase or use correction fluid/tape. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

   Part B: Extended answer
   Answer all questions. Write your answers in the spaces provided in this Question/Answer booklet preferably using a blue/black pen. Do not use erasable or gel pens.

   When calculating answers, show all your working clearly. Your working should be in sufficient detail to allow your answers to be checked readily and for marks to be awarded for reasoning. In final answers, include appropriate units where applicable.

3. You must be careful to confine your answers to the specific questions asked and to follow any instructions that are specific to a particular question.

4. Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

5. The Data Book is not to be handed in with your Question/Answer booklet.

See next page

Section One: Core content **40% (75 Marks)**

This section has **two** parts.

Part A: Multiple-choice Answer **all** questions

Part B: Extended answer Answer **all** questions

Suggested working time: 70 minutes.

Part A: Multiple-choice **10% (10 Marks)**

This part has **10** questions. Answer **all** questions on the separate Multiple-choice answer sheet provided. For each question, shade the box to indicate your answer. Use only a blue or black pen to shade the boxes. Do not use erasable or gel pens. If you make a mistake, place a cross through that square, then shade your new answer. Do not erase or use correction fluid/tape. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

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1. When choosing from a number of alternative designs, the selected option should always be the one that

   (a) is the least expensive to produce.
   (b) best meets the requirements of the design brief.
   (c) uses materials that are ethically sourced and recyclable.
   (d) is easiest to package and transport to market.

2. Which of the following sources of energy releases harmful emissions to the atmosphere when operating?

   (a) biomass
   (b) geothermal
   (c) nuclear
   (d) wind

3. Of the alloys, cast iron, brass, stainless steel and solder, carbon is a constituent of

   (a) stainless steel only.
   (b) stainless steel and cast iron.
   (c) stainless steel and brass.
   (d) stainless steel and solder.

4. Alloys are always characterised by

   (a) being non-magnetic.
   (b) containing a metal and a non-metal.
   (c) exhibiting metallic properties.
   (d) consisting mostly of iron.

See next page

5. The power of an electric motor that does 480 kJ of work in 1 hour and 20 minutes is

(a) 100 W.
(b) 111 W.
(c) 6000 W.
(d) 8000 W.

6. Life cycle analysis of an engineered product is **best** described as identifying where improvements can be made to

(a) make the workplace safer for employees and contractors.
(b) increase the durability and effectiveness of the product.
(c) reduce material and energy inputs and environmental impacts.
(d) make production more efficient by using advanced manufacturing.

7. The input of an energy system is 600 kW h and its output is 459 kW h. If there are two stages between the input and output, and the efficiency of the first stage is 90%, then the efficiency of the second stage is

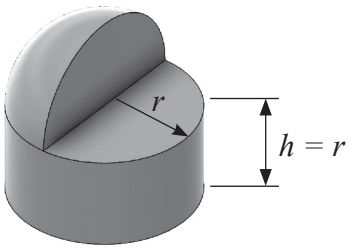
(a) 15.00%.
(b) 68.85%.
(c) 76.50%.
(d) 85.00%.

8. In order to minimise harm to the occupants of a car involved in a crash, the design of the crumple zone of an automobile is intended to collapse when impacted by another object. Crumple zone design requires the use of materials that have a high degree of

(a) hardness.
(b) toughness.
(c) stiffness.
(d) elasticity.

9. A solid form comprising a cylinder combined with a quarter of a sphere is illustrated below. The surface area of this solid form can be determined using

(a) $4\pi r^2$.
(b) $4.5\pi r^2$.
(c) $5\pi r^2$.
(d) $5.5\pi r^2$.



10. Many homes in Western Australia have reduced their electricity costs by fitting photovoltaic panels to roofs. Excess production during the day can be stored in batteries and these can be used to supply energy during the night. Which of the following choices **best** fits the energy conversions used by this system?

(a) thermal to electrical to electromagnetic to electrical
(b) thermal to electromagnetic to electrochemical to electrical
(c) electromagnetic to thermal to electrochemical to electrical
(d) electromagnetic to electrical to electrochemical to electrical

See next page

Part B: Extended answer **30% (65 Marks)**

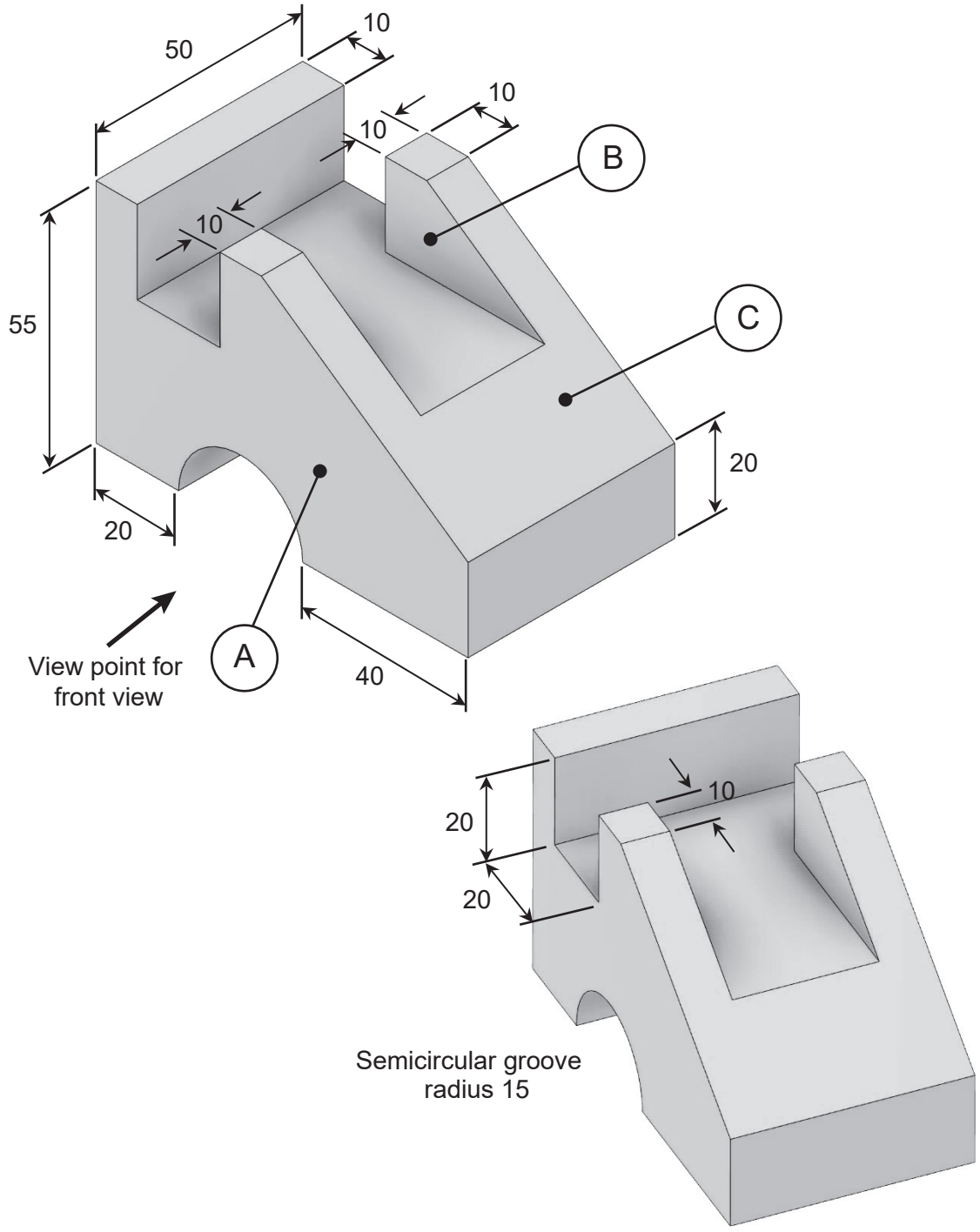
This section has **three** questions. Answer **all** questions. Write your answers in the spaces provided.

When calculating answers show all of your working clearly. Your working should be in sufficient detail to allow your answers to be checked readily and for marks to be awarded for reasoning. In final answers, include appropriate units where applicable.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

See next page

Question 11 **(22 marks)**

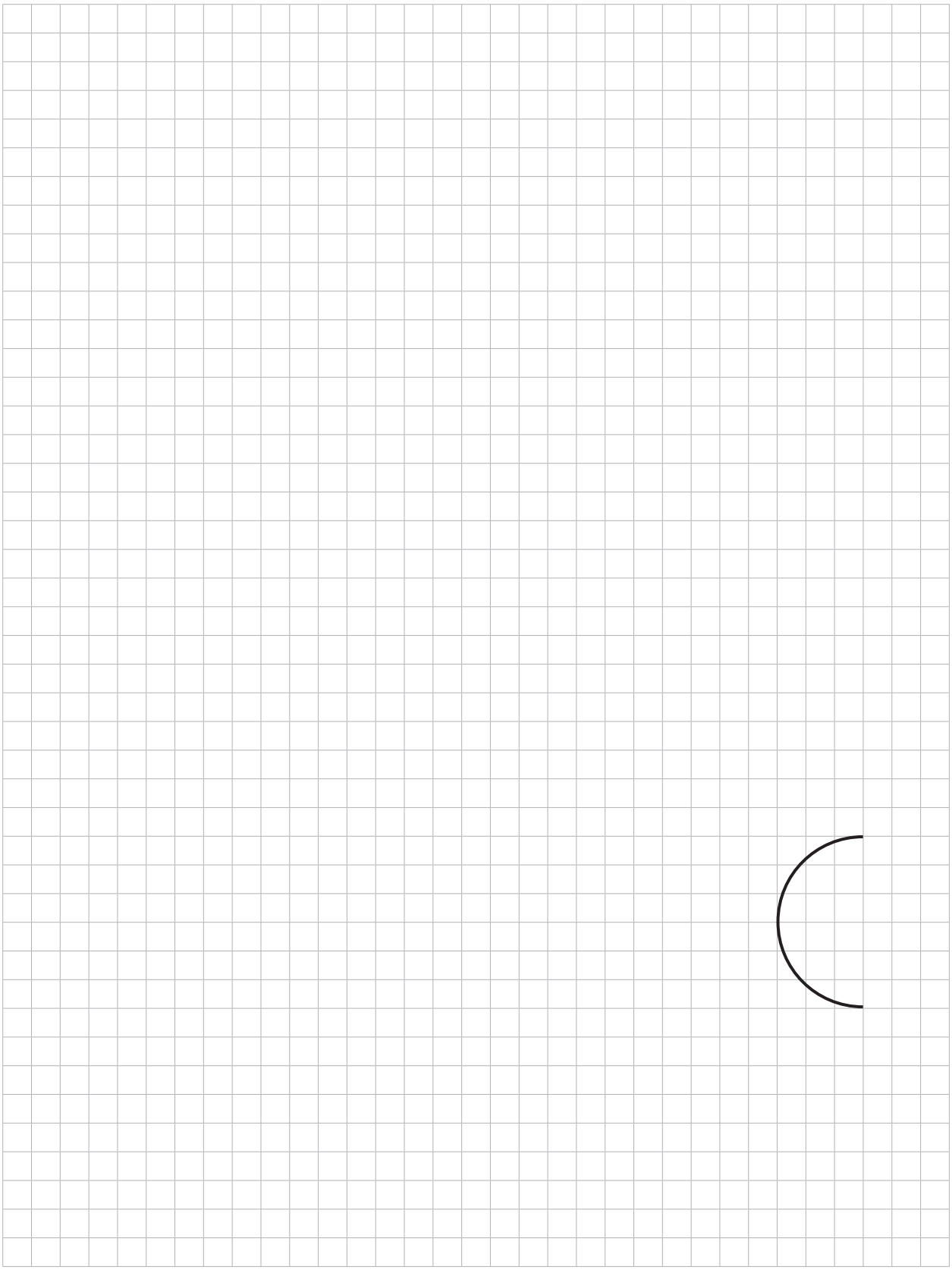


The two drawings of a 3D-printed block shown above are from slightly different viewpoints. Surface C slopes at 34.992° relative to horizontal. The semicircular groove passes all the way through the block. All measurements indicated are in millimetres.

