



## ATAR course examination, 2017

### Question/Answer booklet

# ENGINEERING STUDIES

Please place your student identification label in this box

Student number: In figures

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In words

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### Time allowed for this paper

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

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

Mechanical

Mechatronics

### Materials required/recommended for this paper

#### *To be provided by the supervisor*

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

Number of additional answer booklets used (if applicable):

#### *To be provided by the candidate*

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

Special items: non-programmable calculators approved for use in this examination

### Important note to candidates

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

## Structure of this paper

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

## Instructions to candidates

- The rules for the conduct of the Western Australian external examinations are detailed in the *Year 12 Information Handbook 2017*. Sitting this examination implies that you agree to abide by these rules.
- 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. 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.

- 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.
- Supplementary pages for the use of planning/continuing your answer to a question have been 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.
- The Data book is not to be handed in with your Question/Answer booklet.

**See next page**

**Section One: Core content****40% (70 Marks)**

This section has **two (2)** parts.

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

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

Suggested working time: 70 minutes.

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

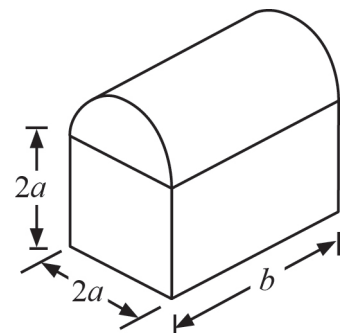
This part has **10** questions. Answer **all** questions on the separate Multiple-choice answer sheet provided. For each question, shade the box to indicate your answer. Use only a blue or black pen to shade the boxes. If you make a mistake, place a cross through that square, then shade your new answer. 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. The power developed by an electric pump can be measured in
  - (a) joules per hour.
  - (b) joules.
  - (c) watts per second.
  - (d) newtons per second.
  
2. Used vehicle batteries can present a serious waste problem. The separation of these batteries into their components (lead, acid and plastic) is a practical example of
  - (a) regeneration.
  - (b) waste reduction.
  - (c) designed obsolescence.
  - (d) recycling.
  
3. The Water Corporation wishes to lay a new section of above-ground pipe in a region east of Perth. Which of the following would be the engineering consultant's first step in this work?
  - (a) test different types of pipeline systems
  - (b) construct detailed drawings of the pipeline
  - (c) undertake an environmental impact study
  - (d) prepare a planning application
  
4. An electronics company is obtaining anthropometric data for the design of a new model mobile phone. Which of the following is the **most** important human dimension the designers need to consider?
  - (a) the average width of the hand
  - (b) the average length of the index finger
  - (c) the average distance from ear to mouth
  - (d) the average width of the ear

**See next page**

5. A design brief is intended to
- specify the requirements of the client.
  - specify the materials to be used in manufacture.
  - set the production timeline.
  - achieve all of the above.
6. Which of the following formulae would be correct for the total surface area of a cylindrical rod of height ' $h$ ' and radius ' $r$ '?
- $2\pi r(r + h)$
  - $\pi r(2r + h)$
  - $\pi r(r + 2h)$
  - $2\pi r^2(1 + h)$
7. An advantage of a solar panel compared to a wind generator is that it requires less maintenance. This is because
- wind generators are in harsh environments.
  - solar panels have no moving parts.
  - wind generators are designed to have a short life span.
  - solar panels produce lower voltage.
8. Which of the following would **best** allow an energy source to be referred to as renewable?
- No energy is lost in its production.
  - It can be produced at a zero cost.
  - The energy source can be naturally replenished.
  - The energy is produced from biological sources.
9. Copper wire is used to make electrical cable because it is a very good conductor. Another of its properties that makes it suitable for this purpose is that it is
- elastic.
  - malleable.
  - plastic.
  - ductile.
10. The diagram on the right is of a letterbox with a length ' $b$ ' and a cross section that is a semicircle on top of a square with a base of length ' $2a$ '. Which of the following would be the correct formula for the total volume of the letter box?



See next page

## Section One: Core content

## Part B: Extended answer

30% (60 Marks)

This section has **three (3)** questions. Answer **all** questions. Write your answers in the spaces provided.

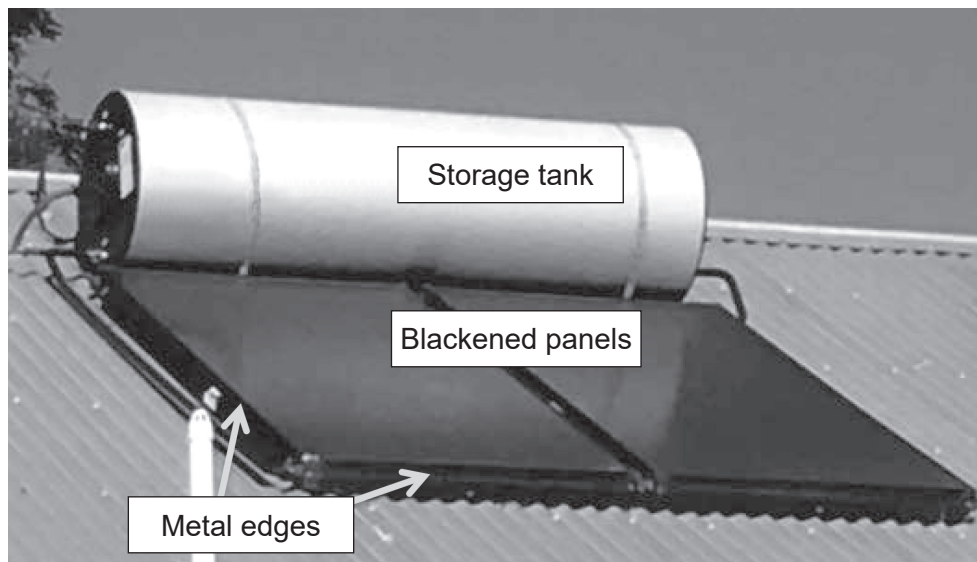
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## Question 11

(24 marks)



A typical solar hot water system mounted on the roof of a house has two blackened panels with a total area of  $4 \text{ m}^2$  positioned side by side, with a cylindrical 360 litre storage tank connected horizontally above them, as shown in the photograph above. The length of the storage tank is 1.6 m, the same as the width of the two panels. The water is carried to and from the storage tank by copper pipes attached to the surface of the panels.

- (a) Calculate the internal radius of the tank, given that one litre is the same as  $0.001 \text{ m}^3$ .  
(4 marks)

See next page

**Question 11** (continued)

The water can be heated in two ways. When the sun is shining, the radiation from it is absorbed by the panels and transferred to the water. If there is insufficient radiation from the sun, the water in the storage tank can be heated by an electric or gas heater backup.

It requires 4180 joules of energy to raise the temperature of 1 L of water by each degree Celsius. The water in the hot water system is initially at 22 °C and is to be heated to 76 °C.

- (b) Show that the energy needed to heat a full tank (360 L) of water from 22 °C to 76 °C is 81.2 MJ. (4 marks)
- (c) If the efficiency of such a hot water system using solar energy is 60%, how much solar energy must fall on the panels to heat a full tank of water from 22 °C to 76 °C? (2 marks)
- (d) The average effective solar irradiance in Perth on a given day in June on these panels is 2.96 kW m<sup>-2</sup>. How many minutes would it take to heat a full tank of water from 22 °C to 76 °C? Assume 100% efficiency. (4 marks)

- (e) On a very cloudy and cold day, the electric heater backup used 84.4 MJ of energy to bring the temperature of a full tank of water to the maximum 76 °C. How many kilowatt hours of electricity does this represent? (2 marks)

- (f) The average solar irradiance on a horizontal surface in Perth in June is 2.62 kWh m<sup>-2</sup>. The panels are not, however, horizontal but generally fixed at an angle of 58° to the horizontal. If they could be moved, the best angles to the horizontal are 43° in winter and 73° in summer.

- (i) Why are the panels placed at this set angle of 58° to the horizontal and not horizontally? (1 mark)

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- (ii) Why are the pipes and panel surfaces painted black? (1 mark)

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- (g) Is a solar hot water system a renewable or non-renewable energy system? Give a reason for your answer. (2 marks)

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**Question 11** (continued)

- (h) The government is encouraging more people to install solar hot water systems. State a positive environmental impact that this would have. (1 mark)

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- (i) Suggest a metal **most** suited to being used for the edges and supports of the panels. (1 mark)

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- (j) Give **two** reasons why you chose your answer to part (i) above. (2 marks)

One: \_\_\_\_\_

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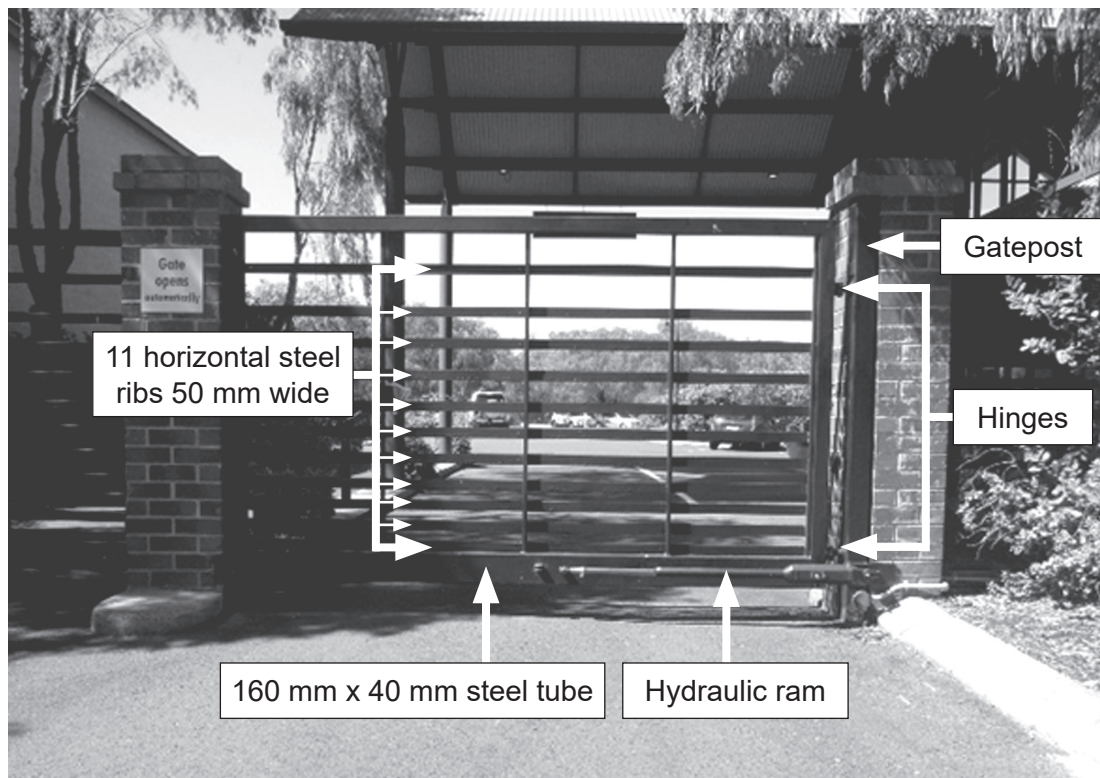
Two: \_\_\_\_\_

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## Question 12

(23 marks)



The picture above is of an electrically-operated and electronically-controlled gate. Its external dimensions are 3 m wide and 1.8 m high and it is constructed from structural steel.

