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

ATAR course examination, 2021

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.

2022/5856
Web version of 2021/62071

Ref: 21-025

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	4	4		77	30
Section Two **Mechanical** Part A: Multiple-choice	10	10	110	10	10
Part B: Extended answer	5	5		105	50
Section Two **Mechatronics** Part A: Multiple-choice	10	10	110	10	10
Part B: Extended answer	6	6		105	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 2021: 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.

   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% (87 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. All renewable sources of energy

   (a) are non-polluting.
   (b) have low impact on the environment.
   (c) are available indefinitely.
   (d) do not produce greenhouse gases.

2. Energy is

   (a) the rate at which work is done.
   (b) the capacity of a system to do work.
   (c) stored by a moving body.
   (d) the rate of using power.

3. Life cycle analysis primarily focuses on

   (a) recycling or responsible disposal of unwanted goods, thereby reducing issues associated with landfill and other forms of pollution.
   (b) identifying safety issues at each stage of the production of goods, with the goal of reducing exposure of workers to hazards that cause injury or poor health.
   (c) material and energy inputs, and environmental impacts that are associated with engineered goods and services.
   (d) speeding up production of goods so these can get to market quicker and thus improve company and shareholder profits.

4. Stainless steel is a form of steel that has a much greater resistance to corrosion than structural steel. This is a result of the addition of

   (a) nickel and chromium.
   (b) tungsten and silicon.
   (c) copper and zinc.
   (d) aluminium and manganese.

See next page

5. The term used to describe the ability of a material to resist failure under load is its

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

6. The electrical energy produced by a wind generator is measured in which of the following units?

(a) kN
(b) kWh
(c) kJ s^{-1}
(d) J s^{-1}

7. Which of the following is used to coat iron in the process called galvanising?

(a) nickel
(b) tin
(c) zinc
(d) aluminium

8. Many houses, businesses and schools have reduced their electricity costs by fitting solar panels to roofs. Which of the following **best** describes this energy conversion of solar panels?

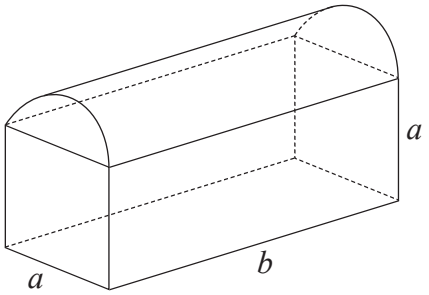
(a) electromagnetic to thermal
(b) thermal to electrical
(c) electrochemical to electrical
(d) electromagnetic to electrical

9. The mass of 1 cm^3 of pure water at room temperature is

(a) 1 g.
(b) 10 g.
(c) 100 g.
(d) 1 kg.

10. The diagram below is of half a cylinder placed on top of a rectangular prism. The diameter of the cylinder and sides of the square end of the prism are all a units long and the lengths of both the half cylinder and square prism are b units. Which of the following formulas will give the correct value for the total volume of this shape?

(a) $b(a^2 + \pi a^2/8)$
(b) $a^2b(\pi/8 + 2)$
(c) $b(a^2 + \pi a^2 b/4)$
(d) $ab^2(1 + \pi b/8)$



See next page

Part B: Extended answer **30% (77 Marks)**

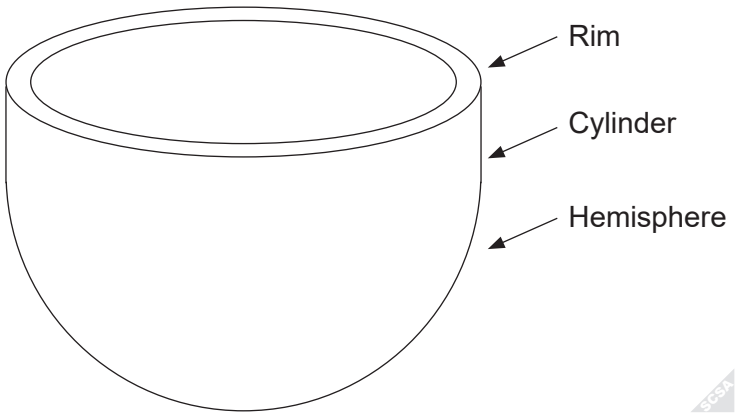
This part has **four** questions. Answer **all** questions. Write your answers in the spaces provided.

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 **(21 marks)**

Illustrated below is a fish pond made from reinforced concrete. The reinforced concrete contains structural steel mesh and bar that constitute 3% of the volume of the construction material. The fish pond's structure is an open-ended cylinder blended with a hemispherical base. The cylindrical section has an external diameter of 1600 mm and height of 400 mm. The wall thickness of the entire structure is 80 mm.



(a) Calculate the mass of the fish pond when it is empty. (7 marks)

Mass (kg) = _____

Question 11 (continued)

(b) The fish pond is filled to 85% of its capacity with water. Calculate the distance between the surface of the water and the rim of the fish pond. (6 marks)

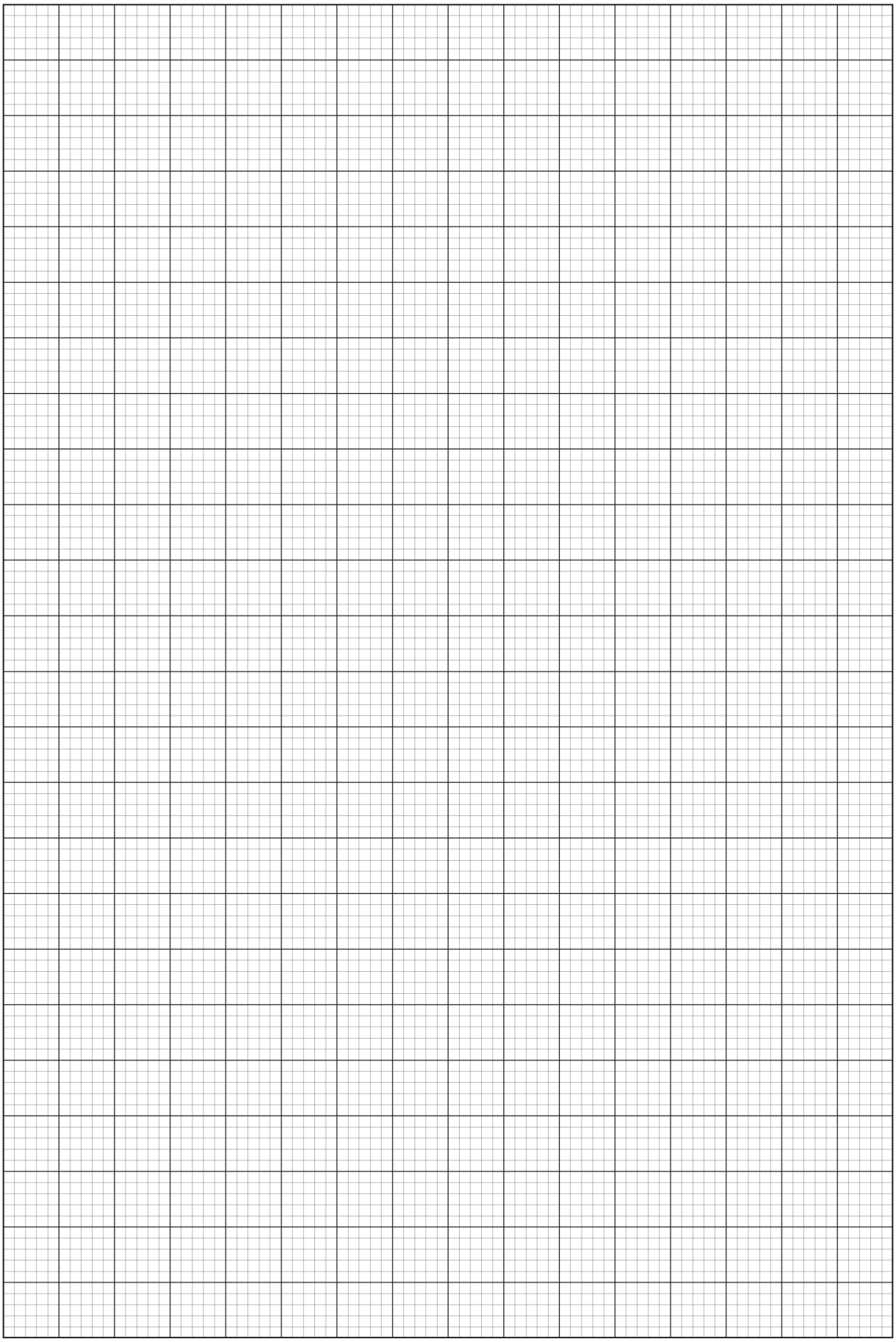
Distance (m) = _____

(c) Use the grid provided on page 7 to draw a fully-dimensioned top and front view of the assembled fish pond. The layout, types of lines and method of dimensioning must comply with the conventions for a third angle orthographic projection. All dimensions are in millimetres.

Use a ruler for straight lines. Circular features can be drawn in freehand.

Note: The larger squares of the grid represent 200 mm × 200 mm. (8 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 12 **(21 marks)**

Knowledge and understanding of materials and their properties are crucial for good engineering design.

Materials can be classified into different types. One class of materials is described as composites.

(a) Define the term 'composite material'. (2 marks)

(b) Give an example of a composite material and explain why it fits this class of materials. (3 marks)

Example:

Explanation:

Properties of materials are an especially important consideration when selecting the best material for a particular engineered product.

(c) For each of the **four** properties listed below, provide a definition of the property, give an example of an engineered product where this property is crucial for its intended use, and provide a reason why it is used for this purpose. Your focus must be on how or where the engineered product is used and **not** on its manufacture.

Note: You are required to provide a different example for each of the four listed properties. A selected engineered product cannot be repeated.

(i) Stiffness (4 marks)

Definition:

Engineered product:

Reason:

(ii) Toughness (4 marks)

Definition: _____

_____

Engineered product: _____

Reason: _____

_____

_____

_____

(iii) Elasticity (4 marks)

Definition: _____

_____

Engineered product: _____

Reason: _____

_____

_____

_____

(iv) Plasticity (4 marks)

Definition: _____

_____

Engineered product: _____

Reason: _____

_____

_____

_____

See next page

Question 13 **(18 marks)**

When an engineered product reaches the end of its useful life, three possible actions for its future are to reuse, recycle or dispose of it. These terms each have specific meanings and may refer to the whole product or parts of it.

(a) Name a suitable engineered product for each action and describe how that action might be carried out for that product.

Note: You are required to provide a different engineered product for each of the three listed actions.

(i) Reuse (3 marks)

Engineered product: _____

Description: _____

_____

_____

_____

_____

(ii) Recycle (3 marks)

Engineered product: _____

Description: _____

_____

_____

_____

_____

(iii) Dispose (3 marks)

Engineered product: _____

Description: _____

_____

_____

_____

_____

See next page

(b) Identify **three** benefits that arise if an unwanted engineered product is reused or recycled. For each benefit describe why it is significant. (9 marks)

Benefit one: _____

_____

Significance: _____

_____

_____

_____

_____

Benefit two: _____

_____

Significance: _____

_____

_____

_____

_____

Benefit three: _____

_____

Significance: _____

_____

_____

_____

_____

See next page

Question 14 **(17 marks)**

The method by which light bulbs produce light has changed over the years. Three common examples, in their order of development and use, are shown below. Their construction materials include some, or all, of the following – glass, ceramics, plastics and metal. The glass bulb of the incandescent light is filled with an inert gas (argon) and that of the compact fluorescent lamp (CFL) is filled with mercury vapour. The light emitting diode (LED) bulb, which has a plastic cover, produces light using light emission diodes and does not require any special gas.
To a large degree, these developments have been driven by safety, energy efficiency, and environmental issues.

Incandescent

CFL

LED

Below is a table containing comparative data on light output and power ratings for each of the three types of bulbs.

