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

WACE
Western Australian Certificate of Education

Western Australian Certificate of Education
Sample Examination, 2016
Question/Answer Booklet

ENGINEERING STUDIES

Please place your student identification label in this box

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

In words _____

_____

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

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

Mechanical ☐

Mechatronics ☐

Number of additional answer booklets used (if applicable): ☐

Materials required/recommended for this paper
To be provided by the supervisor
This Question/Answer Booklet
Multiple-choice Answer Sheet
Data Book

To be provided by the candidate
Standard items: pens (blue/black preferred), pencils (including coloured), sharpener, correction fluid/tape, eraser, ruler, highlighters

Special items: up to three non-programmable calculators approved for use in the WACE examinations

Important note to candidates
No other items may be taken into the examination room. It is **your** responsibility to ensure that you do not have any unauthorised notes or other items of a non-personal nature in the examination room. If you have any unauthorised material with you, hand it to the supervisor **before** reading any further.

2014/10126

Structure of this paper

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: **Core content** Part A: Multiple-choice Part B: Extended answer	 10 3	 10 3	70	 10 45	 10 30
Section Two: **Mechanical** Part A: Multiple-choice Part B: Extended answer	 10 6	 10 6	110	 10 100	 10 50
Section Two: **Mechatronics** Part A: Multiple-choice Part B: Extended answer	 10 7	 10 7	110	 10 100	 10 50
				Total	100

Instructions to candidates

1. The rules for the conduct of Western Australian external examinations are detailed in the *Year 12 Information Handbook 2016*. Sitting this examination implies that you agree to abide by these rules.
2. Section One: You must answer **all** questions.

   Section Two: You must choose to answer only **one (1)** of the specialist fields. In the specialist field you have chosen, answer **all** questions.

   In both Section One and Section Two, answer the questions according to the following instructions.

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

   Part B: Extended answer
   Answer **all** questions. Write your answers in the spaces provided in this Question/Answer Booklet.
3. You must be careful to confine your responses to the specific questions asked and to follow any instructions that are specific to a particular question.
4. Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.
   - Planning: If you use the spare pages for planning, indicate this clearly at the top of the page.
   - Continuing an answer: If you need to use the space to continue an answer, indicate in the original answer space where the answer is continued, i.e. give the page number. Fill in the number of the question that you are continuing to answer at the top of the page.
5. The Data Book is **not** to be handed in with your Question/Answer Booklet.

See next page

Section One: Core content **40% (55 Marks)**

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

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

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

Suggested working time: 70 minutes.

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

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

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1. Brass and solder (lead/tin) are most appropriately classified as

   (a) pure metals.
   (b) ferrous alloys.
   (c) non-ferrous alloys.
   (d) composites.

2. A system has an input of 265 kW and an efficiency of 74%. The output of this system would be

   (a) 19.61 kW.
   (b) 196 100 W.
   (c) 358.1 kW.
   (d) 3.58 kW.

3. Global mobile phone ownership continues to increase, while the average life span of a mobile phone decreases. Manufacturers are under pressure to take greater responsibility for which one of the following stages of the mobile phone life cycle?

   (a) materials acquisition
   (b) processing materials
   (c) manufacture
   (d) reuse/recycle/disposal

4. The selection of the **best** light bulb for use in your bedside reading lamp should be based primarily on its

(a) power consumption.
(b) light output.
(c) life expectancy.
(d) cost.

5. When producing an orthographic drawing of a new product/design, the primary objective is to

(a) produce an attractive image suitable for the marketing of the product.
(b) produce as many drawings as required to show every surface of the product.
(c) clearly show all the essential dimensions/details of the product such that a third party could successfully manufacture it.
(d) allow for the accurate costing of the materials required.

6. A time line for a manufacturing task describes

(a) a series of dates by which each stage of the task should be completed.
(b) an estimate of the overall time taken to complete a task.
(c) the maximum time before starting on the task.
(d) the date at which the project must be completed.

7. The use of photovoltaic solar energy panels to produce electric power is described as being sustainable because these

(a) produce a continuous supply of electricity.
(b) do not consume any resources from the Earth in their operation.
(c) convert the Sun’s energy into electricity at very little cost.
(d) can be recycled at very little cost.

8. A ductile material would be used when it needs to be

(a) welded for fabrication.
(b) resistant to corrosion.
(c) deformed during fabrication.
(d) hardened to resist abrasion.

See next page

9. The surface area (A) of a cylindrical tank with a diameter of D and a height of H, including the top and bottom, is given by which one of the following?

(a) $A = \pi D^2 H + \frac{\pi D}{2}$

(b) $A = \pi D H^2 + 2 \pi D^2$

(c) $A = \pi D H + 2 \pi D$

(d) $A = \pi D H + \frac{\pi D^2}{2}$

10. An item of equipment could be described as being recyclable if

(a) it is accepted as waste at the local waste collection depot.
(b) it can be sold on to a new owner.
(c) all of its components can be reused for some other purpose.
(d) it is biodegradable and can be safely buried in the ground.

Section One: Core content

Part B: Extended answer **30% (45 Marks)**

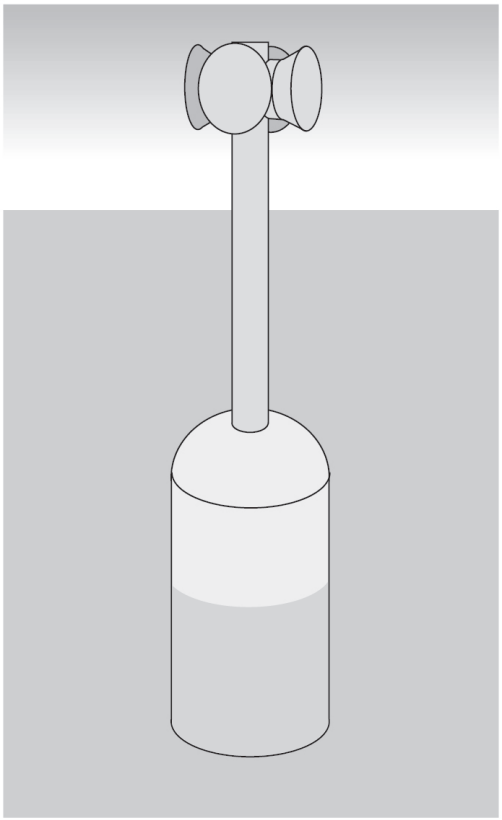
This part has **three (3)** questions. Answer **all** questions. Write your answers in the spaces provided.

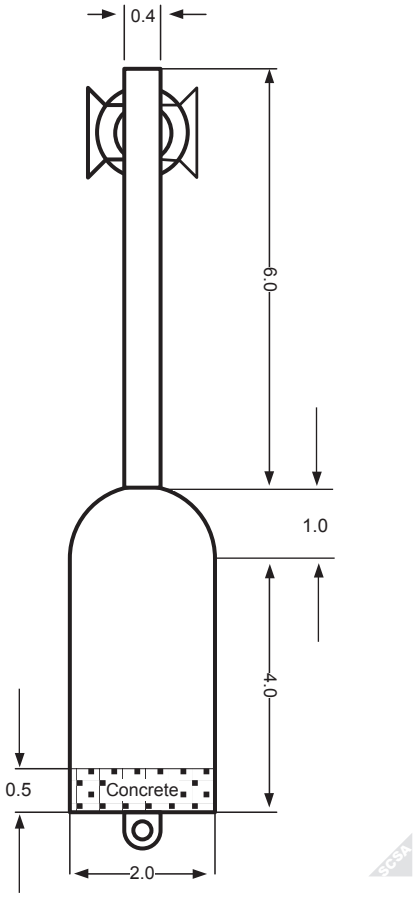
Spare pages are included at the end of this booklet. They can be used for planning your responses and/or as additional space if required to continue an answer.

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

Question 11 **(15 marks)**

The following drawings show a marine buoy of the type that is often used to mark navigation channels in the ocean. The buoy has a cylindrical body section with a hemispherical cap. It is topped by a cylindrical post on which four navigation lights are mounted. The buoy is held in position by an anchor chain connected to the lug at the bottom. To ensure that the buoy floats in an upright position it is partially filled with concrete.





Cross Section

The buoy is made from 8 mm thick stainless steel. Each of the navigation lights (and the associated electronics) weighs 300 kg. The anchoring lug weights 20 kg. All dimensions are in metres.

Show **all** workings.

