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

ATAR course examination, 2023

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** Part A: Multiple-choice	10	10	70	10	10
Part B: Extended answer	3	3		70	30
Section Two **Mechanical** Part A: Multiple-choice	10	10	110	10	10
Part B: Extended answer	6	6		100	50
Section Two **Mechatronics** Part A: Multiple-choice	10	10	110	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 2023: 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% (80 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. Which of the following is the **most** important design criterion for a folding chair?

   (a) it has low mass and is easy to transport and store
   (b) it will not collapse under the weight of the user
   (c) its appearance is attractive and will look stylish
   (d) it is comfortable to sit on for extended periods of time

2. Testing is conducted throughout the product design and manufacture process primarily to

   (a) enable the manufacturer to be aware of faults in the product.
   (b) create efficiencies that will reduce the time to produce the product.
   (c) reduce the likelihood of product returns due to failures.
   (d) enable sales staff to explain to consumers how to use the product.

3. Three systems, 'A', 'B' and 'C', operate in cascade (the output of A is the input to B, and the output of B is the input to C). The individual systems have an energy efficiency of 85%, 90% and 75% respectively. To achieve an energy output of 500 kWh at the output of C, the input at A would need to be

   (a) 286.87 kWh.
   (b) 397.06 kWh.
   (c) 629.63 kWh.
   (d) 871.46 kWh.

4. A common characteristic of all sustainable sources of energy is that they will **not**

   (a) produce greenhouse gases.
   (b) affect the environment.
   (c) be exhausted in the long-term.
   (d) require maintenance to operate.

See next page

5. An engineered product is **best** described as being recyclable if

(a) the materials it is made from can be returned to the production of new products.
(b) it can be sold on or handed down to a new owner who will use it.
(c) it is a reliable, high-quality product that can be used over and over again.
(d) when placed in landfill, it can harmlessly be broken down by microbes.

6. Work is

(a) the rate of transfer of energy by a force acting on an object as it is displaced.
(b) the transfer of energy by a force acting on an object as it is displaced.
(c) done when a force acting on an object results in no change to its position.
(d) found in an object that was stationary and is now in motion.

7. The correct 3rd angle orthographic convention for drawing a centreline is

(a) a continuous thin line.
(b) a continuous thick line.
(c) short evenly spaced dashed lines.
(d) alternating short and long dashed lines.

8. Materials that can be squeezed between rollers into thin sheets rely on which two of the following properties?

I malleability
II compressive strength
III toughness
IV hardness

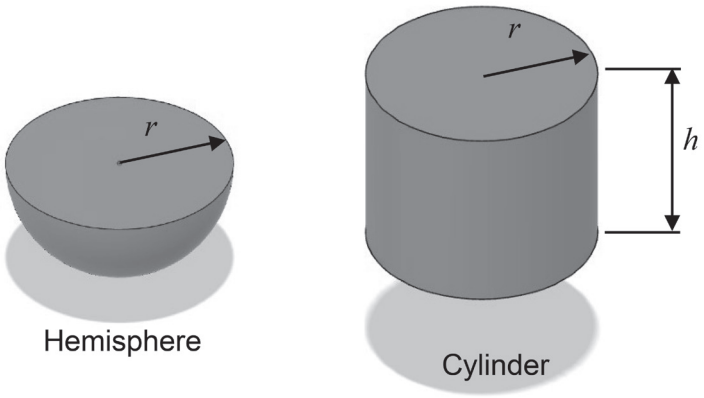
(a) I and II
(b) I and III
(c) II and III
(d) II and IV

9. The materials listed below are made into wires of equal length. If each of these wires is designed to have the same electrical conductivity, which one will have the greatest mass? Use information for density and electrical conductivity in the Data Book to assist with making your choice.

(a) brass
(b) copper
(c) gold
(d) aluminium

See next page

10. Illustrated below are two solid forms. One is a hemisphere and the other is a cylinder.



The combined surface area of these two solid forms can be determined using

(a) $2\pi r^2 + 2\pi rh$.
(b) $3\pi r^2 + 2\pi rh$.
(c) $4\pi r^2 + 2\pi rh$.
(d) $5\pi r^2 + 2\pi rh$.

See next page

Part B: Extended answer **30% (70 Marks)**

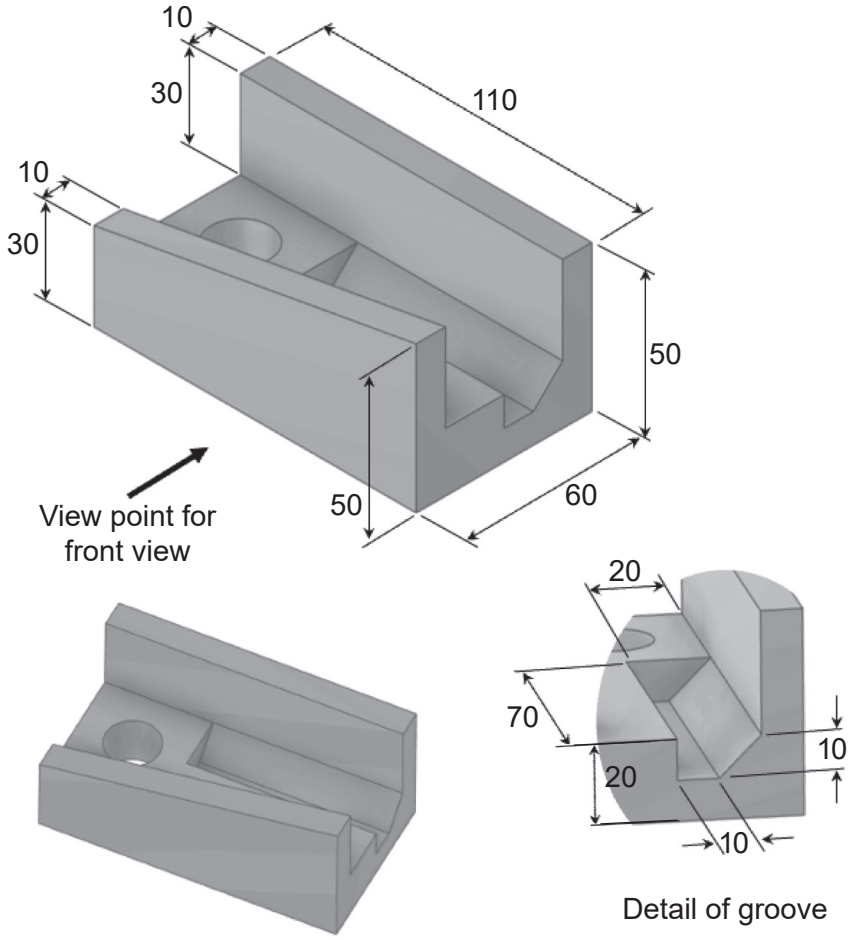
This section has **three** questions. Answer **all** questions. Write your answers in the spaces provided.

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.

Question 11 **(24 marks)**

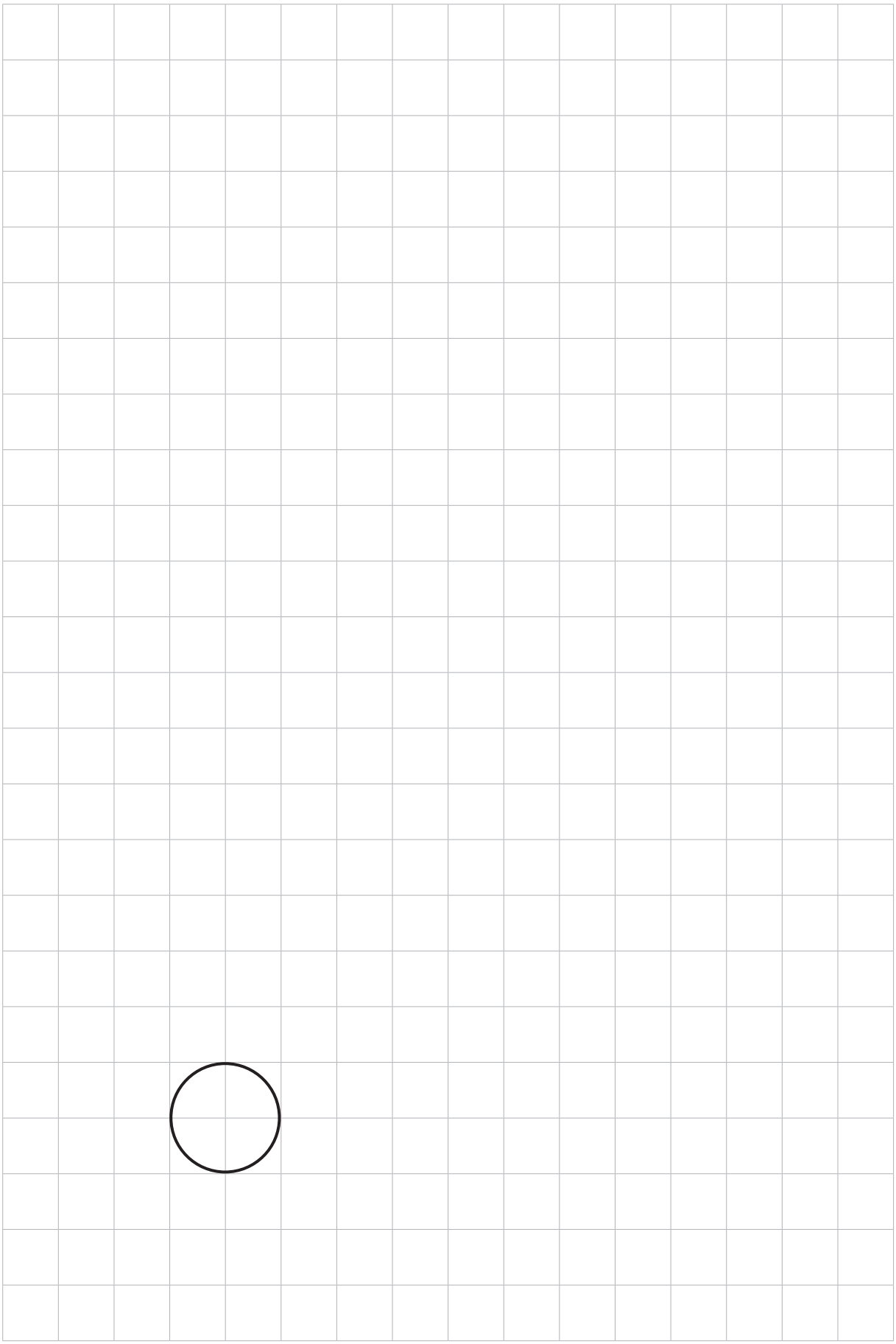
Below are pictorial drawings of a machined metal block. All dimensions are in millimetres. The hole near its left end passes all the way through the material. The hole is 20 mm in diameter and its centre is located 20 mm from the left end along the midline of the block.



