X036/701

TECHNOLOGICAL STUDIES
ADVANCED HIGHER

100 marks are allocated to this paper.

Answer **all** questions in Section A (60 marks).

Answer **two** questions from Section B (20 marks each).

Where appropriate, you may use sketches to illustrate your answer.

Programs should be planned using a flowchart or other suitable method.

Reference should be made to the Advanced Higher Data Booklet (2008 edition) which is provided.

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SECTION A

Attempt all the questions in this Section. (Total 60 marks)

1. In a bottling plant, lids are fitted to bottles as they pass along a conveyor belt to a packing point. After each batch of 40 bottles has had lids fitted, a motor is switched on for a short time to direct the flow of bottles to a different packing point. The control system is represented by the circuit shown in Figure Q1.
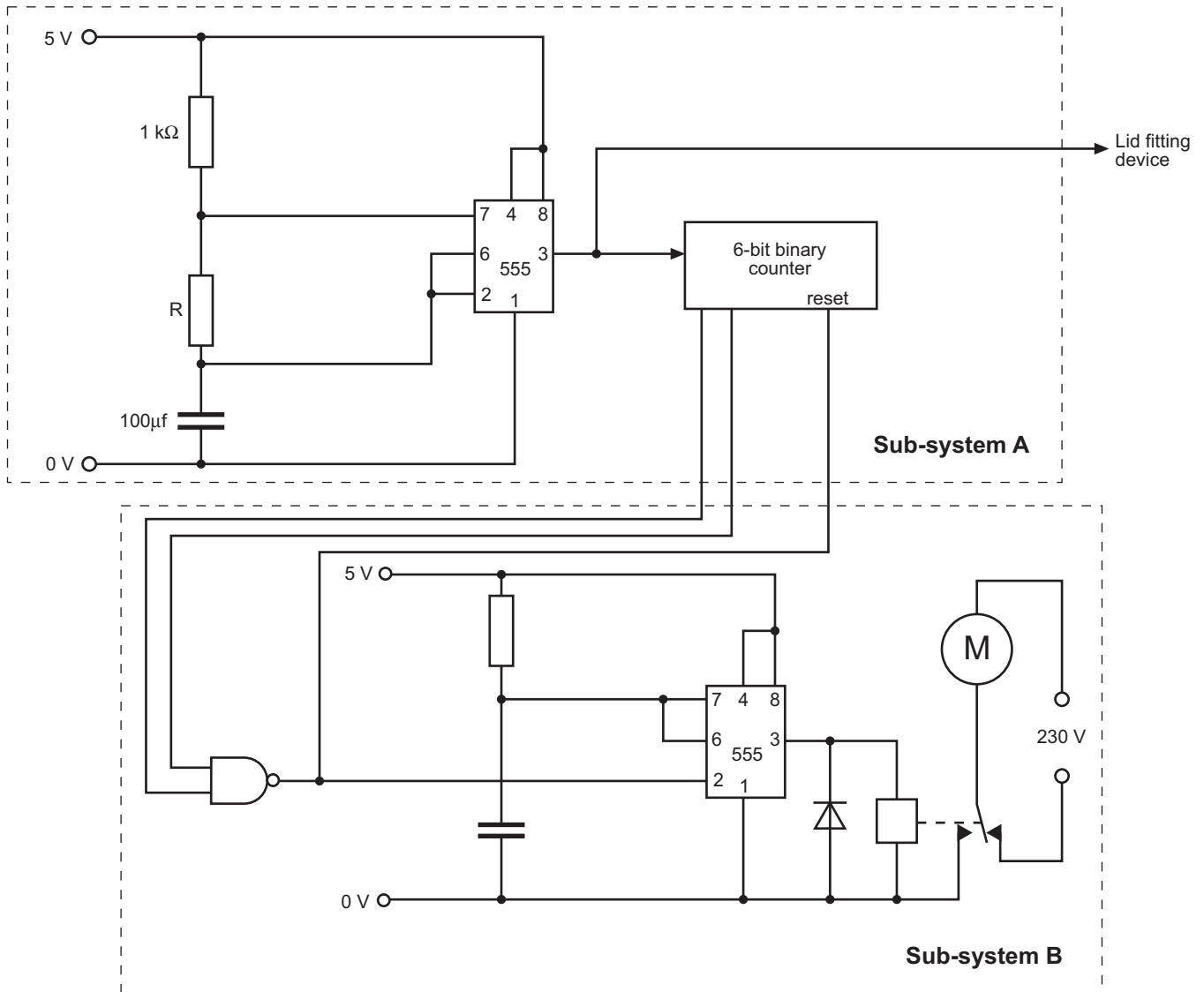

Figure Q1

(*a*) Explain in detail how the circuit shown in Figure Q1 operates, with reference to sub-system A and sub-system B. **4**

The circuit shown in Figure Q1 actuates the lid-fitting device every 1·2 seconds.

(*b*) Calculate the value of resistor R in sub-system A. **2**

The 6-bit binary counter is constructed from positive-edge D-type bistables.

(*c*) Draw the bistable circuit for the binary counter, showing clearly the connections to the outputs which actuate sub-system B. **3**

(9)

2. "Periscope depth" is the depth of a submarine below the water surface that allows the submarine's main hull to remain submerged whilst still allowing the periscope to protrude above the surface. A PID control system is used to automatically control the depth of the submarine shown in Figure Q2(*a*).
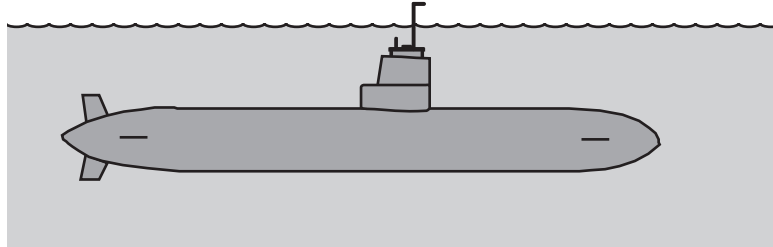

Figure Q2(*a*)
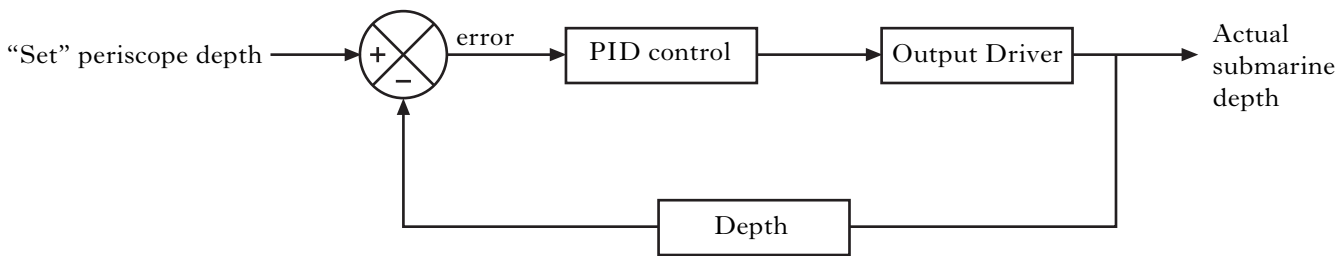
The control system is shown in Figure Q2(*b*).

