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

ATAR course examination, 2022

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.

2022/58937

Ref: 22-026

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		65	30
Section Two **Mechanical** Part A: Multiple-choice	10	10	110	10	10
Part B: Extended answer	6	6		110	50
Section Two **Mechatronics** Part A: Multiple-choice	10	10	110	10	10
Part B: Extended answer	6	6		110	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 2022: 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.

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

This section has **two** parts.

Part A:	Multiple-choice	Answer **all** questions
Part B:	Extended answer	Answer **all** questions

Suggested working time: 70 minutes.

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

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

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1. An electric motor is connected to an electrical grid powered by a coal-burning power station. The sequence in which the different forms of energy are transferred is

   (a) electro-chemical, thermal, kinetic, electrical, kinetic.
   (b) chemical, thermal, kinetic, electrical, kinetic.
   (c) kinetic, potential, electrical, potential, kinetic.
   (d) thermal, potential, kinetic, electrical, kinetic.

2. A small wind turbine used on a boat produces 420 W of power. If its efficiency is 70%, then the input power of the wind is

   (a) 294 W.
   (b) 546 W.
   (c) 600 W.
   (d) 1820 W.

3. 125 kJ of energy is required to raise a load in 20 s. What is the power of this system?

   (a) 200 W
   (b) 6250 W
   (c) 12 500 W
   (d) 2 500 000 W

4. A solid sphere is cut into quarters. Which of the following formulae could be used to calculate the total surface area of one quarter?

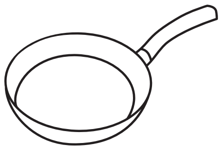
   (a) πr^2
   (b) $1.5\pi r^2$
   (c) $2\pi r^2$
   (d) $3\pi r^2$

5. The property that allows a metal sheet to be permanently deformed into a required shape is its

(a) ductility.
(b) elasticity.
(c) strength.
(d) hardness.

6. A metal frypan used for cooking is heated over a gas burner. Which of the following materials would be the **best** choice for the handle of the frypan, given that the handle will be gripped using bare hands when cooking?

(a) aluminium
(b) stainless steel
(c) copper
(d) cast iron



7. The **most** important factor that should be considered in the design of a freestanding chest of drawers is that it must

(a) have an attractive finish that matches the room décor.
(b) be made from sustainably-sourced materials.
(c) not tip over when multiple drawers are pulled open.
(d) be easy to assemble and disassemble for ease of transport.

8. Orthographic drawings use different types of lines. When these lines overlap, only one type can be shown. Which of the following statements is correct?

(a) centrelines take precedence over hidden detail lines
(b) hidden detail lines take precedence over outlines
(c) centrelines take precedence over outlines
(d) hidden detail lines take precedence over centrelines

9. Which of the following statements **best** describes a prototype of an engineered product and its purpose? A prototype is a

(a) fully-functioning version of a design that is used to test a concept or process.
(b) non-functioning model of a design that is used to show what it will look like.
(c) mathematical model that uses calculations to predict how the design will perform.
(d) complete set of documents that allows a third party to manufacture a design.

10. An engineering firm wants to expand its product range. It is proposed that folding furniture would be a possibility, since the firm has expertise in working with metal tubing. The next step should be to

(a) contact financial institutions and investors to secure funding.
(b) hire extra staff and buy additional machinery and tools required for manufacturing.
(c) design the folding furniture and place orders for stock material and parts.
(d) conduct market research to determine demand and potential sales.

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

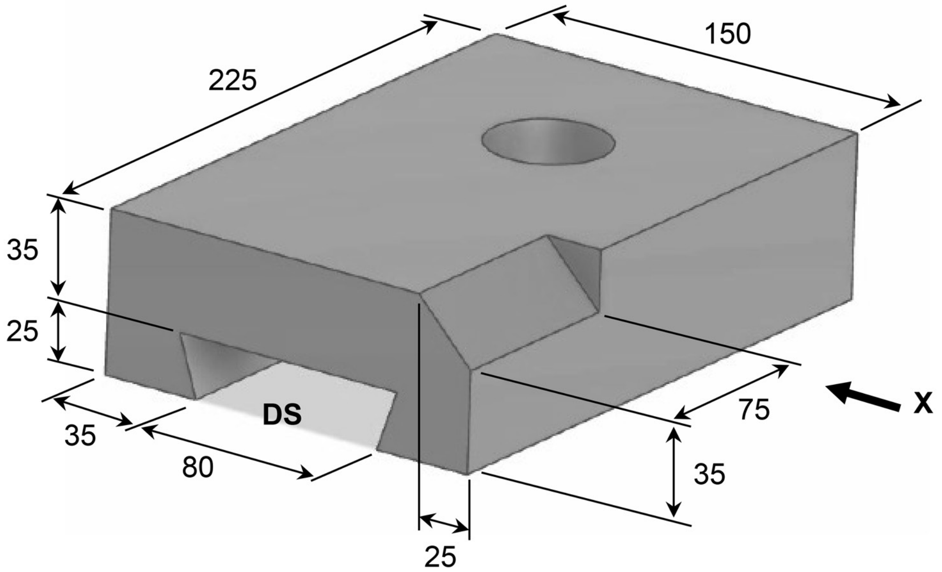
This section has **four** questions. Answer **all** questions. Write your answers in the spaces provided.