(a) Use the grid on page 7 to draw a fully dimensioned top, front and right end view of the machined block. Each square of the grid represents 10 mm × 10 mm. The drawing is full size and must follow 3rd angle orthographic conventions. Each view must be labelled.

To fit the drawing on the grid the page must be turned to a landscape orientation, i.e. sideways. The circle that is printed on the grid is the diameter 20 mm hole as seen in the top view. (11 marks)

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 volume of metal in the machined block. Answer in units of mm^3. (5 marks)

Volume (mm^3) _____

(c) The machined block is made from aluminium. Calculate the mass of the machined block in units of kg. If you could not calculate an answer for part (b), use 165 000 mm^3. (3 marks)

Mass (kg) _____

See next page

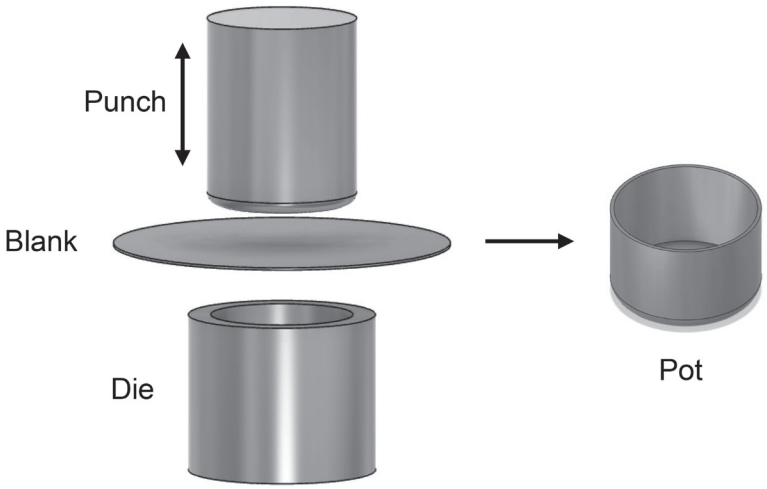
(d) Calculate the total area of the surfaces that are directly seen only in the top view of the machined block. Answer in units of mm^2. (5 marks)

Total area (mm^2) _____

Question 12 **(24 marks)**

A saucepan, like the one shown below, is an item of cookware that is used for heating and cooking liquids on a stovetop. For the purpose of the questions that follow, assume that the type of stovetop uses gas burners.

The pot of the saucepan is made from stainless steel. To manufacture the pot, a circular blank of stainless steel sheet is placed between a punch and a die. The punch pushes down on the blank and presses it into the die. The punch then withdraws and the newly formed pot is ejected from the die. This is illustrated below.



(a) Name **one** of the properties that stainless steel must possess if the pot is to be formed in the manner described above. Define the property and explain why it is essential for this method of manufacture. (4 marks)

Name: _____

Definition: _____

_____

Explanation: _____

_____

_____

_____

See next page

(b) Considering how and where a saucepan is used, name **three** properties that make stainless steel a good choice of material for the pot of a saucepan. Define each property and provide a justification for its inclusion. (12 marks)

One:

Name: _____

Definition: _____

_____

Justification: _____

_____

_____

_____

Two:

Name: _____

Definition: _____

_____

Justification: _____

_____

_____

_____

Three:

Name: _____

Definition: _____

_____

Justification: _____

_____

_____

_____

See next page

Question 12 (continued)

(c) The handle of the saucepan is often made from stainless steel or a polymer, but the base is clad with copper or aluminium. Outline a reason for using these choices of material for the handle and the base of the pot. (4 marks)

Stainless steel or polymer handle: _____

_____

_____

_____

Copper or aluminium clad base: _____

_____

_____

_____

(d) Stainless steel, copper and aluminium are all forms of metal. List **four** characteristics that identify a material as being a typical metal. (4 marks)

One: _____

_____

Two: _____

_____

Three: _____

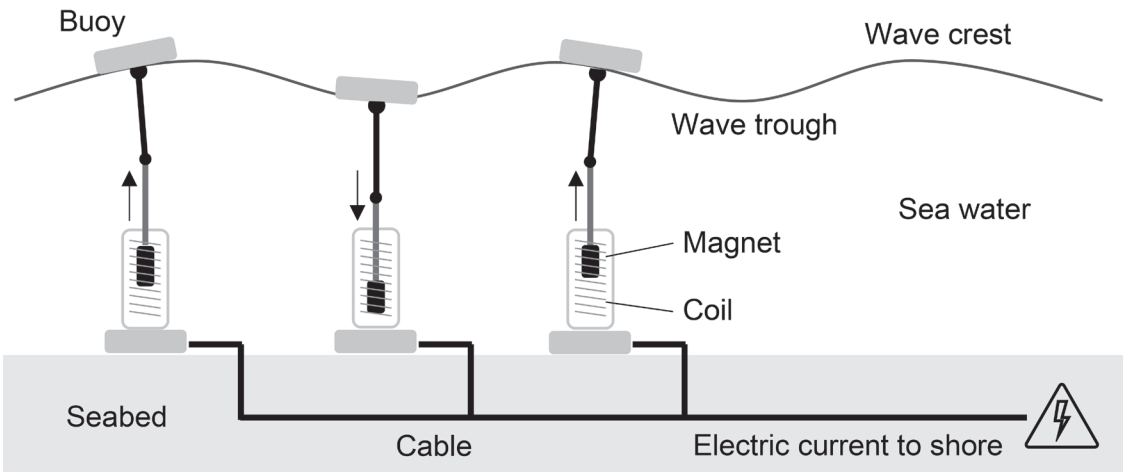
_____

Four: _____

_____

Question 13 **(22 marks)**

The diagram below shows a design for a point absorber wave energy converter (WEC). The WEC generates energy from the ocean by utilising a linear generator and a floating structure (buoy) that is raised and lowered vertically as a wave passes through. The reciprocating motion of the magnet within the linear generator induces an electric current in coils that are fitted inside a waterproof housing. Cables along the seabed pass the electricity to shore.



(a) List and describe **two** challenges associated with implementing and operating a wave energy converter located in deep water. (6 marks)

Challenge one: _____

_____

Description: _____

_____

_____

_____

Challenge two: _____

_____

Description: _____

_____

_____

_____

Question 13 (continued)

The total energy contained in a unit area of an ocean wave (sea surface area) is calculated using:

$$\alpha = \frac{\rho g H^2}{8}$$

Where
α = energy in joules per square metre (J m^{-2})
ρ = density of seawater (kg m^{-3})
g = acceleration due to gravity (9.8 m s^{-2})
H = wave height in metres (m).

(b) Calculate α for a wave height of 4 m. Answer using units of kilojoules per square metre (kJ m^{-2}). (4 marks)

α (kJ m^{-2}) _____

(c) Calculate the sea surface area of the wave from part (b) required to supply sufficient energy to operate a 2 kW heater for 2 hours. Assume an energy conversion efficiency of 86%. Answer using units of square metres (m^2). If you could not calculate an answer for part (b), use 20 kJ m^{-2}. (3 marks)

Sea surface area of wave (m^2) = _____

See next page

The power P of a wave with crest width one metre is calculated using:

$$P = \frac{\rho g^2 H^2 T}{32\pi}$$

Where
P = power in watts (W)
ρ = density of sea water (kg m^{-3})
g = acceleration due to gravity (9.8 m s^{-2})
H = wave height in metres (m)
T = wave period in seconds (s).

(d) Calculate the power of a wave of height 4 m and wave period 8 seconds assuming that the crest width is 7 m. Answer in units of kilowatts (kW). (5 marks)

Power of wave (kW) = _____

Question 13 (continued)

The life cycle analysis (LCA) of an engineered product is broken into seven stages. These are:

- materials acquisition
- processing materials
- manufacture
- packaging
- transport to location
- maintenance and/or operation
- reuse/recycle/disposal.

(e) For a wave energy converter (WEC), select any **two** of the seven LCA stages, and for each selected stage formulate a specific, well-reasoned question that would require answering by the manufacturer of the WEC to inform the public that impacts will be minimised. The two questions must each have a different theme, i.e. do **not** repeat the same (or very similar) question. (4 marks)

One:

LCA stage: _____

Question: _____

_____

_____

_____

_____

_____

Two:

LCA stage: _____

Question: _____

_____

_____

_____

_____

_____

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 2023.

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

Specialist field	✓	Question numbers	Pages
Mechanical	☐	14–29	18–34
Mechatronics	☐	30–45	35–57

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.

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14. Which of the following is the same as working in the units of N mm^{-2}?

    (a) Pa
    (b) kPa
    (c) MPa
    (d) GPa

15. An object of length L and negligible cross-section is fixed at one end and able to rotate about the fixed point. If a force, F, acts on the object, choose the statement below that **best** describes the conditions for the maximum turning moment to be achieved.

    F acts at

    (a) 45 degrees to the length L, and distance L from the fixed point.
    (b) 90 degrees to the length L, and distance L from the fixed point.
    (c) 0 degrees to the length L, and distance L from the fixed point.
    (d) 90 degrees to the length L, and distance $\frac{L}{2}$ from the fixed point.

16. The same stress is applied to two different materials within their proportional limits. The material with the lower Young's Modulus in comparison to the other material will

    (a) elongate less.
    (b) elongate the same amount.
    (c) elongate more.
    (d) undergo plastic deformation.

17. When considering the manufacturing process for a steel alloy axle, cold drawing is often chosen over other processes due to which of the following advantages?

    (a) precision measurements, improved yield strength and better surface finish
    (b) precision measurements, improved corrosion resistance and better surface finish
    (c) greater hardness, improved corrosion resistance and increased toughness
    (d) improved ductility, improved toughness and improved yield strength

See next page

18. A mass moving up an incline (slope) angled at x degrees to the horizontal will experience a decelerating force, the magnitude of which is given by

(a) $mg \tan(x)$.
(b) $mg \cos(x)$.
(c) mg.
(d) $mg \sin(x)$.

19. An object moving in a straight line with a uniformly decreasing velocity has

(a) constant positive acceleration.
(b) constant negative acceleration.
(c) increasing deceleration.
(d) no acceleration.

20. A spanner with a mass of 0.125 kg falls from scaffold at a height of 24 m. Ignoring air resistance, what would be the kinetic energy of the spanner immediately before impact on the concrete pad directly below?

(a) 29.4 J
(b) 294 J
(c) 2.94 kJ
(d) 29.4 kJ

21. Two sections of circular tube, 'A' and 'B', have the same wall thickness, with Section A having half the outer diameter of Section B. Comparing the second moment of area, which of the following statements is true?

(a) the second moment of area is the same as they have the same thickness
(b) the second moment of area of A is greater that B
(c) the second moment of area of B is greater than A
(d) there is not enough information provided to draw a conclusion

22. New industry standards require the Factor of Safety (*FS*) for a stainless steel crane cable to increase from *FS* = 2 to *FS* = 3. For this to occur, which of the following **must** change?

