BOARD OF STUDIES
NEW SOUTH WALES

1999 HSC
Engineering Science
Enhanced Examination Report

Published by
Board of Studies NSW
GPO Box 5300
Sydney NSW 2001
Australia

Tel: (02) 9367 8111
Fax: (02) 9262 6270
Internet: http://www.boardofstudies.nsw.edu.au

March 2000

ISBN 0 7313 4450 2

2000113

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1999 HIGHER SCHOOL CERTIFICATE ENGINEERING SCIENCE ENHANCED EXAMINATION REPORT

Introduction

The Enhanced Examination Report replaces the standard HSC examination report in selected subjects. It contains additional information, and, in this report, includes marking criteria, candidate responses and detailed examiners comments on aspects of questions asked in both the 2/3 Unit Common and 3 Unit Additional Engineering Science HSC Examinations. Some solutions by candidates have been included to highlight points made by markers.

In 1999 approximately 1395 candidates sat for the 2/3 Unit Common Examination, and 163 candidates sat for the 3 Unit Examination. This year, as in previous years, the top 2 Unit result was achieved by a 3 Unit candidate.

The majority of candidates attempted all questions required. Some candidates displayed outstanding knowledge by their comprehensive and complete answers. This was a great encouragement to the markers, to see candidates who were fully prepared for the examinations. The standard of the candidates appears to be similar to previous years.

Procedures for HSC Marking

The Marking Process

The complete 2/3 Unit Common Engineering Science Examination is split into Sections I and II. Section I is marked in Newcastle and Section II, along with the 3 Unit paper, is marked in Sydney. The markers are carefully selected from experienced teachers and university lecturers and are appointed to mark a specific question which relates to their area of expertise.

The Examination Committee presents a set of answers to the Supervisor of Marking for consideration. A meeting, between the Examination Committee, the Supervisor of Marking and the Senior Markers is held to discuss and confirm the best answer for each question. The HSC markers further develop the range of accepted responses and marking scales for each question by pilot marking a range of scripts. The marking scales are examined and confirmed by the Supervisor of Marking before the actual marking commences.

During the marking, questionable responses are analysed and discussed with the Senior Marker, and an appropriate mark is awarded. The Supervisor of Marking overviews the marking process to ensure the scales are correctly used and that all candidates' responses are marked fairly. Marking scales may include checklists and concept lists. As the marking proceeds, each marker keeps a tally of the marks awarded for the question they are marking. These marker tallies are statistically examined each day and are used as a check, along with systematic checkmarking by the Senior Marker, to ensure the accuracy of the marking procedure. During the marking, control scripts are circulated for marking to ensure the reliability of the marking to the agreed marking scales. The marking is monitored to ensure that the first candidate response marked receives the same consideration as the last.

A correct solution for each question is contained in this report. It is impossible to provide a full range of answers for publication for any one question, as there are often many methods and combinations possible in providing a solution. For example, candidates may commence with an analytical solution, use a part graphical solution and revert to an analytical solution to calculate an answer. Similarly, candidates may use auxiliary views, rebattment, or independent constructions to find true lengths of lines, all of which may provide the same solution. The marking scales are designed to provide flexibility, and to allow for alternative methods at arriving at a solution and to fairly discriminate between the Engineering Science candidates.

A report is also prepared with marker comments and marking scales for the information of the Engineering Science HSC Examination Committee. This is used by the Examination Committee to review and refine setting of questions for the following year's examination.

This enhanced report includes comments on the responses given by candidates made by Markers and Senior Markers and includes some part solutions given by candidates.

Allocation of Marks

Some general principles on the allocation of marks within each question are given below. They may be helpful in understanding how the marking scales are determined.

General

- A N/A (Not Attempted) is awarded when there is no evidence (blank response) to any part of the question.
- A zero is awarded to an answer which is not blank and which deserves no marks in the marking scheme.
- Emphasis is placed on working when marks are allocated.
- Where possible marks are allocated on the basis of degree of difficulty and to reward each correct response.
- Marks are attributed to correct and accurate use of terminology.
- Conflicting information given in an answer is penalised.
- Restating or rewording the information given in the question is not acceptable.
- Marks are awarded rather than subtracted (positive response).
- Candidates are expected to write sentences in response to questions that ask for definitions, descriptions or explanations. If the question asks the candidate to state, or list, then keywords are rewarded and a sentence is not expected.

Materials

- When assessing diagrams, micro or macrostructures or graphs, it is expected that they should reasonably reflect accepted practice of drawing such diagrams.
- When labels are applied to drawings they should be concise and specifically related to the diagram.
- Emphasis is to be placed on concepts/methods used.

Engineering Mechanics

- Concept errors are not awarded marks, however, errors made in one part of the question, and carried forward to the next part of the same question, are not penalised twice. In Mechanics, providing the error carried forward does not make the answer any easier, then no penalty is applied.
- No marks are awarded for restating a formula given on the formulae sheet.
- Calculation errors are only applied once in a solution to a question.
- Correct answers where no working is found are given full marks.

- An incorrect answer with no working is awarded no marks.
- $g = 10\ m/s^2$ or $g = 9.8\ m/s^2$ are both acceptable for gravity.
- Graphical solutions are acceptable in deriving solutions in mechanics.
- The use of measurements (angles and distances) from scaled drawings in questions is acceptable.
- When more than one solution is shown, and one is crossed out, the solution not crossed out is marked.
- When one solution is given and crossed out, the solution is marked.
- When two solutions are given, one right and one wrong and an answer is not placed in the space provided then marks awarded are at the discretion of the Senior Marker and Supervisor of Marking.
- It is acceptable for candidates to change the units on the paper, providing it conforms to SI standards. For example, 1200N changed to 1.2 kN. Otherwise, units as indicated in the answer statement must be given.

Graphics

- Projections in graphics questions should not be erased, as these often display the method used in solving the problem. Marks are awarded for correct methods/concepts.
- Sectioning, linework and general standards related to Graphics are to conform to AS1100.
- Unless requested in the question, labels for plotted points are not required.
- Evidence of calculating true lengths in triangulation problems should be expected. Analytical calculations are acceptable, but not encouraged.
- In intersection problems, end points and change-over points should be clearly shown. Joining points in correct order completes the 'visibility' of the view. Visibility is an important component of all orthogonal drawings.
- Evidence of recognised technical drawing construction methods is required for all solutions to Graphics problems.

Additional comments are included in the comments with each question.

Advice to Candidates:

Candidates will notice on reading the enhanced report that examiners and markers recommend that more time be spent in examining a range of components of the Prescribed Topics. It is obvious from responses that many candidates have not examined, in any depth, all aspects of these topics. For example, when studying the bicycle, as well as analysing the overall machine, examine component parts such as spokes, handlebars, rims, brake components and centre bracket components.

Looking back over a number of past papers, components become the theme for many questions, particularly in Section II of the examination paper. Physical examination, sketching a shape description, sectioning to reveal threads and details, microstructural examination, formal drawing of aspects of components, discussion on manufacture, properties, service properties, materials used, mechanical operation or requirements, will ensure a better prepared candidate.

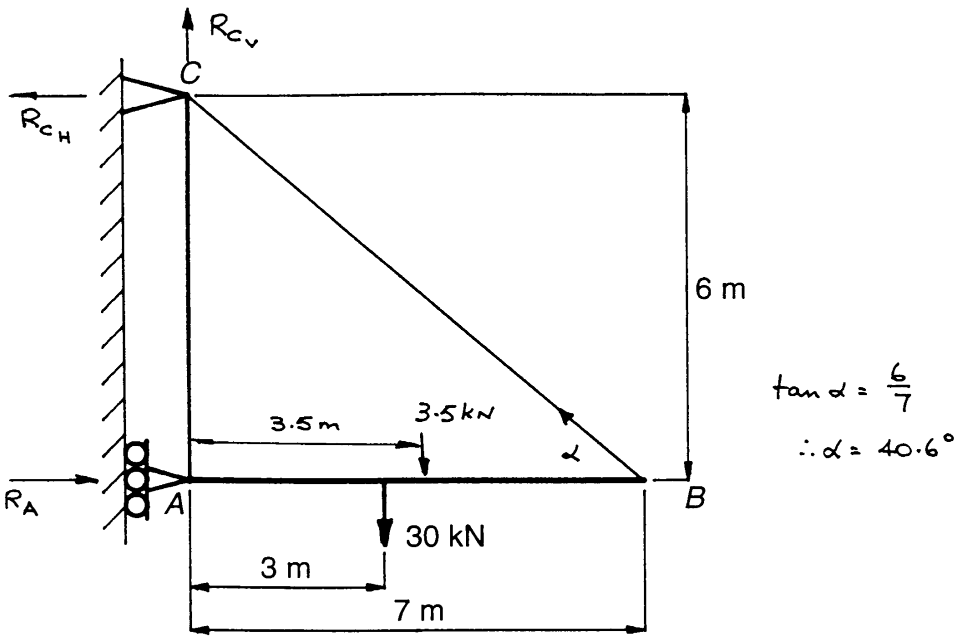
2/3 Unit Common

Section I

Question 1

This was a good question, testing a broad range of concepts and challenging most candidates. The more able had little difficulty in obtaining full or near full marks.

A simple jib-crane truss is shown in the figure below. The crane assembly is connected to a vertical wall by a pin support at C and a roller support at A. The beam AB has a mass of 50 kg/m acting through the centre of the beam. Members AC and BC are relatively light, round cables and their mass should be ignored.



(a) *For one set of conditions, a vertical load of 30kN is applied to the beam AB at a point 3 metres to the right of A.*

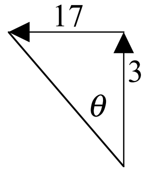
(i) *Determine the reactions at the supports A and C*

Weight of beam = 50 _ 10 _ 7
= 3500 N
= 3.5 kN (at mid point)

$(R_A \times 6) - (30 \times 3) - (3.5 \times 3.5) = 0$

$\therefore + \Sigma M_C = 0$

$R_A = \dfrac{102.25}{6} = 17 \text{ kN}\rightarrow$



$+\uparrow \Sigma v = 0$

$R_A - 30 - 3.5 = 0$

$\therefore R_{c_v} = 33.5 \text{ kN}\uparrow$

$+\rightarrow \Sigma H = 0$

$R_c = \sqrt{(17)^2 + (33.5)^2}$
$= 37.6$ kN

$\theta = \tan^{-1} \dfrac{33.5}{17}$
$= 63°$

$17 - R_{C_H} = 17$ kN←

Answer: Magnitude of Reaction at A 17 kN. Direction →

Magnitude of Reaction at *C* 37.6 kN. Direction 63º

The most common error in this question was the omission of the weight force. Candidates had to read the question carefully to use the 50 kg/m data in calculating the weight force. In many cases candidates relied only on the diagram for data, and incorrectly simplified the problem.

The following solution is typical of this error.

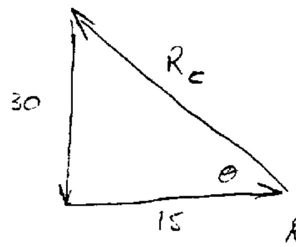
(a) For one set of conditions, a vertical load of 30 kN is applied to the beam *AB* at a point 3 metres to the right of *A*. $4\frac{1}{2}$ 4

(i) Determine the reactions at the supports *A* and *C*.

$\Sigma M_C = 0$

$30 \times 3 = R_A \times 6$

$R_A = 15$ kN →



$\theta = \tan^{-1}\left(\frac{30}{15}\right)$

$= 63.43°$

$R_C = \frac{15}{\cos 63.43°}$

$= 33.54$ kN

#1

Magnitude of reaction at *A* ......15........ kN. Direction ....Horizontally →....

Magnitude of reaction at *C* ...33.54..... kN. Direction ....63.43°....

Other common errors included:

The point of application of the weight force not being in the centre of the beam AB.

Considering the reaction of the wall only occurring at C, and therefore omitting the horizontal Reaction at A.

Although taking moments about C is not incorrect, it often caused confusion later in the question.

Candidates should be encouraged to use a more systematic approach to the analytical solution of this type of question. Few (if any) candidates attempted a full or graphical solution.

(ii) Determine the magnitude and nature of the axial force in member BC.

$+ \Sigma M_c = 0$

(F_{BC} sin 40.6° _ 7) – (30 _ 3) – (3.5 _ 3.5) = 0

$\therefore F_{BC} = \frac{102.25}{4.65} = 22.5$ kN(T)

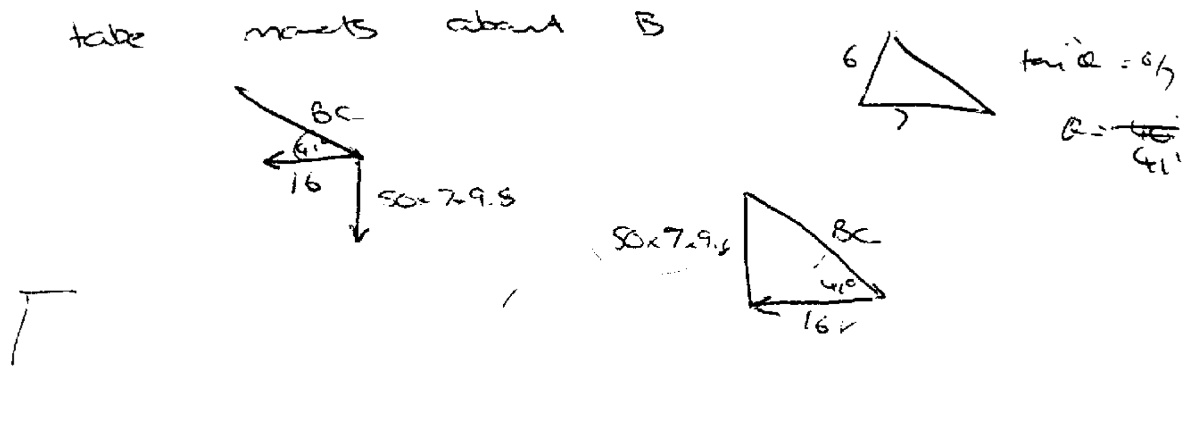
Answer: Axial force in member BC 22.5 kN

Nature of axial force in member BC tension

This question was not well understood by the majority of candidates even though several methods (both graphical and analytical) could be used in its solution. The concept of an axial force was not well understood by many candidates.

Incorrect responses were many and varied with most candidates obtaining part marks, such as in the following example.

(ii) Determine the magnitude and nature of the axial force in member *BC*. 2



Axial force in member *BC* .....54.55..... kN

Nature of axial force in member *BC* .....T.....

The nature of the force (tension), although answered correctly by the majority of candidates, gives some cause for concern, particularly when the question states that CB is a light round cable.

(b) The 30 kN force is moved to joint B. Select the most appropriate term: increase, decrease or remain the same, to complete the following sentences.

Answers: *(i) The axial force in member BC would increase*

(ii) The horizontal component of the reaction at A would increase

This question was generally well done by the majority of candidates, indicating they understood the basic concept of 'moments'. Candidates who gave an incorrect response might benefit from a practical approach, using spring balances and a string, to demonstrate the concept of moments.

(c) For another set of conditions, the maximum working axial force in the diagonal member BC is 53 kN. The steel used in the member has a yield stress of 300 MPa. Using a factor of safety of 1.5, determine the minimum diameter of member BC.

$$FS = \frac{\sigma \text{ yield}}{\sigma \text{ working}}$$

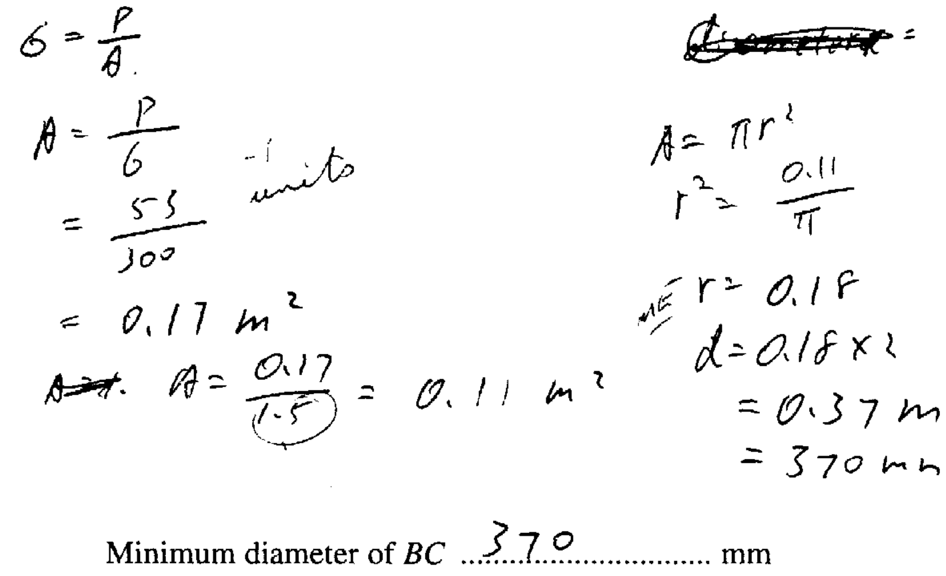
$$1.5 = \frac{300}{\sigma \text{ working}}$$

$$\sigma \text{ working} = \frac{300}{1.5} = 200 \text{ MPa}$$

σ	=	$\dfrac{P}{A}$	A	=	$\dfrac{\pi d^2}{4}$
200	=	$\dfrac{53 \times 10^3}{A}$	d^2	=	$\dfrac{4 \times 265}{\pi}$
$\therefore$ A	=	265 mm^2	$\therefore$ d	=	18.4 mm

Answer: Minimum diameter of *BC* 18.4 mm

The greatest single cause of errors in this question appeared to be due to poor setting out and organisation of the answer, such as the example following:



$\sigma = \dfrac{P}{A}$

$A = \dfrac{P}{\sigma}$ -1 units

$= \dfrac{53}{300}$

$= 0.17\ m^2$

~~Ans~~. $A = \dfrac{0.17}{1.5} = 0.11\ m^2$

$A = \pi r^2$

$r^2 = \dfrac{0.11}{\pi}$

$r = 0.18$

$d = 0.18 \times 2$

$= 0.37\ m$

$= 370\ mm$

Minimum diameter of *BC* ..370.......... mm

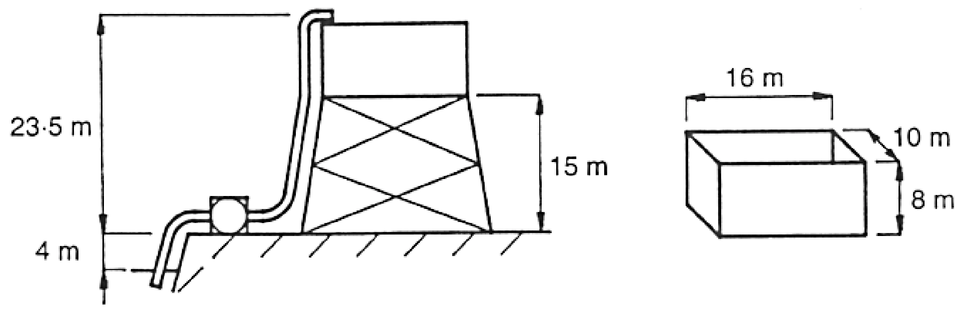
A more systematic and organised approach would have benefited many candidates. Other common errors included:

- Poor or no understanding of the factor of safety. If the material has to be used safely, the working stress has to be less than the yield stress of the material. The amount that it needs to be lower is governed by the factor of safety.
- Use of incompatible units or direct substitution of given values into formula (stress = load/area).
- Incorrect manipulation of formulae and simple algebraic errors.

It is interesting to note that this question was similar in structure and concept to Question 1 in 1998. Obviously candidates who spend time revising past HSC examinations can obtain considerable benefit.

Question 2

(a) *A pumping system and water tank are shown below. (The dimensions of the water tank are also given.) The pump draws water from the river and supplies the tank. The tank sits on a frame 15 m above the ground.*



(i) *Determine the work done to pump the water from the river to half-fill the tank. (1 cubic metre of water has a mass of 1000 kg.)*

Volume of water = $16 \times 10 \times 4$

= $640\ \text{m}^2$

Mass of water = 640×10^3 kg

PE = mgh

= $640 \times 10^3 \times 10 \times 27.5$ h = 23.5 + 4

= 176×10^6 J   = 27.5 m

Answer: Work done 176 MJ

This part of the question was well attempted by the majority of candidates. The most common and successful approach involved using potential energy to calculate the work done. Other candidates used the work formula to arrive at a solution. Candidates had to realise that the pump had to raise the water 23.5 m + 4 m, and was independent of the redundant 15m and half-tank height.

Calculating and halving the volume of the tank to determine the correct mass of water to be lifted was carried out effectively, using the data given.

Two good solutions are given below:

= Fs.   Volume tank = $16 \times 10 \times 8 = 1280\ \text{m}^3$.

$\frac{1}{2}$ fill = $640\ \text{m}^3$.

= 640 000 kg.

$\therefore F = 64 \times 10^4 \times 9.8$

$= 6.276 \times 10^6$ N.

$S = 4 + 23.5 = 27.5$ m.

4

$\therefore W = 6.276 \times 10^6 \times 27.5$

$= 172.48 \times 10^6$ J

Work done ....172.48.... MJ

PE = mgh.
= ?
= $640 \times 10^3 \times 9.8 \times 27.5$
= 172,480,000
= 172.48 MJ.

V = $16 \times 10 \times 8$
= $1280 \div 2$
= $640 m^3$.
∴ m = 640×10^3 kg.