Figure Q2(*b*)

Worksheet Q2 shows three incomplete depth-time graphs for the responses of control systems to a **step-change** to periscope depth.

(*a*) On **Worksheet Q2**, sketch the responses to a step-change in depth for the following types of control system:

   (i) a proportional control system with the gain factor "k" set **too low**;   **1**

   (ii) a proportional control system with the gain factor "k" set **too high**;   **1**

   (iii) a Proportional, Integral and Derivative control system.   **1**

(*b*) Explain the advantage of adding **Integral** control to a proportional control system.   **1**

(*c*) Explain the advantage of adding **Derivative** control to a proportional control system.   **1**

(5)

[Turn over

3. The linear thruster shown in Figure Q3 moves the work-table of a computer-controlled milling machine.
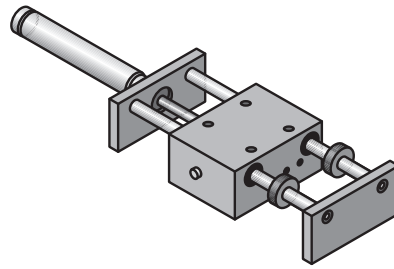

Figure Q3

The thruster is moved by a stepper motor controlled by a microcontroller. A sub-procedure *stepper* turns the motor through **one complete** revolution. The operating sequence of the coils is shown in the table below.

Step	Coil 4 (pin7)	Coil 3 (pin6)	Coil 2 (pin5)	Coil 1 (pin4)
1	1	0	1	0
2	1	0	0	1
3	0	1	0	1
4	0	1	1	0
1	1	0	1	0

The stepper motor has a step angle of $7 \cdot 5\,^\circ$. The time delay between pulses, in milliseconds, is stored in the register file DELAYTIME.

(*a*) Write, in assembler code, the sub-procedure *stepper*. **4**

Note: The register files COUNTER and DELAYTIME have been set up, and TRISB has been initialised. The sub-procedure *pause* produces a time delay of 1 ms multiplied by the value in the Working Register W.

In order to prevent damage, the program *softstop* decelerates the thruster gradually when an outstroke sensor connected to pin 0 goes high. This is achieved by increasing the value held in DELAYTIME. The value is initially set at 1 ms and is increased by 1 ms each time *stepper* is called (in a loop) until the time delay is 10 ms. DELAYTIME is then increased by 2 ms each time *stepper* is called, up to 30 ms, after which the motor stops and the program ends.

(*b*) Write, in assembler code, the program *softstop*. **4**

(8)

4. A training device for weightlifters is shown in Figure Q4. The device guides the user to repeat exercises at timed intervals, and is based on 5 sets of exercises each consisting of 8 repetitions. The display indicates the number of repetitions that have been completed within a set, and the number of sets still to be done. At the end of each set, the SETS display decreases by one, and the REPETITION display resets to zero.
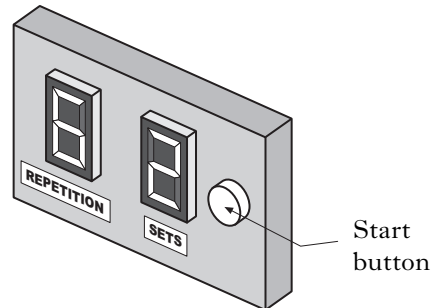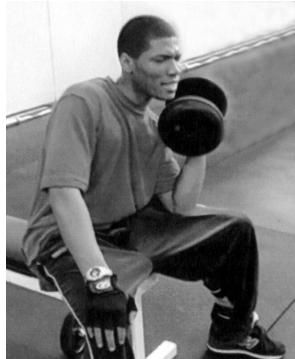

Figure Q4

The two counters in the system are constructed from negative-edge-triggered J-K bistables. The REPETITION display is controlled by an up-counter and the SETS display by a down-counter. The specification for the counting sub-system is shown below.

- The REPETITION counter counts up each time it is clocked until it reaches 8 when it resets to 0 and a signal is sent to the SETS counter.

- When the Start button is pressed, the SETS counter sets to 5 and then counts down each time it is clocked by the signal from the REPETITION counter.

- The outputs from each counter are connected to a "BCD to 7-segment display" decoder.

On **Worksheet Q4** complete the circuit to fulfill the specification described above.

7

(7)

[Turn over

5. A naval architect is considering the catastrophic effects of extreme wave sizes on the structure of heavily laden supertankers as shown in Figure Q5(*a*).
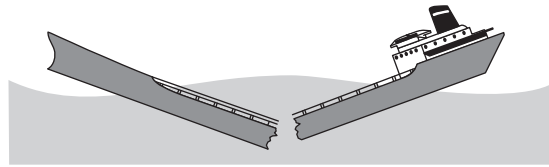

Figure Q5(*a*)

Two different wave scenarios being investigated are shown in Figure Q5(*b*) and Figure Q5(*c*).
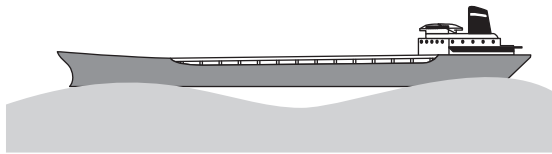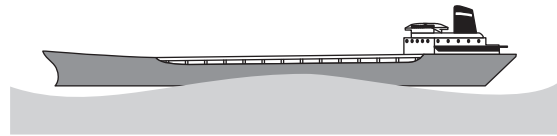

Figure Q5(*b*) Scenario 1

Figure Q5(*c*) Scenario 2

(*a*) State in which scenario the ship is "hogging" and in which the ship is "sagging". **1**

A simplified free-body diagram for Scenario 1 is shown on **Worksheet Q5(a)**.

The diagram shows the loading and support conditions.

(*b*) On **Worksheet Q5(a)** plot the shear-force diagram. **2**

(*c*) Calculate the bending-moment acting at 0 m, 10 m, 20 m, 30 m, 40 m and 50 m distances from the left end of the diagram. **6**

(*d*) On **Worksheet Q5(a)** plot the complete bending-moment diagram. **2**

The shear-force diagram for Scenario 2 is shown on **Worksheet Q5(b)**.

(*e*) On **Worksheet Q5(b)** draw the free-body diagram for this scenario. **2**

(13)

6. The plant propagator shown in Figure Q6 is operated using microcontroller proportional control. It is designed to assist plant cuttings to develop roots by maintaining suitable temperature and soil moisture-content levels, by means of a heater and a water sprinkler.
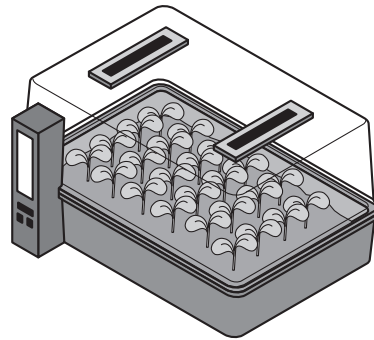

Figure Q6

The heater is controlled using the sub-procedure *heat* which switches the heater on and off 30 times using the two register files MARK and SPACE which have been preloaded with the correct time delays in milliseconds.