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 **(18 marks)**

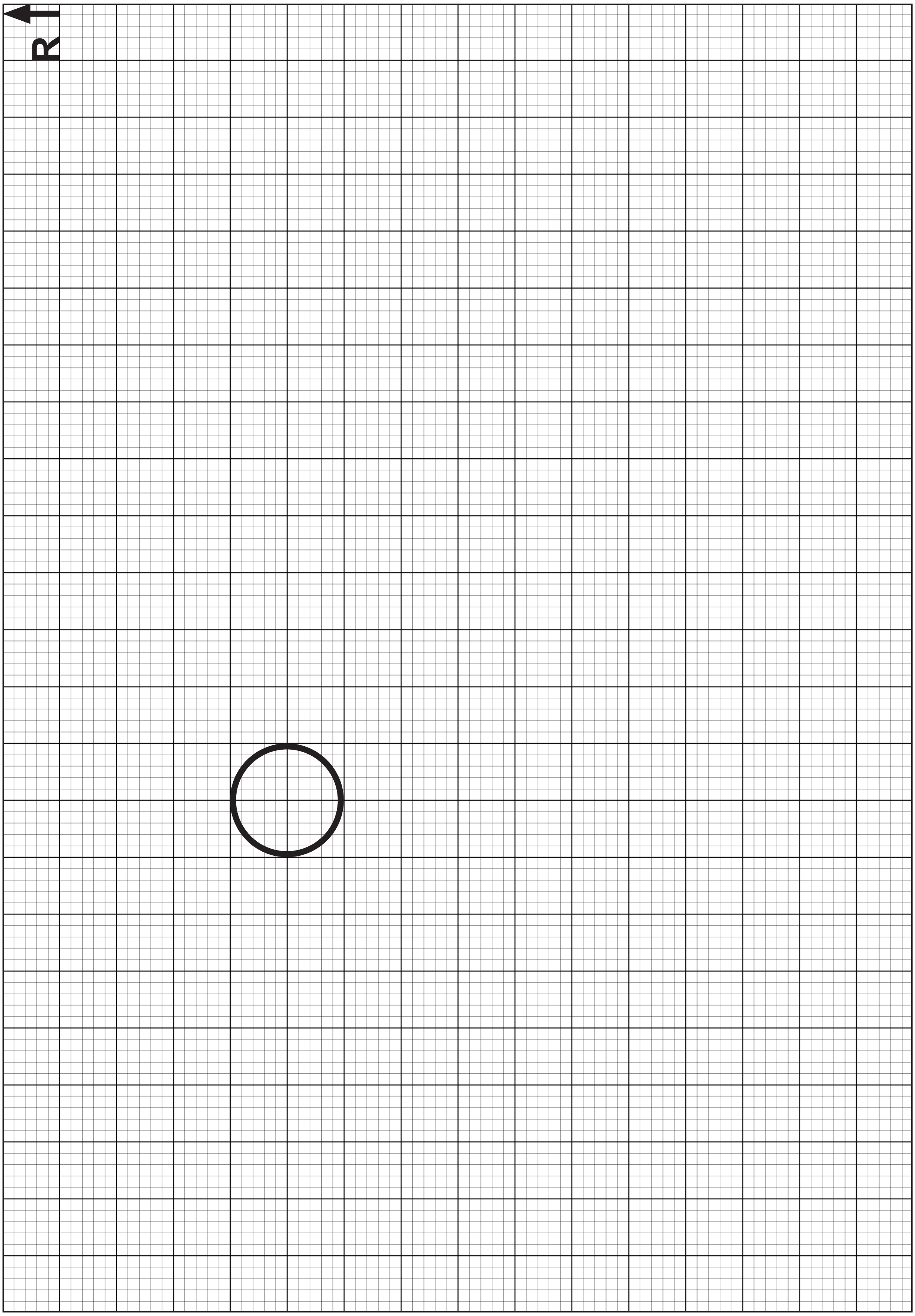
The machined block diagram below includes a dovetail slot (marked DS). This feature passes horizontally through the entire length of the block and is 20 mm wider at its top than at its bottom. The front view is from the viewpoint X, as indicated on the diagram. The circular hole, seen on the top surface, passes vertically through the block and is 50 mm in diameter. Its centre is on the midline along the length of the block and 75 mm from the right-hand end, from viewpoint X.



(a) Using 3rd angle orthographic conventions, complete fully-dimensioned drawings of the top, front and right-hand end views on the grid provided on page 7. The hole, as seen on the top view, is already given. (12 marks)

Note 1: The larger squares of the grid represent 25 mm × 25 mm

Note 2: To fit the required three views, use the grid sideways. The top right corner of the grid is indicated by an arrow and letter R.



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.

Question 11 (continued)

(b) Calculate the density of the material used for the machined block, in units of kg m^{-3}, given that its mass is 3922 g. (6 marks)

Density (kg m^{-3}) = ____________________

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Question 12 **(13 marks)**

The engineering design process has four aspects: investigating, devising, producing and evaluating.

(a) Decisions are made throughout the engineering design process that focus on selecting the best option from multiple considerations for a particular aspect of the design.

Explain how you would make the best choice between alternative options during the process. (4 marks)

Life cycle analysis of engineered products includes both investigating and evaluating, and is becoming an increasingly important consideration when planning and undertaking engineering products and activities.

(b) List **three** components that are the focal points when analysing the stages of the life cycle of an engineered product. (3 marks)

One:

Two:

Three:

(c) For **two** of the key components identified in part (b), provide an example of where or how each would be used, **and** an explanation of why it is beneficial. (6 marks)

One: ____

____

Explanation: ____

____

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____

____

Two: ____

____

Explanation: ____

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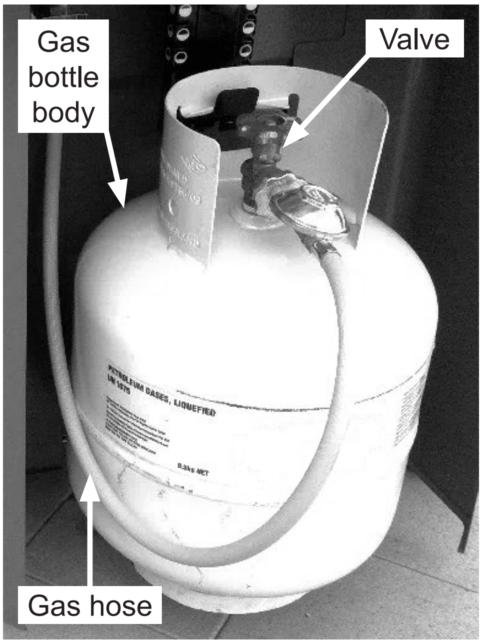
Question 13 **(16 marks)**

Steel gas bottles, like the one shown below, are commonly used to supply fuel for caravan appliances, camping equipment and barbeques. A bottle is filled with petroleum gas that is stored under high pressure as a liquid. When the valve at the top of the bottle is opened, the liquid turns into a highly flammable gas that flows through a hose to a burner. This gas can be ignited into a flame.



The selection of an appropriate construction material for the gas bottle is crucial if it is to be used in a safe and effective manner. This requires careful consideration of properties of the material, and how and where the gas bottle is used, rather than how it is manufactured.

(a) Name and define **three** of these properties and justify why each is a requirement of the material used in the gas bottle body. (12 marks)

Property one: ______________________________

Definition: ______________________________

____

Justification: ______________________________

____

____

____

Property two: ______________________________

Definition: ______________________________

____

Justification: ______________________________

____

____

____

Property three: ______________________________

Definition: ______________________________

____

Justification: ______________________________

____

____

____

(b) While the gas bottle is made from steel, the valve at the top of the bottle is brass. Classify these materials into separate categories and outline the main similarity and difference between these classifications. (4 marks)

Classification of steel: ______________________________

Classification of brass: ______________________________

Similarity: ______________________________

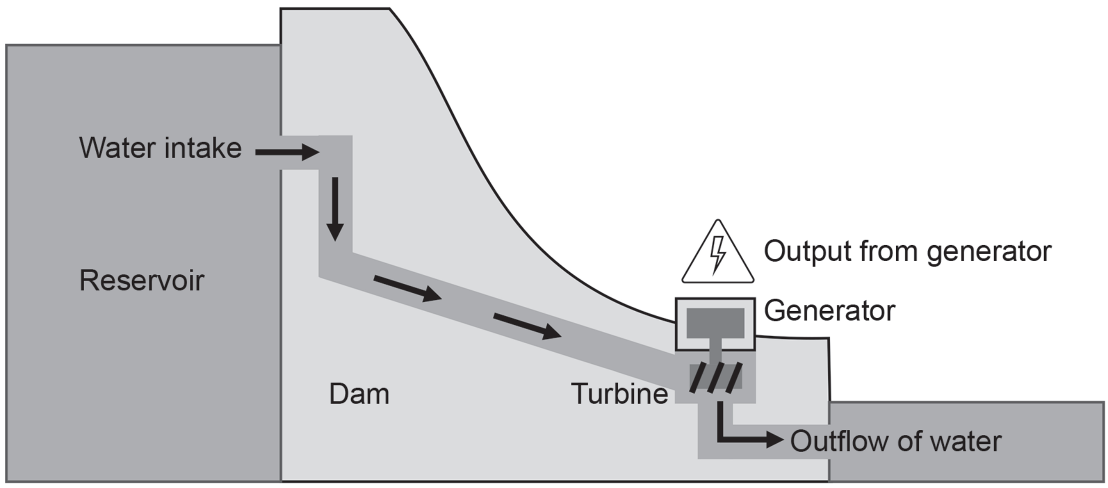
____

Difference: ______________________________

____

Question 14 **(18 marks)**

Hydroelectricity is electrical energy generated by channelling moving water through turbines. The flowing water applies pressure to large blades in the turbine, causing their support shaft to rotate. This in turn drives a generator that converts the shaft's rotation into electrical energy. The most common system is one that uses the controlled release of water stored in a large dam.