Work done ......172.48...... MJ

Areas that caused difficulty were:

– Determining the correct height from the three dimensions given on the diagram.
– Failing to use a value for g in the equations.
– Converting the final answer from joules to mega joules

(ii) The tank is to be half-filled with water in 25 minutes. Determine the power required of the pumping system if it has an efficiency of 70%.

$$P = \frac{W}{t} = \frac{176 \times 10^6}{1500} = 117.3 \text{ kW}$$

$$t = 25 \text{ min} = 25 \times 60 \text{ s} = 1500 \text{ s}$$

$$\eta = \frac{\text{output}}{\text{input}}$$

$$\frac{70}{100} = \frac{117.3}{\text{input}}$$

$$\therefore \text{Input power} = \frac{117.3}{0.7} = 167.6$$

Answer: Power required 167.6 kW

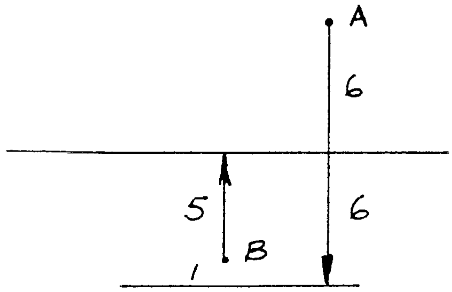
The majority of candidates were able to calculate the power required by transferring the previous answer into the correct equation. Candidates who incorrectly answered part (a) and carried the data into this part of the question, were not penalised in this part of the question.

A small number of candidates failed to convert time to seconds.

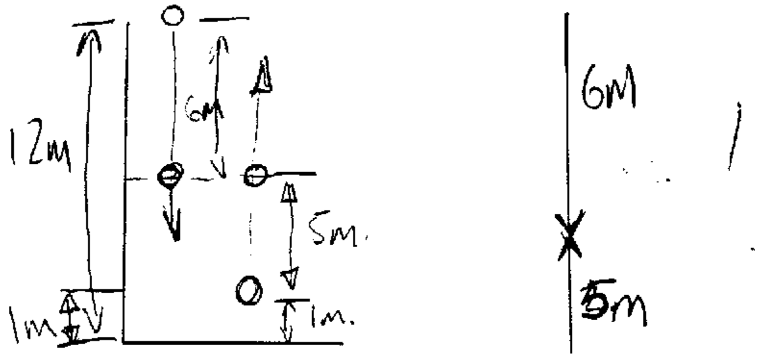
Calculating the efficiency was not handled as well, with many candidates confusing output with input, or incorrectly multiplying the output by a factor of 1.3 (a misinterpretation of 70% efficiency). The conversion of units was generally well executed.

(b) Ball A is released from rest at a height of 12 metres from the ground. At the same time, a second ball B is thrown vertically upwards from a height of 1 metre above the ground. The balls pass one another at a height of 6 metres from the ground.

(i) Draw a free-body diagram representing the situation.



Well answered. Most candidates were able to draw a clear free-body diagram that indicated correct understanding of the information given. A typical good response is given below:



(ii) *Determine the velocity at which ball B is thrown upwards.*

Time for A to travel 6 m

$$s = ut + \frac{1}{2}at^2$$

$$6 = 0 + \frac{1}{2}10 \times t^2$$

$$\therefore t = 1.2 \text{ s}$$

Velocity of B after 1.2 s and travelling 5 m

$$s = ut + \frac{1}{2}at^2$$

$$5 = 1.2u + \frac{1}{2}(-10)(1.2)^2$$

$$1.2u = 5 + 7.2$$

$$\therefore u = \frac{12.2}{1.2} = 10.16 \text{ m/s}$$

Answer: Velocity 10.2 m/s

This question was reasonably well done by candidates. The use of time to establish a relationship between the two moving balls allowed candidates to select the appropriate equations to arrive at a correct solution.

Ball A: $u = 0$, $a = 9.8$, $s = 6$, $t = ?$

$s = ut + \frac{1}{2}at^2$

$6 = \frac{1}{2} \times 9.8\, t^2$

$t = 1.1$

Ball B: $u = ?$, $s = 5\text{m}$, $a = -9.8$, $t = 1.1$

$s = ut + \frac{1}{2}at^2$

$5 = u \times 1.1 + \frac{1}{2} \times -9.8 \times (1.1)^2$

$u = 9.9\ \text{ms}^{-1}$

Velocity ....9.9........ m/s

Common errors included using a distance of 6 metres for ball *B*, using zero as a value for v (incorrectly assuming ball *B* comes to rest at a height of 6 metres) and not using a negative g value for ball *B*.

(b) A girl runs along a wharf to jump onto her boat that has started to drift. The boat is drifting with a velocity of 1 m/s in the same direction that she is running. The boat has a mass of 300 kg.

Determine the combined velocity of the girl and boat if the girl's weight is 65 kg and her velocity is 3.5 m/s when she jumps onto the boat.

$$m_1u_1 + m_2u_2 = (m_1 + m_2)v$$

$$(300 \times 1) + (65 \times 3.5) = 365v$$

$$\therefore v = \frac{527.5}{365} = 1.44 \text{ m/s}$$

$m_1 = 300$ kg
$u_1 = 1$ m/s
$m_2 = 65$ kg
$u_2 = 3.5$ m/s
$v = ?$

Answer: Combined velocity 1.44 m/s

Very well answered by the majority of candidates. Candidates were able to demonstrate a sound understanding of conservation of momentum, using the correct formula to calculate the combined velocity.

Question 3

This question was a good test of process knowledge. Most candidates attempted this part of the question.

Responses varied from a poor understanding of manufacturing processes to a reasonable level of understanding of correct processes.

(a) Four ceramic products are given in the table below. Complete the table by stating the most suitable forming process for each product.

Product	*Manufacturing process*
Toilet bowl	Answer: Slip cast
Glass bottle	Answer: Blow moulding
Quality sheet glass	Answer: Float process
Clay house-brick	Answer: Extrusion

The majority of responses for the toilet bowl (slip casting process) were correct.

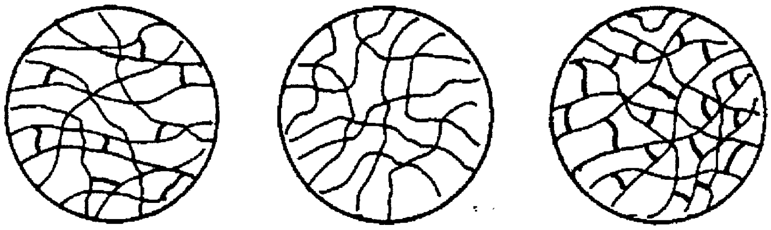
The majority of responses for the glass bottle (blow moulding or press and blow) were correct.

Many candidates had difficulty correctly identifying the most suitable process for forming quality sheet glass (float process) and the clay house-brick (extrusion).

(b) (i) The following items are manufactured from various polymers.

- *Plastic food wrap*
- *Bicycle brake block*
- *Inflatable inner tube*

Three polymeric structures are shown below. Write the name of the item below the diagram that best represents its polymeric structure.



Answers: Inflatable tube   Plastic food wrap   Bicycle brake block

This part was attempted by the majority of candidates with most responses showing a good understanding of the polymeric structures, applications and uses. The plastic foodwrap was the best known response.

A number of candidates failed to relate the diagrams with the items provided, using labels such as thermosetting polymer or ebonite, indicating perhaps a failure to fully read the question. Many did not recognise the difference in the levels of cross-linking indicated in the remaining two structures.

(ii) *Cross-linking is evident in one or more of the structures show above.*

Name and describe a process used to achieve cross-linking.

Answer: Name   Vulcanising

Description   Addition of sulphur (up to 5%) to natural rubber then heated to a suitable temperature.

Most candidates who attempted this part of the question knew the correct name of the process (vulcanising), but quite often did not describe the process sufficiently well. They indicated addition of sulphur or metal oxides to rubber, but often failed to mention that heating and pressure of the mixture was required to vulcanise.

Some candidates confused the process with metal heat treatment processes, while others answered, incorrectly, 'polymerisation' as the name of the process. A typical good response follows:

Name Vulcanisation ✓

Description This process is applied to rubber to promote vulcanisation. It involves the addition of sulphur, which consequently brakes the double bonds in the rubber chains and forms new covalent crosslinks between chains

Poor responses typically defined metal processes, as in the following example:

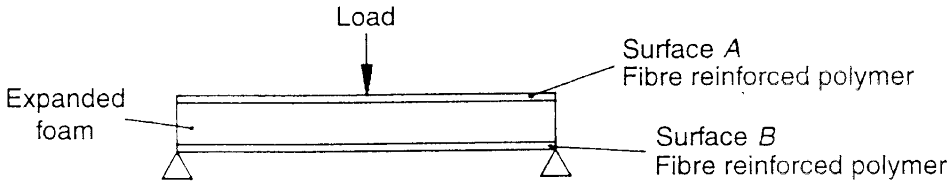
Name ....HEAT - TREATMENT...

Description ....THE......MATERIAL........IS.......HEAT.......TO......MAKE.

...THE.....GRAINS......REFORM..., ..THUS......ACHIVING....THE....DESIRED

......STRENGTH...

(c) *A cross-section through the wall of a structural component used in the marine and aircraft industry is shown below.*



(i) *The panel is loaded as shown. State the surface area (A or B) that will require the greater number of fibres.*

Answer: *B*

Well answered by the majority of candidates showing a good understanding of simply supported beam loadings. Some candidates did not indicate *B* (correct) or *A* (incorrect), but wrote other answers eg. ‘expanded foam’ (incorrect).

(ii) *State ONE reason for the use of the foam.*

Answer: Separation of the surfaces

Attempted by most candidates, but some had difficulty in expressing a valid reason for using the foam eg. insulation / rigidity, or were too general with their response eg. strength.

(iii) *Name a suitable material for the expanded foam.*

Answer: Polyurethane

Attempted by most candidates, with the majority able to correctly identify a suitable material eg. polystyrene / polyurethane.

(iv) *State the purpose of the fibre in the reinforced polymer.*

Answer: Increase tensile strength

Attempted by most candidates with responses often being too general eg. ‘strength’ rather than ‘increased tensile strength’ / ‘improved impact strength’.

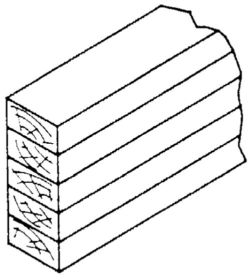
(v) *Name a suitable material for the fibre in the reinforced polymer.*

Answer: Glass fibre

Answered by the majority of candidates correctly, indicating a good knowledge of fibre reinforcing.

The most common responses were ‘glass’/ ‘carbon’. Others suitable include Kevlar, polyester, E-Glass, S-Glass.

(d) *Structural beams are often laminated, as shown below, rather than cut from solid timber.*



State TWO structural advantages of using laminated beams for long spans in building structures.

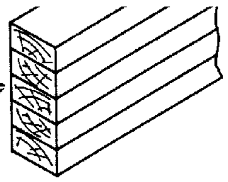
Advantage 1 Answer: Reduces the effects of defects in wood.

Advantage 2 Answer: Less shrinkage and improved stability.

Attempted by the majority of candidates, but many candidates failed to identify STRUCTURAL advantages, answering in terms of physical, service or environmental advantages of laminated beams.

Candidates need to read questions carefully, identifying key indicators or words in the question.

The following example was a good response that received full marks:



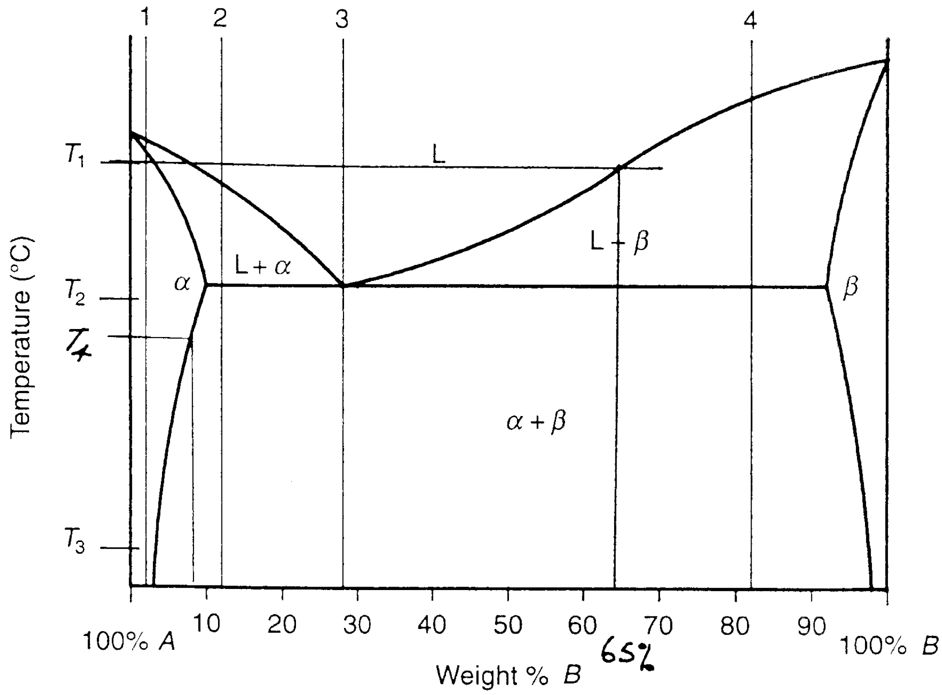
State TWO structural advantages of using laminated beams for long spans in building structures.

Advantage 1 glue gives extra strength ✓

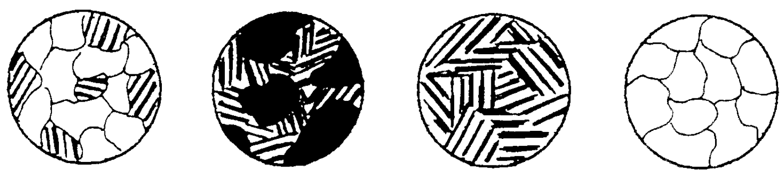
Advantage 2 a more uniform beam created ✓ by alternating radial grain directions (no warping, bending)

Question 4

(a) *The phase diagram for a binary alloy system of metal A and metal B is given below. Four alloy compositions are also indicated on the diagram.*



(i) *Match each of the microstructures shown below with the alloys 1, 2 ,3 or 4, shown in the phase diagram. Assume that each alloy was cooled under equilibrium conditions.*



Answer: Alloy **2** Alloy **4** Alloy **3** Alloy **1**

This part was generally well answered.

An appropriate sequence for answering this part is:

1 Select the eutectic composition as Alloy 3.

2 Determine the alpha phase as the white grain because of the single phase Alloy 1

3 Alloy 2 must contain the white phase plus a eutectic matrix.

4 The remaining microstructure must be Alloy 4 by elimination or by determining that there is only one alloy with a beta phase

(ii) *Determine the composition of the liquid at temperature T_1 for a 20% A – 80% B alloy under equilibrium conditions.*

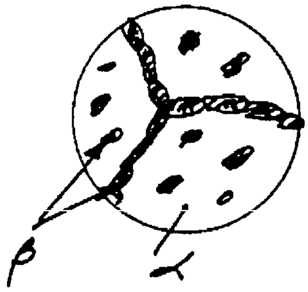
Answer: Composition of liquid 65% *B*, 35% *A*

This part was generally well answered.

Many candidates forgot to include 'B' with their answer, ie. 65% B, 35% A.

In this case full marks were awarded if the candidate showed construction on the phase diagram. This is another indication why candidates must show all working and construction in examinations.

(iii) *Describe the changes to the microstructure of a 92% A – 8% B alloy as it cools from temperature T_2 to T_3, under equilibrium conditions. Draw and label the microstructure of the alloy at temperature T_3.*

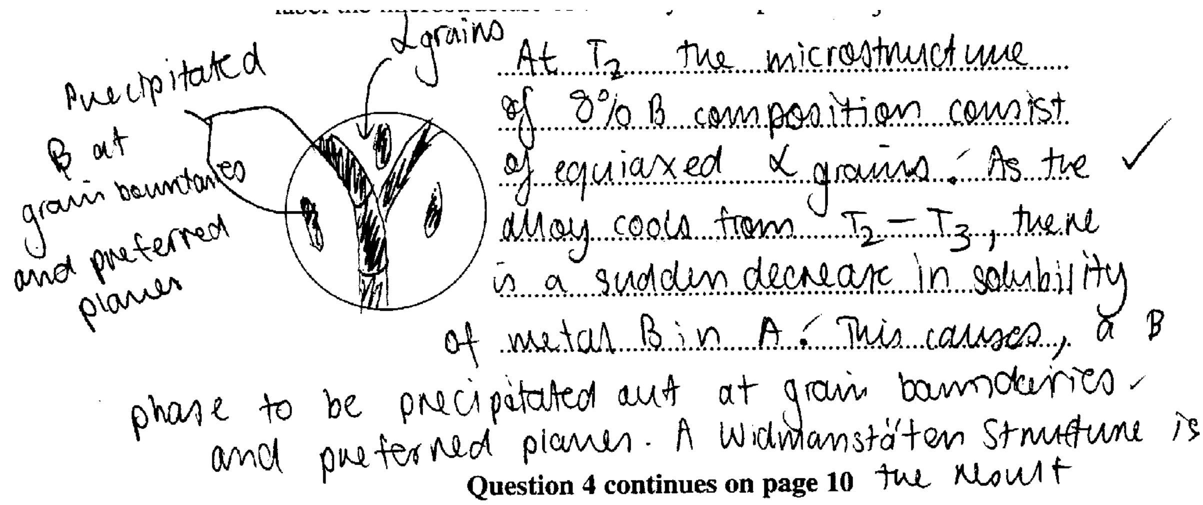


Answer: B precipitates out of the solid solution (at T_4) at the grain boundaries and within grains.

Average response to a typical question involving partial solid solubility, cooling through a solvus line.

Candidates often included steel phases in their answers, which is inappropriate.

Many candidates thought B or A or alpha + beta eutectic is precipitated, when the diagram clearly shows beta precipitates from alpha in the solid state, to produce a structure of alpha + beta phases. Some excellent responses were given:

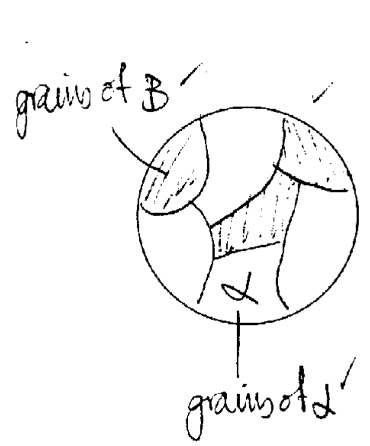

Precipitated β at grain boundaries and preferred planes

α grains

At T_2 the microstructure of 8% B composition consist of equiaxed α grains. As the alloy cools from $T_2 - T_3$, there is a sudden decrease in solubility of metal B in A. This causes a B phase to be precipitated out at grain boundaries and preferred planes. A Widmanstäten Structure is the result

Question 4 continues on page 10

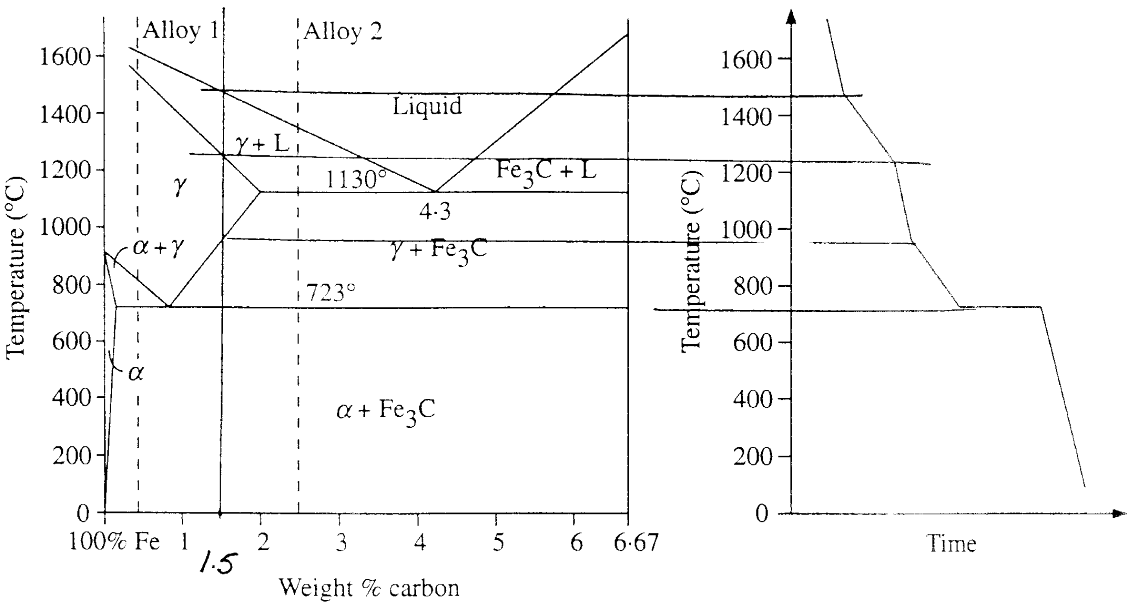
Other responses missed the concept of cooling through the solvus line:



It starts at full α phase the when it hits the solvus line it goes into part α + B phase

2

(b) *A portion of the iron-carbon phase diagram is given below. A cooling curve for a particular alloy is also given.*



(*i*) *Determine the composition of the alloy represented by the cooling curve shown above.*

Answer: Composition 1.5 % carbon

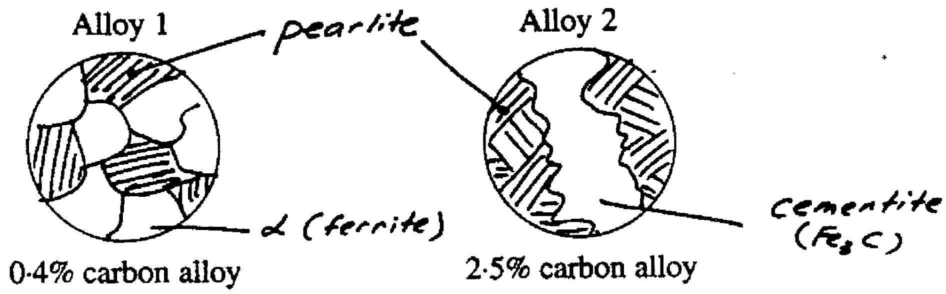
This part was well answered with full marks allocated for answers between the range of 1.4% and 1.6% carbon without showing construction on the phase diagram.