(a) increase the safe working stress
(b) decrease the safe working stress
(c) increase the ultimate tensile strength of stainless steel
(d) decrease the ultimate tensile strength of stainless steel

23. A weightless cantilever beam supports a point load at its unsupported end. If the length of the beam was increased by 10%, the maximum deflection of the beam would

(a) decrease by about 10%.
(b) decrease by about 33%.
(c) increase by about 10%.
(d) increase by about 33%.

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 **(17 marks)**

Bungee jumping is an activity in which the participant, known as the 'jumper', leaps from a high platform attached to a very strong elastic rope. Once the rope, under the influence of the falling mass of the jumper, exceeds its 'natural' full length, it absorbs energy to slow down and eventually halt the fall. Being elastic, the rope then contracts and pulls the jumper upwards. What follows is a decreasing cycle of downward and upward movements until the mass of the jumper comes to a rest suspended by the rope.

A bungee jumper of mass 80 kg is tied to a bungee rope with one end fixed on an elevated platform located at a safe height above ground level. The 'natural' length of the rope (when not under tension) is 30 m and the rope can be assumed to be weightless. The rope has a circular cross section of radius 25 mm and a Young's Modulus of 3 N mm^{-2}.

(a) Calculate v, the velocity of the jumper when the rope is extended to its 'natural' length after they jump off the platform. (3 marks)

v (m s^{-1}) = _____

See next page

(b) If the mass of the jumper is increased to 100 kg, outline the effect on the velocity of the mass 30 m into the jump. (2 marks)

(c) Calculate the elongation of the rope once an 80 kg jumper has come to rest. (5 marks)

Elongation (m) = _____

(d) If the mass of the jumper was increased from 80 kg to 100 kg, the elongation of the rope (once the jumper comes to rest) would increase. Explain why. (3 marks)

See next page

Question 24 (continued)

(e) If we want to limit the deceleration acting on the jumper to 2.5 times gravity, calculate the minimum extension of the rope beyond its 'natural' length (30 m). If you did not get an answer for part (a) use 20 m s^{-1}. (4 marks)

Extension of rope (m) = _____

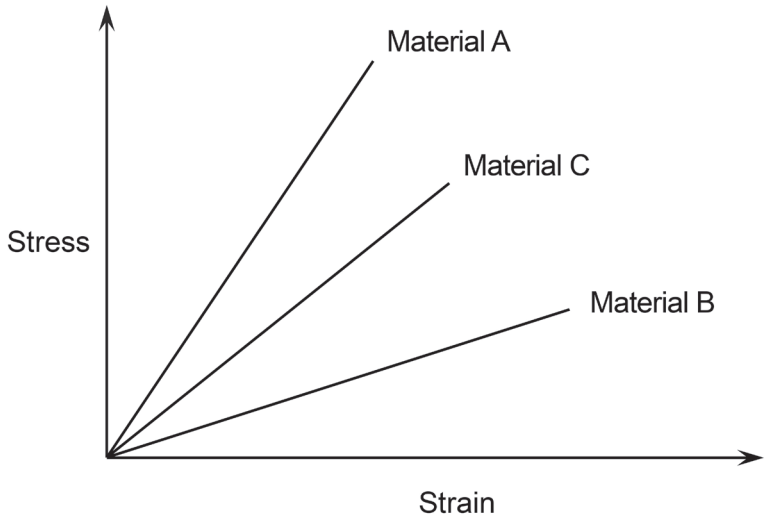
See next page

Question 25 **(20 marks)**

Data information for materials A, B and C show that they have the following Young's Moduli.

Young's Modulus
250 kN mm^{-2}
300 kN mm^{-2}
380 kN mm^{-2}

Testing on the three materials has given the stress-strain curve (in the elastic region) below.



(a) (i) State the correct values of Young's Modulus for each material. (3 marks)

Material A (kN mm^{-2}): _____

Material B (kN mm^{-2}): _____

Material C (kN mm^{-2}): _____

(ii) Outline the reason for your answers in part (a)(i). (2 marks)

_____

_____

_____

_____

Question 25 (continued)

You are provided with one sample each of aluminium, copper and brass. Each sample is in the form of a round section rod, 10 mm in diameter and 1000 mm in length and each sample is tested by applying tensile loads.

(b) (i) Of the three materials, the brass sample was found to require the lowest maximum tensile force applied to it before it exceeded its yield stress. Explain why. (3 marks)

(ii) Calculate F, the value of the tensile force for the brass sample in newtons (N). (3 marks)

F (N) = _____

See next page

(c) (i) The copper sample was observed to have the least elongation when placed under the tensile force calculated in part (b)(ii). Outline why. (2 marks)

_____

_____

_____

_____

(ii) Calculate the elongation of the copper sample in units of mm. If you could not calculate an answer for part (b)(ii), use 4000 N. (3 marks)

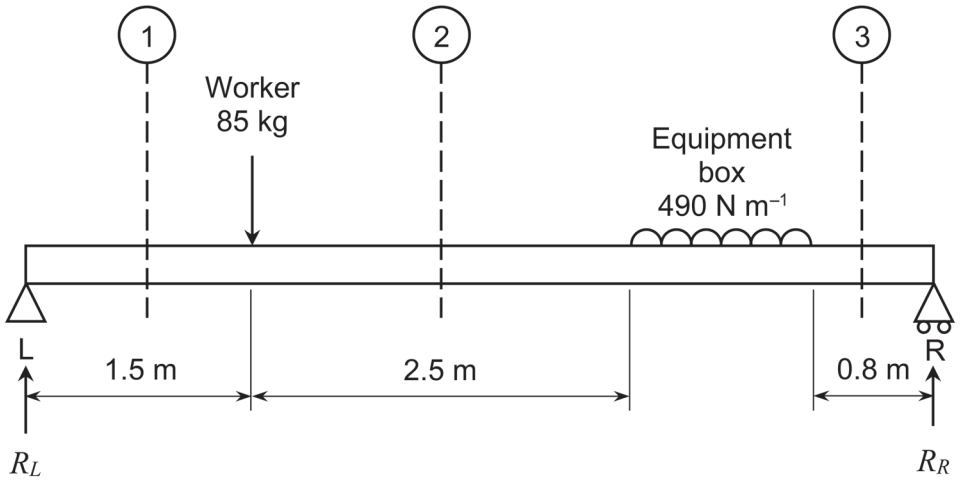
Elongation (mm) = _____

(d) Calculate FS, the Factor of Safety for the aluminium sample when subjected to the force calculated in part (b)(ii). If you could not calculate an answer for part (b)(ii), use 4000 N. (4 marks)

FS = _____

See next page

Question 26 **(12 marks)**



A beam being used as a work platform is 6 m long and is supported at both ends. A worker and an equipment box are positioned on the platform as shown in the above diagram. The worker has a mass of 85 kg and the equipment box has a uniformly distributed load density of 490 N m^{-1}. The reaction forces at the ends of the beam, i.e. R_L and R_R, are 761.95 N and 659.05 N respectively, acting upwards.

(a) Calculate the shear forces at the **three** cross-sections of the beam, as shown in the diagram above. (7 marks)

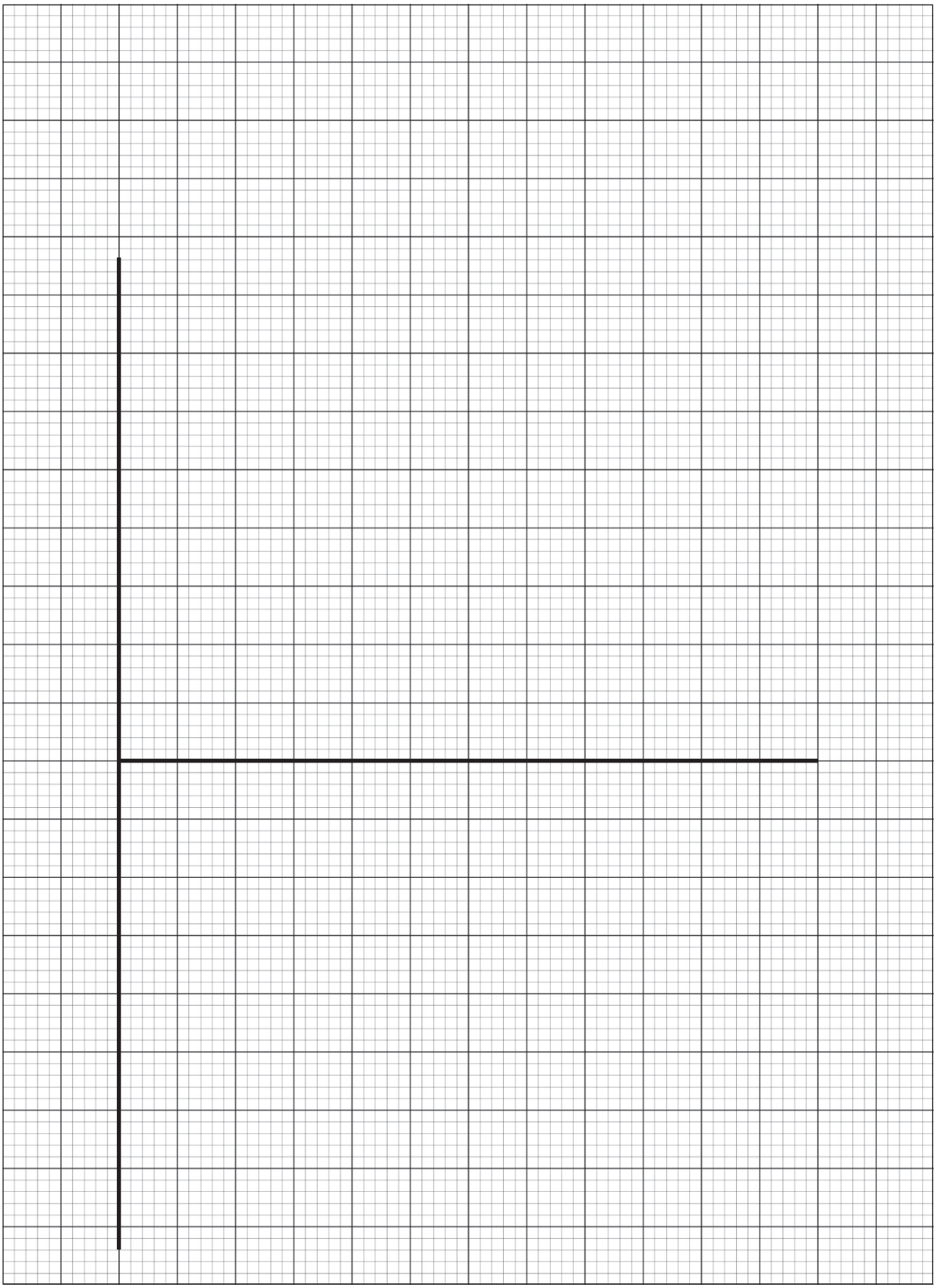
SF_1 (N) = _____

SF_2 (N) = _____

SF_3 (N) = _____

See next page

(b) On the grid below, sketch a fully-labelled and suitably scaled shear force diagram of the loaded beam. The shear forces at either end of the beam must also be included. You may wish to draw a free body diagram at the top of the grid. The axes for the shear force diagram have been provided. (5 marks)

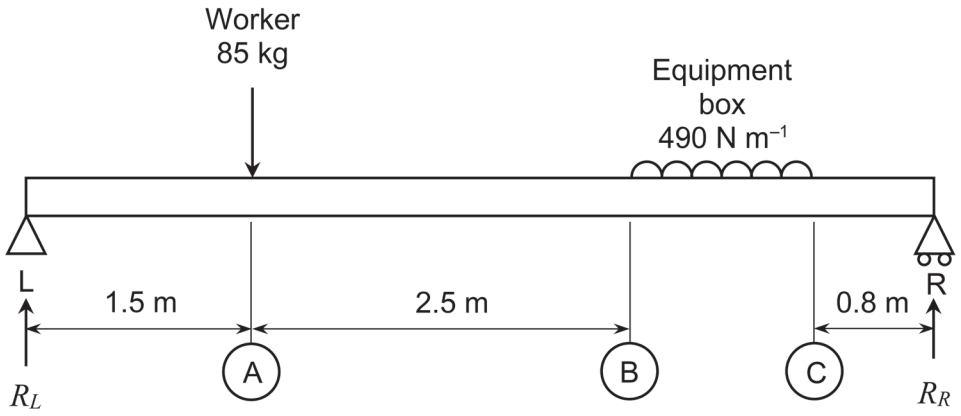


A spare grid is provided at the end of this Question/Answer booklet. If you need to use it, cross out this attempt and indicate that you have redrawn it on the spare grid.