(a) Using 3rd angle orthographic projection conventions, complete fully dimensioned* and labelled drawings of the top, front and right end views of the block on the grid provided on page 7. The semicircular groove, as seen in the front view, is given. Each square of the grid represents 5 mm × 5 mm. (9 marks)

* No need to dimension angles.

See next page



A spare grid is provided at the end of this Question/Answer booklet. If you need to use it, cross out this attempt and indicate that you have redrawn it on the spare grid.

See next page

Question 11 (continued)

(b) Calculate the perimeter of the surface labelled 'A' on the drawing on page 6. Answer in units of millimetres (mm). (3 marks)

Perimeter of surface A (mm) = _____

(c) Prove by calculation that the area of the surface labelled 'B' is very close to 486 mm^2. (3 marks)

See next page

(d) The block is 3D-printed using acrylonitrile butadiene styrene (ABS). The density of ABS is 1050 kg m^3 and the block is printed as a solid, i.e. 100% fill. Calculate the mass of the block. Answer in units of kilograms (kg). (7 marks)

Mass of block (kg) = _____

See next page

Question 12 **(23 marks)**

Selecting an appropriate construction material is very important if an engineered product is to function safely and perform its intended task effectively and efficiently.

(a) For each of the following engineered products, name and define a requisite property of the material it is made from. For each property, explain how it ensures the product functions as it is intended **and** explain the outcome to the functionality of the product if the material does not contain that property. Do **not** repeat a property when answering this question. (12 marks)

Handle of hammer

Property and definition:

Explanation:

Bicycle helmet

Property and definition:

Explanation:

See next page

Ladder to clean second storey windows

Property and definition:

Explanation:

Staples to bind paper

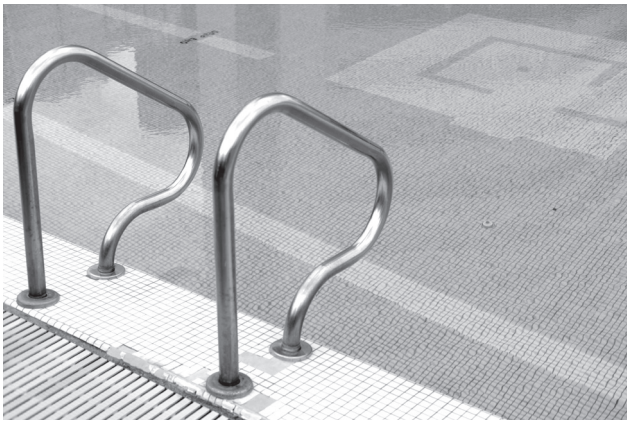
Property and definition:

Explanation:

See next page

Question 12 (continued)

Stainless steel rather than aluminium is used as the construction material for handrails fitted to a swimming pool. An example is shown in the image below.



Aluminium and stainless steel have similar corrosion properties.

(b) Referring to properties other than corrosion, describe **two** reasons why stainless steel is preferred to aluminium as the construction material for handrails of a swimming pool. (4 marks)

One: _____

_____

_____

_____

Two: _____

_____

_____

_____

Materials such as concrete, fibre reinforced plastic, plywood and galvanised iron are classified as composite materials.

(c) Describe what is meant by the term ‘composite material’. (3 marks)

_____

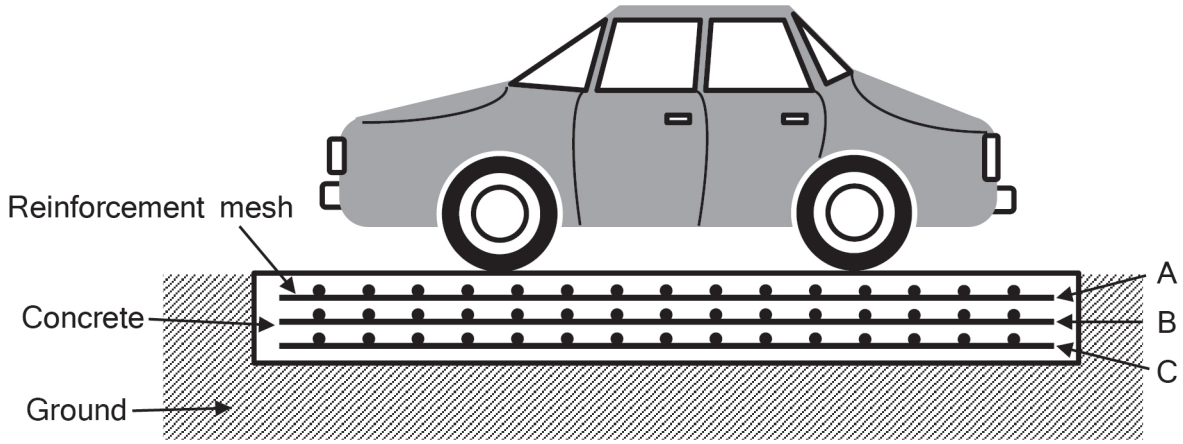
_____

_____

_____

_____

_____



A reinforced concrete driveway is about to be installed on a property. Before pouring the concrete, the installer is considering three locations for the reinforcement mesh. These are 'A', 'B' and 'C', as shown in the diagram above.

(d) Identify the location (A, B or C) that should be used for the mesh. Justify your choice. (4 marks)

Location: _____

Justification: _____

_____

_____

_____

_____

_____

_____

See next page

Question 13 **(20 marks)**

In a nuclear fission reaction, uranium-235 (U-235) nuclei are split into two smaller nuclei to release thermal energy. This is used to heat water into high-pressure steam that is forced through turbines that drive a generator to produce electrical energy ready for distribution to customers.

Nuclear power stations can use the relationship below to determine E_T, the total electrical energy produced in kW h from their fuel rods:

$$E_T = \eta \beta m \kappa$$

where:
η is the efficiency expressed as a decimal
β is the enrichment factor expressed as a decimal
m is the mass of the fuel rod in grams
κ is 24 475 kW h of energy per gram released by U-235.

While it is generally not made public, most nuclear power stations operate at approximately 33% efficiency in converting nuclear energy to electrical energy. Suppose an operating nuclear power station uses uranium fuel rods that have an enrichment factor of 4.3% in U-235 isotopes. It consumes 67 kg of fuel rods each day to supply 23.3 GW h of electricity to a grid for that same duration.

(a) Prove by calculation that the power station using the supplied fuel rods should be able to deliver to an electricity grid a daily supply very close to 23.3 GW h of electrical energy.
(3 marks)

See next page

A typical household uses an average of 73.8 MJ of energy each day.

(b) Determine the maximum number of households the power station could supply if production meets the daily target of 23.3 GW h from part (a). (3 marks)

Maximum number of households = _____

With projected population growth in the area expected to rise to 1.4 million households and average consumption of electrical energy per household expected to remain the same, the power station will need to increase the daily output to meet demand. Engineers decide to investigate how to meet this predicted future output by improving the efficiency of the power station, rather than by consuming more nuclear fuel.

(c) (i) Calculate the future daily output that will be required by the power station. Answer in units of gigawatt hours (GW h). (1 mark)

Future daily output (GW h) = _____

(ii) Calculate η, the new efficiency value necessary for the power station to meet this target. Answer as a percentage (%). (3 marks)

η (%) = _____

See next page

Question 13 (continued)

(d) State **two** advantages of producing electrical power using nuclear energy and, for each advantage, state **one** reason why this is viewed as being beneficial. (4 marks)

Advantage one: _____

_____

Reason: _____

_____

Advantage two: _____

_____

Reason: _____

_____

(e) State **two** disadvantages of using nuclear energy to produce electricity. For each disadvantage, state **two** reasons why this is viewed as being detrimental. (6 marks)

Disadvantage one: _____

_____

Reason one: _____

_____

Reason two: _____

_____

Disadvantage two: _____

_____

Reason one: _____

_____

Reason two: _____

_____

End of Section One

See next page

Section Two: Specialist fields **60% (110 Marks)**

Candidates are required to choose one of the following options, according to which specialist field they studied in 2024.

Tick **one** of the boxes below to indicate your choice of option.

Specialist field	✓	Question numbers	Pages
Mechanical	☐	14–29	18–36
Mechatronics	☐	30–45	37–57

Now turn to the relevant pages and answer the questions for the specialist field you have selected.

See next page

Section Two: Specialist field – Mechanical **60% (110 Marks)**

This section has **two** parts.

Part A: Multiple-choice Answer **all** questions

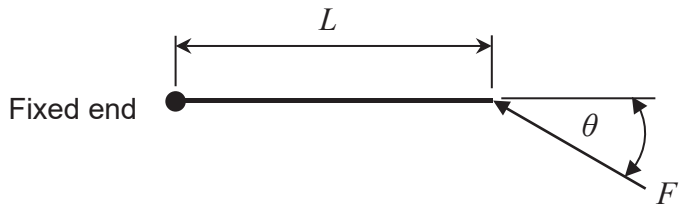
Part B: Extended answer Answer **all** questions

Suggested working time: 110 minutes.

Part A: Multiple-choice **10% (10 Marks)**

This part has **10** questions. Answer **all** questions on the separate Multiple-choice answer sheet provided. For each question, shade the box to indicate your answer. Use only a blue or black pen to shade the boxes. Do not use erasable or gel pens. If you make a mistake, place a cross through that square, then shade your new answer. Do not erase or use correction fluid/tape. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

14.