Outside this tolerance, if candidates showed correct construction technique they were awarded full marks.

Correct construction involved:

projecting horizontal lines from arrest points on the cooling curve to intersect phase boundaries on the phase diagram, then a vertical line is drawn through these intersection points and the composition is determined from the composition axis of the phase diagram.

(ii) Alloy 1 (0.4% carbon in iron) and alloy 2 (2.5% carbon in iron) are cooled, under equilibrium conditions, to room temperature. Draw and label the microstructure of each alloy.



In answering this question, many candidates showed poor skills in sketching microstructures.

Two distinct phases had to be shown, with pearlite as a 'striped' grain and ferrite and cementite as white grains.

Drawing two similar microstructures with different grains shaded, incurred a penalty.

No elongated grains were accepted because the structures result from equilibrium cooling.

When a question requires candidates to 'draw and label', marks are allocated for the sketch and the labeling.

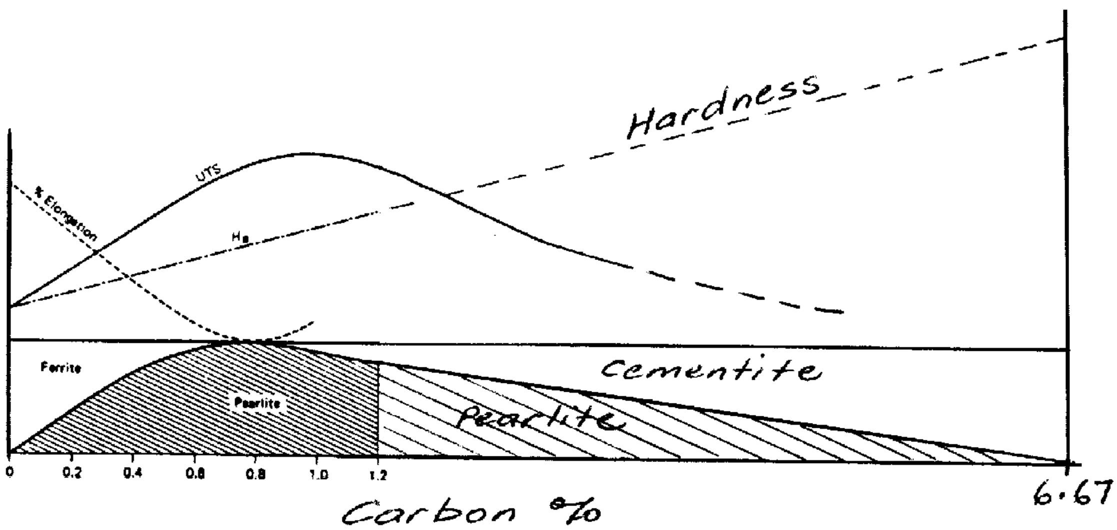
Slow cooling of the 2.5% carbon cast iron will form massive cementite in a matrix of pearlite. If there is not sufficient graphitising elements present (eg > 1.5% silicon), as in this case, graphite will not form.

(iii) *Alloy 1 is relatively soft while alloy 2 is relatively hard. State ONE reason for this difference in mechanical properties.*

Answer: Alloy 1 has more ferrite (soft and ductile)

A good response with candidates realising that a metal with more ferrite, which is soft and ductile, will be softer than a metal with a high proportion of hard, brittle cementite.

In the iron–carbon phase diagram given, as carbon increases so the presence of cementite increases, until at 6.67% C, the structure becomes 100% cementite. It follows that as the carbon content increases so does the amount of cementite; therefore less ferrite increased hardness, decreased strength. The following modification of a 'popular summary' of mechanical properties and structure indicates the relationship.



In industrial terms, the presence of graphitising impurities such as silicon (most powerful element), manganese, sulphur and phosphorus coupled with faster than equilibrium cooling rates causes the metastable cementite Fe_3C to decompose to Fe and C (ferrite and graphite), producing a grey cast iron. In practical terms the main use for white cast iron is for the production of malleable iron products. White cast iron derives its name from the appearance of its fracture surface (white). It is hard and brittle due to the presence of massive amounts of cementite.

In this question, candidates were asked to relate the change in structure to the change in properties, and as the phase diagram referred to was the iron-carbon (iron-iron carbide) the changes to properties should have been in terms of the presence of ferrite and cementite, the two phases indicated on the diagram for the composition specified.

(iv) Determine which alloy, 1 or 2, has the lower casting temperature.

Answer: Alloy 2

Very well answered with candidates correctly reading melting temperatures off the liquidus phase boundary on the phase diagram.

Question 5

All of question 5 was generally poorly answered with 5(a) having better quality responses than 5(b).

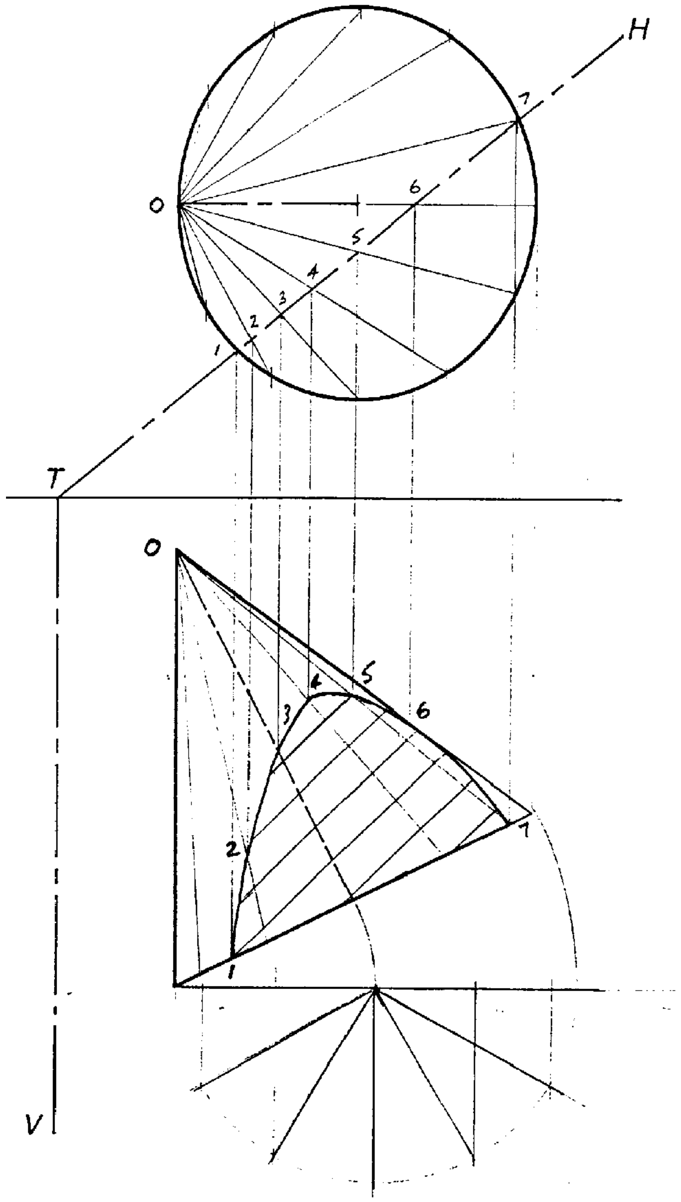
(a) The top view and incomplete sectional front view of a cone inclined to the horizontal plane are shown below in third-angle projection.

The cone is cut by a vertical section plane as shown.

Complete the sectional front view.

The most popular solution is given below:

Answer:



Despite being the best answered of the two, in 5(a) candidates seemed to have a poor perception of where the apex was located as a result of the cone being tilted. This led to incorrect insertion of generators although many used what could be described as a random placement of generators. Despite this, in most cases, while the curve of intersection was located, many were inaccurately joined.

Projection of intersection points from top to front view also caused many problems for candidates as they were frequently inaccurate. Location of the extremity points was generally well done although individual points were frequently not clearly indicated. Moreover, the extreme right-hand corner of the front view was frequently not omitted.

A significant number of candidates appeared to have little idea of conic sections generated from cones, which are cut by planes of intersection.

Many candidates chose not to attempt this question despite it being easier than it first appeared.

(b) The top view and front view of a truncated square prism are given below in third-angle projection.

Project a right-side view of the prism so that surface A is seen as the true shape. Show visible and hidden outline.

This question was very poorly done with very few candidates achieving full marks.

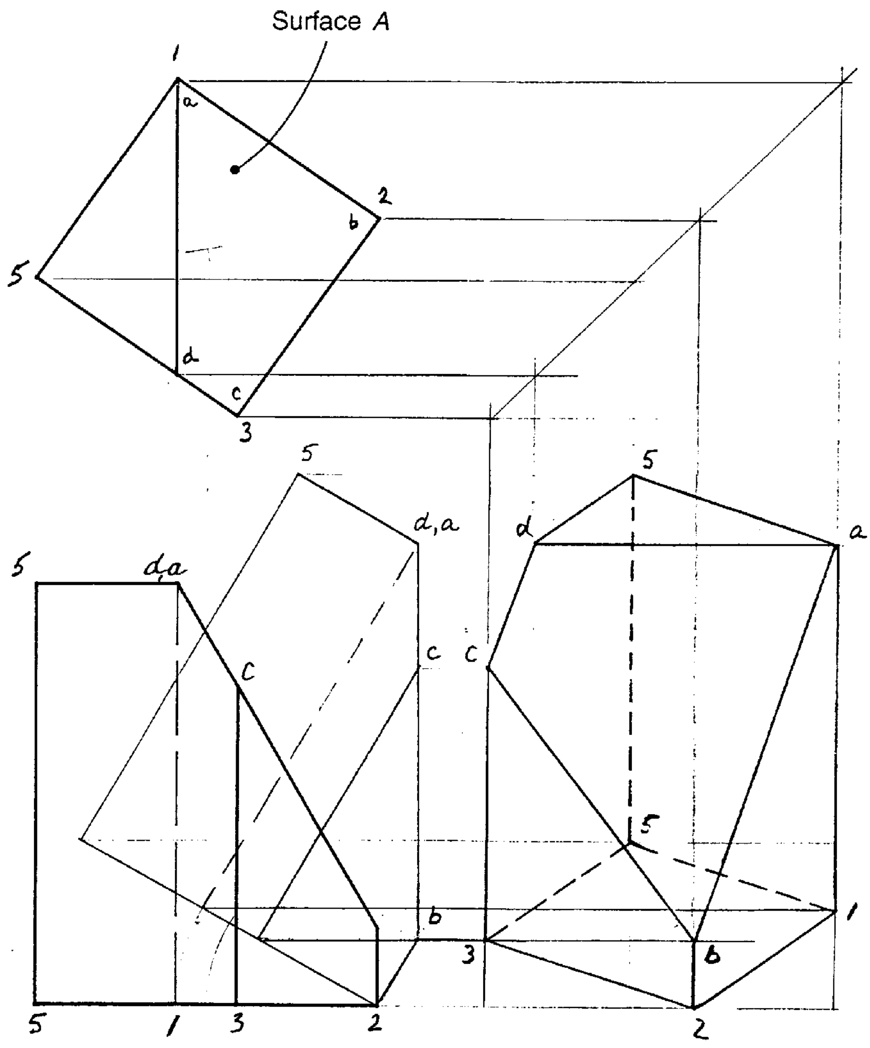
Most candidates simply projected a right-side view with no true shape of 'Surface A' given. Of these solutions, many were not able to follow the solution through and indicate the sloping 'Surface A'. There seemed to be a widespread lack of understanding of the basic principles of orthogonal projection.

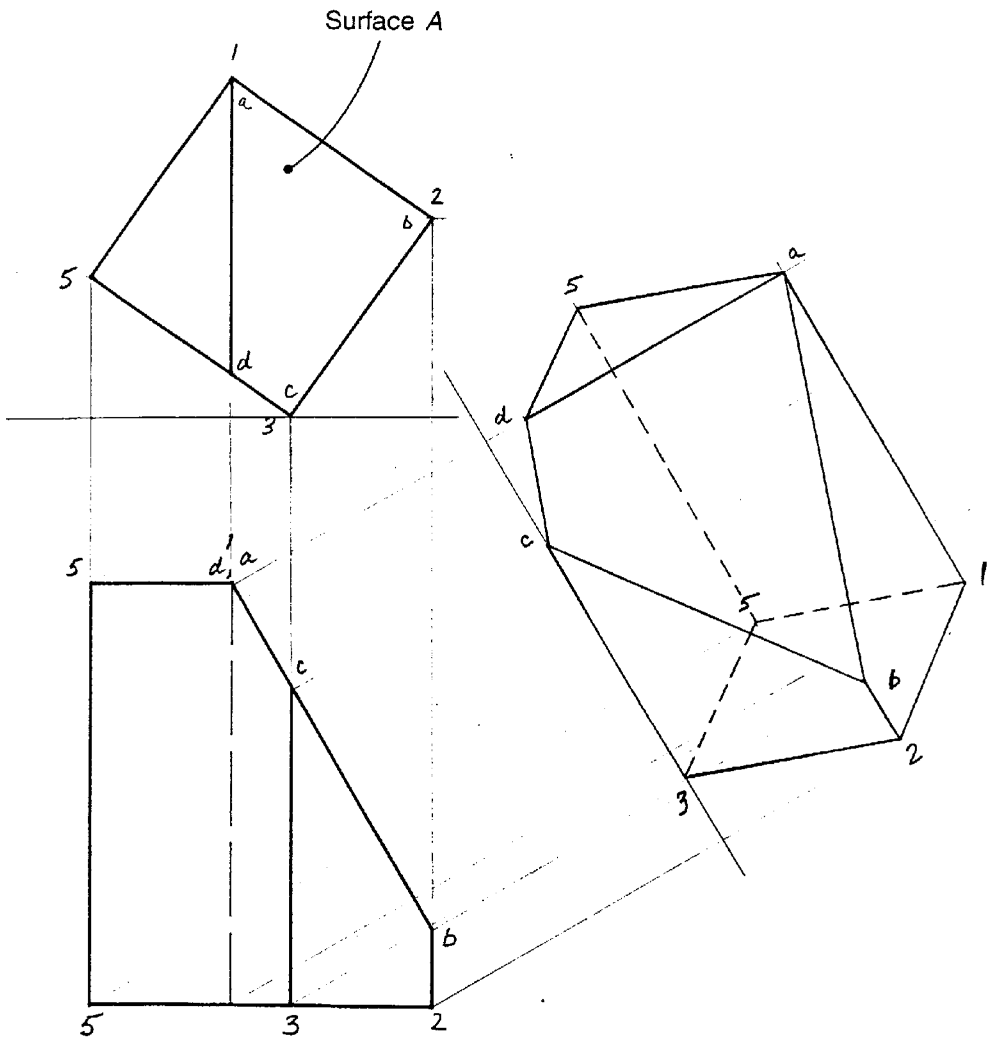
Other candidates projected up and out to the right perpendicular to 'Surface A' which provided the true shape without the complete auxiliary view. Very few candidates projected an accurate and complete auxiliary view. Rotating (tilting) the solid to obtain the 'right side view', which showed 'Surface A' as true shape, was attempted by a small number of candidates.

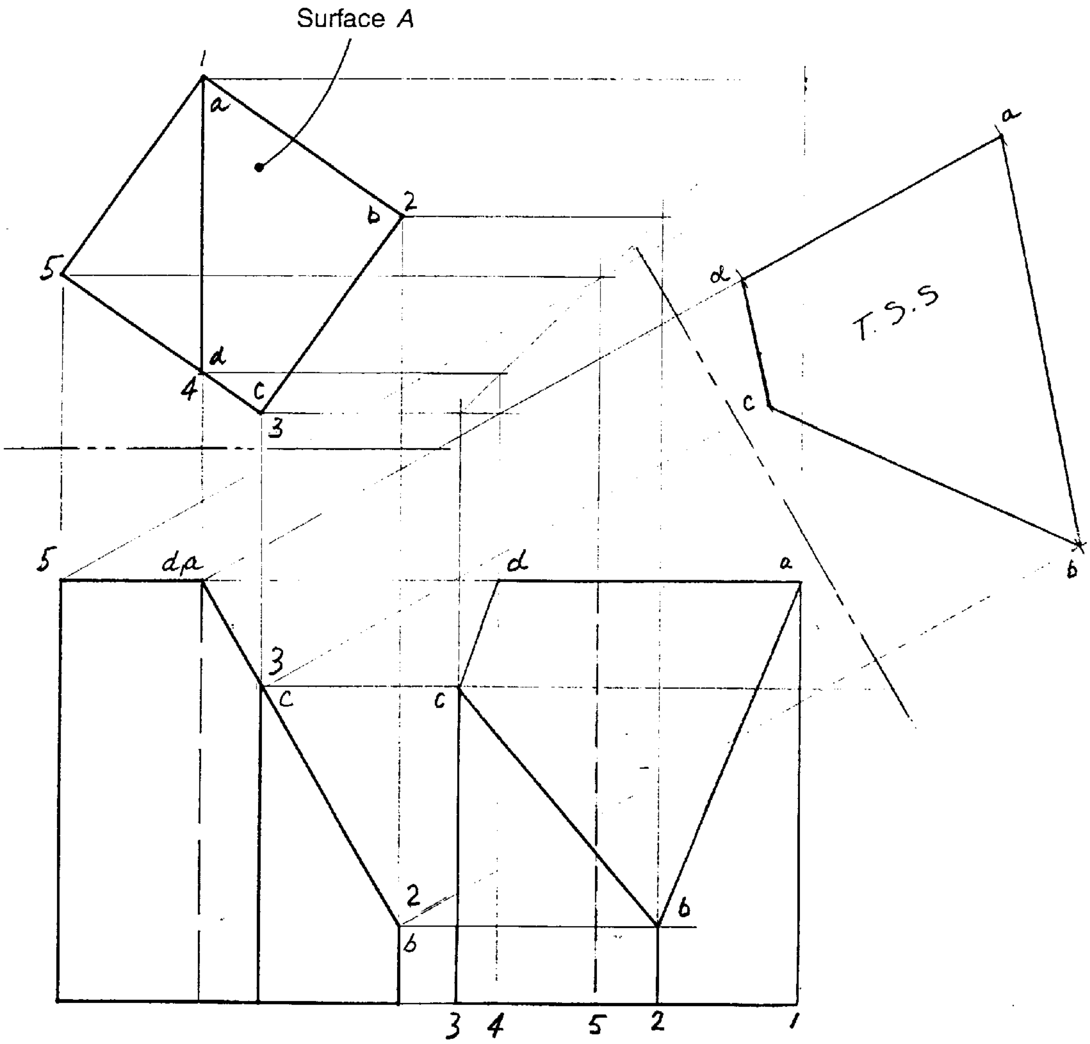
Linework and accuracy generally tended to be of poor quality with the most common errors being inaccurate projection, non-parallel projection lines, incorrect angles and inaccurate stepping off of distances. Also evident was a lack of knowledge of AS1100 in relation to line standards.

Many candidates displayed an incorrect perception of the difference between an invisible and hidden outline and the incorrect sectioning of true shapes. Hidden outline refers to the external edges of a solid. Section planes that make imaginary cuts through solids to produce sectional views have the 'cut' surfaces shown with sectioning lines. The solid in this question has no section plane as such. It is a modified square prism, thus all projections of 'Surface A' should be shown just as any other face of the solid, without sectioning.

An example is given below of a solution projected from the 'Surface A' to produce an auxiliary view with the true shape of 'Surface A' shown. This is followed by two other solutions.