(a) Show that the surface area of the buoy and post is close to 42.2 m^2 (exclude the lug and the lights). (7 marks)

See next page

Question 11 (continued)

(b) Using the surface area from (a) show that the total weight of the buoy, including all its parts, is approximately 7500 kg. (5 marks)

(c) If the buoy was floating in calm water, how far would it sink into the water? The buoy will displace an amount of water equal to its own weight. (3 marks)

See next page

Question 12 **(15 marks)**

(a) Smart phones are becoming essential communication tools in the modern world. The designers of the current generation of smart phones work with a long list of criteria for the phones they develop. Aside from the basic function of a phone to reliably receive and send calls or text messages, identify **four** other realistic criteria that you would expect to see used in the development of a new smart phone design that would improve its performance. For each criterion indicate how it contributes to the quality of the design.

(4 marks)

Criterion one: _____

_____

Criterion's contribution: _____

_____

Criterion two: _____

_____

Criterion's contribution: _____

_____

Criterion three: _____

_____

Criterion's contribution: _____

_____

Criterion four: _____

_____

Criterion's contribution: _____

_____

See next page

Question 12 (continued)

(b) Smart phone chassis, casings and circuitry are often made using a combination of plastic, stainless steel and aluminium. In the following table describe a property of each of these materials that makes them a popular choice for this application.
Note: the chassis is the internal structural support (backbone) of the phone. (3 marks)

Material	Property of material
Plastic	
Stainless steel	
Aluminium	

(c) The diagram on page 11 shows an orthographic drawing of an after-market smart phone protector casing, i.e. a casing that can protect the phone from minor abrasions and normal wear and tear.

Using the diagram, determine the following dimensions: (3 marks)

the distance from the top of the casing to the centre of the lowest hole in the left side view

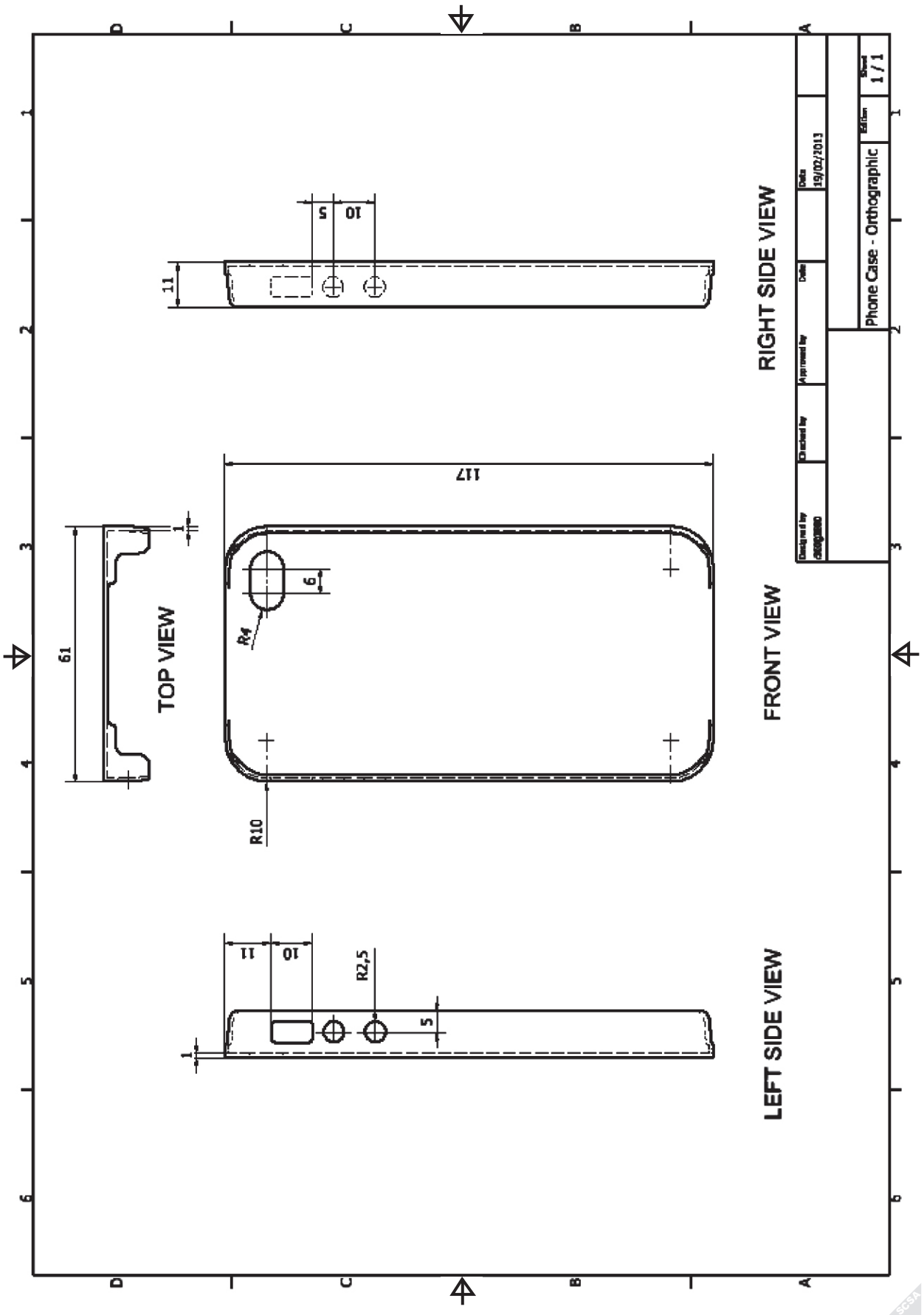
_____

the diameter of each of the circular holes

_____

the wall thickness of the phone casing.

_____



See next page

Question 12 (continued)

(d) In the blank space below, draw a dimensioned pictorial view of the phone casing. Present the casing using a view/orientation of your choice in order to best display all of its features. Include only major dimensions (length, width and depth). (5 marks)

See next page

Question 13 **(15 marks)**

It is important to keep in mind that motor vehicles have an impact on the environment through their carbon dioxide (CO_2) emissions and their life cycle.

According to the 2012 Motor Vehicle Census by the Australian Bureau of Statistics, there were 16.7 million vehicles registered in Australia as at 31 January 2012. Among these, 13.6 million vehicles were registered with a fuel type of petrol, 2.7 million vehicles with diesel fuel, and a much lower number with LPG fuel.

Table A presents an indicative guide on the amount of CO_2 emitted from the exhaust for each litre of a particular fuel.

Table A: CO_2 Emissions per litre of fuel consumed

Fuel type	CO_2 emissions (kg/L)
Petrol	2.3
Diesel	2.7
LPG	1.6

Table B shows an indicative guide on the fuel consumption and the CO_2 emissions for a particular type of petrol vehicle.

Table B: Fuel consumption and CO_2 emissions from various types of petrol vehicles

Vehicle type	Fuel consumption (L/100 km)	CO_2 emissions (g/km)
Small	6	138
Medium	8	184
Large	10	230
4WD	12	276

(a) Based on the statistics presented in Table A, state whether the following statement can be justified, and provide a reason: (2 marks)

'For the same distance travelled, an LPG vehicle will always produce less CO_2 emissions than an equivalent petrol or diesel vehicle.'

Can the statement be justified? Circle your answer: Yes No

Reason: _____

_____

_____

_____

Question 13 (continued)

(b) Calculate the fuel efficiency of a 4WD petrol vehicle. Give your answer in units of kilometres per litre, and show **all** workings. (2 marks)

(c) Given that the price of petrol is 150 cents per litre, calculate the annual cost of petrol in dollars and the annual emission of CO_2 in kg for a medium-sized petrol vehicle that has travelled 15 000 km in a year. Show **all** workings. (4 marks)