In the diagram above, an object of length L and negligible cross-section is fixed at one end and able to move through a plane about the fixed point. A force F acts on the unfixed end of the object and creates a turning moment of $0.5FL$. The angle θ, between the force F and the axial length of the object is

(a) 30 degrees.
(b) 45 degrees.
(c) 60 degrees.
(d) 90 degrees.

15. If Material A has a stress-strain curve with a gradient in the linear region that is 10 times that of Material B, then for a given stress the elongation of A equals

(a) 31% of the elongation of B.
(b) 10 times of the elongation of B.
(c) the elongation of B.
(d) 10% of the elongation of B.

16. Two identical masses, M1 and M2, are moving up separate inclines. The incline for M2 is steeper than for M1. Which of the following is the correct statement?

(a) The decelerating force on M1 is greater than the decelerating force on M2.
(b) The decelerating force on M1 is less than the decelerating force on M2.
(c) The decelerating forces are the same in both cases.
(d) There are no decelerating forces acting on the masses.

See next page

17. For a given working stress, the material that provides a higher Factor of Safety is

(a) cast iron.
(b) copper.
(c) structural steel.
(d) brass.

18. The area under the stress-strain curve up to the point of fracture is an indication/measure of the material's

(a) yield point.
(b) toughness.
(c) elasticity.
(d) resilience.

19. Two beams are simply supported at both ends. Beam A is 10 m long and Beam B is 30 m long, and each are subjected to the same uniformly distributed load per unit length (ω) along their respective lengths. The deflection of Beam B is

(a) 81 times the deflection of A.
(b) 27 times the deflection of A.
(c) 9 times the deflection of A.
(d) 3 times the deflection of A.

20. If the stress exerted on an object is 13.35 kN mm^{-2}, this is the same as

(a) 133.5 kPa.
(b) 133 500 Pa.
(c) 13.35 MPa.
(d) 13.35 GPa.

21. A solid object is released to freefall from a bridge. Just before impact with the ground, the object has a velocity of v. Which of the following could be used to determine h, the height the object is above the ground, at the point where it has lost 20% of its gravitational potential energy?

(a) $h = 0.1 \frac{v^2}{g}$

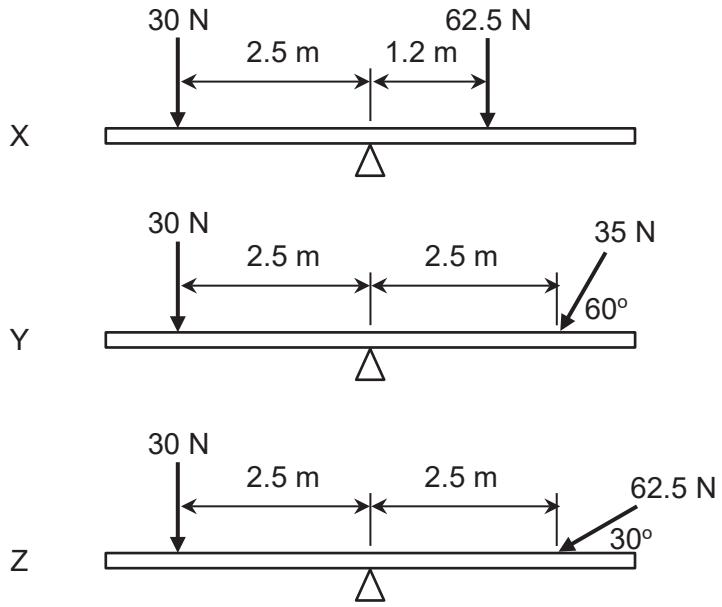
(b) $h = 0.4 \frac{v^2}{g}$

(c) $h = 0.625 \frac{v^2}{g}$

(d) $h = 2.5 \frac{v^2}{g}$

See next page

22. Three beams, each with the fulcrum in the midpoint of the beam and each with two loads, are shown in diagrams below.



Which of the following statements is true? Beams

(a) X and Y will rotate clockwise.
(b) X and Z will rotate clockwise.
(c) Y and Z will rotate clockwise.
(d) Y and Z will rotate anticlockwise.

23. A long solid object has a rectangular cross-section with height dimension, h, three times the breadth dimension, b. The second moment of area is given by which of the following?

(a) $\frac{9b^4}{4}$

(b) $\frac{b^4}{4}$

(c) $\frac{b^3}{3}$

(d) $\frac{16b^3}{3}$

See next page

Part B: Extended answer **50% (100 Marks)**

This section has **six** questions. Answer **all** questions. Write your answers in the spaces provided.

When calculating answers, show all your working clearly. Your working should be in sufficient detail to allow your answers to be checked readily and for marks to be awarded for reasoning. In final answers, include appropriate units where applicable.

Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Question 24 **(15 marks)**

(a) A stress of 75 N mm^{-2} is applied to wire samples of aluminium, brass and copper.

(i) Identify which of the samples will enter the plastic region of deformation and which will remain within the elastic region by circling the correct answer. (3 marks)

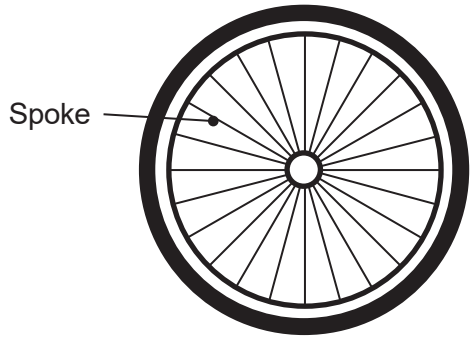
aluminium	plastic region	**or**	elastic region
brass	plastic region	**or**	elastic region
copper	plastic region	**or**	elastic region

(ii) Explain the reasoning for your answers. (2 marks)

See next page

Question 24 (continued)

A bicycle wheel consists of a tyre, a rim, multiple spokes and a hub. The spokes are wires that connect the rim to the hub and are tensioned to keep the wheel in shape and support the tyre. The tensioning of the spokes is similar to two teams pulling at each end of a rope in a tug-of-war.



The spokes of the bicycle wheel shown above are made from stainless steel, are 293 mm long and have a circular cross-section.

(b) Calculate the diameter of a spoke used for the bicycle wheel. The tensile loading of the spoke is 150 N and the stress is 52.91 N mm^{-2}. Answer in units of millimetres (mm).

(5 marks)

Diameter (mm) = _____

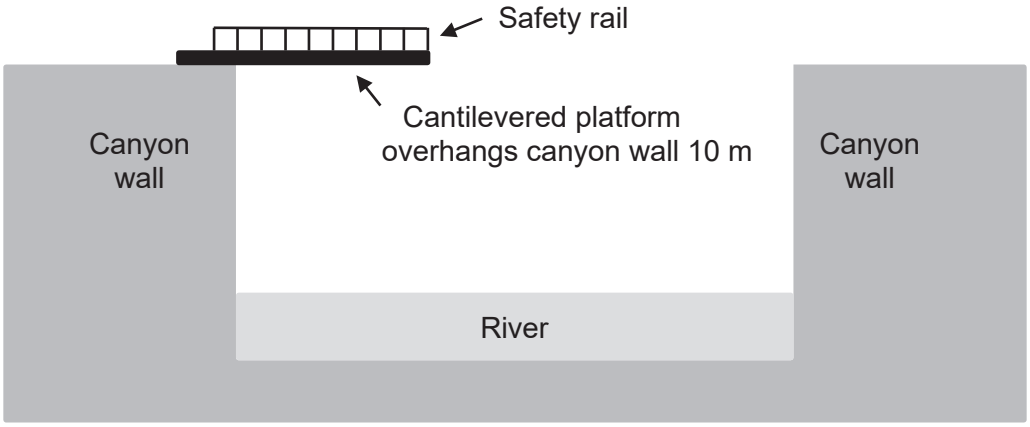
(c) Calculate the elongation of a spoke under the conditions described. Answer in units of millimetres (mm). (5 marks)

Elongation (mm) = _____

See next page

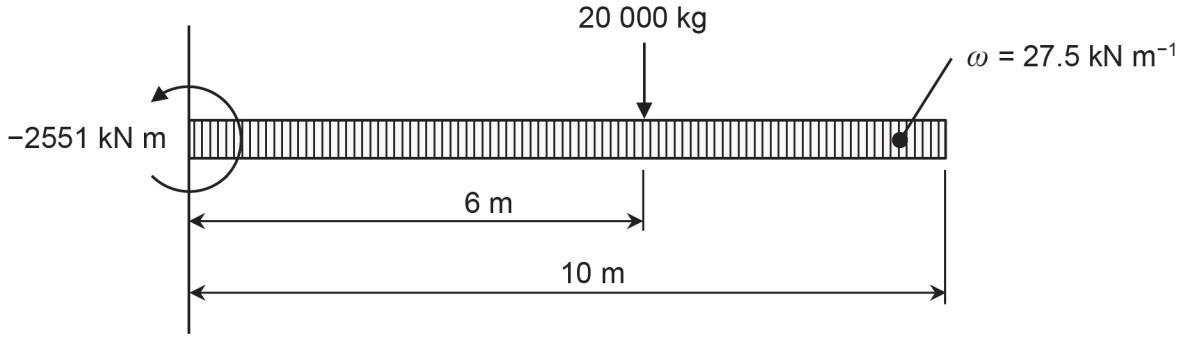
Question 25 **(12 marks)**

The local tourist centre has proposed to build a cantilevered viewing platform that extends 10 metres over a canyon and river that flows within it. The platform will be supported at the top of a cliff face and people can walk onto the platform and look down at the scenery below.