The frame of the gate is fabricated from rectangular structural tube steel with a thickness of 4 mm. The external dimensions of the top and sides of the frame are 80 mm wide  $\times$  40 mm deep and the steel tube at the bottom is 160 mm high  $\times$  40 mm deep. The bottom tube goes all the way across the base and the sides are welded on top of it. It has a plastic plug at each end to keep water out.

The 11 horizontal ribs are solid steel plate of width 50 mm and thickness 7 mm and the vertical ribs are 15 mm square steel bar. Both of these are fitted within the frame.

- (a) Calculate the total mass of the horizontal steel ribs. (5 marks)

**Question 12** (continued)

- (b) What is the function of the vertical and horizontal ribs welded inside the frame? (1 mark)

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- (c) Calculate the volume of steel in the bottom beam of the gate frame. (4 marks)

The gatepost on the right of the gate is 12 cm square tube, with a height of 2.2 m above the ground. It has a square cover on its top. The post is bolted to the brick pillar at several places along its height. The gap between the gate and the post is 6 cm. The gate swings from the post on two hinges bolted to the gatepost.

- (d) Give a structural reason why the hinges are bolted to a steel post and not directly to the brick pillar. Justify your answer. (2 marks)

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The gate is opened and closed by a horizontal hydraulic ram driven by an electric motor. This ram is connected to the gatepost at one end and 1.4 m along the bottom of the gate frame at the other and the gate has no contact with the brick pillar on its left-hand side. When this gate was originally fitted, it had a steel mesh grid covering the area within the tube steel frame and there was a resistance to it opening. It was found when the mesh was removed that this problem disappeared.

- (e) Give a possible problem caused by this mesh that made the gate difficult to open and a reason why the removal of the mesh solved this problem. (2 marks)

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The process for the manufacture of this gate would have started with a design brief and finished with selection of the final design solution.

- (f) In the table below, list **four** other steps in the design process between the design brief and the final design and provide a short description of each. (8 marks)

Step in design process	Description of each design step
Design brief	Description not required
Final design solution	Description not required

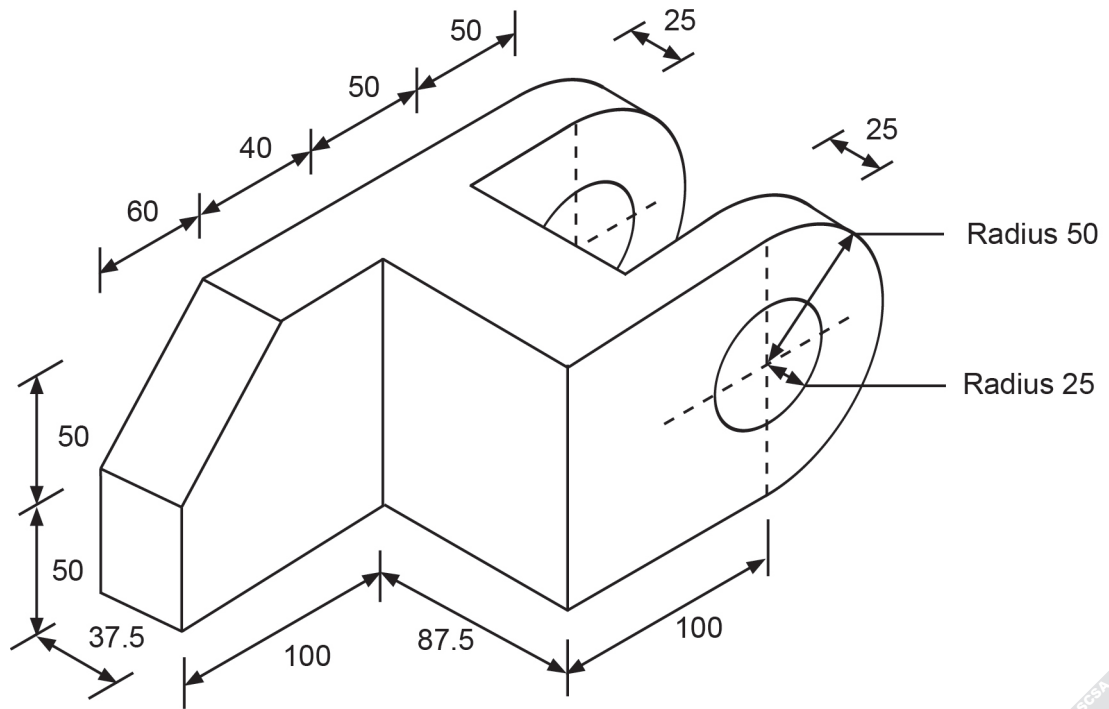
- (g) At what stage in the design process should any problem with the mesh have been realised? (1 mark)

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Question 13

(13 marks)

Below is a dimensioned isometric drawing of a machined fitting made from brass.



- (a) On the grid provided on page 13, draw a scaled, labelled and dimensioned orthographic projection of this fitting, showing all **three** views. (11 marks)

This fitting was manufactured from a solid block of brass with original external dimensions of 250 mm × 100 mm × 125 mm. The circular hole was placed in the original block before any machining commenced.

- (b) What volume of metal, in cubic millimetres, was removed from the original block by the drill used to make the holes? (2 marks)



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

Candidates are required to choose one of the following options, according to which specialist field they studied in 2017.

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

Specialist field	✓	Question numbers	Pages
Mechanical	<input type="checkbox"/>	14–29	<b>15–33</b>
Mechatronics	<input type="checkbox"/>	30–45	<b>34–50</b>

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

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

This section has **two (2)** parts.

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

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

Suggested working time: 110 minutes.

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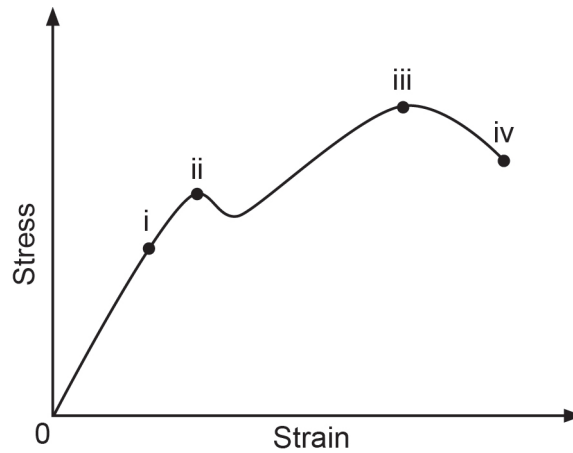
**Part A: Multiple-choice****10% (10 Marks)**

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. If you make a mistake, place a cross through that square, then shade your new answer. Do not erase or use correction fluid/tape. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

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14. Toughness is best defined as the
- (a) energy absorbed by a material without fracturing.
  - (b) energy absorbed by a material without yielding.
  - (c) area under the stress-strain graph up to the point of yielding.
  - (d) ability of a material to resist deformation.
15. Which of the following measurements is equivalent to 10 megapascals (MPa)?
- (a) 10 N mm<sup>-2</sup>
  - (b) 10 kN m<sup>-2</sup>
  - (c) 10 000 N mm<sup>-2</sup>
  - (d) 1000 kPa

16. The figure below shows the stress/strain graph for a ductile material.



Which of the labelled points on the graph represents the elastic limit of the material?

- (a) i
  - (b) ii
  - (c) iii
  - (d) iv
17. The formal definition of 'work' is that work is done when
- (a) the potential energy of an object in motion increases.
  - (b) an object moves in the direction of an applied force.
  - (c) the kinetic energy of an object in motion increases.
  - (d) the total potential energy of a system increases.

The following information applies to Questions 18 and 19 and requires information from the Data book.

A load of 1 kN is applied to four different material samples. Each sample has a length of 10 cm and diameter of 1 cm.

18. Which material would extend the **most**?
- (a) brass
  - (b) cast iron
  - (c) copper
  - (d) zinc
19. If the diameter of a sample was halved, the stress in the sample would
- a) double.
  - (b) remain unchanged.
  - (c) quadruple.
  - (d) halve.

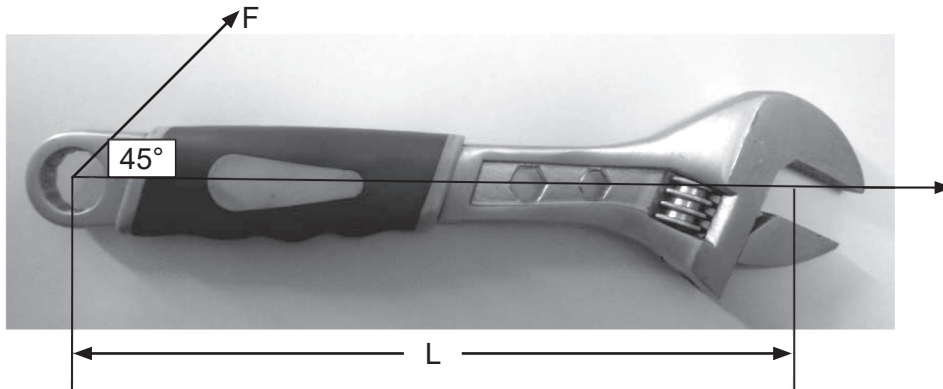


20. A ball is thrown vertically into the air. Which one of the following statements describes its trajectory correctly? You can ignore air resistance.
- (a) The acceleration of the ball decreases as the height of the ball increases.
  - (b) The acceleration of the ball is constant.
  - (c) The acceleration of the ball increases as the height of the ball increases.
  - (d) The acceleration of the ball is greater on the way down than on the way up.

