



X823/77/11

Engineering Science

Duration — 2 hours 30 minutes

Total marks — 75

SECTION 1 — 35 marks

Attempt ALL questions.

SECTION 2 — 40 marks

Attempt ALL questions.

You may refer to the Advanced Higher Engineering Science Data Booklet.

Write your answers clearly in the answer booklet provided. In the answer booklet, you must clearly identify the question number you are attempting.

For questions 2 (b), 7 (a) and (b), 8 (e) and 9 (g), write your answers clearly in the worksheets provided in the answer booklet.

Show all working and units where appropriate.

The number of significant figures expressed in a final answer should be equivalent to the least significant data value given in the question. Answers that have two more figures or one less figure than this will be accepted.

Use **blue** or **black** ink.

Before leaving the examination room you must give your answer booklet to the Invigilator; if you do not, you may lose all the marks for this paper.

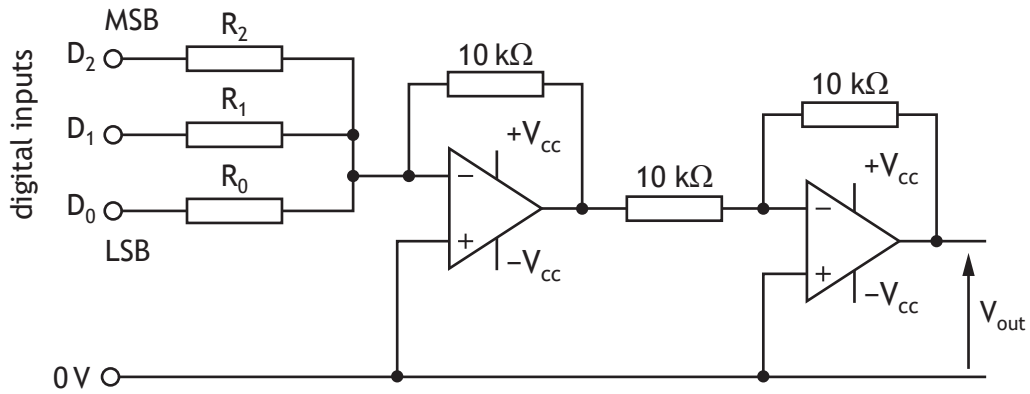


* X 8 2 3 7 7 1 1 *

SECTION 1 — 35 marks

Attempt ALL questions

1. A student designed a 3-bit digital to analogue converter (DAC). The circuit is shown below.



Circuit specifications

- $V_{out} = 12\text{ V}$ when digital input is 111_{LSB}
- Logic 1 = 5 V
- Logic 0 = 0 V

(a) Calculate suitable resistor values for R_0 , R_1 and R_2 .

3

(b) State the number of different analogue voltage values that can be produced by this circuit.

1

2. The Aberdeen Western Peripheral Route is a recent example of government-funded capital investment in Scotland's infrastructure.

- (a) State the meanings of the terms **oncost** and **direct cost**, as used in cost-management during large civil engineering projects.

2

A project manager constructed the precedence table below for a part of the main project.

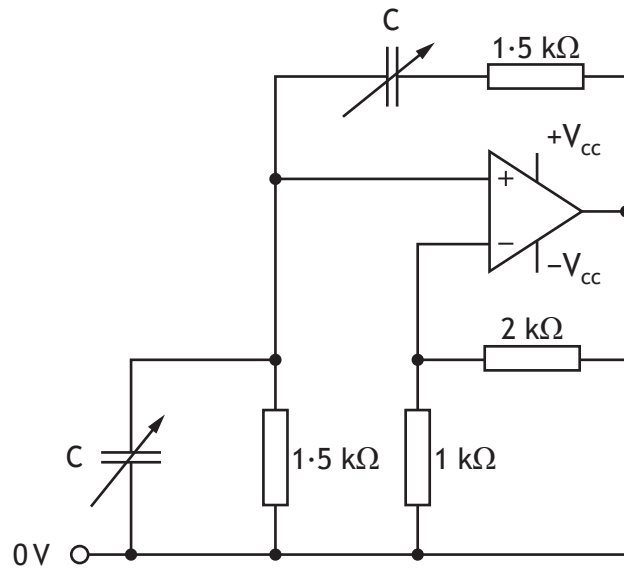
Activity	Duration (weeks)	Precedents
A	3	----
B	2	----
C	4	----
D	5	A,B
E	7	A,C
F	1	D,E
G	1	F

- (b) Determine a critical path for this series of activities by completing the network diagram on the **worksheet for question 2(b)**.

3

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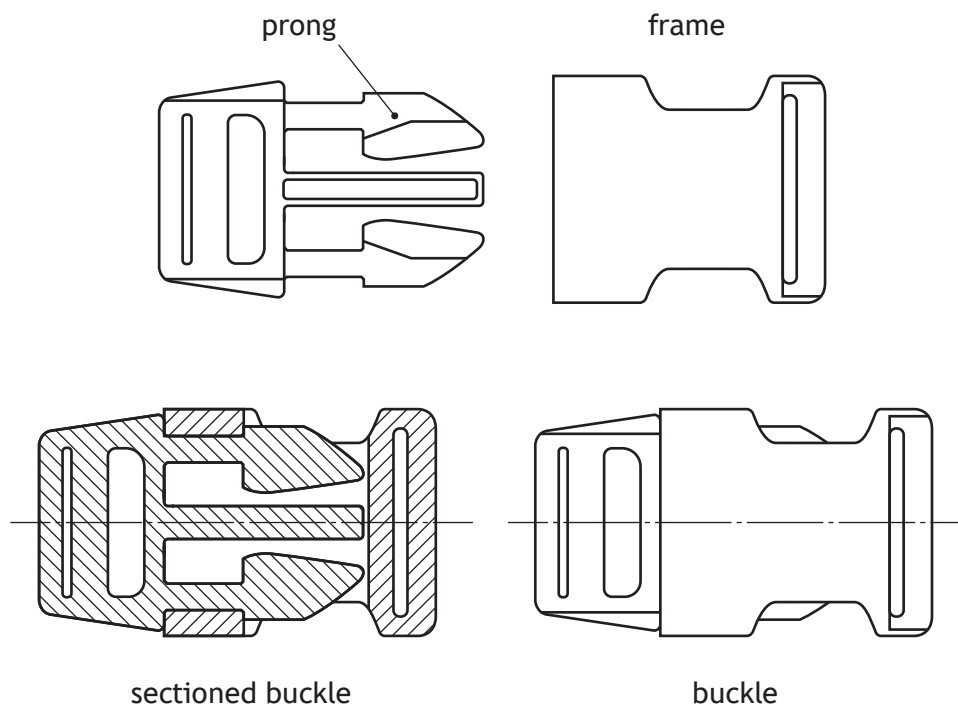
3. A Wien Bridge oscillator circuit is being designed to produce a range of frequencies. The circuit is fitted with two variable capacitors designed to be varied simultaneously.



