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

WACE
Western Australian Certificate of Education

ENGINEERING STUDIES

Sample Examination 2016

Marking Key

Marking keys are an explicit statement about what the examiner expects of candidates when they respond to a question. They are essential to fair assessment because their proper construction underpins reliability and validity.

2014/22052

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

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

1	c
2	b
3	d
4	b
5	c
6	a
7	b
8	c
9	d
10	c

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

Question 11 **(15 marks)**

(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)

Description	Marks
Surface area of hemisphere = $0.5 \times 4 \times \pi \times r^2$ $= 0.5 \times 4 \times 3.14159 \times 1.0^2$ $= 6.283\ m^2$ Surface area of base cylinder sides= $2 \times \pi \times r \times h$ $= 2 \times 3.14158 \times 1.0 \times 4.0$ $= 25.132\ m^2$ Surface areas of base cylinder bottom = $\pi \times r^2$ $= 3.14159 \times 1.0^2$ $= 3.142\ m^2$ Surface area of post = $2 \times \pi \times r \times h$ $= 2 \times 3.14159 \times 0.2 \times 6.0$ $= 7.540\ m^2$ Surface area of top of post = $\pi \times r^2$ $= 3.14159 \times (0.2)^2$ $= 0.125\ m^2$ Total surface area = 6.283 + 25.132 + 3.142 + 7.540 + 0.125 $= 42.222\ m^2$	1–7
5 × 1 marks for each part of buoy + 1 mark for correct total + 1 mark for process	
Total	**7**

Note: if the area of the top of the post is not included there must be a statement explaining why (1 mark)

(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)

Description	Marks
Weight of buoy= surface area × thickness × density = 42.2 × 0.008 × 7600 = 2567.1 kg	1
Weight of lights = 4 × 300 = 1200 kg	1
Weight of concrete = $\pi \times r^2 \times h \times \rho$ =3.14159 × 1.0^2 × 0.5 × 2400 = 3769.9 kg (Candidate may account for the wall thickness, giving about 60kg less concrete)	1–2
Weight of lug = 20.0 kg Total weight = 2567.1 + 1200 + 3769.9 + 20.0 = 7557.0 kg	1
It is acceptable that a candidate may attempt to calculate the volume (and weight) of steel in the body part of the buoy from first principles rather than using the surface area from part (a).	
Total	**5**

(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)

Description	Marks
Volume of water to be displaced = weight/density of sea water = 7557/1022 = 7.394 m^3 Distance up cylinder = displaced vol/area of cylinder =7.394 / ($\pi \times 1.0^2$) = 2.353 m Therefore the buoy will sink to about 2.353 m above the bottom of the buoy.	1–3
2 marks to get total of displaced volume (max 1 mark if fresh water density is used) 1 mark to compute distance up cylindrical section	
Total	**3**

Note: if part (b) is not attempted, use of 7500 kg is acceptable (answer ~ 2.39 m)

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)

Description	Marks
Criterion one: Shatter resistant screen Criterion's contibution: Use of a tougher material or protective covering. Criterion two : Longer phone usage per battery charge Criterion's contibution: Use a battery with a higher energy density or use a bigger battery Criterion three: Lighter weight. Criterion's contibution: Reduction in size of phone or use of lighter more exotic materials to retain necessary strength. Criterion four: Improve user-friendliness/ use of intuitive technologies Criterion's contibution: Focus on software development – survey market and adapt to consumer needs and usage behaviours	1–4
0 or 1 marks each. Marker Note: Accept other reasonable responses showing logic and plausibility	
Total	**4**

(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)

Description	Marks
<table><tr><th>Material</th><th>Property of material</th></tr><tr><td>Plastics</td><td>Toughness or suitable for injection moulding</td></tr><tr><td>Stainless steel</td><td>Rust resistance or strength</td></tr><tr><td>Aluminium</td><td>Lightweight or corrosion resistance</td></tr></table>	1–3
Marker Note: Accept other reasonable responses showing logic and plausibility.	
Total	**3**

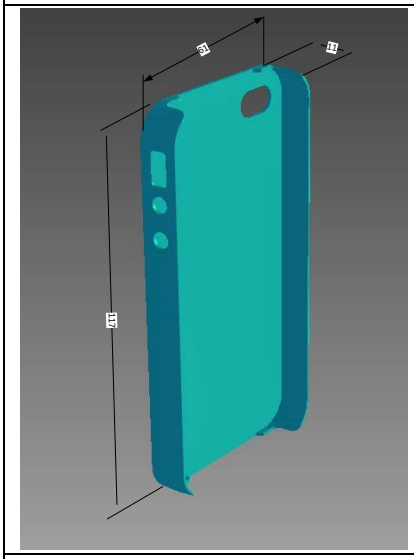
(c) The diagram on page 11 shows an orthographic drawing of an after-market smart phone protector casing, i.e. a casing that can protect the phone from minor abrasions and normal wear and tear.

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

the distance from the top of the casing to the centre of the lower hole
the diameter of each of the circular holes
the wall thickness of the phone casing.

