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Examiners' report

FURTHER MATHEMATICS A

H245
For first teaching in 2017

Y544/01 Summer 2019 series

Version 1

Contents

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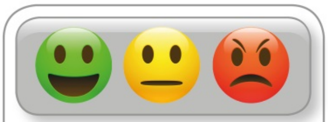

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Introduction

Our examiners' reports are produced to offer constructive feedback on candidates' performance in the examinations. They provide useful guidance for future candidates. The reports will include a general commentary on candidates' performance, identify technical aspects examined in the questions and highlight good performance and where performance could be improved. The reports will also explain aspects that caused difficulty and why the difficulties arose, whether through a lack of knowledge, poor examination technique, or any other identifiable and explainable reason.

Where overall performance on a question/part was considered good, with no particular areas to highlight, these questions have not been included in the report. A full copy of the question paper can be downloaded from OCR.

Paper Y544 series overview

Y544 Discrete Mathematics is one of the options available for A Level Further Mathematics A. This was the first A Level assessment of Y544 Discrete Mathematics.

The exam involves understanding pure mathematics techniques that apply to discrete objects and their application to modelling and solving problems. The areas studied include counting, graphs and networks, algorithms, critical path analysis, linear programming and game theory.

Much excellent work was seen, although a small number of candidates did not seem to have taken on board that as an A Level Further Maths paper for the reformed qualification it required a deeper level of engagement than the legacy qualification's D1 and D2 papers.

Written explanations were often done well. Explanations need only be brief and are usually best when supported with appropriate calculations or other question specific details.

There was evidence that most of the candidates were well prepared, had a good appreciation of the new topics and had used the practice papers in their preparation.

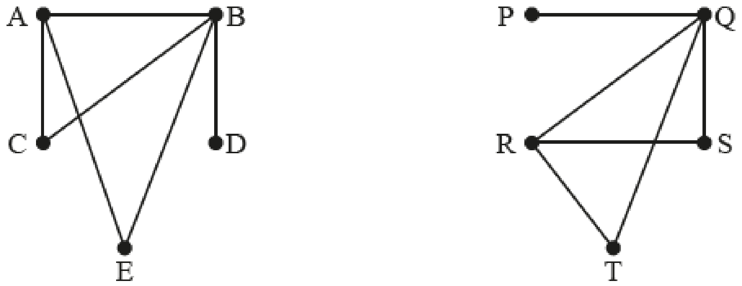
Some candidates used the additional answer space on page 12 of the answer booklet; even if this is only used for rough work the question number should be given. Some candidates used a continuation booklet instead of using the additional answer space; centres should encourage candidates to use the additional answer space first and only work in a continuation booklet if the additional answer space is full.

The answer space provided in the answer booklet should always be sufficient to accommodate an answer but may be more space than is needed. This can be a useful guide, along with the number of marks available, for the amount of detail required in a response.

Candidates should be aware of the OCR command words (which are available to download as a poster in both A2 and A4 versions from 'Assessment guides' at https://www.ocr.org.uk/qualifications/as-and-a-level/further-mathematics-a-h235-h245-from-2017/assessment) and the formulae booklet (which is given at the end of the Specification, as well as being available to download at the above link).

Question 1(a)(i)

1 Two graphs are shown below.



Graph G1 Graph G2

(a) **(i)** Prove that the graphs are isomorphic. **[2]**

This question addressed item 7.02j in the specification ('Construct an isomorphism either by a reasoned argument or by explicit labelling of vertices. Includes understanding that having the same degree sequence… is… not sufficient to show isomorphism.')

	AfL	The easiest way to demonstrate isomorphism is to set up a full correspondence between the vertex labels (A↔R, B↔Q, etc.). Descriptions involving moving the graphs around should be supported with labelled diagrams. Written descriptions of the arcs and which vertices they connect are usually more appropriate for showing that two graphs are not isomorphic.

Question 1(a)(ii)

(ii) Verify that Euler's formula holds for graph G1. **[2]**

The command word 'verify' means that the values need to be substituted into the formula. This of course required candidates to know the statement of Euler's formula and the values of V, E and R. The table was provided in the answer booklet to help candidates to show how they knew these values.

	OCR support	OCR's command words poster is available to download in both A2 and A4 versions from 'Assessment guides' at https://www.ocr.org.uk/qualifications/as-and-a-level/further-mathematics-a-h235-h245-from-2017/assessment/.