(a) Explain **two** advantages that hydroelectric systems have compared with solar panels. (6 marks)

One: ____

____

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Two: ____

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(b) State **three** requirements for selecting a suitable location to install a large-scale dam with a hydroelectric system. (3 marks)

One: ____

____

Two: ____

____

Three: ____

____

To calculate the power generated by a turbine in a hydroelectric system, the following formula is used:

$$P = m \times g \times H_{NET} \times \eta$$

where

P = power in watts
m = mass of the water flowing per second, measured in kilograms
g = constant for gravity = 9.80 m s^{-2}
H_{GROSS} = difference in height between where water enters the system to where it exits from the turbine, measured in metres
H_{NET} = $0.9 \times H_{GROSS}$
η = efficiency of the system

(c) Calculate the efficiency of a hydroelectric system that has the following parameters:
- the power generated by the turbine is 514 kW
- the entry and exit heights of the system are 415 m and 378 m respectively
- 2.1 cubic metres of pure water flows through the turbine every second. (4 marks)

η = ______________________

Question 14 (continued)

Due to restrictions on water use enforced by environmental agencies, the operators of the hydroelectric system are only permitted to operate the turbine such that over a 24 hour period, the output is half of its theoretical maximum.

(d) (i) Provide **two** reasons why the environmental agencies might place such a restriction on the operators of the hydroelectric system. (2 marks)

One: ____

____

Two: ____

____

(ii) Calculate, in MWh, how much energy would be produced by the 514 kW turbine over a 365 day year, if its output is half the theoretical maximum. (3 marks)

Energy produced (MWh) = ____________________

End of Section One

Section Two: Specialist fields **60% (120 Marks)**

Candidates are required to choose one of the following options, according to which specialist field they studied in 2022.

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

Specialist field	✓	Question numbers	Pages
Mechanical	☐	15–30	18–37
Mechatronics	☐	31–46	38–57

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

Section Two: Specialist field – Mechanical **60% (120 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. A force F acts on a body for t seconds, moving it forward a distance of 2.5 metres. The power needed to do this is

(a) Ft
(b) $2.5Ft$
(c) $\frac{0.4F}{t}$
(d) $\frac{2.5F}{t}$

16. The pressure on an object is 1 pascal. An equivalent way of writing this is

(a) 1 N m^{-2}.
(b) 1 kN mm^{-2}.
(c) 1 N mm^{-2}.
(d) 1 N m^{-3}.

17. Within a loaded pin-jointed truss, the members will be either in tension or compression (axial loads). The common name for a truss member that is in compression is a

(a) tie member.
(b) reaction member.
(c) strut member.
(d) moment arm.

18. If an object is thrown upwards at an angle to the horizontal, which of the following is true? The acceleration of the object

(a) in both the horizontal and vertical directions is due to gravity.
(b) in the vertical direction is zero and in the horizontal direction it is the acceleration due to gravity.
(c) in the horizontal direction is zero and in the vertical direction it is the acceleration due to gravity.
(d) is zero in both the horizontal and vertical directions.

19. A mechanic is undoing a wheel-nut on the rim of a truck tyre with a long-handled wrench. The applied torque is the product of the applied force and

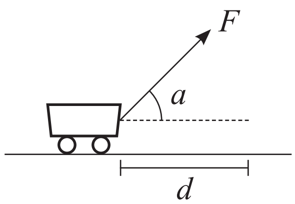
(a) its perpendicular distance of the wrench from the nut.
(b) the overall length of the wrench and its handle.
(c) the inside radius of the wheel of the truck.
(d) its perpendicular distance from the centre of the nut.

20. The resilience of a material is determined by calculating the area under the stress-strain graph up to the

(a) point of failure.
(b) ultimate tensile strength.
(c) elastic limit.
(d) proportional limit.

21. A machine pulls a cart along parallel rails, via a steel cable, with a force F. The cable makes an angle of α to the cart's direction of motion. If the cart is moved a distance d by the force F, what is the work that is done?

(a) Fd
(b) $Fd \cos \alpha$
(c) $Fd \sin \alpha$
(d) $Fd \tan \alpha$



22. A horizontal beam, supported at both ends, is subjected to a uniformly distributed load along its whole length. At which point will the bending moment be at its maximum?

(a) always at the extreme ends of the beam
(b) where the shear force is at its minimum
(c) always at the centre of the beam
(d) where the shear force is at its maximum

23. If a body of mass m falls from a height h above ground level, the velocity of the body when it reaches ground level is given by

(a) $v = (gh)^{0.5}$
(b) $v = (2gh)^{0.5}$
(c) $v = (gh)^{2}$
(d) $v = (0.5gh)^{2}$

24. Stainless steel has an ultimate tensile strength (UTS) of 860 N mm^{-2}, and a yield stress of 502 N mm^{-2}. If a Factor of Safety of 2 was used for a particular application, would the stainless steel used in that application continue to behave elastically when experiencing its maximum safe working stress?

(a) Yes, because the safe maximum working stress is always less than the yield stress.
(b) Yes, because the safe working stress remains below the UTS for stainless steel.
(c) No, it would undergo permanent deformation as the elastic limit would be exceeded.
(d) No, it would fail as the safe working stress would exceed the UTS for stainless steel.

Part B: Extended answer **50% (110 Marks)**

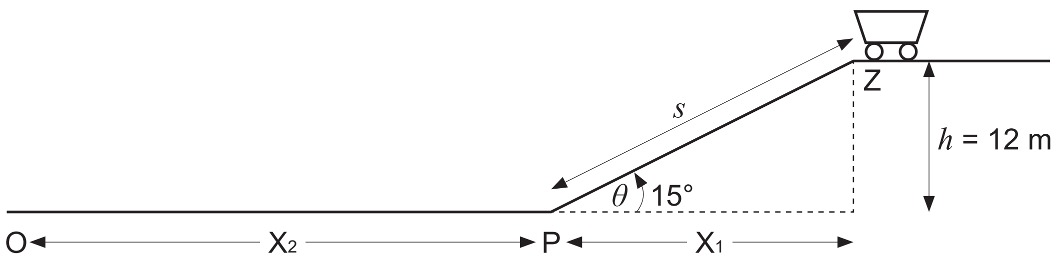
This section has **six** questions. Answer **all** questions. Write your answers in the spaces provided.