Light Output (Lumens)	Power (Watts)		
	Incandescent	CFL	LED
450	40	10	5
840	60	15	7
1100	75	20	10
1600	100	26	13

The projected life of each type of bulb is: 1000 hours for incandescent, 8000 hours for CFL and 25 000 hours for LED.

(a) Identify and describe briefly **two** safety issues that have, in part, influenced changes to bulb design. (2 marks)

One: _____

_____

Two: _____

_____

See next page

(b) Using the information provided on page 12, calculate the cost of running an incandescent bulb continuously for 120 days and contrast this with the cost of running an LED bulb for the same duration. The light output of both forms of bulb is 840 lumens and the cost of electricity is 26.2 cents per kilowatt hour. (4 marks)

Incandescent bulb	LED bulb
Cost of operation	Cost of operation

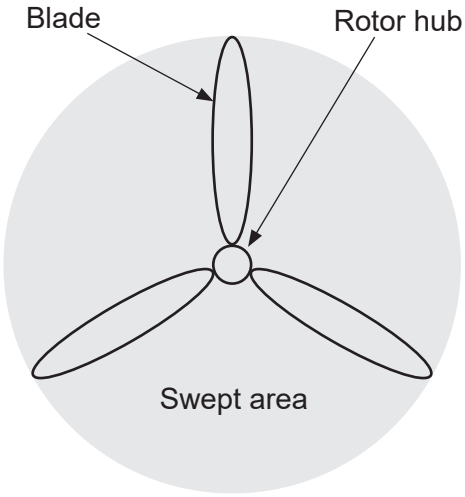
According to one study, a typical coal-fired power station emits approximately 915 kg of carbon dioxide for each MWh of electricity it produces.

(c) Calculate how much extra carbon dioxide (CO_2) is produced by a power station to run a 75 W incandescent bulb for 2500 hours compared with the equivalent light output LED bulb. (5 marks)

Extra CO_2 (kg) = _____

See next page

Question 14 (continued)



The use of a wind turbine to produce electricity will reduce the carbon footprint even further since no carbon dioxide will be emitted by the turbine when a suitable wind is blowing. To calculate wind power, the following formula can be used:

$$P = 0.5\,\rho\,A\,v^3$$

where P is wind power in watts, ρ is the density of air (assume 1.2 kg m^{-3}), A is swept area of the blades in each revolution (see diagram above) measured in m^2, and v is the wind velocity (assume 10 m s^{-1}).

Collectable power is limited to 60% of available wind power. For the purposes of this question, other losses due to mechanical parts of the system can be ignored.

(d) Calculate the required length of a turbine blade, as measured from the centre of the rotor hub, such that the collected wind power is 3.46 MW. (6 marks)

Length of blade (m) = _____

End of Section One

See next page

Section Two: Specialist fields **60% (115 Marks)**

Candidates are required to choose one of the following options, according to which specialist field they studied in 2021.

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

Specialist field	✓	Question numbers	Pages
Mechanical	☐	15–29	16–39
Mechatronics	☐	30–45	40–58

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% (115 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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15. If D is the outer diameter of a circular metal rod, what does the following formula calculate? The

$$\frac{\pi D^4}{64}$$

(a) cross-sectional area of the rod
(b) second moment of area of the rod
(c) volume of the rod
(d) fourth moment of area of the rod

16. If you are given a stress strain curve for steel that ends at the yield point, which of the following **cannot** be determined?

(a) elastic limit
(b) Young's Modulus
(c) resilience
(d) ultimate tensile stress

17. Which of the following is used in the pressing of steel?

(a) tool and die
(b) furnace
(c) kiln
(d) shears

18. Which of the following is measured in units of N kg^{-1}?

(a) strain
(b) stress
(c) acceleration
(d) energy

See next page

19. A cantilevered beam has a universally distributed load U and a point load F at its unsupported end. Which of the following equations gives the beam's deflection, y?

(a) $y = U + (FL^3/3EI)$
(b) $y = F + (5 \times U \times L^3/384EI)$
(c) $y = (FL^3/3EI) + (UL^3/8EI)$
(d) None of the above.

20. A force of F Newtons is applied to a mass for t seconds and displaces it 1 metre. The same force magnitude, but in an opposing direction, is applied over the same time but fails to move it from its rest position. How much power is consumed over this whole process?

(a) Ft W
(b) 0 J s^{-1}
(c) 0 Nm s^{-1}
(d) $2 \times F/t$ J s^{-1}

21. The values of Young's Modulus for several materials are compared. Having a smaller numerical value for Young's Modulus can best be correlated with an increase in

(a) toughness.
(b) ultimate tensile strength.
(c) resilience.
(d) ductility.

22. A force has been resolved into the two components, 30 N south and 20 N west. What was the initial magnitude of the force?

(a) 50 N
(b) 10 N south west
(c) 36 N
(d) 50 N south west

23. A 0.2% strain on a stress-strain curve for stainless steel is called the

(a) ultimate strain.
(b) elastic strain.
(c) proportional strain.
(d) yield strain.

24. A 10 kg ball has an initial velocity of 15 m s^{-1} and a final velocity of 5 m s^{-1} one second later. The ball's acceleration is

(a) negative and its maximum magnitude is 10.
(b) negative and its average magnitude is 10.
(c) positive and its maximum magnitude is 10.
(d) positive and its average magnitude is 10.

See next page

Part B: Extended answer **50% (105 Marks)**

This part has **five** 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.

All questions in Part B are based on the design of a new flying fox (also a known as a zip line), which will be similar to the one shown below and on page 19, running from a riverbank to a bridge.

Existing flying fox frame, riverbank side

See next page

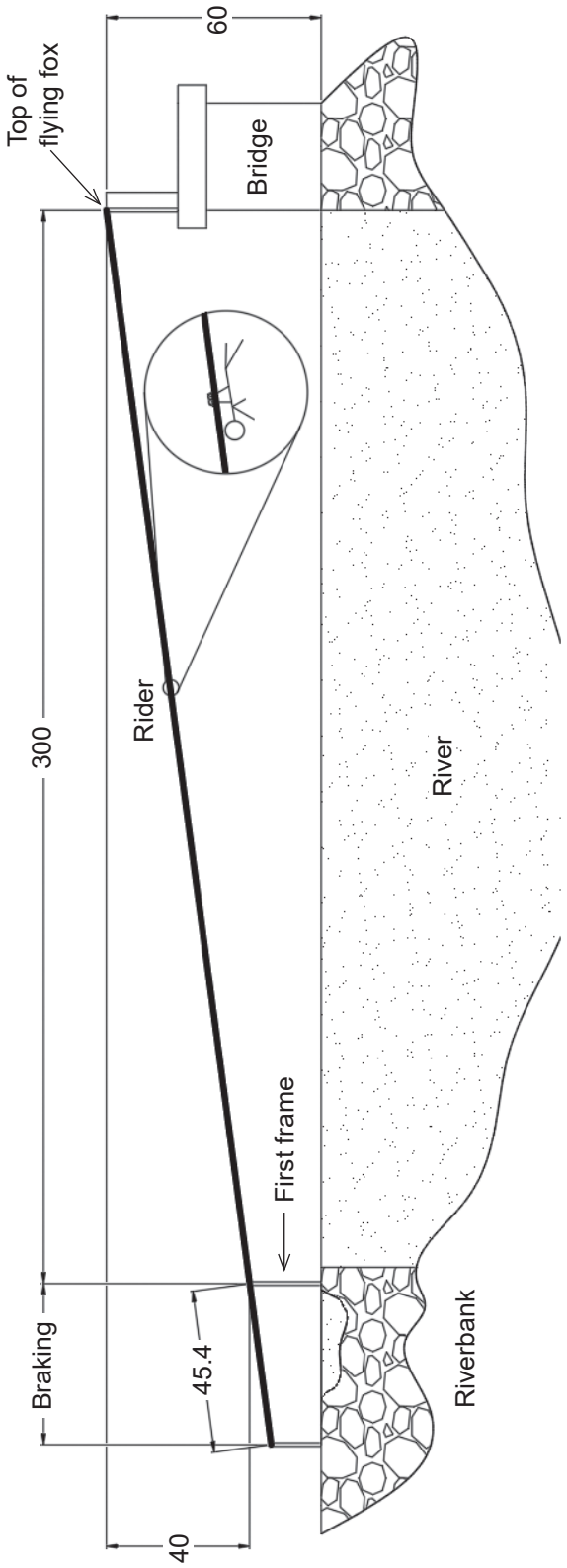
Existing flying fox frame, bridge side

See next page

Question 25 **(16 marks)**

The design of a new flying fox is shown in the diagram below.

Assume the rider's centre of mass travels along the cable, (which is assumed not to deflect) and all other parts of the travelling assembly have a negligible mass. Dimensions are in metres.



Flying fox

See next page

(a) Calculate the potential energy of a 120 kg rider as they are about to set off from the bridge on the flying fox. The height is determined by the difference between the top of the flying fox and the top of the first frame. (2 marks)

Potential energy (J) = _____

(b) Calculate the kinetic energy of a 120 kg rider as they pass the first riverbank frame while travelling on the flying fox. Assume total energy losses of 5%. (2 marks)

Kinetic energy (J) = _____

See next page

Question 25 (continued)

(c) Calculate the magnitude of the velocity with which the 120 kg rider passes the first riverbank frame in km h^{-1}. If you could not determine a value in part (b), assume the person has 50 kJ of kinetic energy. (4 marks)

Magnitude of velocity (km h^{-1}) = _____

(d) State **two** possible sources of energy loss in operating the flying fox. (2 marks)

One: _____

Two: _____

See next page

(e) The velocity as the rider enters the braking portion of the ride is considered to be too fast. It is decided that the maximum velocity of the rider will be reduced to 50 km h^{-1} by adjusting the height of the first riverbank frame.

(i) Calculate the new height of the first riverbank frame. (4 marks)

Height (m) = _____

(ii) Explain what changes, if any, would need to be made to the height of the riverbank frame, if the rider's design weight was changed to 150 kg. (2 marks)

_____

_____

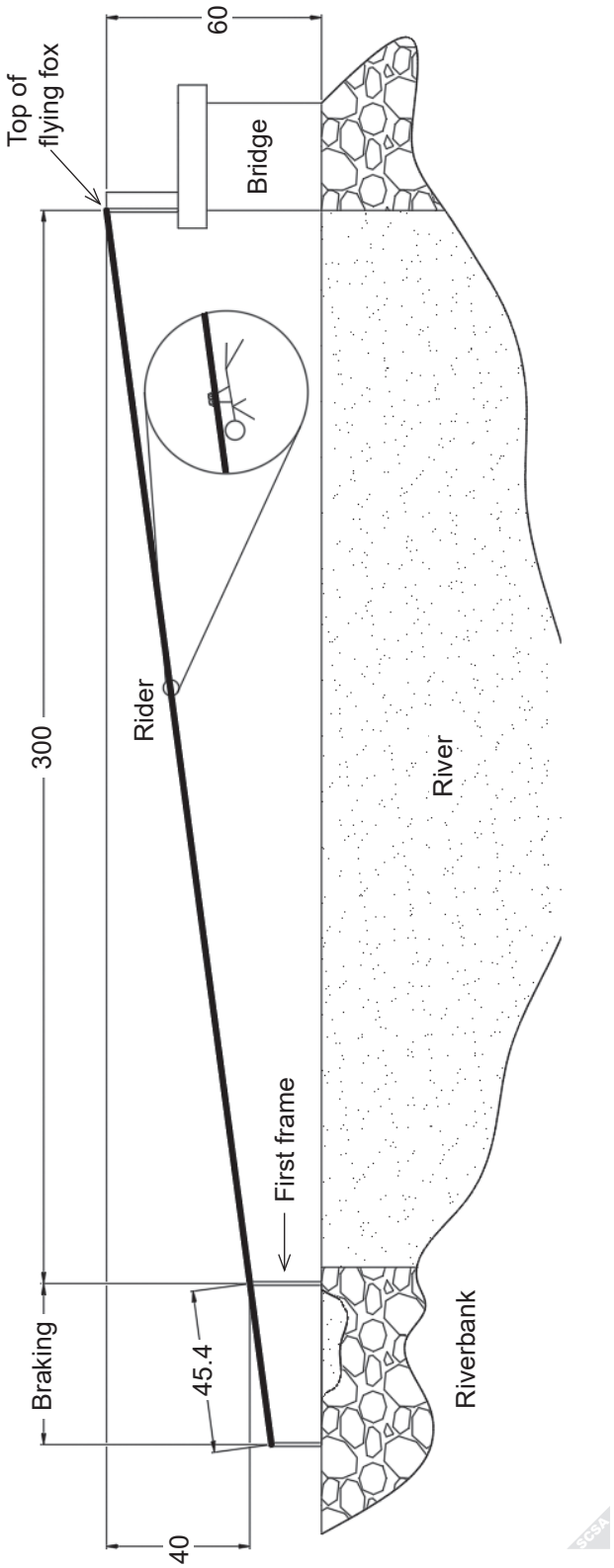
_____

_____

_____

Question 26 **(12 marks)**

This question refers to the same design of a new flying fox as Question 25. The diagram is repeated below for ease of reference.