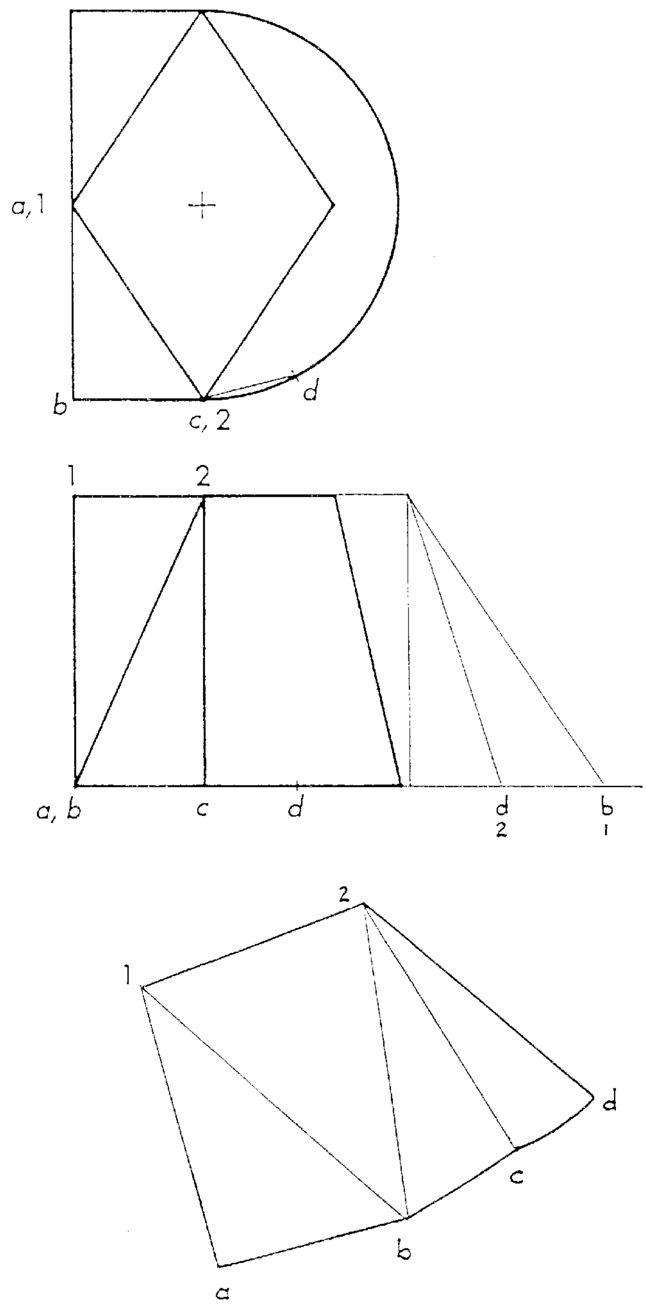

Surface A
1
a
2
b
5
d
c
3
5
1
d, a
c
b
5
3
2
a
5
d
c
1
5
b
2
3


Surface A
1
a
2
b
5
d
4
c
3
T.S.S
a
d
c
b
5
d,a
d
a
3
c
c
2
b
b
3
4
5
2
1

Question 6

(a) *The top view and front view of a transition piece are shown below in third-angle projection. Complete a pattern of the surface abcd* 21. *The starting position for the seam* 1*a is given.*

Answer:



An intermediate point between 'c' and 'd' would have produced a more accurate curve between these two points. A large number of candidates showed a straight line between 'c' and 'd' in their solution.

Note that 'b1' can be found by recognising that the angle 'ab' is a right angle or by using a TL diagram.

Many candidates had problems recognising existing true lengths from front and top views.

A considerable number of candidates used the given line for starting 'a1' instead of the true length.

'a1' and '12' were frequently transferred incorrectly.

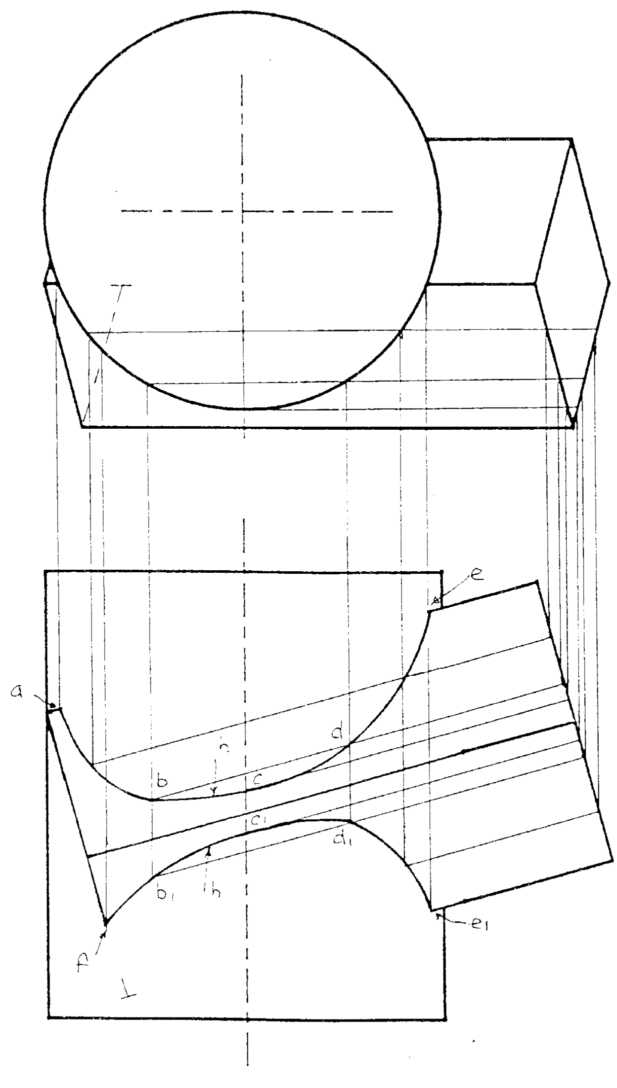
A clear distinction between outlines, fold lines and construction lines needs to be evident.

Many candidates had problems visualising the shape. A line on the development was often incorrectly shown between 'a' and '2'.

(b) *The top view and incomplete front view of a cylinder intersecting with a square prism are given below in third-angle projection.*

Complete the front view, showing only visible outline.

Answer:



The majority of candidates recognised that the lines of intersection were curved.

Plotting of the two centre points could have been produced more accurately by extending the vertical centre line in the top view, before projecting horizontally.

The preferred, more accurate solution for the lower left hand point, was to draw the base edge, in the top view, until it contacted the cylinder.

Use of vertical section planes was not clearly understood by a majority of candidates.

Many candidates drew curves without plotting points, this solution scored zero marks.

Section II

Question 7

The design of modern-day bicycles has developed over a short period of time, from a Tourer to BMX to a Mountain bike. (Please see exam paper for illustrations.)

(a) *Complete the table below by filling in a statement next to each point.*

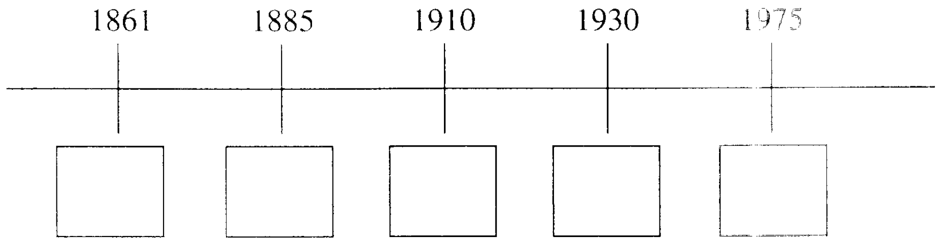
	Tourer	*BMX*	*Mountain*
Purpose of the design	• 'on road' design • cheap transport to work	• for racing, jumps and general rugged 'off road' use • built for younger age groups	***Answer:*** • For hilly/all terrain • Hybrid- cross purposes • Built for all ages
Features of speed mechanism design	• large wheels • 3 speed hub, single cable	• small wheels • had little or no design for speed	***Answer:*** • Medium, large wheels • Large range of gear ratios
Features of frame and components	***Answer:*** • Mild/alloy/low C./ steel frame • Brazed lug construction • Narrow tyres	• aluminium alloy frame • small rugged frame • high-strength wheels • gusset construction for frame	• carbon fibre, alloy steel and aluminium • large strong frame • light weight • hydraulic brakes and suspension

This part of the question was well answered by candidates. The sample responses offered by the examiners prompted candidates to model their responses along similar themes. As the samples were basic ideas such as 'cheap transport to work' it was both anticipated and acceptable that candidates would give answers of a similar type. Most candidates followed these examples when describing the purpose of the mountain bike and correct answers referred to the purpose as an 'all terrain bike', 'built for all age groups', 'recreational use' or made a parallel statement from the given description of the tourer, 'cheap transport', to describe its purpose.

Candidates were asked to make six statements to answer this part of the question. Many candidates chose to give more than six and, in many instances, the extra answer contributed nothing of value to the marks awarded by the examiners. While some of these extra answers were irrelevant, others were incorrect observations or, in some instances, contradicted correct answers that were also stated by the candidate. Candidates are reminded to respond to the question asked in the format required in order to gain maximum marks.

(b) *Social values, events and materials development have played on important part in the evolution of bicycle design.*

Write the number of each statement in the correct box on the time line.

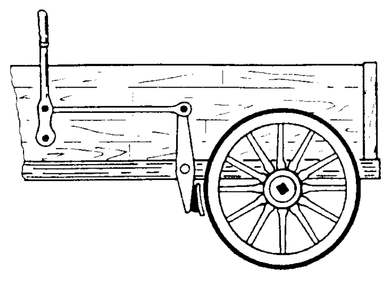


1. *Mass production techniques reduce costs, leading to greater demand for the bicycle.*
2. *Society sees the importance of fitness and a reduction in pollution.*
3. *Rover Safety with pneumatic tyres provides a safer, more comfortable ride.*
4. *The bicycle increased in popularity at this stage of its development, due to its use as cheap transport to work.*
5. *The Velocipede had a sprung frame, 2 cart wheels and a simple string-operated brake.*

This question examined candidates' knowledge of the parallel development of technology and societal influences. The format included five dates and five historical statements and candidates had to place the five statements in correct time-line order.

Most candidates placed the Velocipede (Statements 5) with the first (left-hand) box and related it to the 1861 date. Equally, most placed Statement 2 about society seeing the importance of fitness and reduction in pollution last, matching the 1975 date. Fewer candidates placed the development of the Rover Safety bicycle with the 1885 date. Many candidates found difficulty in correctly placing Statement 1 with the 1910 date and Statement 4 with 1930. The correct sequence of statements is 5, 3, 1, 4, 2.

(c) *A variety of materials have been used as the friction components in the development of brake systems, as shown in the diagrams below. Give TWO reasons for the use of each material.*

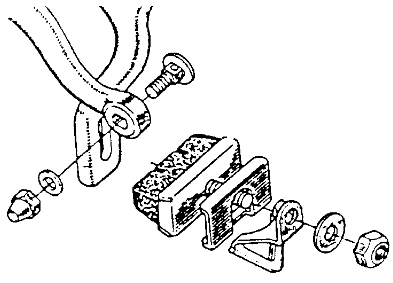


Curved wooden brake shoe

Answer:

Reason Ease of production. Easily replaced. Adequate friction for slow vehicle.

1. Material common at the time / vulcanised rubber not available.
2. Replaceable shoe softer than metal type.

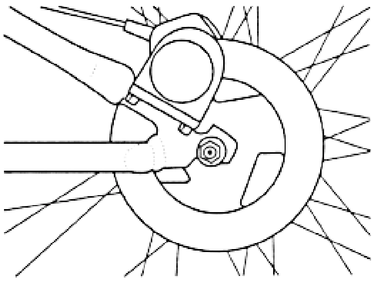


Brake block (rubber)

Answer:

Reason

1. Vulcanised rubber now available. Suitable for light vehicles (bikes).
2. Better / good frictional properties. Compatible material with bike rims.



Disc pad (cermet composite)

Answer:

Reason

1. Best combination of wear and frictional properties.
2. Dissipates heat energy well. Cermets are strong in compression.

When given a full line on which to supply a reason, candidates are encouraged to answer in a sentence that incorporates the reason. A sentence allows the reason to be placed in context! This is not always possible with single word answers. Words such as 'durable' or 'cheap' don’t really provide a reason for the use of the material. Good responses included reasons describing the service properties of each material or they made meaningful mention of the availability of the material within the era in which the braking system was built. Poorer responses included references to the braking system rather than to the material as required.

A correct response to this question should match the service properties to the action (and age) of each braking mechanism pictured in the question. Basic knowledge about mechanisms should be central to any study of brakes. This part of the question was not answered well.

Question 8

(a) A bicycle and rider start from rest and roll down a slope of 1 : 2. The bicycle and rider have a combined mass of 105 kg. After a period of 12 seconds the bicycle and rider reach a maximum velocity of 30 km/h.

(i) Determine the acceleration of the rider down the slope.

u	=	0	v	=	u + at
v	=	30 km/h	8.33	=	0 + 12a
	=	8.33 m/s	a	=	0.69 m/s^2

Answer: Acceleration 0.69 m/s^2

Most candidates answered this part of the question correctly. Some candidates introduced irrelevant data and some used more complex equations than required. The most common errors occurred when candidates failed to convert km/h to m/s as this did not allow them to calculate the time in seconds.

To assist in the analysis of this and other mechanics questions candidates should:

– underline key points in the question;

– list the data relevant to each solution;

– convert to common units;

– write appropriate formulae before substituting data.

These simple points would help many candidates produce solutions which better answer the question and better inform the markers.

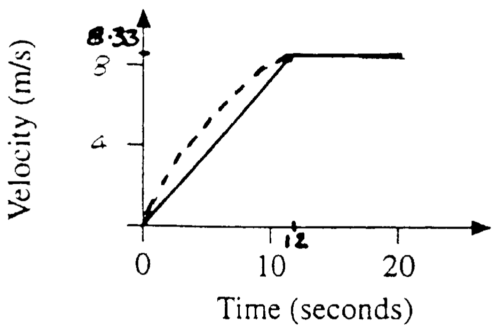
(ii) Determine the resistance to motion when the rider is travelling at 30 km/h.

F	=	mgsinJ = R
∴ resistance to motion	=	mgsinJ
	=	105 × 10 × sin26.56
	=	469.6 N

Answer: 469.6 N

This question was often incorrectly analysed with the majority of candidates not realising that resistance to motion was equal to the force down the slope. Many candidates incorrectly used F = ma and usually substituted in the mass from the previous answer. Some candidates incorrectly identified that the force down the slope was equal to N where the normal force was mgcos.

(iii) On the axes provided below, plot a velocity-time graph that represents the rider's journey for the first 20 seconds.



v = 8.3 m/s at 12 sec

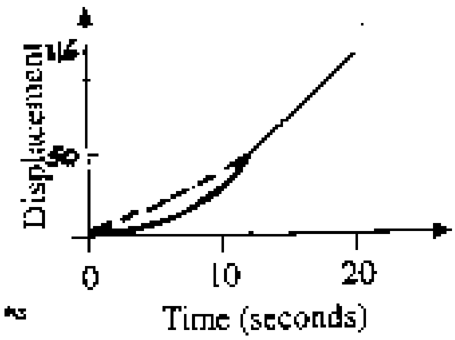
v = 8.3 m/s at 20 sec

This question required candidates to plot velocity up to 12 seconds and then between 12 & 20 seconds. Some candidates failed to plot a change in the the graph at 12 seconds. A common response is shown below.

Some candidates failed to include the magnitude and units of the velocity on the axis of their graph while others failed to convert the velocities to m/s.

Candidates should be advised to draw and accurately label any graphs.

(iv) *On the axes provided below, sketch the displacement-time graph for the first 20 seconds.*



$s = ut + \_at^{2}$

$= 0 + \_\_ 0.69 \_ 12^2$

$= 49.7$ m

$s_{20sec} = s_{0to12sec} + s_{12to20sec}$

$= 49.7 + 66.64$

$= 116.6$

This question was poorly attempted as many candidates did not analyse the question correctly. This question required the candidates to SKETCH the graph and not to accurately plot data. Many candidates determined displacement at 12 seconds and 20 seconds and plotted a proportional relationship between time and displacement for the whole period, while, in fact, there was an important change at 12 seconds. Many candidates failed to correctly identify a curve from 0–12 seconds, and straight line from 12–20 seconds, as the relationships in this answer.

(b) (i) *For the same rider, now travelling on a level road at 25 km/h, the resistance to motion is 275 N. The rider must exert an average force of 350 N on the pedal to maintain this speed.*

Determine the mechanical advantage of the system.

$$MA = \frac{L}{E}$$

$$= \frac{275}{350}$$

$$= 0.7857$$

Answer: Mechanical advantage 0.7857

This question was generally well answered. The most common mistake was reversing the load (output) and effort (input). Some candidates incorrectly identified effort as the total mass of rider and bike (mg) rather than the effort stated in the question.

(ii) *While travelling at a speed of 25 km/h the rider suddenly increases the average pedal force to 500 N. The tractive force at the rear wheel increases in proportion to the increase in pedal force.*

Determine the acceleration of the bicycle and rider.

$500 - 350 = 150$ N

$150 \times 0.7857 = 117.85$ N

$117.85 = ma$

$117.85 = 105a$

$a = 1.12$ m/s^2

Answer: Acceleration 1.12 m/s^2

Only a few candidates answered this question correctly. Many candidates failed to use mechanical advantage when calculating the proportional increase in the load while others incorrectly attempted to solve this question using only F = ma.

(c) *For another set of conditions, the rider's velocity is 30 km/h. The brakes are then applied for 6 seconds, reducing the velocity to 5 km/h. Determine the energy absorbed by the brakes. Assume that the energy lost is due to the application of the brakes only.*

30 km/h = 8.3 m/s
5 km/h = 1.39 m/s

$$KE = \frac{1}{2}m(u^2 - v^2) \quad \text{or} \quad \frac{1}{2}mu^2 - \frac{1}{2}mv^2$$

$$= \frac{1}{2} \times 105(8.33^2 - 1.39^2) \qquad = \frac{1}{2} \times 105 \times 8.33^2 - \frac{1}{2} \times 105 \times 1.39^2$$

$$= \frac{1}{2} \times 105 \times 67.5 \qquad = 3541.6 \text{ J}$$

$$= 3541.6 \text{ J}$$

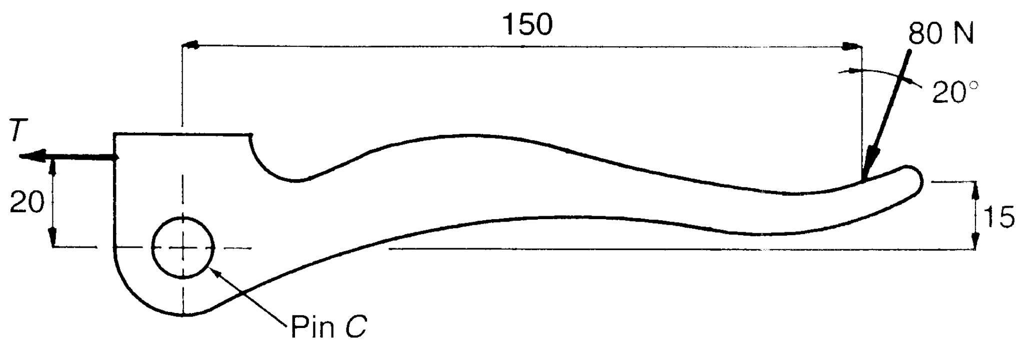
Answer: Energy absorbed 3541.6 J

The majority of candidates knew to apply the kinetic energy equation in this question to reach a solution. However, many failed to understand that the difference in kinetic energy at the two velocities was the correct solution to the problem. Some candidates correctly transferred the kinetic energy equation from the data sheet and then failed to square the velocities in their solution. Candidates incorrectly attempted to simplify the problem by finding the difference between the velocities and then using this figure in a kinetic energy equation.

Some candidates attempted to solve this question by finding distances and then acceleration and finally applying the work equation. A small percentage of candidates used impulse and power equations to derive the change in energy. Correct solutions were possible using both these methods.

Question 9

(a) *Details of a handle used in a bicycle brake system are shown in the diagram.*



(i) *Determine the tension T in the cable if a load of 80 N is applied to the handle as shown in the diagram.*

$\Sigma M_c = 0 = (T \times 20) + (27.36 \times 5) - (75.18 \times 150)$

$T = 543.3$ N

Answer: Tension *T* Graphically 500 N or Analytically 543.3 N

This part of the question was generally well done by most candidates. However, it was surprising how many candidates still prefer to attempt the more difficult analytical solution. Of these analytical solutions, many omitted the horizontal component of the 80 N force in their moments equation. Teachers are again reminded that measured distances from the diagrams are acceptable and often reduce a complicated analytical solution to a simple equation,

eg $(T \times 12) = (80 \times 81)$

(ii) Determine the resultant shear force acting on Pin C

Using cosine rule

$a^2 = 80^2 + 543^2 - 2 \times 80 \times 543 \times \cos 110^\circ$

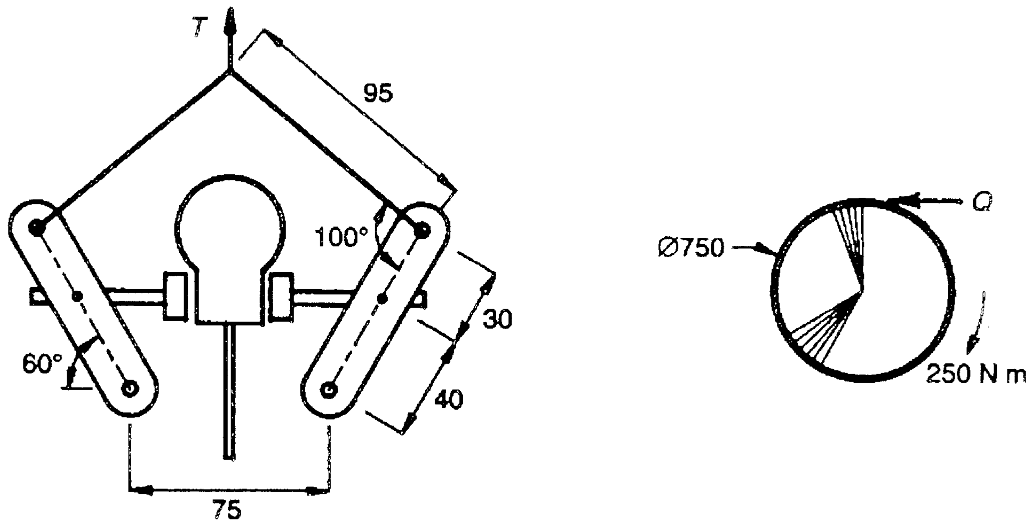
$a = 575.3$ N

Answer: Shear force 530 or 590 N

Candidates with incorrect answers for (i) were not penalised for using this answer to solve (ii).