21. Which one of the following is a unit for work?

- (a) joules/second
- (b) watts/second
- (c) newton second
- (d) watt second

22. The wrench shown below is being used to tighten a nut. A force  $F$  is applied at an angle of  $45^\circ$  to the wrench at a distance  $L$  from the centre of the nut.



The moment applied to the wrench under these conditions is closest to

- (a)  $1.2 FL$ .
  - (b)  $1.4 FL$ .
  - (c)  $1.0 FL$ .
  - (d)  $0.71 FL$ .
23. The coat hook shown is made from metal. Which of the processes below would be the **best** to use to manufacture it?

- (a) pressing
- (b) cold drawing
- (c) casting
- (d) forging



## Part B: Extended answer

50% (100 Marks)

This part has **six (6)** questions. Answer **all** questions. Write your answers in the spaces provided.

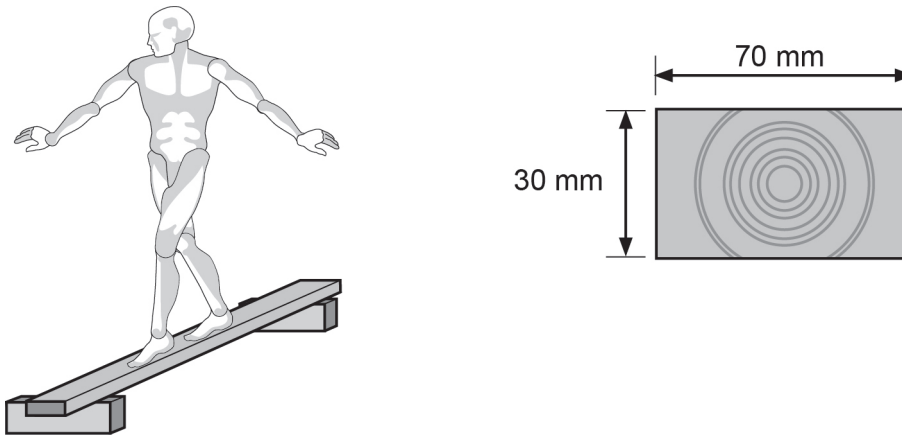
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## Question 24

(12 marks)

A 60 kg person walks across a simply-supported timber balance beam. The supports are 1.5 m apart. The beam has a width of 70 mm and a height of 30 mm as shown. Consider the weight of the person as a point source in your answers.



- (a) Complete the following by circling the correct answer. (2 marks)

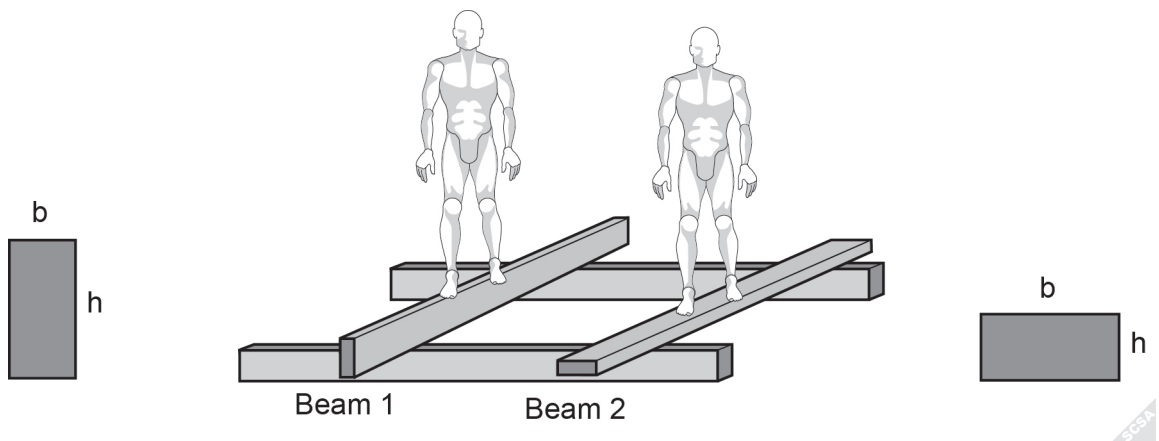
The top surface of the beam is under:                      tension                      compression

The bottom surface of the beam is under:                      tension                      compression

- (b) Calculate the second moment of area of the beam about its horizontal centroidal axis. (2 marks)

- (c) Calculate the maximum deflection in millimetres of the beam when the person stands at its centre. Convert your maximum deflection to metres. (You can ignore the mass of the timber beam in your calculations.) (5 marks)

Beams 1 and 2 shown in the diagram are identical; however, Beam 1 is rotated 90° along its longitudinal axis relative to Beam 2, as shown in the diagram.



- (d) If two people with the same mass stand in the middle of each of the beams as shown, which beam will have the greater maximum deflection? Circle your answer and provide an explanation. (3 marks)

Beam 1

Beam 2

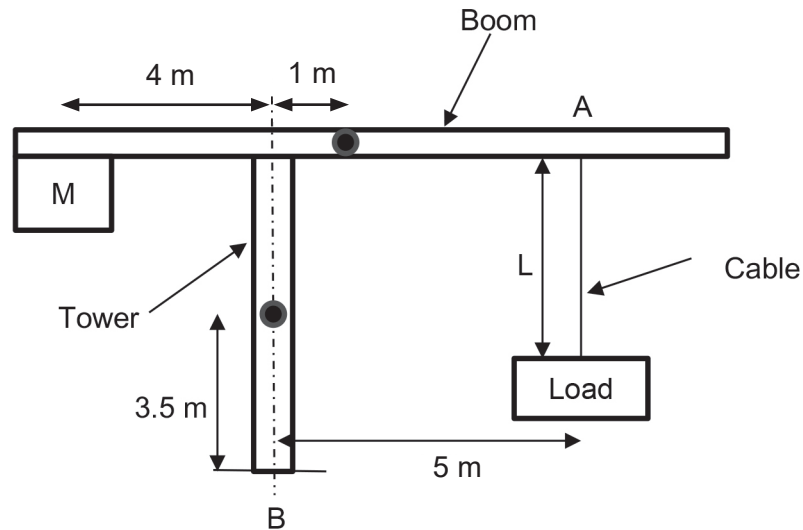
Explanation: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

## Question 25

(26 marks)

The diagram below is of a tower crane used to lift construction materials. The materials are lifted vertically by a winch at A which is 5 m from the centreline of the tower. A steel cable with a 15 mm diameter connects the load to the winch.

The mass of the boom is 1500 kg and its centre of mass is 1 m to the right of the centreline of the tower. The tower has a mass of 1000 kg and its centre of mass is 3.5 m above support B. The counterweight has a mass of 15 000 kg and its centre of mass is 4 m from the centreline of the tower. The weight of the load is 70 kN.



- (a) Calculate the vertical reaction force at B.

(3 marks)

- (b) Calculate the reaction moment at B. State whether the moment is clockwise or anticlockwise. (4 marks)

- (c) The winch now lifts the 70 kN load 2 m above the position shown in a time of 20 seconds.

- (i) Calculate the change in potential energy of the load. (2 marks)

**Question 25** (continued)

- (ii) Calculate the efficiency of the winch if it consumes 10 kW of electrical power while lifting the load. (4 marks)
- (d) Calculate the tensile force in the cable if it accelerates 1000 kg vertically upward at  $1.5 \text{ m s}^{-2}$ . (4 marks)
- (e) Applying a load to the cable causes it to increase in length from 4000 mm to 4008 mm. Calculate the strain in the cable. (3 marks)

- (f) Calculate the safe working stress of the cable if its ultimate tensile stress is 1000 MPa and the factor of safety is 2.5. (2 marks)

- (g) Name and justify **two** physical properties of steel that make it a suitable material for use in the manufacture of the cable. (4 marks)

Property one:

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Property two:

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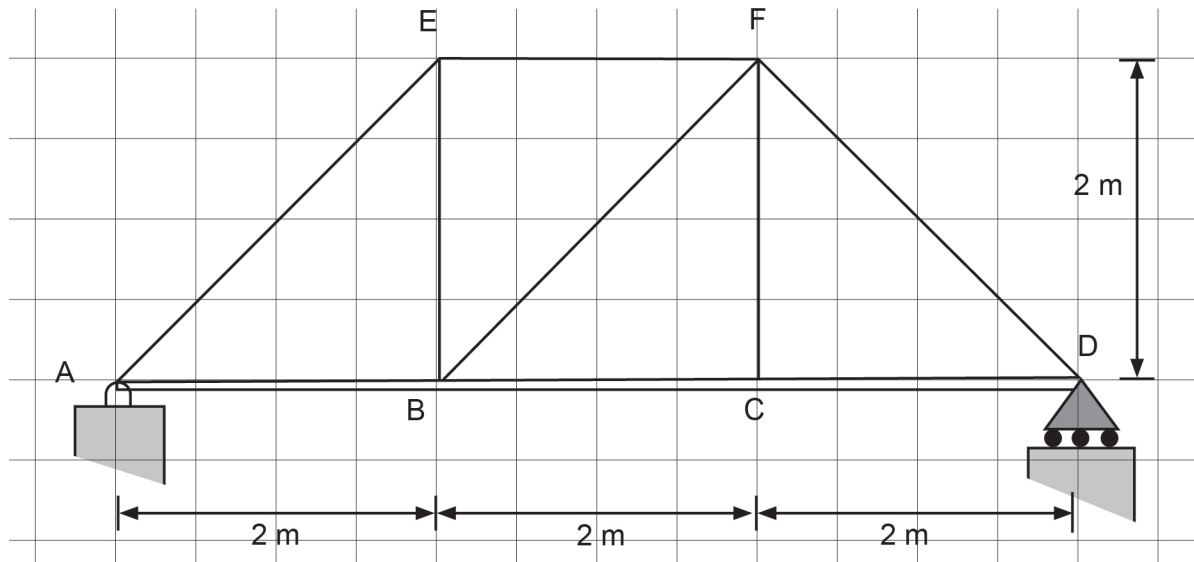
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## Question 26

(16 marks)

The truss shown is used as a road bridge to span a small creek. Members AB, BC and CD support a road deck which acts as a  $1 \text{ kN m}^{-1}$  uniformly distributed load. At the instant shown, a car applies a point load of  $12 \text{ kN}$  vertically downward at Point B. Assume that the weight of all members can be ignored in your calculations.



- (a) Show that the vertical reaction force at A is  $11\,000 \text{ N}$ . (4 marks)

- (b) Determine the size of angle BAE. (1 mark)



(c) Calculate the force in Member AE. (4 marks)

(d) Is Member AE under compression or tension? Circle your answer below and provide an explanation. (3 marks)

tension

compression

Explanation: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Member CF is a 150 mm × 150 mm × 8 mm square hollow section as shown in the diagram below.