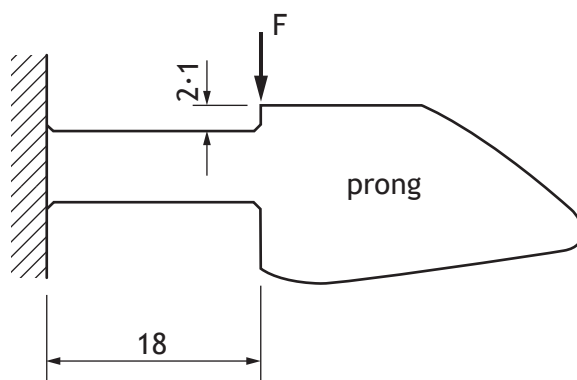
The circuit must produce frequencies in the range 10 kHz – 25 kHz.

- (a) State the type of waveform produced by this circuit. 1
- (b) Calculate the range of values required for the variable capacitors. 2

4. A buckle comprises two separate parts that clip together. The prongs fit into a frame. The end of each prong deflects on entering the frame and then springs back to its original position to secure the joint.



The dimensions of the prong are shown below.



all dimensions in mm

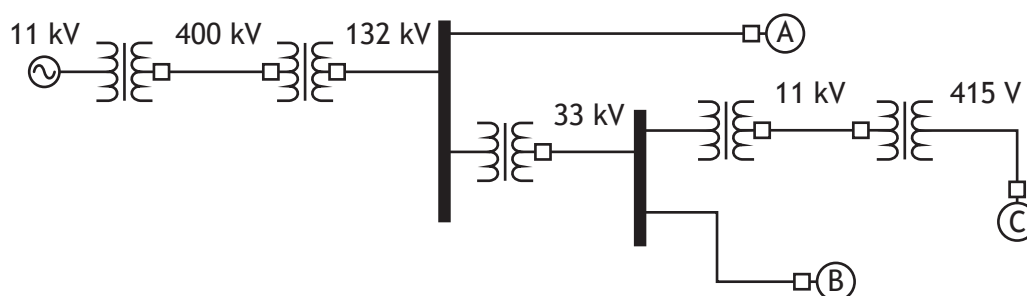
The prong can be considered to be a cantilever beam under the action of a point load. The 18 mm length of the prong has a second moment of area of 6.75 mm^4 and is made from polypropylene plastic.

Calculate the force, F , applied at the point shown, required to deflect this point by the necessary 2.1 mm.

3

[Turn over

5. A simplified National Grid line diagram is shown below.



Note that the 415 V equates to 230 V AC on a single phase.

(a) With reference to the diagram

- (i) explain why it is necessary to vary transmission voltages across the grid
- (ii) identify typical customers at points A, B and C.

2

1

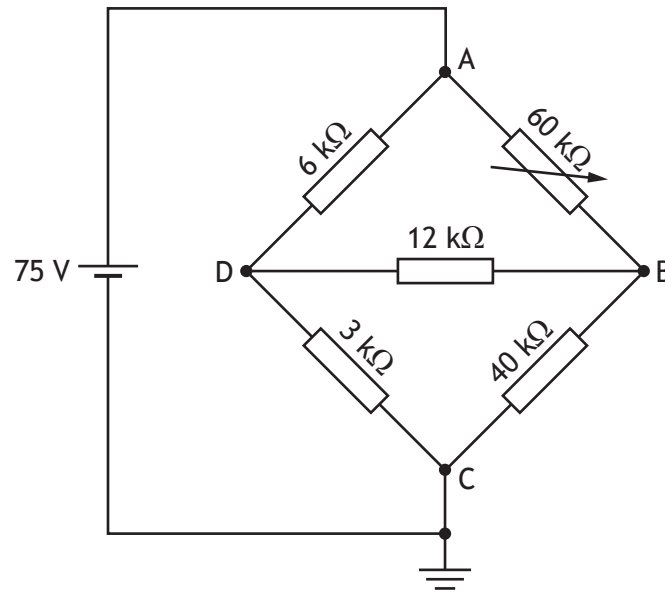
A transmission cable runs between the 33 kV – 11 kV transformer and the 11 kV – 415 V transformer. The power transmitted from the first transformer via the cable is 110 kVA when its secondary winding is at 11 kV. The transmission cable has a resistance of $494 \mu\Omega\text{m}^{-1}$. The two transformers are separated by a distance of 12 km.

Note that 1 kVA is equivalent to 1 kW.

(b) Calculate the efficiency of the power transmission between the two transformers.

3

6. A student is experimenting with the circuit shown below.

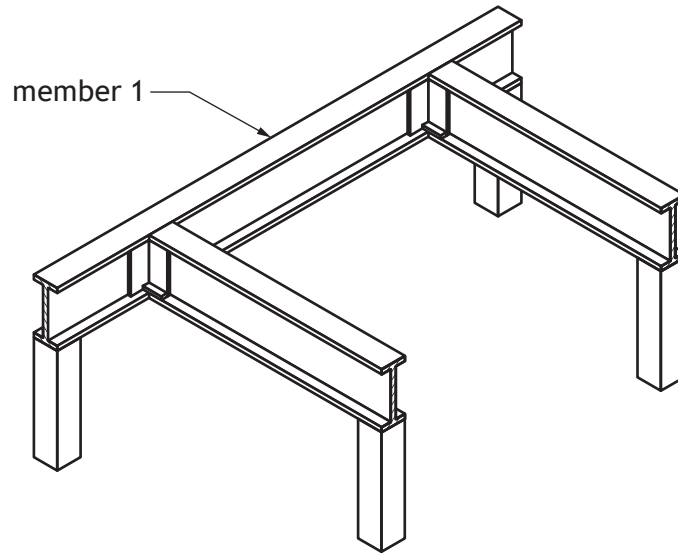


Calculate, using nodal analysis, the current flowing through the $12\text{ k}\Omega$ resistor when the variable resistor is set to the value shown in the diagram.