Again the graphical solution was simpler than the analytical as the resultant is measured from the same force diagram as the tension force T found in part (i). Some candidates had difficulty in understanding the 'resultant shear force' concept and tried to calculate a stress even though no pin size was given in the question.

(b) Details of a centre-pull bicycle brake system, and a bicycle wheel are given in the diagrams. The wheel is held stationary by the brake system while a 250 N m torque is applied to the wheel. The coefficient of friction between the brake block and the wheel rim is 0.75.



(i) Determine the tangential friction force Q required to prevent the rotation of the wheel.

$M = F_a \times d$

$250 = F_Q \times 0.375$

$F_Q = 666.6$

Answer: Force *Q* 666.6 N

Most candidates scored well in this part of the question although some were unable to relate the wheel on the right of the illustration to this part of the question. Of these many used $F = \mu N$ incorrectly. In this type of question it would be useful if teachers were able to spend time in helping candidates understand and distinguish between 'tangential friction force' and 'normal'. This conceptual error cost many candidates marks.

(ii) *For a different set of conditions the tangential friction force is 800 N. Determine the tension T in the brake cable required to produce the 800 N force.*

$F_l = 800$ ie. 400 on each side

$$N = \frac{F_l}{\mu} = \frac{400}{0.75} = 533 \text{ N}$$

$N \times d_1 = T_R \times d_2$

$533 \times 34.64 = T_R \times 68.94$

$T_R = 267.85$

$$\frac{267.85}{\sin 50} = \frac{T_T}{\sin 80}$$

$T_T = 344.34$ N

Answer: Tension *T* 344.34 N

Candidates found this the most difficult part of the question and as a result it was answered very poorly. Candidates incorrectly used the 800 N force as the normal not the tangential force. Many failed to halve the normal (half force in each brake pad). Again the graphical solution is far easier than the analytical solution with this type of problem.

Candidates should be encouraged to:

– consider a graphical solution or at least sketch a diagram of the problem;

– look for a solution using measured distances obtainable from the diagram;

– attempt a complex analytical solution only if the graphical solution is not possible.

(iii) *For a different set of conditions, the tension in the brake cable is 1·2 kN. The cable has a gauge length of 300 mm and a diameter of 1·5 mm. The steel used in the cable has a modulus of elasticity of 210 MPA.*

Determine the extension of the cable.

$$E = \frac{\sigma}{\varepsilon}$$

$$E = \frac{FL}{A_E}$$

$$e = \frac{FL}{EA}$$

$$= \frac{1.2 \times 10^3 \times 0.3}{\frac{\pi \times 1.5^2}{4} \times 10^{-6} \times 210 \times 10^6}$$

$F = 1.2 \times 10^3$

$L = 0.3$

$$A = \frac{\pi d^2}{4} = \frac{\pi 1.5^2 \times 10^{-6}}{4}$$

$E = 210 \times 10^6$

$$= \frac{0.36 \times 10^3}{1.767 \times 210}$$

$= 0.970$ m

$= 970$ mm

Answer: Extension 970 mm

Most candidates scored very well in this part of the question. It was pleasing to see that most candidates understood the relationship between Young's modulus, stress and strain.

Of those candidates who lost marks, a number were unable to derive E = FL/eA from the information on the formula sheet. Candidates often used incompatible units making it more difficult for examiners to identify and award marks. The data in the question was such that the answer was unrealistic. Only elastomers can extend three times their original length without failure.

Question 10

(a) Lugs are used in the joining of a bicycle frame.

(i) 1 Name a method used to join the lug to the frame

Answer: Brazing / Hard Soldering.

Less than half of the candidates understood that lugs were brazed to the frame. Many candidates incorrectly named a welding process such as MIG, TIG, oxy and resistance welding.

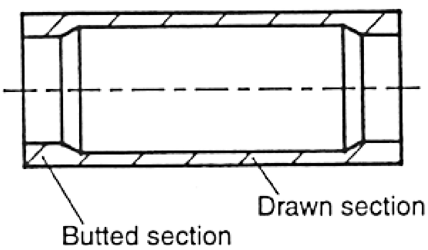
2 List TWO reasons for the use of this lug joining method.

Answer: (I) Increased joint surface area.

(II) Minimal grain change in the heat affected area.

Many candidates displayed a poor understanding of the purpose of the lug. A lug is a physical 'connection' between two frame parts used to increase the joint surface area. Brazing is used when a ductile joint is required that has both resistance to fatigue and good strength properties. This occurs as the phase of the brazing rod cold-works with flexing and continues to increase the strength of the joint. As welding occurs at a much higher temperature, melting the parent metal and recrystalising the structure in the heat affected zone, it is not suitable for this application.

(ii) The following steel tube has been cold drawn to form butted ends by using a combination of cold-drawing processes.



1 What is the main advantage of butting the tube ends?

Answer: Increased bend or shear strength close to join/ Reduced overall weight.

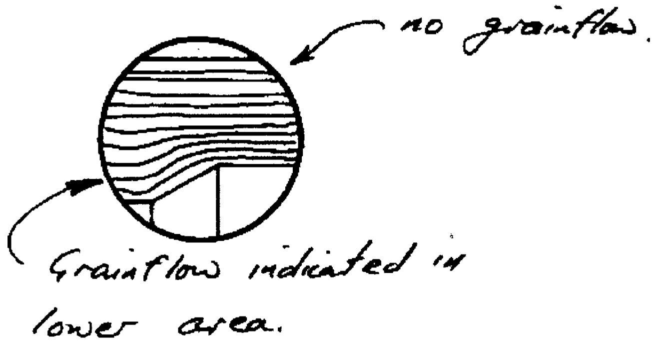
2 *If 0.3%C seamless steel tube is used to form the butted tube, state a change in mechanical properties caused by this process.*

Answer: Increased strength, stiffness / work hardening.

Around half of the candidates were unable to give satisfactory responses to these parts. General, unacceptable terms such as 'strong' and 'hard' were common. A qualifying term such as 'increased' or 'greater' should preface the mechanical or physical property stated.

3 *Draw the grain structure of the tube wall at the butted section.*

Answer:



A number of candidates did not recognise that the grainflow occurs at the lower section only where the deformation is greatest. Many incorrectly showed equiaxed grains indicating that a hot-working process had been used or the material had been recrystalised.

(b) *The cowling of a lawn mower is produced by injection-moulding a 10% glass-filled nylon composite.*

(i) *If injection-moulding is used within glass fibre and a granulated form of nylon, give TWO reasons for the use of injection moulding.*

Answer: 1. High dimensional accuracy

2. Automated process / mass production

The majority of candidates gave at least one correct response but only 70% gave a second correct response. Many candidates incorrectly stated that injection-moulding is a process used to mix the nylon and glass fibre together.

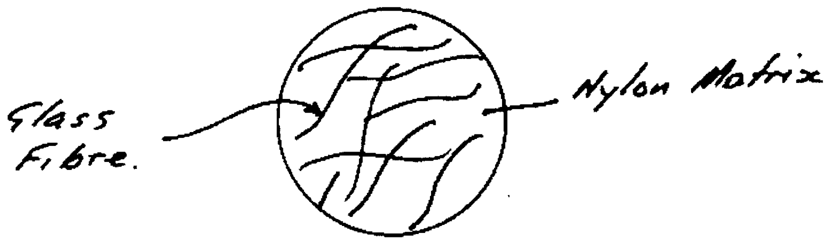
(ii) *At what stage is the glass fibre added to the composite in the manufacture of the cowling?*

Answer: Glass fibre is mixed with the nylon in its liquid state.

Many candidates recognised that the nylon must be in a molten state to enable the glass fibre to be mixed. The majority, however, incorrectly believed that this took place in the heating chamber around the torpedo within the injection-moulding machine.

(iii) *Draw and label a macrostructure of 10% glass-filled nylon.*

Answer:



This section was generally well answered. Common errors occurred with candidates stating that the glass fibres 'crosslinked' the nylon or that polymerisation occurred between the nylon chains. Candidates need to understand that the glass fibre is simply a filler that doesn't chemically combine with the polymer.

(c) *Brake drums are often made from grey cast iron.*

(i) *List THREE reasons for the use of cast iron in the brake drum.*

Answer: 1 Compatibility

2 Suitable coefficient of friction

3 Good heat resistance

This was well answered by the majority of candidates who understood the need for heat to be taken away from the friction surface in order for the brakes to function efficiently.

(ii) *Name the most appropriate type of casting used to make the brake drums.*

Answer: Shell moulding / Sand casting

Around seventy percent of the candidates correctly selected sand casting or shell moulding. Other candidates often selected a casting process that was inappropriate such as die-casting and investment casting.

Question 11

A lawn mower assembly bolt is manufactured from cold-drawn 0.2% carbon steel. The head and thread are formed by cold-working processes.

(a) *Both the cold-drawn stock and the finished bolt are to be tested to examine properties and detect faults. Name and describe a different non-destructive test that could be used for each situation.*

Answer: (i) *Cold-drawn stock*

Name of test Vicker's Diamond Pyramid Test

Description of test A small diamond pyramid indentor is forced into the stock surface by a known load and the indentation measured to indicate hardness.

(ii) *Finished bolt*

Name of test Visual Inspection

Description of test Various parts of the bolt are examined using gauges to satisfy prescribed tolerances (eg. head, shank and thread sizes).

Many responses demonstrated a general knowledge of non-destructive testing but omitted specific details. Candidates are encouraged to answer the question fully where sufficient space is provided in the paper. Candidates should consider revising processes in a series of important points each pertaining to the relevant stage in the testing process.

eg Dye Penetrant Test:

- apply fluorescent dye;
- wipe off excess dye;
- examine surface under ultra-violet light.

Many candidates did not distinguish between the stock and the finished bolt when naming appropriate tests for each. Some candidates answered in terms of the purpose of the test rather than a description. Some candidates also included destructive tests in their response. Candidates are encouraged to underline key words and phrases in the question to focus their attention.

A typical good response is given below:

(ii) Finished bolt

Name of test Radiography

Description of test X-rays or γ radiation are passed through the bolt and onto a sensitive film the cracks and flaws absorb more radiation and appear as dark areas on the film

(b) *State TWO advantages that cold rolling of the thread has over machining of the thread.*

Answer: *Advantage 1* Increased strength and hardness.

Advantage 2 Increased production rates and reduced metal waste.

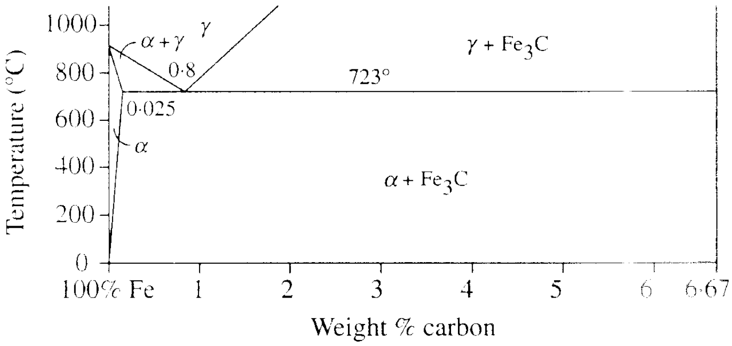
Candidates are encouraged to focus on the advantages in the properties of the finished bolt or in the manufacturing process. Suitable properties may be mechanical, such as improved toughness. They may also be physical, such as 'grainflow follows thread profile' or 'reduced planes of weakness at thread'. Service properties, such as 'improved wear resistance due to work-hardening at thread' or 'increased tensile strength', are also acceptable. Candidates are reminded that answers need to relate to engineering principles and that sketches can be used to explain written answers, as shown in the good response below.

Advantage 1 No directional properties.

Advantage 2 Work hardening increases toughness.

(c) *Two samples of cold-drawn 0.2% carbon steel stock are to be prepared for microscopic examination. One sample was process annealed. The second sample was normalised.*

(i) *With reference to the partial iron-carbon diagram, describe in detail the procedure used for each heat treatment process.*



Answer: 1 *Process annealing*

The 0.2% carbon steel is heated to below the lower critical temperature, soaked to allow ferrite to recrystallise and cooled to room temperature.

2 *Normalising*

Heat the steel above the upper critical temperature, soak until all austenite and then cool to room temperature in still air.

Many candidates did not clearly identify the correct heating temperature for process annealing and frequently omitted the soaking stage. Both these points are very important to the success of the process. Many other candidates described full annealing but did not show an understanding of the differences between this and process annealing. In some cases the response described the purpose of the treatment or its affect on grain structure but did not describe the actual process. It is essential that candidates concentrate their answer on the question being asked.

1 **Process annealing**

The steel is heated to just below the L.C.T. (723°) and soaked for a predetermined time. It is then cooled slowly. The ferrite will recrystallise while the pearlite remains elongated.

Some candidates were able to show a deeper understanding of the topic by describing correctly both the process and its effect on grain structure.

Candidates had a good general knowledge of normalising as a heat treatment process but often did not provide enough specific detail about the heating temperatures required and the cooling rate. As with the process annealing, the soak stage was often overlooked. Soaking is necessary to allow the whole mass to heat through and obtain a uniform temperature. When revising, candidates are encouraged to summarise processes in stages using key points:

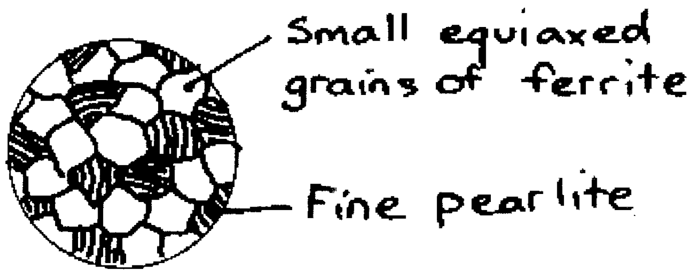
– heating details;
– soaking time;
– cooling rate.

2 Normalising

The steel is heated into the γ region and allowed to cool in air creating recrystallised grains of small size

(ii) *Draw and label the microstructure resulting from the normalising process.*

This question showed an improvement from previous years in the quality of drawings and labels, with most candidates giving more carefully drawn responses. Future candidates are reminded that carelessly drawn microstructures that appear to contain voids between the grains are not acceptable. Labels and leaders pointing to the relevant parts of the microstructure both need to be clear. Candidates are also reminded that they do not need to fill in the entire space, if time is short, as it is far better to draw carefully in part of the space so that the entire structure is adequately represented. A good student response is given below:



(iii) *Normalising and process annealing result in different mechanical properties. State which heat treatment process results in:*

1 *higher strength*

2 *higher hardness.*

Answer: *1* Normalising

2 Normalising

This question was not well answered as the properties associated with process annealing were not well known to candidates. When revising, candidates are encouraged to summarise processes in table form as shown below.

Name of Process	*Description of Process*	*Purpose*	*Resulting Structure*	*Properties*

Question 12

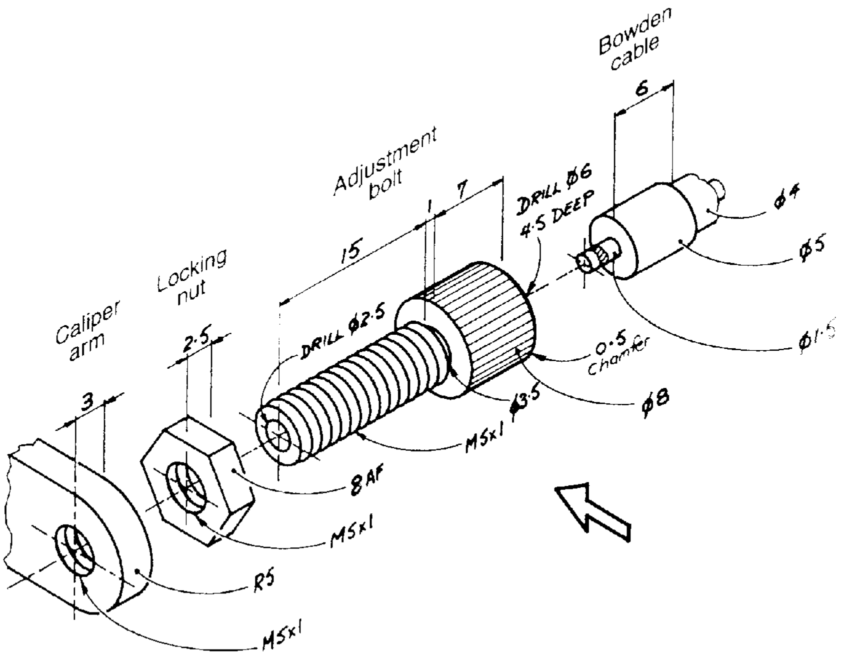
Shape and size details of a brake-cable tensioning assembly for a bicycle are given below in the exploded pictorial drawing.

The head of the adjustment bolt is 5 mm from the caliper arm.

The centre cable of the Bowden cable should extend 1 mm beyond the end of the adjustment bolt.

The position of the left end of the adjustment bolt has been given.

Complete, using a scale of 5 : 1, a half-sectioned front view of the assembled parts when viewed in the direction of the arrow.



This question examines aspects and disciplines in Engineering Drawing including: interpreting and reading pictorial representation of engineered components; assembly drawing; detail drawing; sectioning of components; and application of AS 1100 drawing standards.

The mean was slightly below half marks for this question, with very few candidates receiving full marks or zero.

The marking scale is designed to objectively and consistently recognise and reward all correct responses made by candidates. In designing the marking scale, the correct solution is broken into a number of components, or features, and these are then examined for: representation of the shape concept; size; relationship with other features; and representation according to the AS1100 drawing standards.

As an example, the drill hole of 6 mm diameter and 4.5 mm length, in the question, would be broken down into the following four responses for marking:

Drill hole outline, shape of the end of the drill hole, diameter 6 mm, length 4.5 mm, 60º angle for the drill end.

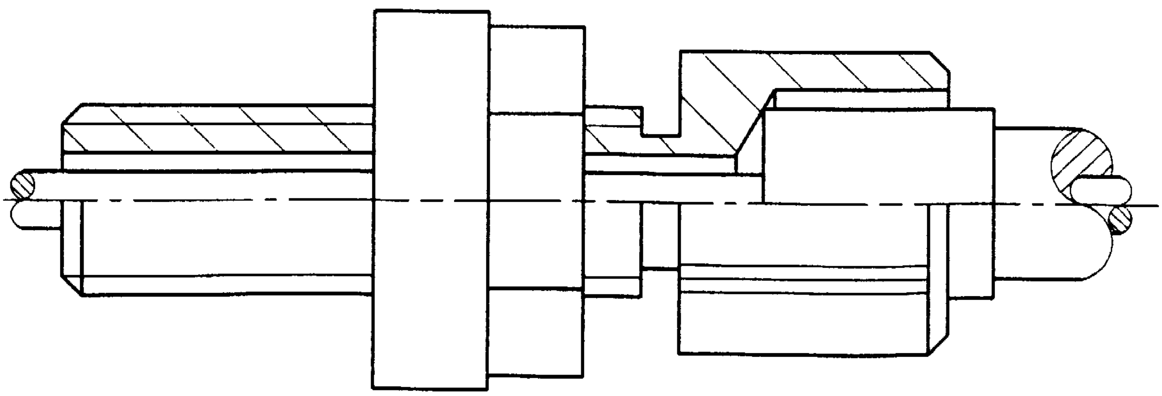
All components are treated in this manner by allocating a tick to each aspect of the component. This system follows every step which is taken by the student to complete the response to the question.

Once the ticks for each component are totalled, a conversion scale is used to convert the number of ticks obtained to a final mark. For example, a candidate who totals 34 correct responses would score a final mark of 9.5 for the question this year. The conversion process allows candidates to achieve full marks and marks in respect to the correctness of the solution. The marking detail is included below.

Adjustment Bolt	Shank	, 45°,	✓ ✓ ✓	
	Thread	, ø5, 0.5, Thin Black	✓ ✓ ✓ ✓	
	Shoulder	, L15/16	✓ ✓	
	Step	, ø3.5, L1	✓ ✓ ✓	12
	Head	, ø8, L7, , L0.5	✓ ✓ ✓ ✓ ✓	5
	Hole	, ø2.5	✓ ✓	
		, ø6, L4.5, 60°	✓ ✓ ✓ ✓	6
		½ Sect. Concept, Spacing, Thin Black	✓ ✓ ✓	
		Knurl, Spacing, Thin Black	✓ ✓ ✓	6
Locking Nut		, 8AF, T2.5, ½ Sect. Concept, Position	✓ ✓ ✓ ✓ ✓	
Caliper Arm		, R5, L3, ½ Sect. Concept, Position(5mm)	✓ ✓ ✓ ✓ ✓	10
Bowden Cable	Centre	, L1, , ø1.5, extend out R	✓ ✓ ✓ ✓ ✓	
	End	, ø5, L6, Position	✓ ✓ ✓ ✓	
	Casing	, ø4	✓ ✓	11

0-1	2-3	4-5	6-7	8-9	10-11	12-13	14-15	16-17	18-19	20-21	22-23	24-25
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
26-27	28	29	30-31	32-33	34	35	36-37	38-39	40-43	44-46	47-50	
13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	

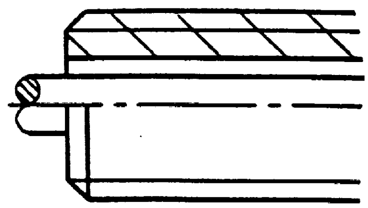
Answer:



The candidates' responses to this question indicated a reasonable knowledge of general assembly drawing; however some aspects of the question were poorly answered. Many candidates failed to display an understanding of the practical manufacture, assembly and use of machined parts. This was made evident by: failure to assemble the nut against the caliper; poor understanding of the drilling and cutting of an external thread; and not sectioning the adjusting bolt as one complete solid piece of metal. This could be redressed by examining a wide range of components/parts of the integrated topic area, discussing their manufacture, measuring and sketching views, sectioning and assembly.