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 25 **(15 marks)**

A trolley of mass 70 kg is used to transport ore in part of a mine shaft from point Z, 12 metres above ground level, to point O at ground level down an incline of length s. This incline makes an angle of 15° to the horizontal at point P. To return to point Z, it is mechanically dragged up the incline.



(a) Calculate the force that must be applied to drag the empty trolley from P to Z up the incline. Ignore friction in your calculations. (5 marks)

Force (N) = ______________________

Question 25 (continued)

Once back at Z, the trolley is loaded with 50 kg of ore. It then makes a return journey down the slope to point O.

(b) Calculate the magnitude of the trolley's velocity at point P (the bottom of the slope), assuming the system is frictionless and only under the influence of gravity. (4 marks)

Velocity (m s^{-1}) = ____________________________

Friction causes the trolley to decelerate at 2 m s^{-2} on the flat surface between points P and O.

(c) Calculate the minimum distance required for it to come to rest at point O. If you did not calculate a velocity in part (b), use 20 m s^{-1}. (3 marks)

Distance (m) = ____________________________

(d) Determine the acceleration due to gravity acting on the trolley in the direction of the incline, as it rolls from Z to P. (3 marks)

Acceleration (m s^{-2}) = ____________________

Question 26 **(25 marks)**

A 4 m long diving board, fixed at its left-hand end, has a self-weight of 50 N m^{-1} uniformly distributed along its length.

(a) Using appropriate calculations, show that the magnitude and direction of the reaction force at the cantilever point (fixed end) of the diving board is 788 N upward when a 60 kg diver stands at the extreme end of the board about to dive into the pool. (4 marks)

(b) Using appropriate calculations, show that the total bending moment at the fixed point of the diving board is 2752 N m. (3 marks)

(c) Draw a shear force diagram of the arrangement as described, using the grid provided below. Show all working including important/critical points **and** formula for shear force (SF) as a function of distance, x, along the diving board (measured from the fixed end).

(9 marks)

Shear force diagram

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.

Question 26 (continued)

(d) Draw a bending moment diagram of the arrangement as described, using the grid provided below. Show all working including important/critical points **and** formula for bending moment (BM) as a function of distance, x, along the diving board (measured from the fixed end). (9 marks)

Bending moment diagram

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

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Question 27 **(27 marks)**

Several 1.50 m lengths of a single strand of a multi-strand wire were laboratory tested to determine if a multicore cable manufactured from it would be suitable for a particular task where it would be under tension.

Multiple tests were conducted, the average results obtained for each weight are given in the table below. The tests were conducted by joining the top end of the wire to a connection in the roof and adding masses to the lower end until the wire broke. The original diameter of this single strand of wire was measured as 0.230 mm.

The extension measurements made against their corresponding weights were entered into the table below and the relevant values for stress and strain calculated.

Weight (N)	0.50	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Extension (mm)	0.16	0.31	0.46	0.62	0.76	0.93	1.15	1.9
Stress (× 10^7) (N m^{-2})	1.20	2.41		4.82	6.02	7.23	8.43	9.64
Strain (× 10^{-4})	1.06	2.07	3.07	4.13		6.20	7.67	12.7

(a) Outline why tests were conducted on several strands of wire and not just a single test on one strand. (2 marks)

(b) Calculate the area of the cross-section of a single strand of wire. (2 marks)

Area (mm^2) = ____________

(c) Complete the table above by determining the **two** missing values. Show all working. (4 marks)

(d) Use the data from the table on page 28, and the grid provided below, to draw a fully-labelled stress/strain graph for this wire. (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.

Question 27 (continued)

(e) From your graph, determine a value for Young's Modulus. Show all working. (3 marks)

Young's Modulus = ______________________

(f) Refer to the Data Book to suggest an appropriate metal that the wire is made of. (1 mark)

____

(g) From your graph, estimate the stress at which the elastic limit was reached. State a reason for your answer. (2 marks)

____

____

____

____

(h) Using the value you determined for the gradient, calculate the strain on the wire when a weight of 0.560 N was hanging from its lower end. (4 marks)

Strain = ______________________

(i) State the value of Young's Modulus for a cable comprising 100 strands of this same wire, and outline how you obtained this value. (2 marks)

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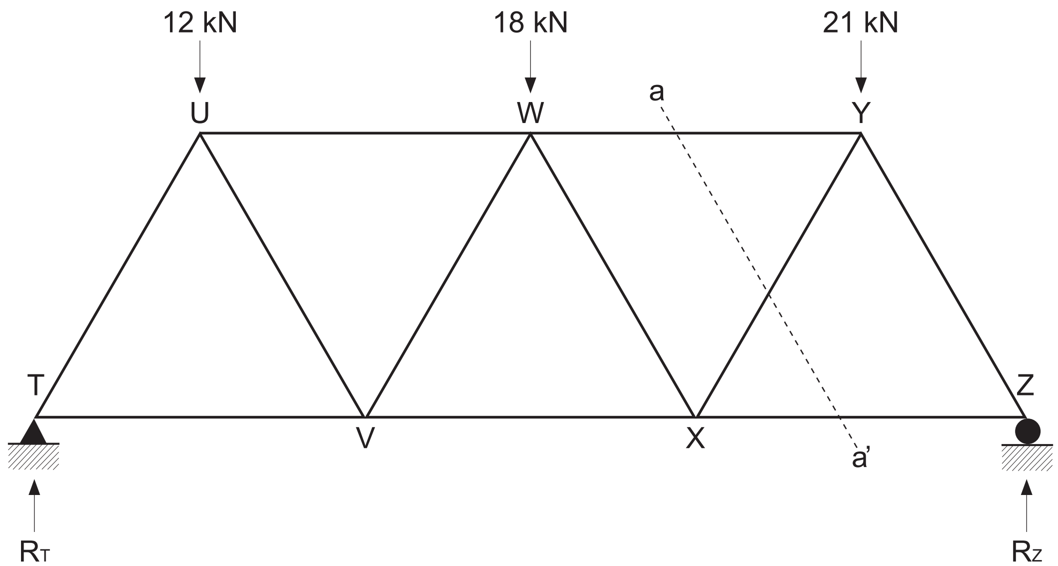
Question 28 **(22 marks)**

The structure shown below is referred to as a Warren Truss. This is used in engineering structures, such as simple bridges.

The length of each member is 1 metre, and point loads of 12 kN, 18 kN and 21 kN are applied at points U, W and Y respectively.



(a) Explain why is important for a static structure, such as a bridge or building, to satisfy the equations 'sum of horizontal/vertical forces equals zero' and 'sum of moments about a point equals zero'. (3 marks)

(b) Calculate the reaction forces at the supports Z and T. (5 marks)

Reaction force at Z (kN) = ____________________

Reaction force at T (kN) = ____________________

(c) Working to the left of the section aa', use the method of sections to calculate the force in member XY. Specify if the member is in tension or compression. (4 marks)

Force in XY (kN) = ____________________

Tension or compression: ____________________

Question 28 (continued)

(d) Working to the left of the section aa', use the method of sections to calculate the force in member WY. Specify if the member is in tension or compression. (5 marks)

Force in WY (kN) = ______________________

Tension or compression: ______________________

(e) Working to the left of section aa', use the method of sections to calculate the force in member XZ. Specify if the member is in tension or compression. (5 marks)

Force in XZ (kN) = ______________________

Tension or compression: ______________________

Question 29 **(17 marks)**

A client has engaged your engineering firm to analyse the behaviour of both a solid and a tubular cylindrical beam. In particular, for each beam they wish to analyse the second moment of area, the amount of material required to construct the beam and how it deflects under its own weight.