See next page

Question 27 **(12 marks)**

This question refers to the same beam specifications as Question 26. The diagram is repeated for ease of reference.



(a) Calculate the bending moments at the **three** locations labelled 'A', 'B' and 'C'. (7 marks)

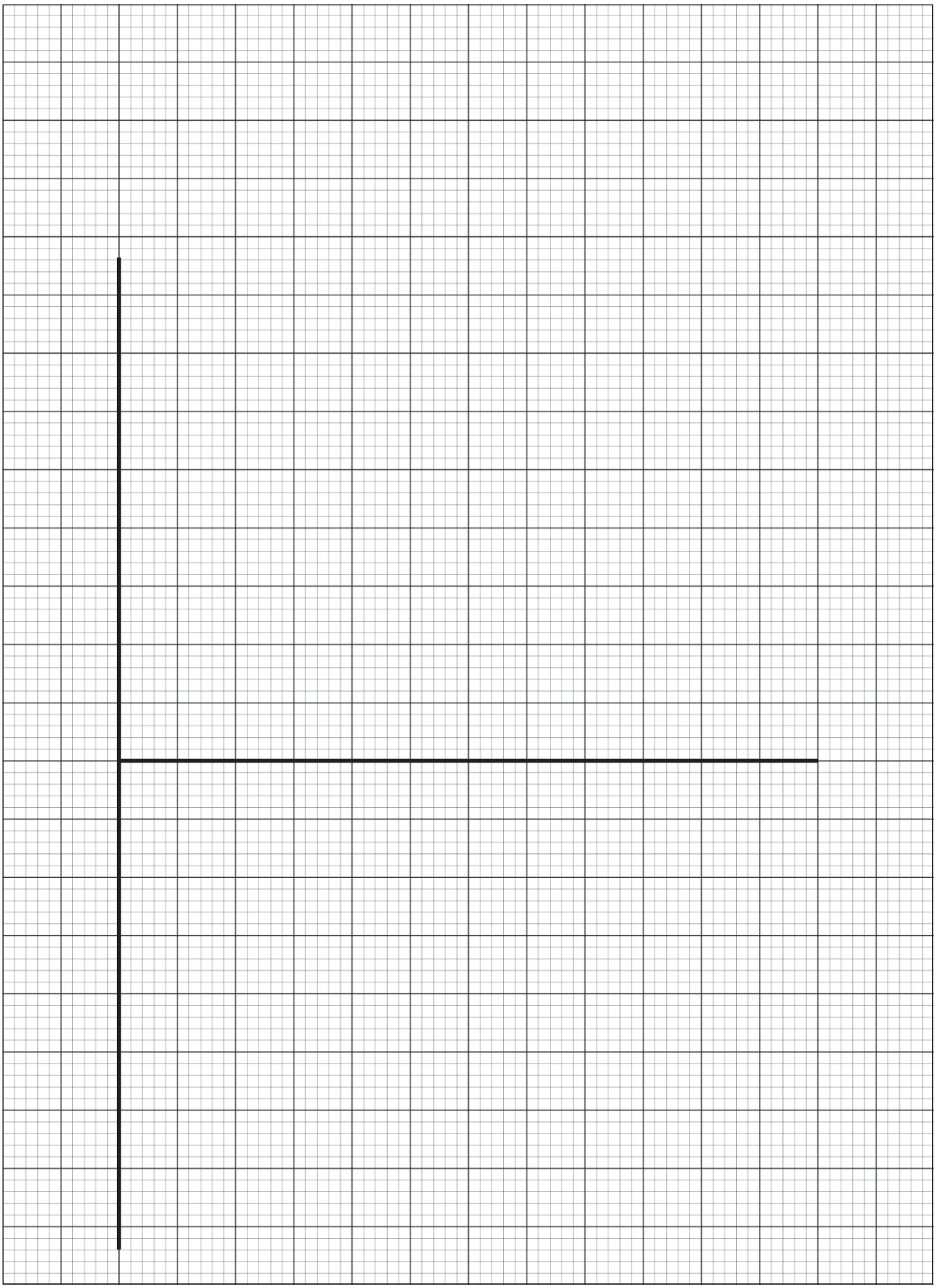
BM_A (N m) = _____

BM_B (N m) = _____

BM_C (N m) = _____

See next page

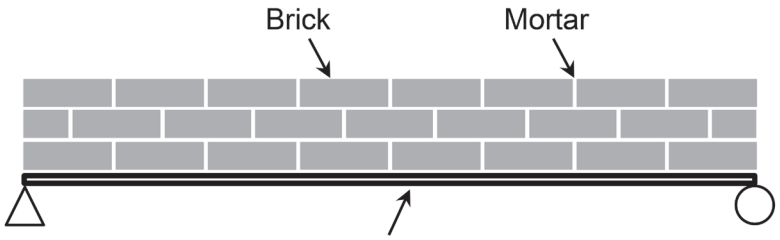
(b) On the grid below, sketch a fully-labelled and suitably scaled bending moment diagram of the loaded beam. The bending moments at either end of the beam must also be included. You may wish to draw a free body diagram at the top of the grid. The axes for the bending moment diagram have been provided. (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.

See next page

Question 28 **(16 marks)**



Structural steel lintel 1910 mm long × 25 mm high × 110 mm wide

Part of the design for a house includes a feature in which three rows of eight bricks, each bonded with 10 mm thick mortar, will span between supports at either end. This is shown in the above diagram. A lintel (a type of beam) made of structural steel is used to support the bricks and mortar. An individual brick has a mass of 2.5 kg. The mortar that binds the bricks together has a total mass of 13.6 kg. The combination of bricks and mortar constitutes a uniformly distributed load and is laid on the 110 mm wide surface of the lintel.

(a) Calculate ω, the uniformly distributed load per unit length along the lintel. Answer in units of N m^{-1}. Ignore the mass of the lintel. (4 marks)

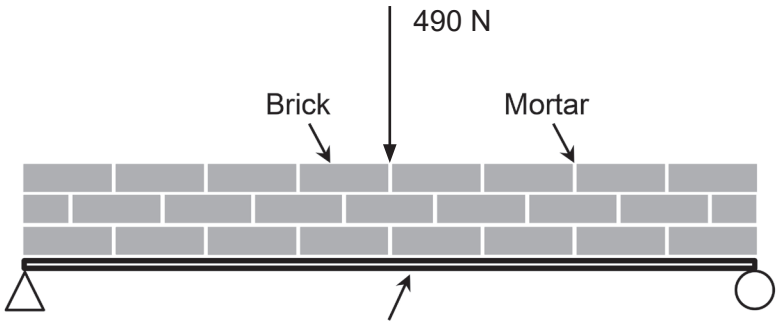
ω (N m^{-1}) = _____

The lintel has a solid rectangular cross section 25 mm high × 110 wide and is 1910 mm long.

(b) Calculate the deflection of the lintel at its centre. Answer in units of millimetres (mm). If you could not calculate an answer for part (a), use ω = 350 N m^{-1}. (7 marks)

Deflection (mm) = _____

See next page



Structural steel lintel 1910 mm long × 25 mm high × 110 mm wide

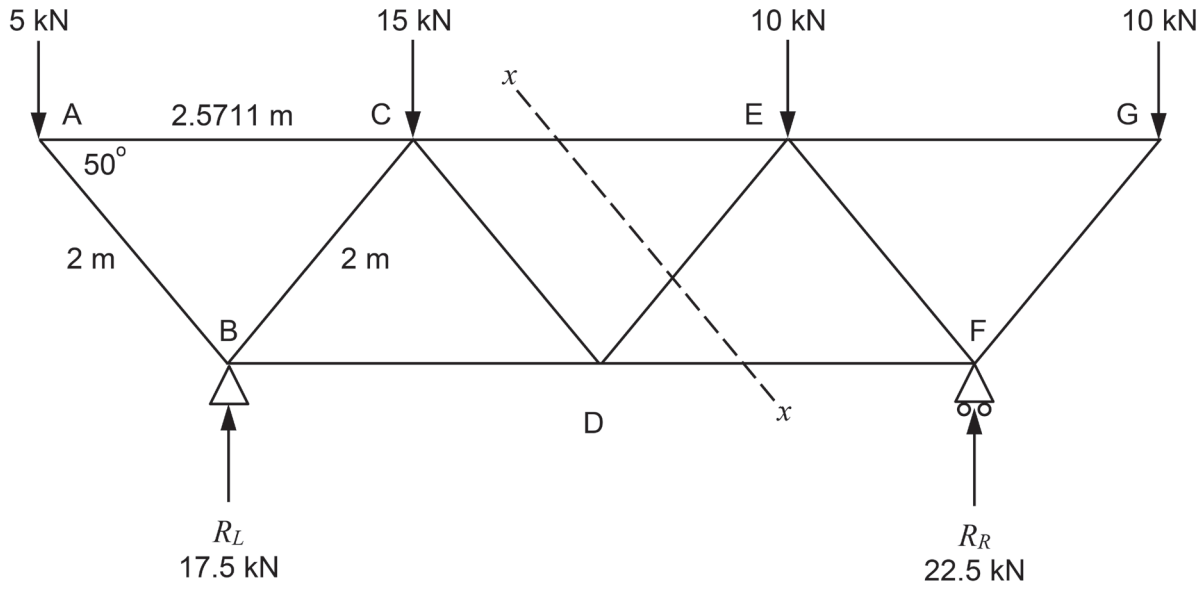
Suppose a point load of 490 N acting downwards is added at the centre of the lintel. This is shown in the diagram above.