Question 1(b) and (c)

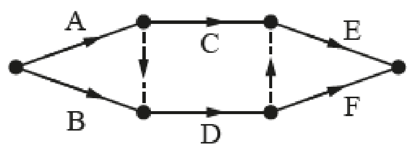
(b) Describe how it is possible to add 4 arcs to graph G1 to make a non-planar graph with 5 vertices. **[2]**

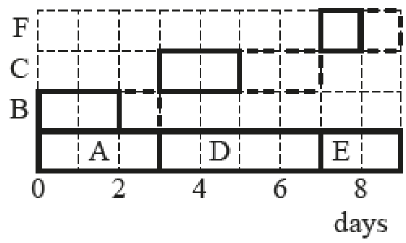
(c) Describe how it is possible to add a vertex U and 4 arcs to graph G2 to make a connected non-planar graph with 6 vertices. **[2]**

Candidates usually realised that these parts were about using Kuratowski's theorem. In part (b) the addition of the arcs AD, CD, CE and DE completed the graph K_5. In part (c) some candidates tried to use subdivision, but this increased the number of arcs. Since in part (b) 4 arcs were needed to make K_5, the only way to achieve a non-planar graph with 6 vertices (by only adding 4 arcs) was to form a graph that contained $K_{3,3}$ as a subgraph. $K_{3,3}$ has 6 vertices each with degree 3, so the bipartite graph with sets {P, S, T} and {Q, R, U} can be formed by adding the arcs UP, US, UT and PR.

Question 2(a) and (b)

2 A project is represented by the activity network and cascade chart below. The table showing the number of workers needed for each activity is incomplete. Each activity needs at least 1 worker.





Activity	Workers
A	2
B	x
C	
D	
E	
F	

(a) Complete the table in the Printed Answer Booklet to show the immediate predecessors for each activity. **[2]**

(b) Calculate the latest start time for each non-critical activity. **[1]**

Most candidates were able to complete the two tables correctly. Some gave the earliest start time for F instead of the latest start time.

Question 2(c)

The minimum number of workers needed is 5.

(c) What type of problem (existence, construction, enumeration or optimisation) is the allocation of a number of workers to the activities? **[1]**

Candidates were told that the minimum number of workers needed is 5 and the problem was to allocate these 5 workers to the activities. What is required is to construct a solution that fulfils the given requirements, so this is a construction problem.

It is not an existence problem because candidates had already been told that it is possible to complete the project with 5 workers. It is not an optimisation problem because the number of workers and project completion time were both given.

Question 2(d)(i) and (d)(ii)

There are 8 workers available who can do activities A and B.

(d) **(i)** Find the number of ways that the workers for activity A can be chosen. **[1]**

(ii) When the workers have been chosen for activity A, find the total number of ways of choosing the workers for activity B for all the different possible values of x, where $x \geqslant 1$. **[2]**

In part (i) most candidates were able to calculate that there were 28 ways to choose 2 workers from 8.

?	**Misconception**	Although 8 workers were available, the earlier stem still applies so only 5 workers are required.

In part (ii) *x* could be 1, 2 or 3. The number of ways of choosing 1, 2 and 3 workers from the remaining 6 are 6, 15 and 20 respectively, giving a total of 41.

Question 3(a)

3 A problem is represented as the initial simplex tableau below.

P	x	y	z	s	t	RHS
1	−2	0	1	0	0	0
0	1	1	1	1	0	60
0	2	3	4	0	1	60

(a) Write the problem as a linear programming formulation in the standard algebraic form with no slack variables. **[3]**

	AfL	The standard algebraic formulation for a linear programming problem is given in specification item 7.06a ('maximise (or minimise) objective subject to inequality constraints, and trivial constraints of the form variable ≥ 0').

Many candidates gave an objective function without the word 'maximise' and several left out the trivial constraints.

Exemplar 1

3(a)

$P = 2x - z$

$x + y + z \leqslant 60$

$2x + 3y + 4z \leqslant 60$

This candidate has written each row of the tableau algebraically, but has not written the problem in the standard algebraic form.

Question 3(b) and (c)

(b) Carry out one iteration of the simplex algorithm. **[3]**

(c) Show algebraically how each row of the tableau found in part **(b)** is calculated. **[3]**

Most candidates were able to carry out the iteration accurately.

Part (c) addressed specification item 7.07f ('Be able to explain algebraically some of the calculations used in the simplex algorithm'). This is a new topic item that has not been examined before.