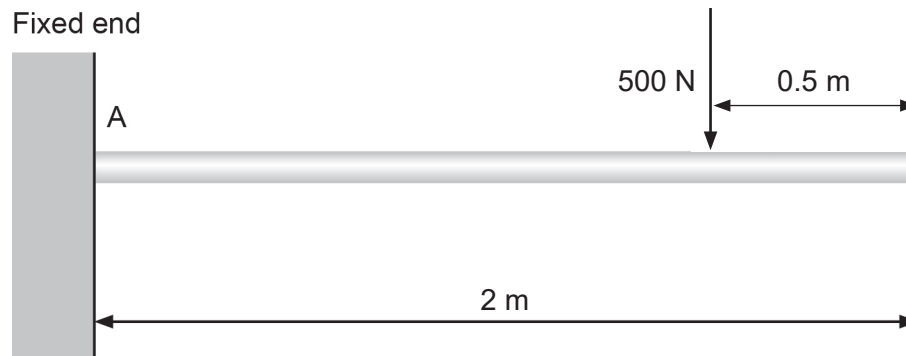


(e) If the tension force in CF is 12 kN, calculate the stress in Member CF. (4 marks)

## Question 27

(16 marks)

The diagram below shows a 2 m long cantilevered beam that supports a road sign (not shown). The beam is a circular tube section made from structural steel. The circular tube section has an outside diameter of 150 mm and an inside diameter of 145 mm. The weight of the road sign is 500 N and it acts as shown 0.5 m from the right end of the beam.



- (a) Show that the total weight of the beam is 713 N.

(5 marks)

(b) Calculate the reaction force and moment at the fixed end A.

(i) Force

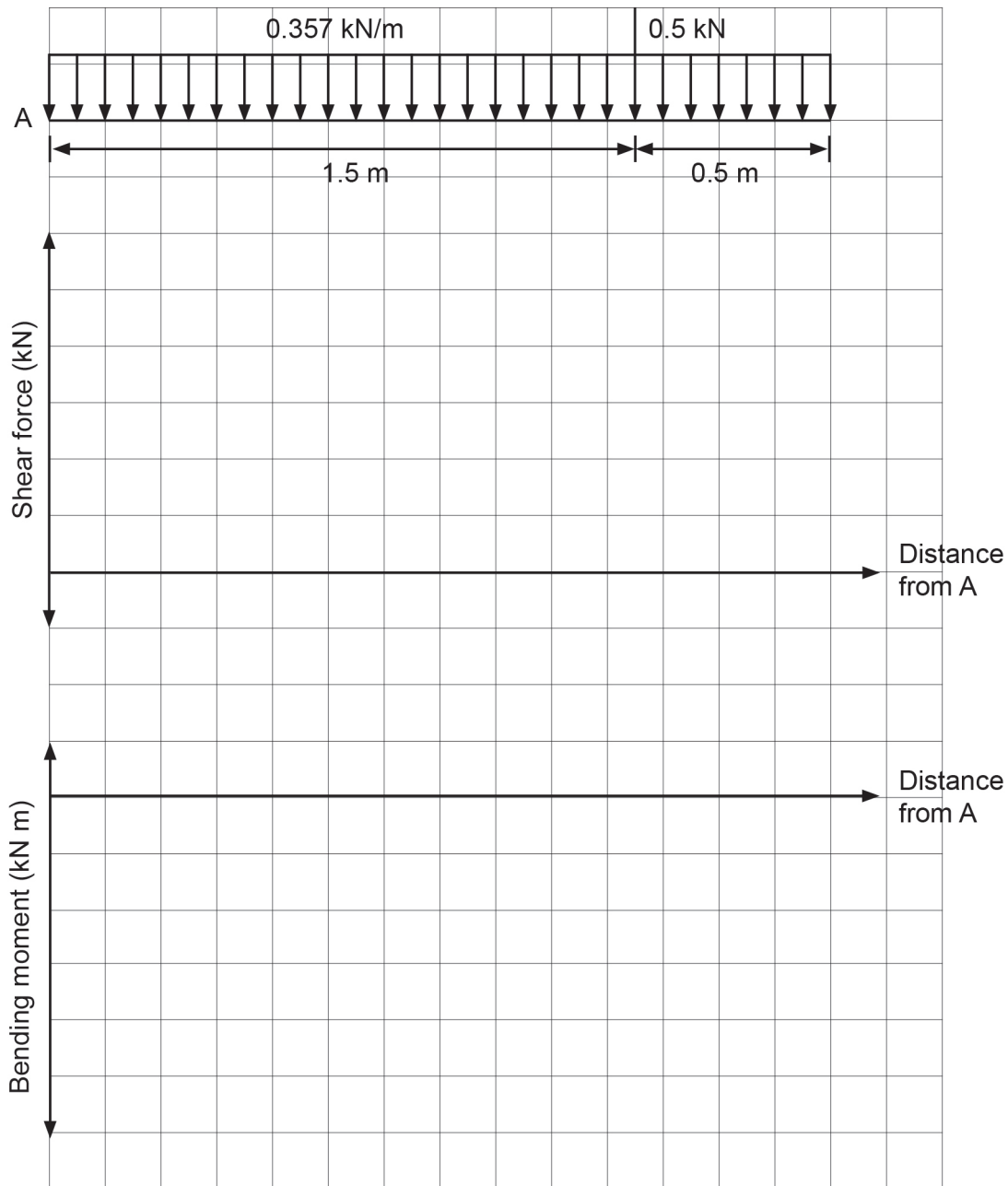
(2 marks)

(ii) Moment

(3 marks)

Question 27 (continued)

- (c) Using the grid below, and taking into account all relevant forces, construct a shear force diagram and a bending moment diagram for the beam. (6 marks)



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

## Question 28

(17 marks)

A shot tower is a tower designed for the production of small-diameter lead balls for muzzle-loading rifles. In a shot tower, lead is heated until it is molten and then dropped in predetermined masses through a copper sieve high in the tower and allowed to fall freely. The surface tension in the liquid lead causes it to form tiny spherical balls which partially cool and solidify as they fall. These partially-cooled balls are caught at the floor of the tower in a water-filled basin.



For each of the following question parts, assume that the molten lead masses are dropped from 25 m above the base of the tower and ignore air resistance.

- (a) Calculate the mass of a spherical lead shot if it has a radius of 3 mm. Assume that the density of lead is  $11\,300\text{ kg m}^{-3}$ . (4 marks)

**Question 28** (continued)

(b) Calculate the time that a lead shot takes to drop to the bottom of the tower. (3 marks)

(c) Calculate the speed of a falling lead shot when it is at a height of 10 m above the base of the tower. (4 marks)

- (d) A lead shot with a mass of 3 g is now dropped from the top of the tower. Calculate its height above the base of the tower when its kinetic energy is 0.59 J. (3 marks)

- (e) This 3 g lead shot and another lead shot with a mass of 5 g were dropped from the tower at the same time. Did the 3 g lead shot or the 5 g lead shot hit the bottom of the tower first or did they hit at the same time? You can ignore the effects of air resistance. Circle your answer and provide an explanation. (3 marks)

3 g lead shot first

5 g lead shot first

same time

Explanation: \_\_\_\_\_

\_\_\_\_\_

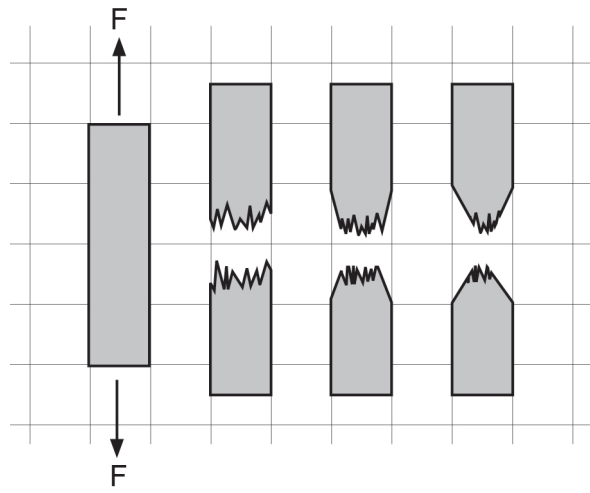
\_\_\_\_\_

\_\_\_\_\_

## Question 29

(13 marks)

During a tensile test, a sample is subjected to a tension force until it fails. The results from the tensile test are used to define the stress/strain curve for the material.



A cylindrical brass sample with an initial length of 5 cm and diameter of 3 mm is subjected to a tensile test.

- (a) Calculate the force required to break the sample. (4 marks)
- (b) Calculate the length of the sample when a 300 N force is applied, given it is still in the elastic region. (5 marks)



- (c) As the sample is stretched it begins to plastically deform. Define what is meant by plastic deformation in the context of material testing. (2 marks)

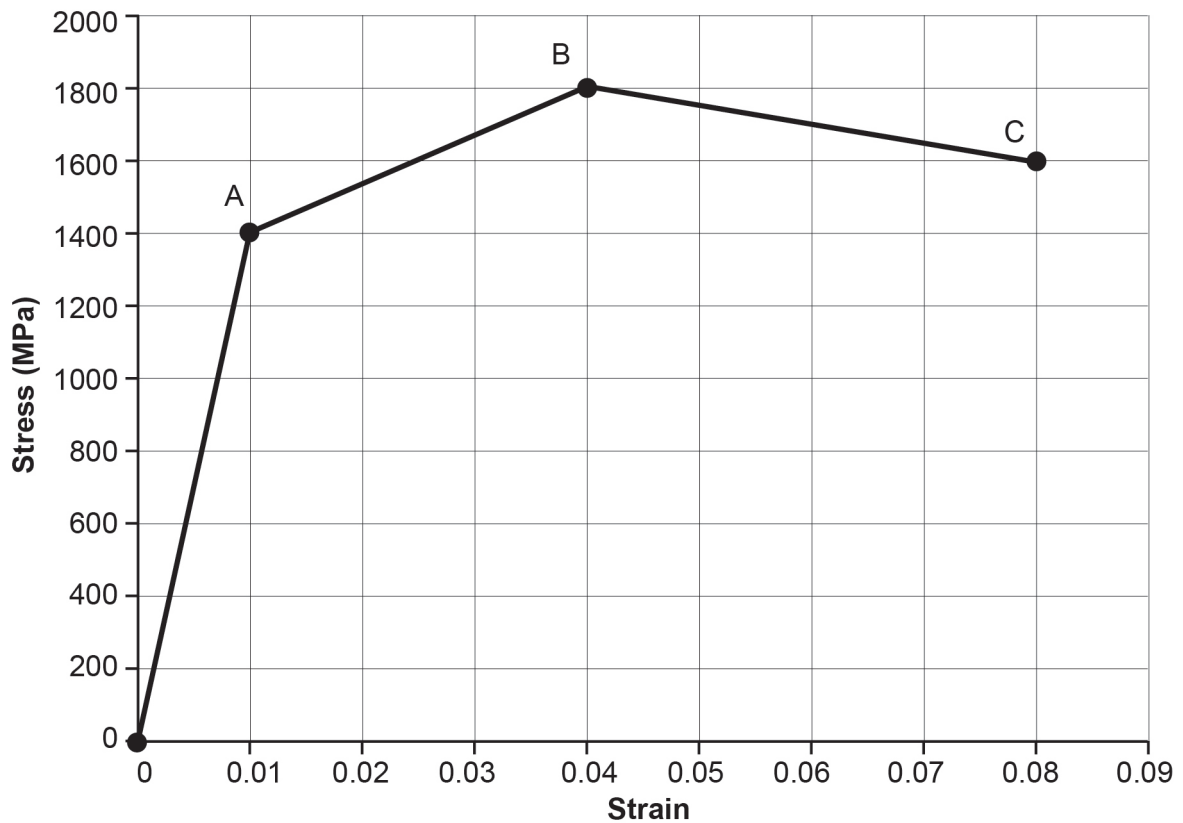
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The stress/strain graph of a different material sample is shown in the graph below.