(c) Calculate the new value of the lintel's deflection at its centre. Answer in units of millimetres (mm). (5 marks)

Deflection (mm) = _____

See next page

Question 29 **(23 marks)**



The above diagram is a simply supported truss arrangement, a structure that is typically used as internal supports for metal roofs in large warehouses. It is made up of members that form isosceles triangles. The equal length sides of these triangles are 2 m long and the uneven length side is 2.5711 m long. The equal size internal angles are 50°. The support reactions and external point loads are all given on the diagram.

(a) Using calculations, show that the length of the uneven side of the isosceles triangle is 2.5711 m. (2 marks)

(b) Using calculations, show that the reactions R_L and R_R are 17.5 kN and 22.5 kN respectively. (6 marks)

See next page

(c) Working to the left of section xx, use the method of sections to calculate F_{CE}, the force in member CE and indicate whether the force is tension or compression. (5 marks)

F_{CE} (kN) = _____

Tension or compression: _____

(d) Working to the left of section xx, use the method of sections to calculate F_{DF}, the force in member DF and indicate whether the force is tension or compression. (5 marks)

F_{DF} (kN) = _____

Tension or compression: _____

See next page

Question 29 (continued)

(e) Working to the left of section xx, use the method of sections to calculate F_{DE}, the force in member DE and indicate whether the force is tension or compression. (5 marks)

F_{DE} (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.

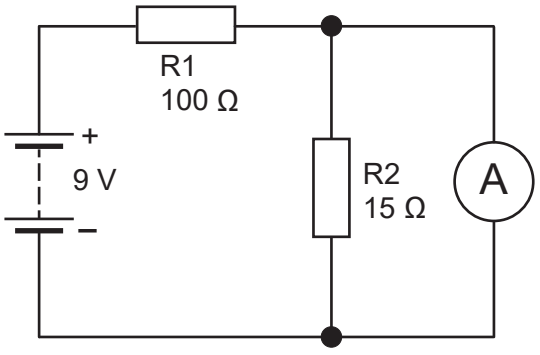
---

30. In a DC circuit, which of the following electronic components do **not** obey Ohm's law?

I diode
II resistor
III transistor
IV relay coil

(a) I and II
(b) I and III
(c) I and IV
(d) III and IV

31. An ammeter is connected to a circuit, as shown in the following diagram.



The current measured by the ammeter will be

(a) 0 mA.
(b) 78 mA.
(c) 90 mA.
(d) 600 mA.

See next page

32. Two capacitors of unequal value are connected in series. The total capacitance of this arrangement is always

(a) the difference between the two values.
(b) less than the value of the smaller capacitor.
(c) greater than the value of the smaller capacitor.
(d) greater than the value of the larger capacitor.

33. If the current through a resistor is halved, then the power it dissipates as heat will be

(a) quartered.
(b) halved.
(c) doubled.
(d) unaffected.

34. The coloured bands of four 4-band E12 series resistors are listed below. Which option has the highest resistance?

(a) blue grey black gold
(b) green blue red red
(c) brown black orange brown
(d) orange white red red

35. For an NPN transistor operating in its forward-active region, which of the following statements is correct?

The

(a) base current is larger than the collector current.
(b) base current is larger than the emitter current.
(c) collector current is smaller than the emitter current.
(d) emitter current is smaller than the collector current.

36. When developing and testing a program to control a mechatronic device, the program is rewritten and downloaded multiple times to a microcontroller. Prior to saving changes to the new version of the program, it is temporarily stored in the microcontroller's

(a) ALU.
(b) ROM.
(c) ADC.
(d) RAM.

37. Which of the following is an example of an open-loop system?

(a) automated sliding gate
(b) automobile cruise-control
(c) missile tracking system
(d) electric clothes iron

See next page

38. The driver sprocket of a chain and sprocket drive system has 24 teeth and its follower sprocket has 18 teeth. Which of the following statements is true?

The

(a) driver will rotate more quickly than the follower.
(b) driver will have a greater turning force than the follower.
(c) chain will move with greater speed around the follower.
(d) mechanical advantage (MA) of the system is greater than 1.

39. Which of the following will vary with changes to the duty cycle of a pulse width modulation signal?

I the amplitude of the output pulses
II the frequency of the output pulses
III the time the signal is high
IV the time the signal is low

(a) I and II
(b) II and III
(c) II and IV
(d) III and IV

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.

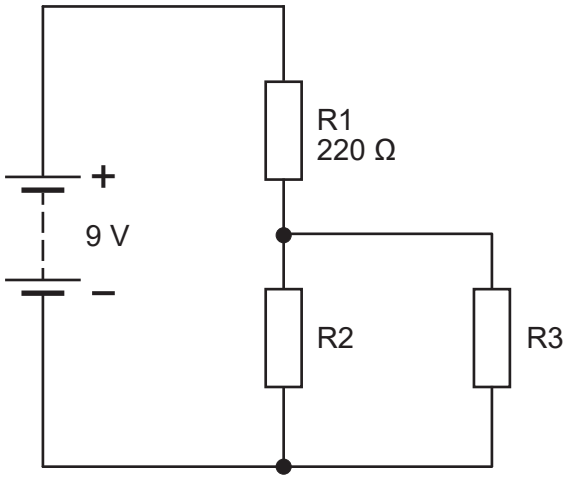
When calculating answers, show all your working clearly. Your working should be in sufficient detail to allow your answers to be checked readily and for marks to be awarded for reasoning. In final answers, include appropriate units where applicable.

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.

See next page

Question 40 **(12 marks)**

When designing electronic circuits, engineers often place components into series and parallel arrangements. Sometimes these arrangements are series only, parallel only, or a mix of both.

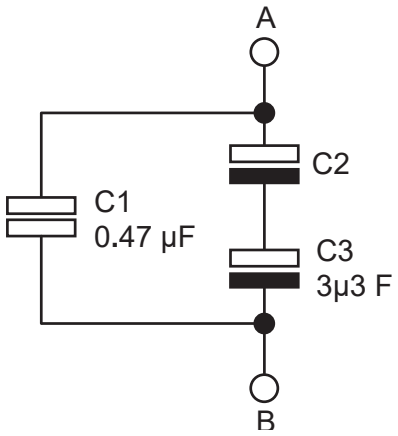


(a) The circuit shown above contains three resistors. The value of R1 is known (220 Ω) but the values for R2 and R3 are not. R2 and R3 have identical values, i.e. R2 = R3. Calculate the required values for R2 and R3 such that the circuit will draw 18 mA of current. (5 marks)

R2 (Ω) = R3 (Ω) = _____

See next page

Question 40 (continued)



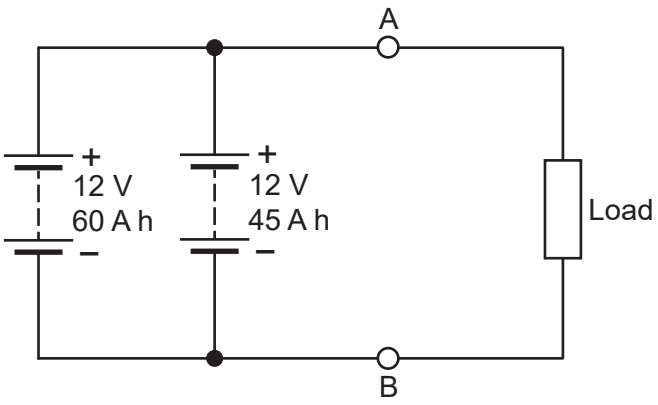
(b) The capacitor network shown above contains one non-polarised capacitor, C1, and two polarised capacitors, C2 and C3.

(i) The non-polarised capacitor, C1, has a 3-digit number printed on its side. State these digits. (1 mark)

_____

(ii) C_{AB}, the capacitance between nodes A and B, is 1.79 µF. Calculate C_2, the capacitance of C2. Answer in units of microfarads (µF). (3 marks)

C_2 (µF) = _____



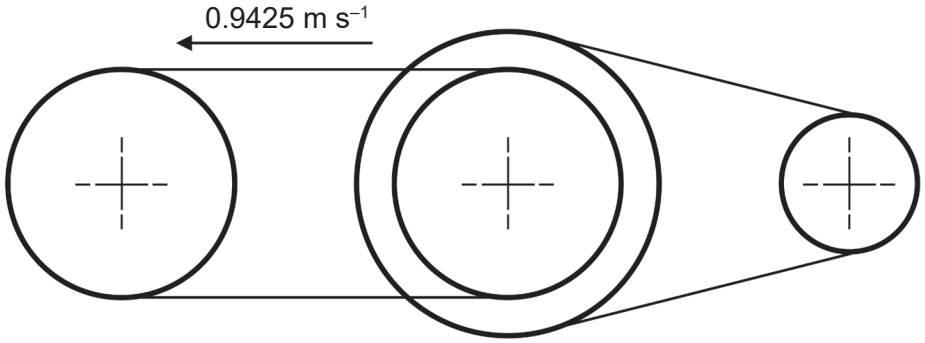
The battery pack in the above circuit is required to deliver a current of 1.8 A over a period of 125 hours with a duty cycle of 65%. To achieve this, a third battery will need to be fitted between nodes 'A' and 'B' on the circuit. The load for the circuit is represented by a resistor.

(c) Calculate the minimum required current capacity of the third battery. Answer in units of amp-hours (A h). (3 marks)

Minimum current capacity of third battery (A h) = _____

See next page

Question 41 **(14 marks)**



The pulley drive system shown above includes the following features:

(I) Pulley B is a step pulley. This consists of a smaller and a larger pulley that are fixed together and share a common shaft – similar to the concept of a compound gear in a gear drive system.
(II) When the system is operating, the pulley belt that connects Pulley A to the smaller diameter Pulley B is moving at a speed of 0.9425 m s^{-1}.
(III) Assume that the system is 100% efficient, i.e. there are no losses due to friction or the belt slipping.
(IV) Dimensions for the pulleys are given in millimetres (mm).