AfL	The explanation should involve the algebraic substitution of x, in particular giving an expression for $x = \dots$. From the tableau: $2x + 3y + 4z + t = 60$ so $x = 30 – 1.5y – 2z – 0.5t$ Eliminating x from each of the other equations gives $P – 2(30 – 1.5y – 2z – 0.5t) + z = 0$ so $P + 3y + 5z + t = 60$ $(30 – 1.5y – 2z – 0.5t) + y + z + s = 60$ so $-0.5y – z + s – 0.5t = 60$

Question 4(a), (b) and (c)

4 An algorithm must have an input, an output, be deterministic and finite.

(a) Why is a counter sometimes used in an algorithm? **[1]**

A computer takes 0.2 seconds to sort a list of 500 numbers.

(b) How long would you expect the computer to take to sort a list of 5000 numbers? **[1]**

Simon says that he can sort a list of numbers 'just by looking at them'.

(c) Explain to Simon why sorting algorithms are needed. **[2]**

These three parts were done well, with most candidates giving concise and accurate answers.

Part (a) referred back to the stem, and was about using a counter in a stopping condition to make sure that an algorithm is finite.

Part (b) required candidates to know that, in general, sorting algorithms have quadratic order as a function of the length of the list. This is given in the specification under item 7.03j

Exemplar 2

4(c) computers can't tell by just looking for programs to work they need to have algorithms for sorting

for a huge list of numbers a computer with an appropriate algorithm can sort much faster than a human just looking

This candidate has addressed the two aspects in part (c). An algorithmic method is needed for a computer program and an ad hoc method is not suitable for a large problem

Question 4(d), (e) and (f)

(d) Demonstrate how quick sort works by using it to sort the following list into **increasing** order. You should indicate the pivots used and which values are already known to be in their correct position.

41 17 8 33 29 **[4]**

For an average case the efficiency of quick sort is $O(n \log n)$, where n is the number of items in the list.

(e) Explain why quick sort is typically quicker than bubble sort and shuttle sort. **[1]**

When the number of comparisons made is used as a measure of the efficiency, the worst case for quick sort is no more efficient than the worst case for bubble sort.

An arrangement of the five numbers from part **(d)** makes up a new list that is to be sorted using the bubble sort or the quick sort.

(f) Without writing out all the passes, determine

- the worst case list
- the total number of comparisons for the worst case list

for each of the algorithms in turn. **[3]**

	AfL	The hierarchy of orders is given in the formulae booklet. Quick sort is given in the formulae booklet. The first value in any sublist will be used as the pivot, unless specified otherwise. Bubble sort is given in the formulae booklet, including the stopping condition.

In part (d), the first pass used 41 as the pivot and resulted in the list 17 8 33 29 41; the second pass used 17 as the pivot and resulted in the list 8 17 33 29 41; the sublist 8 had a single entry and the other sublist used the pivot 33 so the third pass resulted in the list 8 17 29 33 41; the remaining sublist 29 had a single entry, so no further passes were required.

In part (e), candidates were told that for an average case the efficiency of quick sort is $O(n \log n)$ and, as in part (b), should have known that in general bubble sort and shuttle sort are $O(n^2)$. Using the hierarchy of orders to give $O(n \log n) \subset O(n^2)$ was then sufficient to complete the explanation.

In part (f) the five numbers from part (d) needed to be used. There are several arrangements that give a worst case for quick sort, all that is needed is that at each pass there is only one sublist so the first value in the sublist is always either the smallest or the largest value that has not yet been used as a pivot. For bubble sort the worst case is when the algorithm does not terminate early, this is when the original list is in decreasing order.

Question 5(a) and (b)

5 A network is represented by the distance matrix below. For this network a direct connection between two vertices is always shorter than an indirect connection.

	A	B	C	D	E	F	G	H
A	-	130	100	-	-	250	-	-
B	130	-	-	50	-	-	170	100
C	100	-	-	-	80	170	-	90
D	-	50	-	-	-	-	120	-
E	-	-	80	-	-	140	-	120
F	250	-	170	-	140	-	-	-
G	-	170	-	120	-	-	-	90
H	-	100	90	-	120	-	90	-

(a) How does the distance matrix show that the arcs are undirected? **[1]**

The shortest distance from A to E is 180.

(b) Write down the shortest route from A to E. **[1]**

All that was needed in part (a) was to observe that the matrix is symmetric (about the lead diagonal). Some candidates answered a different question to the one asked by discussing the fact that all the entries are positive, or that there are '-' entries. Some candidates just gave a single example and did not indicate that this was true for all connected pairs of vertices. Some said that when there is an arc between two vertices there is also an arc between the vertices 'the other way round', rather than saying that the distances for these two entries are the same.