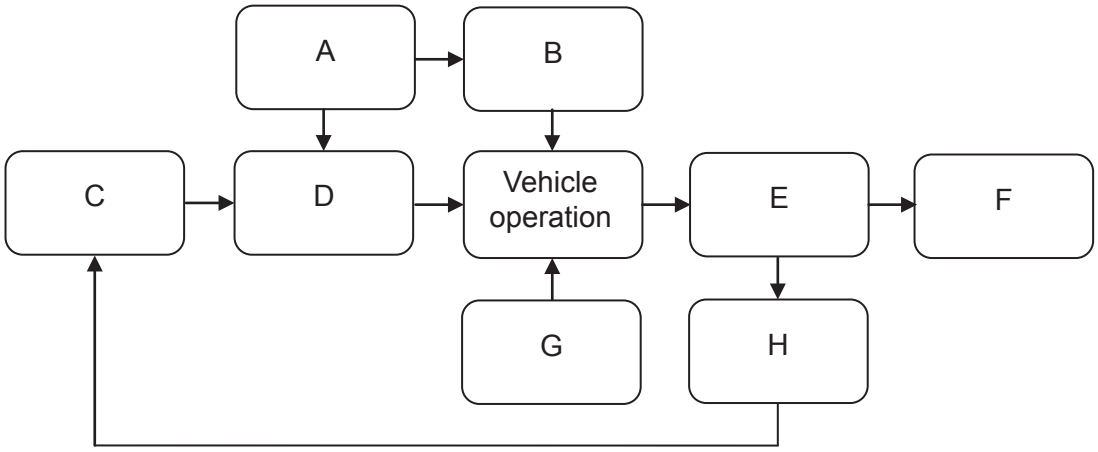
Annual petrol cost ($):

Annual CO_2 emission (kg):

(d) Suppose a driver of a medium-sized petrol vehicle has learned to drive more efficiently, resulting in a drop of fuel consumption from 8 L/100 km to 7 L/100 km, and also manages to reduce their distance driven from 15 000 km to 10 000 km per year. Determine the annual CO_2 emission, in kg, as a result of this. Show **all** workings. (3 marks)

(e) Complete the simplified life cycle diagram of a vehicle as shown below by matching the following labels (1–8) to the boxes (A–H). (4 marks)

Label 1 – Recycling
Label 2 – Raw materials
Label 3 – Waste products
Label 4 – Fuel production
Label 5 – Landfill and emissions
Label 6 – Vehicle production
Label 7 – Energy sources
Label 8 – Vehicle maintenance



Use the above diagram (with pencil and eraser) to develop your answer and once complete show your answers below by writing the label number next to each box label.

Box A: _____ Box E: _____

Box B: _____ Box F: _____

Box C: _____ Box G: _____

Box D: _____ Box H: _____

End of Section One
See next page

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

Candidates are required to choose one of the following options, according to which specialist field they studied in 2016.

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

Specialist field	✓	Question numbers	Pages
Mechanical	☐	14–29	17–36
Mechatronics	☐	30–46	37–54

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

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

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

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

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

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

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

Suggested working time: 110 minutes.

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

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

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14. 'Work' can be defined as

    (a) a measure of the energy expended by a force in moving an object a certain distance.
    (b) power × time.
    (c) force × distance.
    (d) all of the above.

15. The maximum bending moment experienced within a cantilevered beam that has a single load at its unsupported end will occur

    (a) at the beam's midpoint.
    (b) at the point where the beam extends from its supporting structure.
    (c) at the end of the beam where the external load is applied.
    (d) evenly throughout the beam.

16. The process of forging would be used to manufacture a machine component in preference to the process of casting when

    (a) a highly complex shape needs to be produced.
    (b) the part will **not** be subjected to high-stress-inducing loads.
    (c) the part will be routinely subjected to a variety of high-stress-inducing loads.
    (d) the grain formation/direction within the part is not important.

See next page

17. A sandbag is dropped from a hot air balloon that is rising steadily on a windless day. Neglecting aerodynamic friction, the kinetic energy of the bag immediately before impact would be

(a) zero.
(b) equal to its kinetic energy at the moment of release.
(c) equal to its potential energy at the moment of release.
(d) greater than its potential energy at the moment of release.

18. Which one of the following is the most appropriate alternative unit that can be exchanged directly for megapascals (MPa)?

(a) $N\ m^{-2}$
(b) $N\ mm^{-2}$
(c) $kN\ mm^{-2}$
(d) $MN\ mm^{-2}$

19. Structural steel has an ultimate tensile stress of 400 $N\ mm^{-2}$. If a factor of safety of 2 was used for a particular application, would the steel contained in the part continue to behave elastically when experiencing its maximum safe working stress?

(a) Yes, because the safe working stress remains below the material's yield stress.
(b) No, the material would deform permanently as this would exceed the yield stress.
(c) Yes, because the safe working stress remains below the material's ultimate tensile stress.
(d) No, the material would fail as this would exceed the ultimate tensile stress.

20. When comparing the shear force diagram and bending moment diagram of a centrally loaded beam that is simply supported at each end, the point of maximum bending moment corresponds with the point where

(a) the shear force diagram crosses the X axis.
(b) the bending moment diagram crosses the X axis.
(c) shear force is at its maximum value.
(d) shear force is at its minimum value.

21. When comparing stress-strain curves of two different materials, the material with the higher gradient within the proportional section of its graph will have a higher

(a) yield stress value.
(b) ultimate tensile stress value.
(c) elastic limit.
(d) Young's modulus value.

See next page

22. A horizontal beam is simply supported at both ends and is loaded centrally. Which of the following **best** describes the resulting forces within the beam?

(a) The beam will experience tensile forces above its neutral axis and compressive forces below the neutral axis.
(b) The beam will experience no forces along its neutral axis and only compressive forces elsewhere.
(c) The beam will experience no forces along its neutral axis and only tensile forces elsewhere.
(d) The beam will experience compressive forces above its neutral axis and tensile forces below its neutral axis.

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

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

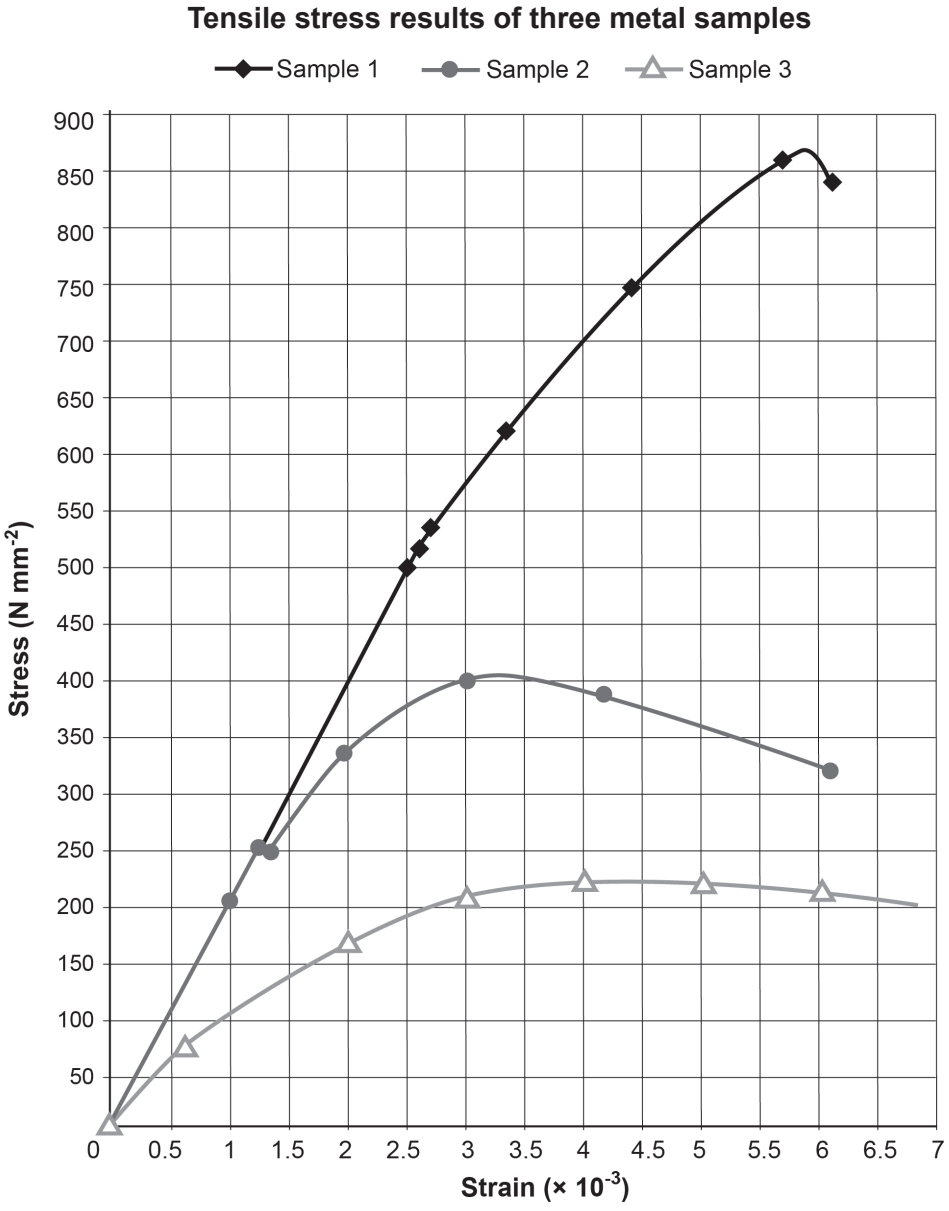
See next page

Part B: Extended answer **50% (100 Marks)**

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

Question 24 **(17 marks)**

Below is a stress/strain graph containing the resulting curves produced by three metal samples when they were each subjected to a tensile test.