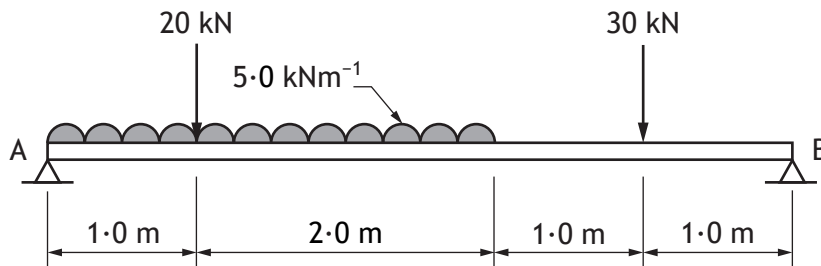
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7. Structural members in a steel-framed building are used to support partition walls within the building. Three such members are shown below.



Member 1 can be modelled as a simply-supported beam under the action of two vertical point loads of 20 kN and 30 kN and a uniformly distributed load (UDL) of 5.0 kNm^{-1} , as shown below.



- (a) Draw, on the axes provided on the **worksheet for question 7(a)**, a shear force diagram for the beam. 4
- (b) Complete the table on the **worksheet for question 7(b)** with values for the bending moment at the specified points along the beam. 3
- (c) Describe, with the aid of a sketch, the shape of the bending moment diagram for the beam. 2

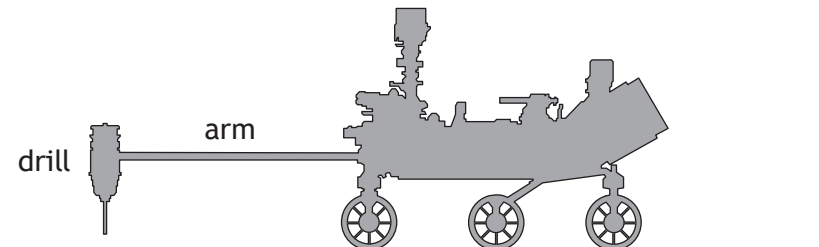
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SECTION 2 — 40 marks

Attempt ALL questions

8. A space mission is planned to place an autonomous vehicle (rover) on the surface of the planet Mars. One of the rover's functions is to drill into the surface of the planet for samples. A drill is fitted on the end of an articulated arm. The mass of the drill is 50 kg.



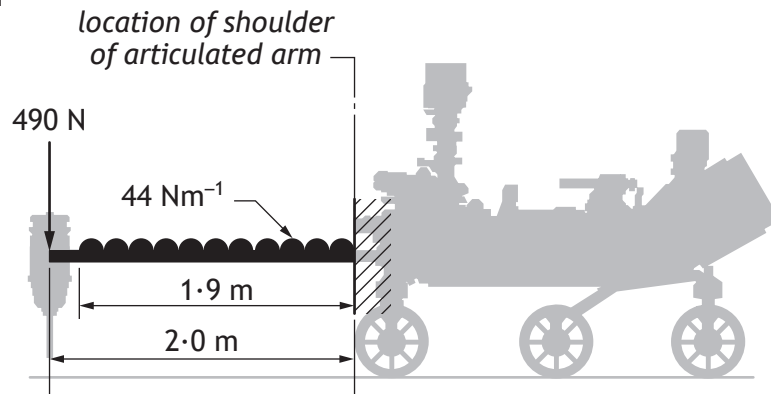
Two arrangements were considered for structural calculations.

- Condition 1: fully extended arm, drill held in position above the ground.
- Condition 2: during drilling, the drill reaction force lifts the rover off its front and mid wheels, so that its weight is supported only by the rear wheels and the drill.

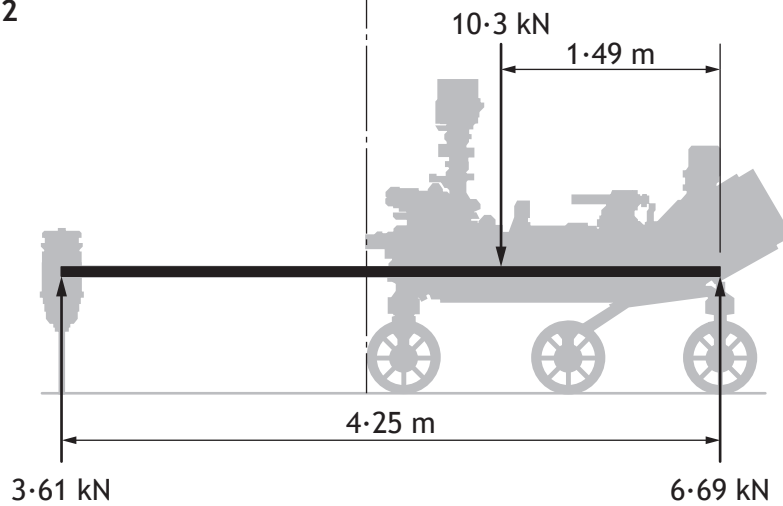
The loads associated with both these conditions are shown opposite.

8. (continued)

condition 1



condition 2



The rover was designed to prevent the arm failing under the worst-case operating condition in terms of the bending moment applied to the arm at its shoulder.

- (a) Using the information given about condition 1 and condition 2 above, determine which of the two conditions should be considered the worst-case operating condition.