Cross-sectional view of the cantilevered viewing platform overlooking the river

The platform has a uniformly distributed self-weight of 27.5 kN m^{-1} and, as part of the testing of the facility, a point load of 20 000 kg mass is applied 6 metres from the supported end. The reaction moment at the supported end is −2551 kN m (assuming clockwise rotation is positive and anticlockwise is negative). This information is shown in the beam diagram below:



(a) Calculate the shear forces at the following **four** locations. Answer in units of kilonewtons (kN). (7 marks)

SF_1 = the supported end
SF_2 = just to the left of the 20 000 kg mass
SF_3 = just to the right of the 20 000 kg mass
SF_4 = the unsupported end

SF_1 (kN) = _____

SF_2 (kN) = _____

SF_3 (kN) = _____

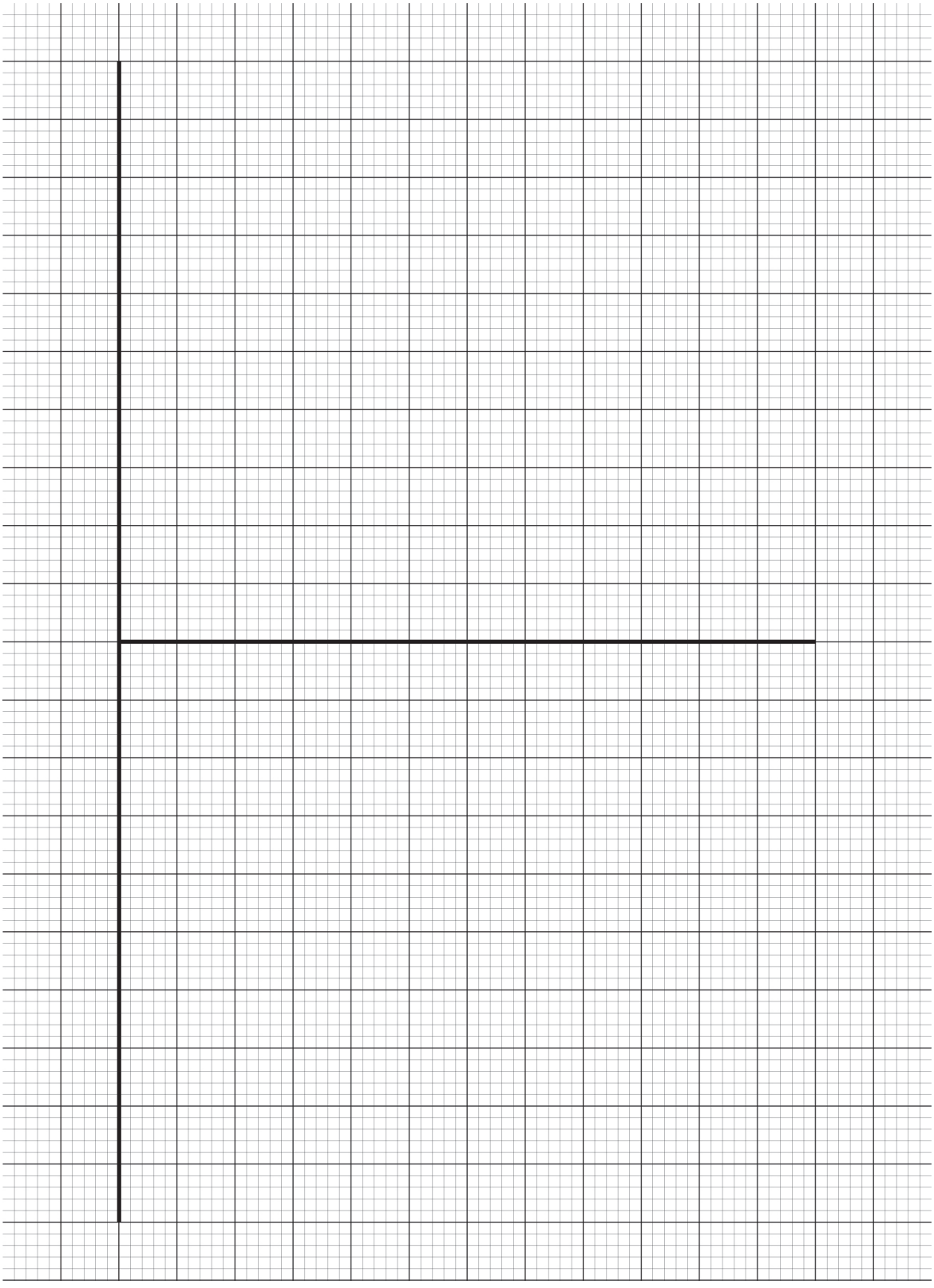
SF_4 (kN) = _____

See next page

Question 25 (continued)

(b) On the grid provided below, sketch a suitably scaled and fully labelled shear force diagram of the loaded beam. Both axes for the shear force diagram have been provided.

(5 marks)



A spare grid is provided at the end of this Question/Answer booklet. If you need to use it, cross out this attempt and indicate that you have redrawn it on the spare grid.

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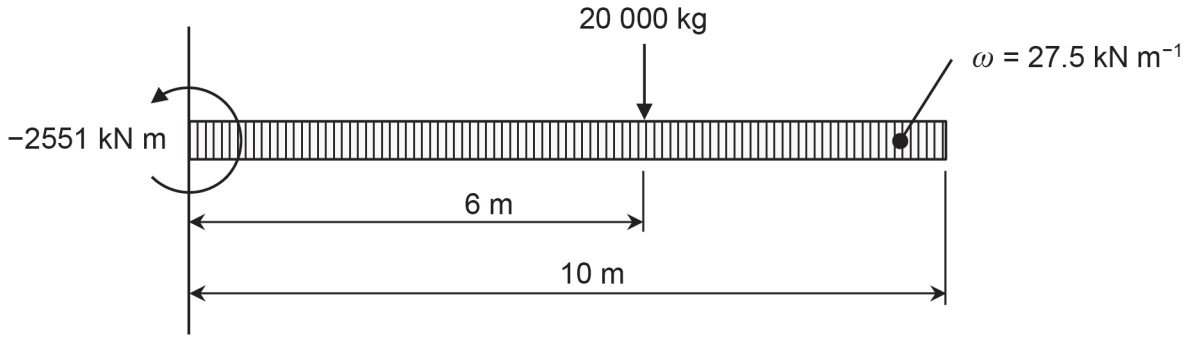
Question 26 **(12 marks)**



The beam diagram shown above is identical to that used for Question 25 on page 24.

(a) Working from left to right, calculate the bending moments at the following **four** locations. Answer in units of kilonewton metres (kN m). (8 marks)

BM_1 = the supported end
BM_2 = 3 m to the right of the supported end
BM_3 = 6 m to the right of the supported end
BM_4 = the unsupported end

BM_1 (kN m) = _____

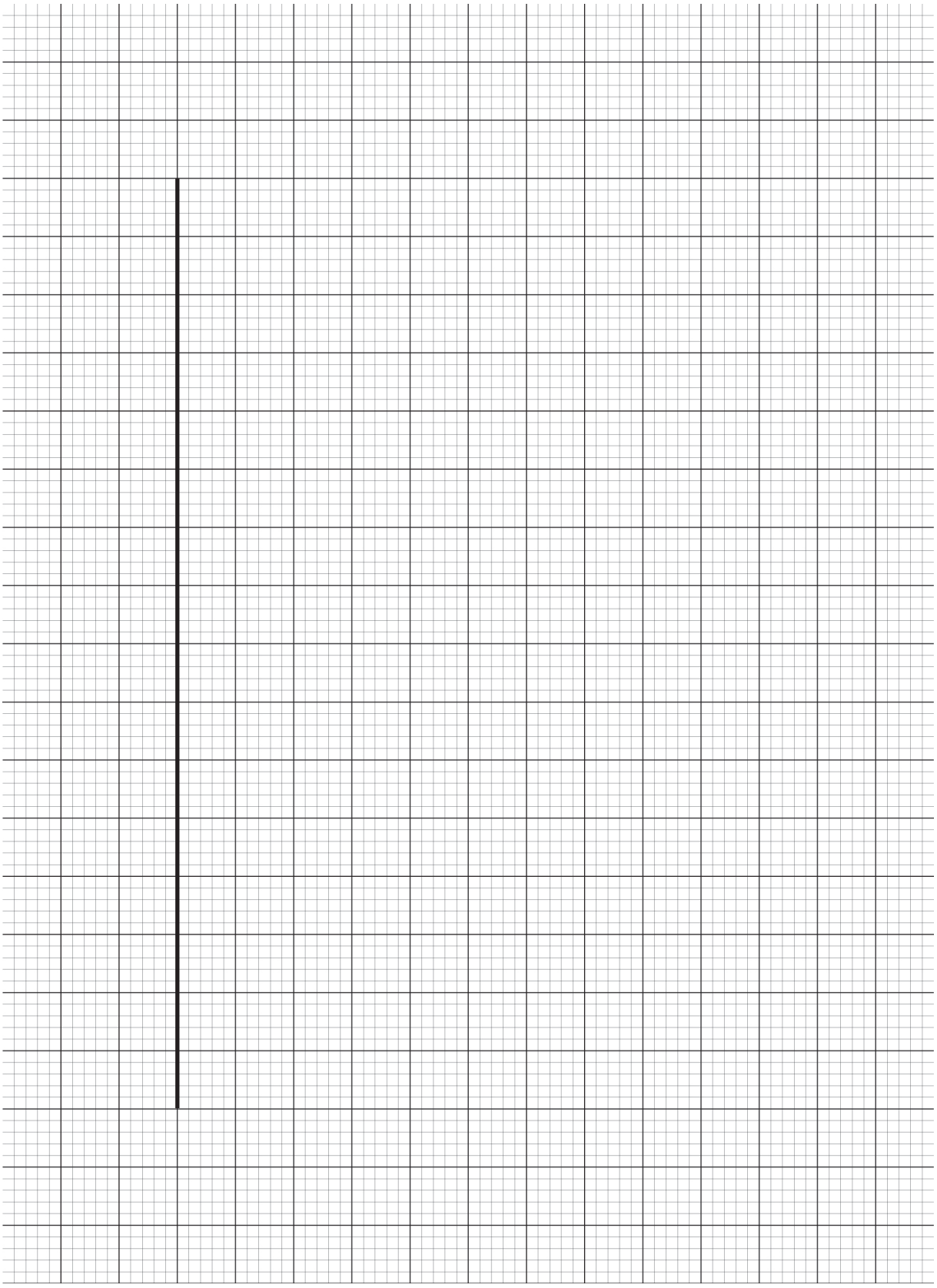
BM_2 (kN m) = _____

BM_3 (kN m) = _____

BM_4 (kN m) = _____

See next page

(b) On the grid provided below, sketch a suitably scaled and fully labelled bending moment diagram of the loaded beam. The vertical axis for the bending moment diagram has been provided. (4 marks)



A spare grid is provided at the end of this Question/Answer booklet. If you need to use it, cross out this attempt and indicate that you have redrawn it on the spare grid.

See next page

Question 27 **(19 marks)**

A raceway has been built that allows high performance motor vehicles to conduct time trials over a straight-line distance of 400 metres.

(a) Consider one trial where a vehicle accelerates uniformly from rest for the whole 400 m distance, completing the trial in 14.2 seconds.

(i) Calculate a, the uniform acceleration of the vehicle. Answer in units of metres per second squared (m s^{-2}). (3 marks)

a (m s^{-2}) = _____

(ii) Calculate v, the velocity of the vehicle, at the 400 m mark. Answer in units of kilometres per hour (km h^{-1}). If you could not obtain an answer for part (a)(i) then use a = 4.0 m s^{-2}. (3 marks)

v (km h^{-1}) = _____

(b) During a trial of a different vehicle on the same track, it was measured to be travelling at 216 km h^{-1} at the 400 m mark, 13.333 seconds after it left the start line.