See next page

(a) Identify each of the three metal samples that have produced the graphed data on page 20 and state the identifying values you used. You may need to refer to information provided in the **Data Book** to assist with this identification. (6 marks)

Sample 1: _____

Identified by: _____

_____

Sample 2: _____

Identified by: _____

_____

Sample 3: _____

Identified by: _____

_____

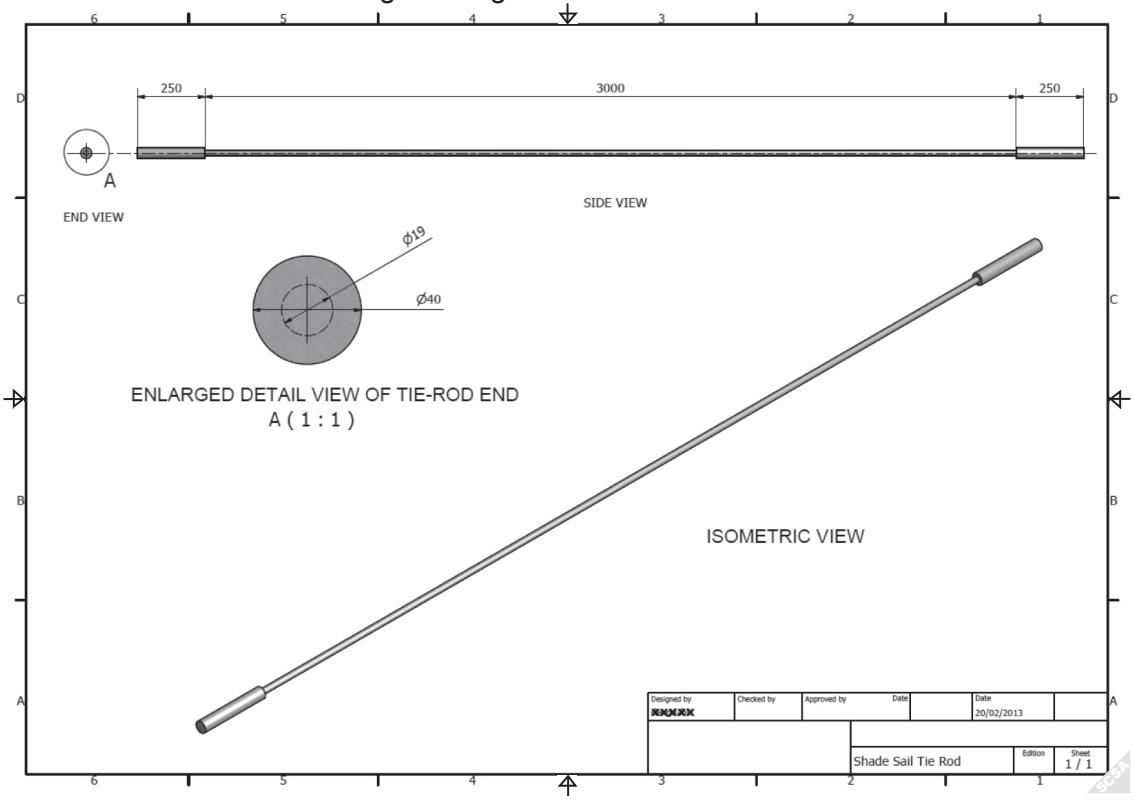
See next page

Question 24 (continued)

The following image shows a part of a playground shade structure.

This playground shade sail structure is located in a coastal area. It has tensile members made of stainless steel to brace each support post in order to prevent excessive bending moments being generated during extreme wind events, such as cyclones.

The main (central) section of the tie-rod has a diameter of 19 mm and is 3 m long. At each end of the rod, leading to the attachment points, the bar increases to a diameter of 40 mm for a length of 0.25 m as shown in the following drawing:



See next page

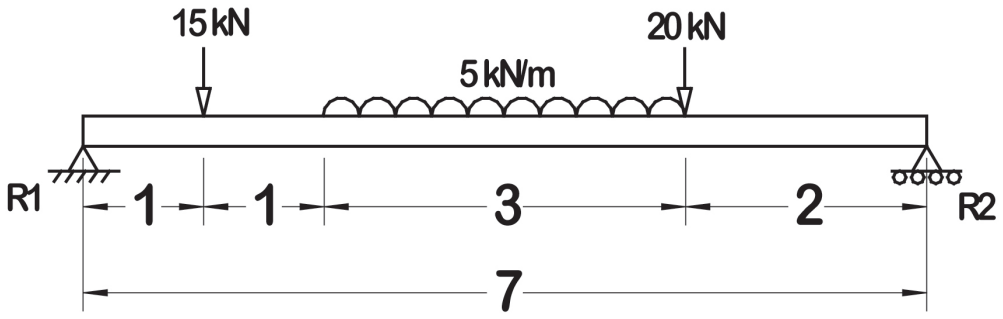
(b) During a recent storm with strong westerly winds, an elongation of 0.19 mm was measured in the 3 m span of one of the supporting tie-rods. Show that the force required to produce this degree of elongation in the 19 mm diameter section is close to 3.6 kN. (5 marks)

(c) When subjected to this peak force, what is the total elongation experienced by the whole rod including the two 0.25 m long, 40 mm diameter rod end sections? (6 marks)

See next page

Question 25 **(21 marks)**

The following questions relate to the simply supported beam shown below.



The reaction force at R1 is 26.07 kN and the reaction force at R2 is 23.93 kN.

(a) Use the condition of equilibrium, $\Sigma CWM = \Sigma ACWM$, to prove that the reaction force at R1 is about 26 kN. Show **all** workings. (3 marks)

(b) Use a condition of equilibrium of your choice to show that the reaction force at R2 is about 24 kN. Show **all** workings. (3 marks)

See next page

(c) Demonstrate through calculation that the position of maximum bending moment in the beam is close to 4.2 m from the left-hand end of the beam. (3 marks)

(d) Demonstrate through calculation that the maximum bending moment in the beam is close to 49 kN m. (3 marks)

See next page

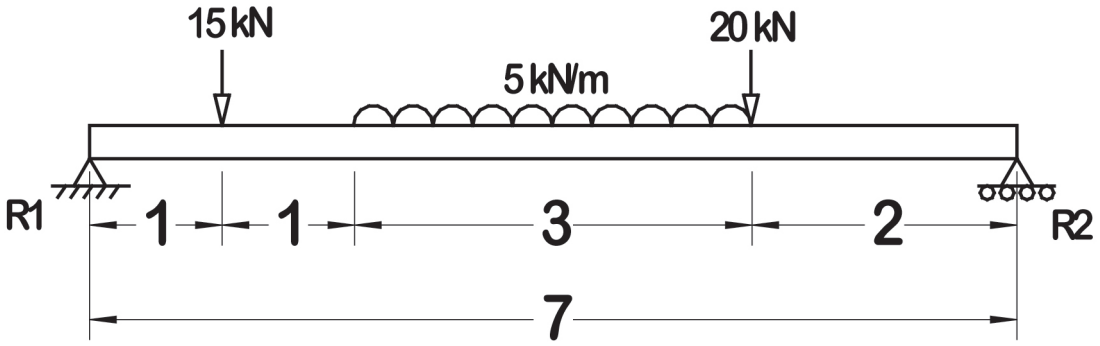
Question 25 (continued)

On the two sets of axes provided below:

(e) Draw a graph of the shear force diagram for the beam. (4 marks)

(f) Draw a graph of the bending moment diagram for the beam including the maximum. (5 marks)

Note: You must include an appropriate scale with correct units on both the X and Y axis of each graph and clearly show the correct values on the key points in each diagram.