Description	Marks
36 mm	1
5 mm	1
1 mm	1
Total	**3**

(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)

Description	Marks
	1–5
Correct shape, including all holes and top & bottom cut-outs (3 marks). Sketch should indicate correct proportioned (1 mark) Three dimensions shown correctly (1 mark) Allow some discretion on other detail. Shading not required.	
Total	**5**

Question 13 **(15 marks)**

(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 trusted? Circle your answer: Yes No

Description	Marks
No	1
Reason (any one good reason) Table A shows that each litre of LPG has the least amount of CO_2 emission. However, this does not implies that LPG vehicle will always produce less CO_2 emissions for a given distance travelled. This is because we do not know (a) the energy content of each fuel and (b) the fuel efficiency of engine must also be taken into consideration. For example, LPG has lower energy content, and so more fuel is consumed to travel a given distance and therefore more CO_2 emissions are produced. Also, the engines designed to operate on diesel can be far more fuel efficient than LPG engines, leading to less fuel consumed and less CO_2 emissions. Alternatively, (c) the CO_2 emissions of vehicle should be measured in terms of kg/km instead of kg/L.	1
Award 1 mark if reason (a) and/or (b) and/or (c) is stated.	
Total	**2**

Note: 'True' is acceptable if followed by a valid reason.

(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)

Description	Marks
The use of correct fuel consumption amount of 12 L / 100 km for 4WD petrol vehicle.	1
fuel efficiency = 1 / fuel consumption = 1 / (12 L / 100 km) = 100 km / 12 L = 8.33 km/L	1
Total	**2**

(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)

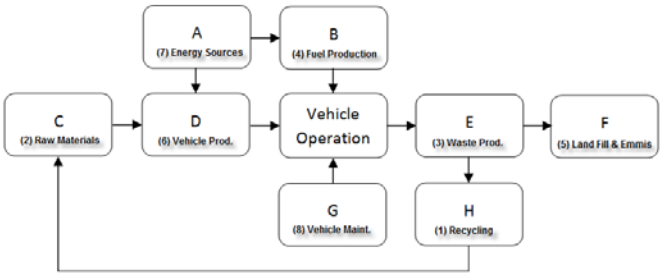
Description	Marks
Annual petrol consumption = 15 000 km × 8/100 L/km = 1200 L	1
Annual petrol cost = annual petrol consumption × unit cost = 1200 L × 150 c/L = 180 000 c = $1 800	1
Annual CO_2 emissions = distance travelled x rate of emission	1
Annual CO_2 emissions = 15 000 km × 184 g/km = 2 760 000 g = 2 760 kg	1
Total	**4**

(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)

Description	Marks
Understand the need to determine the new rate of emission from Table A instead of using wrong data from Table B.	1
Rate of emission = 2.3 kg/L × 7/100 L/km = 0.161 kg/km	1
Annual CO_2 emissions = distance travelled × rate of emission = 10 000 km × 0.161 kg/km = 1 610 kg	1
Total	**3**

(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)

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.

Description	Marks
 Box A = Label 7 Box B = Label 4 Box C = Label 2 Box D = Label 6 Box E = Label 3 Box F = Label 5 Box G = Label 8 Box H = Label 1	1–4
Answers must be written in place provided, though any workings shown on the diagram may be used to clarify any ambiguities. For 1-2 correct labels, award 1 mark For 3-4 correct labels, award 2 mark For 5-7 correct labels, award 3 mark For 8 correct labels, award 4 marks. Note: '7 correct labels' is only possible if the eighth box is unanswered or repeated.	
Total	**4**

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

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

14	d
15	b
16	c
17	d
18	b
19	a
20	a
21	d
22	d
23	c

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

Question 24 **(17 marks)**

(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 Booklet** to assist with this identification. (6 marks)

Description	Marks
Sample 1 - stainless steel Identified by: UTS of 860 N mm^{-2} or Young's modulus value of 200 kN mm^{-2} e.g. $\frac{200}{1\times10^{-3}}$	1–2
Sample 2 - structural steel Identified by: it has a yield stress of 250 N mm^{-2} or UTS of 400 N mm^{-2} or Young's modulus value of 200 kN mm^{-2}	1–2
Sample 3 - Copper Identified by: yield stress of 70 N mm^{-2} or UTS of 220 N mm^{-2} or Young's modulus value of 117 kN mm^{-2} e.g. $\frac{117}{1\times10^{-3}}$	1–2
2 marks each, 1 for material and 1 for justification	
Total	**6**

(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)

Description	Marks
Original Length of section = 3000 mm Cross sectional area = $\pi \times 9.5^2 = 283.385$ mm^2 Elongation = 0.19 mm E (Young's Modulus) stainless steel = 200 kN mm^{-2} Rearrange formula to give $F = \frac{EA\Delta L}{L}$ and insert above values F = (200 × 283.385 × 0.19) / 3000 F = 3.591 kN	1–5
Total	**5**

(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)

Description	Marks
Combined Length of 40mm diameter sections = 500 mm (1 mark) Cross sectional area = $3.14 \times 20^2 = 1256$ mm^2 of 40 mm diameter sections (1 mark) Force applied = 3.58954 kN (also accept 3.6 kN for this input) E (Young's Modulus) Stainless Steel = 200 kN mm^{-2} Rearrange formula to give $\Delta L = \frac{FL}{AE}$ and insert above values (1 mark) ΔL = (3.58954 × 500) / (1256 × 200) (1 mark) ΔL in rod end sections = 0.007145 mm (or 0.007165 mm when 3.6 kN is used for F) (1 mark) Total ΔL in tie rod = 0.007145 mm + 0.19 mm = 0.197 mm (1 mark)	1–6
Total	**6**

Question 25 **(21 marks)**

(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)