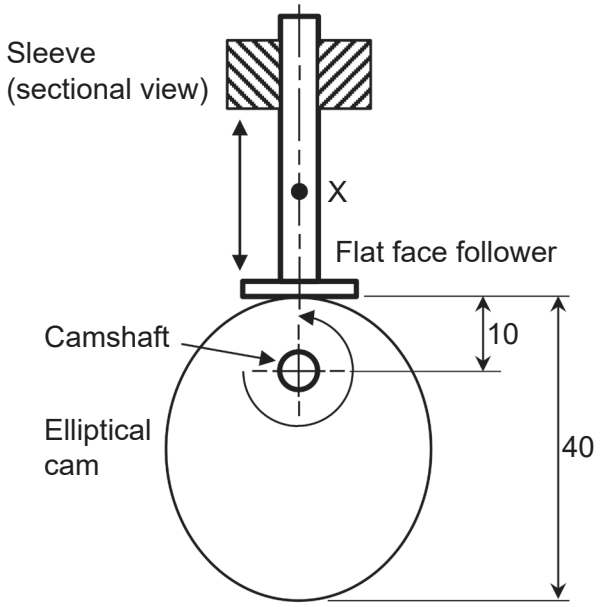
(a) Calculate the speed of rotation of Pulley A, the driver. Answer in units of revolutions per minute (r.p.m.). (4 marks)

Speed of rotation of Pulley A (r.p.m.) = _____

(b) Calculate the speed of rotation of Pulley C, the output of the system. Answer in units of revolutions per minute (r.p.m.). If you could not calculate an answer for part (a), use 220 r.p.m. (4 marks)

Speed of rotation of Pulley C (r.p.m.) = _____

See next page



The mechanism shown to the left, is an elliptical cam with a flat face follower. As the cam rotates around the camshaft, the follower will rise and fall. It slides in a sleeve that remains in a fixed position. Dimensions are given in millimetres (mm).

(c) Calculate the displacement of Point X if the cam is rotated 180° from its position as shown in the diagram. Answer in units of millimetres (mm) and include the direction of the displacement in your answer. (2 marks)

Displacement of Point X (mm) = _____

Direction of displacement = _____

(d) The camshaft is connected to the shaft of Pulley C of the drive system. Calculate the average speed of Point X as the cam is rotated by the pulley drive system while the system is running. Answer in metres per second (m s^{-1}). (4 marks)

Average speed of Point X (m s^{-1}) = _____

See next page

Question 42 **(21 marks)**

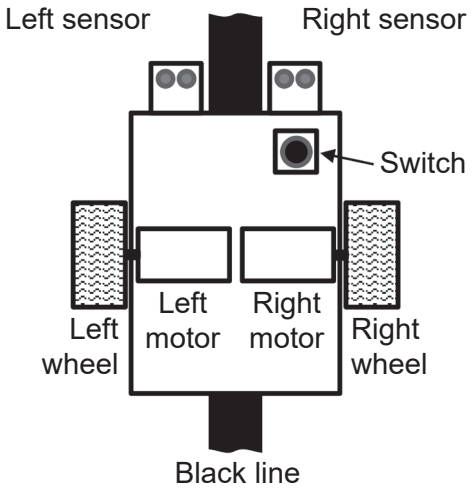


Figure 1

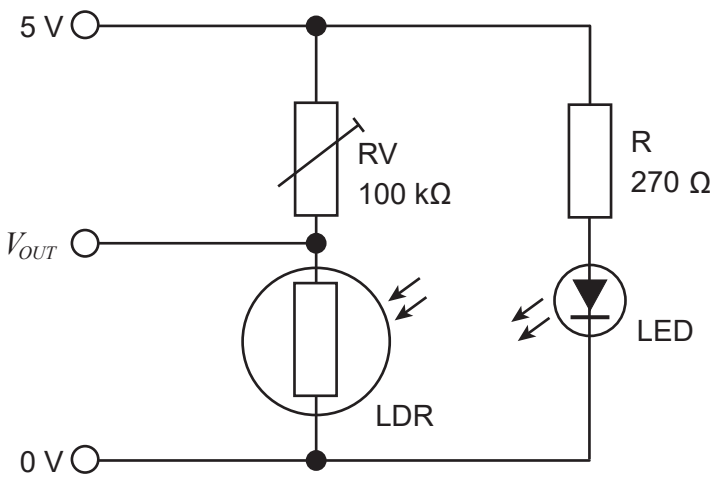


Figure 2

The robotic buggy shown in Figure 1 can follow a black line pathway on a white background by utilising the following features:

(I) two independent sensors, on the left and right, produce analogue signals that change value depending on whether the sensor is over the white background or the black line

(II) two independent reversible motors, on the left and right, drive the buggy forward, cause it to turn to the left or to the right or stop in response to signals from the sensors

(III) the switch is used as a digital input to cause the buggy to get into motion.

The circuitry for one of the sensors is shown in Figure 2. The light emitting diode (LED) is used to produce light that will either be absorbed by the black line or reflected by the white background. The light dependent resistor (LDR) detects the resulting level of light and varies its resistance accordingly.

(a) When the LDR is over the black line, will V_{OUT} be greater or less than when the LDR is over the white background? Outline a reason to support your answer. (2 marks)

See next page

(b) Calculate R_{LDR}, the resistance of the LDR, given that V_{OUT} = 2.62 V and R_{RV}, the resistance of RV = 56 700 Ω. (4 marks)

R_{LDR} (Ω) = _____

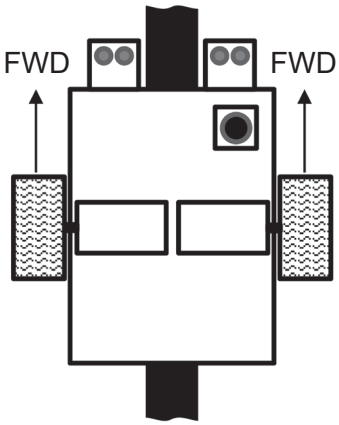
(c) The signal from the sensor of V_{OUT} = 2.62 V is connected to a 10-bit ADC pin of a microcontroller. Calculate the 10-bit value produced by the ADC. Round your answer to the nearest whole number. (3 marks)

10-bit value = _____

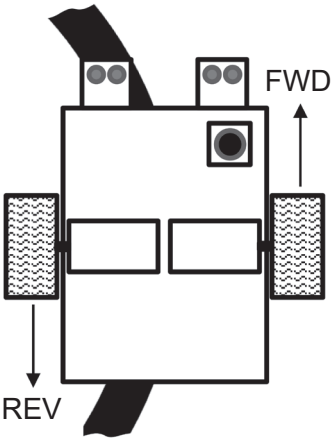
See next page

Question 42 (continued)

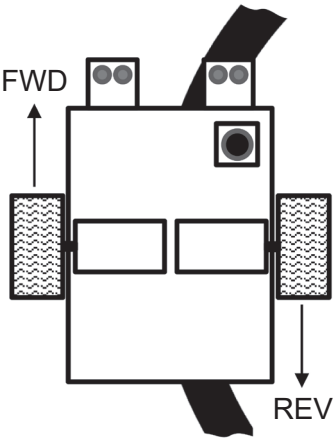
The black line pathway that the buggy follows is a loop comprising straight-line sections linked with left-hand and right-hand curves. Additionally, there are points on the pathway, including its starting position, where the buggy needs to stop so it can be loaded and/or unloaded. These points use a black bar that is positioned across the pathway. Control of the buggy's movement when following the black line pathway is achieved as follows:



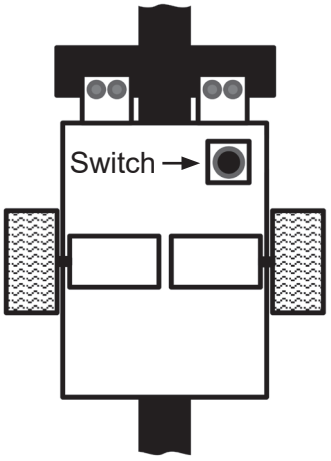
Both sensors either side of black line = drive forward



Left sensor on black line = turn left



Right sensor on black line = turn right



Both sensors on black bar = stop

Specifications for flow chart that controls the buggy
The stationary buggy's starting position is with both sensors on a black bar
The switch must be pressed then released before the buggy will begin to move forward. This action will cause the buggy to move forward for 1 second to clear the black bar
If neither of the sensors detects the black line, the buggy continues to move forward
Whenever a left or right curve is encountered by the buggy, it will manoeuvre to follow the black line
When both sensors detect the next black bar, the buggy stops
The flow chart loops such that if the buggy is stopped at a black bar it can restart its travel along the black line by again pressing then releasing the switch

(d) On page 47, draw a fully-labelled flow chart that will control the buggy when following the black line pathway, such that it will achieve the specifications listed in the above table.

(8 marks)

See next page

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 42 (continued)

(e) Control systems can often be characterised as open-loop or closed-loop.

(i) Describe how the output differs between an open-loop and a closed-loop control system. (2 marks)

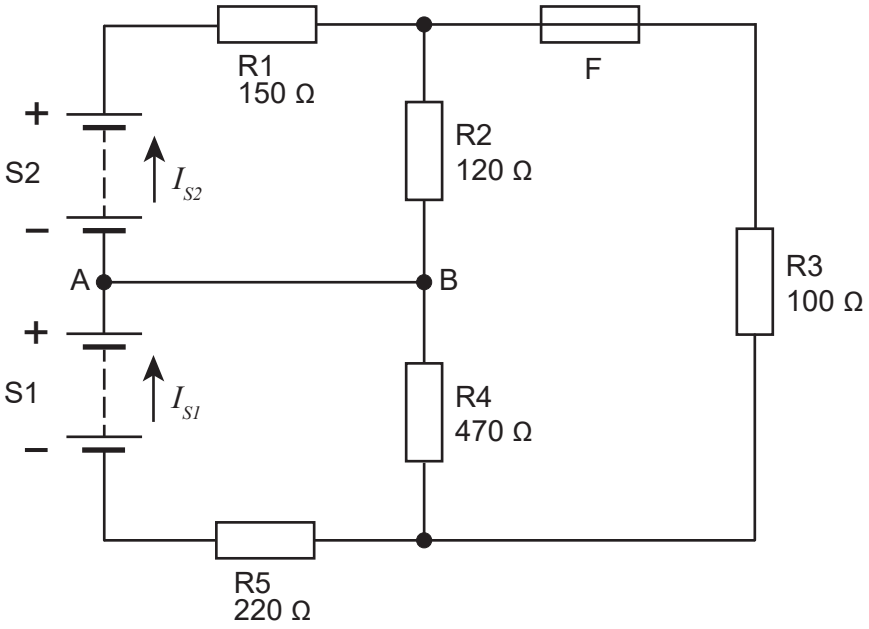
(ii) Is the section of the buggy control system that enables it to track the black line open-loop or closed-loop? Justify your answer. (2 marks)

Open-loop or closed-loop: _____

Justification: _____

See next page

Question 43 **(18 marks)**



The diagram above shows a circuit which includes two batteries, S1 and S2, a fuse, F, and five resistors, R1 – R5. The voltage of S1 is 6 V and the current flowing through it, I_{S1} is 26.1 mA. The voltage of S2 is 9 V and the current flowing through it, I_{S2} is 44.69 mA. The fuse, when intact as shown in the diagram, acts as a conducting wire and has a negligible voltage drop. The values of all the resistors are given on the diagram.