Flying fox

See next page

(a) Calculate the displacement of a rider who has set out from the bridge at the moment they pass the first frame on the riverbank. (3 marks)

Displacement (m) = _____

(b) Between the bridge and the first frame on the riverbank where braking starts, the rider experiences a constant acceleration of 1.23 m s^{-2}. Calculate the maximum velocity of the rider. If you could not determine an answer for part (a), use 300 m as the displacement. (2 marks)

Maximum velocity (m s^{-1}) = _____

(c) If the deceleration in the breaking portion of the ride is a constant 4 m s^{-2} calculate how long the whole ride takes. If you could not determine an answer for part (b), use 25 m s^{-1} for the maximum velocity. (7 marks)

Time (s) = _____

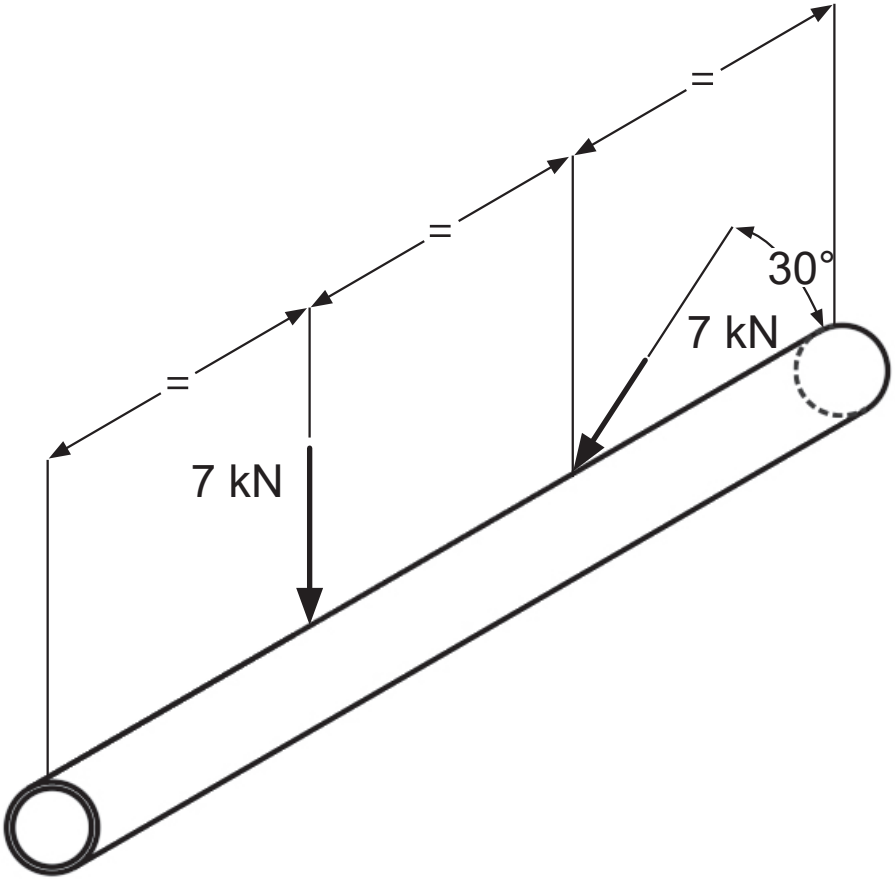
See next page

Question 27 **(26 marks)**

A horizontal beam making up one of the frames is to be investigated for the new flying fox design. The following information and pictorial drawing has been presented to you.

Beam specifications

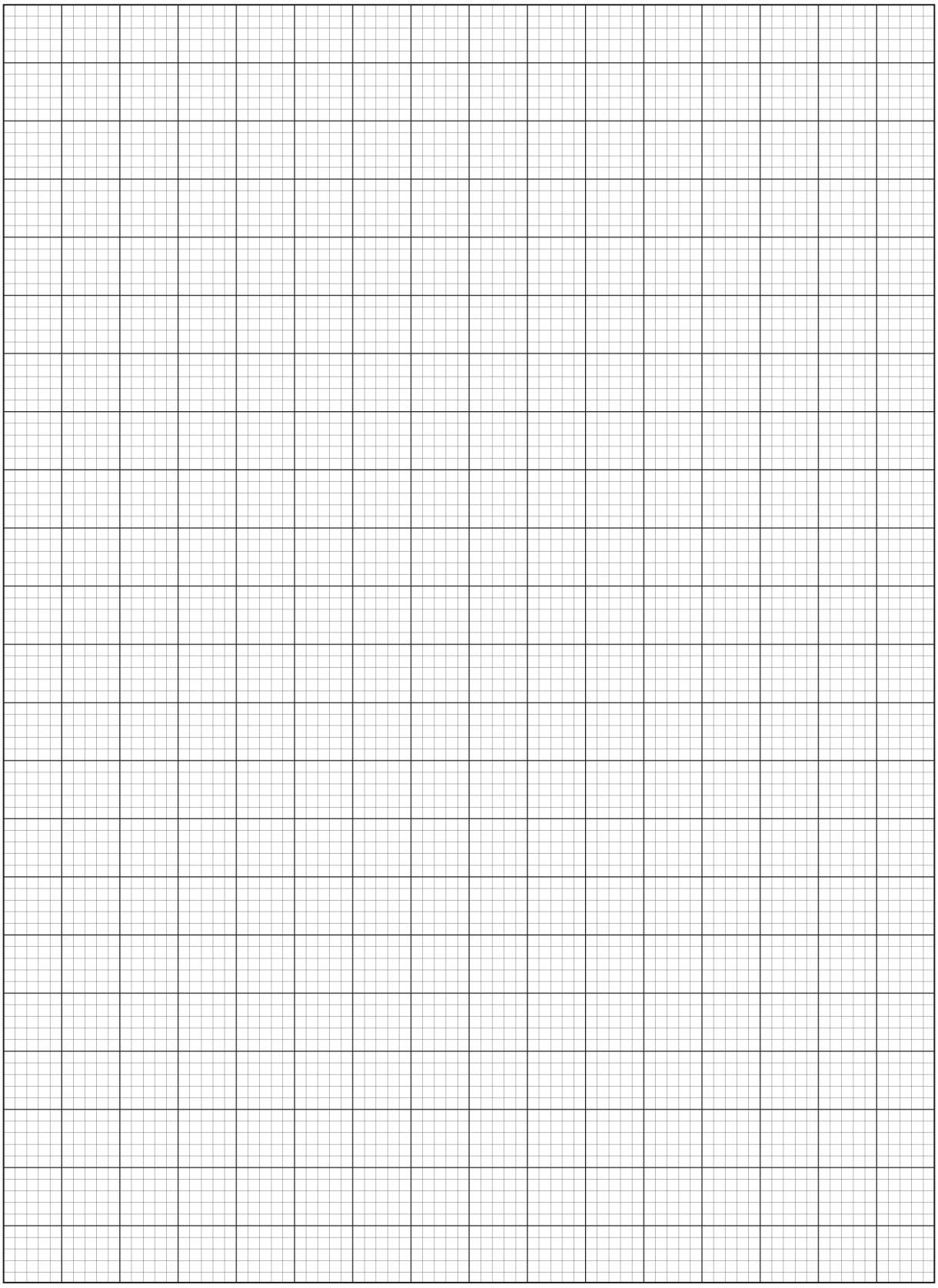
Geometry: Circular hollow section AS1163-C350L0
Total length = 6000 mm
Type: Simply supported
Force drawing:



Reaction force magnitudes:
Horizontally = 6 kN
Vertically = 5.8 kN and 4.7 kN

See next page

(a) Draw the beam diagram on the grid provided below. Include all relevant beam information that will be required for the construction of its shear and bending moment diagrams. All defining lengths must be included in metres. (7 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

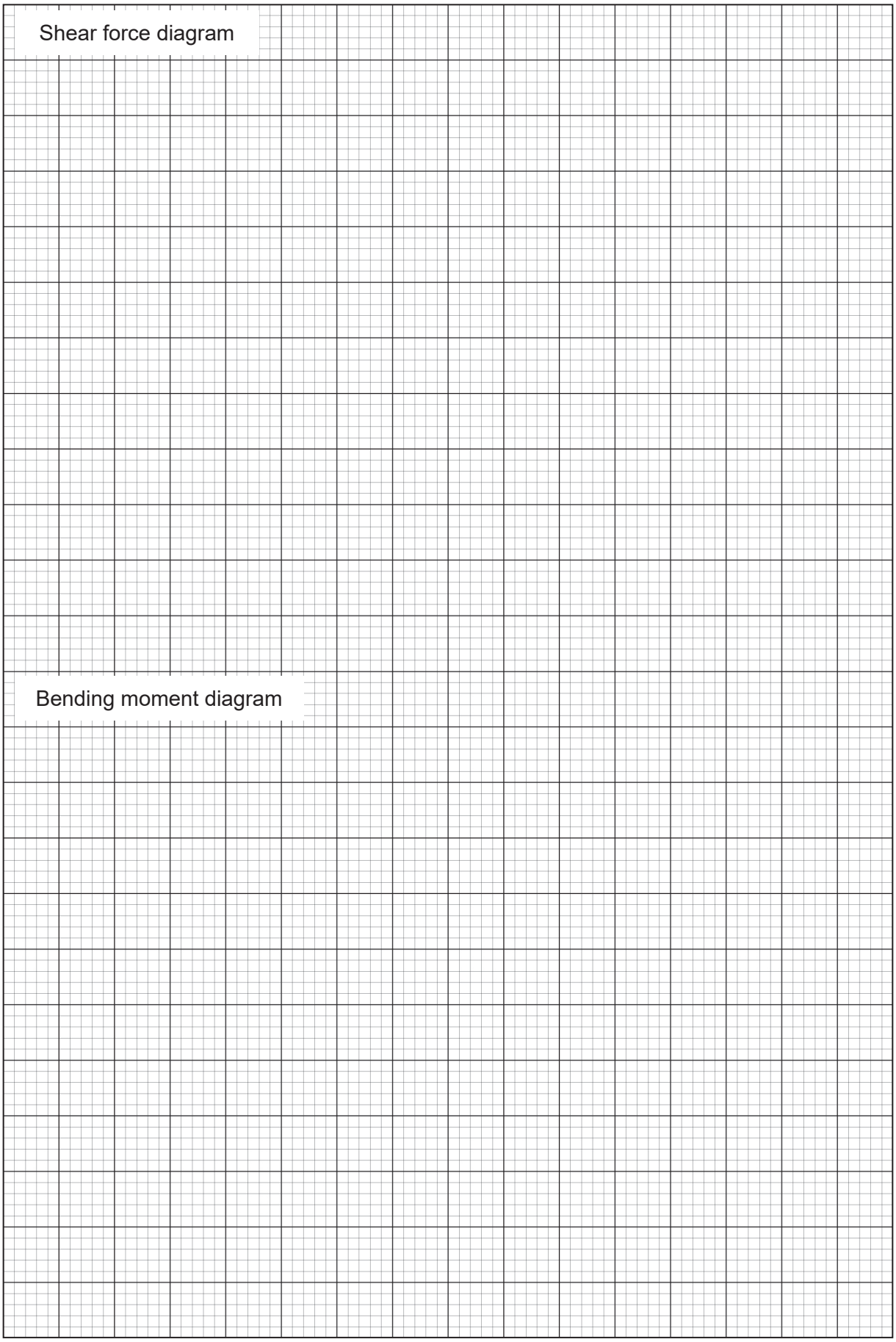
Question 27 (continued)

(b) Draw a shear force diagram for this beam on the grid provided on page 30, under the appropriate heading. In the space below, show all calculations required to construct the shear force diagram. (8 marks)

See next page

(c) Draw a bending moment diagram for this beam on the grid provided on page 30, under the appropriate heading. In the space below, show all calculations required to construct the bending moment diagram. (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.