SF

BM

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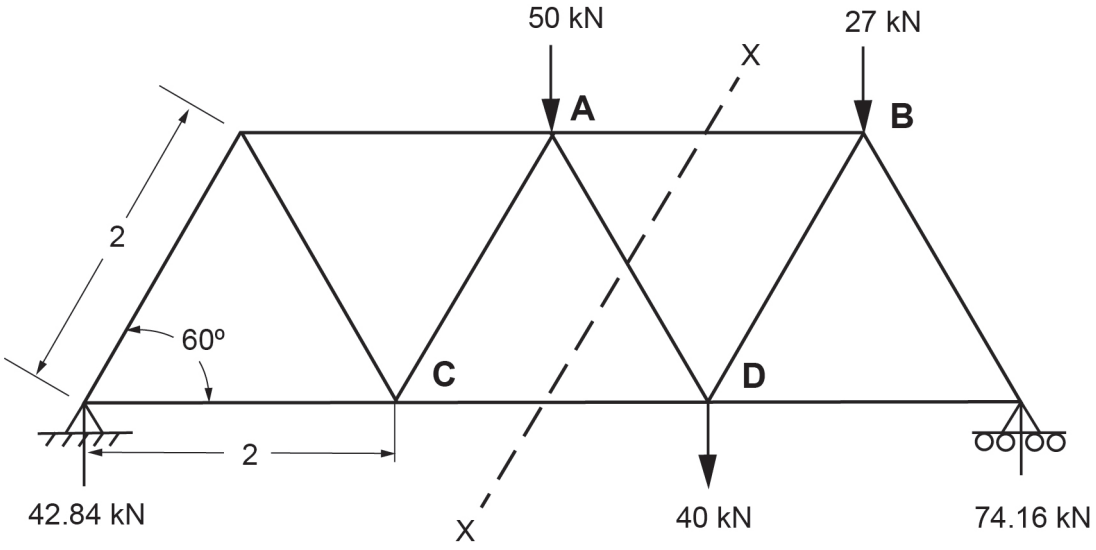
See next page

Question 26 **(12 marks)**



Find the forces in the truss members cut by the section line X-X using the Method of Sections. The members in question are CD, AB, and AD.

In each case indicate whether the members are either in tension or compression (circle the correct option) and explain why.

Show **all** workings.

(a) Find the force in member CD. (4 marks)

F_{CD} = _____ kN in tension/compression because _____

See next page

(b) Find the force in member AB. (4 marks)

F_{AB} = _____ kN in tension/compression because _____

(c) Find the force in member AD. (4 marks)

F_{AD} = _____ kN in tension/compression because _____

See next page

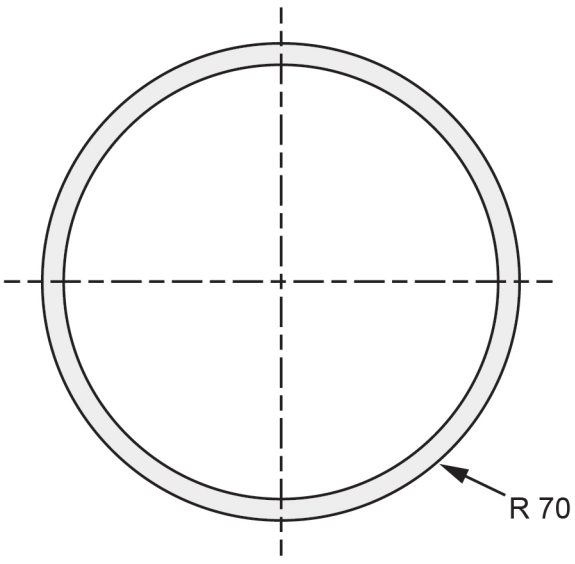
Question 27 **(15 marks)**

A playground located in a sheltered (medium wind level) area has the outer corners of its shade sails supported by (near) vertical posts as shown in Image A. They are made from structural steel using circular tube section with an outside diameter of 140 mm. The post shown in detail in Image B (below) is located on one of the corners of the playground. It has no extra support (e.g. tie-rods) and therefore the post acts as a cantilever, relying entirely on its concrete footing to counteract the moments applied. It is 3 m high and has a single horizontal attachment at the top of the post for the shade sail.

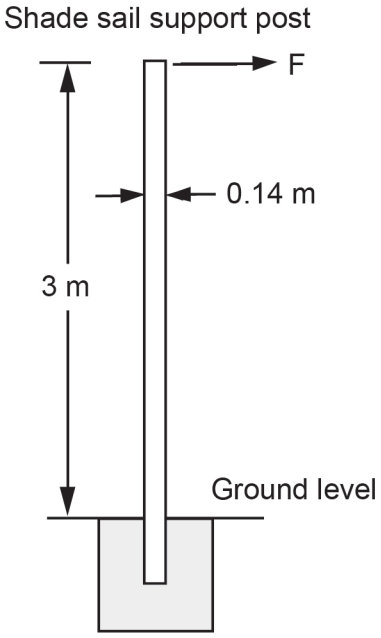
Image A

Image B

See drawings below for details of the post.



Cross section of shade sail post
(structural steel)



Concrete footing

See next page

(a) The wall thickness of the circular tube is 5 mm. Calculate the second moment of area (I_{xx}) of the support using the appropriate formula from the **Data Book**. Show **all** workings. (4 marks)

(b) The support post deflects 4.35 mm at its tip (sail attachment point 'F') due to the static tensile force in the cable holding the shade sail. Calculate the magnitude of this force. Show **all** workings. (5 marks)

(c) Over winter, the shade sails were removed by the local council and put into storage to reduce the chance of potential storm damage. A very strong gust during a winter storm created a uniform distributed load (UDL) on the 3 m length of exposed post. The UDL generated by the wind caused the top of the post to momentarily deflect 0.094 mm.

Calculate the force per metre on the 3 m post caused by the wind. Show **all** workings. (6 marks)

See next page

Question 28 **(15 marks)**

An Australian team is preparing to make an attempt on the world land speed record. They have designed and developed a rocket powered car to eclipse the current world record of 1228 km h^{-1} by travelling at over 1610 km h^{-1}.

Note 1: Critically, the car needs to accelerate and decelerate at no more than 31 m s^{-2} in order to maintain wheel traction and, therefore, control.

Note 2: A world record attempt is based on the time taken to cover a distance of 1609 m (a 'measured mile'), that is the average speed over the course and not the peak speed that may need to be considerably greater.

(a) Given that the car's rocket engine produces 275 kN of thrust and the car has a fully loaded mass of 9.163 tonnes, would its initial rate of acceleration be safe (allowing traction to be maintained) if the rocket was fired giving immediate full thrust? Show **all** workings. (3 marks)

(b) The rocket consumes 112 kg of fuel and liquid oxygen per second as it attempts the land speed record of 2640 km h^{-1}. Identify and describe **one** significant factor that will have a major influence on the acceleration and/or top speed of the car. (2 marks)

See next page

(c) In a hypothetical scenario, the rocket car's record attempt has three phases.

Acceleration phase: from a standing start, the car accelerates at a constant 30 m s^{-2} until it reaches 1580 km h^{-1}.

Course phase: the car enters the 1609 m course at a speed of 1580 km h^{-1}, and its acceleration decreases immediately to a lesser, but still positive and constant, value. The car reaches a peak speed of 1640 km h^{-1} just as it exits the course.