- (d) Explain what happens to the material between Point A and Point B on the graph. (2 marks)

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End of Mechanical Section

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

This section has **two (2)** parts.

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

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

Suggested working time: 110 minutes.

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**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. 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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30. The purpose of an idler gear placed between two gears is to
- (a) enable gear ratios to be changed.
  - (b) enable the two gears to rotate in the same direction.
  - (c) reduce friction in a gear train by improved meshing.
  - (d) prevent rotation when the second gear needs to idle.
31. A DPDT relay has the ability to
- (a) control back emf.
  - (b) smooth the voltage in a circuit.
  - (c) double the current in a circuit.
  - (d) switch two different voltages in a circuit.
32. A microcontroller requires an analogue input voltage of 4.2 V. For testing purposes, which one of the following components could provide this voltage?
- (a) a 7805 regulator
  - (b) three 1.5 V batteries and a silicon diode
  - (c) a 6 V battery and three silicon diodes
  - (d) a 3.7 V phone battery and a silicon diode
33. If the mechanical advantage of a pulley system is 3.5 and the diameter of the input pulley is 150 mm, what is the diameter of the output pulley?
- (a) 525 mm
  - (b) 85.7 mm
  - (c) 262.5 mm
  - (d) 42.86 mm

**See next page**

34. Two resistors are connected in parallel. The first has a value of  $1.2\text{ k}\Omega$ . The combined value of the two resistors is  $300\ \Omega$ . The value of the other resistor is
- (a)  $900\ \Omega$ .
  - (b)  $400\ \Omega$ .
  - (c)  $1.5\text{ k}\Omega$ .
  - (d)  $350\ \Omega$ .
35. An NPN transistor is controlled by its
- (a) collector-emitter voltage.
  - (b) base-collector voltage.
  - (c) base current.
  - (d) collector current.
36. A windscreen wiper on a car uses rotary to
- (a) linear transformation.
  - (b) oscillating transformation.
  - (c) reciprocating transformation.
  - (d) circular transformation.
37. Which one of the following statements is **true**?
- (a) A stepper motor gives feedback to the control circuit.
  - (b) Stepper motors need replacing when their brushes wear out.
  - (c) A stepper motor continues to use power after reaching its rotational position.
  - (d) A unipolar stepper motor has only four wires.
38. Which one of the following statements about a worm and worm wheel is correct?
- (a) In operation, the worm and worm wheel are self-locking.
  - (b) You can rotate the worm by rotating the worm wheel.
  - (c) The number of teeth on the worm is usually higher than the number of teeth on the worm wheel.
  - (d) Only small speed reductions are possible.
39. A super blue LED has a  $3.6\text{ V}$  operating voltage and a current draw of  $20\text{ mA}$ . When operating from a  $5\text{ V}$  supply, the **best** series resistor should be coloured
- (a) red, violet, black and gold.
  - (b) green, blue, brown and gold.
  - (c) red, violet, brown and gold.
  - (d) blue, grey, black and gold.

## Part B: Extended answer

50% (100 Marks)

This part has **six (6)** questions. Answer **all** questions. Write your answers in the spaces provided.

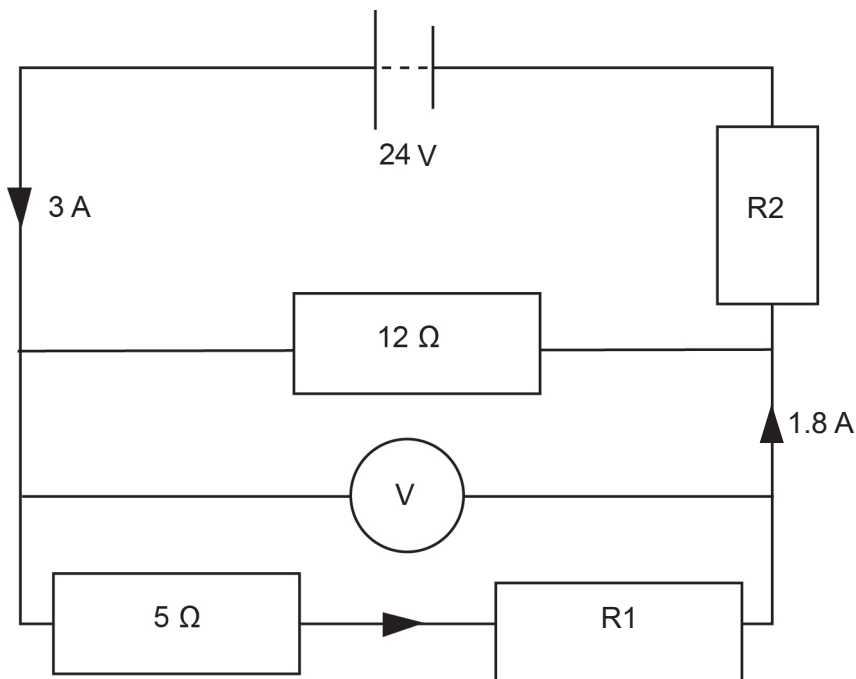
When calculating answers, show all your working clearly. Your working should be in sufficient detail to allow your answers to be checked readily and for marks to be awarded for reasoning. In final answers, include appropriate units where applicable.

Supplementary pages for the use of planning/continuing your answer to a question have been 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

(17 marks)

A 24 V battery is connected to the circuit shown below. The current flowing from the battery is 3 A and the current flowing through R1 is 1.8 A.



- (a) What is the current through the 5 Ω resistor? Give a reason why. (2 marks)

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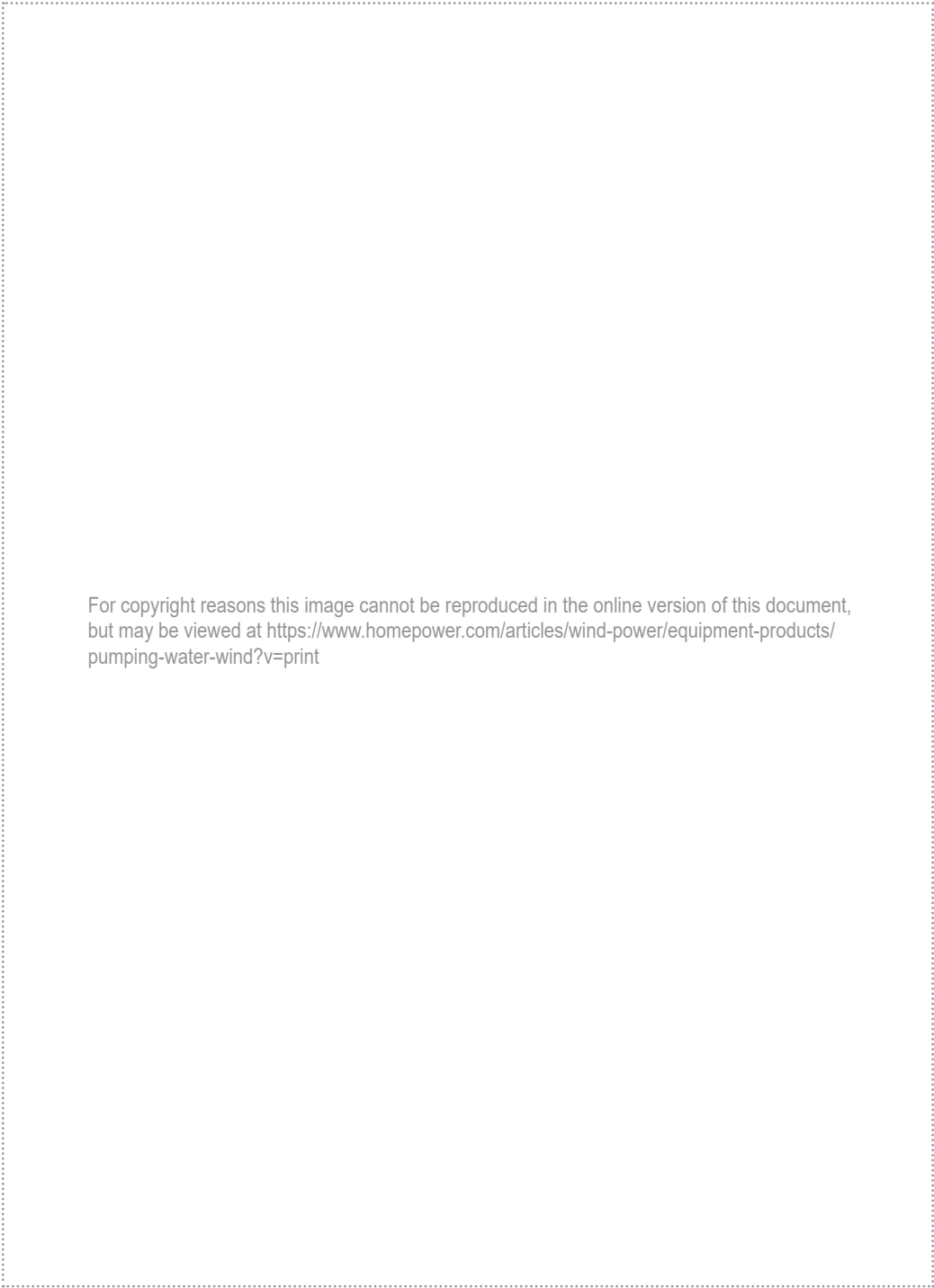
- (b) Calculate the current through the 12 Ω resistor. (2 marks)

See next page

- (c) Show by calculation the potential difference displayed on the voltmeter. (2 marks)
- (d) Calculate the power dissipated in the  $5\ \Omega$  resistor. (2 marks)
- (e) Calculate the value of Resistor R1. (3 marks)
- (f) Calculate the value of Resistor R2. (3 marks)
- (g) If the voltage of the 24 V battery was to drop to 19.6 V, calculate the new reading on the voltmeter. (3 marks)

**Question 41****(8 marks)**

A windmill that pumps water operates by means of blades moving in the wind which turn a wheel shaft connected to a small pinion drive gear. The pinion gear turns a larger bull (driven) gear that is connected to a Pitman arm. The Pitman arm pushes a sliding yoke up and down in a pump rod guide. This lifts a pump rod up and down to a pump that is located in water below.



