Government of **Western Australia**
Curriculum Council

WACE
Western Australian Certificate of Education

Western Australian Certificate of Education
Examination, 2010

Question/Answer Booklet

ENGINEERING STUDIES

Stage 3

Please place your student identification label in this box

Student Number: In figures | | | | | | | | |

In words _____

_____

Time allowed for this paper

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

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

Systems and Control ☐
Mechanical ☐
Electronic/Electrical ☐

Materials required/recommended for this paper

To be provided by the supervisor

This Question/Answer Booklet
Multiple-choice Answer Sheet
Document Booklet
Data Book

To be provided by the candidate

Standard items: pens, pencils, eraser, correction fluid/tape, ruler, highlighters

Special items: non-programmable calculators satisfying the conditions set by the Curriculum Council for this course, measuring and drawing instruments

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 notes or other items of a non-personal nature in the examination room. 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 exam
Section One: **Core content** Part A: Multiple-choice Part B: Extended answer	 10 4	 10 3	 10 50	 10 45	 10 25
Section Two: **Systems and Control** Part A: Multiple-choice Part B: Extended answer	 10 3	 10 3	 10 110	 10 105	 10 55
Section Two: **Mechanical** Part A: Multiple-choice Part B: Extended answer	 10 4	 10 4	 10 110	 10 105	 10 55
Section Two: **Electronic/Electrical** Part A: Multiple-choice Part B: Extended answer	 10 3	 10 3	 10 110	 10 105	 10 55
				Total	100

Instructions to candidates

1. The rules for the conduct of Western Australian external examinations are detailed in the *Year 12 Information Handbook 2010.* Sitting this examination implies that you agree to abide by these rules.

2. Answer the questions according to the following instructions.

   Sections One and Two, Part A:
   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, do not erase or use correction fluid, and shade your new answer. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

   Section One, Part B:
   Write answers in this Question/Answer Booklet. Answer only **three (3)** questions.

   Section Two, Part B:
   You must choose to answer only **one (1)** of the specialist sections.
   Write answers in this Question/Answer Booklet. **All** questions must be answered.

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

4. Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.
   - Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
   - Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

See next page

Section One: Core content **35% (55 Marks)**

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

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

Part B: Extended answer Answer **three (3)** questions

Suggested working time: 60 minutes.

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

This part has **ten (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, do not erase or use correction fluid, and shade your new answer. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

Suggested working time: 10 minutes.

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1. An engineering drawing of a new product using orthographic projection would be expected to include

   (a) a top view.
   (b) an isometric view.
   (c) an axonometric view.
   (d) an exploded view.

2. The process of modelling in design is mainly intended to

   (a) ensure that the final product accurately follows the design specifications.
   (b) assist in understanding the operation of the product before a prototype is manufactured.
   (c) enable the cost of the product to be estimated before manufacturing begins.
   (d) assist in the production of advertising materials to support the marketing of the product.

3. For the production of a new product, the main function of a budget is to provide

   (a) an overview of the timelines for the design and manufacturing process.
   (b) a profile of the expected sales performance of the product.
   (c) the details of the expected production costs and sales income from the product.
   (d) a summary of the staff utilisation during the manufacturing phase.

4. Which one of the following best describes the distinction between drafting and design?

   (a) There is no difference.
   (b) Design occurs first, then drafting.
   (c) Design is the creative work and drafting documents the design.
   (d) Drafting involves the use of computers to assist, while design is just thinking.

See next page

5. To correctly estimate the production of carbon dioxide (CO_2) from the operation of a proposed nuclear power station, which of the following elements should be included?

   I the operation of the power station
   II the mining and pre-processing of the uranium fuel
   III the post-processing of the radioactive waste.

   (a) I only
   (b) II and III only
   (c) I and III only
   (d) I, II and III

6. An inventor comes to you with a proposal to build a new internal combustion engine that runs on water. Your best first response would be to

   (a) respond politely then ignore the proposal.
   (b) ask the inventor to show you his/her test results.
   (c) agree on a profit sharing agreement for when the new engine is sold.
   (d) refuse to see the inventor.

7. It has been proposed that your business should design and manufacture a new battery powered hand drill. Your first task should be to

   (a) produce a prototype design.
   (b) choose an existing model from a competitor, and copy the design.
   (c) review similar products that are already on the market.
   (d) set a selling price, and then decide to manufacture to this price.

8. A design brief is intended to

   (a) specify the requirements of the client.
   (b) specify the materials to be used in manufacture
   (c) set the production time line
   (d) summarise of the marketing strategy for the product.

9. The environmental impacts of a large engineering construction project must be considered in its design primarily because

   (a) they may affect the health of the community at large.
   (b) the design engineer's reputation may be affected.
   (c) the client's reputation may be affected.
   (d) the costs may overrun the budget.

10. The main purpose of testing a product throughout the production process is

    (a) to ensure that faults are found as early as possible in the production process.
    (b) to ensure that all faults are known about before the product is released for sale.
    (c) to reduce the cost of testing.
    (d) not a good idea, because testing should only be done when the product is complete.

See next page

Section One: Core content

Part B: Extended Answer **25% (45 Marks)**

This section has **four (4)** questions. Answer **only three (3)** questions. Write your answers in the spaces provided.

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

Suggested working time: 50 minutes.

Question 11 **(15 marks)**

The two perspective views on the next page show the same sculpture, which is to be manufactured from concrete.

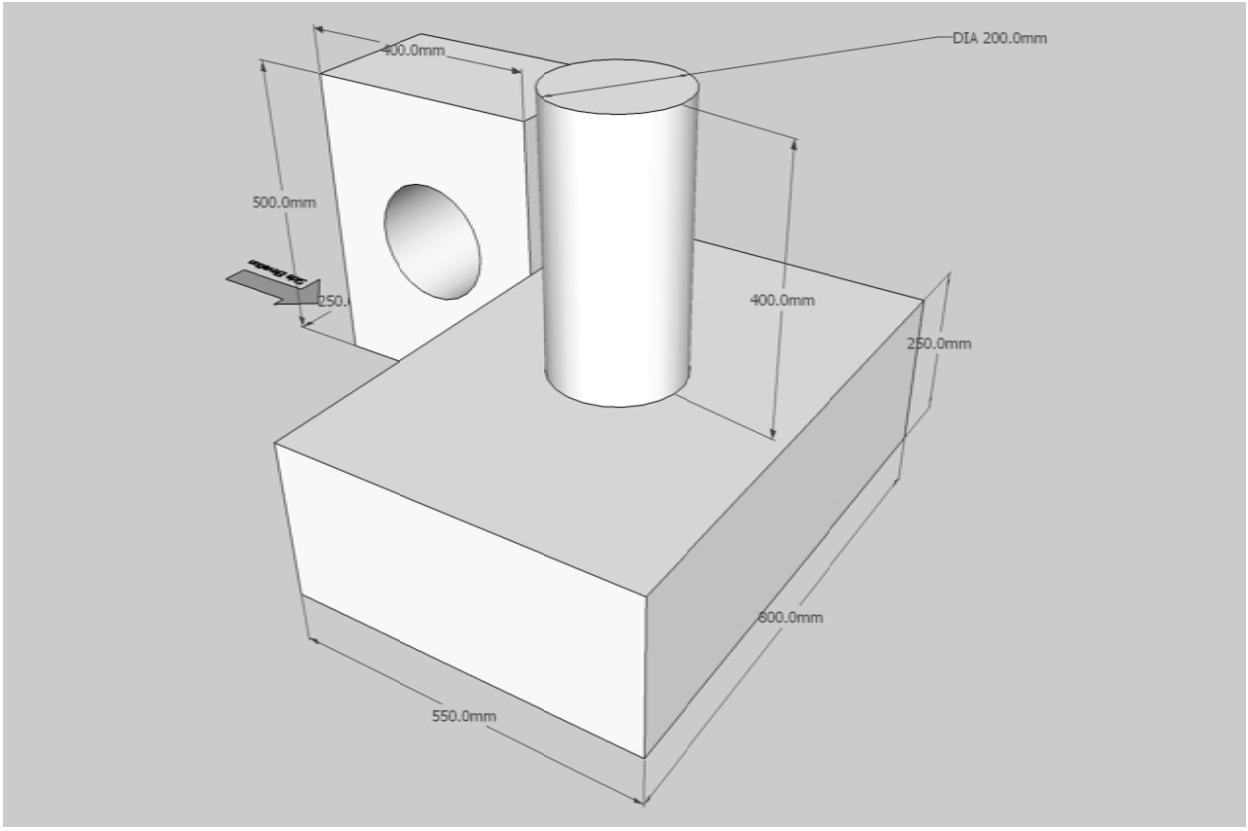
(a) Sketch and label the following orthographic views of this sculpture correctly related to each other using a standard orthographic projection on the graph page provided.

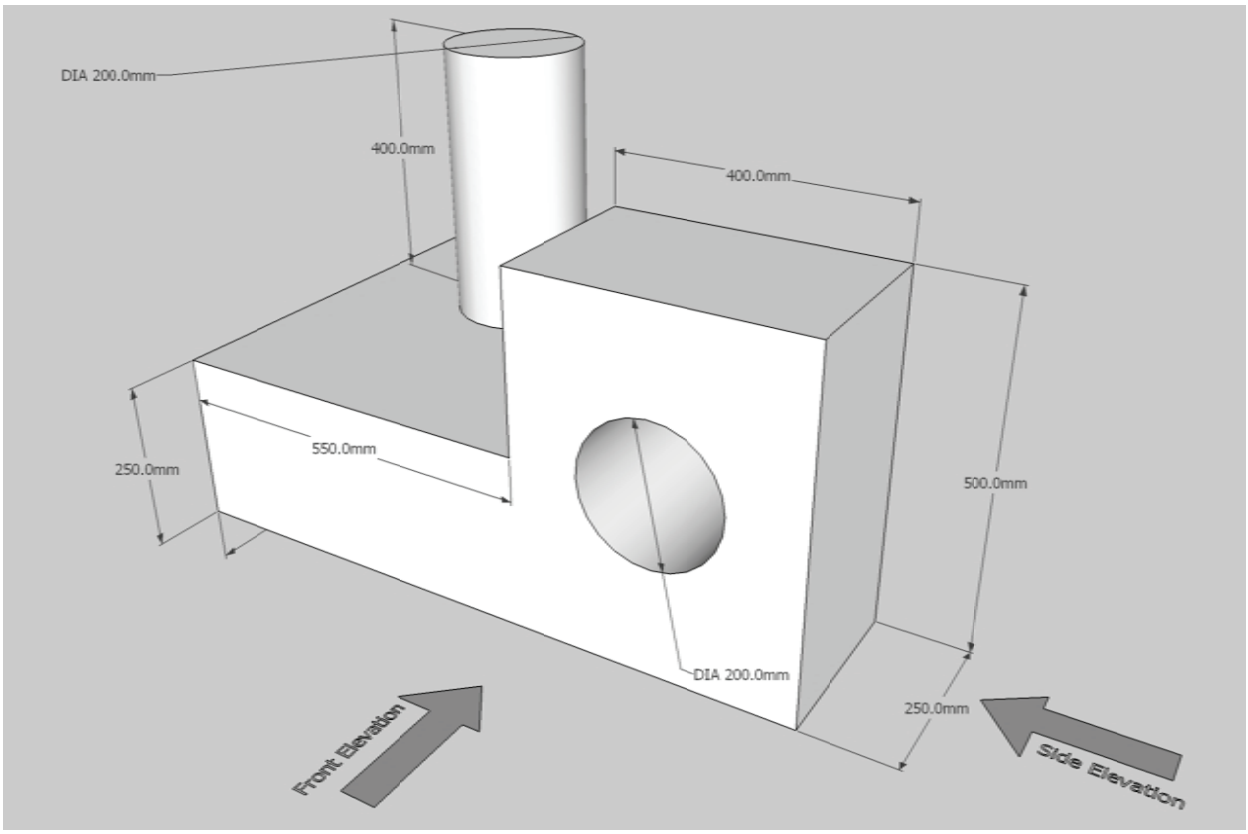
You must ensure you show

(i)	a plan view, looking down from the top	(2 marks)
(ii)	a front elevation in the direction marked	(2 marks)
(iii)	a side elevation in the direction marked	(2 marks)
(iv)	correct relationship between views	(2 marks)
(v)	neat drawings	(2 marks)

Note: The circular elements are located at the centres of their respective block parts. All hidden edges must be shown as dashed lines. Dimensions need not be shown. Assume that each square on the graph page represents 100 mm × 100 mm.

See next page





See next page

See next page

(b) Calculate the volume of concrete, in cubic metres (m^3), required to make this sculpture.

Note that the volume of a rectangular prism is given by volume = length × width × depth.
The formula for the volume of a cylinder is provided in the **Data Book**. (5 marks)

See next page

Question 12 **(15 marks)**

Document 1 'The REVA Electric Car – An Australian Product' in the **Document Booklet** should be read in conjunction with this question.

Answer the following questions about the REVA Electric Car.

(a) Identify **five** reasons why the REVA could be seen as an ideal city car. (5 marks)

One: _____

_____

Two: _____

_____

Three: _____

_____

Four: _____

_____

Five: _____

_____

(b) In Australia, the length of kerbside parking spaces (where vehicles park parallel to the kerb) is usually about 7.5 m per vehicle. This is to allow vehicles of average length (around 5 m) to enter and exit the parking spaces. Describe one possible impact on the design of kerbside parking if vehicles of the same size as the REVA became very popular in cities. (2 marks)

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See next page

(c) The REVA is likely to be more or less suitable for different types of users. For each of the users listed in the following table:

(i) Indicate the suitability of the REVA, and provide one reason for your assessment.
(ii) Describe the requirements for recharging the batteries in the REVA.

Place your answers in the space provided in the following table.