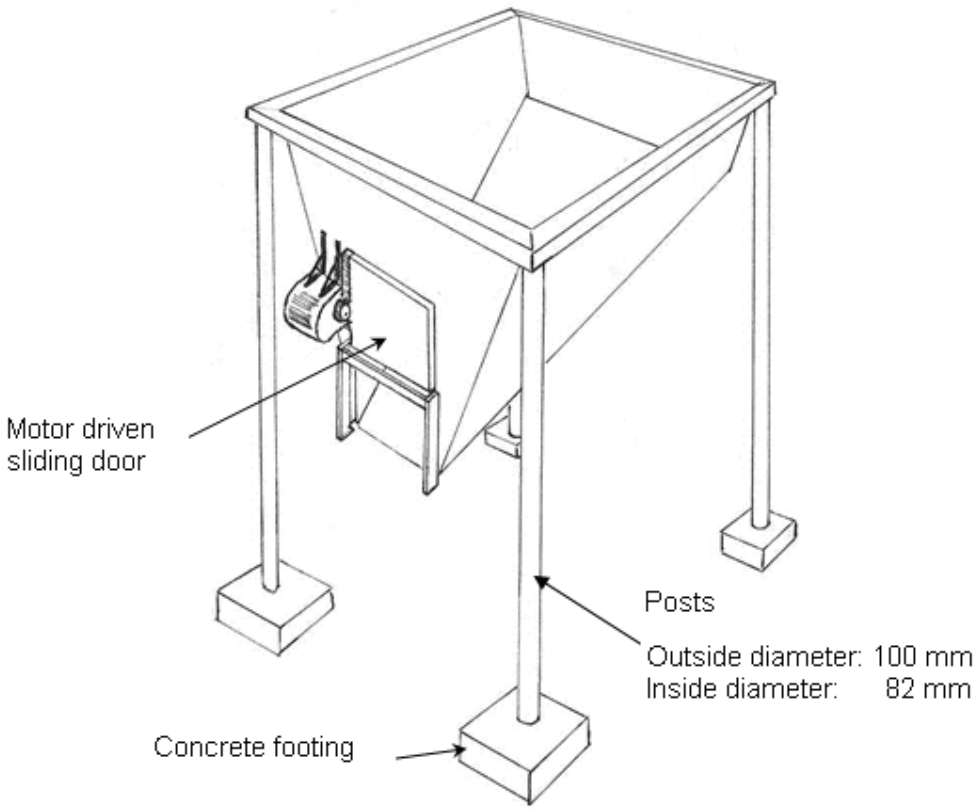
Deceleration phase: On leaving the course at 1640 km h^{-1}, the car decelerates at a constant rate taking 14.69 s to come to a complete stop.

Calculate the total distance travelled by the car in completing this hypothetical record attempt. Show **all** workings. (10 marks)

See next page

Question 29 **(20 marks)**

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



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

(a) The material used to make the hopper must exhibit the properties of toughness and resilience. What is meant by these terms and how do they differ in terms of how they are measured? (3 marks)

See next page

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

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

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

Question 29 (continued)

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

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

End of Section Two: Mechanical

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

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

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

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

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

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

Suggested working time: 110 minutes.

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

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

---

30. Which of the following mechanical drive systems is the best at resisting rotation of its output shaft when the motor driving it is switched off?

    (a) worm and worm wheel
    (b) spur gear drive
    (c) compound gear drive
    (d) chain and sprocket

31. If a typical microcontroller is required to drive a 100 mA load from one of its output pins, then it is

    (a) only possible if none of the other outputs on the device are in use.
    (b) always possible regardless of the number of other outputs in use.
    (c) not possible to source or sink such a load current.
    (d) only possible if the microcontroller supply voltage is doubled.

32. A fixed value resistor used in series with an LED will

    (a) cause the LED to flash on and off in a regular pattern.
    (b) change the colour of the LED.
    (c) change the forward voltage of the LED.
    (d) control the current flowing through the LED.

See next page

33. A motor has been selected to provide positional control over a linkage. The motor has three wires connected to it. It is most likely that the motor is a

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

34. The term 'PWM', which is often associated with controlling the speed of motors, means

(a) pulse width modulation.
(b) power wide management.
(c) programmed with microcontroller.
(d) pulsed wire mode.

35. Battery cells are connected in parallel in order to

(a) increase the voltage output.
(b) increase the current capacity.
(c) increase the power output.
(d) decrease the voltage output.

36. If a thermistor has a negative temperature coefficient, its resistance

(a) increases with a decrease in operating temperature.
(b) decreases with a decrease in operating temperature.
(c) is unaffected by operating temperature.
(d) is unaffected when the operating temperature is above 0 ºC.

37. An idler gear will

(a) increase the velocity ratio of the drive system.
(b) decrease the velocity ratio of the drive system.
(c) have no effect on the velocity ratio of the drive system.
(d) increase the torque of the drive system.

38. A large value and a small value capacitor are connected in series. The total capacitance of this arrangement will be

(a) the addition of the two values.
(b) half of the addition of the two values.
(c) slightly larger than the large value capacitor.
(d) slightly smaller than the small value capacitor.

39. A stepper motor would be **best** used to

(a) drive a winch attached to the front of a 4WD vehicle.
(b) operate a stair climbing machine.
(c) move the cutting head of a laser cutting machine.
(d) operate the steering of a radio controlled model car.

See next page

Part B: Extended answer **50% (100 Marks)**

This part has **seven (7)** questions. Answer **all** questions. Write your answers in the spaces provided.

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

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

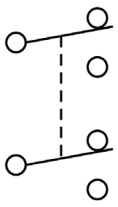
Question 40 **(5 marks)**

The ability to control a DC motor such that it can be rotated clockwise and anti-clockwise plus be stopped when required is very useful, and finds use in applications such as winches, elevators, sliding gates, electric windows in cars and boom gates to name a few. The concept for this form of control is known as an H-bridge and there a number of ways this can be achieved.

One method is to use a double pole double throw (DPDT) switch as the means for controlling the direction of rotation of the motor. Additional switches plus a power supply can be combined with the DPDT switch and DC motor to complete the system.

In the space below complete a labelled drawing of an H-bridge that incorporates the following:

- 12 V battery
- single pole single throw (SPST) switch that can make and break the connection between the 12 V battery and the rest of the circuit
- push to make switch (PTM) that will cause the motor to rotate when pushed and stop it when released
- DPDT switch (shown below) that can be used to reverse the direction of rotation of a DC motor
- DC motor (shown below).



DPDT

See next page

Question 41 **(14 marks)**

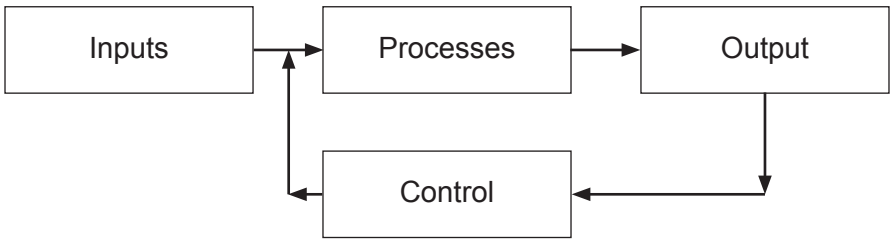
Farmers spend many hours seated in the cabin of a harvester when harvesting a crop. Conditions can vary considerably during the day and make the job very unpleasant. A climate control system will provide heating and cooling as required and bring much needed comfort for the operator of the harvester. Such a system will include a:

- temperature sensor
- fan that can circulate air in the cabin of the harvester
- heating unit
- cooling unit.

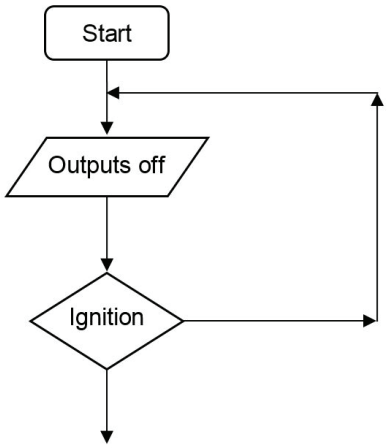
The automated functioning of the climate control system is as follows:

- Turning on the ignition system of the harvester initiates the climate control system.
- When the temperature in the cabin is in the band 24 ºC to 28 ºC then only the fan operates.
- When the temperature in the cabin rises above 28 ºC then the fan and cooling unit operate together and the cooling unit does not switch off until the temperature in the cabin falls to 26 ºC.
- When the temperature in the cabin falls below 24 ºC then the fan and heating unit operate together and the heating unit does not switch off until the temperature in the cabin rises to 26 ºC.

(a) The block diagram of the automated climate control system is shown below. Describe briefly what is occurring within each block. (6 marks)



(b) A microcontroller will operate the climate control system. The beginning of a flow chart is given below. Using standard symbols, complete the flow chart such that it would meet the operational parameters described at the beginning of this question. Label clearly **all** commands and YES/NO decisions. (8 marks)



Question 42 **(17 marks)**

Microcontrollers are designed to be able to detect inputs that may be digital or analogue in nature.