Description	Marks
Taking moments around R2 and with the U.D.L. of 5 kN/m giving a total of 15 kN, centralised at 3.5 m from R2 then: $R1 \times 7 = 20 \times 2 + 15 \times 3.5 + 15 \times 6$	1
$R1$ = 182.5 / 7	1
$R1$ = 26.07 kN	1
Total	**3**

(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)

Description	Marks
$\Sigma Fy = 0$ therefore $R2$ + 26.07 -15 – 15 - 20 = 0	1
$R2$ = 50 – 26.07	1
$R2$ = 23.93 kN	1
or	
Taking moments around R1 and with the U.D.L. of 5 kN/m giving a total of 15 kN, centralised at 3.5 m from R1 then: 15 × 1 + 15 × 3.5 +20 × 5 = R2 × 7	1
$R1$ = 167.5 / 7 = 23.92	1
$R1$ = 23.93 kN	1
There are various ways of calculating the point where the SF crosses the X-axis (SF=0), accept any method providing it is correct.	
Total	**3**

(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)

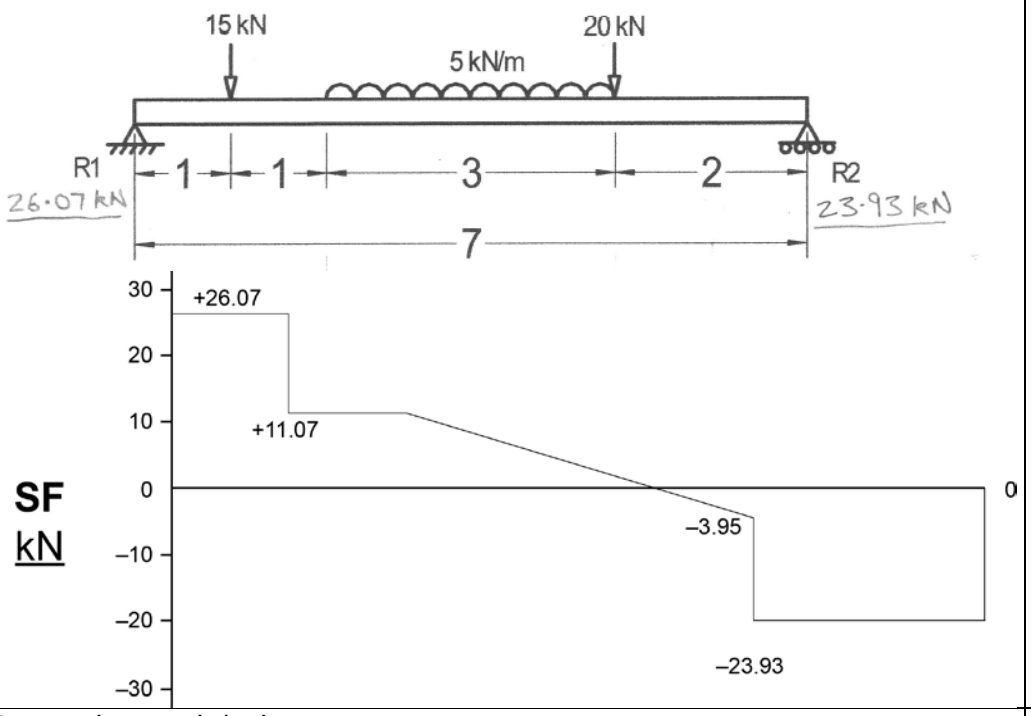
Description	Marks
Shear Force at LHS of UDL = 26.07 kN – 15 kN = 11.07 kN	1
11.07 kN / 5 kN m^{-1} = 2.214 m from LHS of UDL	1
Distance to BM_{max} from R1 is therefore 2 m + 2.214 m = 4.214 m	1
There are various ways of calculating the point where the SF crosses the X-axis (SF=0), accept any method providing it is correct.	
Total	**3**

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

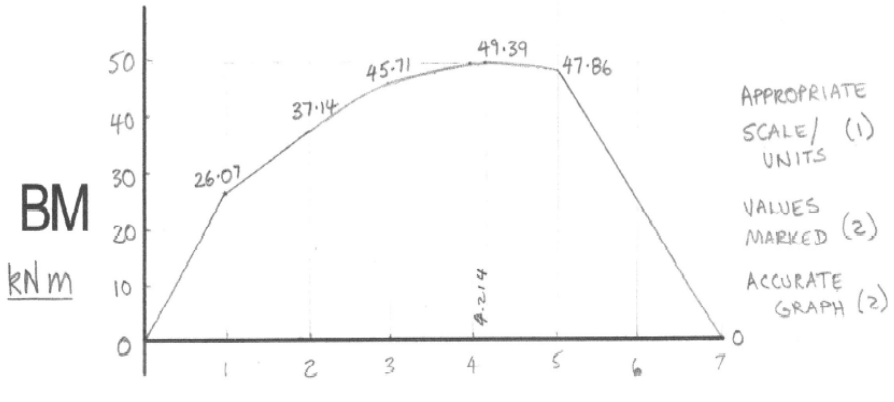
Description	Marks
Taking moments to the left of the BM_{max} Moment due to the UDL = 5 kN m^{-1} × 2.214 m = 11.07 centralised at 2.214 / 2 = 1.107	1
Therefore $BMmax$ = 26.07 kN × 4.214 m – 15 kN × 3.214m – 11.07 kN × 1.107 m	1
= 49.39 kN m	1
Total	**3**