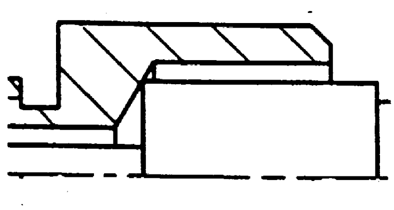
The concept of half-sectioning was poorly understood. Many candidates included full sections, and often included hidden detail. This meant that features such as the parallel knurl were not shown, and therefore marks could not be awarded.

Candidates' understanding of the drawing standards was generally poor.

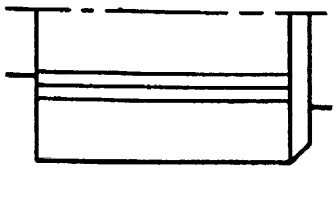


Representation of an external thread. Appropriate thick and thin lines are required. In this case the thread on the adjusting bolt is external, thus the minor diameter of the thread is thin, because it shows the depth of thread. The major diameter is thick as it represents the outside of the bolt.

Representation of the drill end. This should have an included angle of 120º to represent the surface left by the drill in a blind hole. The drawing below also shows the Ø2.5 mm hole meeting the Ø6 mm hole and the correct location of the Ø5 swagged end when fully assembled.

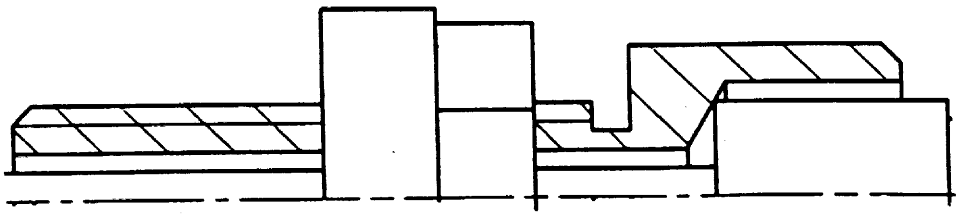


Representation of commonly used machine features, eg. straight knurling.



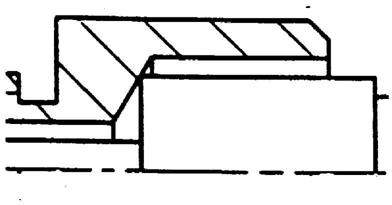
Detail of knurl

Sectioned surfaces. Some candidates still include too many lines, too close together, wasting valuable examination time. Many also failed to hatch the threaded area. Section lines are thin, dark lines.



Detail of sectioning

Candidates also generally failed to interpret correctly and therefore failed to represent the continuing Bowden cable through the adjusting bolt. Many candidates were also unable to represent correctly the end of the cable with a standard break.



Drawing of end of cable

Areas where markers felt there has been a pleasing improvement in candidate responses include: overall shape and sizes of most features, including lengths and diameters; interpretation of the pictorial drawing; drawing the object to the stated Scale of 5:1; and the higher accuracy of the drawings.

Advice to candidates for this type of question includes: take care with the size of the components so that they are drawn accurately; learn AS1100 drawing standards for things like threads, knurls, flats, nuts, bolts and hatching; do not erase any construction lines; use two different clutch pencils for drawing, eg. 0.25 and 0.5 so that variation in line thickness can be easily distinguished. For some candidates 0.25 and 0.7 may be more suitable for their drawing 'hand'; and separate the examination booklets (Sections I and II) to make the drawing easier.

From a teaching point of view, candidates should be given a practical 'hands-on' approach so that they may better understand drilling, tapping of a hole and then cutting the piece in half to view the appearance before sketching or drawing the component. The candidates need to dismantle the components of a bike, lawn mower and braking systems. It has been repeated a number of times in this report that candidates need to examine as many real components of the topic areas as possible. It is obvious by candidates' responses through the paper that many candidates have not examined or discussed the components as would be expected.

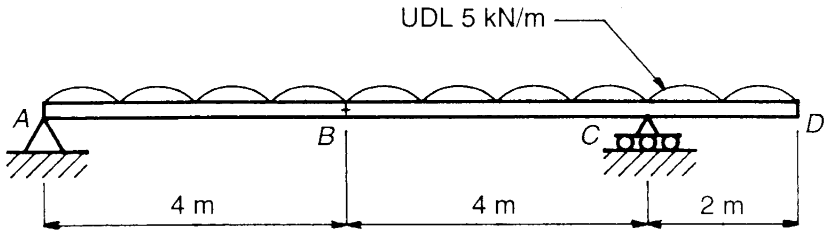
The candidates also need to be familiar with the names and meaning of machining and manufacturing such as drilling, tapping, parting off, knurling and swagging.

3 Unit (Additional)

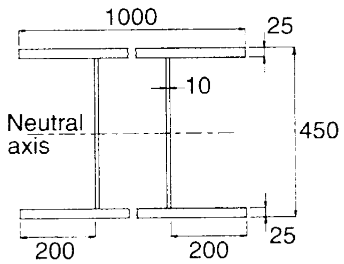
Section I

Question 1

(a) A small steel box girder is to be used as a footbridge, as shown in the diagram below. The girder is simply supported at A and C. The cross-section of the girder is also given. The steel used in the box girder has a density of 7800 kg/m³. The bridge has a uniformly distributed load of 5 kN/m applied.



(i) Determine the weight of the box girder



C.S.A. $= 2 \times 1000 \times 25 + 2 \times 400 \times 10$

$= 58\,000 \text{ mm}^2$

Total V $= 58\,000 \times 10\,000 \div 10^9$

$= 0.58 \text{ m}^3$

Mass $= 0.58 \times 7\,800 = 4\,524 \text{ kg}$

Weight $= 5\,524 \times 9.8$

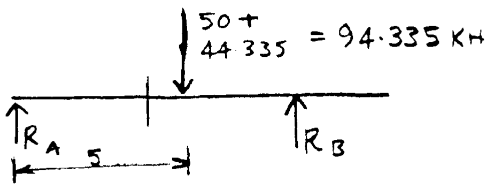
Answer: Weight 44335 N

The first step in solving this problem is to find the volume of the composite shape. Weight can then be found by multiplying the volume by density and $g = 9.8 \text{ ms}^{-2}$.. Candidates had difficulty in calculating the cross-sectional area. Mistakes converting mm to metres were common as well as the incorrect length of the web as 450 rather than 400 mm. Another common error was failing to multiply the cross-sectional area by the length of the beam (10 m) to find the volume. Generally the conversion to weight force was done well.

Points that may prove useful in solving this type of question include:

- shading each part of the composite shape as they are included in the calculation;
- cross-sectional area must always be multiplied by a length to calculate volume;
- candidates should convert the answer to the units required in the answer space, in this case, Newtons (N).

(ii) Determine the reactions at A and C



Total Applied Load $= 5 \times 10$

$= 50$ kN

$+\Sigma M_A = 0$

$0 = -94.335 \times 5 + 8R_c$

$R_c = 58.96$

$+\uparrow\Sigma V = 0$

$0 = R_A - 94.335 + 58.96$

$R_A = 35.37$

Answer: Reaction at A 35.37 kN

Reaction at C 58.96 kN

The total load on the beam is equal to the combination of the applied load and self weight. For a moment calculation the self weight can be assumed to act at the centre of the 10 metre beam. Candidates then had to apportion the load to the supports.

This was a straight forward question but many candidates made elementary mistakes, such as not including the self weight of the girder and incorrectly summing moments by confusing distances and signs.

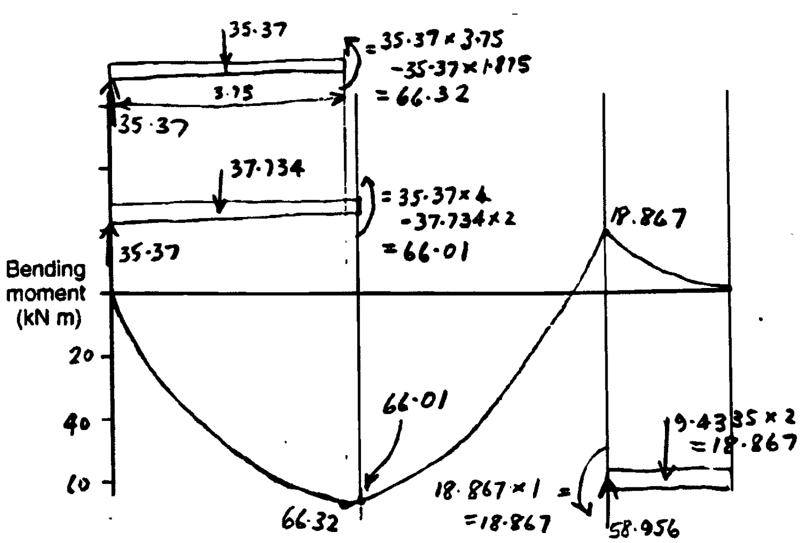
In reaction calculations it is important to:

– draw a free body diagram to identify the forces acting at their correct position;

– keep consistent units throughout the calculation.

(iii) Draw the bending moment diagram for the bridge. Label the values at points B and C.

Answer:



Load / metre

$= \dfrac{94.335}{10}$

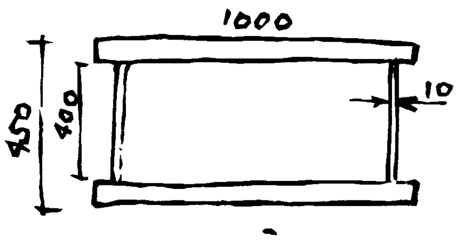
$= 9.4335$ kN/m

Values of the bending moments at points B and C can be found by taking sections and calculating the value at that section. For a given sign convention for bending moment, it must be remembered that the signs will be opposite for a left and right section. Any free end on a beam will always have a bending moment equal to zero. Most candidates recognised that the position of maximum bending moment (which was not required on this occasion) occurs where the shear force is equal to zero. Few candidates, however, calculated the correct value of the bending moments at B and C and therefore failed to draw the correct curve for the diagram.

The following are useful points to consider when drawing a bending moment diagram.

- When calculating the bending moments along a beam, choose to work with a left or right section and not a combination.
- Check to see if there is a self weight that must be included.
- A uniformly distributed load can be taken as acting at the mid-point of a beam or section for calculations.
- A uniformly distributed load will result in a curved bending moment shape
- When isolating a section for investigation, include all forces acting at their correct distances and be sure to use a consistent sign direction.

(iv) The maximum bending stress (225 mm from the neutral axis) is limited to 150 MPa. Determine the maximum bending moment that can be applied to the girder.



$$I = \frac{1000 \times 450^3}{12} - \frac{980 \times 400^3}{12}$$

$$= \frac{91.125 \times 10^9}{12} - \frac{62.72 \times 10^9}{12}$$

$$= 2.367 \times 10^9 \text{ mm}^4$$

$$\sigma = \frac{My}{I}$$

$$M = \frac{\sigma \times I}{y}$$

$$M = \frac{150 \times 10^6 \times 2.367 \times 10^{-3}}{0.225}$$

$$= 1578 \times 10^3 \text{ Nm}$$

Answer: Maximum bending moment 1578 kNm

The second moment of area (I_{xx}) of a composite shape can be found using the equation for the basic shape of a rectangle.

$I_{\text{beam}} = I_{\text{total shape}} - I_{\text{space between flanges}}$

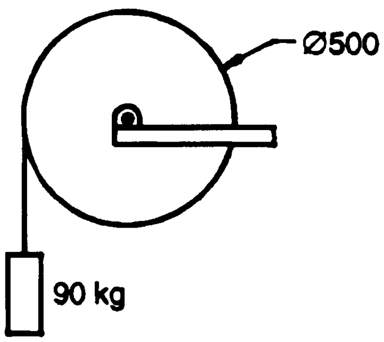
Generally candidates found it very difficult to manipulate and correctly substitute into the above equation. They performed better in the second part of the question.

Hints for teachers and candidates:

- Consistency of units is of utmost importance. Candidates are encouraged to choose a system of units that they understand and then practise using this system in the bending stress equation.
- Practice calculating I_{xx} for different composite shapes

(b) *The pulley shown in the diagram below is used to raise a mass of 90 kg. The pulley has a moment of inertia of 14 kg m^2.*

Determine the energy required to accelerate the load from rest to a velocity of 6 m/s in a distance of 10 m.



$$\begin{aligned} \varpi &= \frac{v}{r} \\ &= \frac{6}{0.25} \\ &= 24 \text{ rads/sec} \end{aligned}$$

$$\begin{aligned} \Delta E &= \Delta PE + \Delta KE_{Load} + \Delta KE_{pulley} \\ &= mgh + \_mv^2 + \_I\varpi^2 \\ &= 90 \times 9.8 \times 10 + \_ \times 90 \times 6^2 + \_ \times 14 \times 24^2 \\ &= 8\,820 + 1\,620 + 4\,032 \\ &= 14\,472 \text{ J} \\ &= 14.472 \times 10^{-3} \text{ MJ} \end{aligned}$$

Answer: Energy 14.472×10^{-3} MJ

The energy of the system, with the load accelerated upwards a distance of 10 m, is made up of the increase in PE and the KE of the mass as well as the increase in the rotational KE of the pulley.

Candidates struggled to correctly identify the three separate energy components of this question. Some candidates approached the solution by a force/torque method of finding the total work done through a rotational displacement of 40 radians. This method also involved the recognition of three separate components of work done by the system.

Hints for teachers and candidates:

– Consistency of units is of utmost importance. Candidates are encouraged to express the logic of their solution in simple terms such as:

  Energy = PE $_{load}$ + KE $_{load}$ + KE $_{pulley}$

– Careful setting out and substitution into each formula should help to eliminate mistakes.

The following is an example of the combination of energy and work methods.

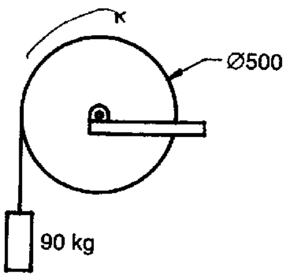
$I = 14\ kgm^2$

$v = 6\ ms^{-1}$

$r\omega = v$

$0.25\omega = 6$

$\omega = 24\ rad\ s^{-1}$



$\omega_f^2 = \omega_i^2 + 2\alpha\theta$

$24^2 = 0 + 2\alpha \times 40$

$\alpha = 7.2\ rad\ s^{-2}$

$T = I\alpha$

$T = 14 \times 7.2$

$T = 100.8$

$2\pi r = P$

$2 \times \pi \times 0.25 = P$

$P = 1.57\ m$

$\frac{10}{1.57} = s$

$s = 6.36$ revs

$\theta = 40$ radians

$e = mgh + T\theta + \frac{1}{2}mv^2$

$e = 90 \times 9.8 \times 10 + 100.8 \times 40 + \frac{1}{2} \times 90 \times 6^2$

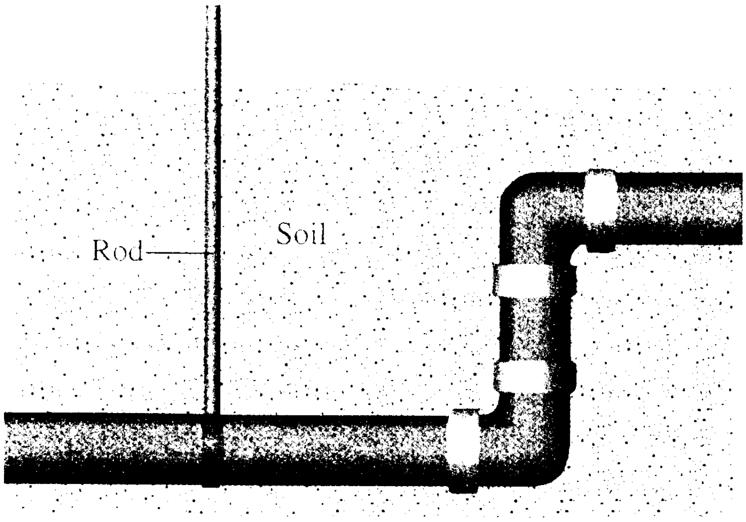
$e = 14472\ J$

$e = 0.014\ MJ$

Energy ..0.014.. MJ

Question 2

(a) To prevent corrosion of an underground iron pipe, a rod is connected to the pipe as shown in the diagram below.



(i) Using the standard electrode potentials, state the most suitable metal for the rod.

Electrode Potentials	
$Ag^{+} + e^{-} \rightarrow Ag$	+ 0.80 V
$Cu^{2+} + 2e^{-} \rightarrow Cu$	+ 0.35V
$Mn^{2+} + 2e^{-} \rightarrow Mn$	– 1.05V
$Fe^{2+} + 2e^{-} \rightarrow Fe$	– 0.41 V
$Mg^{2+} + 2e^{-} \rightarrow Mg$	– 2.36V

Answer: Name of metal Magnesium (Mg)

This question was well answered with most candidates recognising that Mg had a lower electrode potential than Fe although Engineering Science textbooks usually indicate electrode potential with the reverse sign. ie. Mg is usually shown as $Mg = Mg^{2+} + 2e^{-}$ (+2.36V). Candidates need to be aware that electrode potential tables can be listed with either sign convention.

Some candidates reasoned that the rod was a means of supplying an impressed voltage, therefore they chose copper as the most suitable metal as it is a good conductor. Impressed voltage was then given as their answer for part ii. These answers were accepted because the diagram illustrated the rod extending to the surface, which is not normally the case with sacrificial anodes.

(ii) Name and describe the process by which the rod aids in the prevention of corrosion.

Answer: Name — Cathodic Protection (sacrificial anode)

Description — By placing the iron pipe in contact with the magnesium pipe which is above it in the galvanic series. The more active magnesium becomes the anode.

Candidates who recognised the example as a sacrificial anode situation gave very good responses.

(iii) Pure aluminium is another metal that could have been used for this purpose. In practice it is not recommended. State the reason.

Answer: Reason – Aluminium exhibits 'passivity' due to formation of a thin protective oxide film on the surface.

Generally well answered, although some candidates obviously had no knowledge of passivity and answered in terms of other properties such as softness and ductility which are irrelevant in this case.

(iv) Name and describe TWO other preventative measures that could be used to reduce corrosion of the iron pipe.

Answer:

Method 1

Name	Surface Coating: Paints etc.; metal coatings (hot dipping); oxide films; ceramic and plastic coatings.
Description	Seal the iron pipe from contact with the surrounding environment by means of protective coating.

Method 2

Name	Impressed Voltage
Description	Connection to DC power source, supplying the pipe with excess e^- thereby preventing corrosion by making the pipe cathodic.

This was a straight-forward question which was well answered.

(b) (i) Explain the term intergranular corrosion.

Answer: Corrosion that occurs along the grain boundaries (a potential difference exists between the grain boundaries and the rest of the alloy).

Some candidates did not understand that intergranular corrosion is corrosion between the grain and the grain boundary.

(ii) List TWO causes for this type of corrosion.

Answer:

1. Precipitation of a phase occurs faster at grain boundaries; coring; change in composition across each grain.
2. Presence of impurities; Area of high energy; Potential difference at grain boundaries.

   Presence of more than one phase in the metal.

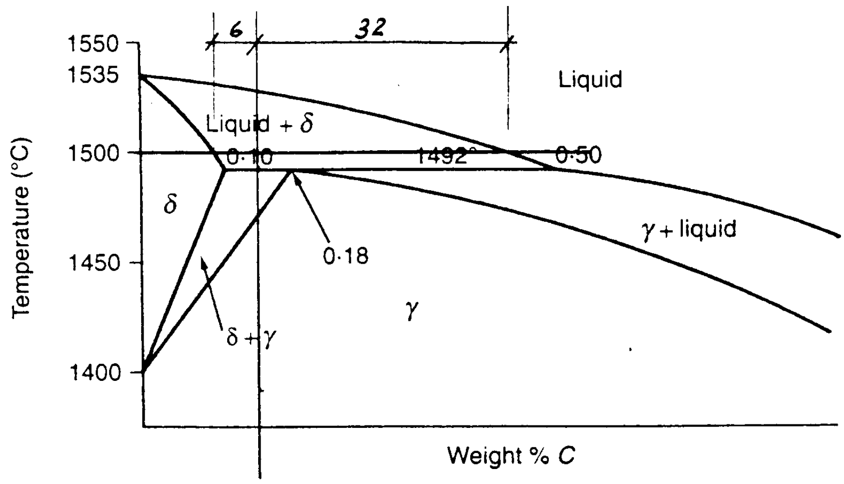
   Different grain orientations in pure metal.

Candidates need to understand that there are a number of possible causes of this type of corrosion.