(a) Explain what is meant by the terms:

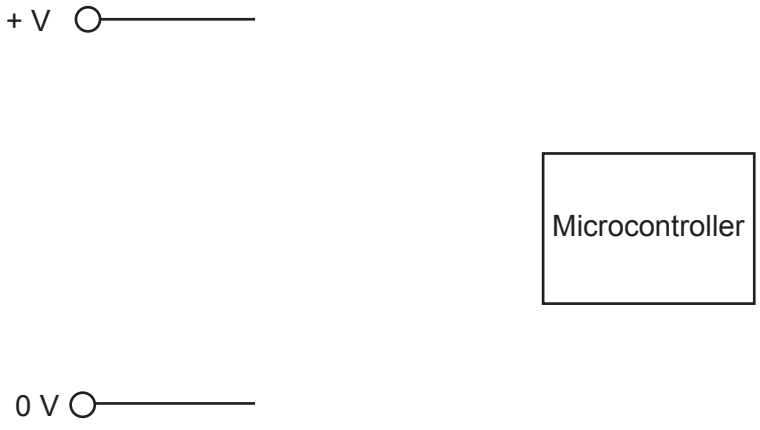
(i) digital input (1 mark)

(ii) analogue input. (1 mark)

See next page

(b) A digital input connected to a microcontroller requires either a pull up or a tie down resistor.

(i) In the space below, complete and label a circuit diagram. Show how a switch and a resistor would be arranged between the positive and negative power supply rails to produce a digital signal that is 'high' when the switch is in its open position. Indicate clearly on the diagram the point at which the signal would be connected to a microcontroller. (3 marks)



(ii) Does your diagram show a pull up or a tie down resistor? Circle your answer: (1 mark)

pull up tie down

(iii) Explain how this digital input arrangement creates a signal to the microcontroller when the switch is open, and also when the switch is closed. (4 marks)

Switch open: _____

_____

_____

_____

Switch closed: _____

_____

_____

_____

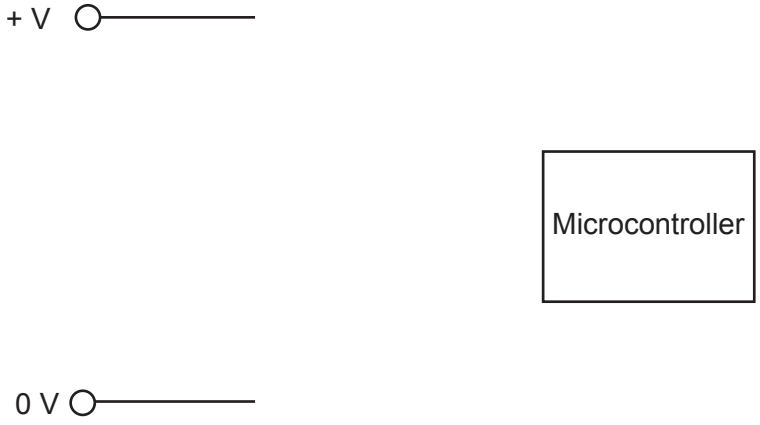
Question 42 (continued)

(c) Light sensors are often used to provide inputs to microcontrollers.

(i) In the space below, complete a sketch of a labelled circuit diagram that shows how a sensor could be made using a light dependent resistor (LDR) and another component such that:

- as conditions become darker the signal to a microcontroller would become lower; and
- the sensor could be calibrated by adjusting the other component.

Indicate clearly on the diagram the point at which the signal from the sensor would be connected to a microcontroller. (3 marks)



(ii) Explain how this sensor changes the signal to the microcontroller when conditions become darker, and also when conditions become brighter. (4 marks)

Darker: _____

_____

_____

_____

Lighter: _____

_____

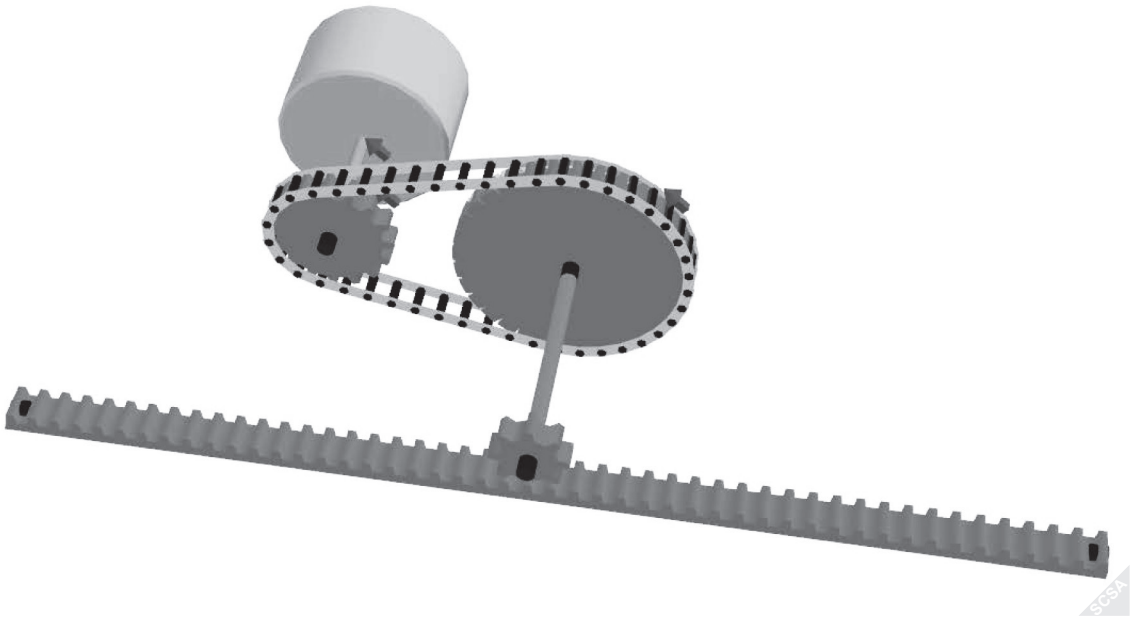
_____

_____

See next page

Question 43 **(12 marks)**

The diagram below shows a schematic representation of a rack and pinion system being driven by an electric motor through a reduction gear system.



The gears are described below:

- The drive motor shaft has 16 teeth.
- The intermediate gear has 32 teeth.
- The pinion has 8 teeth.
- The rack has 48 teeth and has a gear pitch of 10.0 mm.

The motor rotates at 400 rpm in either direction.

(a) Show that the speed of rotation of the intermediate gear is 200 rpm. (2 marks)

See next page

Question 43 (continued)

(b) Show that it will take about 1.5 s for the rack to translate a distance of 400 mm. (4 marks)

(c) If you wished to double the time taken to translate the rack a distance of 400 mm, what change in the design of this gear system (using the same motor) would you suggest? Why? (3 marks)

Change: _____

Explanation: _____

(d) The motor is replaced with a stepper motor so that the position of the rack can be controlled more accurately. The stepper motor has an angular step size of 18º. Calculate the number of steps required to translate the rack 100 mm. Show **all** workings. (3 marks)

See next page

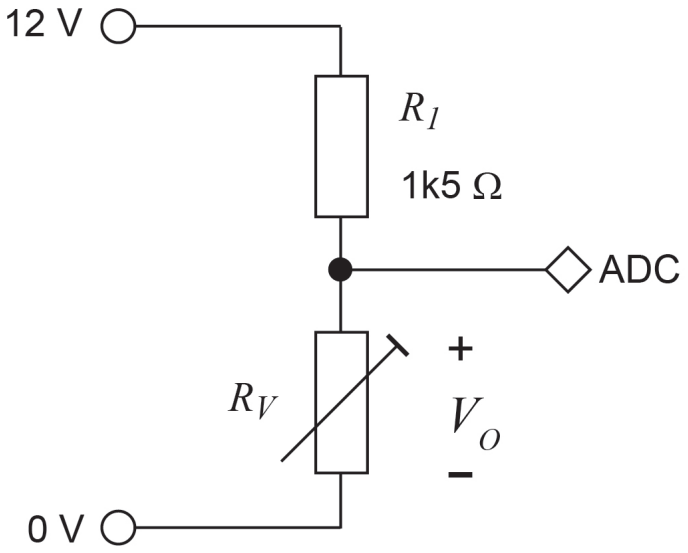
Question 44 **(19 marks)**

To use an analogue signal (say in the range 0 to 12 VDC) in a microprocessor it is necessary to convert this signal into a digital value. The device used for this purpose is an ADC (analogue to digital converter). For many microprocessors this capability is already built into the device, so no additional hardware is required.

The task you have involves controlling the temperature of ginger beer being brewed in a large vat so that the heating system can be managed to maintain the temperature to an accuracy of ±0.1 ºC in the range 20 ºC to 60 ºC. The required temperature can vary according to the type of ginger beer being brewed.

The temperature sensor provides an analogue signal in the range 0 to 12 VDC that is linearly proportional to its design temperature range, i.e. from 0 ºC to 100 ºC.

The ADC on the selected microprocessor has an 8 bit resolution.