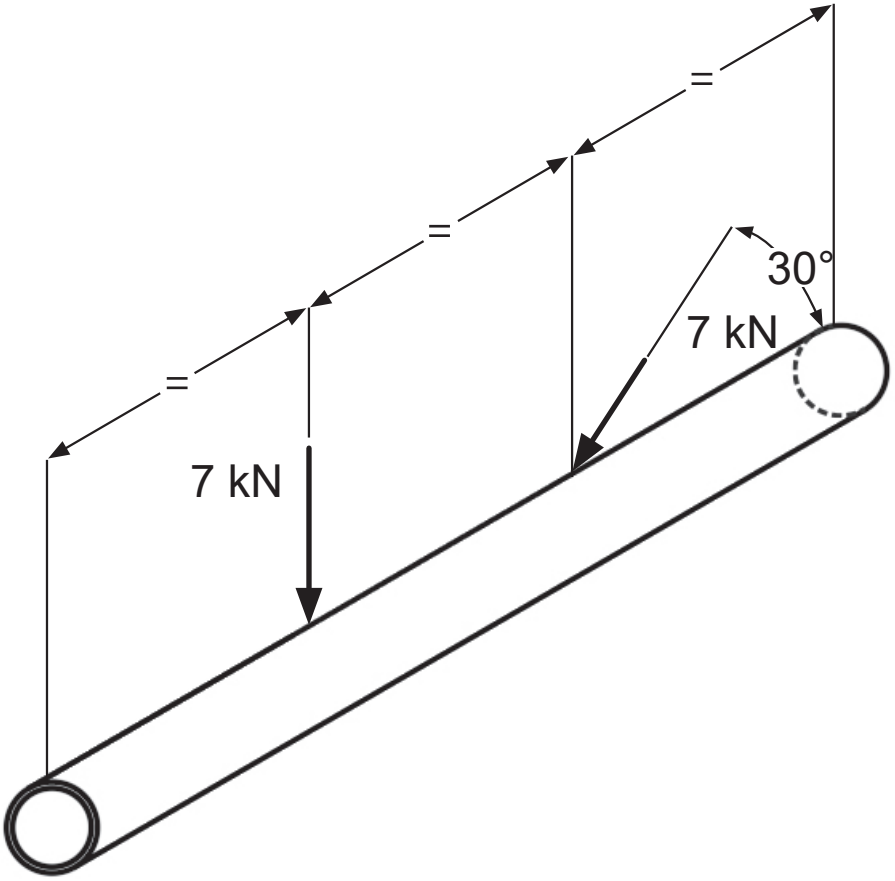
See next page

Question 28 **(21 marks)**

This question refers to the same beam specifications as Question 27. The diagram is repeated for ease of reference.

Beam specifications

Geometry: Circular hollow section AS1163-C350L0
Total length = 6000 mm
Type: Simply supported
Force drawing:

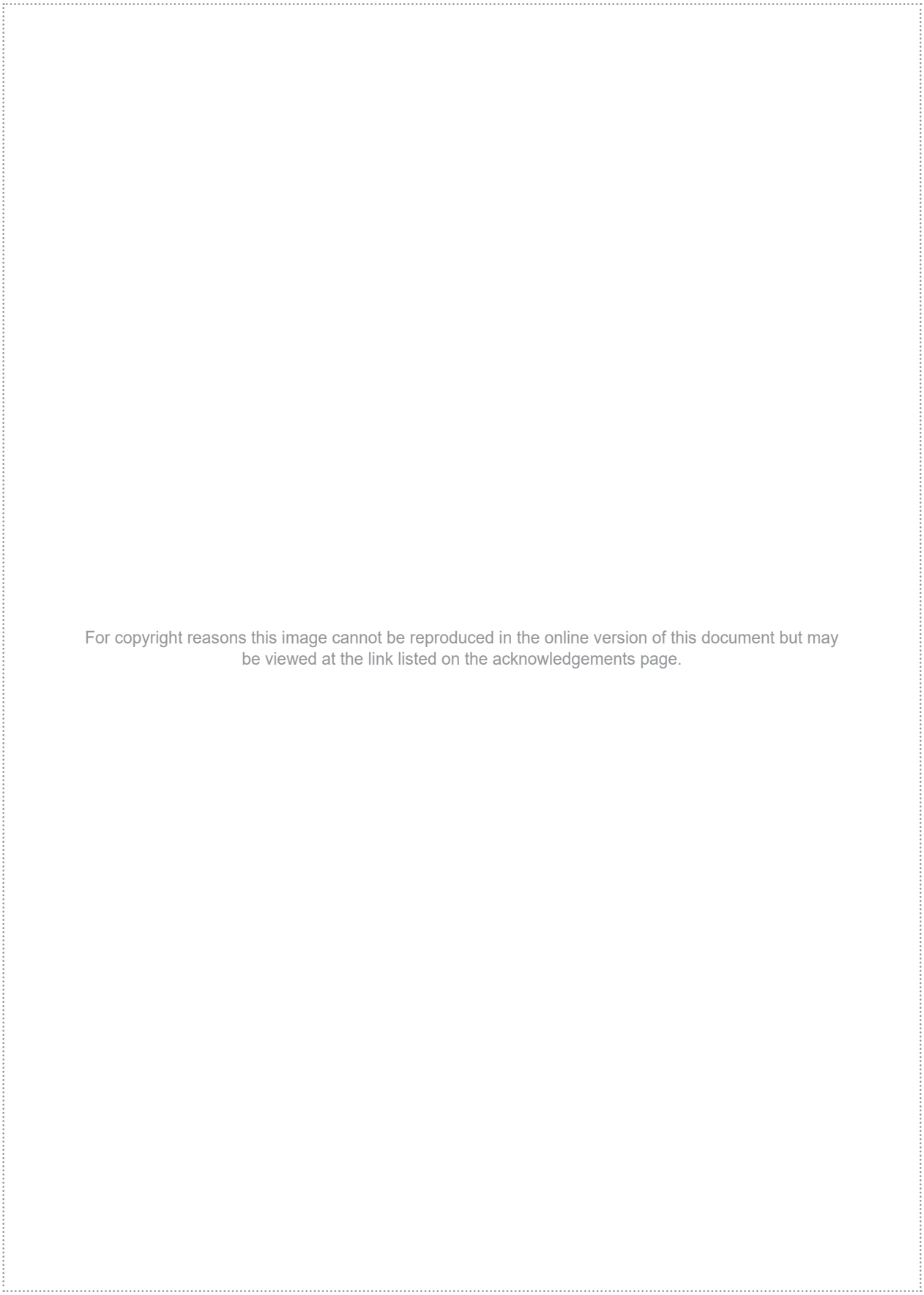


Reaction force magnitudes:
Horizontally = 6 kN
Vertically = 5.8 kN and 4.7 kN

See next page

Question 28 (continued)

The data on this page and page 33 provides the geometric and mechanical properties of the circular hollow section.



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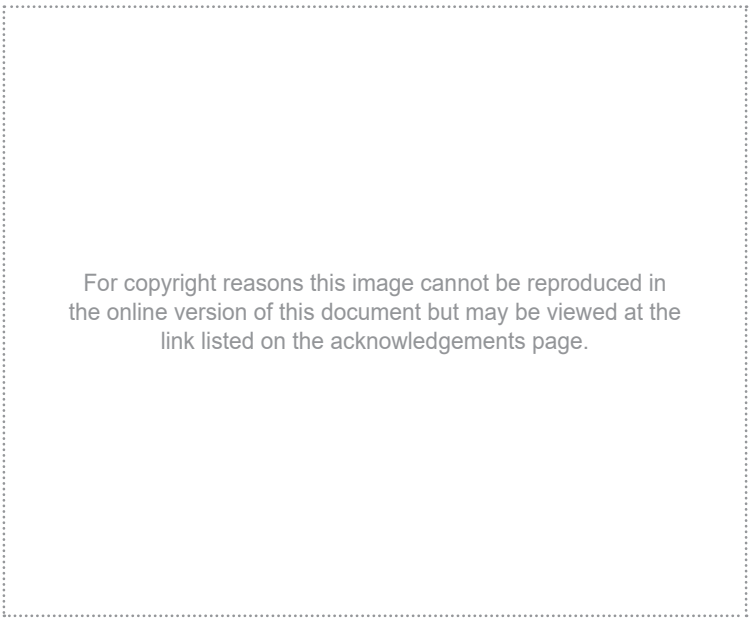


(a) Calculate the maximum stress in the beam cross-section due to the force acting along the axis of the circular hollow section if it has an OD of 165.1 mm, a wall thickness of 3.5 mm and a cross-sectional area of 1528 mm^2. (2 marks)

Maximum stress ($N\ mm^{-2}$) = _____

(b) Would this beam be an acceptable design choice for the new flying fox? Use details in the table describing the geometry and mechanical properties to justify your choice. (3 marks)

_____

_____

_____

_____

_____

_____

_____

_____

_____

See next page

Question 28 (continued)

(c) Using a safety factor of two and the data from pages 32 and 33, calculate and select the most efficient choice for the design from those available. Only consider stress in the beam cross-section due to the force acting along the axial direction only. (4 marks)

(d) Calculate I_{XX} for the section and state if it matches the data on page 32. (5 marks)

See next page

(e) Calculate the deflection of the beam due to its self-weight. (7 marks)

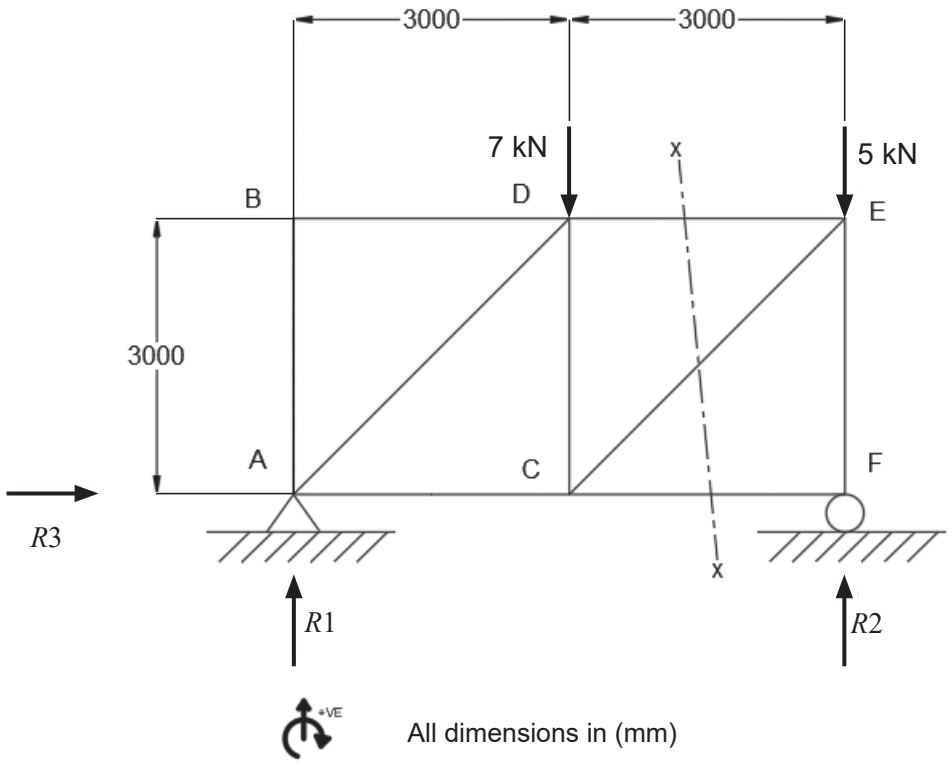
Deflection (mm) = _____

See next page

Question 29 **(30 marks)**

The photograph below is an example of a truss arrangement that makes up a part of the supporting structure for the existing flying fox.