(a) Calculate I_{BA}, the current flowing from node B to node A. Answer using units of amps (A). (2 marks)

I_{BA} (A) = _____

(b) Calculate V_{R3}, the voltage across R3. (4 marks)

V_{R3} (V) = _____

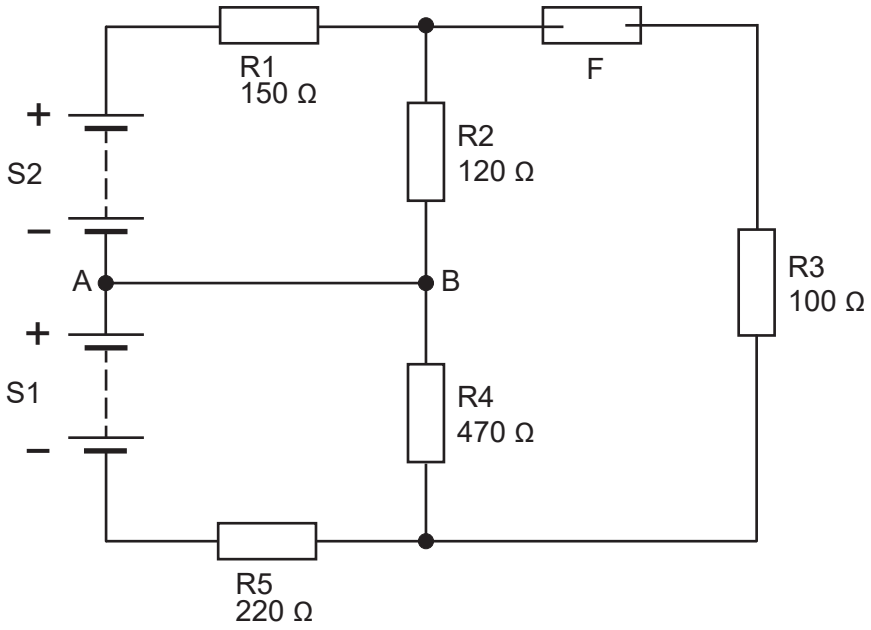
See next page

Question 43 (continued)

(c) Calculate P_{R4}, the power dissipated as heat by R4. Answer using units of watts (W).
(6 marks)

P_{R4} (W) = _____

See next page



Suppose that the fuse becomes open-circuit as shown in the diagram above. This will change the behaviour of the circuit.

(d) Calculate I_{R4}, the current flowing through R4. Answer using units of amps (A). (3 marks)

I_{R4} (A) = _____

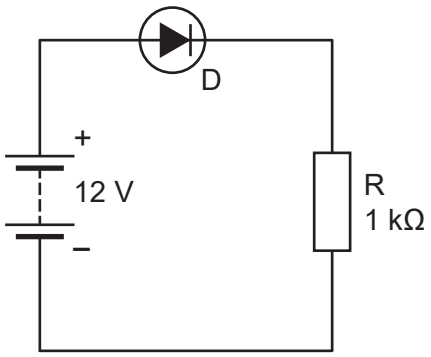
(e) Calculate P_{S2}, the power supplied to the circuit by S2. Answer using units of watts (W). (3 marks)

P_{S2} (W) = _____

See next page

Question 44 **(17 marks)**

When connecting the positive and negative terminals of a battery or DC power supply to a circuit that contains polarity-sensitive components, it is important that the connections are the correct way around. If this is not the case, polarity-sensitive components will not function and may become damaged (sometimes even exploding) and this will cause the circuit to fail.

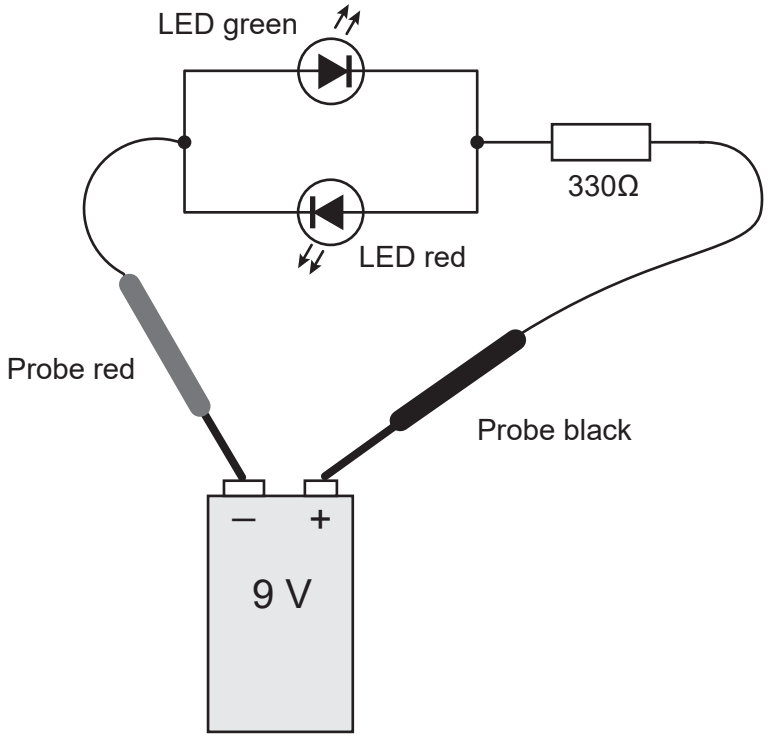


The circuit shown above uses a silicon diode to perform the task of preventing damage that might result if a battery was connected incorrectly to the circuit. In this example, the load of the circuit is represented by a 1 kΩ resistor.

(a) Describe how the diode protects the circuit if the battery terminals are connected incorrectly. (2 marks)

(b) When the battery is connected correctly, the load (resistor) dissipates 129.96 mW of power. Calculate P_S, the power supplied to the circuit by the battery. Answer using units of watts (W). (4 marks)

P_S (W) = _____



To assist in identifying the positive and negative terminals of a battery or a DC power supply, an engineer decides to build a polarity tester, the design of which is shown above. If the probes are placed correctly on the terminals of the battery or DC power supply, then LED green glows. If LED red glows then this indicates reverse polarity.

(c) The LEDs have the following parameters: $V_{LED,GREEN}$ = 1.9 V and $V_{LED,RED}$ = 2.1 V. Calculate P_R, the power dissipated by the resistor, if the probes are placed as shown in the diagram at the top of this page. Answer using units of watts (W). (5 marks)

P_R (W) = _____

See next page

Question 44 (continued)

The engineer has concerns that when testing higher voltages the LEDs might draw too much current and fail due to overheating. A decision is made to adjust the design of the circuit by including a SPDT switch that can switch between the original 330 Ω resistor for lower-voltage testing and a 1 kΩ resistor for higher-voltage testing. The components at hand to construct the circuit are as follows:

Component	Quantity
Probe red	1
Probe black	1
LED green	1
LED red	1
330 Ω resistor	1
1 kΩ resistor	1
SPDT switch	1

(d) Draw a fully-labelled circuit diagram that uses only the listed components to achieve the operations required of the redesigned polarity tester. You do not need to include a battery or DC power supply in the diagram. (6 marks)

See next page

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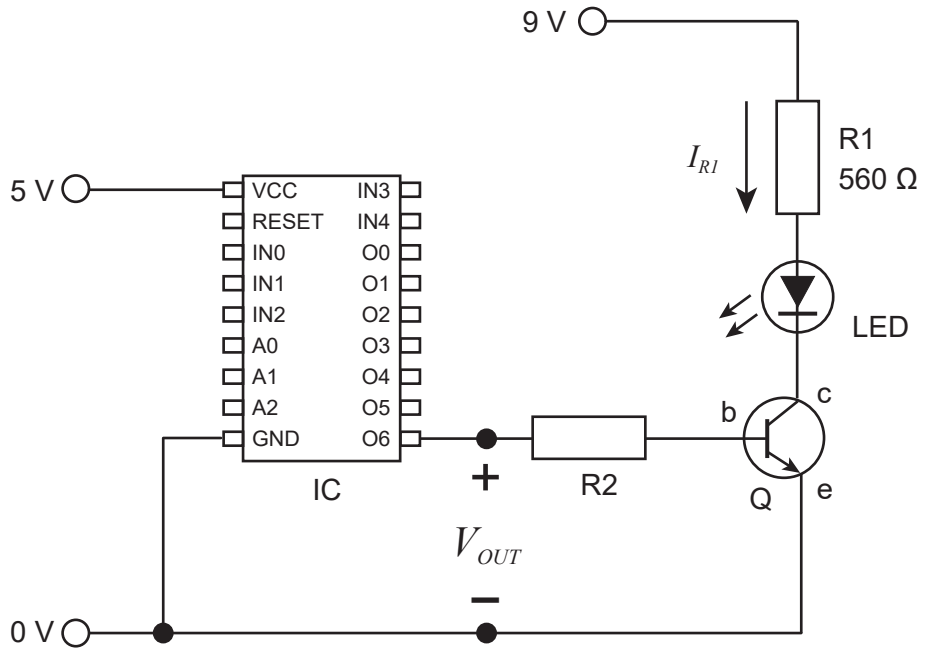
See next page

Question 45 **(18 marks)**



The above circuit has the following parameters:

Microcontroller (IC)	Pin O6 low	V_{OUT} = 0 V
	Pin O6 high	V_{OUT} = 5 V
Transistor (Q)	Gain (β) = 30	
LED	$V_{LED,ON}$ = 1.9 V	

The transistor is operating in its forward-active region. Pin O6 is high and I_{R1}, the current flowing through R1 = 10.75 mA.

(a) Calculate V_{CE}, the collector emitter voltage of the transistor. (4 marks)

V_{CE} (V) = _____

See next page

(b) Calculate R_2, the resistance of R2. (5 marks)

R_2 (Ω) = _____

(c) Calculate I_B, the minimum base current required to cause the transistor to transition from its forward-active region of operation into saturation. Answer using units of amps (A). (6 marks)

I_B (A) = _____

(d) Calculate R_2, the new value of R2 required to achieve the base current calculated in part (c). If you could not determine an answer for part (c), use 0.000 45 A. State the maximum value of an E12 resistor that would be used for a practical circuit. (3 marks)