Teaching Hint

In studying corrosion, candidates need a knowledge of electrode potential, how to combine them and how to distinguish, from an electrochemical table, which metal will be the anode and cathode depending on their position in the table. Candidates need to understand the principles of sacrificial anodes (cathodic protection) by identifying which metals will be anodic and therefore protect metals which are cathodic. They also need to understand the common mechanisms of corrosion, eg anodes corrode by giving up electrons which flow to the cathodes. Candidates also need to understand the common types of corrosion, where they occur and suitable methods of prevention.

(c) *Part of the iron-carbon equilibrium diagram is shown below. An alloy of 0.15% carbon is cooled under equilibrium conditions from 1550° C to 1400° C.*



(i) *Name the phases present and determine the proportion of these phases for this alloy at 1500° C.*

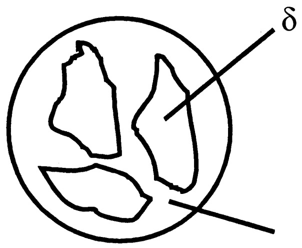
$$\text{Liquid} = \frac{6}{38} \times \frac{100}{1} = 15.8\%$$

$$\text{Solid} = \frac{32}{38} \times \frac{100}{1} = 84.2\%$$

Answer:	Name of phase 1	Liquid	Proportion 16 %
	Name of phase 2	δ Iron (Solid)	Proportion 84 %

Most candidates successfully understood and applied the lever rule to find the phase proportions although the diagram not having a horizontal scale meant a greater tolerance of answers was accepted.

(ii) In the space provided, draw and label the microstructure of the alloy at a temperature of 1490° C.



This question was poorly answered with many candidates not recognising the phases present and how to represent them in a microstructure. Many candidates incorrectly drew their microstructures containing a eutectic (lamellar) structure.

(iii) Name and describe the reaction that occurs at 1492°C.

Answer: Name Peritectic Reaction

Description $L + \delta \Leftrightarrow \Upsilon$

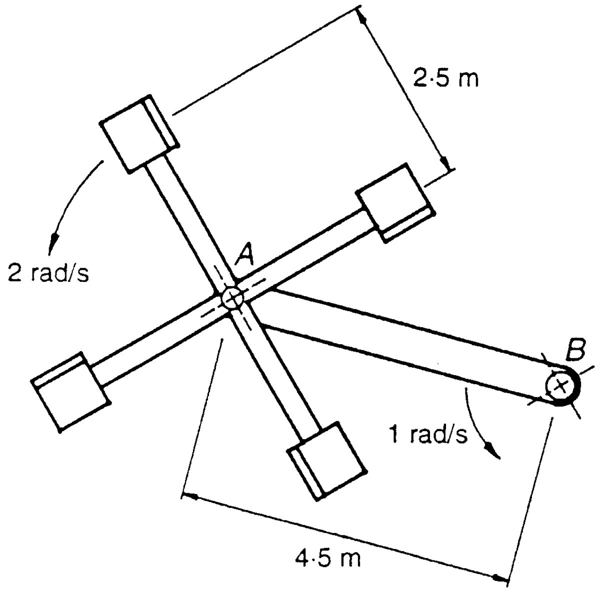
The remaining liquid solidifies and the alloy is single phase austenite in structure.

Generally well answered, but many descriptions did not show any understanding of the reaction beyond stating the formula.

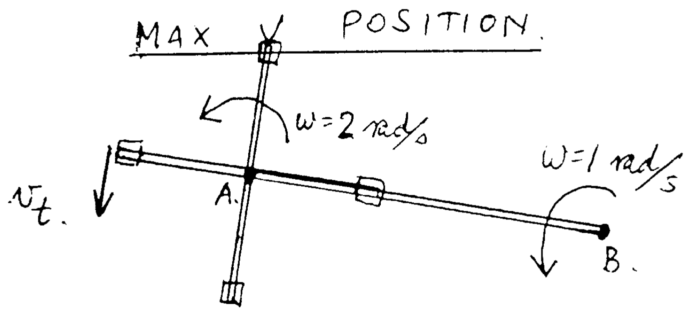
Section II

Question 3

The seats on an amusement park ride, shown below, rotate in the vertical plane. The arm rotates around axle B with a constant angular velocity of 1 rad/s. The minor arm rotates around axle A with a constant angular velocity of 2 rad/s.



(a) *Determine the maximum centrifugal force that an 80 kg person will experience during the ride.*



$v_{total} = \omega_B \times r_{max} + \omega_A \times r_A$
$= 1 \times 7 + 2 \times 2.5$
$= 12$ m/s

$$a_r = \frac{v^2}{r} = \frac{12^2}{7} = 20.57 \text{ m/s}^2$$

$F = ma_r = 80 \times 20.57 = 1\,646$ N

Answer: Centrifugal force 1 646 N

When the mass of 80kg lines up with the arm AB, it experiences a tangential velocity in the same direction (perpendicular to the arms) from both rotations. The total linear velocity v_t can be used to find the value of the radial force. Whilst many candidates recognised the maximum force would occur hen the arms line up with a radius of 7 metres, few candidates realised they could add linear velocities.

Common errors were:

Adding angular velocities with different origins.

1

$$F_c = m\omega^2 r$$
$$F_c = 80 \times (1 + 2)^2 \times 7$$
$$F_c = 5\ 040 \text{ N}$$

2

$$F = m(\omega_A^2 r + \omega_B^2 r_{max})$$
$$F = 80(2^2 \times 2.5 + 1^2 \times 4.5)$$
$$F = 1\ 360 \text{ N}$$

3

$$F = m(\omega_A^2 r + \omega_B^2 r)$$
$$F = 80(2^2 \times 2.5 + 1^2 \times 4.5)$$
$$F = 1\ 160 \text{ N}$$

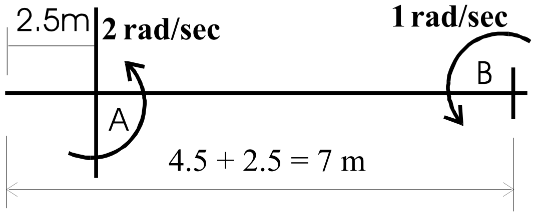
Candidates were not penalised for applying the incorrect formula supplied. The formulae sheet should have read:

$$F_c = \frac{mv^2}{r} = m\omega^2 r$$

When attempting this type of problem candidates should note:

- A free-body diagram identifying position of maximum force and the forces acting is essential in these types of questions.
- A clear understanding of what can be added together in this question is essential, ie angular velocities (ω) cannot be added as they have different origins, whereas linear velocities may be added as they are specific to the object and are vectors in the same direction.
- State your answer in force units as required by the question — candidates often failed to use F = ma after finding their acceleration.

(b) *Determine the maximum linear velocity that the person will experience.*



$$v_{max} = \varpi_B \times r_B + \varpi_A \times r_A$$
$$= 1 \times 7 + 2 \times 2.5$$
$$= 12 \text{ m/s}$$

Answer: Linear velocity 12 m/s

The linear velocities from each rotation are added together, as in the previous part. For the instant that the mass lines up with the major arm, the radius for the larger rotation is taken as 7 metres.

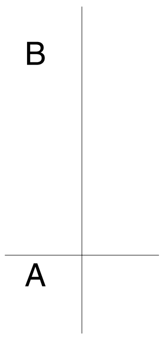
This part was generally well answered. The most common error involved candidates in calculating a linear velocity at A of 4.5 m/s then adding this to a relative velocity for the person of 5 m/s.

When attempting this type of problem candidates should note:

– always use a free body diagram to clarify the problem;

– it may be wise to complete a question on its own merits rather than transferring, possibly incorrect, data from a previous part.

(c) *Determine the maximum g force experienced by the person during the ride.*



Max g force occurs when the mass is in line with A and B and is directly below both.

$$\text{Max } a_r = 20.57 + 9.8$$
$$= 30.37 \text{ m/s}^2$$

$$\text{g force} = \frac{30.37}{9.8} = 3.1$$

Answer: g force 3.1 g

For the instant that the mass lines up with the arm AB and is at the bottom position, the maximum acceleration experienced by the 80 kg person will be found by combining the radial acceleration and the acceleration due to gravity. Comparing this calculated figure to the acceleration due to gravity gave the solution to the problem.

Few candidates were able to combine all the components of this question correctly. Some neglected the weight-force while others didn't realise that the arms needed to be vertical. Many candidates were confused by the 'g force' term, not realising that this was simply a ratio that compared the acceleration of the person to the acceleration of gravity. Some candidates incorrectly calculated a force in Newtons.

When attempting this type of problem candidates should realise:

– a free-body diagram will easily show that the position where maximum 'g force' will be experienced is in the vertically down position;

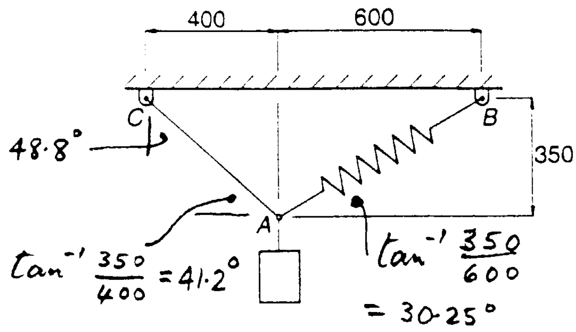
– 'g force', though called a force, has no units and is simply a ratio;

– a 'g force' is calculated by dividing an acceleration by an acceleration.

Question 4

An object is suspended from a beam by a non-elastic cable (AC) and a spring (AB), as shown in the diagram below. The unstretched length of spring AB is 660 mm. The spring stiffness is 475 N/m.

Determine the mass of the suspended object.

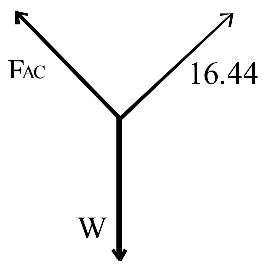


AB^2	$= 350^2 + 600^2$
AB	= 694.62
Extension	= 694.6 – 660
	= 34.62 mm
	= 0.0346 m

Force in the spring = kx

= 475 × 0.0346

= 16.44 N

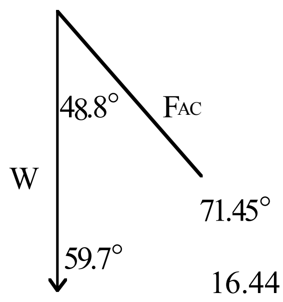


$$\frac{W}{\sin 71.46} = \frac{16.44}{\sin 48.8}$$

$$W = \frac{16.44 \times \sin 71.46}{\sin 48.8}$$

$$= 20.71 \text{ N}$$

$$m = \frac{20.71}{9.8}$$



Answer: Mass 2.1 kg

The force in member AB can be calculated by finding the extension of the spring and multiplying it by the spring constant. An equilibrium statement for forces acting at point A will yield a value for the weight force which can be divided by 'g' to give the mass. Very few candidates answered this question. Many students, when attempting to find the force in AB, erroneously used the extended length of the spring, 694.62 mm rather than the extension of the spring, 694.62 – 660 = 34.62 mm. A simple substitution into the equation F = kx gave the force in the member AB. Few candidates completed this simple manipulation.

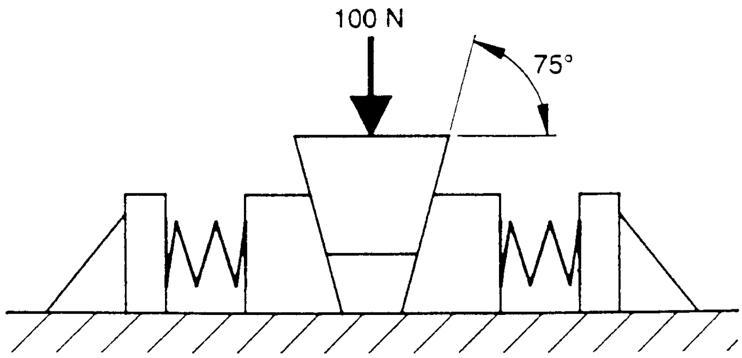
When attempting this type of problem candidates should note:

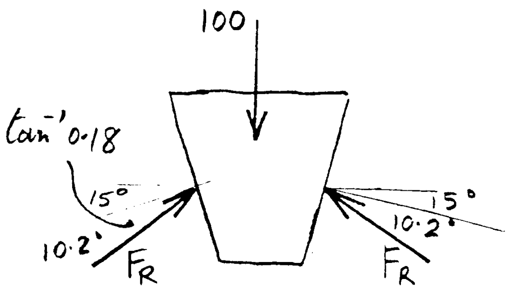
- identify the three forces acting at A by sketching a free-body diagram;
- the force in the spring is found by multiplying the extension by the spring constant;
- the spring constant is given in N/m so the extension must be expressed in metres;
- clearly identify each angle calculated as candidates often confuse angles on diagrams;
- an equilibrium force diagram, with clear arrows, is an important aid;
- ensure that the answer given is in the units required.

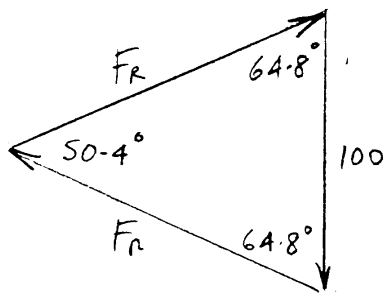
(b) *A system of wedges and springs is used to support a load of 100 N, as shown in the diagram.*

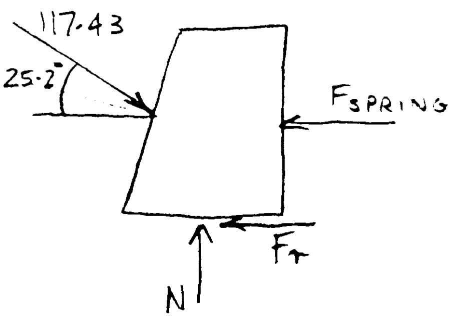
Determine the minimum spring constant for the springs used, necessary to prevent the load from moving down.

Neglect the mass of the blocks. The coefficient of static friction for all surfaces is 0.18.









$$\frac{100}{\sin 50.4} = \frac{F_R}{\sin 64.8}$$

$$100\,\frac{\sin 64.8}{\sin 50.4} = F_R$$

$$= 117.42$$

$N = 117.43 \sin 25.2°$
$= 50\text{ N}$

$F_R = 0.18 \times 50$
$= 8.99\text{ N}$

$\rightarrow + \Sigma F_H = 0$
$= 117.43 \cos 25.2° - 8.99 - F_{spring}$

$F_{spring} = 106.25 - 8.99 = 97.26$

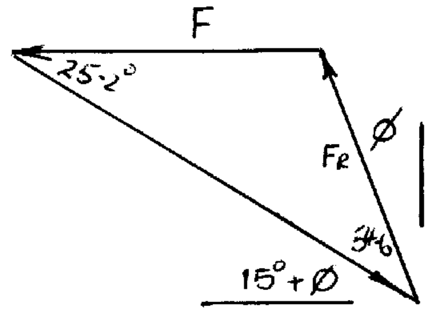
Data does not allow for calculation of spring contraction.

Therefore spring constant cannot be determined**.**

Answer: Spring constant N/m

An alternate solution using the angle of friction where you can identify the forces on the bottom wedge is given below.

FORCES ON BOTTOM WEDGE



$$\phi = \tan \mu$$

$$\phi = 10.2^\circ$$

$$F_R^2 = 50^2 + (0.18 \times 50)^2$$

$$\therefore F_R = 50.8$$

$$\frac{F}{\sin 54.6} = \frac{50.8}{\sin 25.2}$$

$$F = 97.3 \text{ N}$$

The force in the spring can only be determined if a free body-diagram of the sliding wedge is considered. The force between the wedges can be found by analysing the forces on the top wedge. Summing the horizontal forces in the sliding wedge will give the value of the force in the spring which needs to be divided by the contraction of the spring in order to find the spring constant. Unfortunately the data on spring contraction was not given in the question so those candidates who found the force in the spring were awarded full marks.

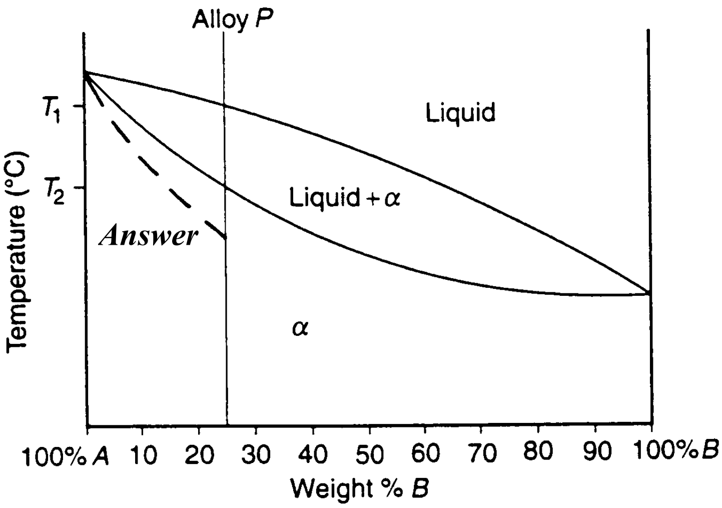
Very few candidates attempted this question and many of those who did appeared to struggle with the concept of friction and the angle of friction.

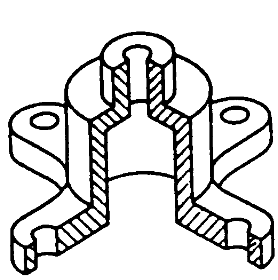
When preparing for this type problem it is important that candidates note:

- focus on an understanding of the forces acting on each wedge;
- don’t neglect friction when analysing the forces in the wedges as wedges depend on friction to work;
- gain a greater understanding of the concept of angle of friction;
- frictional force not only occurs between the wedges but also between the lower wedges on the horizontal surface and the normal reaction at this surface is simply a reaction to the 100 N external force.

Question 5

(a) *The thermal-equilibrium diagram of the alloy system for pure metals A and B is shown below. Alloy P is used to produce the die-casting as shown below. The die-casting is cooled under non-equilibrium conditions.*





(i) *On the thermal-equilibrium diagram, sketch the change in shape of the solidus for alloy P.*

Answer: See broken line above.

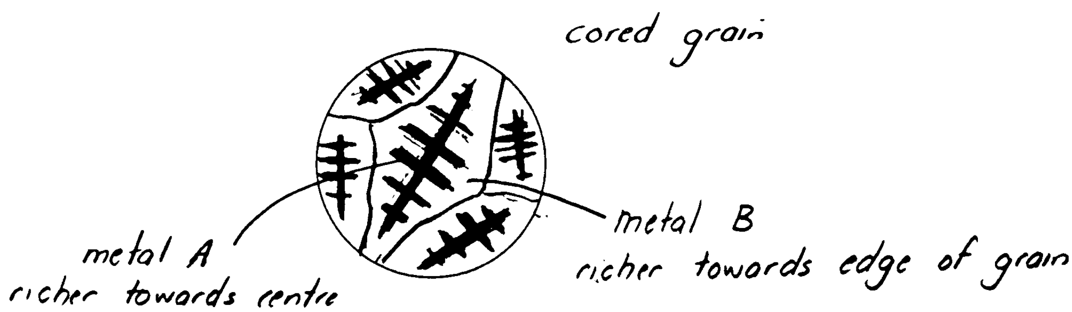
Most candidates were able to draw the non-equilibrium cooling curve.

(ii) *State the name given to the type of grain structure resultant in alloy P.*

Answer: cored grains

Many candidates failed to understand that cored grains are produced by atoms not having sufficient time for diffusion to occur, to even out the composition from the centre to the outside of the grain. Some candidates understood that homogenisation produces a uniform composition across the whole grain but failed to describe how it occurred.

(iii) *Sketch the cross-section of a grain of alloy P at room temperature. Fully label your sketch.*

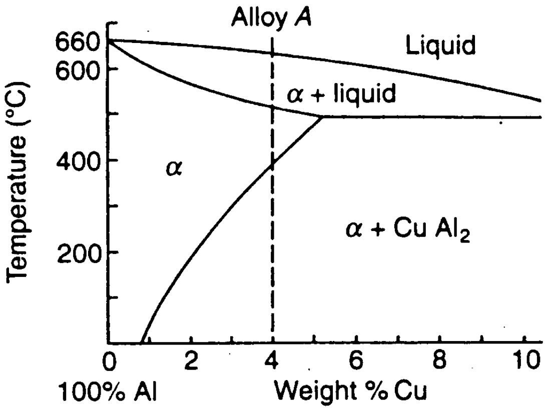


Many candidates did not know how to represent a cored grain. Labelling did not show a composition difference between the centre and the outside of the grain.

(iv) The die-casting is homogenised to alter the grain structure. Describe the effect that this process has at the atomic level of the grains.

Answer: Diffusion of the atoms of Metal A in B takes place giving a uniform composition across the grains ie. removes cored grains.

(b) A portion of the aluminium-copper phase diagram is shown below.

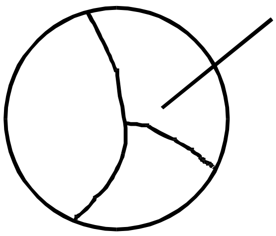


The process of age-hardening an alloy consists of two stages: solution treatment and ageing. Describe each of these stages. Draw and fully label the microstructure of alloy A after each stage.