A truss diagram, including expected loads and dimensions for the new flying fox design, is shown below.



Refer to the photograph and diagram on page 36 to answer the following question.

(a) Calculate the reaction forces $R1$, $R2$ and $R3$. (8 marks)

$R1$ (kN) = _____

$R2$ (kN) = _____

$R3$ (kN) = _____

See next page

Question 29 (continued)

(b) Using the method of sections at x-x, calculate the force in the member CF and state if it is in compression or tension. (7 marks)

Force (kN) = _____

Compression or tension = _____

See next page

(c) Using the method of sections at x-x, calculate the force in the member CE and state if it is in compression or tension. (15 marks)

Force (kN) = _____

Compression or tension = _____

End of Mechanical Section

Section Two: Specialist field – Mechatronics **60% (115 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)**

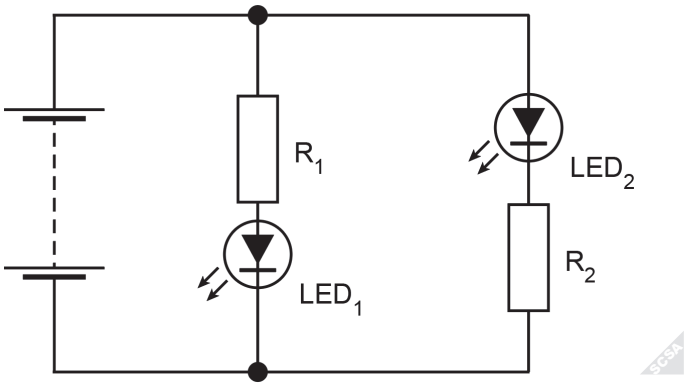
This part has **10** questions. Answer **all** questions on the separate Multiple-choice answer sheet provided. For each question, shade the box to indicate your answer. Use only a blue or black pen to shade the boxes. Do not use erasable or gel pens. If you make a mistake, place a cross through that 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. Two resistors of different values are connected in series across a power supply. Which of the following statements is correct?

(a) the larger value resistor will dissipate the most power
(b) a smaller current will flow through the larger value resistor
(c) more voltage will be dropped off across the smaller value resistor
(d) both resistors will have the same voltage drop

31. In the diagram below, LED_1 and LED_2 are identical as are the resistors R_1 and R_2. Which of the following statements about the LEDs is correct?



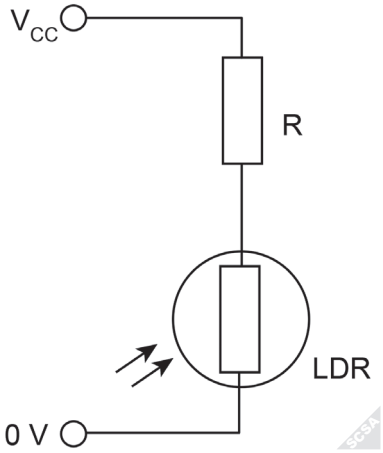
(a) LED_1 will glow more brightly than LED_2
(b) LED_2 will glow more brightly than LED_1
(c) neither of the LEDs will glow
(d) both LEDs will glow with the same brightness

See next page

32. ‘Depletion layer’ is a term associated with which of the following?

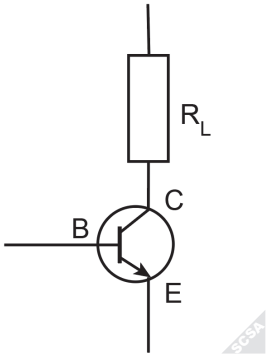
(a) capacitor
(b) diode
(c) battery
(d) coil

33. An LDR and a resistor are connected to a power supply as shown in the diagram. When conditions become brighter the



(a) current through the resistor will decrease.
(b) power dissipated by the resistor will increase.
(c) voltage across the LDR will increase.
(d) resistance of the resistor will increase.

34. Decreasing the base current of an NPN transistor that is in its forward-active region of operation, as shown in the diagram, will cause



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

35. Which of the following is an example of a closed-loop system?

(a) a streetlight that automatically turns on at dusk and off at dawn
(b) a water sprinkler system that turns on and off at set times
(c) an automated garage door that operates via a remote controller
(d) an air-conditioning system for an apartment building

36. Arithmetic operations are performed by a microcontroller’s

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

See next page

37. A motor is required that can position a toothed belt-drive mechanism precisely, without the need for limit switches. The **best** choice would be a

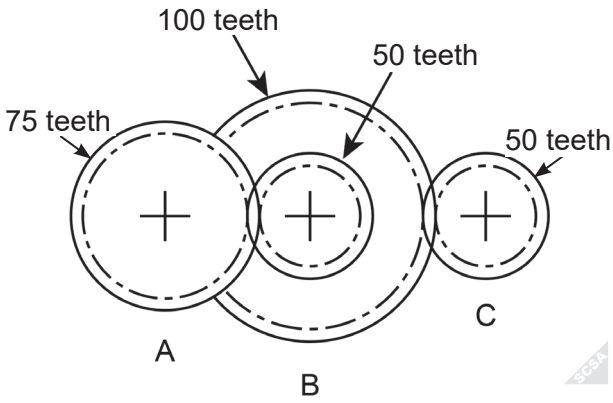
(a) stepper motor.
(b) servo.
(c) DC motor.
(d) DC gearhead motor.

38. A mechanical drive system is required to operate a boom gate at a car park. For reasons of safety, it is important that should there be a power failure and the arm is in a raised position, the arm remains still and does not rotate downward. The **best** drive system to achieve this design criteria is a

(a) chain and sprocket.
(b) worm drive.
(c) rack and pinion.
(d) compound gear train.

39. The gear train illustrated below consists of three separate gears. These are labelled ‘A’, ‘B’ and ‘C’. Gear B is a compound gear. When the system is operating, the speed of rotation of gear B will be

(a) slower than A but faster than C.
(b) faster than A and the same as C.
(c) faster than A but slower than C.
(d) the same as A but slower than C.



See next page

Part B: Extended answer **50% (105 Marks)**

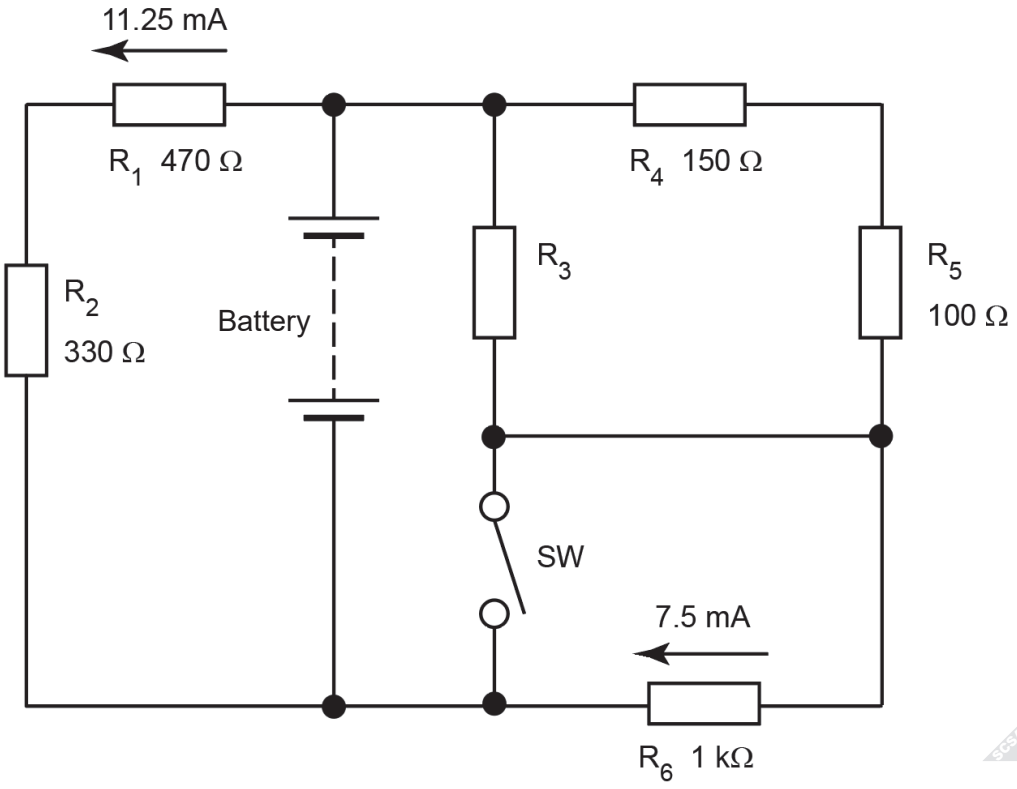
This part has **six** questions. Answer **all** questions. Write your answers in the spaces provided.

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 **(19 marks)**

The circuit shown below includes SW, an SPST switch that is in open-circuit.



(a) Calculate V_{BATT}, the voltage of the battery. (3 marks)

V_{BATT} = _____

Question 40 (continued)

(b) Calculate P_{BATT}, the power supplied to the circuit by the battery. (3 marks)

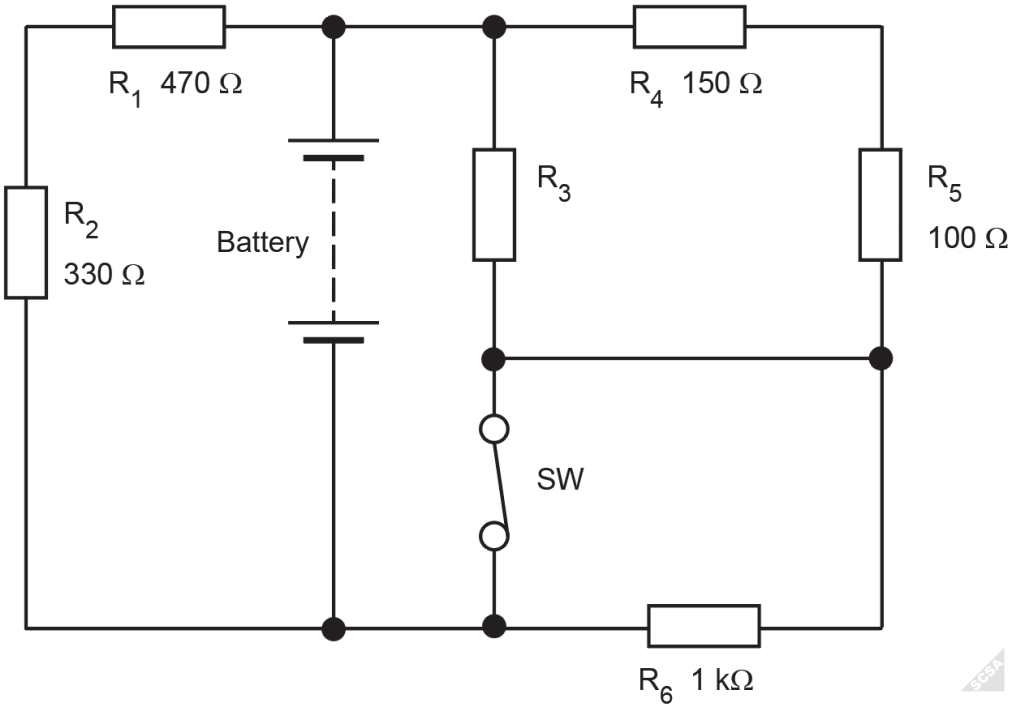
P_{BATT} (W) = _____

(c) Calculate R_3, the resistance of R_3. (7 marks)

R_3 (Ω) = _____

See next page

The SPST switch, SW, is now in closed-circuit, as shown in the circuit diagram below. The resistance of SW is negligible, i.e. assume it is 0 Ω.