User	Suitability	Recharging requirements
Office worker commuting from home to office, a distance of 60 km each way.	Yes/No _____ Why _____ _____ _____	_____ _____ _____ _____
A mother taking two children to school each day (round trip of 10 km) and a trip to the shopping centre once a day (round trip of 20 km).	Yes/No _____ Why _____ _____ _____	_____ _____ _____ _____
Real estate agent visiting 10 properties in a day around the metropolitan area, a total trip of 100 km.	Yes/No _____ Why _____ _____ _____	_____ _____ _____ _____
A farmer living 50 km from the nearest town visiting the town for shopping.	Yes/No _____ Why _____ _____ _____	_____ _____ _____ _____

(8 marks)

See next page

Question 13 **(15 marks)**

This question refers to Document 2 'Putting Wind Power's Effect on Birds into Perspective' that is included in the **Document Booklet**.

You have been asked by a local business owner (your client) to design a small wind turbine adjacent to their factory unit to generate electricity. The proposal is justified because:

- the turbine will produce enough electrical energy to substantially reduce the need to purchase electricity from the grid.
- there will be times when the wind is blowing strongly and the turbine will produce more energy than required in the business. The excess energy can be sold back to the electrical power authority, hence reducing your client's operating costs.
- the business is most anxious to promote its 'green' credentials, and the wind turbine will help achieve this.

You have prepared the design details for the tower and turbine, and all the electrical connections, and these have been submitted to the local council for planning approval. The proposed system will be relatively small, with a propeller span of just 5 m on a tower of 20 m height, compared with a 50 m propeller span on towers of over 100 m height that are common in commercial installations.

As a part of this process, the planning application has been published by the council in the local community newspaper. As a consequence, the council has received a submission from a local bird watching group claiming that the wind turbine will have a major impact on the local population of red-crested parrots. These parrots are known to breed in a nearby area of native bushland, and they are commonly seen in local backyards and road verges searching for items of food (insects, beetles etc).

Your client has now asked you to prepare a response to these objections. As a part of your investigations, you have come across the document 'Putting Wind Power's Effect on Birds into Perspective' which is included in the **Document Booklet**. You can assume that the experiences in the USA (as reported in the document) would apply equally in your client's suburb.

Using the document in the **Document Booklet** as a primary reference:

(a) Complete the following table that identifies the seven sources of bird kill, and the approximate annual number of birds killed in the USA in each case. Where the data available refers to the state of Wisconsin only you may assume that since Wisconsin has about 2% of the population of the USA, this data will represent 2% of the data for the USA as a whole. (7 marks)

Source of bird kill	Estimated no. of birds killed per year in the USA

See next page

(b) Identify and describe three key points that you could use to assist in preparing a response to the objections on behalf of your client. (3 marks)

Point one: _____

_____

_____

Point two: _____

_____

_____

Point three: _____

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_____

(c) Prepare a brief response on behalf of your client that uses the information in the document to support their application to build the wind turbine. (5 marks)

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(5 marks)

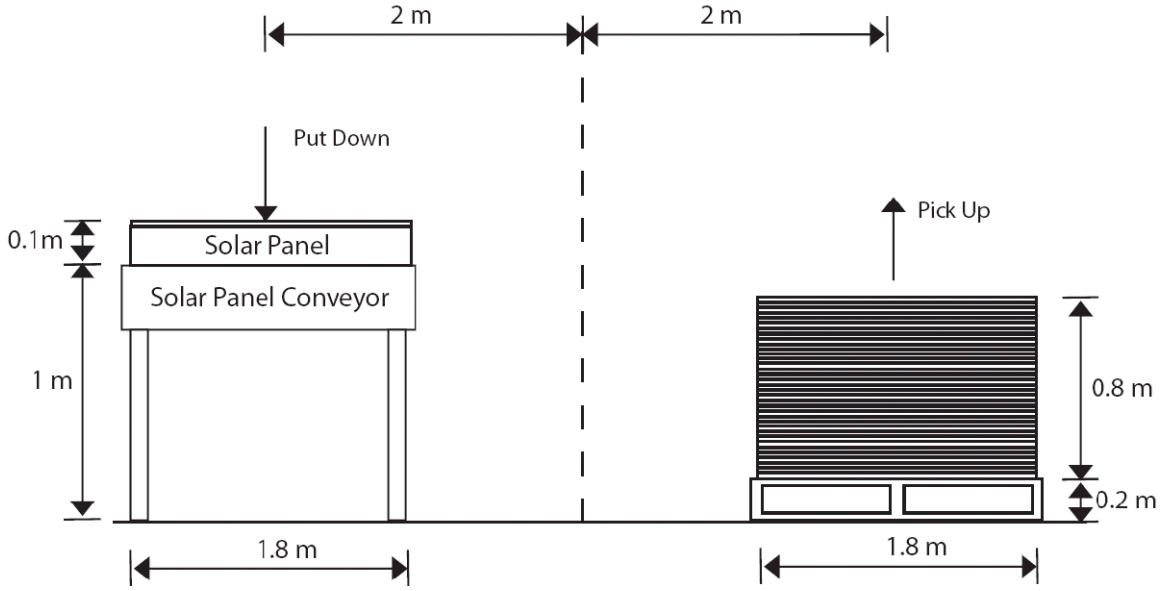
See next page

Question 14 **(15 marks)**

This question refers to Document 3 'IRB4600 Industrial Robot' that is included in the **Document Booklet**.

A robot is to be used to transfer a sheet of glass from a pallet to a conveyor that presents a solar panel pressing. The glass is picked up using a lifting tool with vacuum cups that connect to the end of the robot arm. The robot then places the sheet of glass on top of the solar panel, after which it is clipped into place. The lifting tool should pick up the glass sheet at its mid point.

The following diagram shows the relationships between the stack of glass sheets on the pallet and the conveyor where the solar panels are located for their glass to be added by the robot. The robot is to be positioned so that its centre line is on the dashed line in the diagram.



(a) Given

- Weight of each glass sheet = 5 kg
- Weight of lifting tool = 13 kg
- A safety factor of 2 is to be applied.

(i) Show that the required robot handling capacity must be at least 36 kg. (2 marks)

(ii) Using the data sheet IRB4600, list all robot model variants that will satisfy the payload required. (1 mark)

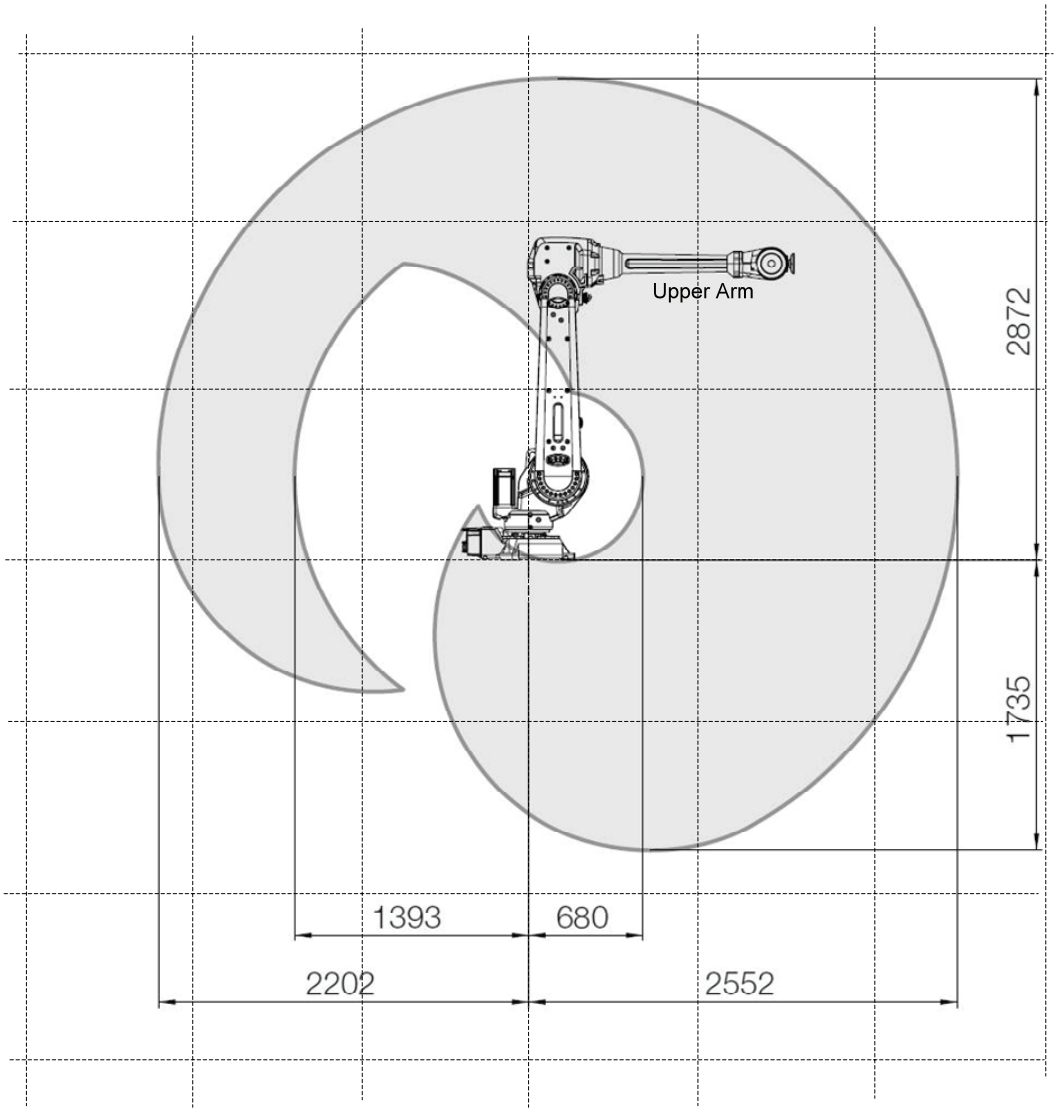
See next page

(b) The following diagram is for IRB 4600-40/2.55, which has been tentatively chosen for the task. The shaded part of the diagram shows the reach of the robot arm. This can be taken as the reach of the centre of the lifting tool in this example application. Since the robot can rotate on its base, this reach diagram can be considered to also rotate about a vertical axis through the centre of the robot. The greater reach as shown on the right-hand side in the diagram can then apply for both for pickup and putdown as the robot rotates through 180°.

The dashed lines are a 1000 × 1000 mm grid that is aligned to the centre of the base of the robot, from which the dimensions are also referenced.

Given the task of picking up a glass sheet from the pallet, it is also reasonable to assume that the upper arm of the robot cannot rotate above a horizontal position (as it is shown in the diagram). If it did, then the lifting tool and perhaps the sheet of glass would clash with the robot arm itself.

While the position of the solar panel on the conveyor is closely controlled, the position of the glass pallet can vary due to the difficulty of placing it with a forklift. It is necessary, therefore, to allow for an error of placement of up to 200 mm on either side of its ideal position. That is, the pallet may be 200 mm closer to, or further away from, the centre line of the robot.



(Partial copy of technical data sheet in **Document Booklet**)

See next page

Your design task is to locate the selected robot in the assembly area to confirm, or otherwise, that it can meet these requirements. You only need to identify one design solution.

For your design solution, sketch and label the following on the diagram on the previous page.

(i) The position of the surface of the floor on which the conveyor and glass pallet are placed.
(ii) The ideal position of the pallet.
(iii) The position of the solar panel ready to have its glass inserted.
(iv) A small circle to indicate the ideal pickup point for the top glass sheet from the pallet.
(v) A small circle to indicate the ideal pickup point for the bottom glass sheet from the pallet.
(vi) A small circle to indicate the putdown point on the solar panel.
(vii) The rectangular region that would include all possible pickup positions.

While the locations and sizes need be approximate only, you should still match the scale of the drawing as best you can with a freehand drawing. (8 marks)

(c) Does your design meet the requirements? Explain your answer. (2 marks)

(d) What options exist in your design for adjusting the height of the robot above the floor level? (2 marks)

End of Section One

See next page

Section Two: Specialist fields **65% (115 Marks)**

Candidates are required to choose one of the following options, according to which specialist field they studied in 2010.

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

Specialist field	✓	Question numbers	Pages
Systems and Control	☐	15–27	**17–33**
Mechanical	☐	28–41	**34–50**
Electronic/Electrical	☐	42–54	**51–68**

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

See next page

Section Two: Specialist field—Systems and Control **65% (115 Marks)**

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

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

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

Suggested working time: 120 minutes.

Part A: Multiple-choice **(10 marks)**

This part has **ten** 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, do not erase or use correction fluid, and shade your new answer. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

Suggested working time: 10 minutes.

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15. To turn ON or OFF a warning light from a microcontroller, you would need to use a

    (a) resistor.
    (b) capacitor.
    (c) relay.
    (d) solenoid.

16. A stepper motor would be best used to

    (a) drive a winch attached to the front of a 4WD (four wheel drive) vehicle.
    (b) operate a stair climbing machine.
    (c) rotate a solar panel a set amount.
    (d) drive a battery operated electric bicycle.

17. The pins that you will find on virtually all integrated circuit devices are

    (a) +5 V and – 5 V.
    (b) ground and earth.
    (c) ground and +5 V.
    (d) 12 V and 5 V.

18. The velocity ratio of a lever is best described as the

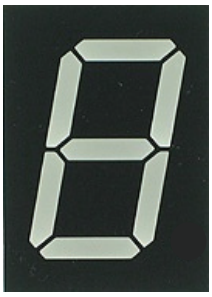
    (a) ratio of the distance moved by the input to the time taken to move the output.
    (b) ratio of the time taken to move the input to the distance moved by the output.
    (c) distance moved by the output divided by the distance moved by the input.
    (d) distance moved by the input divided by the distance moved by the output.

See next page

19. For the control of the speed of a DC motor, PWM stands for

    (a) Pulse Width Modulation.
    (b) Proportional Width Movement.
    (c) Programmed Wired Motor.
    (d) Pulse Wired Motor.

20.



A single 7-segment digital LED display such as that shown above could be used to display, without any confusion,

    (a) any alphabetical character or digit.
    (b) only digits.
    (c) some alphabetical characters and all digits.
    (d) only alphabetical characters.