Inputs	PORTB	Outputs
	7	Heater
	6	Sprinkler
ADC data	3	
Overflow sensor	0	

(*a*) Write, in assembler code, the sub-procedure *heat*. **3**

The temperature inside the propagator is monitored using a temperature sensor connected to an analogue-to-digital converter (ADC). The ADC value is obtained using the sub-procedure *adcread* which stores the actual temperature value in W. The value in W is then subtracted from the desired temperature value which is stored in the register file DESIRED. The result is then stored in the register file ERROR. If the result of the calculation is zero or positive, it is added to the register file MARK. If the result is negative, the corruption in ERROR is corrected, and the value is then subtracted from MARK.

The sprinkler stays on unless the overflow sensor goes high. The sprinkler and heater are then off for 15 seconds to allow the propagator to drain before being switched on again. The program repeats continuously.

(*b*) Write, in assembler code, the main program. **7**

(*c*) Draw a block diagram of the proportional control system for the heater, showing all components. **1**

Note: The register files MARK, SPACE, ERROR and COUNTER have been set up and initial values have been entered in MARK and SPACE. TRISB has been initialised. The sub-procedure *wait* produces a time delay of 0·1s multiplied by the value in the Working Register W. The sub-procedure *pause* produces a time delay of 1ms multiplied by the value in the Working Register W.

(11)

7. Optimum water conditions in the aquarium shown in Figure Q7 are maintained by a number of analogue devices controlled by a microcontroller. The digital signals sent by the microcontroller are converted to analogue signals by a 4-bit digital-to-analogue converter (DAC).
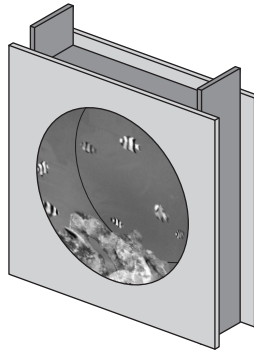

Figure Q7

The DAC has a feedback resistor of 5 kΩ. The inputs to the DAC are each 5 V when set high, and the maximum output is +8 V.

(*a*) Draw a circuit diagram for the DAC showing all significant values. Show working. **6**

For the DAC designed in part (*a*):

(*b*) calculate the output voltage corresponding to a digital input of 1101. **1**

(7)

[*END OF SECTION A*]

SECTION B

Attempt any two questions in this section.

Each question is worth 20 marks

8. The scissor lifting-table shown in Figure Q8(*a*) is raised and lowered using two hydraulic cylinders which are fixed to a support beam as shown.
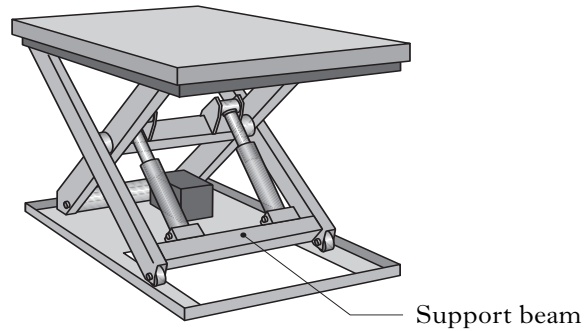

Support beam

Figure Q8(*a*)

The support beam is made from mild steel and is simply supported at its ends as shown in Figure Q8(*b*).
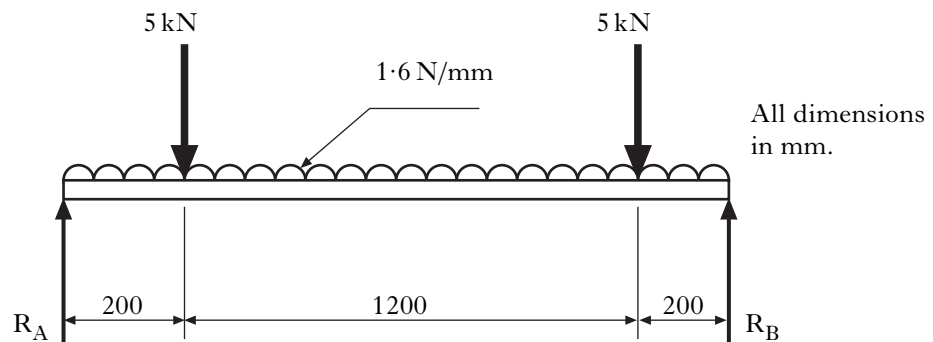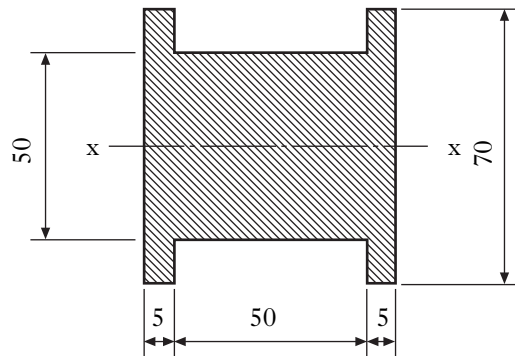

Figure Q8(b)

(*a*) Calculate, for the loading conditions shown in Figure Q8(*b*):

   (i) the reaction force R_A; **1**

   (ii) the maximum bending moment (from first principles). **3**

[Turn over

8. (continued)

The cross-section of the support beam, which is symmetrical about the axis x–x, is shown in Figure Q8(*c*).
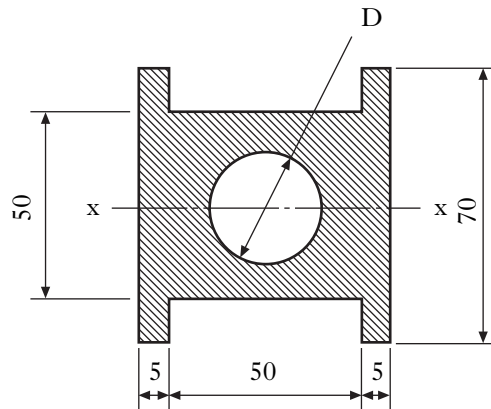

Figure Q8(*c*)

(*b*) Calculate the second moment of area of the solid shape shown in Figure Q8(*c*), about axis x–x. **3**

A hole is required through the centre of the section of the beam, as shown in Figure Q8(*d*), to allow the passage of hydraulic pipes. Under a given loading, the maximum bending moment is $1 \cdot 4 \times 10^6$ Nmm. The maximum bending stress must not exceed 65 N/mm^2.