On the two sets of axes provided below:

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

Description	Marks
	
Appropriate scale/unit	1
Values marked	1
Accurate graph (accept opposite sign convention)	1-2
Total	**4**

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

Description	Marks
	
Appropriate scale units	1
Values marked	1-2
Accurate graph	1-2
Total	**5**

Question 26 **(12 marks)**

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

Description	Marks
Taking the left hand side of the truss into consideration, and initially assuming all members are in tension:	
To find moments around 'A' the perpendicular height of the truss is required. Vertical height of truss = sin60 × 2 = 1.732 units	1
Taking moments around 'A' 42.84 kN × 3 = F_{CD} × 1.732	1
Therefore F_{CD}= 128.52 / 1.732 F_{CD} = 74.2 kN	1
Member in tension as answer is +ve confirming initial assumption	1
Total	**4**

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

Description	Marks
Taking moments around 'D' 42.84 kN × 4 + F_{AB} × 1.732 = 50 × 1	1–2
Therefore F_{AB} = -121.36 / 1.732 F_{AB} = -70 kN	1
Member is in compression as answer is -ve therefore opposing initial tensile assumption	1
Total	**4**

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

Description	Marks
ΣF_v = 0 42.84 kN – 50 kN – (F_{AD} sin 60°) = 0	1–2
F_{AD}= –7.16 / sin 60° F_{AD} = – 8.3 kN	1
Member is in compression (answer is –ve, opposing initial tensile assumption)	1
Total	**4**

Note: this question can be solved using the right hand side of the truss, giving exactly the same answers for each required member. It is also valid to take moments about C.

Question 27 **(15 marks)**

(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)

Description	Marks
$I_{xx} = \frac{\pi(D_o^4 - D_i^4)}{64}$	
$= \frac{\pi(140^4 - 130^4)}{64}$	1
$= \frac{\pi(384\,160\,000 - 285\,610\,000)}{64}$	1–2
$= \frac{309603694.5}{64}$	
$= 4\,837\,557.727\ \text{mm}^4$	1
Total	**4**

(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)

Description	Marks
Identify correct formula and rearrange to give $F = \frac{y3EI_{xx}}{L^3}$	1–2
Therefore F = (4.35 × 3 × 200000 × 4 837 557.727) / 3000^3	1–2
F = 467.63 N	1
Total	**5**

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

Description	Marks
Identify correct formula and rearrange to give $F_{UDL} = \frac{y8EI_{xx}}{L^3}$	1–2
Therefore F_{UDL} = (0.094 × 8 × 200 000 × 4 837 557.727) ÷ 3000^3 F_{UDL} = 26.95 N (includes mark for correct use/conversion of units)	1–2
therefore the force per metre is $\frac{26.95}{3} = 8.98\ \text{N m}^{-1}$	1–2
Total	**6**

Question 28 **(15 marks)**

(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)

Description	Marks
$F=ma$ therefore $a= F/m$	1
a = 275 000 N / 9163 kg	1
a = 30 m s^{-2} therefore yes it would be safe.	1
Total	**3**

(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)

Description	Marks
The huge rate at which the fuel and oxygen are consumed (112 kg per second) will affect the potential acceleration of the car	1
because the overall mass of the vehicle is reduced whilst thrust remains the same.	1
Award marks for other plausible factors	
Total	**2**

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

Description	Marks
Acceleration phase u = 0 m s^{-1} v = 1580 km h^{-1} / 3.6 = 438.89 m s^{-1} a = 30 m s^{-2}	1
Identify and transpose formula to give $s = \frac{v^2 - u^2}{2a}$	1
= $\frac{(438.892)^2}{2 \times 30}$ = 3210 m	1
Course phase s = 1609 m	1
Deceleration phase u = 1640 km h^{-1} / 3.6 = 455.56 m s^{-1} v = 0 m s^{-1} t = 14.69 s	1
First find 'a' using $a = \frac{v-u}{t}$	1
= - 455.56 / 14.69 = - 31 m s^{-1}	1
then find 's' using transposed formula $s = \frac{v^2 - u^2}{2a}$ = - 455.56^2 / (2 × -31) = 3347 m	1
Finally – Total distance covered = 3210 + 1609 + 3347	1
= 8166 m = 8.17 km	1
Total	**10**

Question 29 **(20 marks)**

(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)

Description	Marks
Toughness is the energy absorbed by a material without fracturing.	1
Resilience is the energy absorbed by a material within its linearly elastic range.	1
Toughness is measured by the area under the stress-strain diagram up to the point of failure whilst resilience is the area up to the yield point.	1
Total	**3**

(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)

Description	Marks
$P = \dfrac{F \times s}{t}$	1
$= \dfrac{(62\,500\ \text{N})(0.8\ \text{m})}{10\ \text{s}} = 5000\ \text{W or } 5\ \text{kW}$	1–2
Or $v = \dfrac{s}{t} = \dfrac{0.8}{10} = 0.08$ $P = F \times v = 62.5 \times 0.08 = 5\ \text{kW}$	
Total	**3**

(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)

Description	Marks
$\text{maximum load} = \dfrac{\text{total weight}}{4\,(\text{vertical support posts})}$	1
$\text{maximum load} = \dfrac{(4500 + 145\,500)(9.8)}{4} = 3.675 \times 10^5\ \text{N}$	1–2
Total	**3**