4

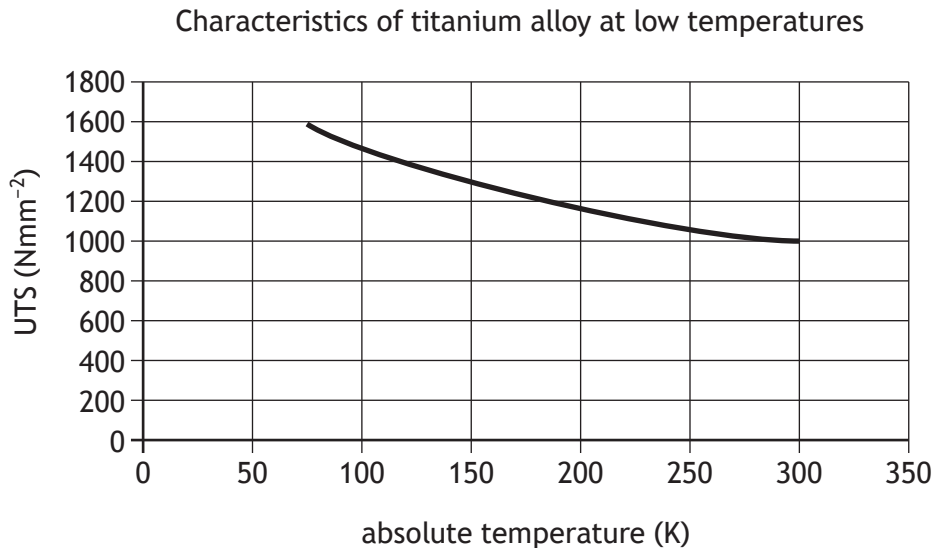
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8. (continued)

The arm is made from titanium alloy of hollow circular cross-section with an outside diameter of 50 mm.

The design of the arm is based on a factor of safety on Earth of 1.25, when the arm's temperature is expected to remain in the range 17°C to 27°C (an absolute temperature range of 290 K to 300 K).

Ultimate tensile stress (UTS) information for titanium is shown below.



Engineers modify the rover, the arm and the drill to save weight. As a result, the worst-case bending moment is reduced to 6.55 kNm.

- (b) Calculate the minimum wall thickness of the arm required to withstand the reduced worst-case bending moment.

4

The Martian gravity is 38% of that of Earth and the temperature of the environment is -150°C (an absolute temperature of 123 K).

- (c) Explain whether the factor of safety of the arm is greater or less on Mars than when on Earth.

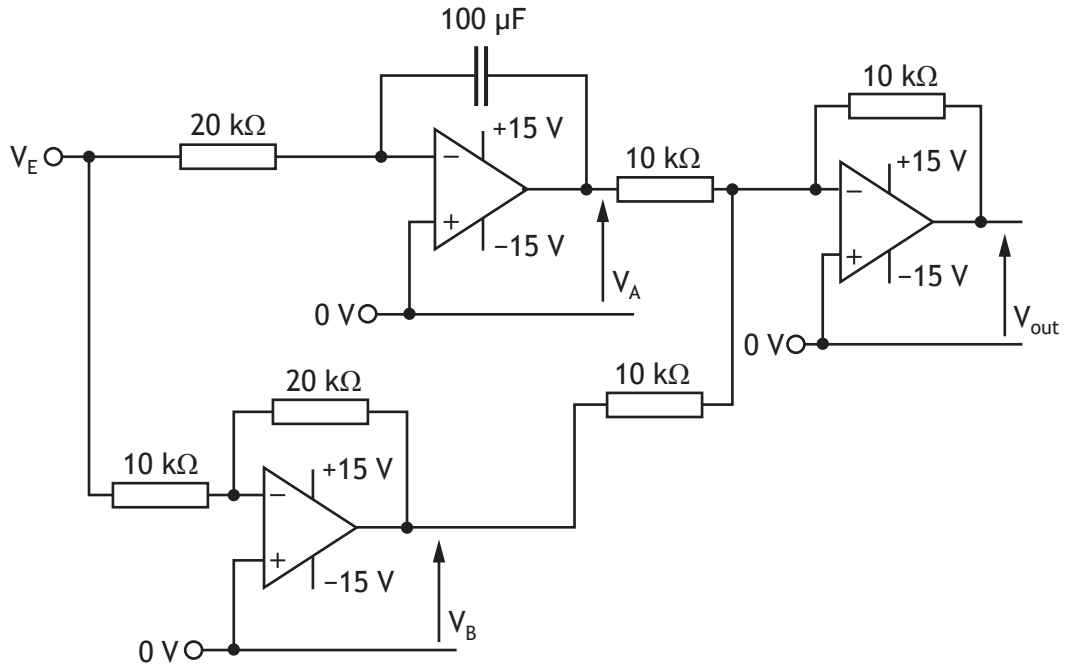
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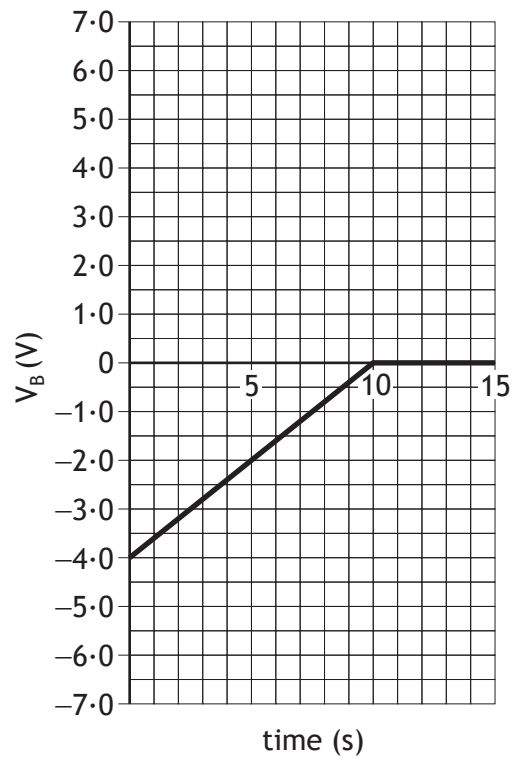
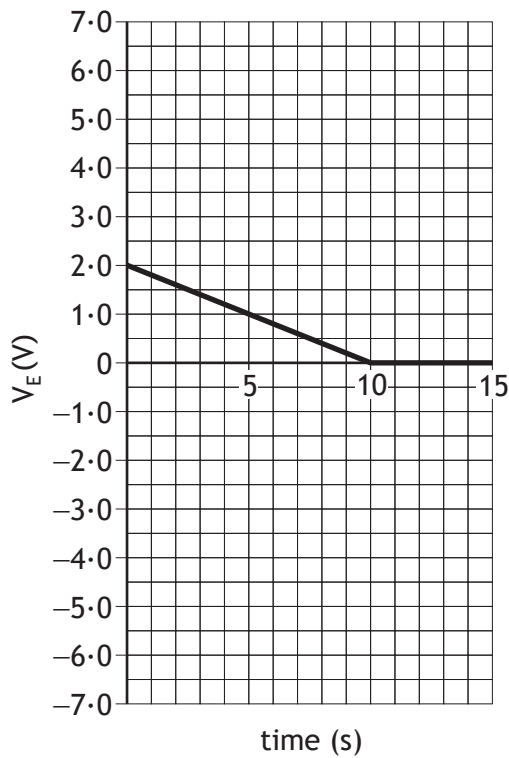
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8. (continued)