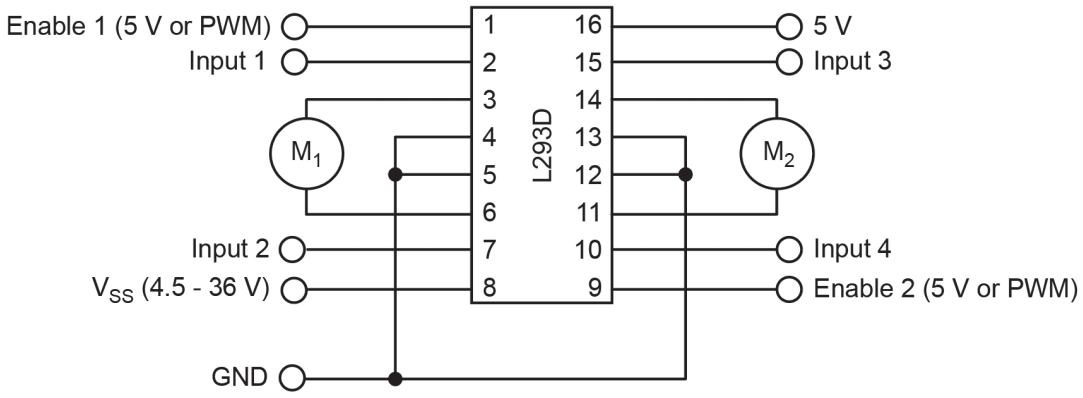
(d) Calculate R_T, the total resistance of the entire resistor network. If you could not calculate an answer for part (c), use 1200 Ω. (6 marks)

$R_T\,(\Omega)$ = _____

See next page

Question 41 **(20 marks)**

The pinout diagram for an L293D motor controller is shown below. The table that follows provides details regarding the function of the pins.



Pin	Function	Pin	Function
1	Enables M_1 to function, plus can be used for speed control	16	Enables internal circuitry of L293D to function
2	Sets one direction of rotation for M_1	15	Sets one direction of rotation for M_2
3	Connects one side of M_1	14	Connects one side of M_2
4	Ground connection	13	Ground connection
5		12	
6	Connects other side of M_1	11	Connects other side of M_2
7	Sets other direction of rotation for M_1	10	Sets other direction of rotation for M_2
8	Supplies power to the motors, i.e. M_1 and M_2	9	Enables M_2 to function, plus can be used for speed control

Speed control for up to two motors is achieved by connecting pins 1 and 9 to output pins of a microcontroller that can produce PWM signals.

(a) (i) State the full name for PWM. (1 mark)

_____

(ii) Provide **three** reasons why this technique of speed control is used for an electric motor rather than by simply adjusting current using a variable resistor between the power supply and the motor. (3 marks)

One: _____

_____

Two: _____

_____

Three: _____

_____

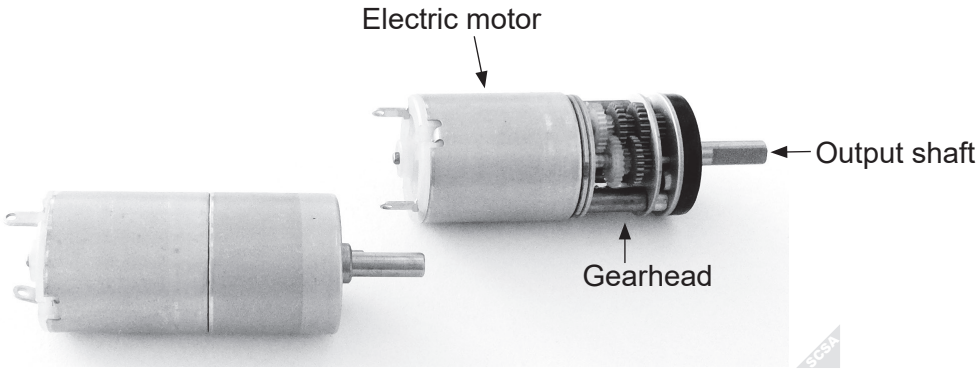
See next page

(iii) Assuming that the motors are required to operate at a PWM frequency of 490 Hz with an 80% duty cycle, calculate the duration of the 'high' and 'low' times for each period. (3 marks)

'High' time (s) = _____

'Low' time (s) = _____

Gearhead motors like the one shown below are often used for mechatronic applications.



(b) (i) The gearhead is designed to produce a high velocity ratio (VR). Identify and explain briefly **one** significant advantage and **one** significant disadvantage of this system. (4 marks)

Advantage: _____

_____

_____

_____

Disadvantage: _____

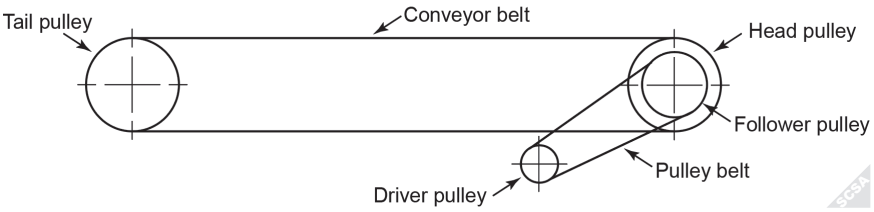
_____

_____

_____

See next page

Question 41 (continued)



(ii) Assume the output shaft of a gearhead motor with a VR of 244 is fitted to the driver pulley of a conveyor belt mechanism similar to that illustrated above. The driver pulley has a diameter of 20 mm and the follower pulley has a diameter of 32 mm. The head and tail pulleys that move and support the conveyor belt are both 50 mm in diameter.

The free-running speed of rotation of the electric motor fitted to the gearhead is 8784 revolutions per minute (rpm). PWM control of the motor is set at a duty cycle of 70%. Losses due to friction, slippage and loading of the motor result in an efficiency of 65%. Calculate the resulting linear speed of the conveyor belt. Answer in units of metres per second (m s^{-1}). (9 marks)

Linear speed of belt (m s^{-1}) = _____

See next page

Question 42 **(20 marks)**

The supply of energy for electrical and electronic circuits is commonly achieved using cells, batteries and capacitors.

(a) The following questions relate to lithium-ion cells marked 3.7 V 2000 mAh.

(i) Lithium-ion cells are described as being 'secondary' cells. State how these differ from 'primary' cells. (1 mark)

_____

_____

(ii) **Three** of these lithium-ion cells are connected in series and connected to a 12 Ω resistor that acts as the load for this circuit. In the space below, sketch a labelled circuit diagram, using the correct circuit symbols given in the Data Book. (2 marks)

(iii) Calculate V_R, the voltage held across the load resistor and, I_R, the current that flows through it. (3 marks)

V_R = _____

I_R = _____

See next page

Question 42 (continued)

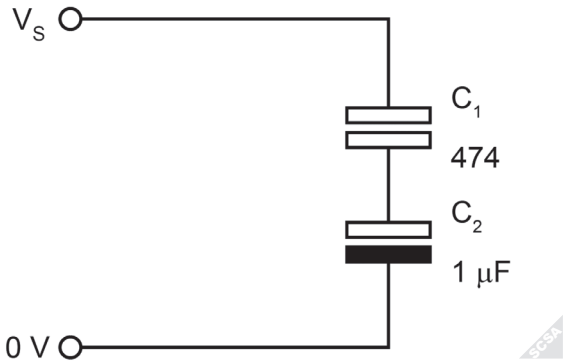
(iv) Calculate the time the battery, made from the three cells joined in series, will be able to supply the current calculated in part (iii) to the circuit. Answer in seconds. If you could not calculate an answer for part (iii) use 950 mA. (3 marks)

Time (s) = _____

(v) Calculate the energy transferred to the resistor by the battery in this time. Answer in units of kilojoules (kJ). (3 marks)

Energy (kJ) = _____

Two capacitors are connected to a power supply as shown in the diagram below. One is marked 474 and the other 1 µF. The voltage across C_2 is 1.918 V.



(b) Calculate C_T, the total capacitance of the network. Answer using units of microfarads (µF). (3 marks)

C_T (µF) = _____

See next page

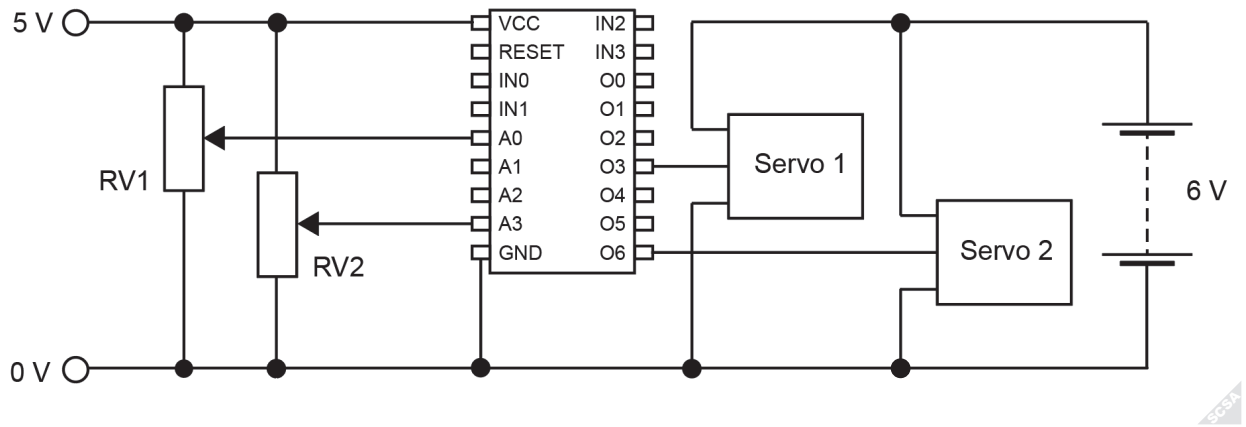
The charge of a capacitor is determined using the formula $Q = CV$ where Q is the charge in units of coulombs, C is the capacitance in units of farads, and V is the voltage across the capacitor.

Additionally, the way that the capacitors are arranged results in $Q_T = Q_{C1} = Q_{C2}$ i.e. total charge of the capacitor network equals the charge of the first capacitor equals the charge of the second capacitor. This is similar to the relationship between parallel resistors and voltage in a resistor network.

(c) Calculate V_S, the voltage of the power supply. (5 marks)

V_S = _____

Question 43 **(12 marks)**



The above circuit features **two** potentiometers and **two** servos connected to a microcontroller.

The outputs of the potentiometers are connected to pins of the microcontroller that each incorporate ADCs with a resolution of 10-bits.