Figure Q8(*d*)

(*c*) Calculate the maximum allowable diameter (D) of the hole, for the stated conditions. **5**

8. (continued)

A pressure sensor is fitted to the hydraulic-fluid pipe to monitor sudden changes in fluid pressure. A circuit diagram of the monitoring system is shown in Figure Q8(*e*).
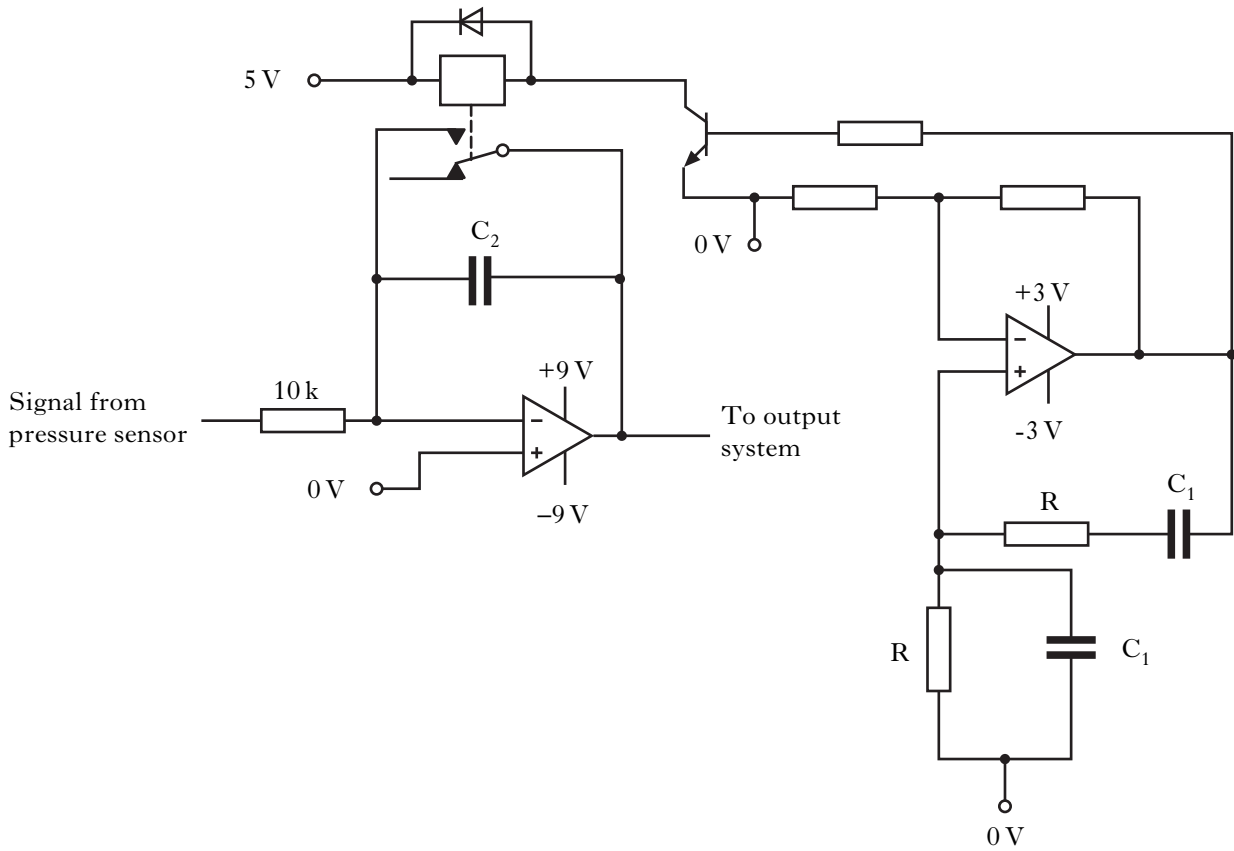
Figure Q8(*e*)

(*d*) Describe the operation of the circuit. **3**

The Wein Bridge oscillator is to have a frequency of 2 Hz, using a resistor R = 5 kΩ.

(*e*) Calculate the value of capacitor C_1. **2**

For a particular load, the constant input voltage to the integrator is +10 V, and 0·2 seconds after the relay contacts open the output voltage is −5 V.

(*f*) Calculate the value of capacitor C_2. **3**

(20)

[Turn over

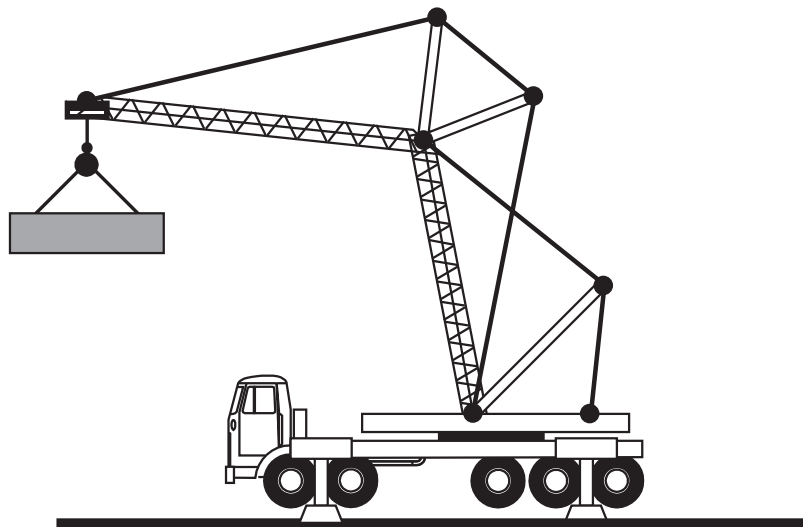**9.** A large mobile crane is shown in Figure Q9(*a*).

Figure Q9(*a*)

Figure Q9(*b*) shows part of the crane jib, sectioned at a particular position, carrying a 20 kN load.
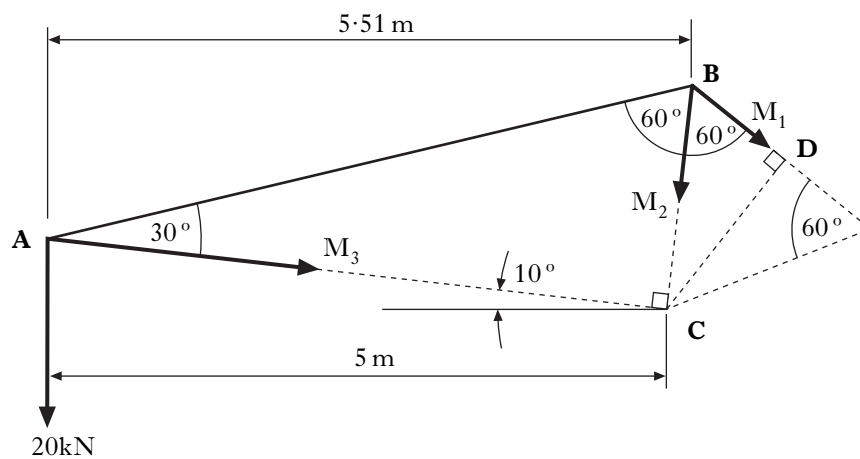

Figure Q9(*b*)

For the conditions shown in Figure Q9(*b*):

(*a*) calculate the distances between:

   (i) A and C; **1**

   (ii) B and C; **1**

   (iii) C and D. **1**

(*b*) Using the *method of sections*, as shown, determine the magnitude and nature of the forces in M_1, M_2 and M_3. Use the distances calculated in part (*a*). **6**

9. (continued)