An op-amp sub-system is used in the control of the robotic arm movement on the rover. The circuit is shown below.



The graphs of the error signal V_E and V_B are shown below.



8. (continued)

From the graph shown opposite it may be seen that the error V_E is given by

$$V_E = 2 - 0.2t$$

where t is time in seconds.

(d) Determine the equation for V_A as a function of time if $V_A = 0$ V when $t = 0$ s.

2

The magnitude of V_{out} reaches a maximum of 5.8 V when $t = 6$ s.

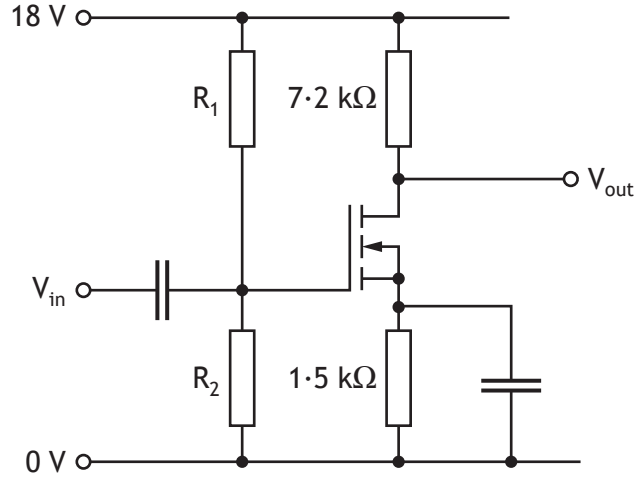
(e) Sketch the graph of V_{out} on the **worksheet for question 8(e)**, showing clearly the values of V_{out} when $t = 0$ s, 6 s, 10 s and 15 s respectively.

3

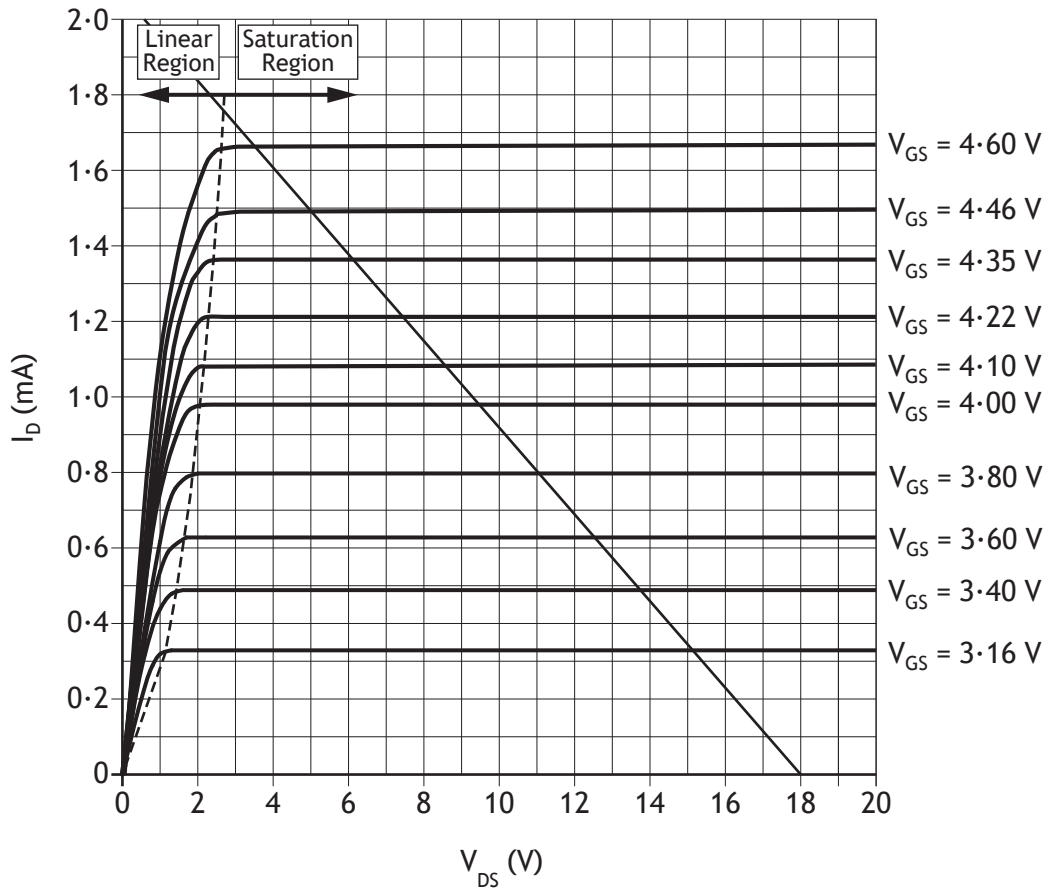
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8. (continued)

A single-stage MOSFET amplifier is being designed to amplify the input from a sound sensor on the rover. The effect of the capacitors can be ignored. The MOSFET threshold voltage is 2.0 V.