(a) Consider a solid cylindrical beam of diameter D = 400 mm. Calculate the second moment of area for such a beam. (2 marks)

Second moment of area (mm^4) = ______________

(b) For a tubular cylindrical beam with the outer diameter D_o equal to twice the inner diameter D_i, calculate the values of D_o and D_i if this beam is to have the same second moment of area as the solid cylindrical beam in part (a) above. (4 marks)

D_o (mm) = ______________

D_i (mm) = ______________

Question 29 (continued)

(c) If the solid cylindrical beam from part (a), on page 35, is used in a practical application, determine the difference in the volume per unit length of material required compared to the tubular cylindrical beam from part (b). If you could not calculate an answer for part (b), assume the outer diameter D_o is 420 mm and the inner diameter D_i is 210 mm. (4 marks)

Difference in volume/unit length (mm^3) = ________

(d) Calculate the mass of the tubular cylindrical beam if its length is 5 m and it is made of structural steel. (2 marks)

Mass (kg) = ________________

(e) If the tubular cylindrical beam is simply supported at both ends, determine the maximum deflection of the beam under the influence of its uniformly distributed weight. If you could not calculate an answer for part (a), assume I_{xx} is 1 250 000 000 mm^4. (5 marks)

Deflection (mm) = ______________

Question 30 **(4 marks)**

Describe how the following modifications made to the tubular cylindrical beam in Question 29 would change the maximum deflection.

(a) A material with a larger value for Young's Modulus. (2 marks)

(b) Increasing both the inner and outer diameter of the beam, such that the amount of material in it remains the same. (2 marks)

End of Mechanical Section

Section Two: Specialist field – Mechatronics **60% (120 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.

---

31. Adding extra cells or batteries in series to supply a circuit of fixed resistance results in

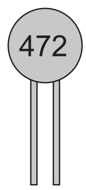
(a) increased current capacity.
(b) a decrease of current.
(c) an increase of power.
(d) a decrease of voltage.

32. When measuring current through a component, the probes of an ammeter are placed such that the ammeter is in

(a) parallel with the component with power connected to the circuit.
(b) series with the component with power connected to the circuit.
(c) parallel with the component with power disconnected from the circuit.
(d) series with the component with power disconnected from the circuit.

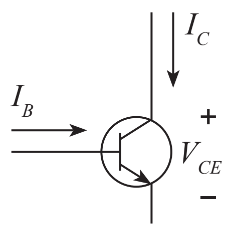
33. A capacitor is marked 472. Its capacitance is

(a) 4700 nF.
(b) 4µ7 F.
(c) 4.7 nF.
(d) 472 pF.



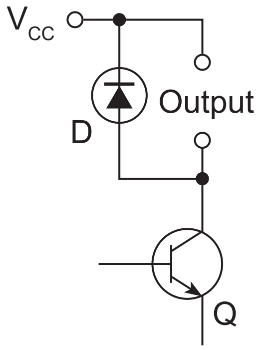
34. When an NPN transistor is in its saturation region of operation, as shown in the diagram, an increase in its base current will result in

(a) an increase in its collector current.
(b) a decrease in its collector current.
(c) its collector-emitter voltage to decrease.
(d) no change to the collector-emitter voltage.



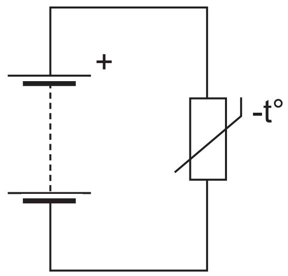
35. A back e.m.f. diode is used with a transistor when controlling devices that are

(a) inductors.
(b) insulators.
(c) semiconductors.
(d) polarity sensitive.



36. As conditions become warmer, the NTC thermistor shown in the diagram will

(a) reduce the current that flows through it.
(b) increase the power it dissipates.
(c) cause the voltage across it to decrease.
(d) increase its resistance.



37. Increasing the velocity ratio of a gear-drive system will cause

(a) an increase in mechanical advantage.
(b) a decrease in mechanical advantage.
(c) an increase in the speed of rotation of the output shaft.
(d) an increase in the speed of rotation of the motor shaft.

38. A rack and pinion is able to convert

(a) linear motion into oscillating motion.
(b) rotary motion into linear motion.
(c) rotary motion into oscillating motion.
(d) oscillating motion into linear motion.

39. ROM is a type of memory used by microcontrollers that

(a) cannot be modified.
(b) can be overwritten and stored.
(c) can be overwritten but not stored.
(d) is read once, then erased.

40. A pulse-width-modulation signal has a frequency of 125 Hz and the duration of each high pulse is 0.006 s. Its duty cycle is

(a) 25%.
(b) 40%.
(c) 60%.
(d) 75%.

Part B: Extended answer **50% (110 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 41 **(19 marks)**

Two forms of control system are open-loop and closed-loop.

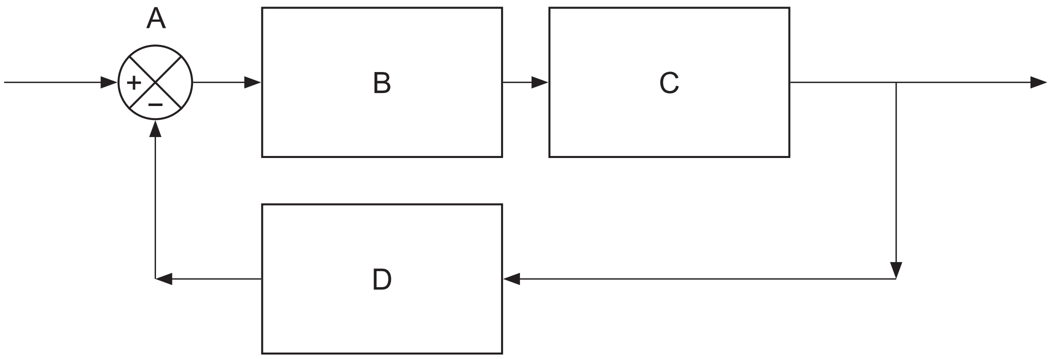
(a) Discuss the fundamental difference between an open-loop control system and a closed-loop control system. (4 marks)

(b) Give an example of each of these forms of control system and outline why the example you have chosen is relevant to its form of control system. (4 marks)

Open-loop:

Closed-loop:

Part (c) refers to the diagram below.