For copyright reasons this image cannot be reproduced in the online version of this document, but may be viewed at <https://www.homepower.com/articles/wind-power/equipment-products/pumping-water-wind?v=print>

**See next page**

- (a) Name the type of motion transformation that occurs between the driven gear and the pump rod. (1 mark)

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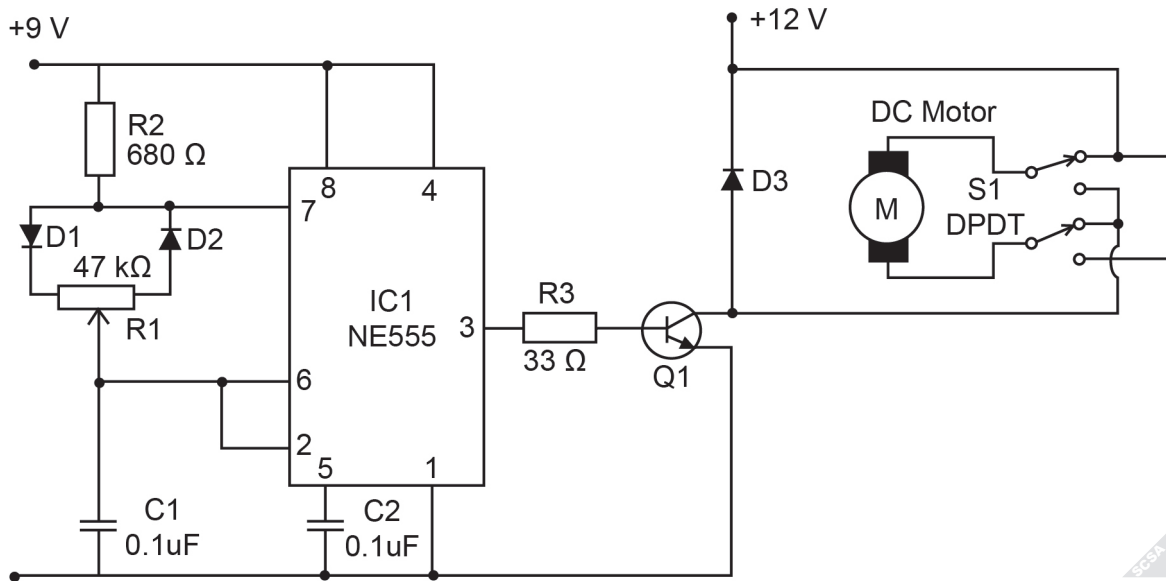
- (b) In the windmill diagram shown, the pinion gear has 14 teeth and the driven gear has 56 teeth. If the wind wheel shaft is turning at 146 rpm, calculate the velocity of the bull (driven) gear. (3 marks)

- (c) If the pump rod has 165 upstrokes in one minute, calculate the velocity of the wind wheel shaft. (4 marks)

Question 42

(10 marks)

The circuit below is used to control a DC motor by pulse width modulation (PWM) on the DC supply to the motor.



- (a) State **two** advantages of using PWM in this circuit rather than lowering the voltage by resistance to control the motor speed. (2 marks)

One: \_\_\_\_\_  
 \_\_\_\_\_  
 Two: \_\_\_\_\_  
 \_\_\_\_\_

- (b) What is the design purpose of Resistor R1? (1 mark)

\_\_\_\_\_  
 \_\_\_\_\_

- (c) What is the design purpose of Transistor Q1? (1 mark)

\_\_\_\_\_  
 \_\_\_\_\_



- (d) What is the design purpose of Diode D3? (1 mark)

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- (e) What is the reason for including Switch S1? (1 mark)

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- (f) A switch could be placed at the +12 V input. Explain the advantage of such a switch. (2 marks)

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- (g) Complete the table below if R2 is a 5% tolerance carbon resistor. (2 marks)

Resistor	Colour code	Maximum value
R2		

## Question 43

(25 marks)

An elevator is installed in a four-storey building. It has the usual UP/DOWN request buttons on the wall near the entrance and the usual destination control panel inside. For safety, the elevator always checks the total weight of occupants and flashes a warning light if a mass of greater than 630 kg is detected. The door then opens and remains open until the weight of passengers is below 630 kg.

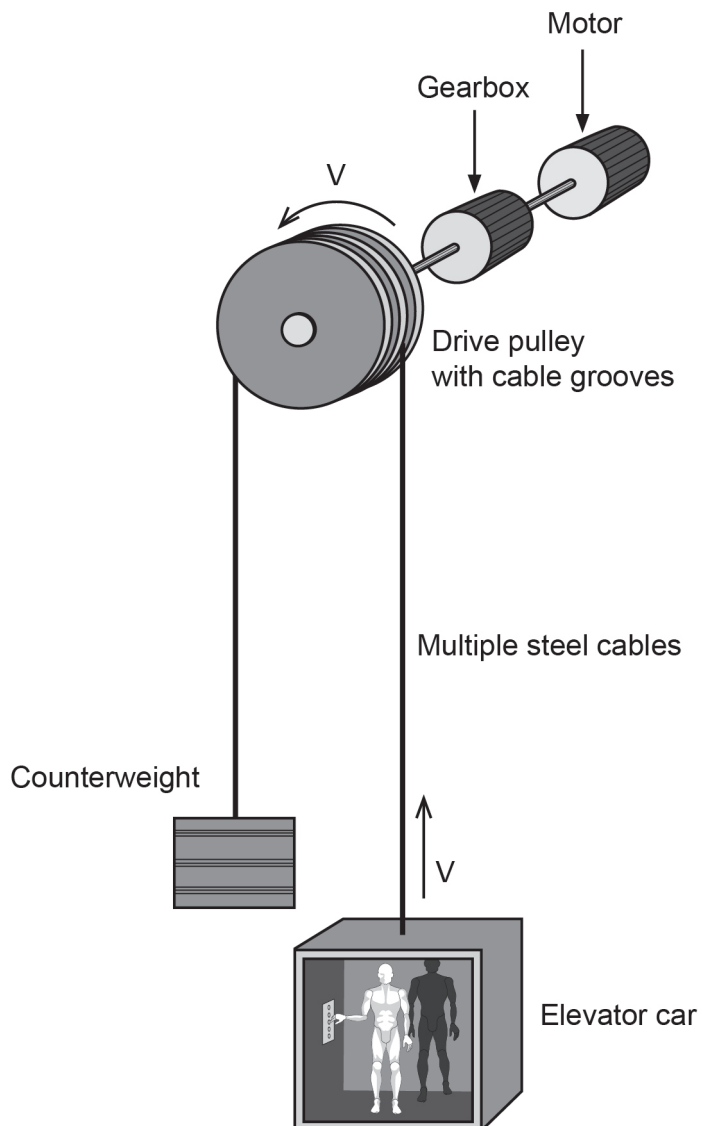
When no request has been made from the UP/DOWN buttons located on the upper floors for two minutes, the elevator always returns to the ground floor. The sequence required for the elevator to operate correctly is shown **without** the weight detection stage included.

1. IDLE AT GROUND FLOOR
2. REQUEST TO MOVE UP OR DOWN
3. DOOR OPENS
4. DOOR CLOSES
5. ELEVATOR MOVES TO REQUESTED FLOOR
6. DOOR OPENS
7. DOOR CLOSES
8. CHECK FOR NEW REQUEST
9. ELEVATOR MOVES TO REQUESTED FLOOR
10. IF NO NEW REQUEST, TWO MINUTE TIMER STARTS
11. ELEVATOR MOVES TO GROUND FLOOR AND REMAINS IDLE

- (a) In the sequence above **circle** each numbered stage that the elevator is almost certain to be unoccupied? (3 marks)
- (b) In the space below, draw a flow chart to show the operation of the elevator. Include the 630 kg weight check and the flashing warning light. (9 marks)

- (c) Below is a diagrammatic representation of a simple drive system for an elevator. The elevator moves vertically at  $1.2 \text{ m s}^{-1}$  and there is no slip between the cable and the drive pulley. The table refers to the specifications of an elevator using this design.

Maximum empty load	Passenger load	Drive pulley RPM	Motor RPM	Motor voltage	Motor current	Gearbox output power
1600 kg	630 kg	15	3660	300 VDC	14 A	3.864 kW



- (i) Calculate the ratio of the gearbox. (2 marks)

**Question 43** (continued)

- (ii) Suggest a type of gearbox that would be best suited to this application. (1 mark)

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- (iii) Calculate the input power to the motor. (2 marks)

- (iv) Calculate the efficiency of the motor and gearbox. (2 marks)

- (v) Name the type of motion transformation between the drive pulley and the elevator. (1 mark)

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- (vi) The counterweight is approximately 2000 kg. Justify this mass. (2 marks)

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In the last 20 years, new designs for elevator motors have appeared. Most are gearless and the motor RPM has been controlled by microprocessors using pulse width modulation (PWM).