Figure Q9(*c*) shows load cells which are built into each of the four legs of the crane.
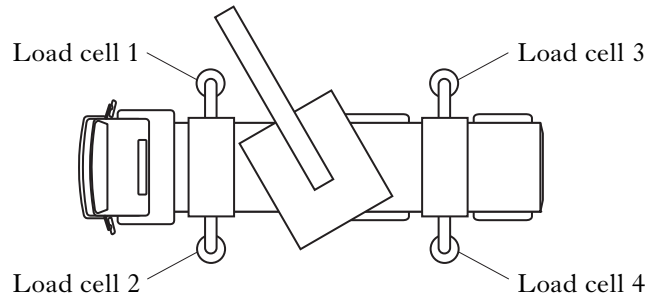

Figure Q9(*c*)

The system shown in Figure Q9(*d*) monitors the load in the legs by sampling in turn the analogue voltage signal from each of the four load cells.
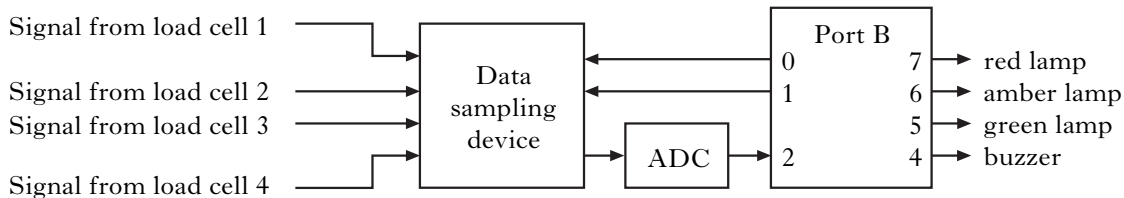

Figure Q9(*d*)

A program *multiplex* instructs the data sampling device to select the required load cell by setting Port B to the appropriate values in a 4-times repeat loop, as shown in the table below. Sub-procedure *adcread* then reads the load-cell signal, converts it into a digital value, and stores it in the register file LOADVAL. A prewritten sub-procedure *storeval* transfers the reading from LOADVAL into the appropriate register file.

Loop count	PORTB value	LOAD CELL	Register file
1	0000 0000	No. 1	DATA1
2	0000 0001	No. 2	DATA2
3	0000 0010	No. 3	DATA3
4	0000 0011	No. 4	DATA4

(*c*) Write, in assembler code, the program *multiplex*.　　　　3

Note: Assume *adcread* and *storeval* have been written, TRISB has been initialised, all register files including COUNTER have been defined.

In order to warn the operator if the crane becomes unstable, the values from the load cells are monitored. The sub-procedure *overload3* monitors the loading in load cell 3 using the value held in the register file DATA3. An amber lamp is illuminated if the value in DATA3 is less than decimal 10. A green lamp illuminates if the value is in the decimal range 10 to 50 inclusive. If the value is greater than decimal 50, a red lamp illuminates, and a buzzer pulses with a mark time of 0·2 seconds and space time of 0·3 seconds, for 5 seconds, before the load cell value is rechecked.

(*d*) Write, in assembler code, the sub-procedure *overload3*.　　　　8

Note: Assume that register file COUNT has been set up. Sub-procedure *wait* produces a time delay of 0·1 seconds multiplied by the value in the Working Register W. Sub-procedure *pause* produces a time delay of 1 ms multiplied by the value in the Working Register W.

(20)

10. A manufacturer of sailing boat accessories is developing the electronic compass shown in Figure Q10(*a*).
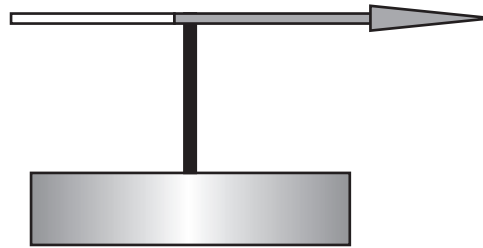

Figure Q10(*a*)

The needle points to North, and a direction sensor produces an analogue voltage proportional to the bearing on which the boat is travelling. A 10-bit ADC converts this voltage into a digital value for processing by a microcontroller.

(*a*)   (i)   Sketch an outline circuit diagram for a 10-bit ADC.   **1**

   (ii)   Explain in detail the operation of this circuit.   **3**

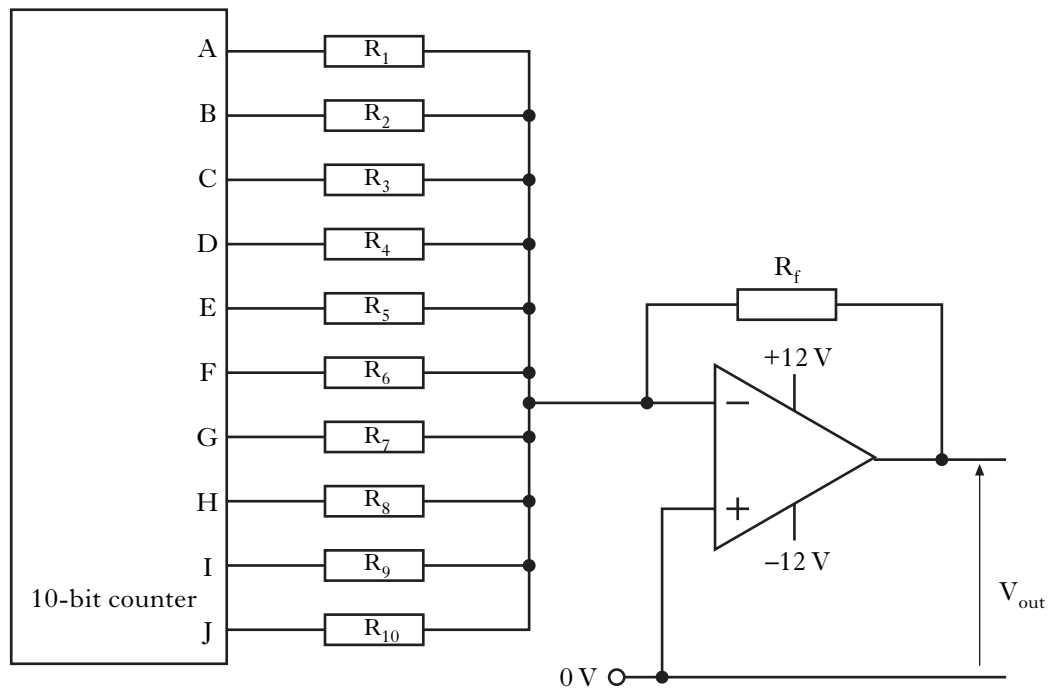Figure Q10(*b*) shows in more detail the circuit diagram for the DAC connected to the counter in the ADC.

Figure Q10(*b*)

When all 10 of the counter bits are high, V_{out} is −8 V. Bit A is the LSB.

(*b*)   Calculate the value of V_{out} when **bit E** is **high** and **all other bits** are **low**.   **2**

The value of resistor R_2 shown in Figure Q10(*b*) is 512 kΩ. The counter output lines are at 5 V when high.