21. To convert a rotational movement from a motor to the linear movement required for an actuator, you would need to use which one of the following drive mechanisms?

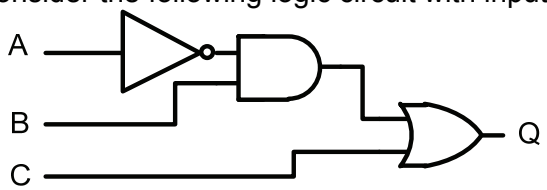
    (a) a rack and pinion gear system
    (b) a belt drive system
    (c) a reduction gear system
    (d) a worm gear system

22. Inputs to a microcontroller are usually conditioned to ensure that

    (a) the voltage levels are at least 5 V.
    (b) the voltage levels are in the range 0 V to +5 V.
    (c) the inputs are electrically isolated from the microcontroller.
    (d) there is a good ground connection.

See next page

23. Consider the following logic circuit with inputs A, B and C, and output Q.



Which one of the following logic expressions best describes this current?

(a) $Q = A \cdot \bar{B} + C$
(b) $Q = \bar{A} \cdot B + C$
(c) $Q = \bar{A} + B \cdot C$
(d) $Q = \overline{(A \cdot B)} + C$

24. In a flow chart, a decision statement is always associated with

(a) a loop in the execution.
(b) a branch in the flow of execution.
(c) a subroutine.
(d) an input operation.

See next page

Part B: Extended answer **55% (105 marks)**

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

Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

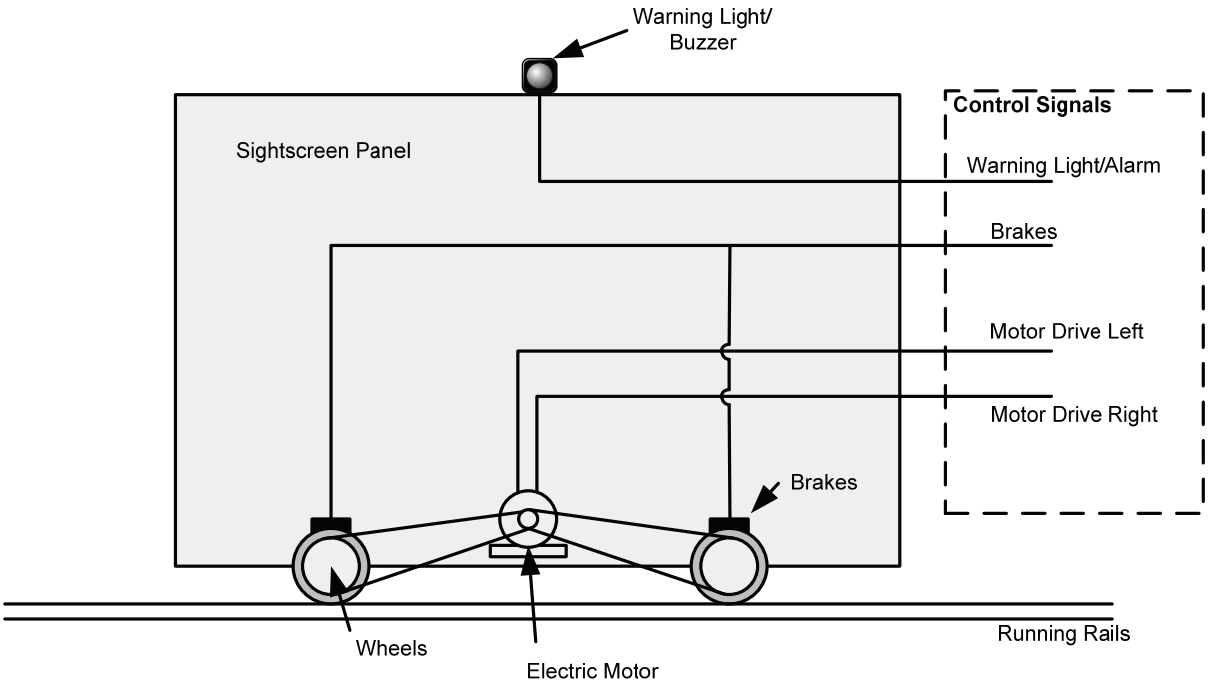
Suggested working time: 110 minutes.

Question 25 **(35 marks)**

You have been asked to advise the operators of your local cricket ground on the design of a new sightscreen. Sightscreens are large rectangular panels that are placed at either end of a cricket ground so that the batsman has a plain background to their sight of the bowler and the ball after it leaves the bowler's hand. Without the sight screen the background might be cluttered with different coloured objects, and even spectators moving about.

Essentially the sightscreen is a large rectangular panel on wheels. It needs to be on wheels so that it can be moved to the left or right, depending on where the bowler chooses to make his/her run-in from. It could be made very large to avoid this problem, but that would mean that a large section of the spectator area would be lost.

The proposed sightscreen will be driven by an electric motor so that it can be easily operated. Here is a schematic view of the sightscreen and its major components.



See next page

The screen will run on two sets of wheels along a prefabricated track just inside the boundary fence. The driving electric motor can be driven forward or backward by two control signals; Motor Drive Left and Motor Drive Right.

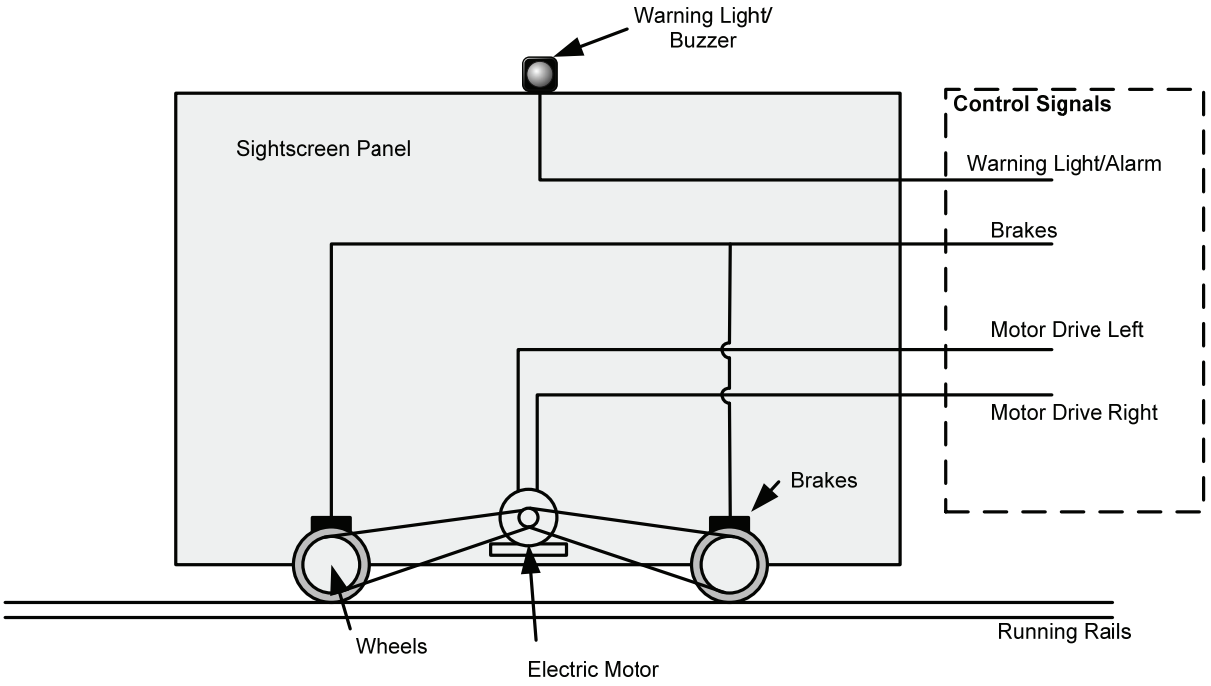
To prevent the sightscreen from moving when it should be stationary, there is an electric brake attached to each wheel. The brakes will also be used to quickly stop the motion of the screen when the motor is turned off. The brakes are activated with the Brakes control signal.

When the screen is actually moving, it is necessary to have a flashing warning light and buzzer operating to warn anyone nearby that it is on the move, as well as to indicate to the players and umpires that the screen is still being moved.

The control signals will be interfaced to a microcontroller and the operator's control box, which will have just two buttons, Move Left and Move Right. Both these are 'push-to-make' switches, i.e. they have to be held down to remain turned on.

(a) The first problem to solve concerns what happens if the operator presses one of the move buttons, then becomes distracted and fails to notice that the screen has run off the end of its rails.

Describe a suitable electronic design solution that would prevent this from happening and explain how it would work. Sketch on the diagram below a schematic representation of your solution, showing and labelling any control signals required.(8 marks)



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(b) The microcontroller chosen will have at least 4 digital input signals and 4 digital output signals. Initially it was agreed that each of the input signals in the system would be connected to an input pin on the microcontroller using a suitable interface conditioner (to ensure that the actual signals were converted to the digital 0 V and 5 V to represent OFF and ON respectively). Similarly, the required output signals (0 V and 5 V) would be connected to suitable driver devices that were capable of providing the voltage/current requirements for the actuator devices.

Provide a sketch of the microcontroller, showing the connections of all required input and output signals. You do not need to be concerned with the conditioning or driver devices.

You can assume that you will need to include signals from the devices used to prevent the screen running past the ends of its running rails (as discussed in part(a)). You can assume that these signals are called LimitLeft and LimitRight . (8 marks)

See next page

(c) The programs in the microprocessor required to move the screen to the left and to the right are very similar. For this part of the question you will consider only the task of moving the screen to the left.

When the power to the sightscreen is turned on, the microprocessor is powered up also, and takes control of the system. Initially the brakes must be activated (turned ON) so that the screen does not move.

When the operator presses the MoveLeft button, the brakes must be released about 0.5 seconds before the power is applied to the drive motor (this provides enough time for the brakes to release fully). Once the power is applied to the drive motor, the warning light/buzzer must be activated.

The screen continues to move until:

(i) the operator releases the MoveLeft button and the power to the drive motor is removed. The brakes must then be applied and the warning light/buzzer turned off; or
(ii) the screen reaches the end of its running rails, and, to prevent damage, the same stopping procedure is followed.

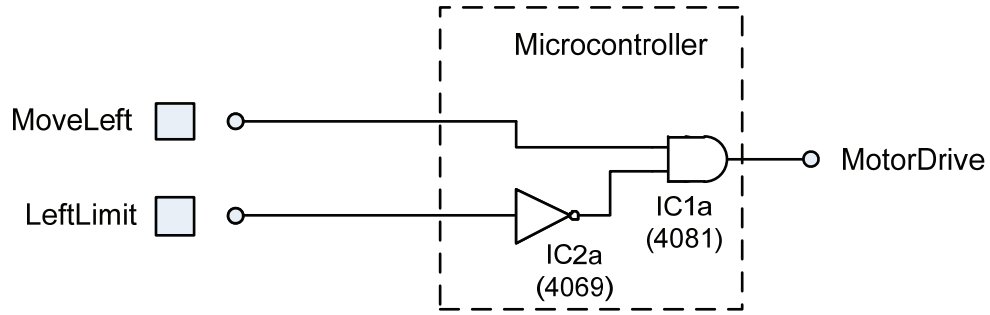
Neatly draw the flow chart for the required program in the microcontroller. (11 marks)

See next page

(d) For the system design, so far we have assumed that the power to the drive motor will be activated when the MoveLeft button is held down by the operator, unless the screen has moved too far and the LimitLeft signal has activated. We can also represent this using the logic diagram below.

In this logic diagram, the MoveLeft signal must be ON, and the LeftLimit signal must be OFF for the MotorDrive signal to be ON. The two logic gates inside the microcontroller box are intended to represent a simplification of the program it is running.

There is some concern about the safe operation of the sightscreen if there is a failure in the microcontroller electronics. It has been decided, therefore, to modify the above diagram to include an extra safety feature that will ensure that if the microcontroller fails, the power to the drive motor will always be turned off if the LeftLimit signal goes ON.



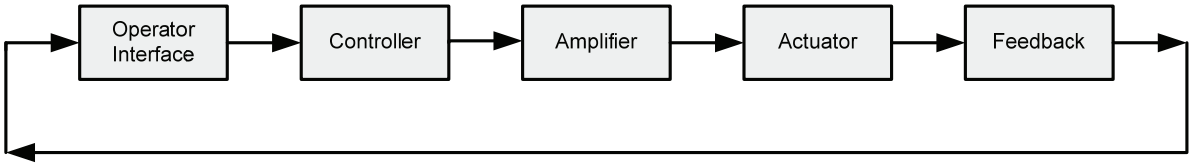
(i) Describe what design changes could be made to the above logic diagram, and how these changes would meet this new requirement. (4 marks)

(ii) Draw your design changes on the above logic diagram. (4 marks)

See next page

Question 26 **(35 marks)**

(a) Most manufacturing systems that involve some sort of motion control can be represented by the following control system block diagram:



Describe the functions of each of these system components: (15 marks)

Operator Interface: _____

Controller: _____

Amplifier: _____

Actuator: _____

See next page

Feedback: _____

(b) In a control system with feedback, the information being returned to the controller indicates that the actuator is providing a response that is less than expected. Explain how you might go about calibrating the actuator for a proportional control strategy that could improve this situation. (5 marks)

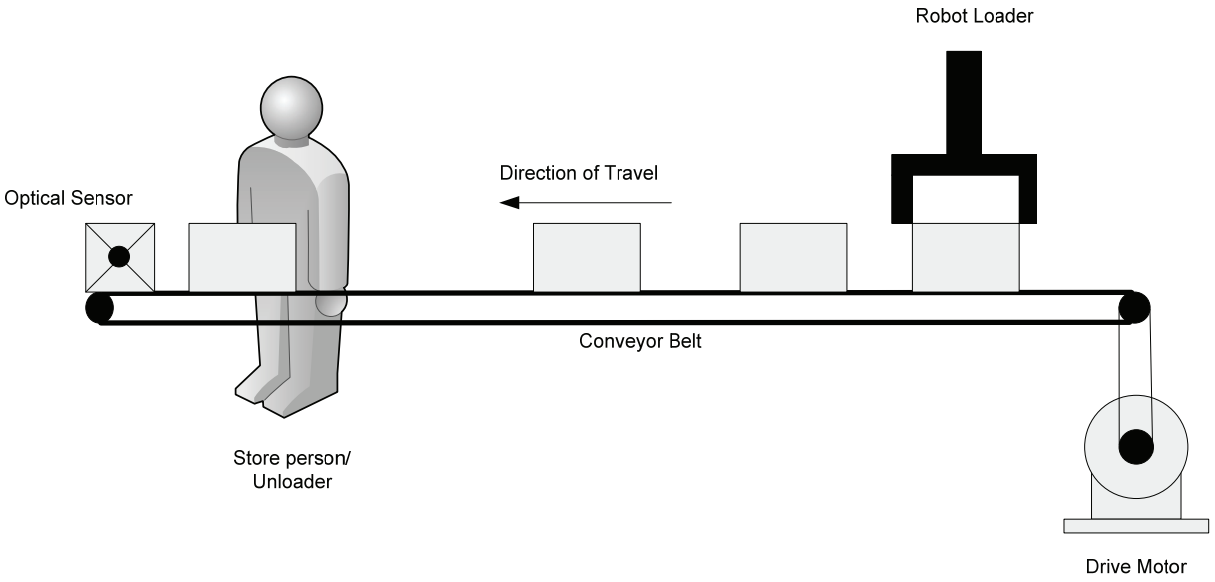
See next page

(c) In a small manufacturing plant, boxes filled with finished products are to be moved from the end of the assembly line to the store room where they will wait until they are required for delivery to customers.