(c) (i) Name and state the purpose of the parts labelled A, B, C and D. (8 marks)

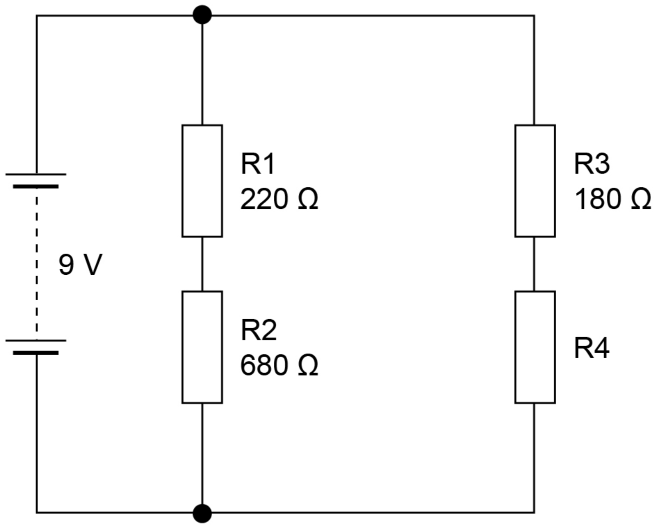
Part	Name	Purpose
A		
B		
C		
D		

Question 41 (continued)

(ii) The type of control system on page 41 makes use of 'negative feedback'. Explain how this works. (3 marks)

Question 42 **(21 marks)**

The circuit shown below includes four resistors, one of which is an unknown resistance.



(a) (i) Calculate I_{R2}, the current that flows through R2. (3 marks)

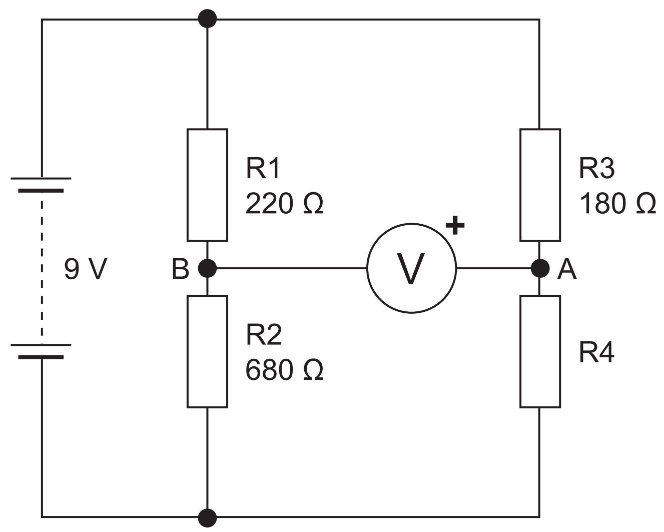
I_{R2} (A) = ______________________

(ii) Calculate P_{R1}, the power dissipated by R1. (3 marks)

P_{R1} (W) = ______________________

Question 42 (continued)

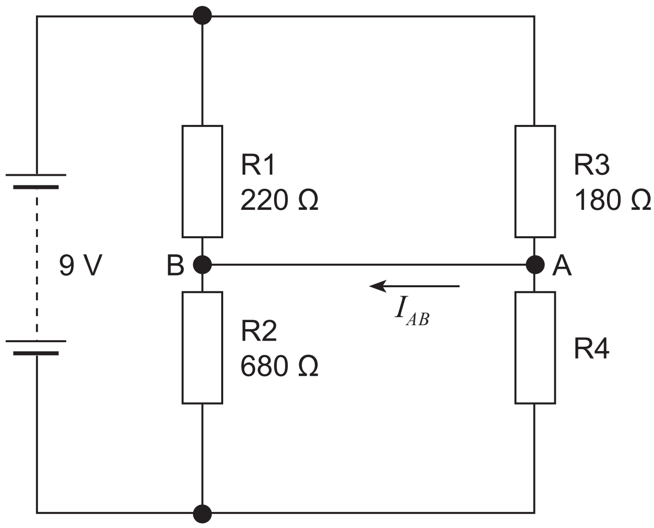
A voltmeter is positioned on the circuit as shown in the diagram below. Assume that the voltmeter has no effect on the behaviour of the circuit; it simply measures the potential difference between points A and B in the circuit. The voltmeter reading, V_{AB}, is 0.58 V.



(b) Calculate $R4$, the resistance of R4. (7 marks)

$R4$ (Ω) = ______________________

The circuit is modified by making a connection between points A and B. This will conduct a current, I_{AB}, that flows in the direction indicated by the labelled arrow.

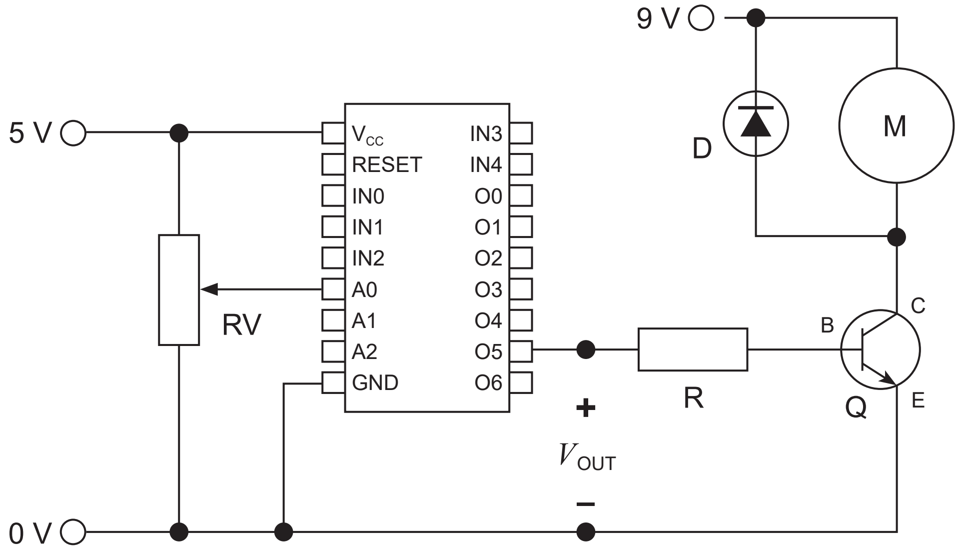


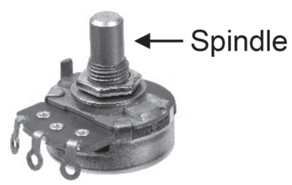
(c) Calculate I_{AB}, the current that flows from A to B. If you could not calculate an answer for part (b), use $R4$ = 1 kΩ. (8 marks)

I_{AB} (A) = ______________________________

Question 43 **(22 marks)**

The circuit shown below is that of a microcontroller that controls a DC motor via a transistor connected to O5, an output pin. This output pin produces a signal of 0 V when it is low, and 5 V when it is high. The gain of the transistor, Q, is β = 40.





RV, a 50 kΩ potentiometer, provides a voltage signal at pin A0 of the microcontroller and this is used for speed control of the motor.