(*c*)   Calculate:

   (i)   the values of R_1, R_3, R_4, R_5, R_6, R_7, R_8, R_9 and R_{10};   **1**

   (ii)   the value of the feedback resistor R_f.   **2**

10. (continued)

The 10-bit counter is constructed using three 4-bit counters similar to the one shown in Figure Q10(*c*).
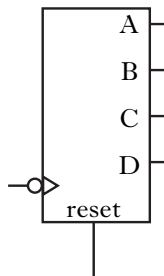

Figure Q10(*c*)

(*d*) Sketch the required circuit for the 10-bit counter, showing all components and relevant connections.

2

The digital display of the compass is produced using a microcontroller connected to a display. To transfer the data from the counter to the microcontroller a Parallel-In-Serial-Out (PISO) shift register is used.

(*e*) Sketch a 10-bit PISO shift register using D-type bistables. **Assume that the parallel data has already been inputted, and that the shift register is now ready for serial transfer**.

2

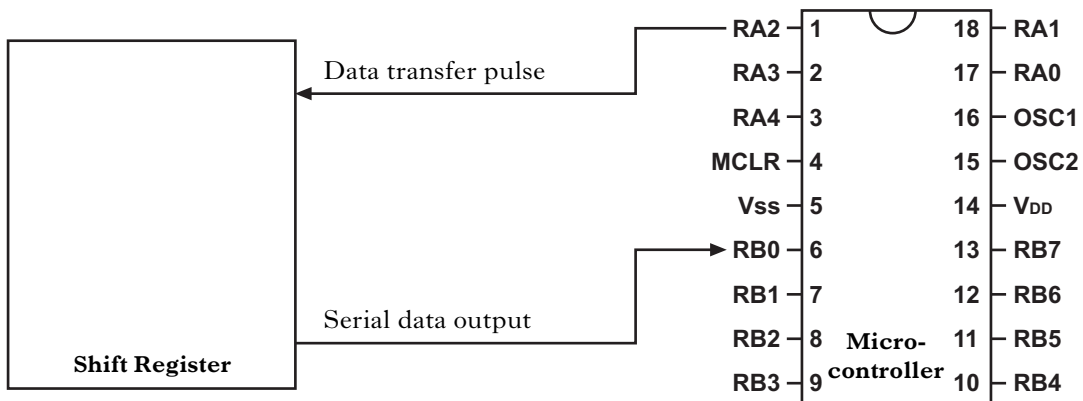The shift register and microcontroller are connected as shown in Figure Q10(*d*).

Figure Q10(*d*)

The serial output of the shift register is connected to pin0 of PORTB in order to allow the transfer of data into the microcontroller. Pin2 of PORTA is used to pulse the shift register high for the time required to produce a data-transfer rate of 1000 bits per second.

A sub-procedure *transfer* uses a seven-times repeat loop in which PORTB is rotated to allow the next data bit to be received. After each rotation, pin2 of PORTA is pulsed high then low in order to clock the shift register at the required rate. When 8 bits of data have been received, the contents of PORTB are moved to the register file BEARING, and the sub-procedure ends.

(*f*) Write, in assembler code, the sub-procedure *transfer*.

7

Note: The sub-procedure *pause* creates a delay of 1 ms multiplied by the value in the Working Register W. Register files CLOCKCOUNT and BEARING have been defined.

[*END OF QUESTION PAPER*]

(20)

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MONDAY, 7 JUNE
1.00 PM – 4.00 PM

TECHNOLOGICAL
STUDIES
ADVANCED HIGHER
Worksheets for Questions 2,
4 and 5

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Full name of centre

Town

Forename(s)

Surname

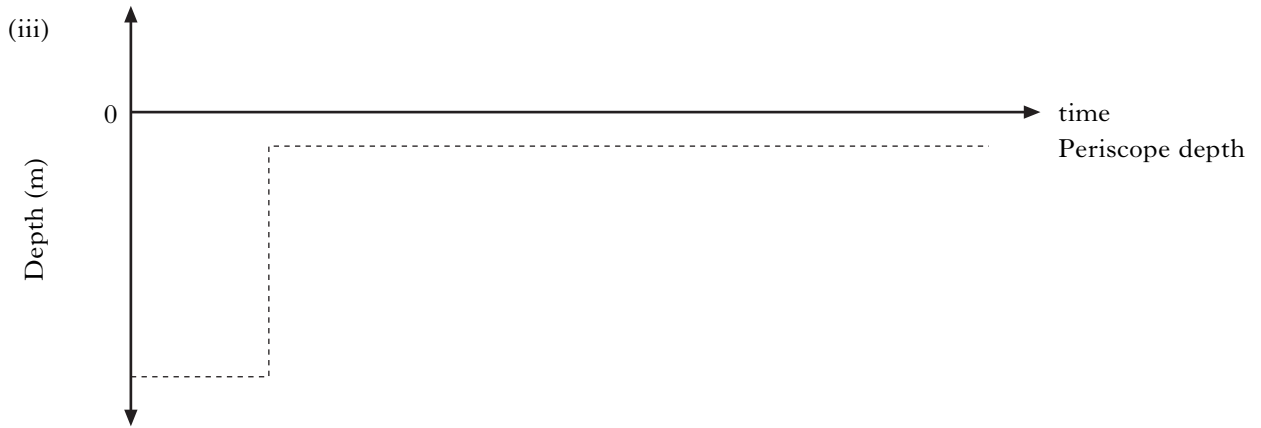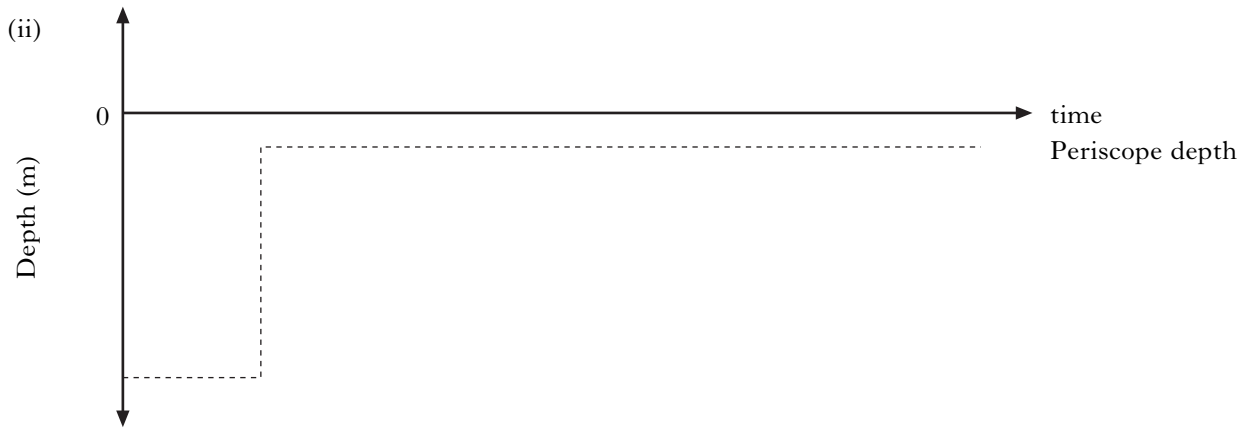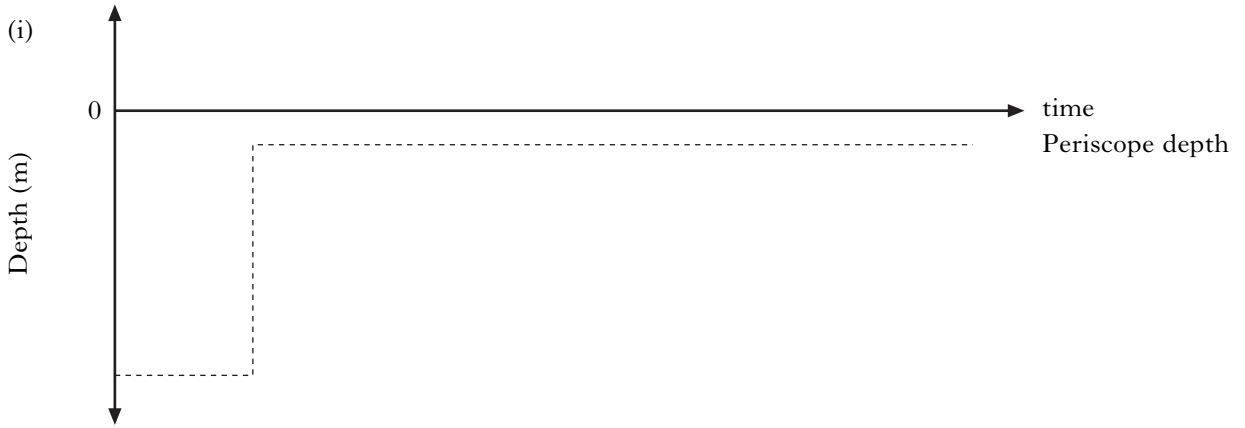Date of birth