The boxes will be placed on one end of the conveyor by a robot mechanism that will pick each box up when it arrives at the end of the production line and place it on the moving conveyor. At the other end of the conveyor, the boxes will be removed manually (by the staff) and stacked in the store.

If a box reaches the very end of the conveyor before it is unloaded, it will trigger an optical sensor (the box will cause a break in the path of a beam of light).

The following diagram provides a schematic view of the system.



This system will work well except when

- the conveyor stops running (for some reason)
- the boxes have not been removed before they reach the end of the conveyor.

(i) Describe two system control strategies that would prevent these situations occurring. (6 marks)

Strategy one: _____

_____

_____

_____

Strategy two: _____

_____

_____

_____

(ii) Sketch on the above diagram the necessary control signals to show how these two strategies would be integrated into the conveyor system. (3 marks)

See next page

(d) To formally specify the control system, the following list of signals has been provided.

Signal	Input/Output	Description
PowerOn	Input	Is ON if the power to the conveyor motor is on, otherwise OFF.
ConveyorRunning	Input	Is ON when the conveyor belt is moving, otherwise OFF. This sensor detects movement of the conveyor and not the power supplied to the motor.
OpticalSensor	Input	Is normally ON, but OFF if a box passes the end of the conveyor and interrupts the light path.
LoadBox	Output	If ON, the robot loader will operate. If OFF, the loader stops.
WarningLight	Output	Is ON if conveyor is running, otherwise OFF

Construct a logic diagram using standard gate devices that ensures that

(i) the main power switch is ON
(ii) the warning light is on when the conveyor is running
(iii) the robot loader can only operate when the conveyor is running
(iv) the conveyor stops if the optical sensor is interrupted (goes OFF). (6 marks)

See next page

Question 27 **(35 marks)**

(a) Logic circuits can be composed of a range of gate types, e.g. AND, OR, NOT, NAND, NOR, XOR. Describe in words the operation of each of these gate types:

(6 marks)

AND: _____

_____

OR: _____

_____

NOT: _____

_____

NAND: _____

_____

NOR: _____

_____

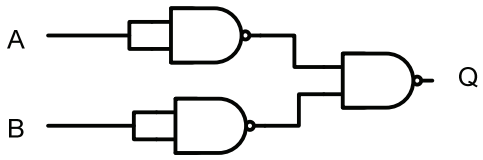
XOR: _____

_____

See next page

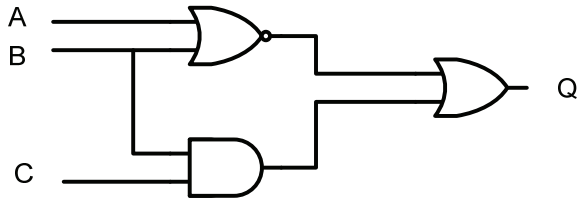
(b) Complete the truth tables (on the right) for the following gate circuits (use 0s and 1s to indicate LOW and HIGH logic levels respectively). A, B, C and D represent inputs, and Q is an output in each case.

(i) (2 marks)



A	B	Q

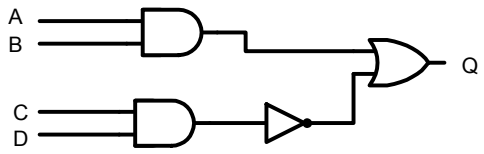
(ii) (4 marks)



A	B	C	Q

See next page

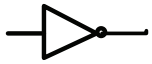
(iii) (8 marks)



A	B	C	D	Q

See next page

(c) It is known that any combination of gates can be replaced by a set of NAND gates that will achieve the same result. For the following single gates, draw the equivalent NAND gate circuit in the following table. (12 marks)

Name	Symbol	Equivalent NAND Gate Circuit
NOT		
AND		
OR		
NOR		

(d) It is sometimes the case that when substituting gates in a circuit with equivalent NAND gates, there will be an increase in the number of gates in the circuit. Explain why it still may be desirable to use circuits composed of only NAND gates. (3 marks)

End of Section Two: Systems and Control

See next page

Section Two: Specialist field—Mechanical **65% (115 Marks)**

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

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

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

Suggested working time: 120 minutes.

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

This part has **ten (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, do not erase or use correction fluid, and shade your new answer. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

Suggested working time: 10 minutes.

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28. Stress-strain graphs produced to estimate the elastic (Young's) modulus for a material show the amount of strain that occurs in the material for a given stress. What type of stress is this referring to?

    (a) hard working
    (b) peer
    (c) bending
    (d) tensile

29. 'Mechanical advantage' is best described as the

    (a) advantage that a mechanical system has over an electronic system.
    (b) ratio of the input force divided by the output force in a mechanical system.
    (c) output force divided by the input force in a mechanical system.
    (d) product of the input and output forces in a mechanical system.

30. Which of the following manufacturing techniques is the easiest way of mass producing complex shapes in an aluminium alloy?

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

31. In which one of the following combinations are both units valid for measuring stress?

    (a) N and kPa
    (b) watt and N
    (c) N m^{-2} and kPa
    (d) mm and kg

See next page

32. ‘Potential energy’ is best described as the energy possessed by an object when it is

(a) able to fall through some distance.
(b) moving at constant velocity.
(c) accelerating with a constant acceleration.
(d) free falling under the influence of gravity.

33. A fatigue failure in a machine component is most likely to have been caused by

(a) lack of lubrication.
(b) excessive temperature.
(c) exposure to water.
(d) repetitive loading.

34. A worker on scaffolding simultaneously kicks a spanner and a bolt. Both fall to the ground below. Ignoring air resistance, which one of the following is true?

(a) Both the spanner and the bolt hit the ground at the same time.
(b) The spanner hits the ground before the bolt.
(c) The bolt hits the ground before the spanner.
(d) There is no way to predict which will hit the ground first.

35. Non-destructive testing **cannot** be used to measure the

(a) elastic modulus of a material.
(b) density of a material.
(c) ultimate strength of a material.
(d) stiffness of a material.

36. Which one of the following sentences is correct?

(a) Wood is a non ferrous but malleable material.
(b) Copper is a non ferrous but malleable material.
(c) Carbon is a ductile and ferrous material.
(d) Brass is a ferrous and non malleable material.

37. You have four identically-dimensioned cylinders made of the following materials:

polypropylene
aluminium
polycarbonate
nylon

Use the **Data Book** to determine which material was used to make the cylinder that weighs the least. This material was

(a) polypropylene.
(b) aluminium.
(c) polycarbonate.
(d) nylon.

See next page

Part B: Extended answer **55% (105 Marks)**

This part has **four (4)** questions. Answer **all** questions. Write your answers in the spaces provided.

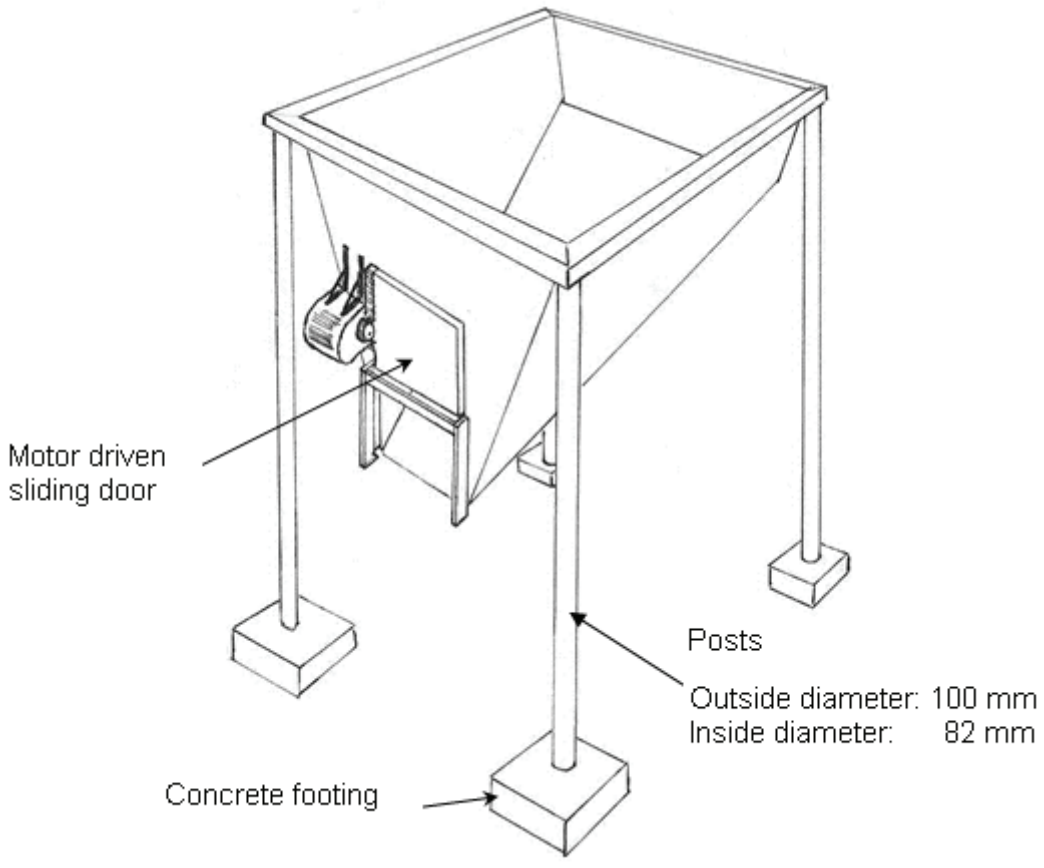
Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

Suggested working time: 110 minutes.

Question 38 **(35 marks)**

The diagram shows a preliminary design study for a hopper to feed iron ore onto an output conveyor for loading onto a transport ship. Ore will be fed into the top of the hopper, and then a sliding door will be used to direct the ore onto the conveyor.



The hopper in the sketch has a mass of 4.5 tonnes (4500 kg) and has a maximum capacity of 145.5 tonnes of ore. The hopper and its frame are supported above the conveyor by circular section tubular posts made of structural steel. Each support post is 3600 mm long and rests on a concrete footing.

See next page

(a) What change could you make to the supporting structure to improve the hopper's ability to sustain horizontal forces caused by wind? Sketch how you would apply your solution on the diagram of the hopper provided on the previous page. (3 marks)

(b) (i) The motor that operates the sliding door has to work against the resistance force provided by the ore. When the hopper is full this force has an average value of 62.5 kN. The door must be able to close an opening of 800 mm in a time of 10 s. Determine the minimum power rating required for this motor. (3 marks)

(ii) Explain why the value that you determined in (b)(i) above is a **minimum** power rating. (3 marks)

See next page

(c) (i) Show that each post carries a load of 367.5 kN when the hopper is full. Assume that the total weight of the hopper and its load of ore is distributed equally to each of the support posts. (3 marks)

(ii) Show that the maximum stress in each support post is approximately 142.8 N mm^{-2}. (5 marks)

(iii) Hence, determine the maximum stress in each concrete footing. (1 mark)

See next page

(d) Assuming that the elastic modulus for structural steel under compression has the same value as when it is under tension, determine the maximum change in length of the support post. (6 marks)

(e) (i) The factor of safety for the compressive stress of the concrete footing is specified as 3. With reference to the **Data Book**, show that the safe working stress for the contact between each post and its concrete footing is approximately 13.3 N mm^{-2}. (4 marks)

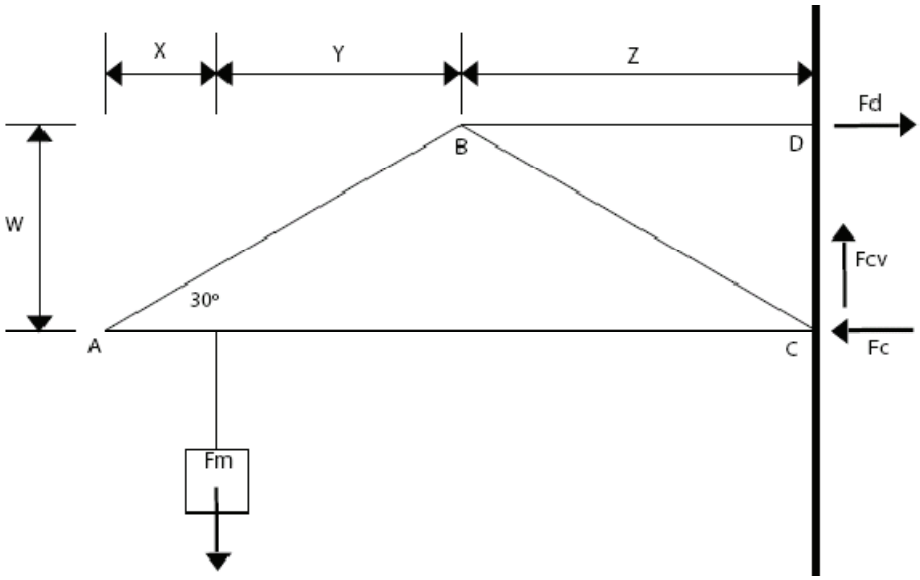
(ii) Explain why it is not recommended to rest the support posts directly on the concrete footing. (2 marks)

See next page

(iii) Sketch a way to make the contact point between each support post and its footing more suitable, and explain how your solution would work. (5 marks)

See next page

Question 39 **(21 marks)**



(a) The pin-jointed truss shown above has pin connections attaching it to the wall at points D and C.