(a) (i) State the full name for ADC. (1 mark)

_____

(ii) The potentiometers are marked as 10 kΩ. If RV1 is adjusted by rotating its spindle such that it produces a value of 812 at pin A0, calculate the resistance between its wiper and 5 V. (3 marks)

Answer : _____

(b) State **three** reasons why it is necessary to connect the GND wires of the servos to the GND pin of the microcontroller. (3 marks)

One: _____

_____

Two: _____

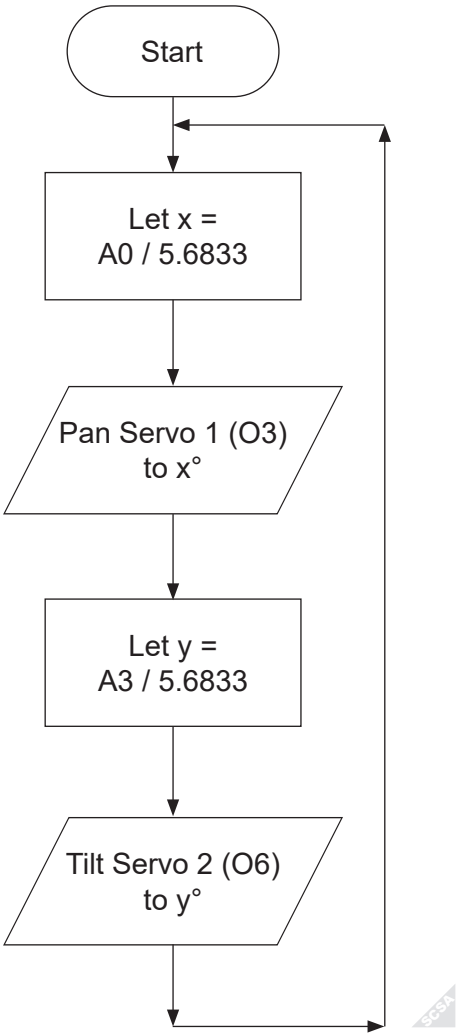
_____

Three: _____

_____

See next page

The circuit shown on page 52 could be used to control and move a 'pan and tilt' mechanism for a small camera. The operator could move the camera remotely on two axes – left/right (pan) and up/down (tilt). The flow chart of the control program to achieve this is shown below.

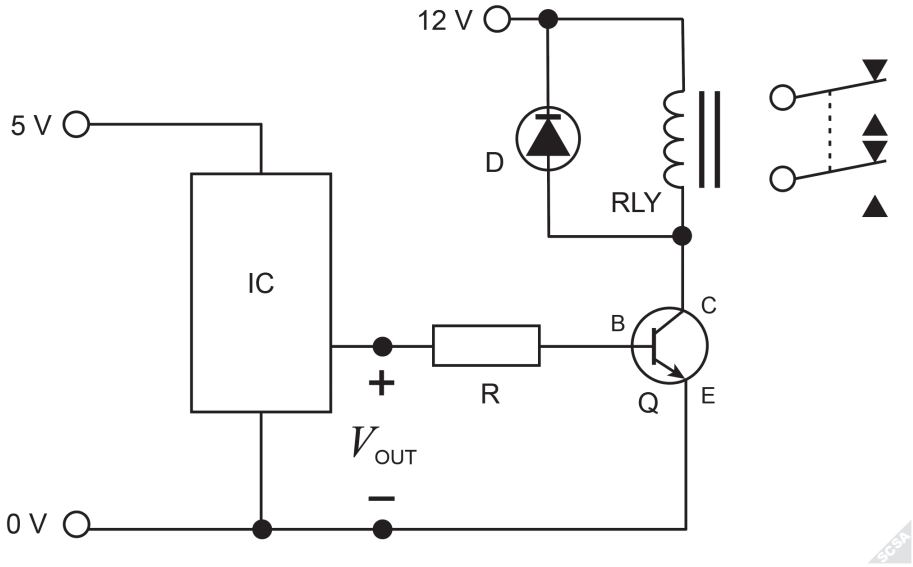


(c) Explain how the control program functions, assuming the servos operate in a 180° arc. (5 marks)

See next page

Question 44 **(19 marks)**

The circuit shown below includes a microcontroller, IC, and a transistor, Q. The circuit parameters are as follows: $V_{OUT,LOW}$ = 0 V, $V_{OUT,HIGH}$ = 5 V, transistor gain (β) = 25 and R_{RLY} = 300 Ω.



(a) Assume the output pin is *low*. Calculate V_{CE}, the voltage across the collector-emitter junction of the transistor. (3 marks)

V_{CE} = _____

(b) Assume the output pin is *high* and P_{RLY}, the power dissipated by the relay is 315 mW.

(i) Calculate V_{CE}, the voltage across the collector-emitter junction of the transistor. (4 marks)

V_{CE} = _____

See next page

(ii) Calculate R, the resistance of the resistor. (5 marks)

R (Ω) = _____

(c) Calculate the maximum value for R, the resistance of the resistor, required to drive the transistor into saturation when the output from the microcontroller is high. (7 marks)

R (Ω) = _____

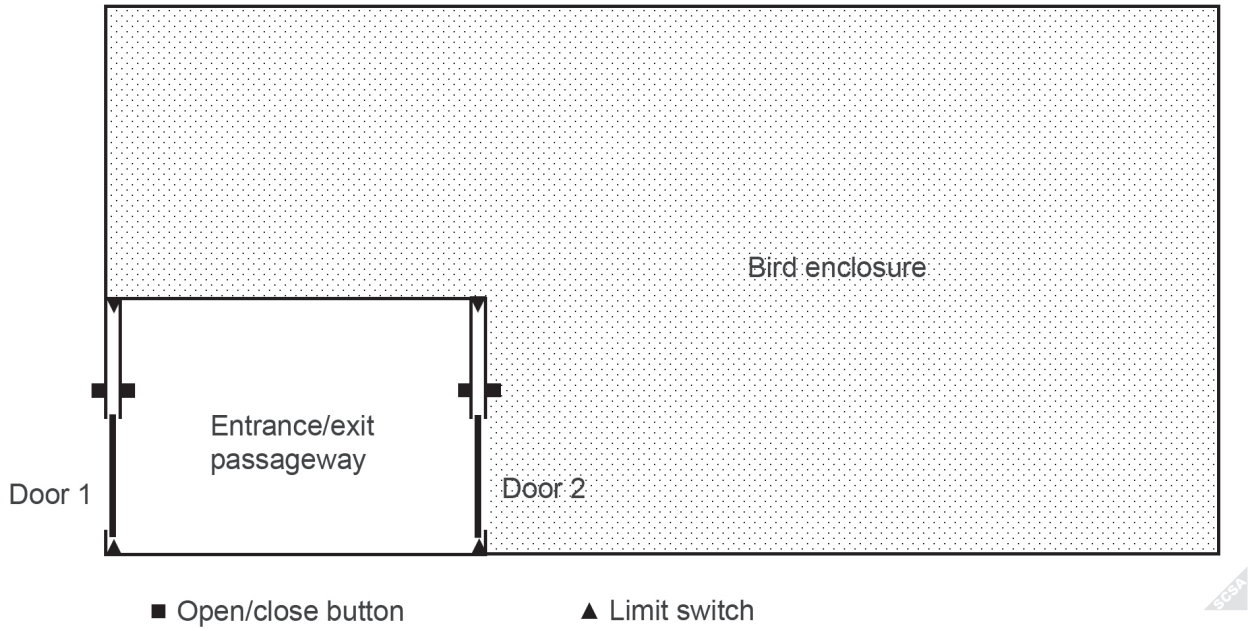
See next page

Question 45 **(15 marks)**

A bird-house complex has been built at a zoo. It consists of a bird enclosure and an entrance/exit passageway. This passageway requires a system to control entrance into the bird enclosure. This consists of two sliding doors, one at each end of an enclosed entrance/exit passageway. Door 1 provides access into the entrance/exit passageway and exit from the bird-house complex. Door 2 provides access from the entrance/exit passageway into the bird enclosure.

Each door is moved by its own reversible electric motor driving rack and pinion mechanisms. To prevent birds from escaping, it is imperative that only one door can be open at a time when entering or exiting the entrance/exit passageway. To activate the system, there are button switches on either side of each door.

Bird-house complex



The system works as follows:

1. To enter the entrance/exit passageway from outside the bird-house complex, press the button outside Door 1. This will cause the door to open. A limit switch will detect when the door is fully open.
2. To close Door 1, press the button located inside the passageway next to Door 1. Another limit switch will detect when the door is fully closed.
3. The buttons either side of Door 1 are wired in parallel. The limit switches are each wired separately.
4. To exit the entrance/exit passageway and enter the bird enclosure, press the button inside the passageway next to Door 2. This will cause the door to open. A limit switch will detect when the door is fully open.
5. To close Door 2, press the button located inside the bird enclosure next to Door 2. Another limit switch will detect when the door is fully closed.
6. The buttons either side of Door 2 are wired in parallel. The limit switches are each wired separately.
7. Exit from the bird enclosure is achieved by following the above steps in reverse.
8. The control system cannot allow both doors to be open at the same time.

See next page

(a) A microcontroller will be used to detect inputs, operate sequences and control outputs. The microcontroller has **ten** digital pins. These can be programmed either as inputs or as outputs. Complete the chart below to assign the required inputs and outputs to the microcontroller's digital pins and state their functional operation. (5 marks)

Digital pin	Input or output	Functional operation
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

See next page

Question 45 (continued)

(b) In the space below, draw a labelled flow chart to operate the bird-house entrance system. Use correct flow chart symbols and identify each by using pin allocations from the chart completed in part (a) e.g. Input 1, Output 2. (10 marks)

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.