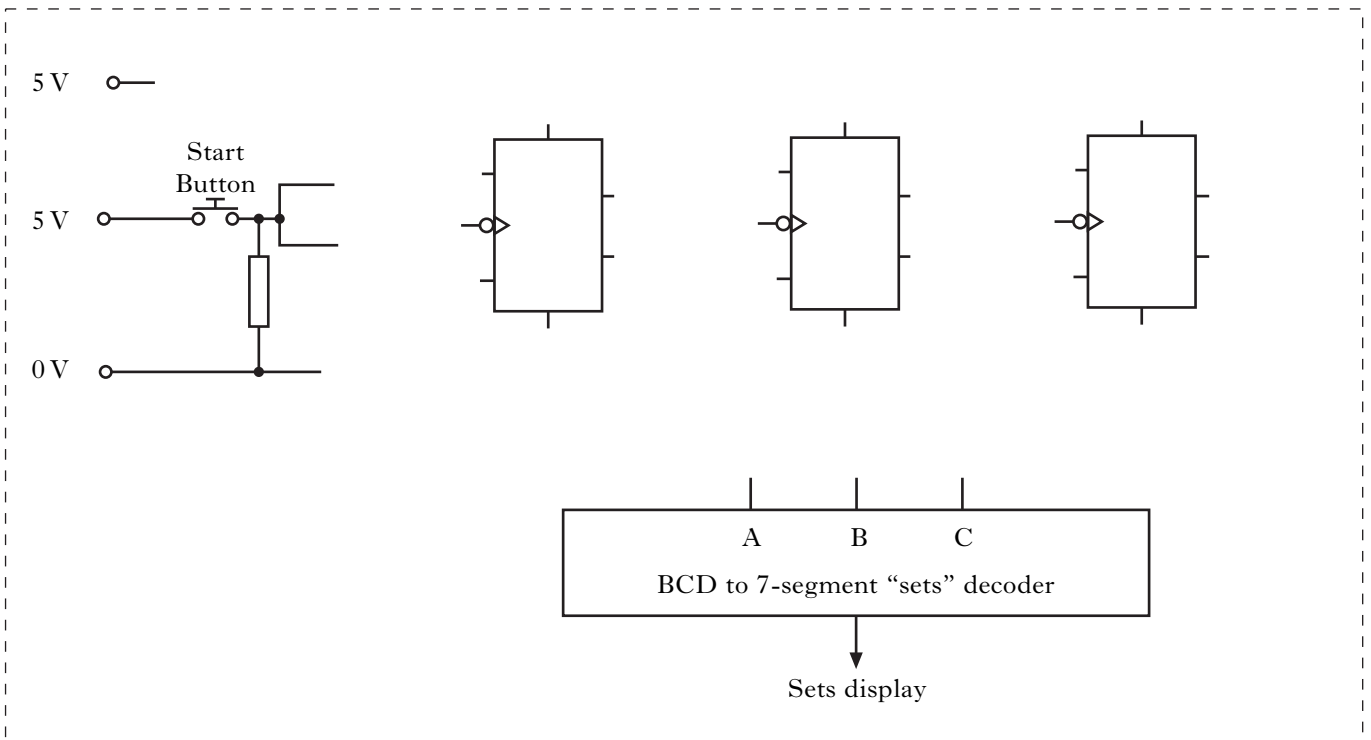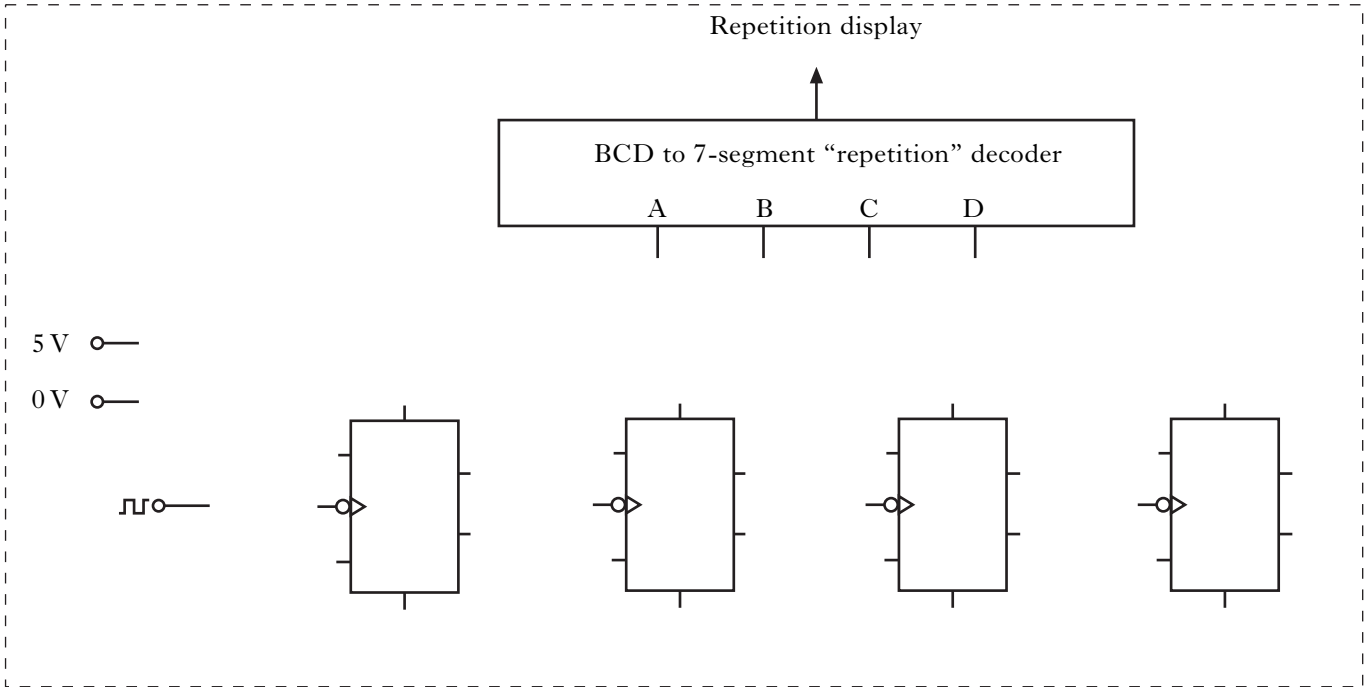| Day	Month	Year	Scottish candidate number	Number of seat

To be inserted inside the front cover of the candidate's answer booklet and returned with it.