The characteristics for the MOSFET are shown below. The load line for the amplifier design has been added.



8. (continued)

The quiescent point is selected to give a drain-source voltage value (V_{DS}) of 10 V.

Design rule: When connected in parallel, R_1 and R_2 would have a total resistance of 100 k Ω .

(f) Calculate the values V_G , R_1 and R_2 required for the selected quiescent point.

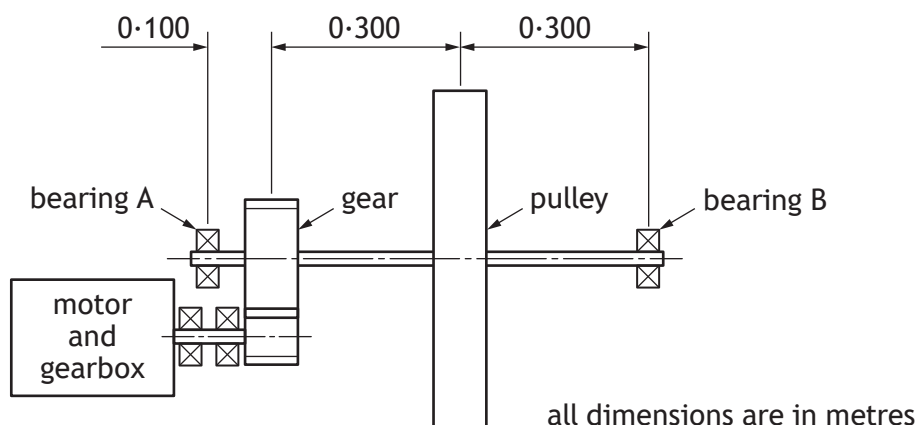
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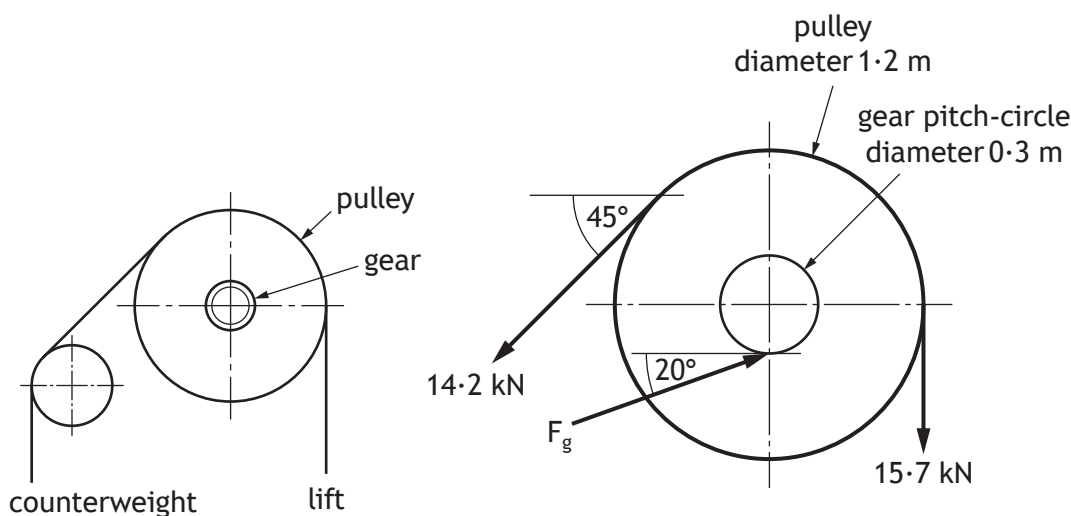
9. Any tall building has lifts to move occupants between floors.

A traditional lift mechanism has a motor driving a pulley through a gearbox. The motor can drive forwards and backwards to raise or lower the lift. A counterweight is used to reduce load on the motor.

The arrangement of the shaft that drives the lift is shown below. The bearings A and B act as simple supports for the shaft. The motor and gearbox drive the shaft through a pair of spur gears. The gears have a pressure angle of 20° . The pulley is attached to the shaft and connected to the lift and counterweight by cables.



At a steady speed and a fixed load when the lift is empty, the forces acting on the pulley and on the gear (as viewed from bearing A) are shown below.



Note that distances are accurate to ± 1 mm and angles to $\pm 0.1^\circ$.

- (a) Calculate the magnitudes of the horizontal and vertical components of the gear force, F_g . 3
- (b) Explain whether the lift is being raised or lowered. 2

9. (continued)

When the lift is fully loaded, the tension in the cable supporting the lift increases from 15.7 kN to 23.55 kN. The cable tension on the other side of the pulley remains at 14.2 kN. The gear force, F_g , is 39.8 kN.

(c) Calculate the magnitude of the resultant force acting on bearing B.

4

In operation, the magnitudes of the motor torque and load torque are described by equations that are functions of the rotational speed, n , measured in revs min^{-1} .

The motor torque

$$T = (600 + 2n)$$

The load torque

$$T_L = 80\sqrt{n}$$

(d) Construct a quadratic equation and hence determine values of n for the condition where the motor drives the load at constant rotational speed.