Show that the horizontal reaction forces at D and C both have a magnitude of $\frac{F_M(z+y)}{w}$. (6 marks)

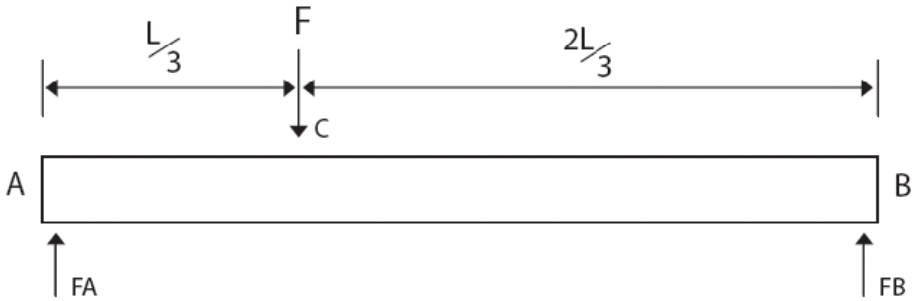
(b) From observation in the above truss, indicate whether the forces in the following members are in tension or compression. (3 marks)

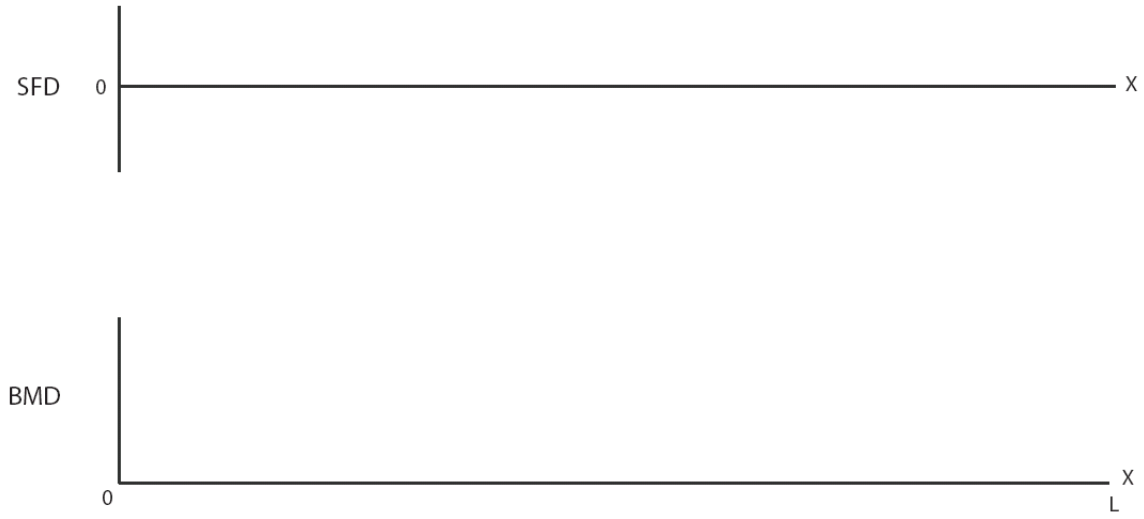
Member BD _____

Member AB _____

Member BC _____

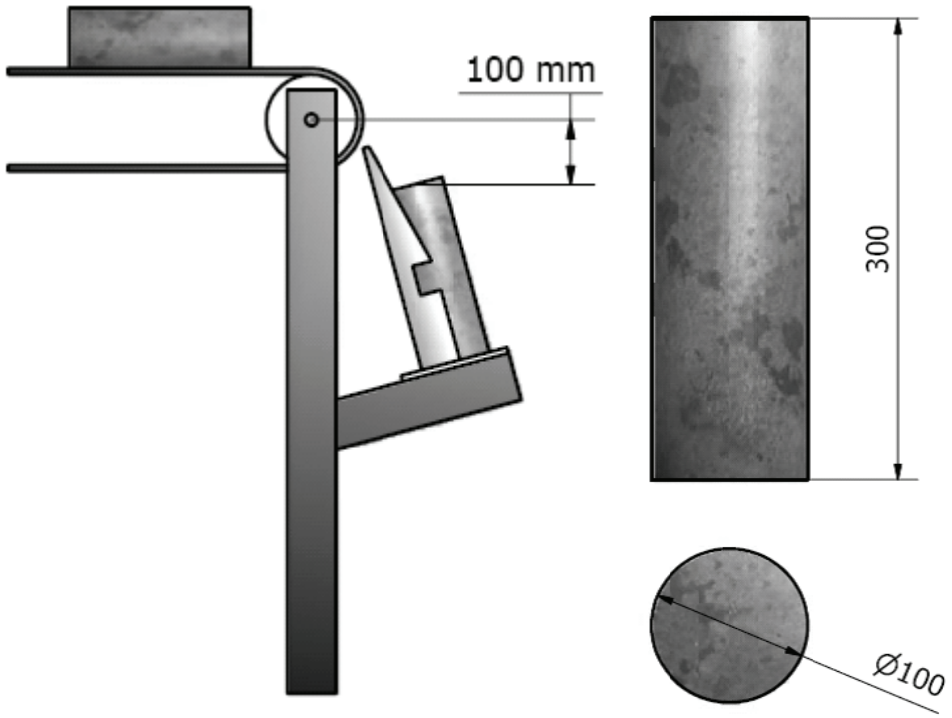
(c) Calculate the necessary values and use the axes on the next page to sketch the shear force and bending moment diagrams for the following beam. Label all the key values in terms of the applied force F and the length of the beam L. (12 marks)





See next page

Question 40 **(30 marks)**



(a) The above system shows a conveyor transporting a cylindrical steel billet. The billet is shown in detail on the right. At the end of the conveyor, the billet transfers into a chute for pickup by a robot for packaging.

When the billet comes to the end of the conveyor it rotates as the conveyor passes around the drive wheel, then free falls a distance of 100 mm into the chute.
The density of the steel billet is 7860 kg m^{-3} and the conveyor's linear speed is 0.5 m s^{-1}.

(i) The velocity of the billet when it hits the chute is about 1.49 m s^{-1}. Calculate the kinetic energy that the chute bracket absorbs when the billet hits the chute.

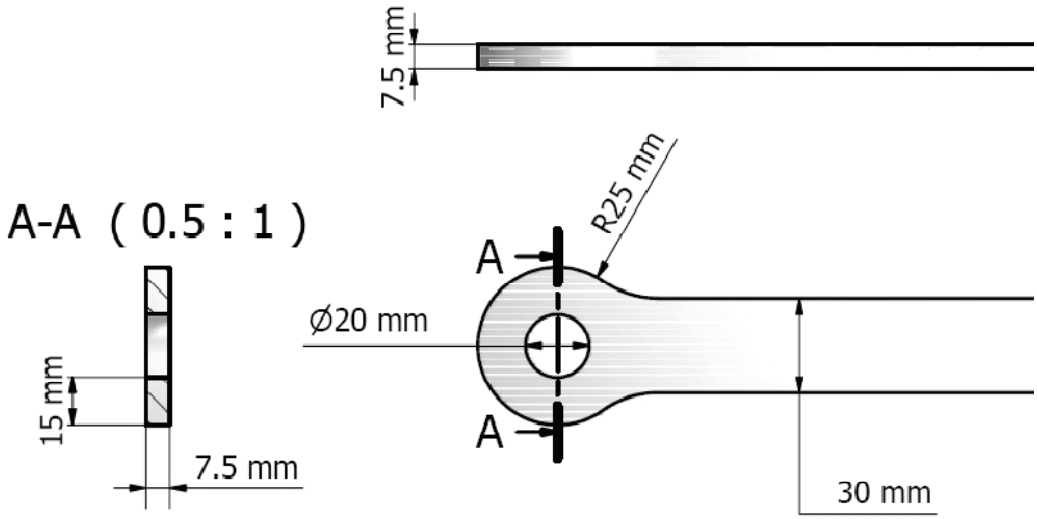
(6 marks)

See next page

(ii) Given that the chute will be subjected to repeated impact loading, what is the name given to material failure that can occur under these conditions? (2 marks)

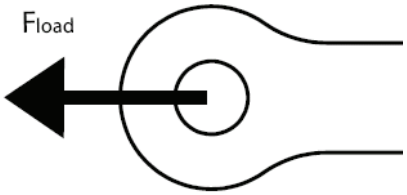
(iii) Describe **four (4)** special precautions that you, as the designer, would need to take to ensure the long term safe operation of the chute and its mounting bracket. (8 marks)

See next page



(b) The above diagram shows the lug at the end of a connection rod used to transfer tensional load through a building structure.

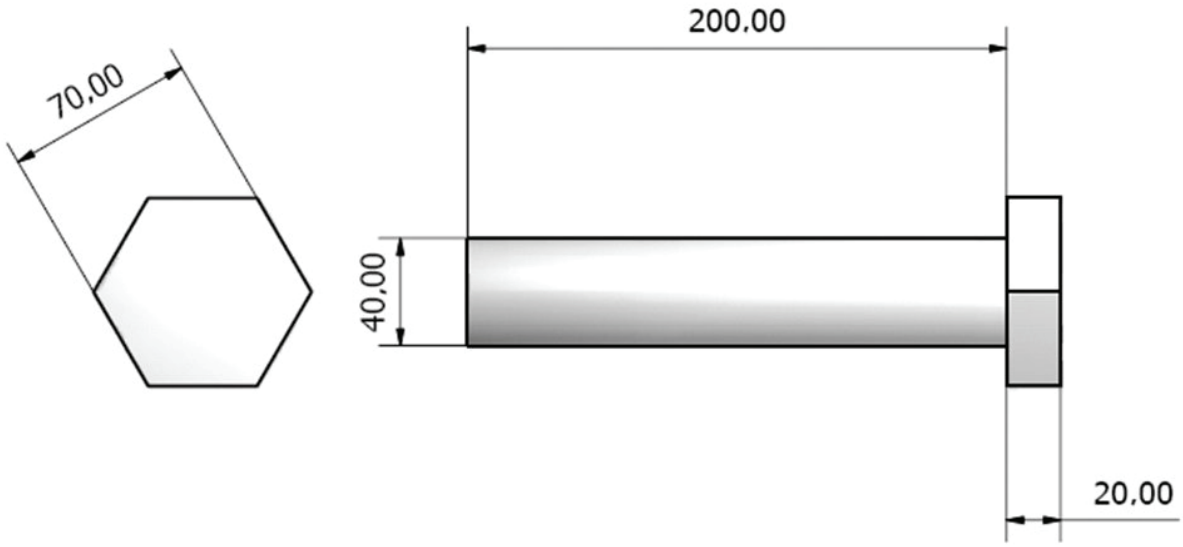
(i) If the lug has a force of 50 kN applied as shown below, calculate the stress in the section of the lug shown in view A-A. (4 marks)



(ii) Given that the material of the rod has an ultimate stress of 400 MPa, calculate the safety factor that applies to this section of rod. (2 marks)

(iii) Suggest a design change that could be used to improve the safety factor. (2 marks)

(c) The steel machine component shown below is made from a cold-drawn steel bar of Ø 40 mm. The hexagonal head is formed by upset forging.



(i) Give **two (2)** reasons why upset forging is preferred to CNC machining for manufacturing this component. (4 marks)

One:

Two:

(ii) State **two (2)** structural changes that would occur in the steel as a result of the forging process. (2 marks)

One: _____

_____

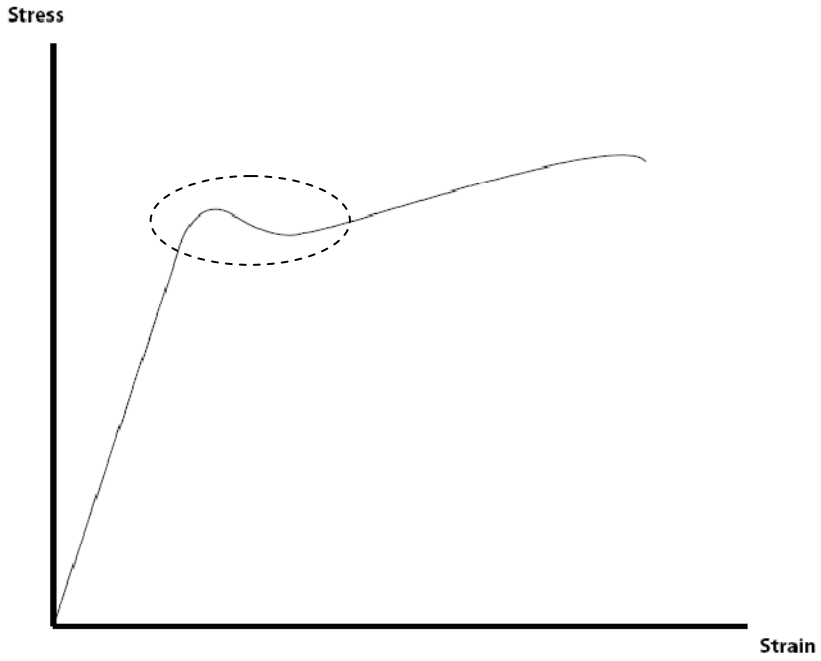
Two: _____

_____

See next page

Question 41 **(19 marks)**

Below is a stress-strain diagram for typical structural grade steel material. The dashed oval is referred to in part (b).