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

Description	Marks
$\sigma = \dfrac{\text{force}}{\text{area}} = \dfrac{\text{load}}{\text{cross-sectional area of steel}}$	1
cross-sectional area of steel $= \pi R^2 - \pi r^2 = \pi(50^2 - 41^2) = 2573\ \text{mm}^{-2}$	1–2
$\text{stress in steel support} = \dfrac{3.675 \times 10^5\ \text{N}}{2573\ \text{mm}^{-2}} = 142.8\ \text{N mm}^{-2}$	1–2
Total	**5**

(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)

Description	Marks
$\text{safety factor} = \frac{\text{ultimate stress}}{\text{safe working stress}}$	1
$3 = \frac{40\ \text{N mm}^{-2}}{\text{safe working stress}}$	1
$\text{safe working stress} = \frac{40\ \text{N mm}^{-2}}{3} = 13.3\ \text{N mm}^{-2}$	1–2
Total	**4**

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

Description	Marks
The actual stress exceeds the safe working stress by a large margin.	1–2
Total	**2**

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

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

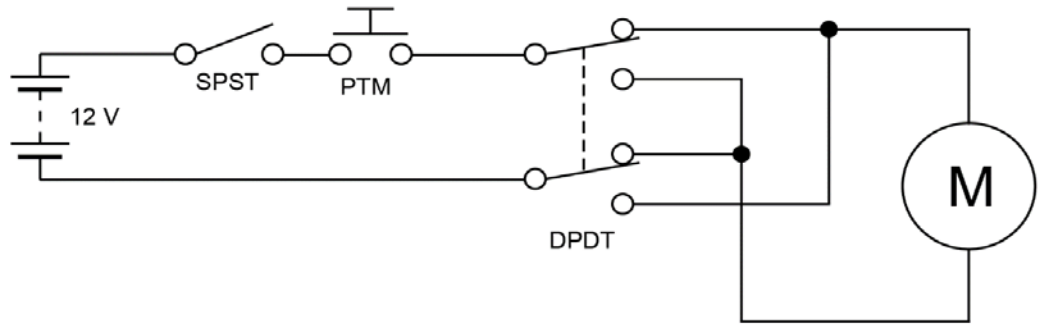
30	a
31	c
32	d
33	d
34	a
35	b
36	a
37	c
38	d
39	c

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

Question 40 **(5 marks)**

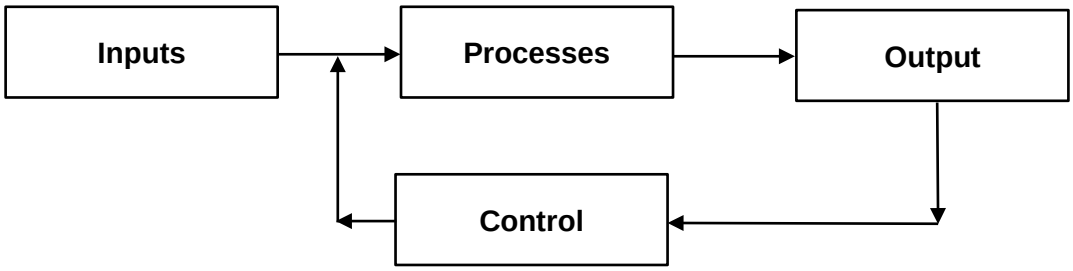
In the space below complete a labelled drawing of an H-bridge that incorporates the following:

- 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).

Description	**Marks**
	
Labelled circuit symbols for 12 V battery, SPST switch and PTM switch	1
SPST switch will make and break connection of circuit to battery	1
PTM switch will enable DC motor to rotate and stop	1
DPDT switch can be used to reverse direction of rotation of DC motor. 1-2 marks for motor terminals being positive on one side and negative on the other and another 1-2 marks if these can be reversed	1–2
Total	**5**