Most candidates were able to give the route A C E in part (b).

Question 5(c)

(c) Use Dijkstra's algorithm on the distance matrix to find the length of the shortest route **from** G to each of the other vertices. **[4]**

	AfL	Dijkstra's algorithm is given in the formulae booklet, including when to record a temporary label.

Some candidates recorded the arc weights in the temporary labels column, some recorded temporary labels that were not smaller than the best temporary label at that vertex and some just made arithmetic errors. However, the vast majority of the candidates gave fully correct responses.

Question 5(d)

The arcs represent roads and the weights represent distances in metres. The total length of all the roads is 1610 metres.

Emily and Stephen have set up a company selling ice-creams from a van.

(d) Emily wants to deliver leaflets to the houses along **each side** of each road. Find the length of the shortest continuous route that Emily can use. **[1]**

The significance of the words in bold is that Emily needs to use each arc in the network twice, so every vertex will have an even degree and the graph will be Eulerian. This means that her distance is double 1610 metres, with nothing else added.

Question 5(e)(i)

(e) Stephen wants to drive along each road in the ice-cream van.

(i) Determine the length of the shortest route for Stephen if he starts **at B**. **[5]**

The command word 'determine' means that 'justification should be given for any results found, including working where appropriate'.

The majority of candidates used the route inspection algorithm to find the length 2030 metres. For a full response candidates needed to show the weights of the six routes between odd vertices as three pairs with their totals (AE + FG = 180 + 350 = 530, AF + EG = 250 + 210 = 460, AG + EF = 280 + 140 = 420) and then choose to repeat ACHG and EF to give the length 420 + 1610 = 2030 metres.

A few candidates realised that the question had not stated that Stephen needed to return the van to the base vertex B. In this case the shortest length is 1880 metres by repeating the shortest route from B to an odd degree vertex (BA = 130) to form a semi-Eulerian graph then and repeating EF = 140.

Question 5(e)(ii)

(ii) Stephen wants to use the shortest possible route.

- Find the length of the shortest possible route.
- Write down the start and end vertices of this route. **[2]**

The difference between this and part (e)(i) is that Stephen can now start and finish at any vertices. Most candidates realised that the least weight route between two odd vertices is EF = 140 and that repeating this gives a length of 140 + 1610 = 1750 metres, with A and G as the start and end vertices.

Question 6(a)

6 The pay-off matrix for a game between two players, Sumi and Vlad, is shown below. If Sumi plays A and Vlad plays X then Sumi gets x points and Vlad gets 1 point.

		Vlad		
		X	Y	Z
Sumi	A	$(x, 1)$	$(4, -2)$	$(2, 0)$
	B	$(3, -1)$	$(6, -4)$	$(-1, 3)$

You are given that cell (A, X) is a Nash Equilibrium solution.

(a) Find the range of possible values of x. **[1]**

Nash Equilibrium is a topic that was not on the legacy qualification. It has been covered in the practice papers and delivery guides for the new qualification available on the OCR website.

For cell (A, X) to be a Nash Equilibrium solution x must be the largest value for Sumi in column A and 1 must be the largest value for Vlad in row X. This holds provided $x \geq 3$ (or $x > 3$ for strict Nash Equilibrium).

Question 6(b)

(b) Explain what the statement 'cell (A, X) is a Nash Equilibrium solution' means for each player. **[2]**

Most candidates seemed to understand what a Nash Equilibrium solution is, but too often they confused it with a play-safe solution or claimed that it was the maximum possible. For a zero-sum game the play-safe will be a Nash Equilibrium solution, but for a game that is not zero-sum there may be multiple Nash Equilibrium solutions and then if the players collaborate they may be able to improve their payoffs by both changing their strategy.

If Sumi (rows) knows that Vlad (columns) will play X then Sumi's highest pay-off is achieved by playing row A, since max(x, 3) = x.

If Vlad (columns) knows that Sumi will play A then Vlad's highest pay-off is achieved by playing column X, since max (1, -2, 0) = 1.

Question 6(c)

(c) Find a cell where each player gets their maximin pay-off. **[3]**

This part addresses the issue that when a game is not zero-sum it may or may not have a stable solution and that the Nash Equilibrium solution is not necessarily stable.