(a) Label on the diagram the following areas or interest (3 marks)

(i) elastic limit
(ii) ultimate tensile stress point
(iii) breaking stress point.

(b) Explain what is happening to the material being tested in the region of the graph marked by the dashed oval. (5 marks)

See next page

(c) Explain the behaviour of the material when it is taken past its breaking stress point. (3 marks)

(d) Material that is stressed past its elastic limit and the stress then removed does not return to its original state.

(i) What is the name given to the type of deformation that occurs? (2 marks)

(ii) If the material was exposed to the same stresses a second time, would the same stress-strain graph be observed? Explain your answer. (4 marks)

(e) What is the name given to the ratio of the ultimate tensile stress to the safe working stress? (2 marks)

End of Section Two: Mechanical

See next page

Section Two: Specialist field—Electronic/Electrical **65% (115 Marks)**

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

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

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

Suggested working time: 120 minutes.

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

This part has **ten (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, do not erase or use correction fluid, and shade your new answer. Marks will not be deducted for incorrect answers. No marks will be given if more than one answer is completed for any question.

Suggested working time: 10 minutes.

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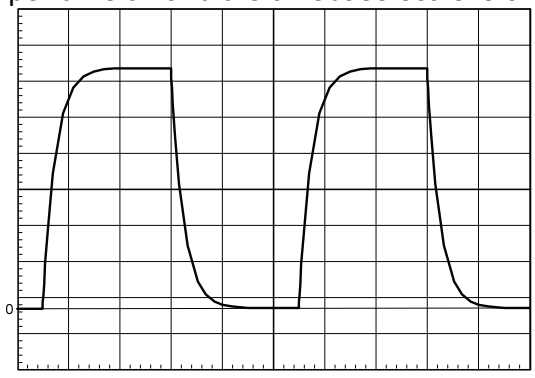
42. A Darlington pair uses two NPN transistors, each having a current gain of 80. The approximate current gain of the pair is

    (a) 80.
    (b) 160.
    (c) 6400.
    (d) 40.

43. Which one of the following statements is **not** true of an ideal capacitor?

    (a) A capacitor stores charge on two plates that are separated by a dielectric material.
    (b) A capacitor stores energy in an electric field between two plates.
    (c) A capacitor blocks the flow of constant electric current.
    (d) A capacitor voltage drop is proportional to the current that flows through it.

44. A periodic waveform is displayed on an oscilloscope as shown in the figure below. The amplitude scale is 1 V per division and the timebase scale is 5 ms per divsion.



The frequency of the waveform is approximately

    (a) 40 Hz.
    (b) 80 Hz.
    (c) 200 Hz.
    (d) 20 Hz.

See next page

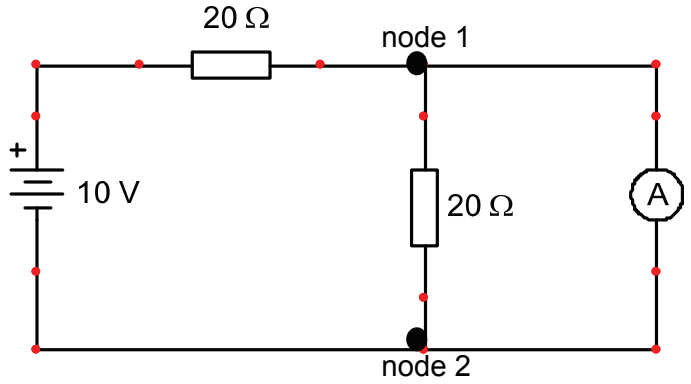
45. In the symbol for a bipolar junction transistor (BJT), the terminal that is distinguished by an arrow is called the

(a) base.
(b) emitter.
(c) collector.
(d) anode.

46. A 100 nF capacitor is connected in parallel with a 10 nF capacitor. The overall capacitance value is

(a) 9.09 nF.
(b) 90 nF.
(c) 110 nF.
(d) 1000 nF.

47. A multimeter is set to measure current. The leads of the multimeter are placed across two nodes of a circuit, as shown in the following figure:



The value measured by the current meter will be

(a) 5 V.
(b) 0 A.
(c) 0.25 A.
(d) 0.5 A.

48. A transistor amplifies an AC signal by

(a) converting DC power from a power supply into AC power.
(b) supplying additional electrons from its space-charge layer.
(c) generating additional power in a chemical reaction.
(d) heating the wires so that the electrons move faster.

See next page

49. A resistor is connected across the terminals of an ideal voltage supply, and dissipates a certain amount of power. A second resistor of equal value is now connected in parallel with the first resistor. The power dissipated by the first resistor

(a) increases.
(b) decreases.
(c) stays the same.
(d) cannot be determined without knowing the values of the resistors and the voltage supply.

50. The joule is a unit of

(a) potential difference.
(b) electrical power.
(c) electrical energy.
(d) charge.

51. Kirchoff's Voltage Law is based on the

(a) conservation of energy.
(b) conservation of charge.
(c) conservation of momentum.
(d) conservation of the environment.

See next page

Part B: Extended answer **55% (105 Marks)**

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

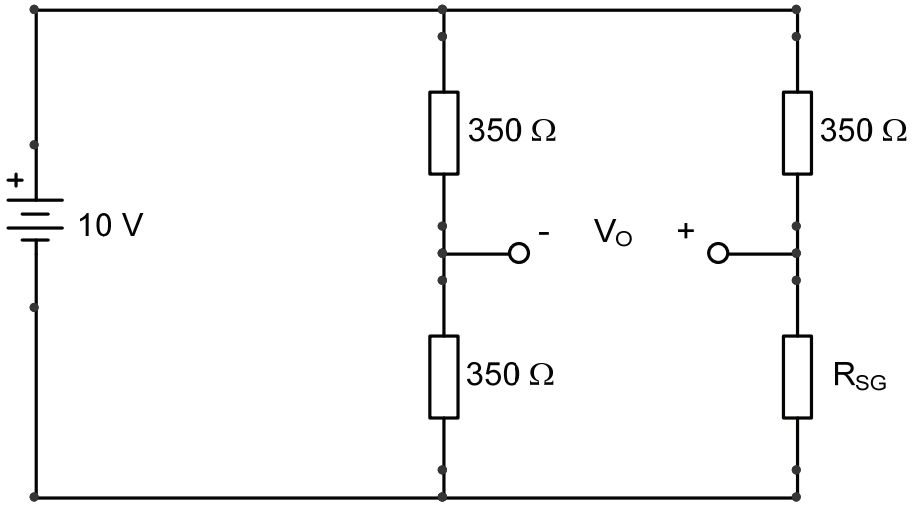
Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

- Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
- Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question(s) that you are continuing to answer at the top of the page.

Suggested working time: 110 minutes.

Question 52 **(35 marks)**

(a) A resistance combination called a Wheatstone bridge is shown in the figure below. The resistor R_{SG} is a strain gauge. Under no strain conditions, the strain gauge resistance is 350 Ω. In a certain application, the resistance of the strain gauge may vary over the range 320 Ω to 380 Ω.

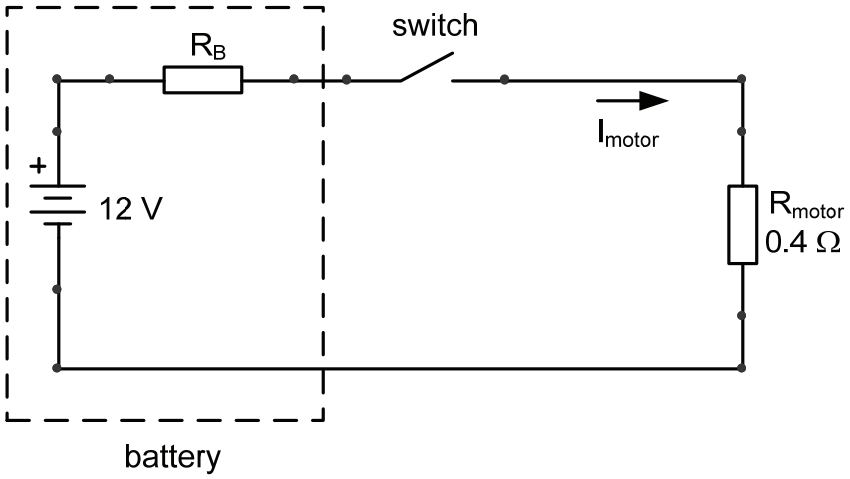


(i) Determine the voltage across the output terminals of the bridge, V_O, under conditions of no strain. (3 marks)

See next page

(ii) When the strain gauge resistance is 380 Ω, what is the new voltage across the output terminals of the bridge, V_O? (4 marks)

(b) A lead-acid battery is used to supply start-up current to a motor when a switch is closed, as shown in the figure below. The battery is represented by an ideal 12 V source in series with a resistance given by R_B = 0.05 Ω; the motor is represented by a 0.4 Ω resistor.



(i) When the switch is closed, what is the current supplied to the motor, I_{motor}? (3 marks)

(ii) When the switch is closed, what is the power dissipated by R_{motor}? (2 marks)

See next page

(iii) When the switch is closed, what is the power supplied by the ideal 12 V source?
(2 marks)

(iv) The lead acid battery is replaced by eight standard flashlight batteries connected in series. Each flashlight battery can be represented by an ideal 1.5 V source in series with a resistance of 20 Ω. The circuit for this new arrangement is the same as that given above, except that there is a new value for R_B. Find the new value for R_B, and then find the new motor current I_{motor} when the switch is closed.
(5 marks)

See next page

(c) A person is standing in a electrical substation when an electrical fault occurs. This fault causes a current of I_{fault} = 30 000 A to flow along the floor of the substation to an earth point. This situation is shown in Figure A, where the person and the floor are represented by resistive networks. The critical current is the current that flows through the heart, I_h.