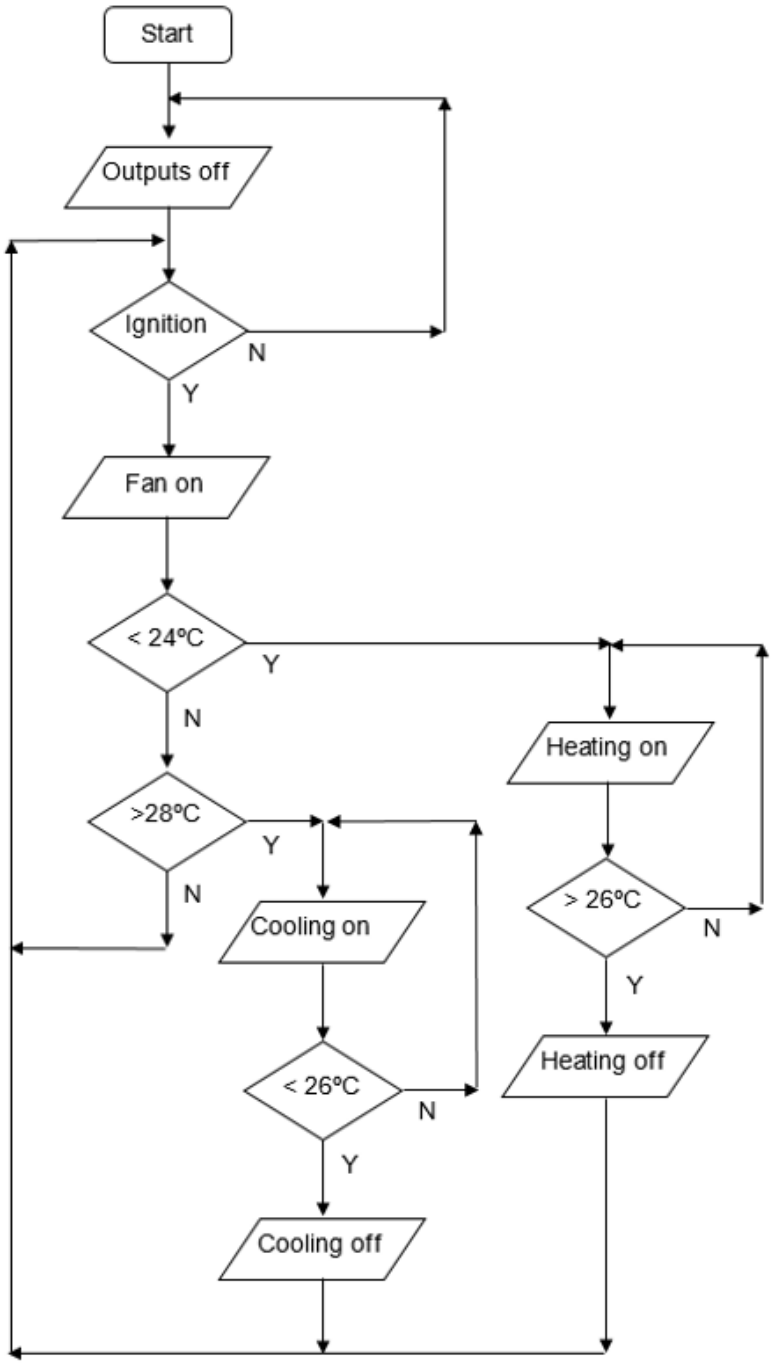
Question 41 **(14 marks)**

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



Description	Marks
Input: There are 2 i.e. The harvester ignition is turned on AND the ambient temperature in the harvester cabin	1
Process: There are 3 i.e. the **fan** turns on AND the **heating unit** turns on or off OR the **cooling unit** turns on or off	1–3
Control: The temperature sensor provides feedback to the process block to determine the status of the heating and cooling units	1
Output: The harvester cabin temperature is regulated between 24 ºC – 28 ºC	1
Total	**6**

(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)



Description	Marks
Five YES/NO decisions with correct feedback loops	1–5
Dead-band 24 ºC – 28 ºC with fan only	1
Correct cooling cycle	1
Correct heating cycle	1
Award marks for variations of the above flowchart provided it will function correctly	
Total	**8**

Question 42 **(17 marks)**

(a) Explain what is meant by the terms:

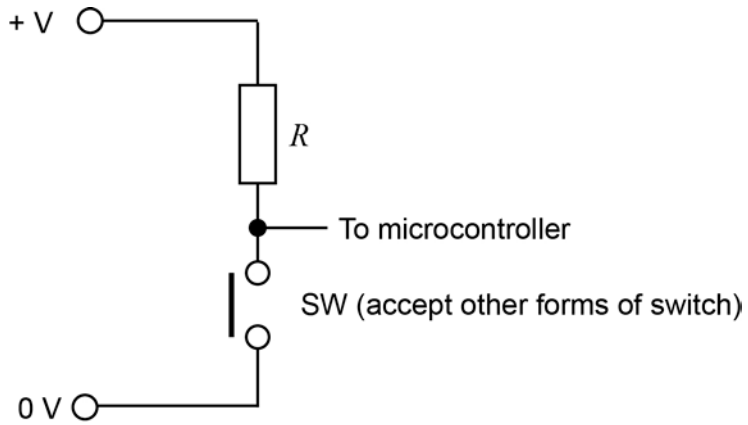
(i) digital input (1 mark)

Description	Marks
A digital signal has only 2 states i.e. it is either on or off (high/low or 1/0 or 5 V/0 V)	1
Total	**1**

(ii) analogue input. (1 mark)

Description	Marks
An analogue signal uses a defined scale	1
or can be anywhere between the minimum and maximum values e.g. 0 V – 5 V	
Total	**1**

(b) (i) In the space below, complete a sketch of a labelled 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)



Description	Marks
Resistor at top	1
Switch under resistor	1
Signal position clearly indicated	1
Total	**3**

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

pull up tie down

Description	Marks
Pull up	1
Total	**1**

(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)

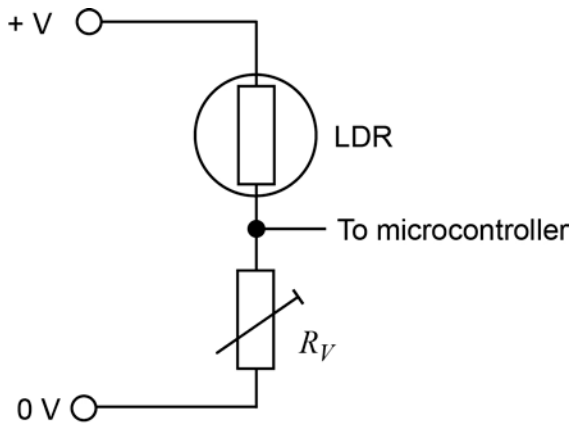
Description	Marks
When the switch is open, no current flows, so there is no voltage drop across R. All the voltage must be across the input pin (or switch) so it is high.	1–2
When the switch is closed, a current flows through R and the switch. The voltage drop is across R so the voltage drop across the input pin and switch will be low.	1–2
Total	**4**