- (d) Besides the increased safety of these large PWM motors, list **three** other advantages over the high-voltage DC motors they have replaced. (3 marks)

One: \_\_\_\_\_

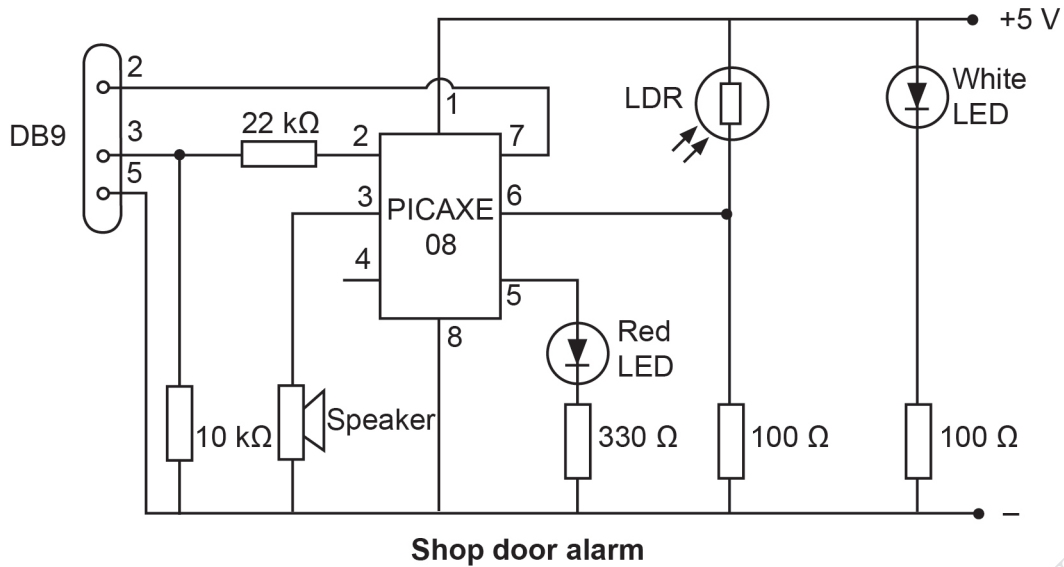
Two: \_\_\_\_\_

Three: \_\_\_\_\_

## Question 44

(19 marks)

A shop door alarm that was designed to use a microcontroller is shown in the circuit below. A high-power white LED illuminates an LDR on the input and the output is a red LED and a piezoelectric speaker. When the LDR is darkened by a person interrupting the light from the white LED, the speaker sounds and the red LED flashes the total count of entries and exits through the door.

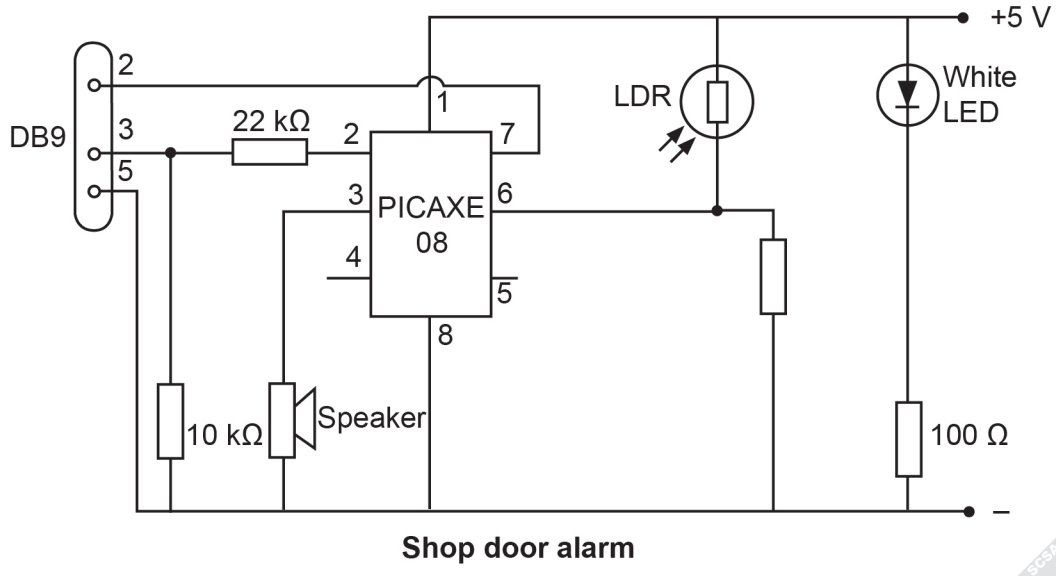


- (a) State the purpose of the DB9 connector. (1 mark)
- 
- (b) State the specific type of input for pin 6 on the IC. (1 mark)
- 
- (c) The white LED draws 24 mA in this circuit. Calculate its operating voltage. (2 marks)

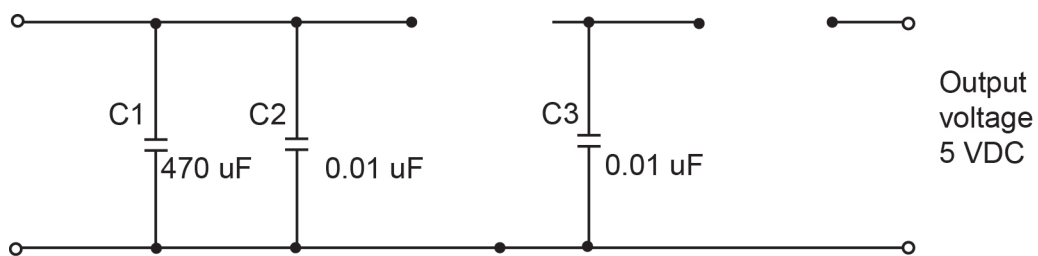
Question 44 (continued)

The shop owner tried to use a 5 V relay in place of the red LED and the 330 Ω resistor but it destroyed the IC because the relay was rated at 50 mA.

- (d) Complete the circuit below using additional components to show how a 5 V relay can be used. Values of the components do **not** have to be shown. (6 marks)



- (e) The power supply needed to operate the shop door alarm is missing some components in the schematic. It requires an input 9 VDC voltage and the 5 V output should have a fuse. Label the voltage input, showing polarity and draw in the labelled components required to make a working circuit. (5 marks)



- (f) Capacitor C3 has three numbers marked on it to indicate its capacitance. What are the numbers? (1 mark)

The circuit is now to be operated from a 12 V battery instead of 9 V.

- (g) What would the output voltage be? (1 mark)

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- (h) What would be a suitable voltage rating for C1? (1 mark)

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- (i) Draw in a switch to the schematic in part (e) to turn the shop door alarm off. (1 mark)

Question 45

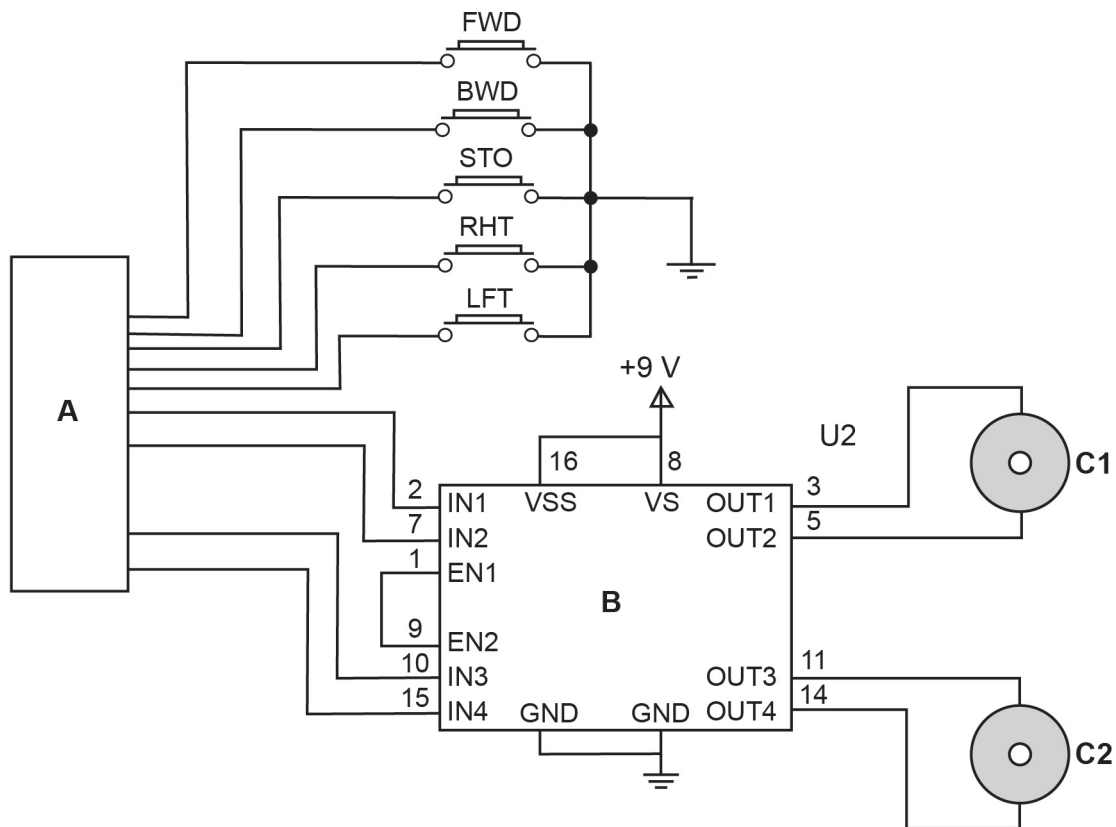
(21 marks)

In designing a small robot car a student considers a number of possibilities for propulsion and steering. The student decides on the differential drive method in which two rear wheels are powered to provide forward motion, backward motion and direction.

(a) Complete the table below to show the direction in which the vehicle will travel. (4 marks)

Left motor motion	Right motor motion	Direction that the vehicle will travel
Forward	Forward	
Forward	Backward	
Backward	Forward	
Backward	Backward	

To control the vehicle, the student decides to use a circuit similar to that shown below.



(b) Name the components A, B and C1/C2 in the circuit shown. (3 marks)

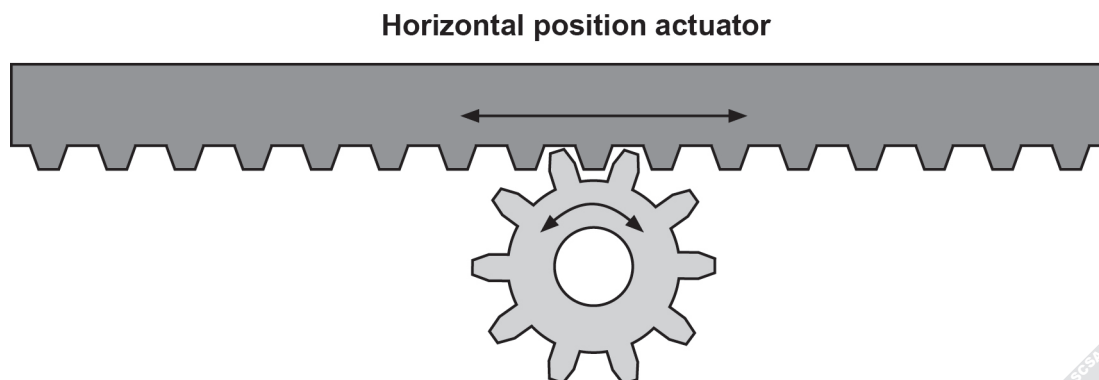
A: \_\_\_\_\_

B: \_\_\_\_\_

C1/C2: \_\_\_\_\_



The following diagram shows an arrangement of gears that convert a rotational motion of the circular gear into a linear motion of the flat gear. The pitch of the gear teeth is 3 mm.