(i) Calculate E_K, the kinetic energy of the vehicle, at the 400 m mark, assuming it has a mass of 1500 kg. Answer in units of joules (J). (3 marks)

E_K (J) = _____

See next page

(ii) Calculate F, the force supplied by the vehicle to reach the 400 m mark at 13.333 seconds after starting. Answer in units of newtons (N). (3 marks)

F (N) = _____

(iii) Calculate P, the average power of the vehicle, in reaching the 400 m mark. Answer in units of watts (W). (3 marks)

P (W) = _____

Racetrack regulations require a minimum length of track to be installed to cater for brake failure. The average friction of the track is a deceleration of 1 m s^{-2} and the maximum expected velocity at the 400 m mark is 65 m s^{-1}.

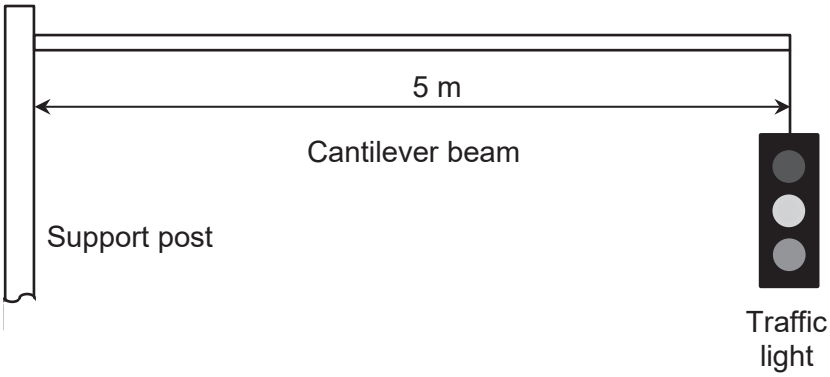
(c) Calculate l, the minimum length of track from the start line to cater for brake failure of a vehicle at the 400 m mark. Answer in units of metres (m). (4 marks)

l (m) = _____

See next page

Question 28 **(21 marks)**

A traffic light with a mass of 52 kg is suspended from the end of a cantilevered beam, as shown in the diagram below. The beam is made of structural steel and is 5 m long. The cross-section of the beam is a circular tube with an outside diameter of 200 mm.



(a) The second moment of area, I_{xx}, of the cantilever beam is 14 568 645 mm^{-4}. Prove by calculation that the wall thickness of the circular tube is 5 mm. (6 marks)

See next page

(b) Prove by calculation that the mass of the cantilever beam (to three decimal places) is 120.225 kg. (5 marks)

(c) Calculate y, the deflection of the cantilever beam at its unsupported end due to its self-weight only. Answer in units of millimetres (mm). (5 marks)

y (mm) = _____

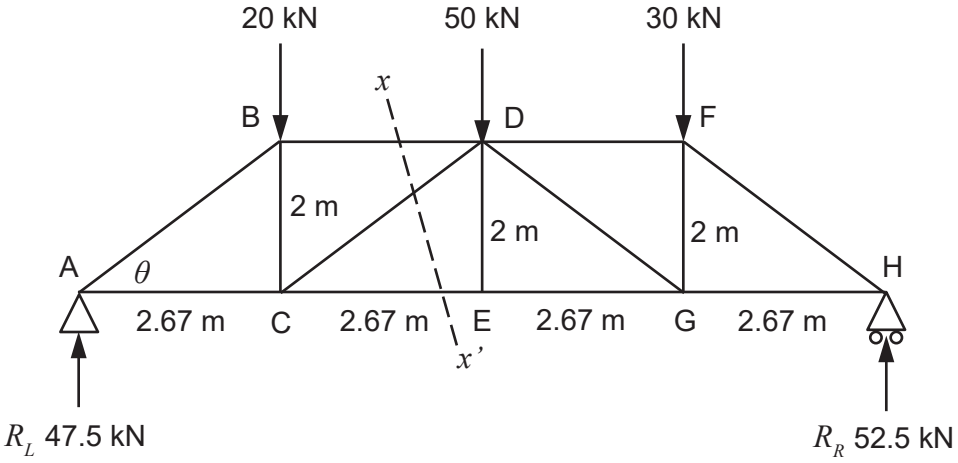
(d) Calculate the total deflection of the cantilever beam at its unsupported end. Answer in units of millimetres (mm). (5 marks)

Total deflection (mm) = _____

See next page

Question 29 **(21 marks)**

The schematic below represents a Howe truss, a structure that has been used in the past to construct bridges.



(a) Prove by calculation that reactions R_R and R_L are 52.5 kN and 47.5 kN respectively. (5 marks)

(b) Prove by calculation that the angle θ is 36.836°. (2 marks)

See next page

(c) By working to the left of section xx', use the method of sections to calculate F_{BD}, the force in Member BD, and identify whether it is in tension or compression. (4 marks)

F_{BD} (kN) = _____

Tension or compression: _____

(d) By working to the left of section xx', use the method of sections to calculate F_{CD}, the force in Member CD, and identify whether it is in tension or compression. (5 marks)

F_{CD} (kN) = _____

Tension or compression: _____

See next page

Question 29 (continued)

(e) By working to the left of section xx', use the method of sections to calculate F_{CE}, the force in Member CE, and indicate whether it is in tension or compression. (5 marks)

F_{CE} (kN) = _____

Tension or compression: _____

End of Mechanical Section

Section Two: Specialist field – Mechatronics **60% (110 Marks)**

This section has **two** parts.

Part A: Multiple-choice Answer **all** questions

Part B: Extended answer Answer **all** questions

Suggested working time: 110 minutes.

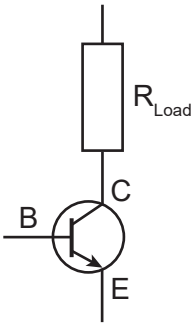
Part A: Multiple-choice **10% (10 Marks)**

This part has **10** questions. Answer **all** questions on the separate Multiple-choice answer sheet provided. For each question, shade the box to indicate your answer. Use only a blue or black pen to shade the boxes. Do not use erasable or gel pens. If you make a mistake, place a cross through that square, then shade your new answer. Do not erase or use correction fluid/tape. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

---

30. An NPN transistor with a load resistor is shown in the diagram below. If the transistor is operating in its saturation region of operation, an increase in its base current will result in

(a) an increase in the power dissipated by the load resistor.
(b) an increase in the transistor's emitter current.
(c) a decrease in the collector-emitter voltage of the transistor.
(d) a decrease in the base-emitter voltage of the transistor.

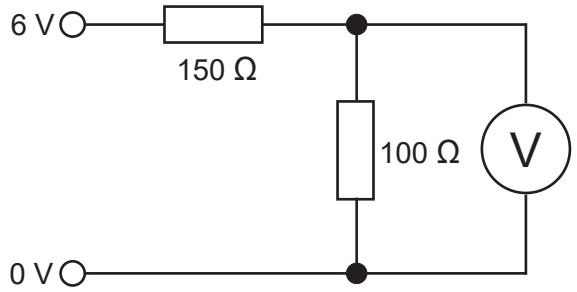


31. A resistor is connected across the terminals of a battery and dissipates a certain amount of power. A second resistor of equal value is now connected in parallel with the first resistor. The power supplied by the battery will

(a) be halved.
(b) remain the same.
(c) double.
(d) quadruple.

See next page

32. In the circuit below, the voltmeter reading is 6 V. Which of the following scenarios would cause this? Note: a closed circuit means the resistor acts as a closed switch and open circuit means the resistor acts as an open switch.



	150 Ω resistor	100 Ω resistor
(a)	working normally	working normally
(b)	open circuit	working normally
(c)	closed circuit	open circuit
(d)	working normally	closed circuit

33. A two stage mechanical drive system has a velocity ratio of 2.5:1 for its first stage and 6:1 for the second stage. The measured output is 130 revolutions per minute (rpm). Which of the following is the input for the system?

(a) 8.66 rpm
(b) 15.29 rpm
(c) 1105 rpm
(d) 1950 rpm

34. A resistor with bands coloured orange white black gold is connected in parallel with a resistor with bands coloured red violet brown gold. The total resistance of this arrangement is

(a) 34.08 Ω.
(b) 159.5 Ω.
(c) 309 Ω.
(d) 660 Ω.

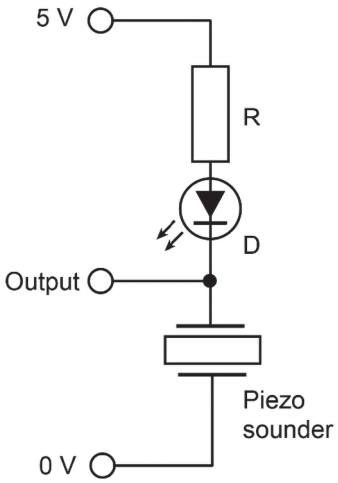
35. If the resolution of an ADC pin of a microcontroller is 10-bit and the range of voltages inputted to it is 0–5 V, then each bit will be an increment of

(a) 4.89 mV.
(b) 19.61 mV.
(c) 48.88 mV.
(d) 500.00 mV.

See next page

36. An LED (with current limiting resistor) and a piezo sounder are connected to an output pin of a microcontroller, as shown in the diagram below. When the output is low, then

(a) both the LED and the piezo sounder will be on.
(b) both the LED and piezo sounder will be off.
(c) the LED will be on and the piezo sounder will be off.
(d) the LED will be off and the piezo sounder will be on.



37. In a closed loop system, the name of the component used for comparing the actual output with the desired input is the

(a) error detector.
(b) feedback sensor.
(c) set point.
(d) output actuator.

38. Which of the following conditions will allow a diode to conduct a current?

(a) anode negative and cathode positive
(b) anode positive and cathode negative
(c) anode and cathode both positive
(d) anode and cathode both negative

39. Which of the following is used to convert constant rotational motion from a motor into constant linear motion?

(a) cam and follower
(b) crank and slider
(c) windscreen wiper
(d) conveyor belt

See next page

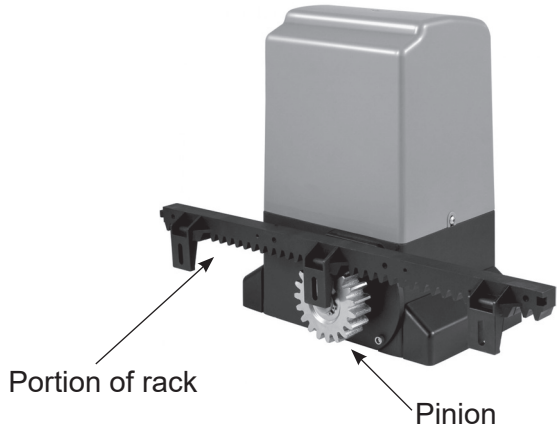
Part B: Extended answer **50% (100 Marks)**

This section has **six** questions. Answer **all** questions. Write your answers in the spaces provided.