(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)



Description	Marks
LDR at top	1
Variable resistor	1
at bottom	1
Signal position clearly indicated	1
Total	**4**

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

Description	Marks
Darker: The LDR resistance increases, so the voltage across the LDR rises. The voltage across Rv must fall. This is the signal.	1–2
Brighter: The LDR resistance decreases, so the voltage across the LDR falls. The voltage across Rv therefore rises.	1–2
Total	**4**

Question 43 **(12 marks)**

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

Description	Marks
400 × 16 = S × 32 S = 400 × 16/32 = 200 rpm	1–2
1 mark for correct formula 1 mark for answer	
Total	**2**

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

Description	Marks
Speed = 200 rpm = 200/60 = 3.3333 revs/s	1
Distance moved/rev = 8 ×10 = 80 mm	1
Revs/400 mm =400/80 = 5.0	1
Time = 5.0/3.3333 = 1.5 s	1
Total	**4**

(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)

Description	Marks
Double the size of the intermediate gear to 64 teeth will halve the rotational speed of the pinion, therefore half the translational speed of the rack. OR Half the size of the motor drive gear to 16 teeth will halve the rotational speed of the intermediate gear and the pinion, therefore half the translational speed of the rack.	1–3
1 mark to indicate a valid change 1–2 marks for effect	
Total	**3**

(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)

Description	Marks
A translation of 100 mm means a rotation of the pinion of (10/8) × 360° = 450°	1
Intermediate gear must rotate the same angle as it is on the same shaft. Rotation of motor shaft × 16 = 450 × 32 Rotation of shaft = 900°	1
Number of steps = 900/18 = 50.	1
Total	**3**

Question 44 **(19 marks)**

(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)

Description		Marks
$7 =$	$\frac{(12 \times 1500)}{(1500 + R_V)}$	1-3
$7 \times (1500 + R_V) =$	$18\,000$	
$7R_V =$	$18\,000 - 10\,500$	
$=$	7500	
$R_{SENSOR} =$	$\frac{7500}{7}$	
$\approx$	$1071\ \Omega$	1

or

$5 =$	$\frac{(12 \times R_V)}{(R_V + 1500)}$	1-3
$5 \times (R_V + 1500) =$	$12R_V$	
$7500 =$	$12R_V - 5R_V$	
$=$	$7R_V$	
therefore $R_V =$	$\frac{7500}{7}$	
$\approx$	$1071\ \Omega$	1
	Total	**4**

(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)

Description	Marks
0- 5 V has a range 0 - 255 (i.e. 256 steps). Therefore each step is 100/255 = 0.392 °C Required accuracy is 0.1 °C, therefore this solution is not acceptable.	1–4
1 mark for relating 256 steps to 100 °C 1 mark for correct step size 1 mark for comparing with required accuracy 1 mark for 'no' conclusion	
Total	**4**

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

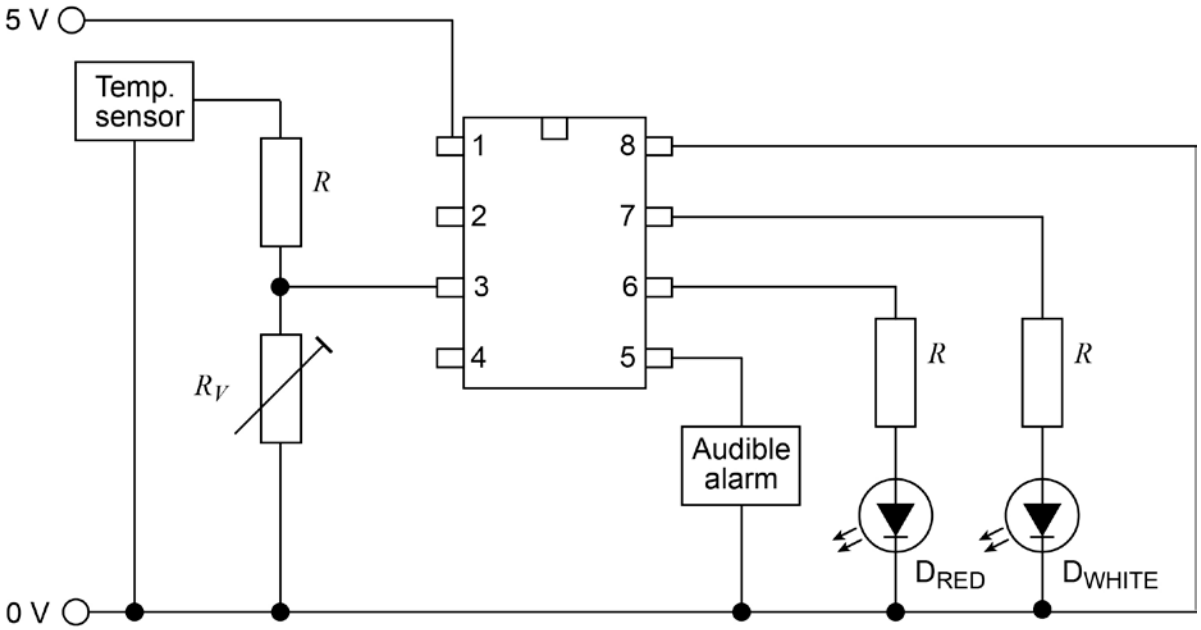
Description	Marks
20 °C would give a value of 255×(20/100) = 51 60 °C would give a value of 255×(60/100) = 153	1–4
Total	**4**