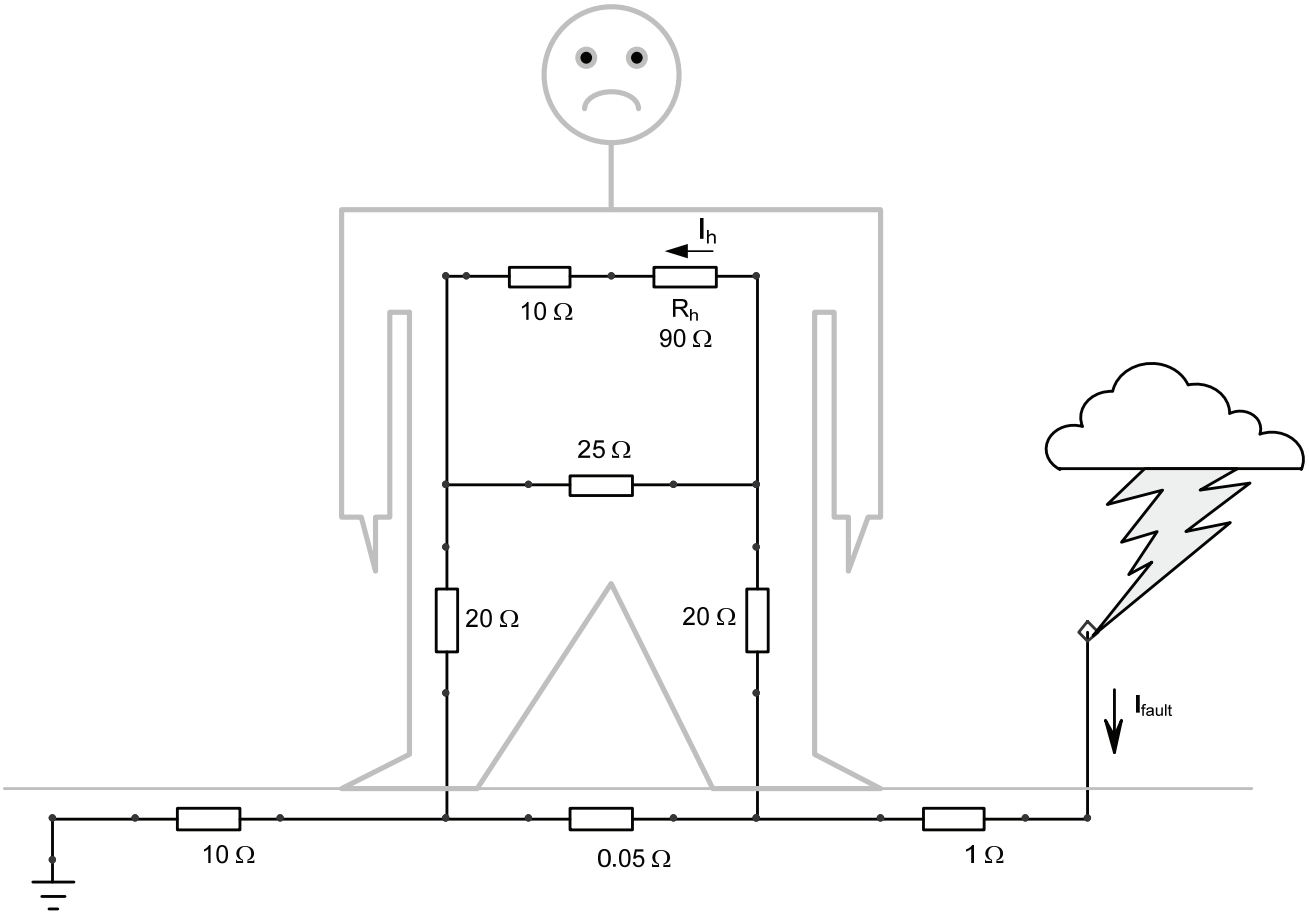


Figure A

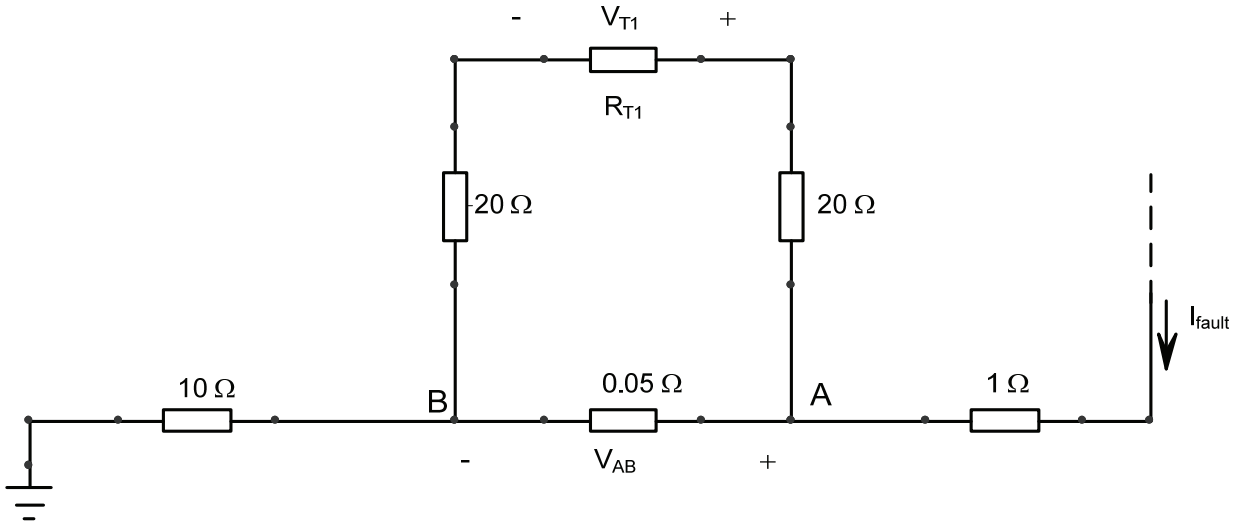


Figure B

See next page

(i) The circuit in Figure A can be simplified using an equivalent resistance R_{T1}, as shown in Figure B.

Show that the value of the equivalent resistance R_{T1} is 20 Ω. (3 marks)

(ii) The circuit can be further simplified by using equivalent resistance R_{T2}, as shown in Figure C.

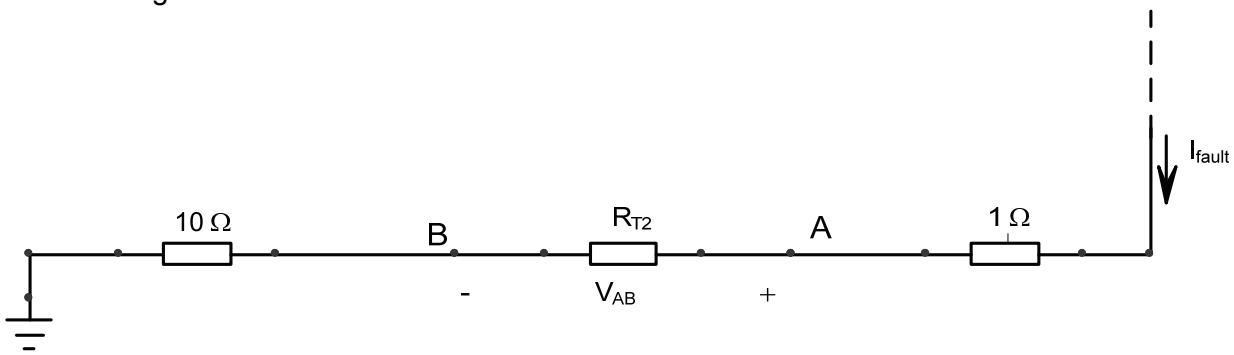


Figure C

Show that the value of the equivalent resistance R_{T2} is 0.05 Ω. (3 marks)

(iii) From the circuit in Figure C, and the result from (ii), show that the voltage V_{AB} is about 1500 V. (In substations, this voltage is called a step potential.) (2 marks)

(iv) From the circuit in Figure B, and the result from (iii), show that the voltage V_{T1} is about 500 V. (3 marks)

See next page

(v) From the circuit in Figure A and the result from (iv), find the heart current I_h.
(2 marks)

(vi) If the person were to take a bigger step while the fault current was flowing, would the heart current increase, decrease or stay the same? Justify your answer.
(3 marks)

Current: _____

Reason: _____

_____

_____

_____

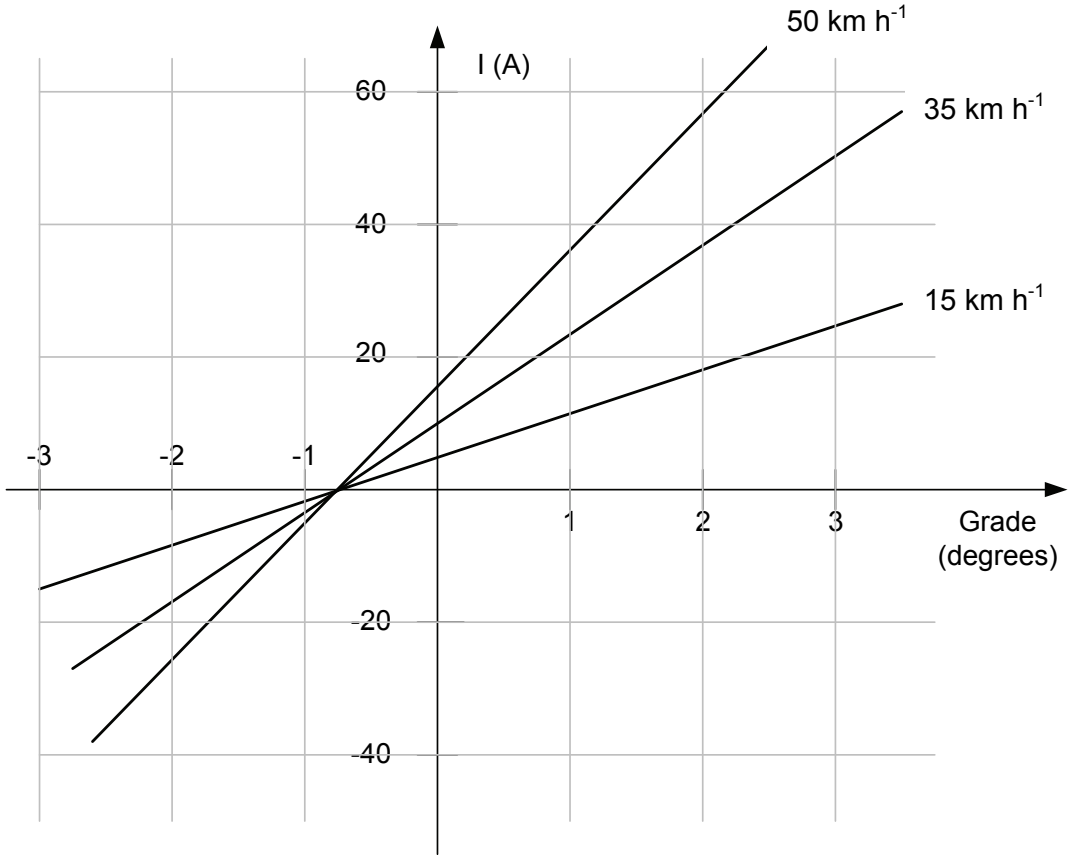
_____

_____

See next page

Question 53 **(35 marks)**

(a) The voltage applied to the DC motor of a tram is constant at 4800 V. However, the current drawn by the motor depends on the steepness of the roadway, as shown in the graph below.

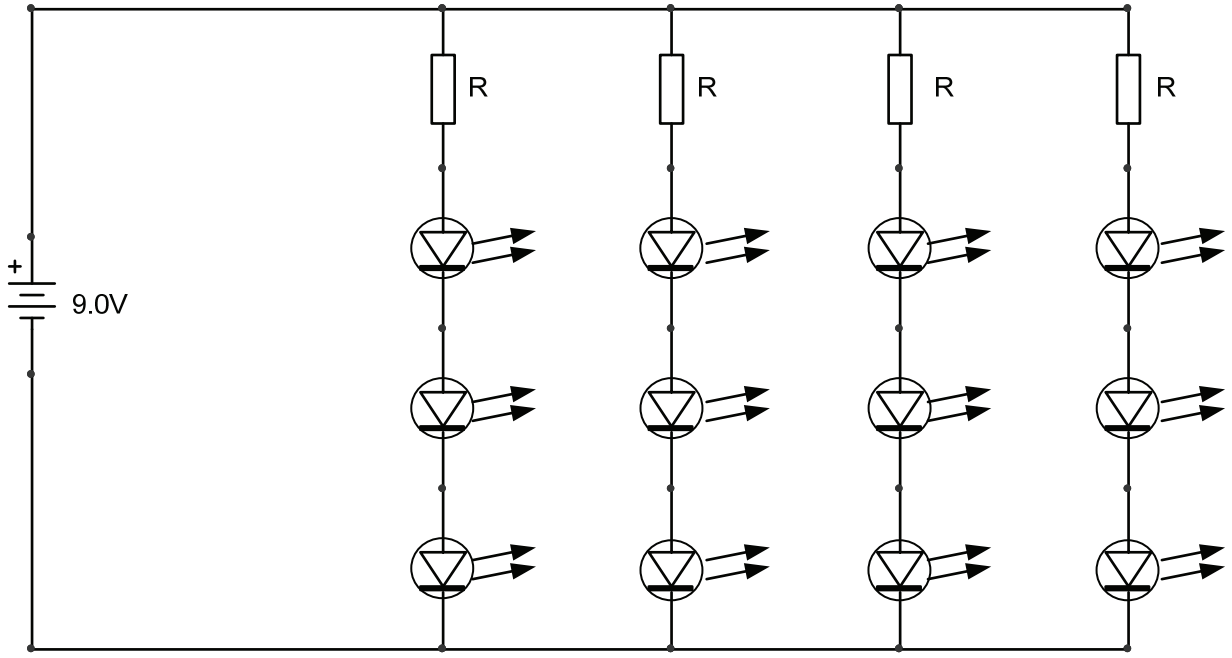


(i) Find the power consumption when the tram is travelling on a level roadway at 35 km h^{-1}. (3 marks)

(ii) When the tram is going downhill, the motor can generate power and return it to the power line, which is a process known as 'regenerative braking'. Find the power generated when the tram is going downhill at a 2° angle at 50 km h^{-1}. (3 marks)

See next page

(b) The circuit shown in figure below represents a circuit of a 12-element traffic-light. The circuit is designed so that the current in each light-emitting diode (LED) is 15 mA. Under these conditions the voltage drop across each LED is 1.5 V.

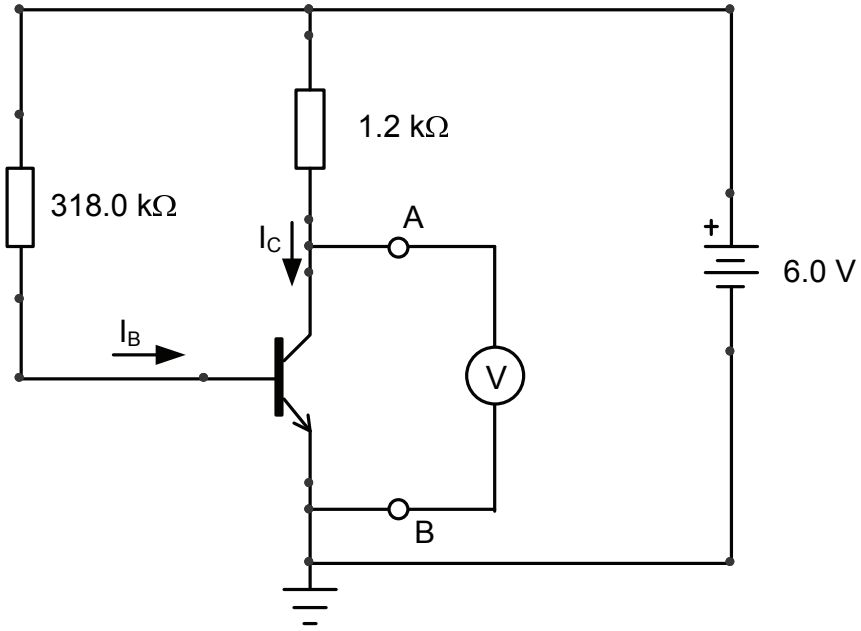


(i) Find the required value for resistor R. (3 marks)

(ii) Find the power supplied by the 9 V source. (3 marks)

See next page

(c) The transistor used in the circuit shown below has an on-voltage of $V_{BE,on}$ = 0.7 V and a saturation voltage of $V_{CE,sat}$ = 0 V, but the current gain h_{FE} is unknown.