When calculating answers, show all your working clearly. Your working should be in sufficient detail to allow your answers to be checked readily and for marks to be awarded for reasoning. In final answers, include appropriate units where applicable.

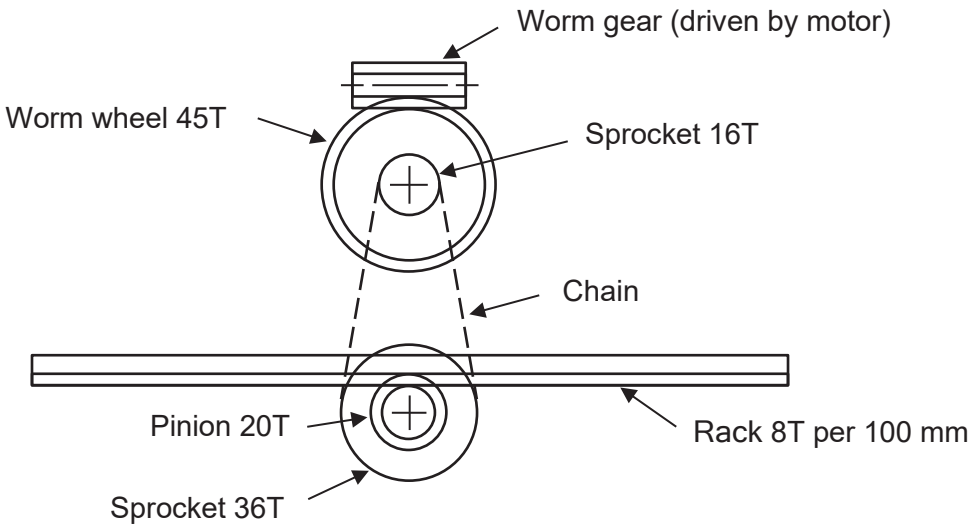
Supplementary pages for planning/continuing your answers to questions are provided at the end of this Question/Answer booklet. If you use these pages to continue an answer, indicate at the original answer where the answer is continued, i.e. give the page number.

Question 40 **(15 marks)**



A sliding gate, like the one shown above left, is opened and closed using a rack and pinion mechanism. The rack is fitted to the gate and the pinion to the output shaft of a motorised unit, like the one shown above right that is fixed in place to the ground.

The drive system of a sliding gate is shown below.



Drive system of sliding gate

See next page

The time it takes for the sliding gate to open fully is 20 seconds over a distance of 4 metres.

(a) Calculate the input speed of the motor that is attached to the worm gear. Assume the drive system is 100% efficient and answer in units of revolutions per minute (rpm). (7 marks)

Input speed of motor (rpm) = _____

To enable the sliding gate to move in either direction, plus be stationary when fully open or fully closed, it must be possible to cause the motor to rotate both forward and reverse, as well as stop.

(b) By referring to the potential difference across the terminals of a DC electric motor, explain how this is achieved by using an H-bridge integrated circuit like an L293D. (3 marks)

_____

_____

_____

_____

_____

_____

See next page

Question 40 (continued)

Suppose the programming of the sliding gate requires the closing cycle to take 5 seconds longer than the opening cycle, i.e. 25 seconds. Without changing the mechanical drive system, this could be achieved using pulse width modulation (pwm) to control the speed of the motor.

(c) If the frequency is 80 Hz, calculate the following pwm parameters:

(i) Period. Answer in units of milliseconds (ms). (2 marks)

Period (ms) = _____

(ii) Duty cycle. Answer as a percentage (%). (2 marks)

Duty cycle (%) = _____

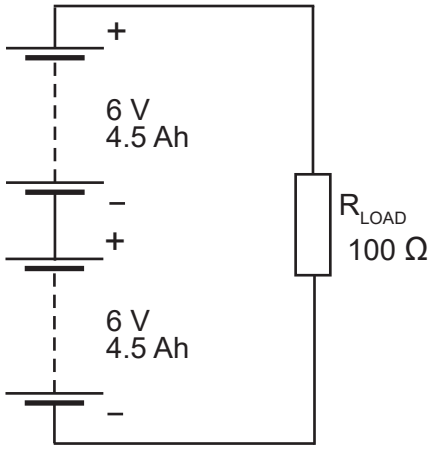
(iii) Low time. Answer in units of milliseconds (ms). (1 mark)

Low time (ms) = _____

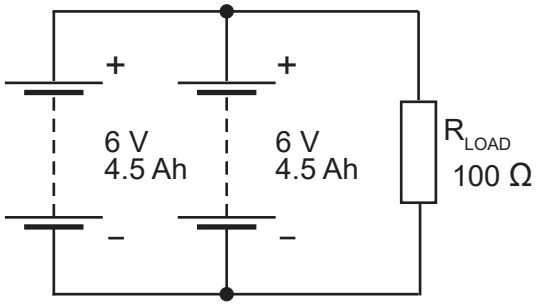
See next page

Question 41 **(17 marks)**

Batteries are a common means of storing and supplying electric charge. Suppose identical batteries (i.e. same voltage and current capacity) are connected to identical loads (represented by a resistor) using two different arrangements, as shown in the diagrams below.



Circuit A



Circuit B

(a) Identify if Circuit A **or** Circuit B will result in a power dissipation by the load that is greater than the other by circling the correct answer. Provide calculations to support your choice. (3 marks)

Circuit A **or** Circuit B (circle your answer)

Supporting calculations

(b) Identify if Circuit A **or** Circuit B will deliver current to the load for a longer period of time by circling the correct answer. Provide calculations to support your choice. (5 marks)

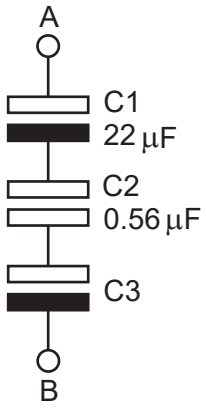
Circuit A **or** Circuit B (circle your answer)

Supporting calculations

See next page

Question 41 (continued)

Capacitors are another means of storing and discharging electric charge. Three capacitors of different values are connected as shown in the diagram below.



(c) The basic structure of a capacitor consists of two plates that store electric charge separated by a thin layer of dielectric material. State **two** purposes of the dielectric material.

(2 marks)

One: _____

_____

Two: _____

_____

(d) A 3-digit code is printed on the side of C2.

(i) State the numbers used for the 3-digit code printed on C2. (1 mark)

_____

(ii) Describe how you determined the numbers used for the 3-digit code printed on C2. (2 marks)

_____

_____

_____

_____

See next page

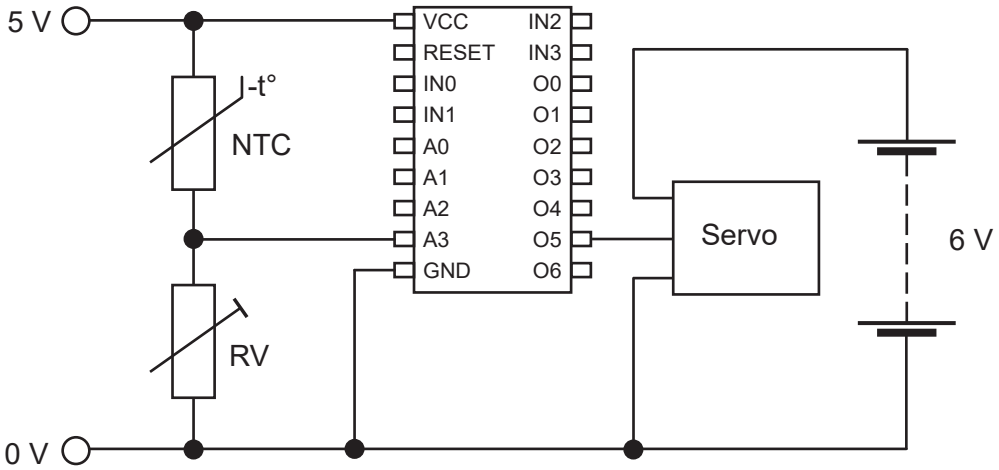
(e) The total capacitance required across AB, C_{AB}, is 0.469 μF. Calculate C_3, the unknown capacitance of C3. Answer in units of microfarads (μF). (4 marks)

C_3 (μF) = _____

See next page

Question 42 **(15 marks)**

The circuit below is designed to cause a 0–180° servo to alter the angular position of its output spindle with changes to the temperature detected by the potential divider that is connected to Pin A3. Such a circuit could be used to control the degree to which a vent or valve is opened or closed to control the flow of gases or liquids in a heat exchange system.



(a) State **two** reasons why it is good practice to use a separate supply of electricity for the servo (6 V battery in the above circuit) to that used for the microcontroller (5 V power supply). (2 marks)

One: _____

_____

Two: _____

_____

(b) State **three** reasons why it is necessary to connect the ground wire of the servo to the GND pin of the microcontroller to enable the circuit to control the servo's movements. (3 marks)

One: _____

_____

Two: _____

_____

Three: _____

_____

See next page

(c) A rise in temperature is detected by NTC in the circuit on page 46. Identify the effect this will have on the following by circling the correct response. (3 marks)

voltage across RV:	decrease	**or**	increase	**or**	no change
resistance of RV:	decrease	**or**	increase	**or**	no change
current through NTC:	decrease	**or**	increase	**or**	no change

(d) Suppose that the 10-bit ADC value produced at Pin A3 is 312 and the resistance of RV is 10 750 Ω. Calculate R_{NTC}, the resistance of NTC. Answer in units of ohms (Ω). (5 marks)

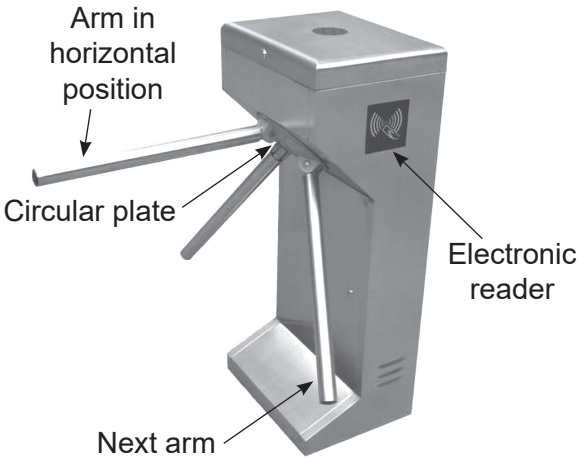
R_{NTC} (Ω) = _____

(e) To control the movement of the servo spindle, the full range of values produced by the ADC at Pin A3 is mapped against the servo's 0–180° range of rotation. Calculate $x°$, the rotation in degrees of the servo spindle when the 10-bit value is as for part (d), i.e. 312. (2 marks)

x° = _____

See next page

Question 43 **(15 marks)**



To control the entry and exit of visitors into a small gallery, a museum installs two turnstiles like the one pictured to the left, one at the entry and the other at the exit.

