AQA

Please write clearly in block capitals.

Centre number | | | | | | Candidate number | | | | |

Surname _____

Forename(s) _____

Candidate signature _____

A-level
FURTHER MATHEMATICS

Paper 3 Discrete

Thursday 13 June 2019 Afternoon Time allowed: 2 hours

Materials
- You must have the AQA formulae and statistical tables booklet for A-level Mathematics and A-level Further Mathematics.
- You should have a scientific calculator that meets the requirements of the specification. (You may use a graphical calculator.)
- You must ensure you have the other optional Question Paper/Answer Book for which you are entered (**either** Mechanics **or** Statistics). You will have 2 hours to complete **both** papers.

Instructions
- Use black ink or black ball-point pen. Pencil should only be used for drawing.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer each question in the space provided for that question. If you require extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- Do **not** write outside the box around each page.
- Show all necessary working; otherwise marks for method may be lost.
- Do all rough work in this book. Cross through any work you do not want to be marked.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
5	
6	
7	
8	
TOTAL	

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 50.

Advice
- Unless stated otherwise, you may quote formulae, without proof, from the booklet.
- You do not necessarily need to use all the space provided.

Do not write outside the box

Answer **all** questions in the spaces provided.

1 Deanna and Will play a zero-sum game.

The game is represented by the following pay-off matrix for Deanna.

		Will		
	Strategy	**X**	**Y**	**Z**
Deanna	**A**	−1	0	2
	B	−2	−1	3
	C	5	−2	−3
	D	6	−2	0

Which strategy is Deanna's play-safe strategy?

Circle your answer.

[1 mark]

A **B** **C** **D**

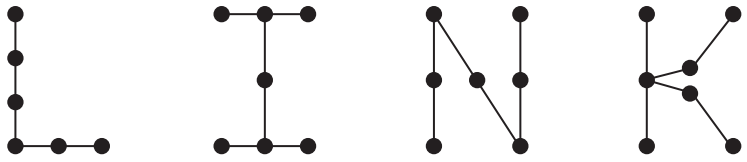
2 The graph *D* is shown in the diagram below.



Which of the graphs below is a subdivision of *D*?

Circle your answer.

[1 mark]



Do not write outside the box

3 The Simplex tableau below is optimal.

P	x	y	z	r	s	value
1	$k^2 + k - 6$	0	0	$k - 1$	1	20
0	0	0	1	1.5	0	6
0	0	1	0	0	0.5	86

3 (a) Deduce the range of values that k must satisfy.

[3 marks]

3 (b) Write down the value of the variable s which corresponds to the optimal value of P.

[1 mark]

Turn over for the next question

Do not write outside the box

4 The connected planar graph P has the adjacency matrix

	A	B	C	D	E
A	0	1	1	0	1
B	1	0	1	0	1
C	1	1	0	1	1
D	0	0	1	0	1
E	1	1	1	1	0

4 (a) Draw P

[1 mark]

4 (b) Using Euler's formula for connected planar graphs, show that P has exactly 5 faces.

[2 marks]

Do not write outside the box

4 (c) Ore's theorem states that a simple graph with n vertices is Hamiltonian if, for every pair of vertices X and Y which are not adjacent,

$$\text{degree of } X + \text{degree of } Y \geq n$$

where $n \geq 3$

Using Ore's theorem, prove that the graph P is Hamiltonian.

Fully justify your answer.

[3 marks]

Turn over for the next question

Do not write outside the box

5 The set S is defined as

$$S = \{A, B, C, D\}$$

where

$$A = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \quad B = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \quad C = \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix} \quad D = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$$

The group G is formed by S under matrix multiplication.

The group H is defined as $H = (\langle \mathrm{i} \rangle, \times)$, where $\mathrm{i}^2 = -1$

5 (a) (i) Prove that B is a generator of G.

Fully justify your answer.

[3 marks]

5 (a) (ii) Show that $G \cong H$.

Fully justify your answer.

[4 marks]

Do not write outside the box

5 (b) (i) Explain why H has no subgroups of order 3

Fully justify your answer.

[2 marks]

5 (b) (ii) Find **all** of the subgroups of H.