(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 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)



Description	Marks
5 V and ground (0 V) connections to pins 1 and 8	1
Temperature sensor shown connected to top of conditioning circuit	1
Conditioning circuit with output connected to pin 3 or 5 or 6	1
White LED **and** current limiting resistor connected to pin 3 or 5 or 6 or 7	1
Red LED **and** current limiting resistor connected to pin 3 or 5 or 6 or 7	1
Audible alarm connected to pin 3 or 5 or 6 or 7	1
Ground (0 V) connections for inputs and outputs	1
The above circuit diagram is a guide only. Accept other variations provided these meet the specifications given in this marking key.	
Total	**7**

Question 45 **(21 marks)**

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

Description	Marks
$\sum\Delta V = 0 =$ $5 - V_R - V_{BE,on}$	
$=$ $5 - (I_R \times R) - 0.7$	
$I_R \times 3900 =$ 4.3	
$I_R =$ $\frac{4.3}{3900}$	1–3
$\approx$ 0.0011 A or 1.1 mA or 1.1×10^{-3} A	1
Total	**4**

(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)

Description	Marks
$I_{RLY} = I_C =$ $I_B \times \beta$ Note : $I_B = I_R$	
$=$ 0.0011×65	1–2
$=$ 0.07167 A or 71.67 mA or 7.17×10^{-2}A	1
Accept 0.715 A if the rounded value of 0.715 A was used.	
Total	**3**

(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)

Description	Marks
$\sum\Delta V = 0 =$ $12 - V_{RLY} - V_{CE}$	
$V_{CE} =$ $12 - (I_{RLY} \times R_{RLY})$	
$=$ $12 - (0.07167 \times 150)$	
$=$ $12 - 10.75$	1–3
$=$ 1.25 V	1
Total	**4**

(c) Calculate the minimum current through R that will drive the transistor into saturation. (3 marks)

Description	Marks
V_{CE} = 0V.	1
$\sum\Delta V = 0 = 12 - V_{RLY} - V_{CE}, SAT$ $= 12 - (I_{RLY} \times 150) - 0$ $I_{RLY} = \frac{12}{150}$	1
=0.08 A.	1
The point at which saturation occurs is the point at which $I_C = I_B \times \beta$ $I_B = \frac{I_C}{\beta}$ but $I_C = I_{RLY}$ $= \frac{0.08}{65}$	1–2
= 0.00123 A N 1.23mA or 1.23×10^{-3}A	1
Total	**6**

(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)

Description	Marks
$\sum\Delta V = 0 =$ $12 - V_{RLY} - V_{CE}$	
$=$ $12 - (I_{RLY} \times R_{RLY}) - V_{CE}$	
$V_{CE} =$ $12 - (0 \times R_{RLY})$	1
$=$ 12 - 0	1
$=$ 12 V	1
Total	**3**

(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)

Description	Marks
When the transistor is operating in its forward-active or saturation region then the diode is reverse-biased and has no effect on the behavior of the circuit.	1
However, when the transistor switches it its cut-off region of operation then electromagnetic energy in the coils of the motor reverts back to electrical energy. There is a brief but very large voltage spike which results in a very large current that will cause the transistor to overheat. This is known as back e.m.f.	1–2
The diode now becomes forward-biased and diverts this back e.m.f. the current away from the transistor until the electrical energy is dissipated.	1
Total	**4**

Question 46 **(9 marks)**

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

Description	Marks
R_T = 470 + (470 || 220) + 180	1
= $470 + \frac{(470 \times 220)}{(470 + 220)} + 180$	
= $470 + \frac{103\,400}{690} + 180$	
= 470 + 149.86 + 180	
= 799.86 Ω ≈ 800 Ω	1
$I_{R1} = I_{R4} = I_T = \frac{12}{R_T}$	1
$= \frac{12}{799.86}$	
= 0.015 A	1
	1
$\Sigma \Delta V = 0 = 12 - V_{R1} - V_{R3} - V_{R4}$	
V_{R3} = 12 – (0.015 × 470) – (0.015 × 180)	
= 12 – 7.05 – 2.7	
= 2.25 V	1
Total	**6**
Alternatively, the problem could be solved using a voltage divider equation. The equivalent resistance for $R_2 \| \| R_3$ would be required.	1
$R_2 \| \| R_3 = \frac{(470 \times 220)}{(470 + 220)}$	
$= \frac{103\,400}{690}$	
= 149.86 Ω ≈ 150 Ω	1
$V_{R2\|\|R3} = V_{R3} = \frac{(12 \times 149.86)}{(470 + 149.86 + 180)}$	1–2
$= \frac{1798.32}{799.86}$	1
= 2.248 V ≈ 2.25 V	1
Total	**6**

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

Description	Marks
$V_{R3} = V_{R2} = I_{R2} \times R_2$	1–2
$I_{R2} = \frac{V_{R2}}{R_2}$	
$= \frac{2.248}{470}$	
= 0.0047836 A or 4.78 mA or 4.78×10^{-3}A	1
Accept other reliable methods for determining I_{R2} e.g. Using Kirchhoff's current law with Ohm's law	
Total	**3**

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