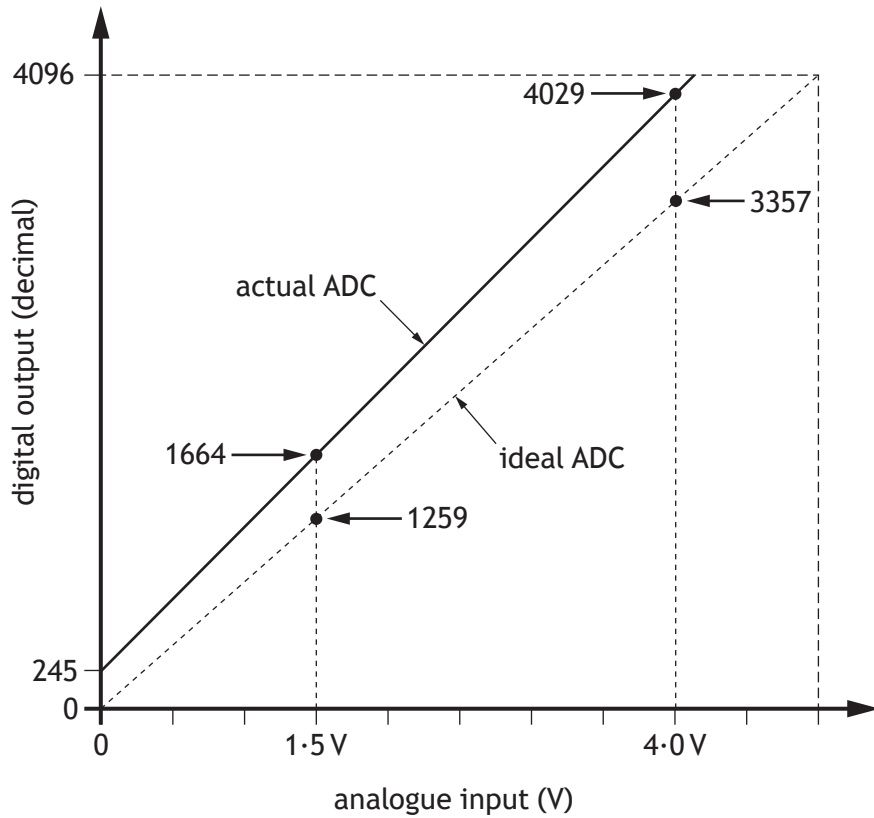
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9. (continued)

The weight of the lift is monitored using a load cell. The load cell's analogue output is converted to a digital signal using a 12-bit analogue to digital converter (ADC) which is integrated in a microcontroller.

The ADC is calibrated by using a highly accurate voltage source. Ideal and actual digital outputs are plotted on the graph below.



The gain error for the ADC is calculated using the formula

$$\text{gain error} = \frac{M_a}{M_i}$$

M_a = actual output line gradient

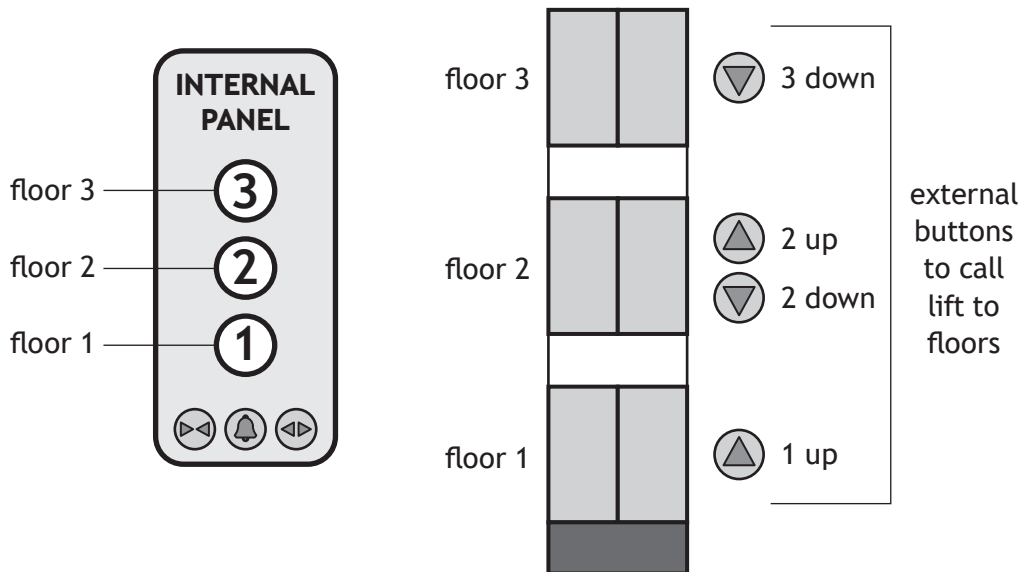
M_i = ideal output line gradient

(e) Calculate the gain error.

3

9. (continued)

The building has many lifts to carry passengers and goods. A student is investigating a lift floor selection program based on a 3-floor model.



The status of the 7 user buttons is stored using an 8-bit binary variable named *flag*. When a button is pressed the corresponding binary digit is set to 1.

Bit	7	6	5	4	3	2	1	0
Button	Any requests?	3 down	2 up	2 down	1 up	floor 3	floor 2	floor 1

Bit 7 is set to 0 if there are no current requests and 1 if any requests have been made.

Example

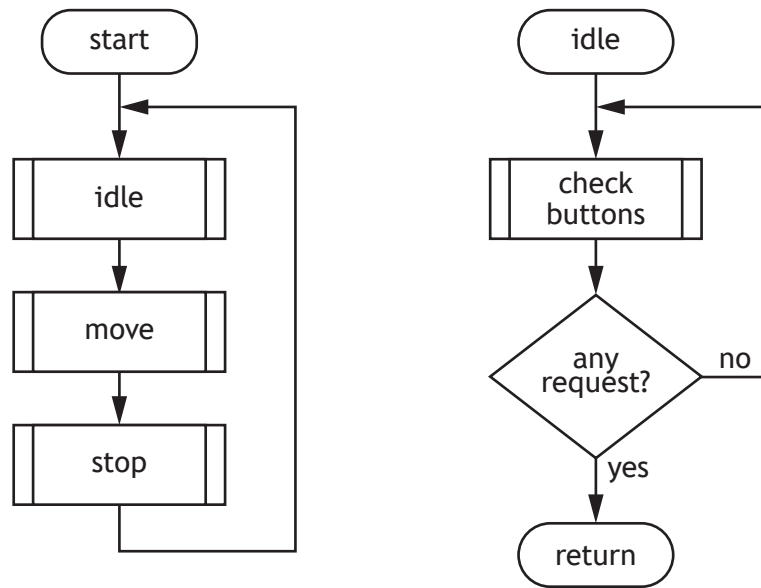
Assume that there have been no requests and *flag* is set to binary 00000000_{LSB} .

If a user on the 2nd floor presses the 2 *up* button and a user inside the lift presses the *floor 3* button, *flag* will update to 10100100_{LSB} .