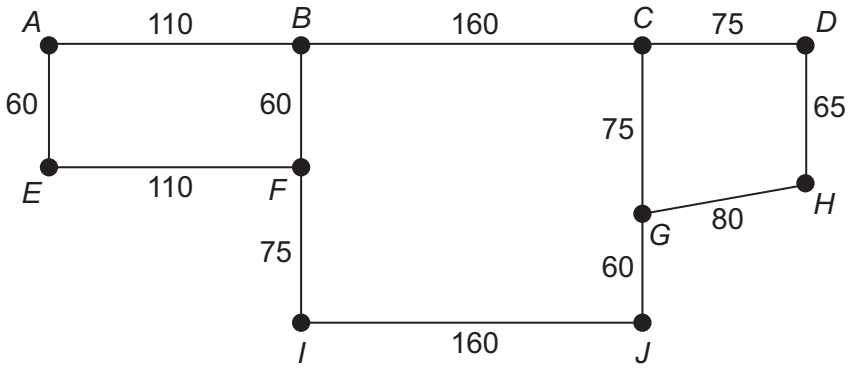
[3 marks]

Do not write outside the box

6 A council wants to monitor how long cars are being parked for in short-stay parking bays in a town centre. They employ a traffic warden to walk along the streets in the town centre and issue fines to drivers who park for longer than the stated time.

The network below shows streets in the town centre which have short-stay parking bays. Each node represents a street corner and the weight of each arc represents the length, in metres, of the street.

The short-stay parking bays are positioned along only one side of each street.



The council assumes that the traffic warden will walk at an average speed of 4.8 kilometres per hour when not issuing fines.

6 (a) To monitor all of the parking bays, the traffic warden needs to walk along every street in the town centre at least once, starting and finishing at the same street corner.

Find the shortest possible time, to the nearest minute, it can take the traffic warden to monitor all of the parking bays.

Fully justify your answer.

[5 marks]

Do not write outside the box

_____

_____

_____

_____

_____

6 (b) Explain why the actual time for the traffic warden to walk along every street in the town centre at least once may be different to the value found in part **(a)**.

[1 mark]

_____

_____

_____

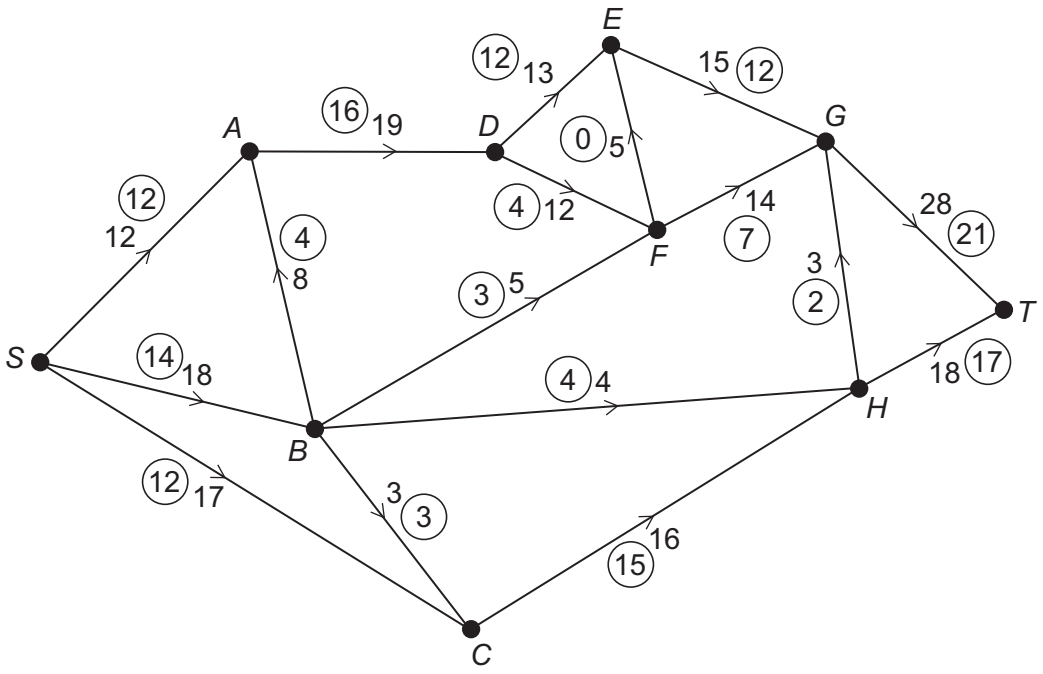
Turn over for the next question

Do not write outside the box

7 **Figure 1** shows a system of water pipes in a manufacturing complex.