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WORKSHEET Q2

(i)

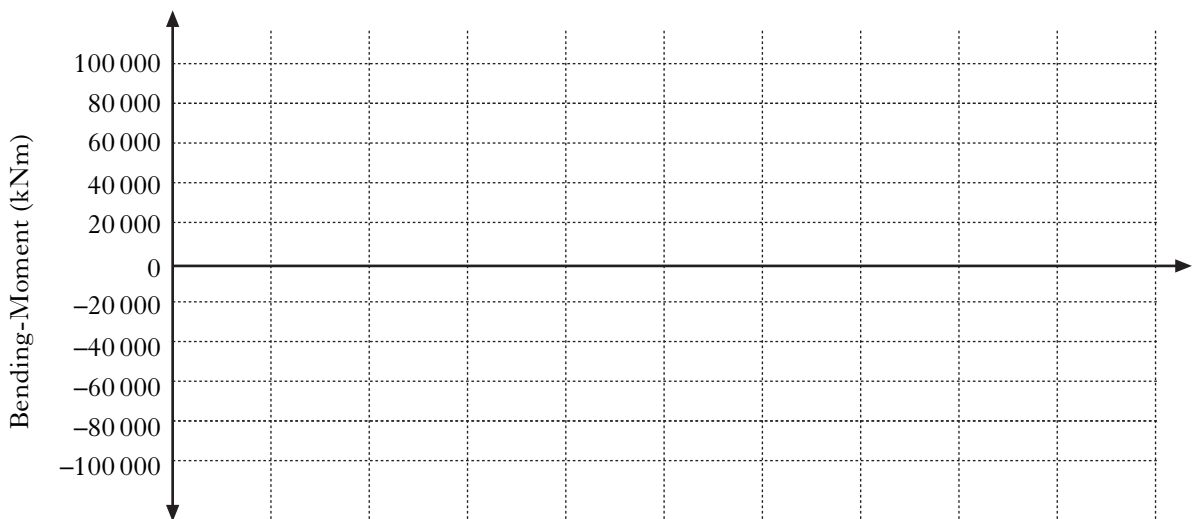Depth (m)   0   time   Periscope depth

(ii)

Depth (m)   0   time   Periscope depth

(iii)

Depth (m)   0   time   Periscope depth

WORKSHEET Q4

Repetition display

BCD to 7-segment "repetition" decoder

A   B   C   D

5 V

0 V

BCD to 7-segment "sets" decoder

5 V

Start
Button

5 V

0 V

A   B   C

Sets display

[Turn over

WORKSHEET Q5(*a*)

Free-Body Diagram

100 m

80 m

10 m

ω = 100 kN/m

5000 kN

5000 kN

Shear-Force (kN)

4000
3000
2000
1000
0
−1000
−2000
−3000
−4000

0 m   10 m   20 m   30 m   40 m   50 m   60 m   70 m   80 m   90 m   100 m

Bending-Moment (kNm)

100 000
80 000
60 000
40 000
20 000
0
−20 000
−40 000
−60 000
−80 000
−100 000

WORKSHEET Q5(*b*)

Free-Body Diagram

| 40 m | 20 m | 40 m |

Shear-Force (kN)

4000
3000
2000
1000
0
−1000
−2000
−3000
−4000
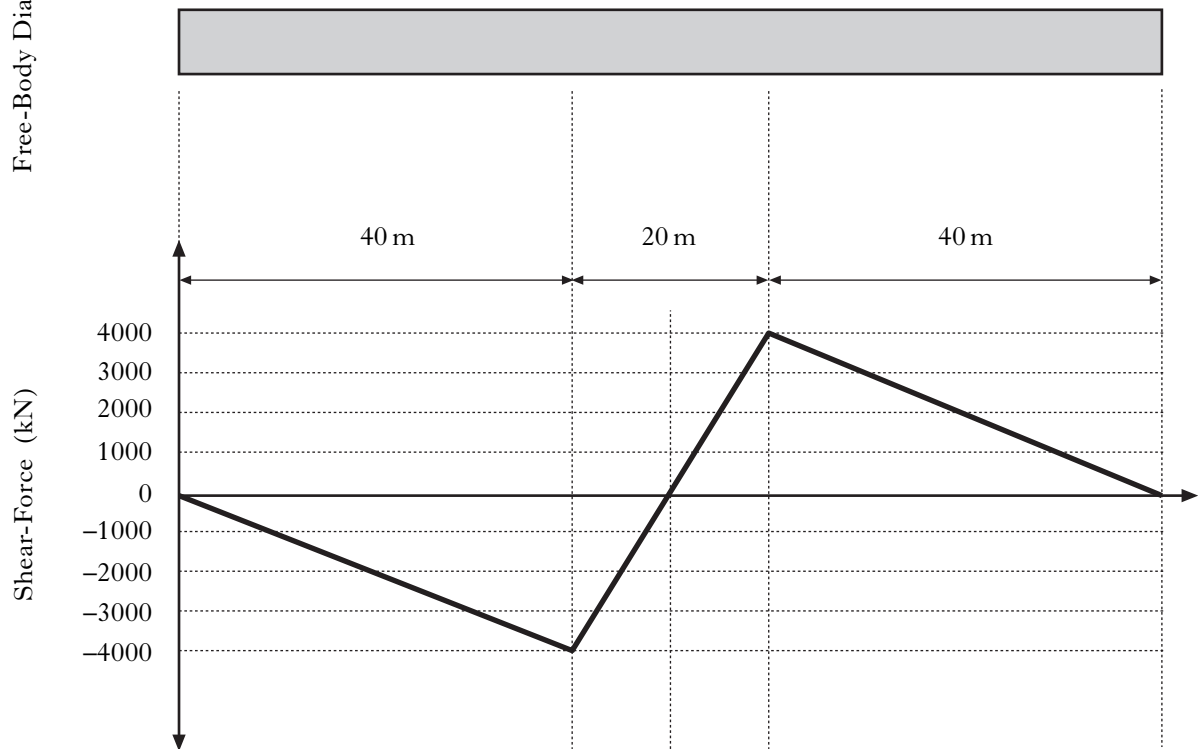
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