[Turn over

9. (continued)

The basic operation of the lift can be explained by the following flowcharts.



The *idle* sub-procedure continually checks the status of the 7 user buttons. When buttons are pressed the *flag* variable is updated and the *move* sub-procedure is called. *move* calculates the destination of the lift and moves the lift towards the destination.

The student writes the following sub-procedure for *check buttons*.

	Arduino		Pbasic
Section A	<pre> int flag = B00000000; int floor1 = 0; int floor2 = 1; int floor3 = 2; int up1 = 3; int down2 = 4; int up2 = 5; int down3 = 6; </pre>	Section A	<pre> symbol flag = b0 symbol floor1 = pinB.0 symbol floor2 = pinB.1 symbol floor3 = pinB.2 symbol up1 = pinB.3 symbol down2 = pinB.4 symbol up2 = pinB.5 symbol down3 = pinB.6 flag = %00000000 </pre>
Section B	<pre> void check_buttons () { if (digitalRead(floor1) == HIGH) {flag = B10000001;} if (digitalRead(floor2) == HIGH) {flag = B10000010;} if (digitalRead(floor3) == HIGH) {flag = B10000100;} if (digitalRead(up1) == HIGH) {flag = B10001000;} if (digitalRead(down2) == HIGH) {flag = B10010000;} if (digitalRead(up2) == HIGH) {flag = B10100000;} if (digitalRead(down3) == HIGH) {flag = B11000000;} } </pre>	Section B	<pre> check_buttons: label1:if floor1 = 0 then label2 flag = %10000001 label2:if floor2 = 0 then label3 flag = %10000010 label3:if floor3 = 0 then label4 flag = %10000100 label4:if up1 = 0 then label5 flag = %10001000 label5:if down2 = 0 then label6 flag = %10010000 label6:if up2 = 0 then label7 flag = %10100000 label7:if down3=0 then label8 flag = %11000000 label8: return </pre>

9. (continued)

After testing, the student detects errors in Section B of the sub-procedure and re-writes it as follows using the ‘bitwise OR’ command ‘|’.

	Arduino		Pbasic
Section B	<pre> void check_buttons () { if (digitalRead(floor1) == HIGH) {flag = flag B10000001;} if (digitalRead(floor2) == HIGH) {flag = flag B10000010;} if (digitalRead(floor3) == HIGH) {flag = flag B10000100;} if (digitalRead(up1) == HIGH) {flag = flag B10001000;} if (digitalRead(down2) == HIGH) {flag = flag B10010000;} if (digitalRead(up2) == HIGH) {flag = flag B10100000;} if (digitalRead(down3) == HIGH) {flag = flag B11000000;} } </pre>	Section B	<pre> check_buttons: label1: if floor1 = 0 then label2 flag = flag %10000001 label2: if floor2 = 0 then label3 flag = flag %10000010 label3: if floor3 = 0 then label4 flag = flag %10000100 label4: if up1 = 0 then label5 flag = flag %10001000 label5: if down2 = 0 then label6 flag = flag %10010000 label6: if up2 = 0 then label7 flag = flag %10100000 label7: if down3=0 then label8 flag = flag %11000000 label8: return </pre>

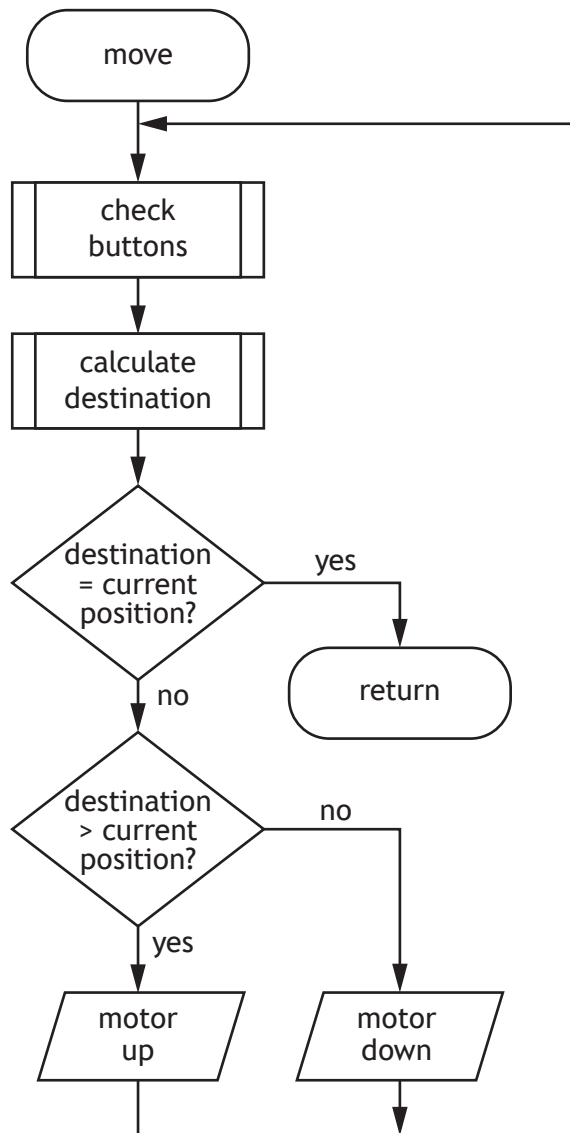
Note that 00110000 | 01010000 gives the result 01110000, where numbers are binary.

(f) Explain why it was necessary to modify the lines of the program in section B.

2

[Turn over for next question

The flowchart for the *move* sub-procedure is shown below.



The *calculate destination* sub-procedure calculates the next destination for the lift based on the following algorithm.

- Continue to travel in the current direction while there are still remaining requests in that same direction.
- If there are no further requests in the current direction then stop and become idle, or change direction if there are requests in the opposite direction.

In order to follow the algorithm, the lift needs to know its current position and the direction of travel, either up or down. It will then calculate a destination based on the status of the requests stored in the variable *flag*.

The student develops a flowchart for the sub-procedure *calculate destination*. The partially completed flowchart is shown in the **worksheet for question 9(g)**.

(g) Complete the flowchart on the **worksheet for question 9(g)**.