The number on each arc represents the upper capacity for each pipe in litres per second. The numbers in the circles represent an initial feasible flow of 38 litres of water per second.

Figure 1



7 (a) (i) Calculate the value of the cut $\{S, A, B, C\}$ $\{D, E, F, G, H, T\}$.

[1 mark]

_____

_____

_____

7 (a) (ii) Explain, in the context of the question, what can be deduced from your answer to part **(a)(i)**.

[1 mark]

_____

_____

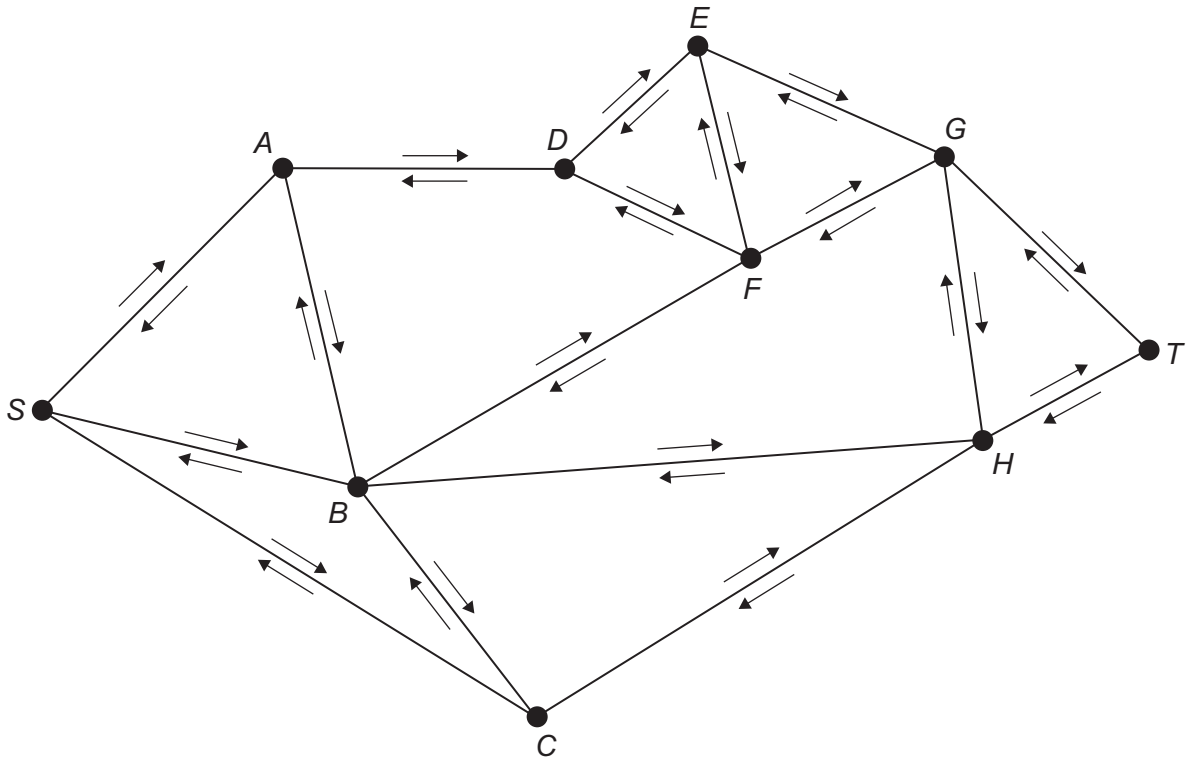
_____

Do not write outside the box

7 (b) (i) Using the initial feasible flow shown in **Figure 1**, indicate on **Figure 2** potential increases and decreases in the flow along each arc.

[2 marks]

Figure 2



7 (b) (ii) Use flow augmentation on **Figure 2** to find the maximum flow through the manufacturing complex.

You must indicate any flow augmenting paths clearly in the table and modify the potential increases and decreases of the flow on **Figure 2**.

[4 marks]

Augmenting Path	Flow

Maximum Flow = _____

Do not write outside the box

7 (c) The management of the manufacturing complex want to increase the maximum amount of water which can flow through the system of pipes. To do this they decide to upgrade one of the water pipes by replacing it with a larger capacity pipe.