- (c) State the common name given to this gear arrangement. On the basis of this name, label the parts on the diagram above. (2 marks)

Name: \_\_\_\_\_

- (d) Calculate the translation distance of the flat gear for **one** revolution of the circular gear. (2 marks)

- (e) If the circular gear was twice the diameter with the same gear pitch, what would be the translation distance for **two** revolutions of the circular gear? (2 marks)

**Question 45** (continued)

- (f) By changing the diameter of the circular gear as described in part (e), would the mechanical advantage be greater or smaller? Give a reason for your answer. (2 marks)

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- (g) Refer to the diagram shown on page 49. How many rotations of the circular gear would be required to provide a translation of 960 mm? (2 marks)

- (h) Complete the table below for a suitable mechanical drive system for each of the applications given. (4 marks)

<b>Application</b>	<b>Drive system</b>
Car alternator and water pump	
Car steering	
Bicycle propulsion	
Car gearbox	

**End of Mechatronics Section**

**End of questions**









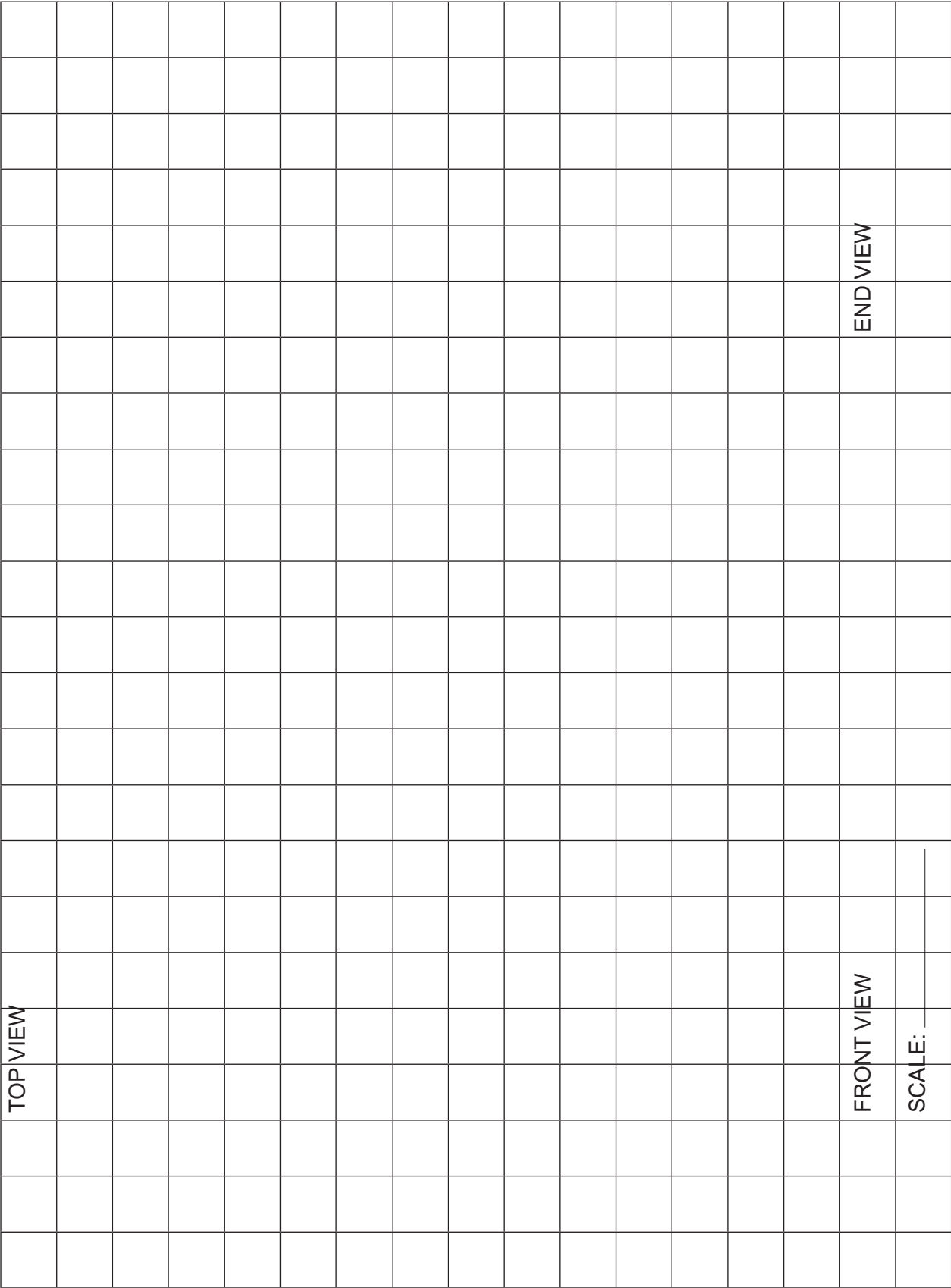




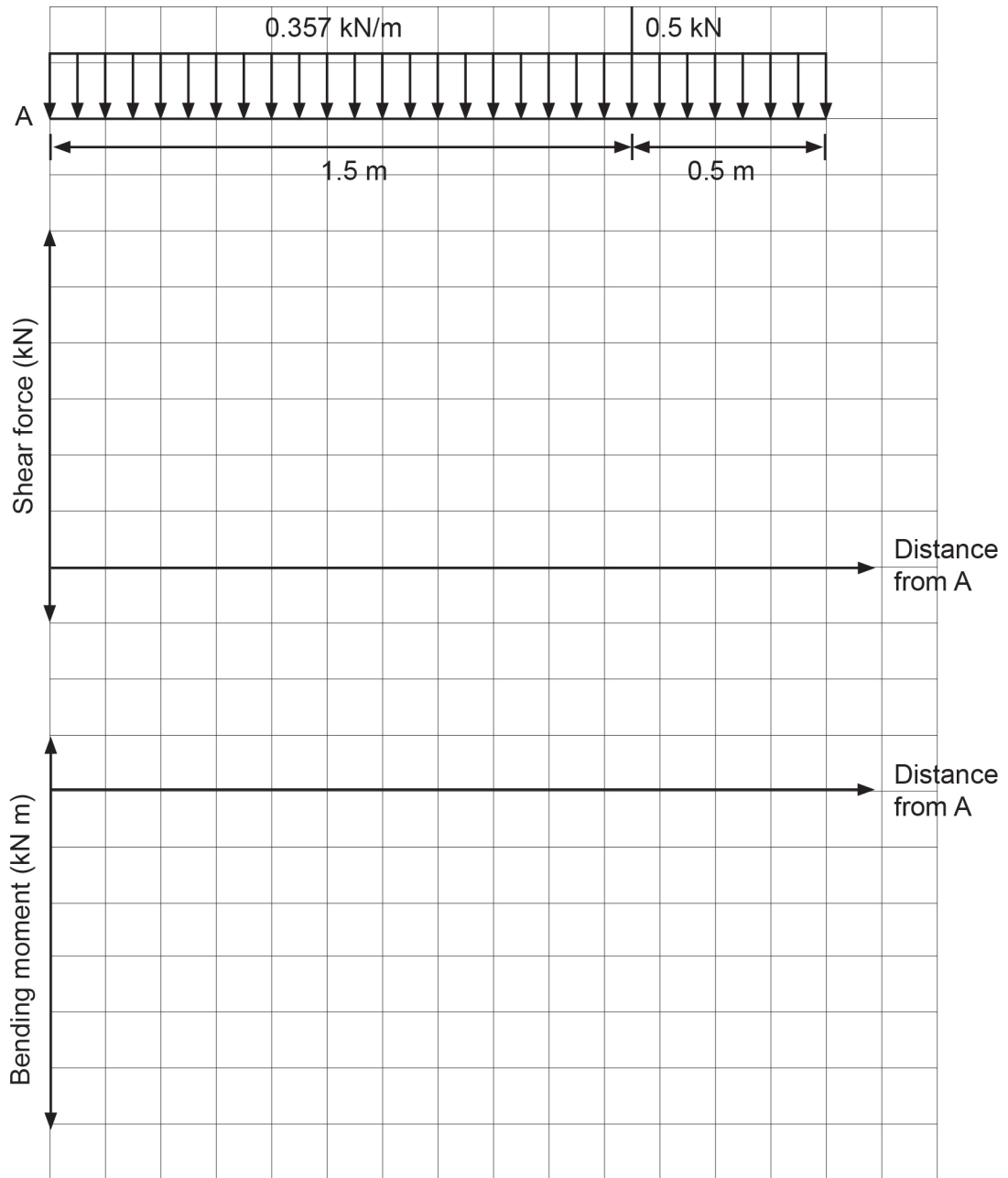




Spare grid



Spare grid



## ACKNOWLEDGEMENTS

- Question 11** Photograph of solar system tank by courtesy of the examining panel.
- Question 12** Photograph of automatic gate by courtesy of the examining panel.
- Question 22** Photograph of wrench by courtesy of the examining panel.
- Question 23** Photograph of coat hook by courtesy of the examining panel.
- Question 28** Image: Matnkat. (2006, August 12). *Clifton Hill shot tower, Melbourne, Australia*. Retrieved April, 2017, from [https://en.wikipedia.org/wiki/Clifton\\_Hill\\_Shot\\_Tower](https://en.wikipedia.org/wiki/Clifton_Hill_Shot_Tower)  
Used under a Creative Commons Attribution 2.5 Generic licence.
- Question 41** Diagram adapted from: Ironman Windmill Co. (1977). *Gear box: Up stroke; Pump: Up stroke*. Retrieved May, 2017, from <https://www.homepower.com/articles/wind-power/equipment-products/pumping-water-wind?v=print> (see 'Gearbox and windmill overview schematic' under 'Inside this article')
- Question 45(a)** Circuit diagram adapted from: Gadgetronicx. (n.d.) *Wiring diagram robot car*. Retrieved May, 2017, from <http://readingrat.net/wiring-diagram-robot-car/>

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