End of Mechatronics Section

Supplementary page

Question number: _____

Supplementary page

Question number: _____

Supplementary page

Question number: _____

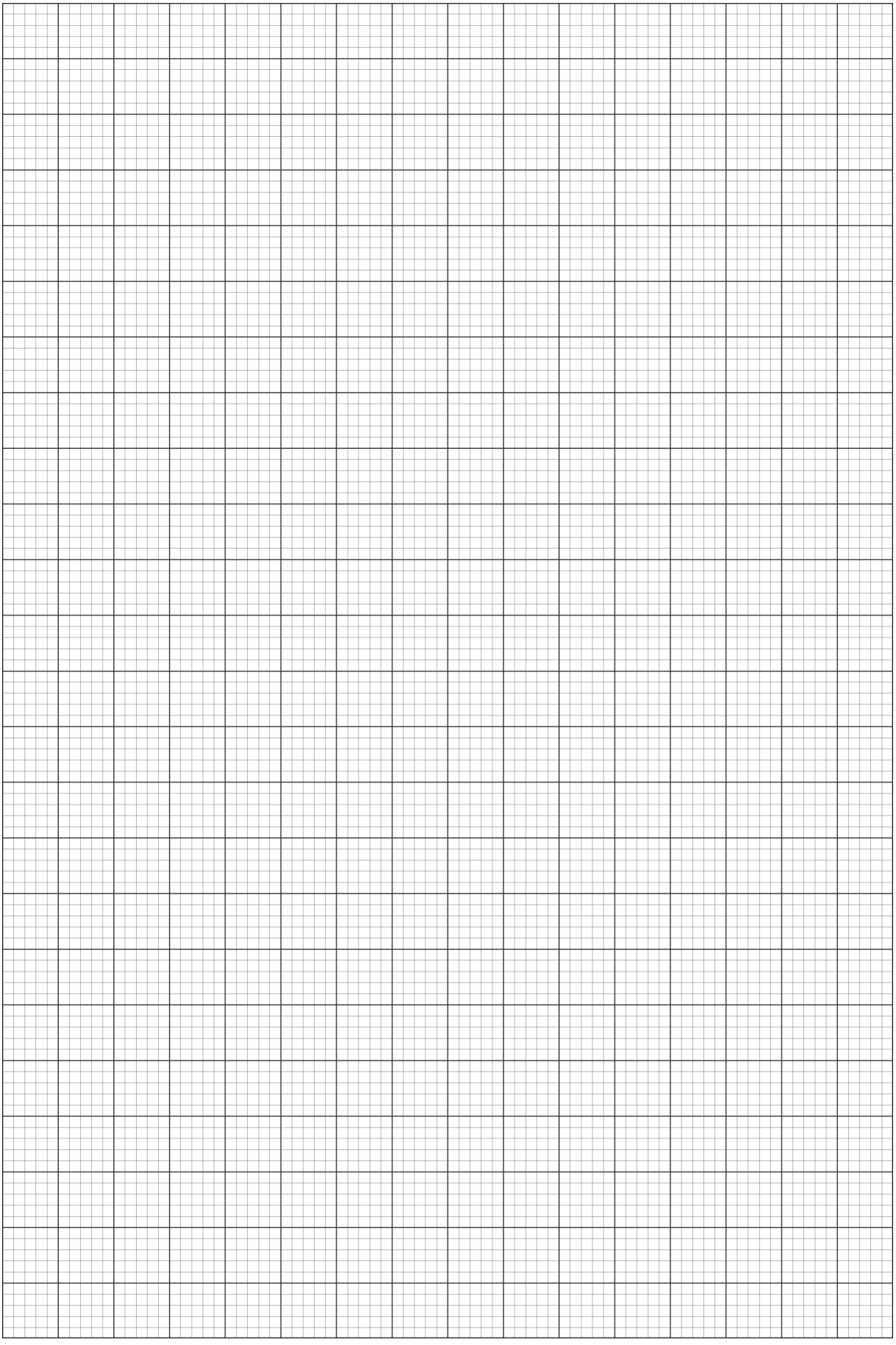
Supplementary page

Question number: _____

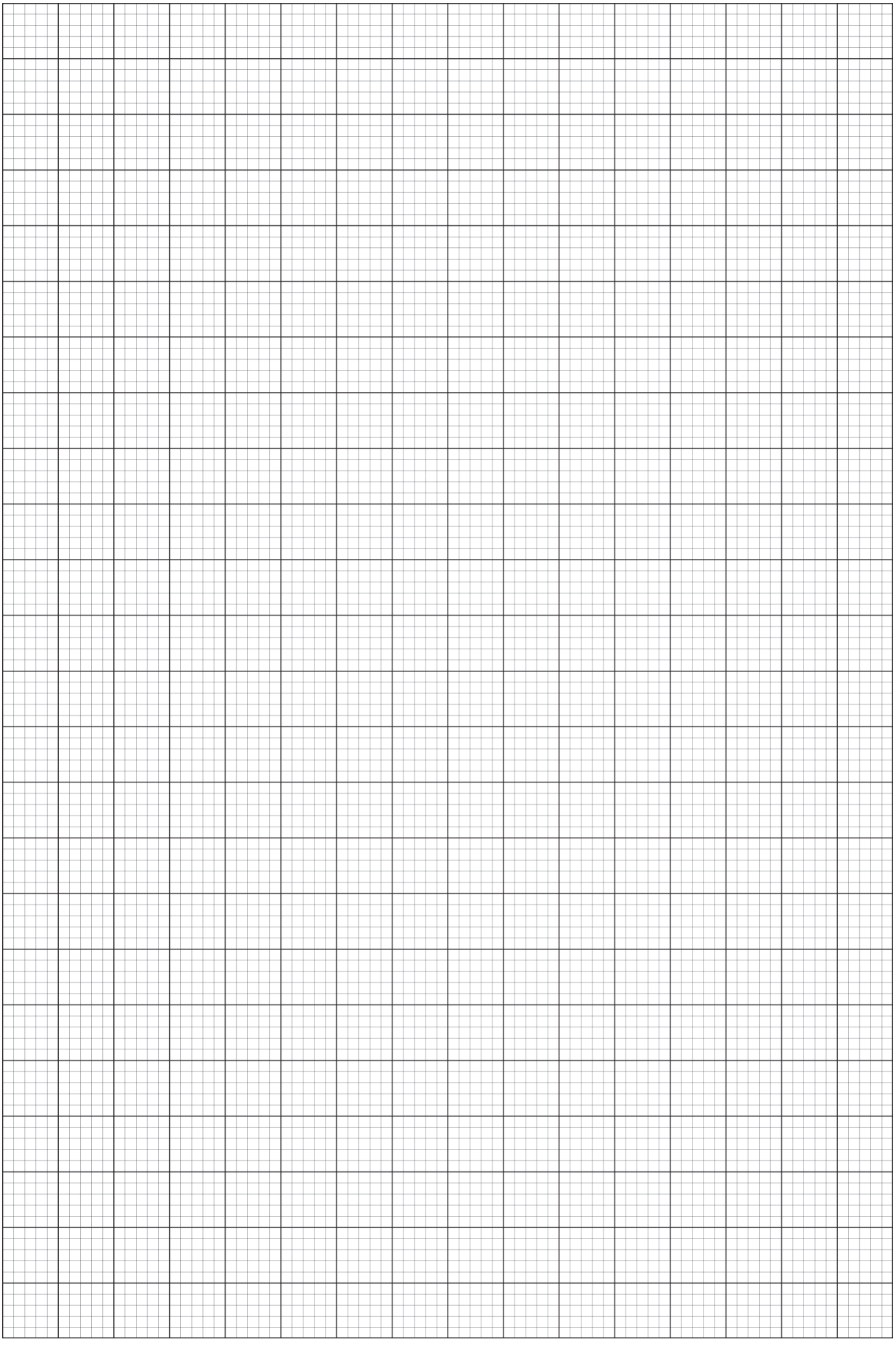
Supplementary page

Question number: _____

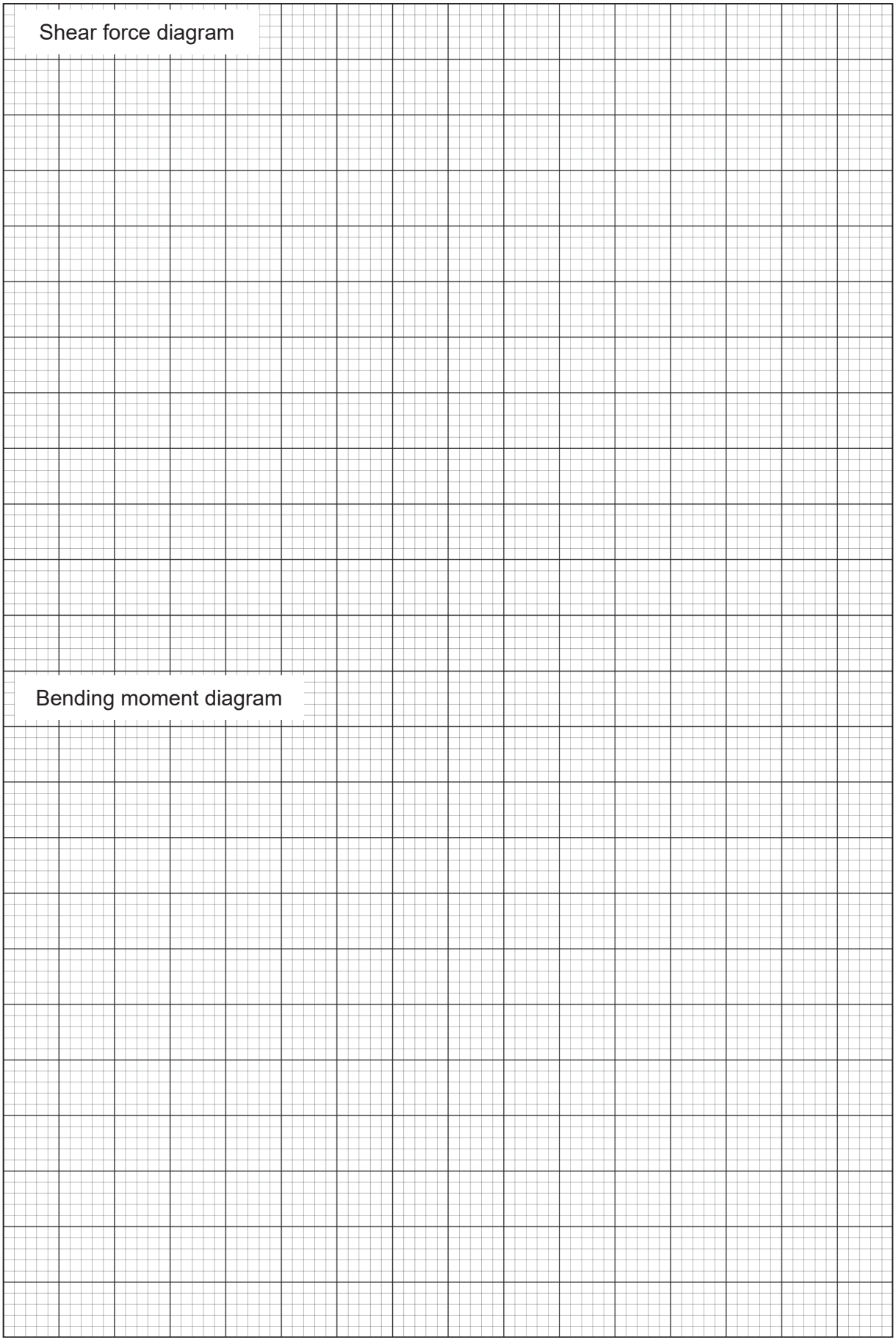
Spare grid



Spare grid



Spare grid



Spare flow chart

ACKNOWLEDGEMENTS

Question 14

KMJ. (2004). *Gluehlampe 01 KMJ* [Photograph of incandescent light bulb]. Retrieved June, 2021, from https://commons.wikimedia.org/wiki/File:Gluehlampe_01_KMJ.jpg
Used under a Creative Commons Attribution-ShareAlike 3.0 Unported licence.

Sun Ladder. (2010). *01 spiral CFL bulb 2010-03-08 (transparent back)* [Photograph]. Retrieved June, 2021, from https://commons.wikimedia.org/wiki/File:01_Spiral_CFL_Bulb_2010-03-08_(transparent_back).png
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Adapted from: Elgato. (2014). *Avea front* [Photograph of LED light bulb]. Retrieved June, 2021, from https://commons.wikimedia.org/wiki/File:Avea_front.jpg
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Question 14(d)

Oast House Archive. (201009). *Little Cheyne Court Wind Farm - geograph.org.uk - 1875915* [Photograph]. Retrieved June, 2021, from https://commons.wikimedia.org/wiki/File:Little_Cheyne_Court_Wind_Farm_-_geograph.org.uk_-_1875915.jpg
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Question 28

Onesteel Market Mills. (2003). Tubeline/ultrapipe circular hollow sections grade C350L0 (AS1163) (Table 1.2(b)). *Cold formed structural hollow sections & profiles* (4th ed.) (p. 13). Retrieved June, 2021, from https://www.edconsteel.com.au/wp-content/uploads/2019/12/coldformed_sections.pdf

Adapted from: Onesteel Market Mills. (2003). Tubeline circular hollow sections grade C350L0 (AS1163) (Table 1.2(c)). *Cold formed structural hollow sections & profiles* (4th ed.) (p. 14). Retrieved June, 2021, from https://www.edconsteel.com.au/wp-content/uploads/2019/12/coldformed_sections.pdf

Onesteel Market Mills. (2003). Mechanical properties: Specific minimum mechanical properties. *Cold formed structural hollow sections & profiles* (4th ed.) (p. 1). Retrieved June, 2021, from https://www.edconsteel.com.au/wp-content/uploads/2019/12/coldformed_sections.pdf

Question 41(b)(ii)

Automated Conveyor Systems Inc. (n.d.). *Model "190RB": Medium duty roller bed belt conveyor* [Photograph]. Retrieved June, 2021, from https://www.automatedconveyors.com/horizontal-powered/model-190rb/

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