A voltage meter connected across the terminals A and B records a voltage of 3.0 V. Use this measured value and the known transistor model parameters to calculate the values for

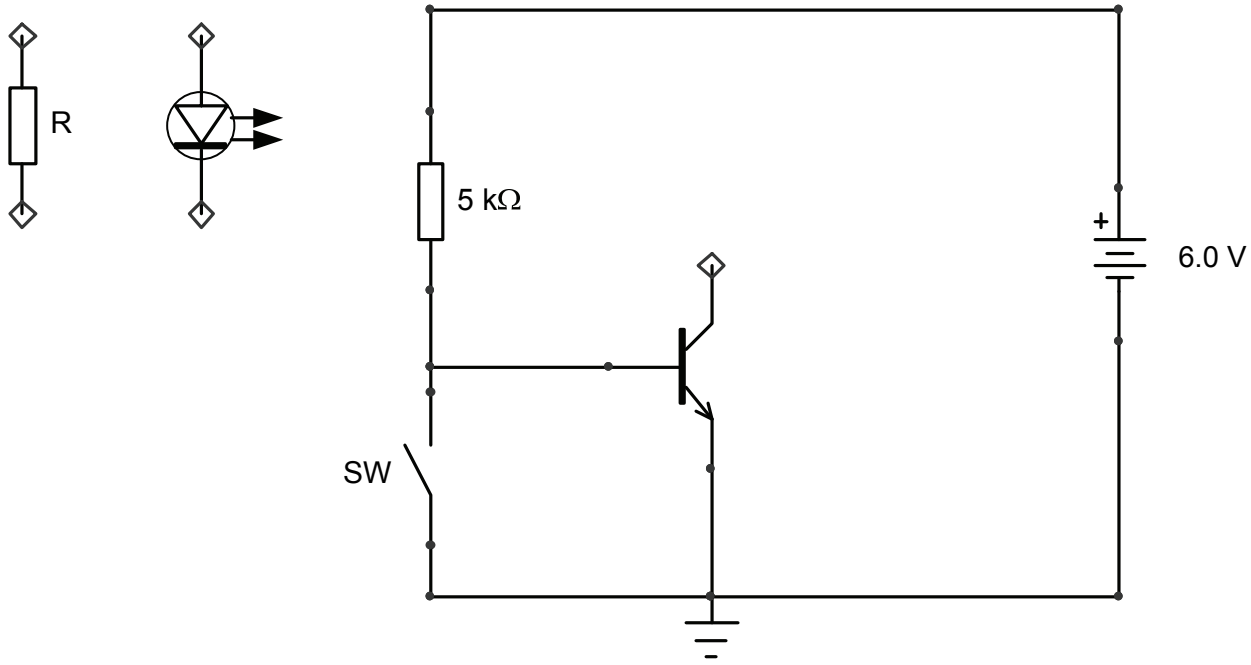
(i) the collector current I_C . (2 marks)

(ii) the base current I_B . (2 marks)

(iii) the current gain of the transistor, h_{FE}. (2 marks)

See next page

(d) A part of a circuit used to turn a LED on and off is shown in the figure below. The transistor model parameters are $V_{BE,on}$ = 0.7 V, $V_{CE,sat}$ = 0 and h_{FE} = 100. When the diode is turned **on**, it will have 15 mA flowing through it, and its voltage drop will be V_D = 1.5 V. Assume that when the transistor is turned on, it will operate in its saturation region. It is required that the LED be turned **on** only when the switch SW is **closed**.



(i) Complete the circuit by connecting a resistor R and the LED into suitable positions in the above diagram (draw the two components in their correct positions in the circuit). (4 marks)

(ii) What is the required value for R? (3 marks)

See next page

(e) Part of a full-wave rectifier stage for a power supply is shown in Figure A below. The waveforms for the source voltage V_S and the required output voltage V_O are shown in Figure B. (Note the direction of the voltage drop V_O.)

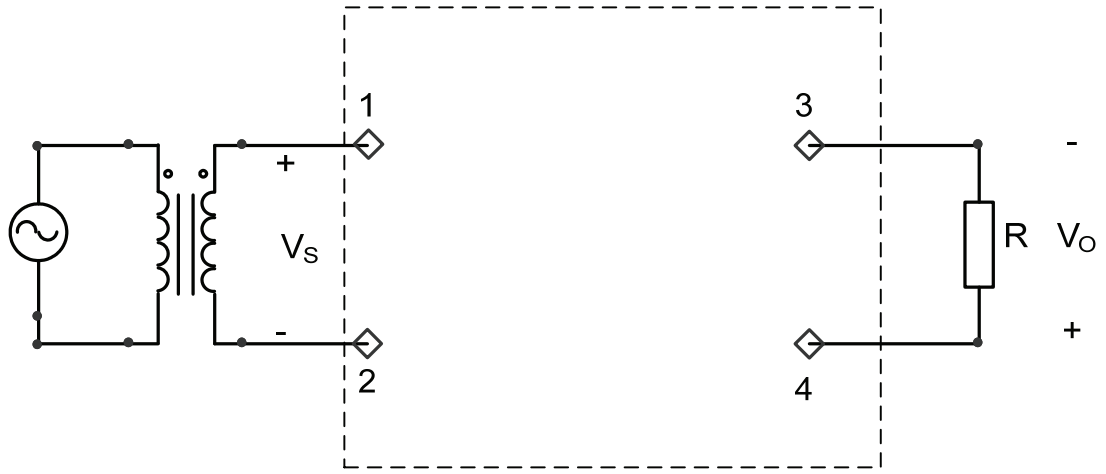


Figure A

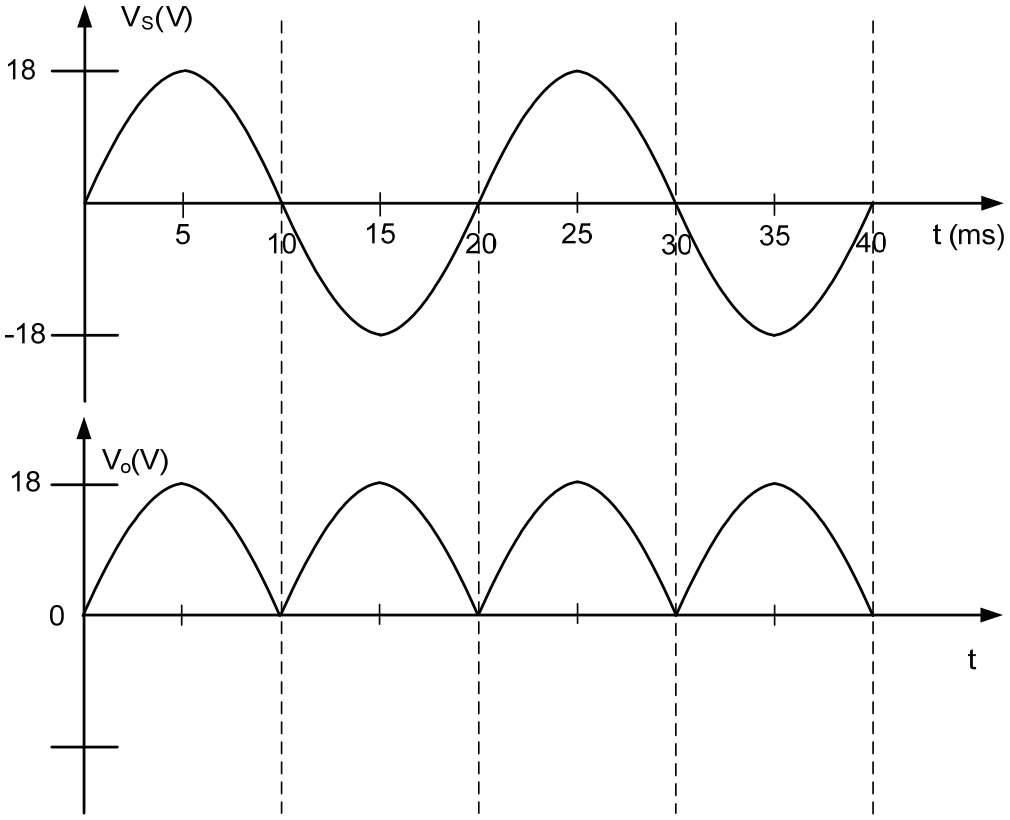


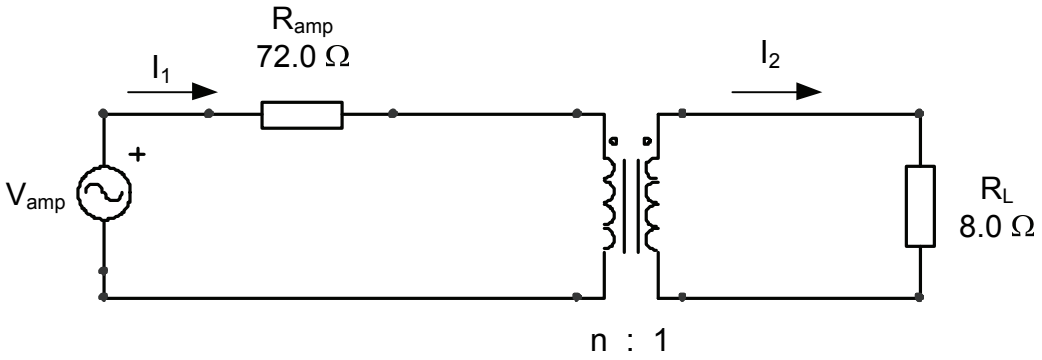
Figure B

(i) On Figure A, complete the rectifier design by adding diodes into the circuit. In the circuit, it should be clear how the diodes are attached to terminals 1, 2, 3 and 4, and the direction of each diode between its respective terminals. (4 marks)

(ii) A capacitor can be added to the rectifier circuit in order to smooth out the variations in output voltage. On Figure A, add a capacitor to the circuit in order to perform this smoothing operation. Show clearly which terminals are connected to this capacitor. (2 marks)

See next page

(f) The figure below shows the output of an amplifier (represented by the voltage source V_{amp} and resistor R_{amp} = 72 Ω) that transfers power to an 8 Ω loudspeaker through a transformer. The transformer turns ratio chosen is such that the power dissipated in the resistor, which is given by $I_1^2 R_{amp}$, is equal to the power dissipated in the loudspeaker, which is $I_2^2 R_L$.

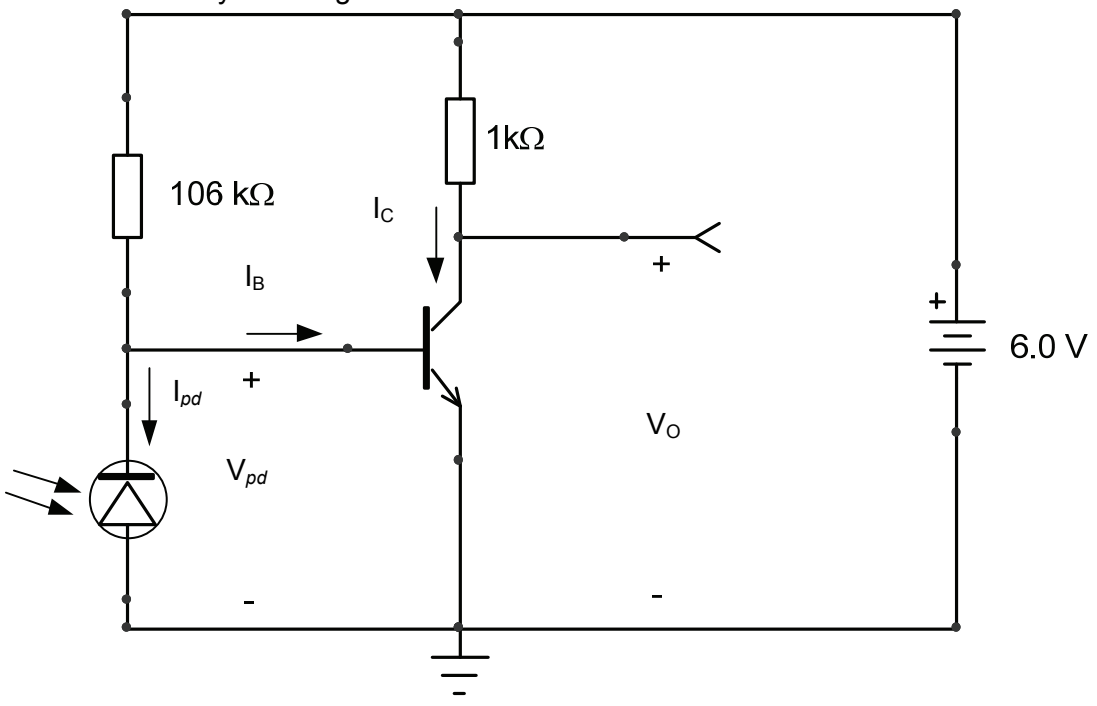


What is the required value for the turns ratio n? (4 marks)

See next page

Question 54 **(35 marks)**

The circuit shown in the figure below is used to convert variations in light into variations in voltage. The circuit uses a transistor with model parameters $V_{BE,on}$ = 0.7 V, $V_{CE,sat}$ = 0 V and h_{FE} = 100. A photodiode is used to convert the incoming light into a current I_{pd} such that I_{pd} is proportional to the intensity of the light.



(a) Assuming that the transistor is turned on, what is the voltage drop across the photodiode, V_{pd}? (2 marks)

(b) If the circuit is placed in a dark room, so that I_{pd} = 0, then calculate

(i) the base current I_B. (3 marks)

(ii) the collector current I_C. (2 marks)

See next page

(iii) the output voltage V_O. (3 marks)

(c) If light shining on photodiode generates a current of I_{pd} = 20 μA, then recalculate:

(i) the base current I_B. (4 marks)

(ii) the collector current I_C. (2 marks)

(iii) the output voltage V_O. (3 marks)

(d) If the light is too bright, the circuit will no longer operate correctly.

(i) Why will the circuit no longer operate correctly? (5 marks)

See next page

(ii) What value of I_{pd} will place the circuit at the boundary of correct/incorrect operation? (5 marks)

(e) The original transistor is replaced by a second transistor. The new transistor has model parameters of $V_{BE,on}$ = 0.7 V, $V_{CE,sat}$ = 0 V and h_{FE} = 200.

When the circuit is placed in a dark room so that I_{pd} = 0, what is the transistor's operating region? Justify your answer. (6 marks)

Operating region: _____

Reason: _____

End of Section Two: Electronic/Electrical

End of questions

Additional working space

Additional working space

Additional working space

Additional working space

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Additional working space

ACKNOWLEDGEMENTS

Section One: Core content

Question 14 Image adapted from: ABB. (2010). *IRB 4600 Industrial Robot*. Retrieved August, 2010, from www05.abb.com/global/scot/scot241.nsf/veritydisplay/bb308d55e31aa0d0c125772e005859ca/$File/IRB%204600%20ROB0109EN_E.pdf .

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