Explain which pipe should be upgraded.

Deduce what effect this upgrade will have on the maximum amount of water which can flow through the system of pipes.

[2 marks]

Do not write outside the box

Turn over for the next question

DO NOT WRITE ON THIS PAGE
ANSWER IN THE SPACES PROVIDED

Do not write outside the box

8 A motor racing team is undertaking a project to build next season's racing car. The project is broken down into 12 separate activities *A*, *B*, ..., *L*, as shown in the precedence table below. Each activity requires one member of the racing team.

Activity	Duration (days)	Immediate Predecessors
A	7	–
B	6	–
C	15	–
D	9	*A*, *B*
E	8	*D*
F	6	*C*, *D*
G	7	*C*
H	14	*E*
I	17	*F*, *G*
J	9	*H*, *I*
K	8	*I*
L	12	*J*, *K*

8 (a) (i) Complete the activity network for the project on **Figure 3**.

[2 marks]

8 (a) (ii) Find the earliest start time and the latest finish time for each activity and show these values on **Figure 3**.

[3 marks]

8 (b) Write down the critical path(s).

[1 mark]

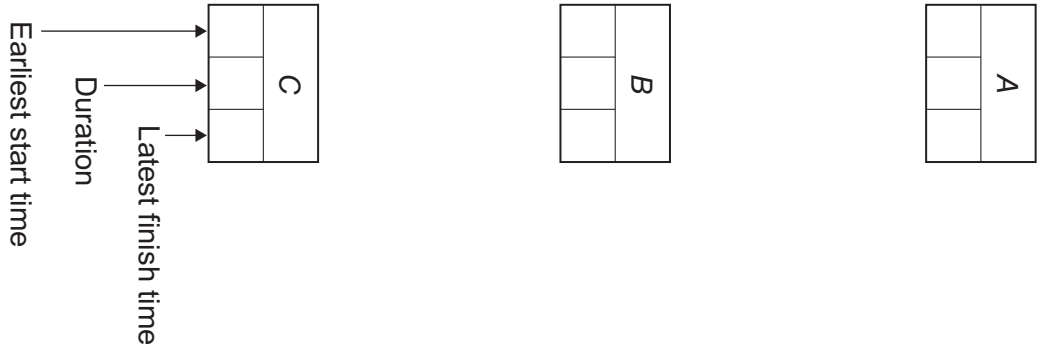
_____

_____

_____

Do not write outside the box

Figure 3



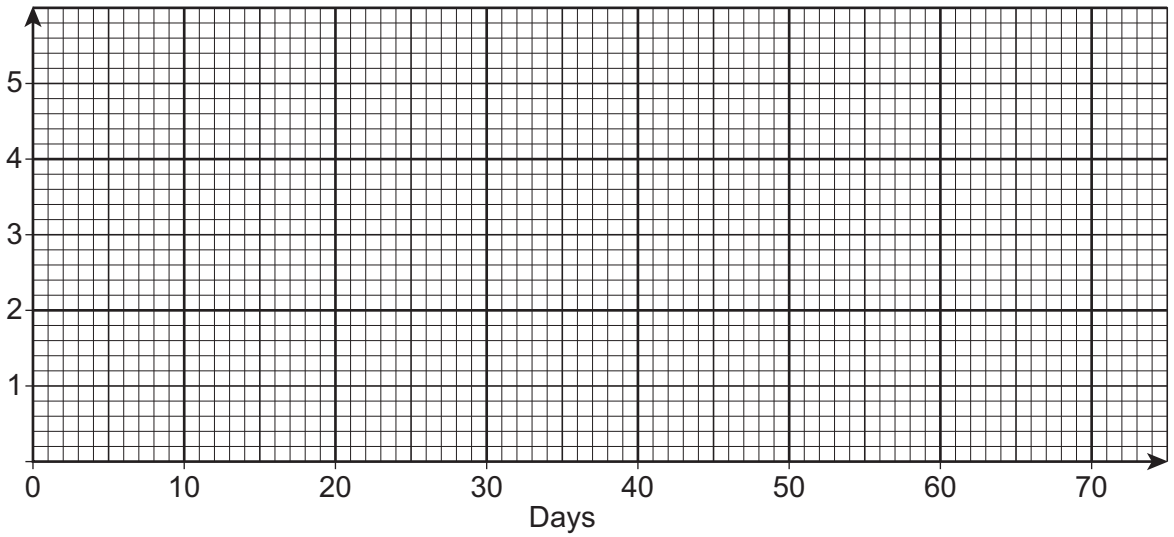
Question 8 continues on the next page

Do not write outside the box

8 (c) (i) Using **Figure 4**, draw a resource histogram for the project to show how the project can be completed in the shortest possible time. Assume that each activity is to start as early as possible.