(a) (i) Explain why the voltage signal detected at pin A0 will change when the spindle of the potentiometer is rotated to a different position. (3 marks)

(ii) Suppose the spindle of the potentiometer is adjusted such that the resistance between the wiper and the connection to ground is 25 660 Ω. The resolution of the ADC at pin A0 is 10-bit. Calculate, to the nearest whole number, the value registered by the ADC. (3 marks)

10-bit value = ______________________

(iii) Pin O5 of the microcontroller utilises 8-bit pulse-width-modulation for speed control of the motor. This 8-bit output is mapped to the 10-bit input from pin A0. Calculate, to the nearest whole number, the 8-bit value produced when the spindle of RV is adjusted as described in part (a)(ii). If you could not calculate an answer for part (a)(ii), assume the 10-bit value is 520. (3 marks)

8-bit value = ______________________

(iv) If the frequency of the pulse-width-modulation at pin O5 is 200 Hz, and the spindle of RV is in the position described in part (a)(ii), calculate the duration of each cycle (period), low time and high time. Answer using milliseconds (ms). If you could not calculate an answer for part (a)(iii), assume the 8-bit value is 125. (3 marks)

Period (ms) = ______________________

Low (ms) = ______________________

High (ms) = ______________________

Question 43 (continued)

For maximum efficiency when using pulse-width-modulation speed control, the transistor needs to be driven into its saturation region of operation when the pulse is high. When this occurs, assume that the power of the motor is 0.81 W.

(b) (i) Calculate R_{MAX}, the maximum value for the resistor connected to the base of the transistor, R, required to drive the transistor into saturation. (5 marks)

R_{MAX} (Ω) = ____________________

(ii) For a practical circuit, an E12 preferred value resistor will need to be used. This should be as close to ideal value as possible and still drive the transistor into saturation. State what value would be selected and give its 4-band colour code, assuming a tolerance of ± 5%. If you could not calculate an answer for part (b)(i), assume it is 200 Ω. (2 marks)

Resistor value (Ω) = ____________________

4-band colour code = ____________________

(iii) If the resistance of the selected resistor is actually 1.5% lower than its marked value, calculate P_R, the power it dissipates as heat. (3 marks)

P_R (W) = ____________________

Question 44 **(19 marks)**

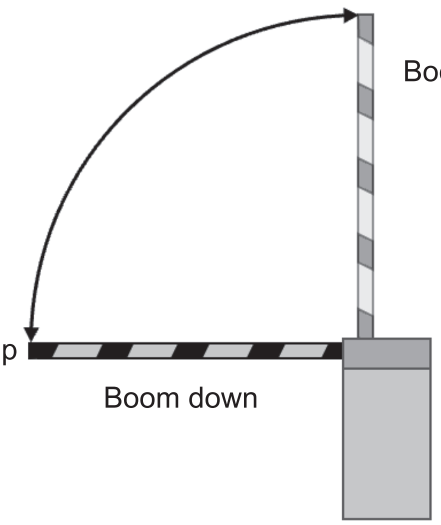
The drive system for a boom gate is illustrated to the right.

At the bottom there is a worm gear that drives the system. The shaft of the worm gear is driven by a 540 r.p.m. reversible electric motor fitted with a gearbox (neither are shown in the diagram).

The worm gear uses a 24-tooth worm wheel connected by a shaft to a 16-tooth sprocket. A chain connects the bottom sprocket to a 24-tooth sprocket at the top.

The boom is attached to, and rotated by, the shaft fitted to the top sprocket.

The length of the boom from the centre of its attachment shaft to its tip is 3.25 m. The boom normally rests in a horizontal position, as shown in the diagram on the right. When it opens, it rotates in an arc to its fully open position, which is 90° vertical. At full speed, the tip moves at 1.021 m s^{-1}.



(a) Calculate $VR_{GEARBOX}$, the velocity ratio of the gearbox fitted to the 540 r.p.m. reversible electric motor if the boom is to rotate at full speed. Assume the system operates at 100% efficiency. (9 marks)

$VR_{GEARBOX}$ = ______________________________

Question 44 (continued)

The boom gate is used to control traffic that enters a carpark. A separate boom gate will control vehicles that leave the carpark; however, for the purposes of this question this exiting system can be ignored. To operate the boom gate at the entrance, the following parameters are required:

I The boom is normally in its lowered position and its drive motor is off. An entering vehicle will, therefore, have to stop in front of the boom.

II The driver of the vehicle presses a switch labelled 'Open'. This will cause the motor to rotate in a direction that will raise the boom.

III When raising the boom, the motor initially spins for 1 second at 50% speed – this is to reduce vibration of the long boom when it starts moving from its resting position. The motor then operates at 100% speed for 3 seconds before switching back to 50% speed as the boom moves closer to its vertical position.

IV At the vertical position, a switch labelled 'Boom up', will detect the boom and the motor will stop.

V Once the vehicle drives through, and is clear of the boom gate, it will be detected by a switch labelled 'Close'.

VI The drive motor will now use the same sequence of speed settings i.e. 50% for 1 second, 100% for 3 seconds and 50% for the remaining movement, to close the boom. A switch labelled 'Boom down' will detect that the boom is back in its horizontal position.

VII The system then loops.

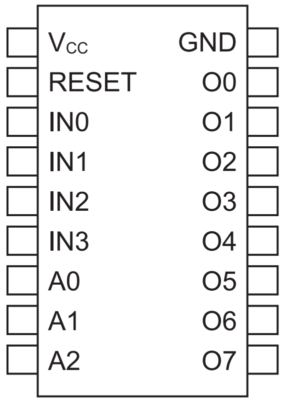
(b) On page 53, create a fully-labelled flow chart that will satisfy all the requirements of the system described above. (10 marks)

START

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

Question 45 **(15 marks)**

The microcontroller shown below requires a 5 VDC supply.



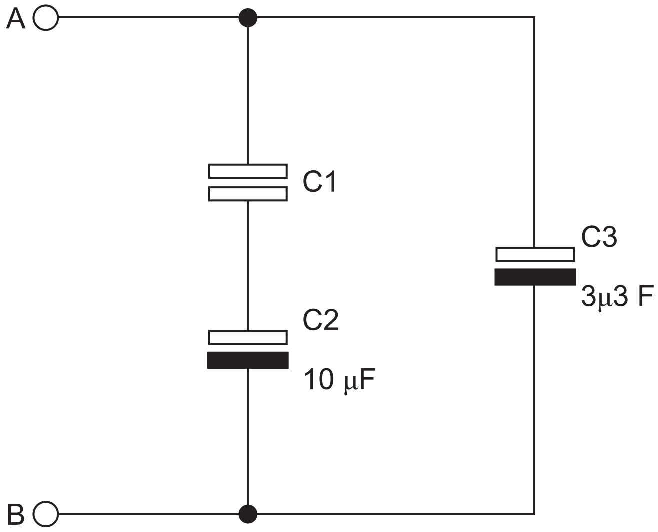
(a) To achieve this, the following need to be added to the circuit: 9 VDC power supply unit, 7805 voltage regulator, and **two** 100 μF capacitors. In the space above, complete a fully labelled circuit diagram that correctly connects these additional components to the microcontroller. (5 marks)

The purpose of the capacitors is to provide 'smoothing'.

(b) (i) For this type of circuit, outline what is meant by 'smoothing'. (2 marks)

(ii) State why this is necessary for a microcontroller. (2 marks)

The capacitance between points A and B of the circuit shown below is very close to 3.4 μF.