Each turnstile has a circular plate with three tubular arms protruding from it. A visitor pushing through the horizontal arm will cause the circular plate to rotate and the next arm to follow behind them and move into the horizontal position.

The two turnstiles are linked to an automated system. Signs mounted above the entry and exit turnstiles (see below), each with inbuilt coloured lights, provide instructions for the visitors on how to enter or exit the gallery.

Entry

Maximum of 10 visitors allowed in gallery

1. If red light is on, 10 visitors are already in the gallery. Please wait for it to turn off before placing ticket on electronic reader
2. Hold ticket on electronic reader
3. When green light turns on, enter gallery by pushing through the turnstile

Exit

1. Hold ticket on electronic reader
2. When green light turns on, exit gallery by pushing through the turnstile

The automated system works by achieving the following four criteria:

(i) Starting the system causes all the lights in the signs to be turned off, both turnstiles to lock and a variable, 'x', to be set such that $x = 0$.

(ii) Entry: Holding a ticket against the electronic reader of the entry turnstile will turn on the green light in the sign above the entry and unlock the turnstile.

As the visitor pushes through the turnstile to enter the gallery, the next arm will follow behind them. When it is detected as being horizontal, it will cause three actions: the green light turns off, the turnstile locks and variable 'x' increases by 1.

(iii) Exit: Holding a ticket against the electronic reader of the exit turnstile will turn on the green light in the sign above the exit and unlock the turnstile.

As the visitor pushes through the turnstile to exit the gallery, the next arm will follow behind them. When it is detected as being horizontal, it will cause three actions: the green light turns off, the turnstile locks and variable 'x' decreases by 1.

(iv) If there are 10 visitors in the gallery, the red light on the sign above the entry turnstile will glow and the entry turnstile remains locked until a visitor exits.

See next page

(a) In the space below, draw a fully labelled flow chart of the system that meets the **four** criteria required to control the turnstiles and coloured light signals by constantly monitoring the number of visitors in the gallery. (12 marks)

Start

A spare flow chart is provided at the end of this Question/Answer booklet. If you need to use it, cross out this attempt and indicate that you have redrawn it on the spare flow chart.

See next page

Question 43 (continued)

(b) Identify whether the turnstile control system is an example of an open loop **or** closed loop system by circling the correct answer. State **two** reasons to support your answer.

(3 marks)

open loop **or** closed loop (circle your answer)

One: _____

_____

Two: _____

_____

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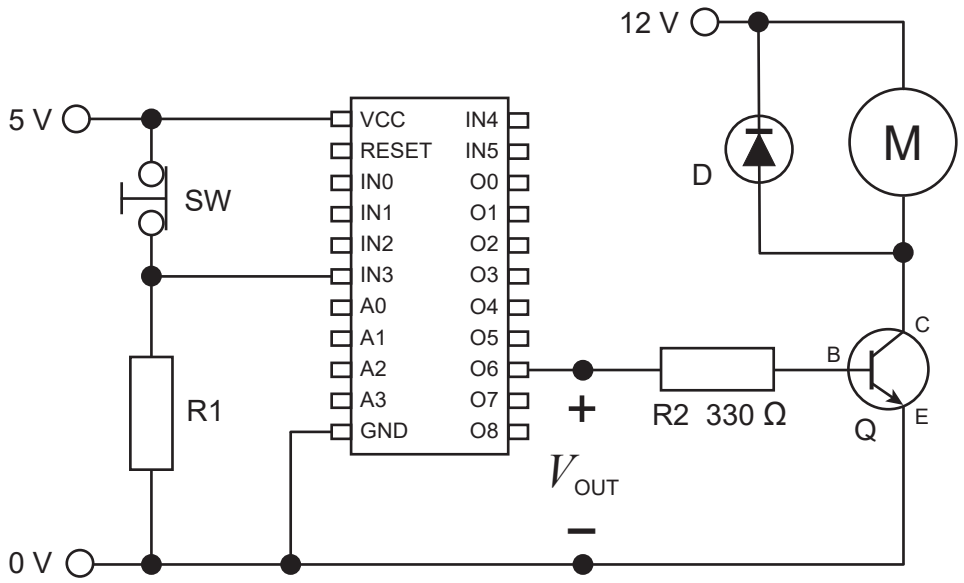
See next page

Question 44 **(23 marks)**

The circuit shown below contains a microcontroller that is interfaced with a digital input and a transistor that controls the current for an electric motor.



(a) When SW, a push-to-break switch, is pressed, will the signal detected at Pin IN3 be high **or** low? Referring to your knowledge of circuit behaviour and a relevant electrical law, explain why. (3 marks)

high **or** low (circle your answer)

Explanation: _____

_____

_____

_____

(b) The diode, D, is an essential component of the above circuit that enables it to function correctly.

(i) When Pin O6 is high the transistor, Q, will allow the motor to draw a current and its spindle will rotate. The diode will have no effect on the behaviour of the circuit. Describe why this is the case. (2 marks)

_____

_____

_____

_____

See next page

(ii) When Pin O6 is low the transistor, Q, will block the flow of current through the motor, causing it to stop rotating. The diode will now protect the transistor from overheating due to back e.m.f. that is generated by magnetic energy in the coils of the motor transforming into a very large voltage spike. Explain how the diode achieves this crucial function. (3 marks)

When Pin O6 of the microcontroller is low then V_{OUT} = 0 V, and when it is high then V_{OUT} = 5 V. The transistor, Q, has a gain (β) of 40.

(c) Suppose O6 is **high**. Shortly after starting, the motor reaches a constant running speed and, V_{CE}, the collector-emitter voltage of Q is measured as a steady 2 V.

(i) Calculate I_E, the emitter current of Q. Answer in units of amps (A). (4 marks)

I_E (A) = _____

See next page

Question 44 (continued)

(ii) Calculate P_M, the power dissipated as heat by the motor when it is at its constant running speed. Answer in units of watts (W). (3 marks)

P_M (W) = _____

(iii) Calculate $P_{Q,TOTAL}$, the total power dissipated as heat by the transistor when the motor is at its constant running speed. Answer in units of watts (W). (5 marks)

$P_{Q,TOTAL}$ (W) = _____

Suppose Pin O6 is now low.

(d) Calculate V_{CE}, the collector emitter voltage of Q. (3 marks)

V_{CE} (V) = _____

See next page

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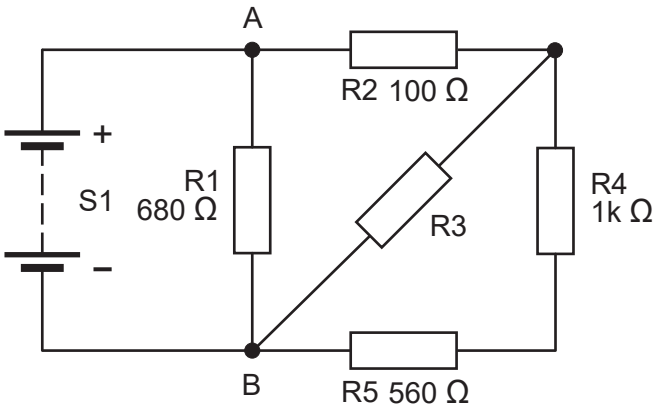
See next page

Question 45 **(15 marks)**

The circuit shown below contains five resistors and is connected to S1, a 9 V battery. The values of all the resistors except R3 are given on the diagram.



R_{AB}, the resistance between nodes A and B on the diagram, is 274.81 Ω.

(a) Calculate I_{R2}, the current that flows through R2. Answer in units of amps (A). (4 marks)

I_{R2} (A) = _____

(b) Calculate V_{R3}, the voltage across R3. If you could not calculate an answer for part (a), use 0.0196 A. (3 marks)

V_{R3} (V) = _____

See next page

(c) Calculate P_{R5}, the power dissipated by R5. Answer in units of watts (W). (4 marks)

P_{R5} (W) = _____

(d) Calculate R_3, the unknown resistance of R3. Answer in units of ohms (Ω). (4 marks)