(a) The 12 V maximum output from the temperature sensor is not compatible with what can be accepted by an ADC pin of a microcontroller. It will need to be conditioned such that the maximum voltage detected at an ADC pin is 5 V. This can be achieved by using a voltage divider as an interfacing circuit as shown above. Calculate the resistance value of R_V such that V_O = 5 V when the output from the temperature sensor is at its maximum of 12 V. Show **all** workings. (4 marks)

See next page

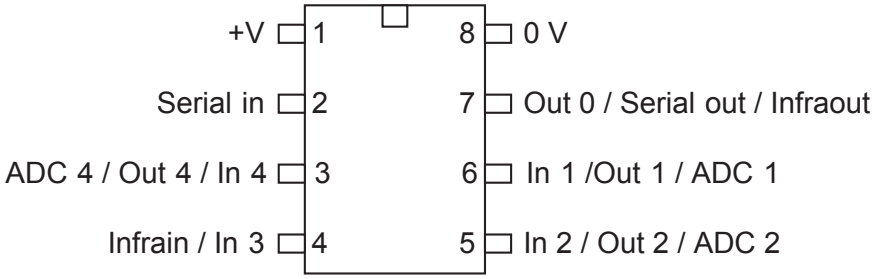
Question 44 (continued)

(b) If one of the ADC inputs on the microprocessor was used to connect to the temperature input circuit, calculate the accuracy of the temperature value available in the microprocessor for computations in the control task. Would this accuracy be acceptable if the required accuracy is ± 0.1 °C? Why? Show **all** workings. (4 marks)

(c) Calculate the digital values that will be observed in the microprocessor for the expected low and high values at temperatures of 20.0 ºC to 60.0 ºC respectively. Show **all** workings. (4 marks)

See next page

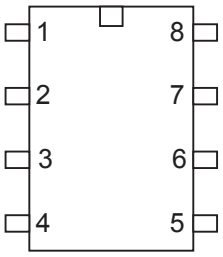
(d) If the temperature goes outside the range of 20 ºC to 60 ºC, the brewing process may become unstable and some alarm signals should be generated. Should the temperature drop below 20 ºC then a white LED will begin to flash. Similarly, if the temperature rises above 60 ºC then a red LED will begin to flash. In both cases an audible output will also turn on to make a shrill sound.



Using the space provided, complete a labelled schematic diagram that has the following:

- 5 V supply voltage and ground connection to microcontroller
- 0-12 V temperature sensor
- 0-5 V conditioning circuit
- Conditioned temperature signal connected to microcontroller
- LEDs and one (1) audible alarm connected directly to the microcontroller
- Ground (0 V) connections wherever required.

Correct circuit symbols **must** be used with the exception of the 0-12 V temperature sensor and audible alarm which can be drawn as labelled boxes. (7 marks)

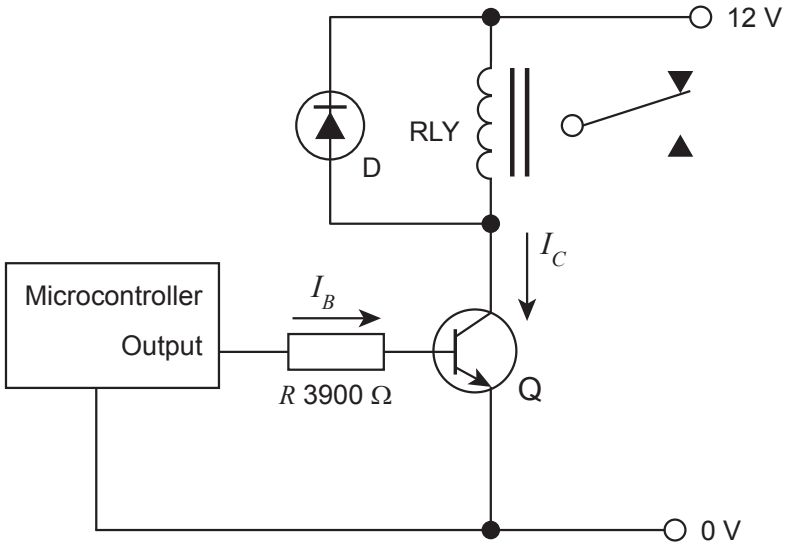


See next page

Question 45 **(24 marks)**

A microcontroller is used to turn a SPDT relay on and off by using a transistor driver as shown below in the circuit diagram. The transistor parameters are $V_{BE,on}$ = 0.7 V, $V_{CE,sat}$ = 0 V and gain (also known as β or h_{FE}) = 65.

The output for the microcontroller is 5 V when 'high' and 0 V when 'low'.



(a) Calculate the value for current that flows through R when the microcontroller output pin goes 'high'. Show **all** workings. (4 marks)

See next page

(b) Assume that the transistor is operating in its forward-active region.

(i) Calculate the current that is flowing through the relay coil when the microcontroller output is 'high'. Show **all** workings. (3 marks)

(ii) The resistance of the relay coil is 150 Ω. Calculate the voltage that is held across the collector-emitter of the transistor, V_{CE}. Show **all** workings. (4 marks)

(c) Calculate the minimum current through R that will drive the transistor into saturation. (6 marks)

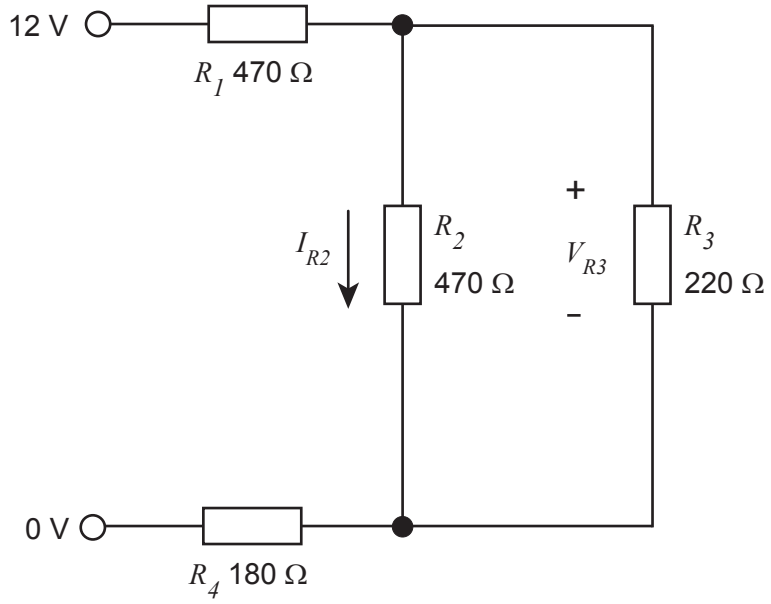
See next page

Question 45 (continued)

(d) When the microcontroller output is 'low' the transistor is operating in its cut-off region. Calculate the voltage drop across the collector-emitter of Q, i.e. V_{CE}. Show **all** workings. (3 marks)

(e) Explain why the diode has been positioned in the manner as shown in the circuit diagram. Refer to the **three** regions of operation of an NPN transistor and the behaviour of a rectifier diode in your answer. (4 marks)

Question 46 **(9 marks)**



Examine the circuit diagram of a resistor network shown above.

(a) Calculate V_{R3}, the voltage across R_3. Show **all** workings. (6 marks)

See next page

Question 46 (continued)

(b) Calculate the current, I_{R2}, passing through the resistor R_2. Show **all** workings. (3 marks)

End of Section Two: Mechatronics
End of Questions

Additional working space

Additional working space

Additional working space

ACKNOWLEDGEMENTS

Section One

Question 13

Text adapted from: Australian Bureau of Statistics. (2012). *9309.0–Motor vehicle census, Australia, 31 Jan 2012*. Retrieved March, 2013, from www.abs.gov.au/ausstats/abs@.nsf/mf/9309.0/. Used under the Creative Commons attribution 2.5 Australia licence http://creativecommons.org/licenses/by/2.5/au/

Table A adapted from: Department of Sustainability, Environment, Water, Population and Communities. (2008). *CO2 Tailpipe emissions/Litre of fuel consumed*. Retrieved March, 2013, from www.environment.gov.au/settlements/transport/fuelguide/environment.html

Table B adapted from: Department of Sustainability, Environment, Water, Population and Communities. (2008). *CO2 Tailpipe emissions from petrol vehicles*. Retrieved March, 2013, from www.environment.gov.au/settlements/transport/fuelguide/environment.html

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