(c) (i) Calculate $C1$, the capacitance of C1. Answer in units of μF. (5 marks)

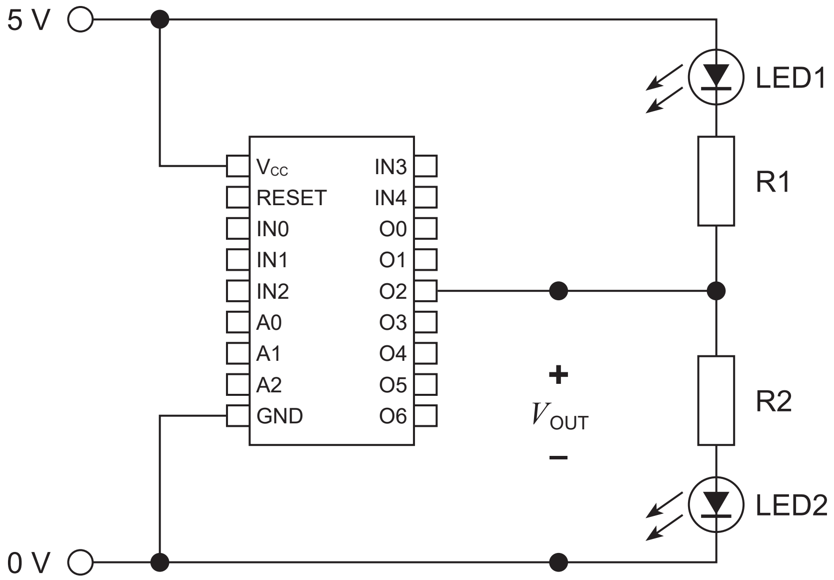
$C1$ (μF) = ______________________

(ii) C1 is a non-polarised capacitor, its value is marked using a 3-digit number. What is its 3-digit marking? (1 mark)

3-digit number is ______________________

Question 46 **(14 marks)**

The circuit shown below is designed to control two LEDs using a single output pin, in this case, O2. When O2 is low, one of the LEDs will be on and the other off, and when O2 is high, the states of the LEDs will be the opposite. V_{OUT} will be 0 V when O2 is low, and 5 V when O2 is high.



(a) (i) State which of the LEDs will glow when O2 is low. Explain why. (3 marks)

(ii) Outline why the other LED will be off when O2 is low. (2 marks)

(iii) When O2 changes from low to high, the LED that was previously glowing will now be off. Explain why this occurs. (3 marks)

(b) Given that the forward-voltage of LED1 = 1.9 V, and R1 is 330 Ω, calculate P_T, the total power dissipated by these two components when LED1 is glowing. (6 marks)

P_T (W) = ____________________

End of Mechatronics Section

Supplementary page

Question number: ______________

Supplementary page

Question number: ____________

Supplementary page

Question number: ____________

Supplementary page

Question number: ____________

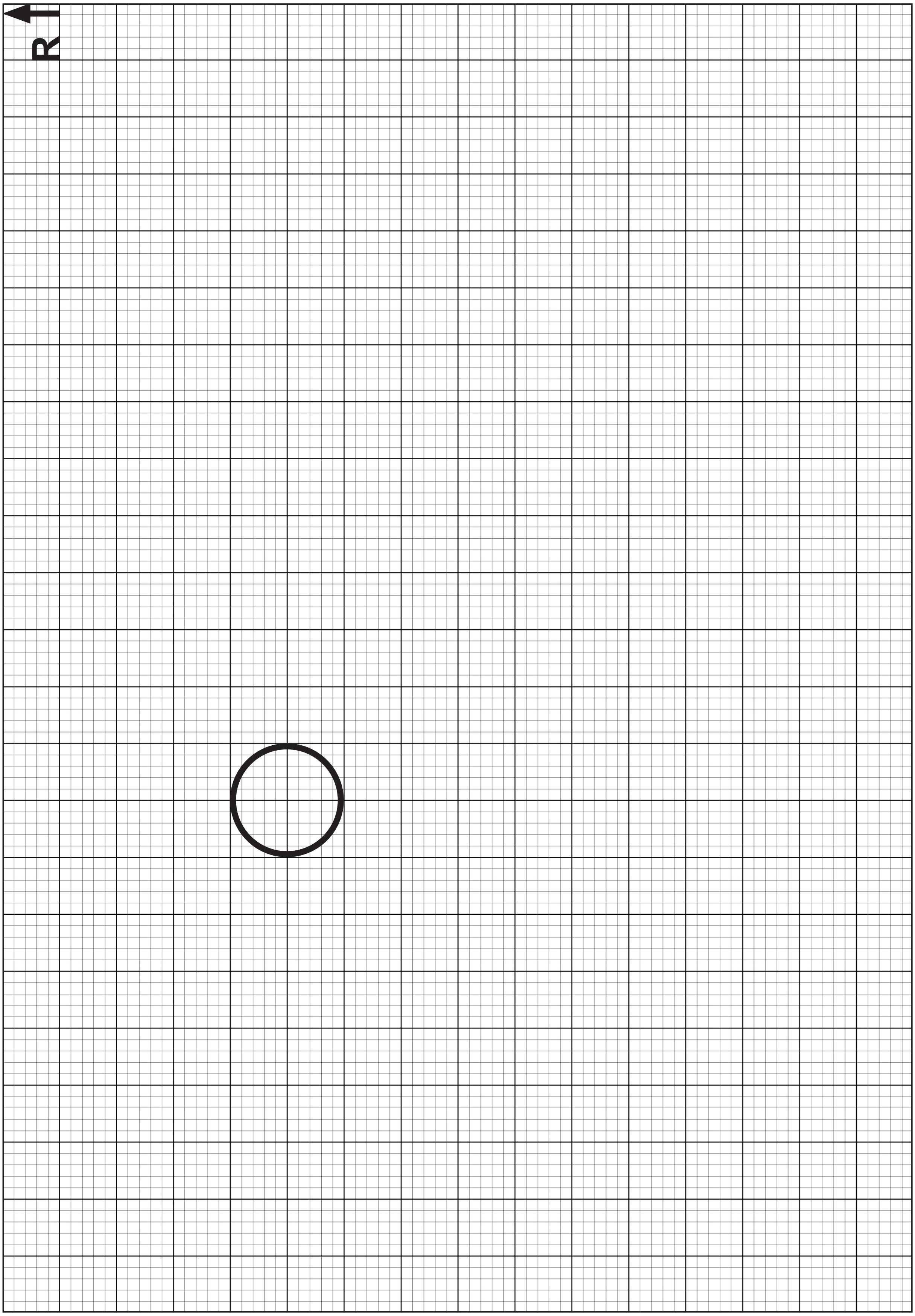
Supplementary page

Question number: ____________

Supplementary page

Question number: ____________

Spare grid for Question 11(a)



Spare grid for Questions 26(c) and 26(d)

Shear force diagram

Bending moment diagram

Spare grid for Question 27(d)

Spare flow chart for Question 44(b)

START

ACKNOWLEDGEMENTS

Question 6	Spawn101. (n.d.). *Illustration of black and white isolated frying pan cartoon drawing*. Retrieved May, 2022, from https://image.shutterstock.com/image-vector/illustration-black-white-isolated-frying-260nw-544078672.jpg
Question 43(a)	Amos, E. (2019). *Electronic component potentiometer* [Photograph]. Retrieved May, 2022, from https://upload.wikimedia.org/wikipedia/commons/0/0a/Electronic-Component-Potentiometer.jpg

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