R_3 (Ω) = _____

End of questions

Supplementary page

Question number: _____

Supplementary page

Question number: _____

Supplementary page

Question number: _____

Supplementary page

Question number: _____

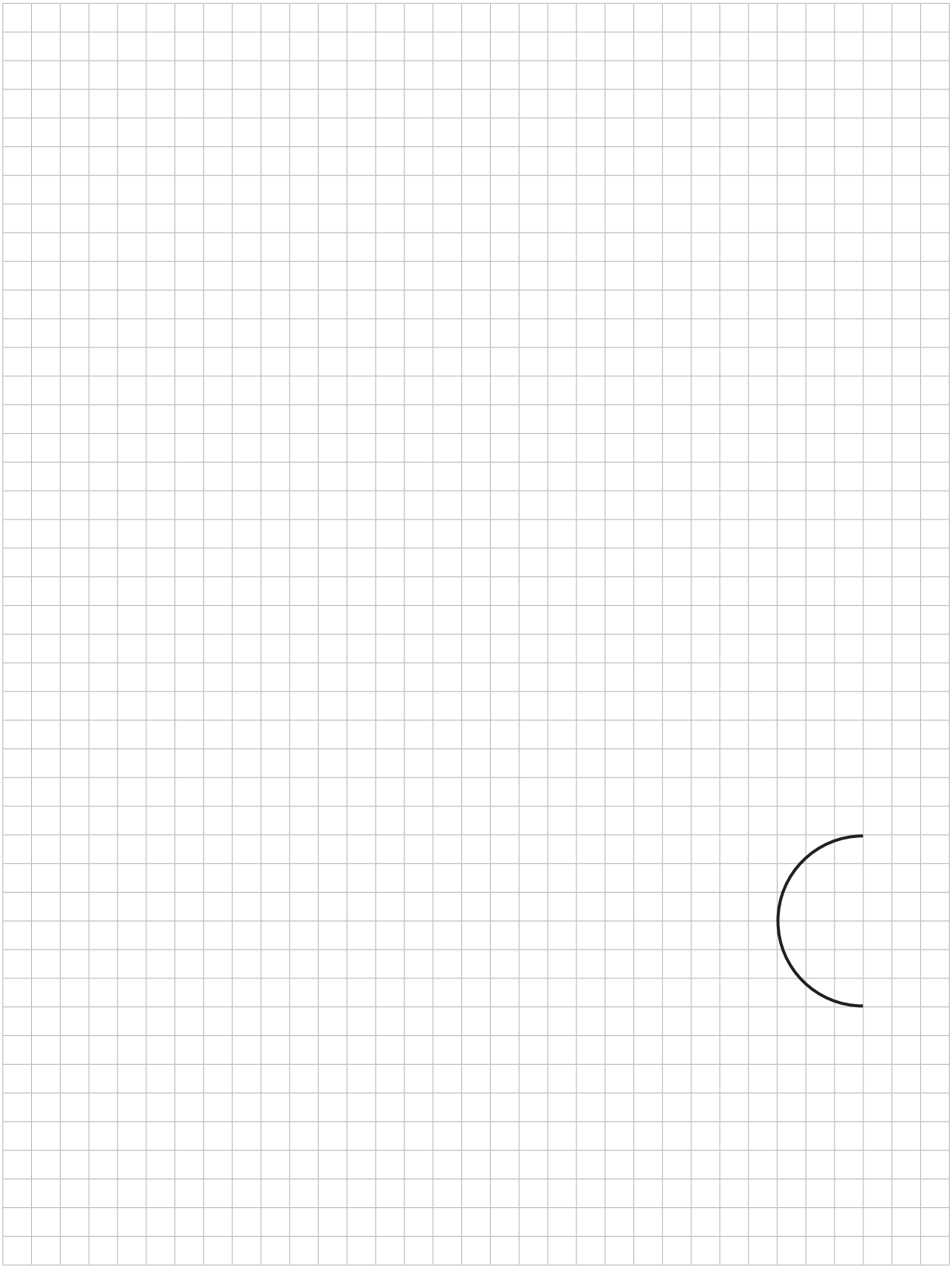
Supplementary page

Question number: _____

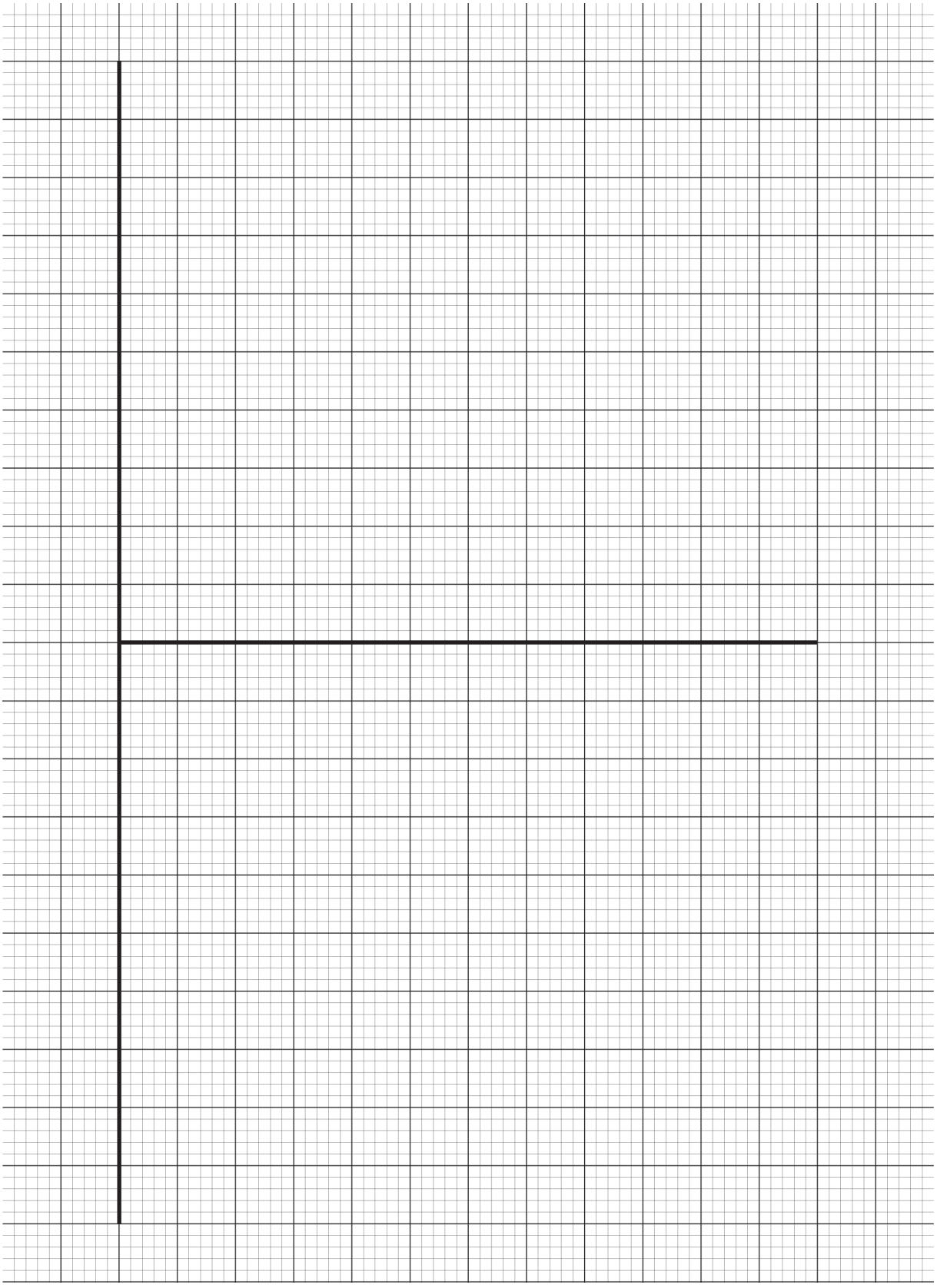
Supplementary page

Question number: _____

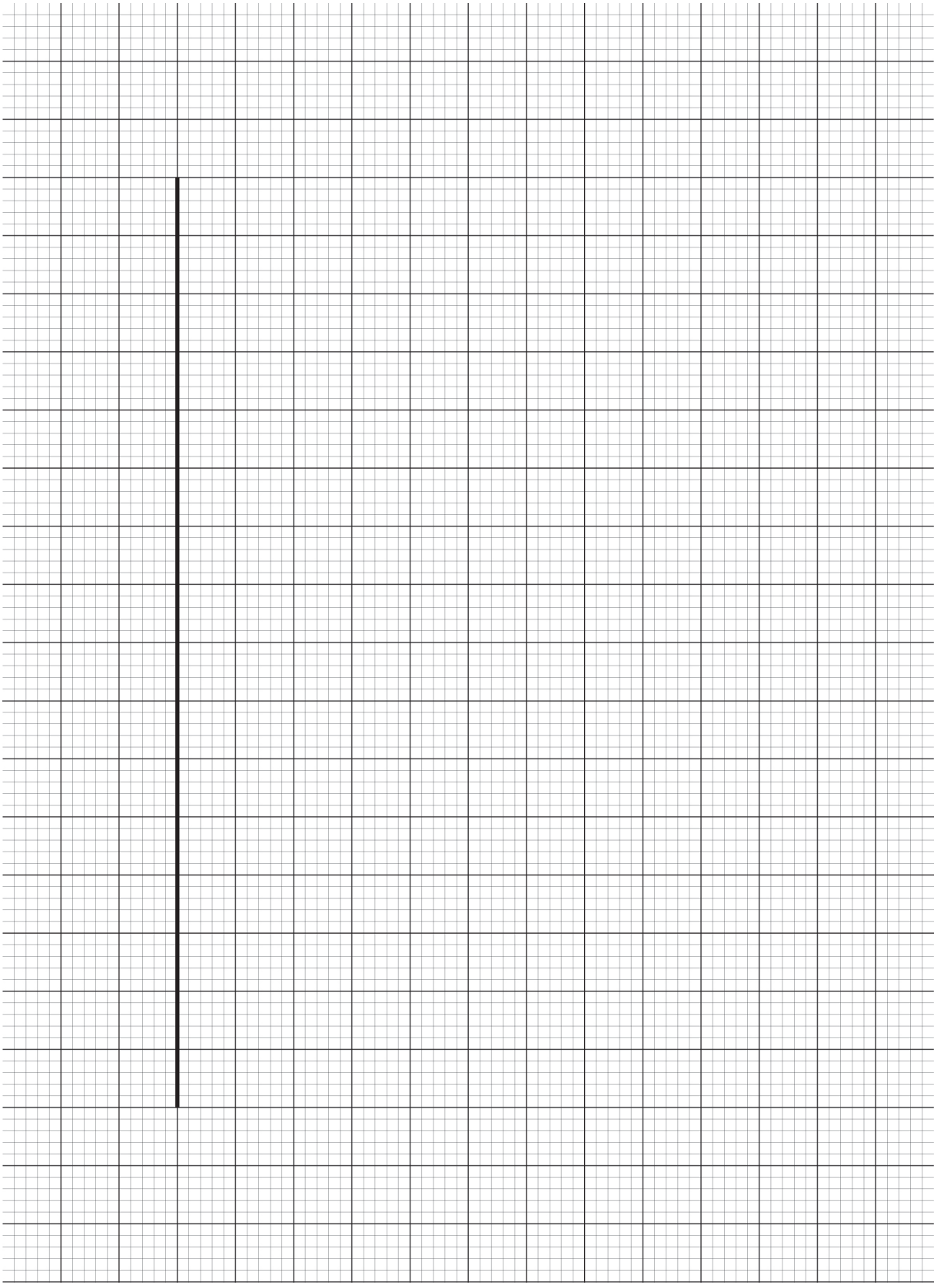
Spare grid for Question 11(a)



Spare grid for Question 25(b)



Spare grid for Question 26(b)



Spare flow chart for Question 43(a)

ACKNOWLEDGEMENTS

Question 12(b) Barbhuiya, T. (2019). *Steel Ladder to Swimming Pool* [Photograph]. Retrieved July, 2024, from https://www.pexels.com/photo/steel-ladder-to-swimming-pool-11484104/

Question 40 [Photograph of an automatic sliding metal gate]. (n.d.). Retrieved, May, 2024, from https://i.pinimg.com/originals/48/77/c1/4877c1c90bf3542d0a359a0b5b05e72c.jpg

[Photograph of an automatic gate opener]. (n.d.). Retrieved, May, 2024, from https://www.vevor.com.au/automatic-gate-opener-c_10530/vevor-sliding-gate-opener-automatic-1800-kg-5-m-gear-track-750w-remote-control-p_010626029017

Question 43 [Photograph of a stainless steel turnstile]. (n.d.). Retrieved, May, 2024, from https://5.imimg.com/data5/QO/LN/MY-9772935/automatic-tripod-turnstile-gate-500x500.jpg

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