[2 marks]

Figure 4



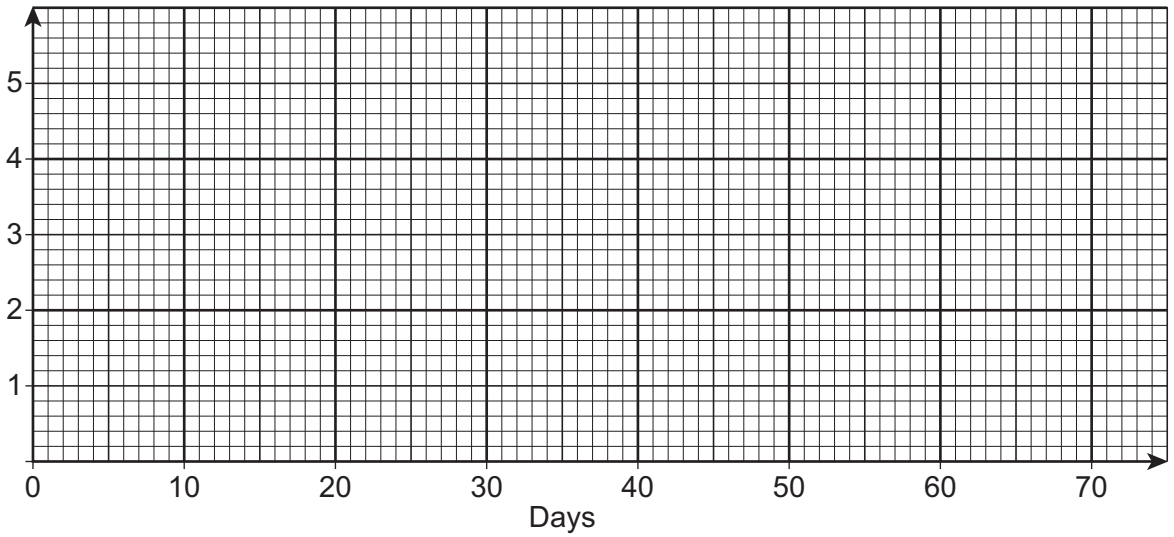
8 (c) (ii) The racing team's boss assigns two members of the racing team to work on the project.

Explain the effect this has on the minimum completion time for the project.

You may use **Figure 5** in your answer.

[2 marks]

Figure 5



Do not write outside the box

END OF QUESTIONS

Do not write outside the box

There are no questions printed on this page

DO NOT WRITE ON THIS PAGE
ANSWER IN THE SPACES PROVIDED

Do not write outside the box

Question number	**Additional page, if required.** **Write the question numbers in the left-hand margin.**

Do not write outside the box

Question number	**Additional page, if required.** **Write the question numbers in the left-hand margin.**

Do not write outside the box

Question number	**Additional page, if required.** **Write the question numbers in the left-hand margin.**

Do not write outside the box

Question number	**Additional page, if required.** **Write the question numbers in the left-hand margin.**

Do not write outside the box

Question number	**Additional page, if required.** **Write the question numbers in the left-hand margin.**

Do not write outside the box

Question number	**Additional page, if required.** **Write the question numbers in the left-hand margin.**

Copyright information

For confidentiality purposes, from the November 2015 examination series, acknowledgements of third-party copyright material are published in a separate booklet rather than including them on the examination paper or support materials. This booklet is published after each examination series and is available for free download from www.aqa.org.uk after the live examination series.

Permission to reproduce all copyright material has been applied for. In some cases, efforts to contact copyright-holders may have been unsuccessful and AQA will be happy to rectify any omissions of acknowledgements. If you have any queries please contact the Copyright Team, AQA, Stag Hill House, Guildford, GU2 7XJ.

Copyright © 2019 AQA and its licensors. All rights reserved.