Answer:

Solution treatment

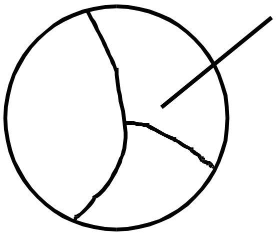
The alloy is heated to approximately 450^{o}C so that the Cu Al_2 is fully absorbed into the α solution. It is then quenched so that the copper atoms are held in super saturated solid solution within the aluminium.



solid solution of α

Ageing

The alloy is held at room temperature for five to seven days (or artificially aged – reheated to 120^{o} C) to allow a very fine precipitation of the Cu Al_2 throughout the matrix.

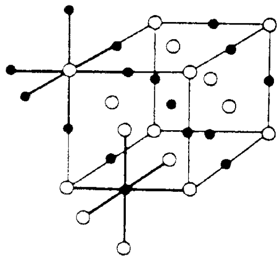


solid solution of α
submicroscopic precipitate ($CuAl_2$)

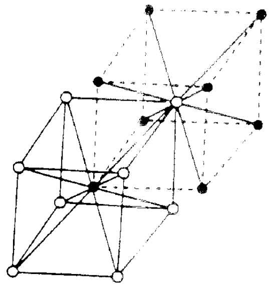
Candidates generally understood that the question involved the process of age hardening, but did not show understanding of the different steps involved. Many candidates could not draw and label the microstructures correctly.

Question 6

(a) The unit cells of sodium chloride and caesium chloride are shown below:



Sodium chloride (NaCl)
(● Na, ○ Cl)



Caesium chloride (CsCl)
(● Cs, ○ Cl)

(i) Name and describe the type of bond that exists between sodium and chlorine.

Answer: Name of bond — Ionic bond

Description of bond — Transfer of electrons forming +ve and –ve ions. These ions attract each other forming strong bonds.

This question was not well answered considering it was a very fundamental concept. Candidates should have a thorough knowledge of all the primary bonds (Ionic, Covalent and Metallic) and the arrangement of electrons within each bond.

(*ii*) *Determine the coordination numbers of the caesium chloride structure and the sodium chloride structure.*

Answer: Caesium chloride structure 8

Sodium chloride structure 6

Co-ordination numbers were correctly stated in most cases.

(iii) The coordination numbers of sodium chloride and caesium chloride differ. State a reason for this difference.

Answer:

Reason

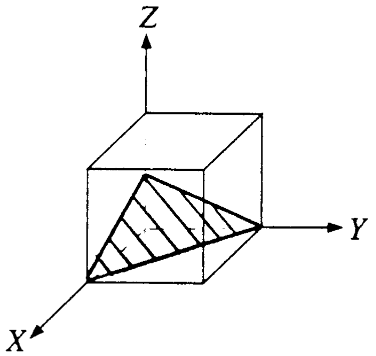
NaCl – because of the ion size ratio, equal number of Na ions and Cl ions (6 of each) are arranged in a cubic lattice. This gives a coordination number of 6.

CaCl – exhibits a higher ion size ratio giving a BCC type structure that has a coordination number of 8.

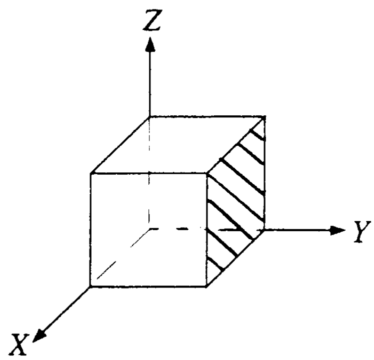
This proved to be a difficult concept for candidates to understand. The difference in co-ordination numbers resulted from the different lattice structures caused by the differing ionic radii ratios of the bonded elements.

(b) *(i)* *On the sketches below, draw the (112) plane and the (010) plane.*

Answer:



(112) plane



(010) plane

The planes were generally well drawn and this question was well attempted.

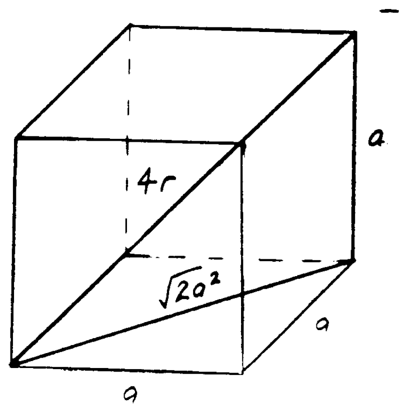
(ii) *State the Miller indices of the plane on which slip is more likely to occur in a body centred cubic structure. State a reason for your choice.*

Answer: Miller indices (110)

Reason – plane of higher atomic density

Many candidates incorrectly stated the Miller indices, but gave the correct response for the reason.

(c) *The atomic radius of an iron atom is 0.124 nm. Iron crystallises as BCC. Calculate the lattice parameter of the unit cell.*



$r = 0.124$

$4r = 0.496$

To find a, use Pythagoras' Theorem

$$(4r)^2 = a^2 + (\sqrt{2a^2})^2$$

$$(4r)^2 = 3a^2$$

$$\frac{(4r)^2}{3} = a^2$$

$$\sqrt{\frac{(4r)^2}{3}} = a$$

Answer: Lattice parameter 0.286 nm

A poorly answered question with many candidates having no idea of what a lattice parameter is or how to calculate it. Good candidates used a sketch as an aid in helping them calculate their answer. Some candidates calculated the parameter for a FCC lattice.

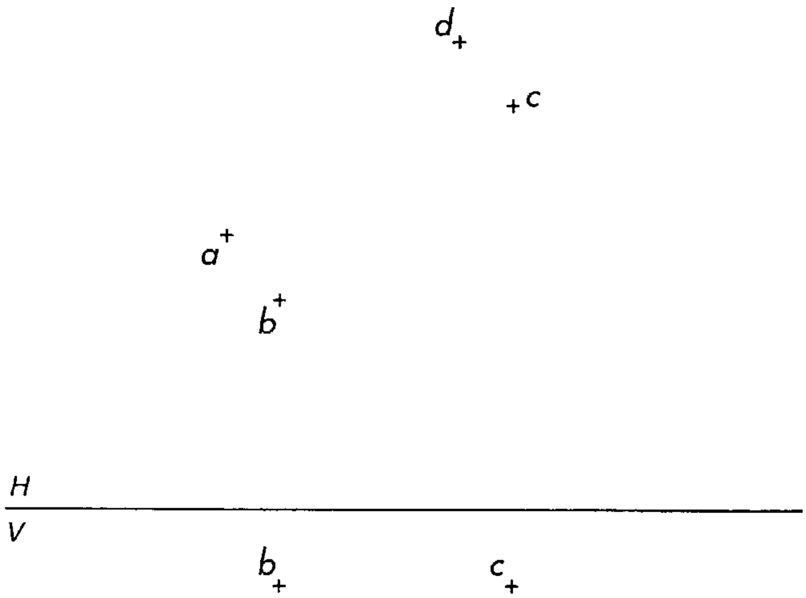
Section III

Question 7

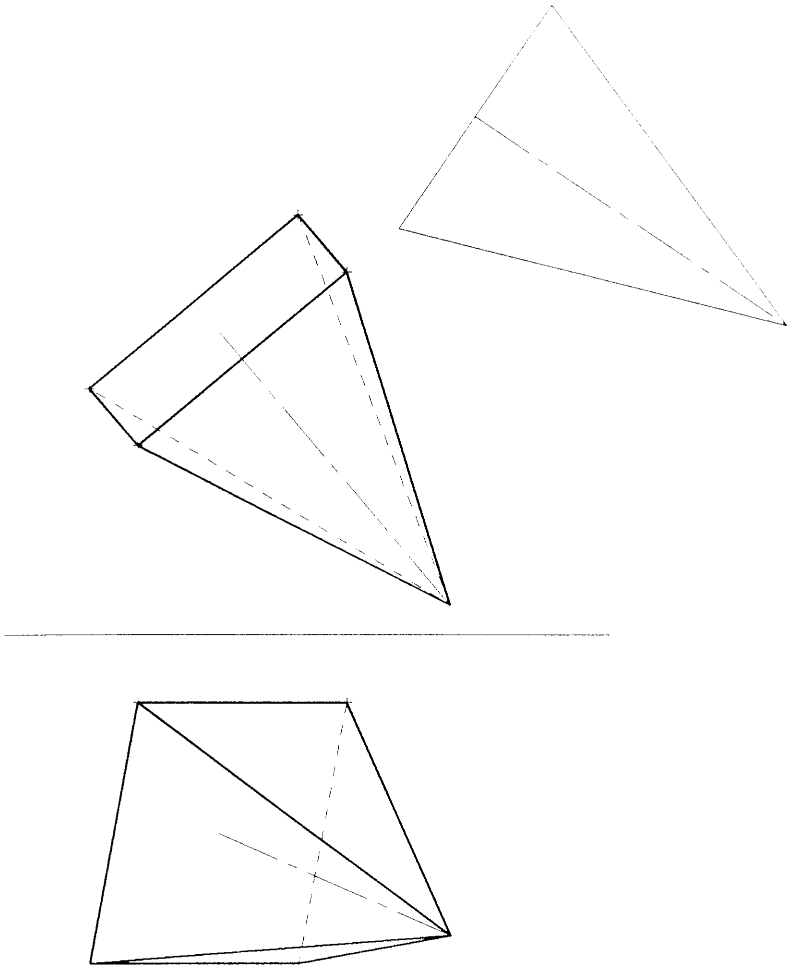
The top view of the corners of the base of a regular square pyramid, A, B, C and D, is given below. The front view of the corners B and C of the same square pyramid is also given below.

The pyramid has been inclined to both the horizontal plane and vertical plane. The length of the axis is 55 mm.

Complete the top view and the front view of the pyramid.



Answer:



The majority of candidates did not attempt this question. Those who did, failed to understand the need for an auxiliary view to find and use the 'true length' of the axis - projected to the top view. Candidates who visualised and completed a square pyramid in both views were rewarded with marks. Some candidates failed to realise that in a regular pyramid, the axis is perpendicular to the base. Overall, candidates were able to identify visible and hidden outline in both views.

Suggested steps to assist in the completion of a solution:

1. Join *abcd* in top view.
2. Recognise *ad* and *bc* as true lengths.
3. Project an auxiliary view perpendicular to the top views of *bc* and *ad* to give an edge view of base.
4. On the auxiliary view, draw the axis perpendicular to base and measure true length of 55 mm.
5. Project back to the top view and locate the apex position on the axis which is perpendicular to *ad* and *bc* .
6. Project down from the top view and using distances from the auxiliary view plot the base and apex in the front view.
7. Firm in the outline and complete the hidden detail.

Question 8

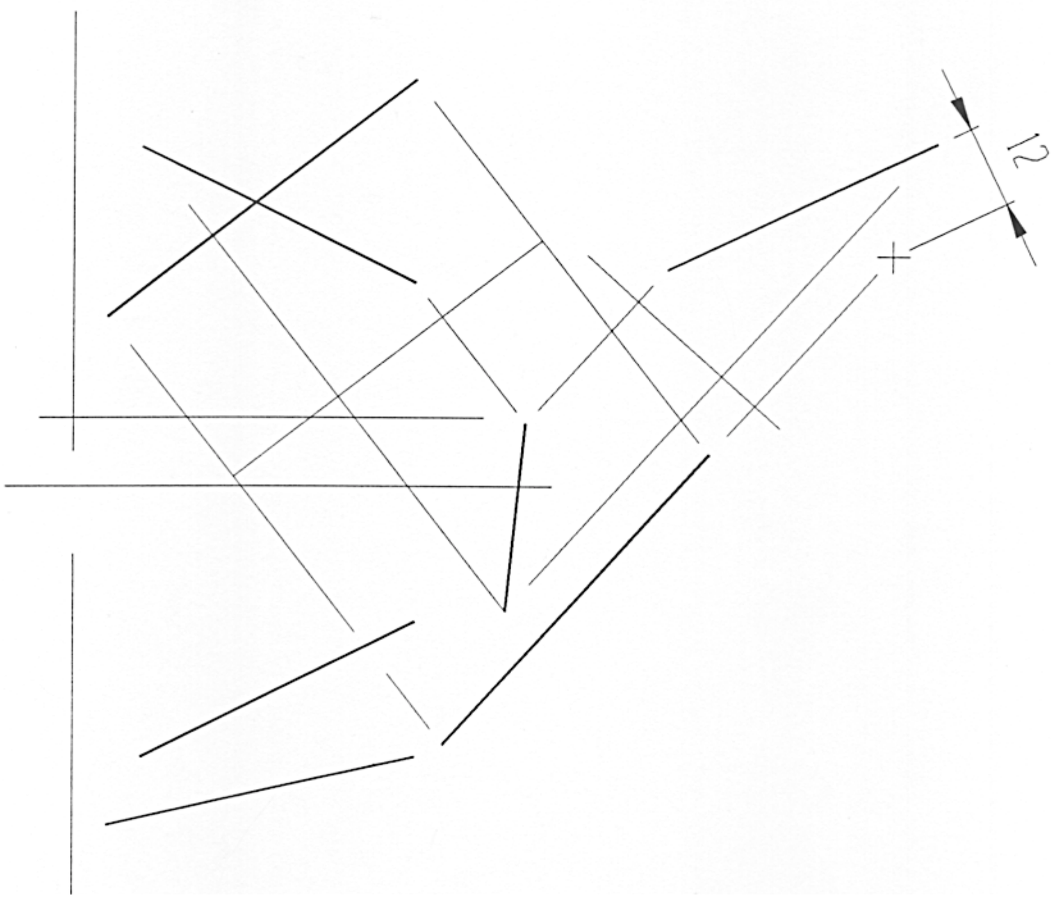
The coordinates of four points A, B, C and D are given in the table below.

	X	Y	Z
A	5	15	15
B	50	50	25
C	10	40	25
D	50	20	45

Draw the top view and the front view of the two lines AB and CD on the axes given below.

Graphically determine the shortest distance between the two lines AB and CD.

Answer:



The majority of candidates attempting this question were able to locate the points and draw the lines in both views. Some candidates confused the y and z directions. Most candidates realised that an auxiliary plane was necessary and attempted to find the true length of one line. Candidates who rotated the apparent view could not find a solution.

Some candidates, on establishing a true length view could not proceed to the next step; that is, to place a plane perpendicular to the true length line and project a point view. The shortest distance is then the perpendicular measurement between the line and the point.

This question produced a wide range with a significant number achieving full marks.

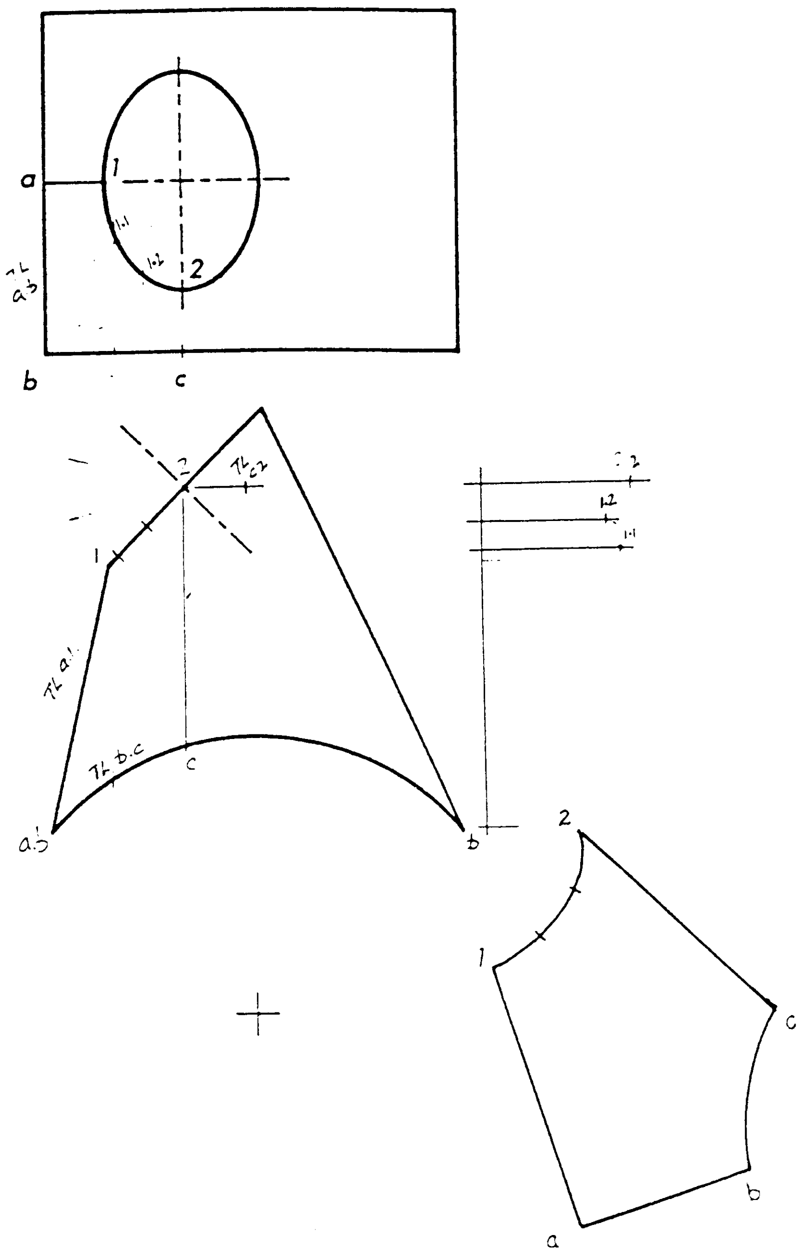
Candidates (and teachers) may find it beneficial to practise using co-ordinate geometry early in their drawing experience so that the correct coordinate standards are remembered.

Question 9

The top view and front view of a transition piece are shown below in a third-angle projection. Draw a pattern for the surface abc21.

The starting position for the seam a1 is indicated below.

Answer:



The development of the transition piece was a variation on a commonly asked question. Marks were awarded for recognising the need to triangulate the surface, establishing 'true lengths' for use in triangulation, plotting points and then making a suitable outline.

Some common mistakes were:

– failure to divide the portion of ellipse between points 1 and 2 into smaller sections to ensure accuracy.

– failure to recognise and draw curve *bc* which is given as a true shape in the original drawing.

– failure to accurately determine true lengths, particularly around the ellipse.

Suggested steps to assist in the completion of a solution:

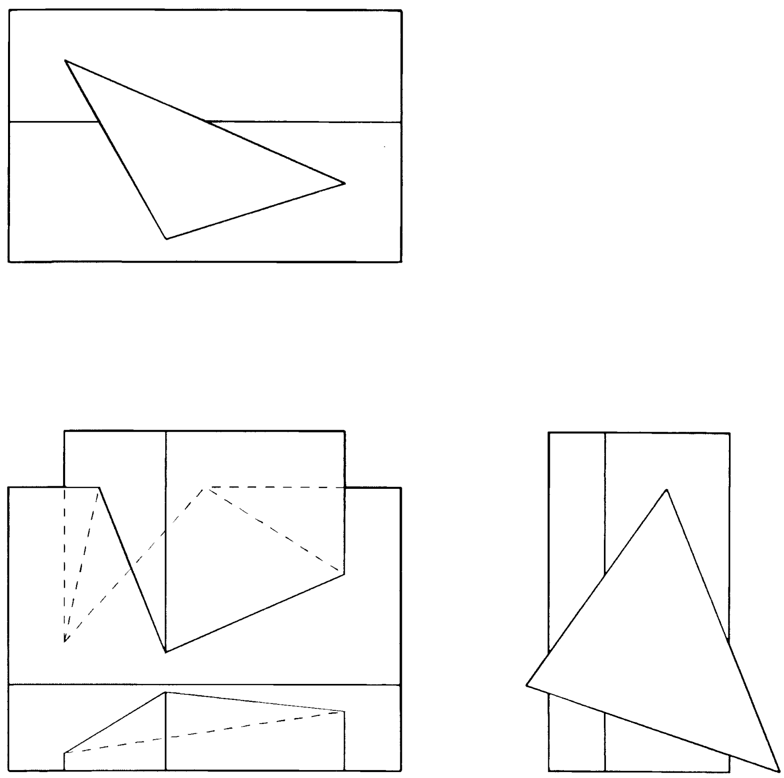
1. Triangulate surface *abc21* , dividing the section of ellipse *12* into at least three parts. Labelling these points is not essential but will assist in completing an accurate drawing.
2. Calculate all true lengths using a suitable method. Remember that both the straight line and curves need to be done. A true length diagram that combines 'front view heights' and 'top view lengths' may help to avoid confusion. Again, labelling is helpful.
3. Transferring these true lengths with a pair of dividers or compasses will assist accuracy.
4. Using only true lengths, complete the development commencing with triangle *1ab*. Curve *bc* is shown as a true shape on the given front view and can be drawn with a compass.
5. A thick black continuous outline is required.

Question 10

The top view, right-side view and incomplete front view of two intersecting triangular prisms are given below in third-angle projection.

Complete the front view, showing both visible and hidden outline.

Answer:



The solution to this problem fell into two parts:

- The correct location of eight points of intersection
- The visualisation of both visible and hidden outlines

Most candidates attempted this question, with the majority able to locate some points of intersection and some visible lines. An objective marking scale was employed and a wide spread of marks resulted.

Common mistakes were:

- seeing the horizontal solid as a cylinder.
- missing crucial hidden detail, particularly on the lower portion.

Suggested steps to assist in the completion of a solution:

1. Letter all lines in both views: then identify, and number in cyclic order, all intersection points in the top view. This doesn't achieve marks but avoids confusion.
2. Project these points to the front view either directly or via the right side view.
3. Identify the visibility of the lines of intersection in the front view by looking through the vertical plane at the top view. Join the points accordingly using the appropriate lines.