R_2 (Ω) = _____

E12 resistor = _____

End of Mechatronics Section

Supplementary page

Question number: _____

Supplementary page

Question number: _____

Supplementary page

Question number: _____

Supplementary page

Question number: _____

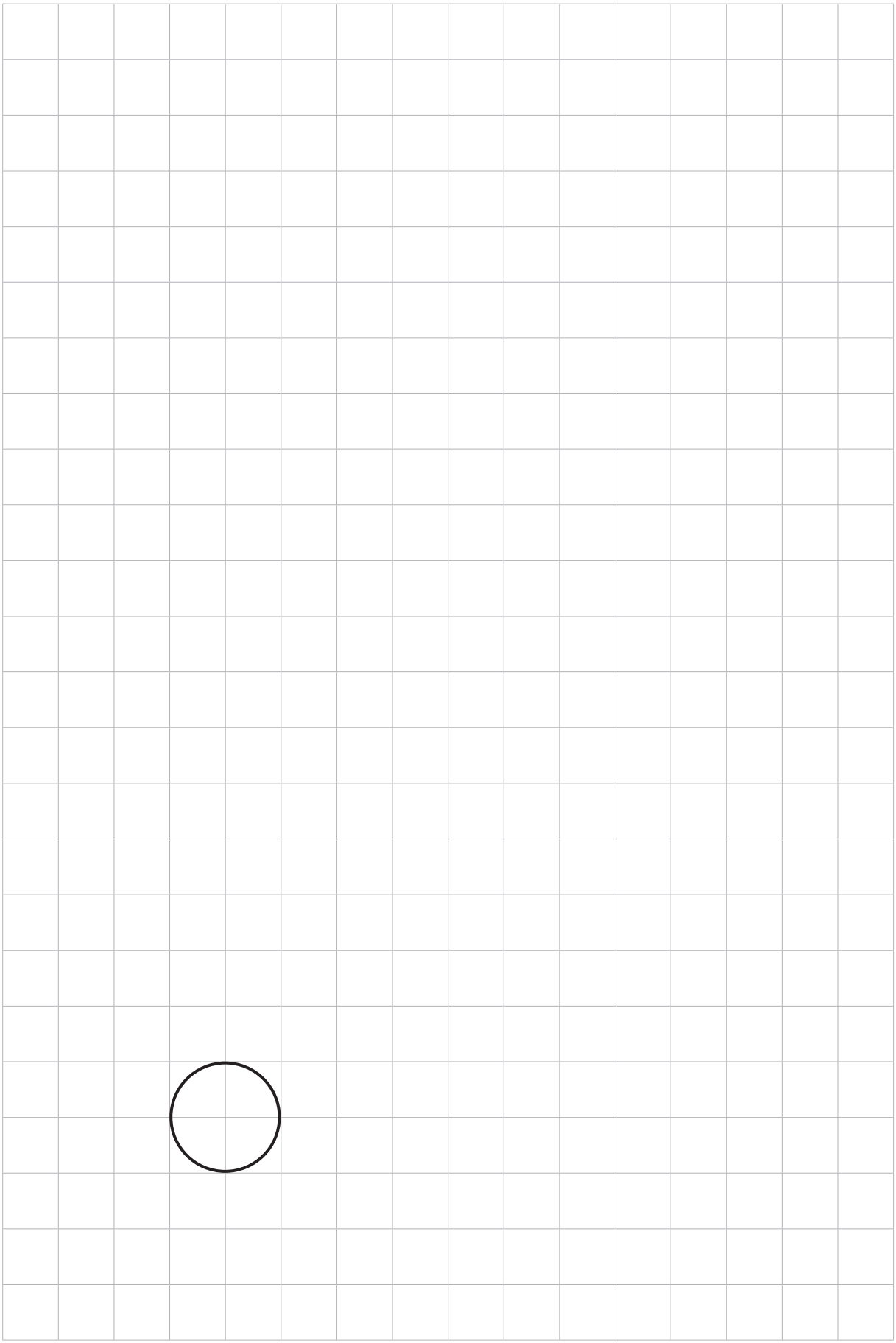
Supplementary page

Question number: _____

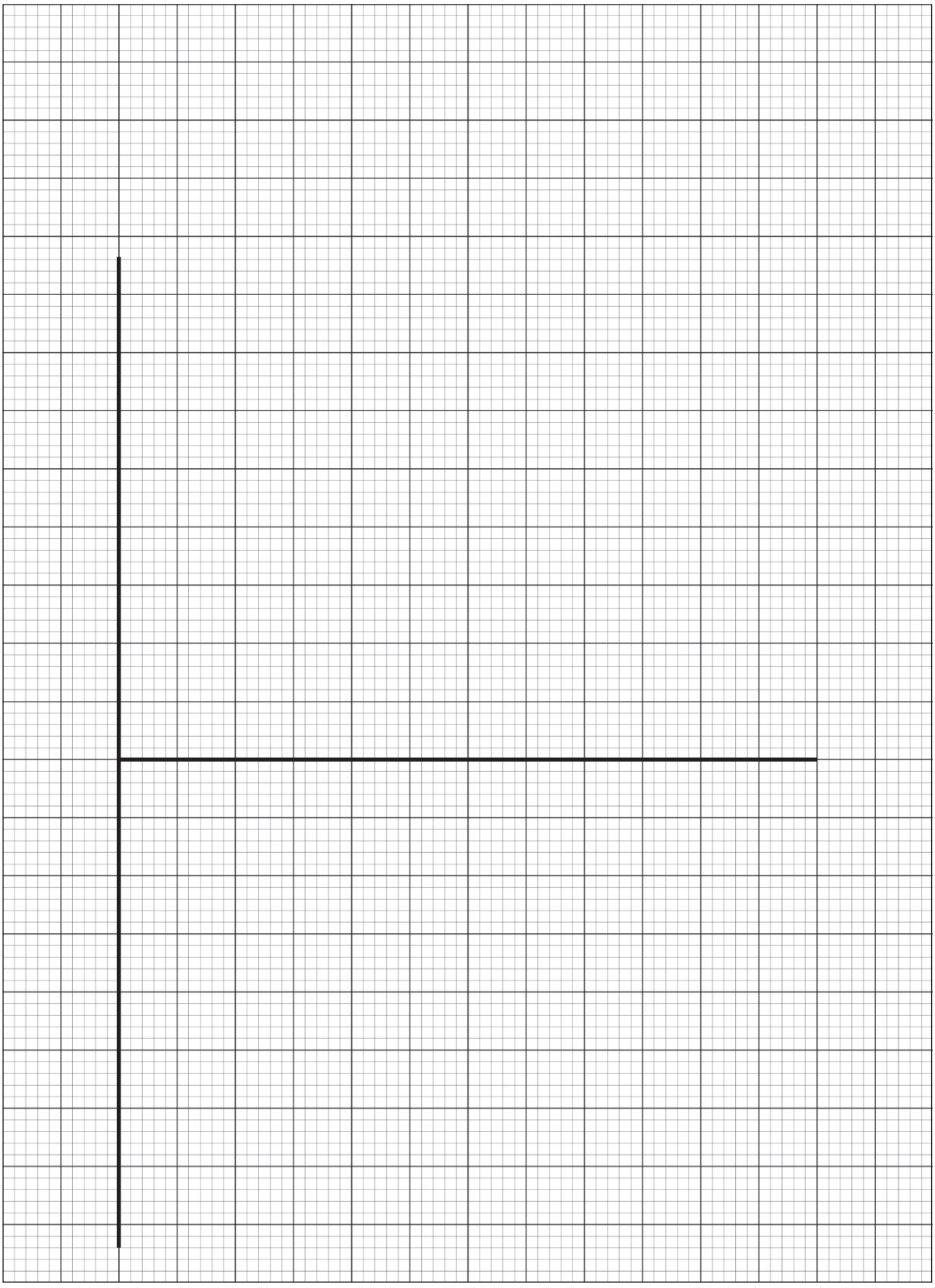
Supplementary page

Question number: _____

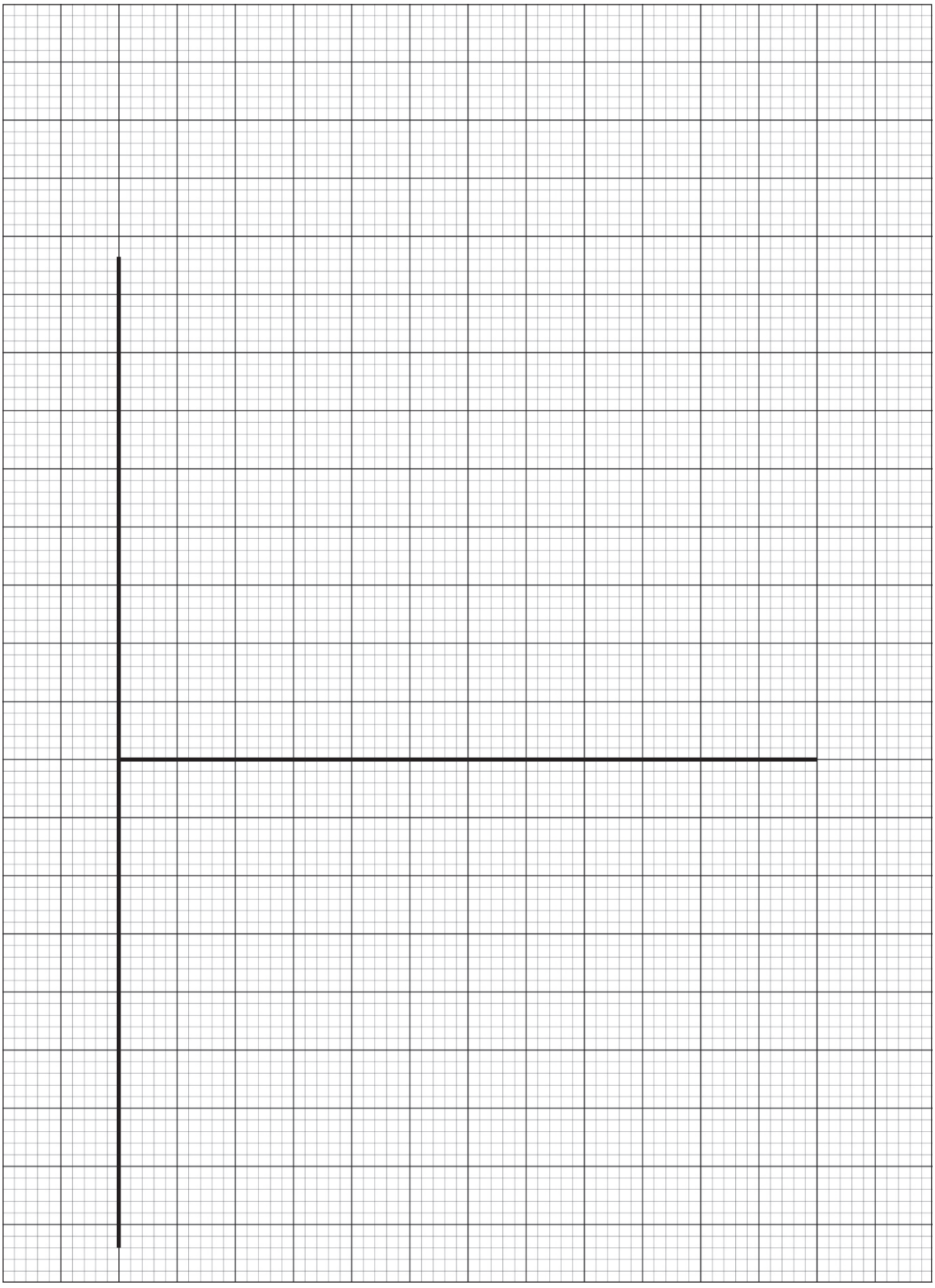
Spare grid for Question 11(a)



Spare grid for Question 26(b)



Spare grid for Question 27(b)



Spare flow chart for Question 42(d)

ACKNOWLEDGEMENTS

Question 24 Eremin, D. (2022). [Photograph of a person bungee jumping over a valley]. Retrieved May, 2023, from https://www.pexels.com/photo/person-bungee-jumping-over-valley-11440267/

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