The row minima for Sumi are min(x, 4, 2) = 2 and min(3, 6, -1) = -1, the maximin pay-off for Sumi is max(2, -1) = 2 by choosing strategy A.

The column minima for Vlad are min(1, -1) = -1, min(-2, -4) = -4 and min(0, 3) = 0, the maximin pay-off for Vlad is max(-1, -4, 0) = 0 by choosing strategy Z.

Cell (A, Z) gives the maximin pay-off of 2 for Sumi (rows) and 0 for Vlad (columns).

Question 6(d)

Suppose, **instead**, that the game can be converted to a zero-sum game.

(d) Determine the optimal strategy for Sumi for the zero-sum game.

- Record the pay-offs for Sumi when the game is converted to a zero-sum game.
- Describe how Sumi should play using this strategy. **[7]**

The total payoffs for each cell are: x + 1, 4 + -2, 2 + 0, 3 + -1, 6 + -4, -1 + 3. When x = 1, each of these gives the same total = 2. One way to make the game zero-sum is for each player to pay 1 (half the total for each cell) each time they play.

This gives a pay-off matrix for Sumi (rows) with payoffs 0, 3 1 and 2, 5, -2 (or a non-zero multiple of these). This game is unstable, since row maximin (0) $\neq$ col minimax (1) so a mixed strategy is needed.

Some candidates realised that column Y is now dominated (for Vlad) by column Z. The mixed strategy has Sumi choosing randomly between strategies A and B with probabilities p and 1 – p. The expected pay-off for Sumi when Vlad chooses each column can be calculated and used to find the optimal value of p and interpret it in context.

This question was done well by many candidates, although some left x as an unknown and were not able to progress very much, while some made algebraic slips and a few used Sumi's payoffs for the original (unconverted) game.

Question 7(a)

7 Sam is making pies.

There is exactly enough pastry to make 7 large pies or 20 medium pies or 36 small pies, or some mixture of large, medium and small pies.

This is represented as a constraint $180x + 63y + 35z \leqslant 1260$.

(a) Write down what x, y and z represent. **[2]**

Candidates usually realised that the variables represented the number of pies made and most of them recognised that, because fewer large pies could be made, the variable representing the number of large pies had the largest coefficient, with similar reasoning for the variables representing the number of medium pies made and the number of small pies made.

Question 7(b)

There is exactly enough filling to make 5 large pies or 12 medium pies or 18 small pies, or some mixture of large, medium and small pies.

(b) Express this as a constraint of the form $ax + by + cz \leqslant d$, where a, b, c and d are integers. **[2]**

This was done well by those candidates who had identified the variables correctly. The coefficients need to be in the ratio 1/5 : 1/12 : 1/18, multiplying by any multiple of 5, 12 and 18 gives integer coefficients.

A minority of candidates gave their answer as an equation rather than an inequality, as described in the question.

Question 7(c)

The number of small pies must equal the total number of large and medium pies.

(c) Show that making exactly 9 small pies is inconsistent with the constraints. **[2]**

There is clearly enough pastry to make 9 small pies and a total of 9 medium and large pies, provided not too many large pies are made. The problem arises with the filling constraint.

Candidates uses various approaches to eliminate at least one variable from the filling constraint and show that if $z = x + y = 9$ then the number of large pies has to be negative, which is impossible. Alternatively, some candidates explained that because medium pies needed less pastry and less filling than large pies they only needed to consider the case when $x = 0$, $y = 9$ and $z = 9$.

Exemplar 3

7(c)

$z = 9$

$\cancel{35 \times 9 = 315} \le 1260$

$\cancel{30 \times 9 = 270}$

$z = x + y \qquad 9 = x + y \qquad y = 9 - x$

$180x + 63y \le 1260 - 35 \times 9$

$180x + 63y \le 945$

$108x + 45y \le 540 - 30 \times 9$

$108x + 45y \le 270$

$180x + 63(9 - x) = 117x \cancel{8} + 567$

$117x \le 378$

$x \le 3.23$

$108x + 45(9 - x) = 63x + 405$

$63x \le -135$

$\cancel{x} \quad x \le -2.14$

cannot have a negative number of large pies

This candidate has eliminated z and then y to get two inequalities for x and explained why $x \le -2.14$ is impossible.

	AfL	Some candidates substituted for one variable to get (correct) inequalities in the other two variables for the pastry constraint and the filling constraint, but then treated these simultaneous inequalities as if they were simultaneous equations and subtracted them. It is not valid to subtract inequalities.

Question 7(d)

(d) Determine the maximum number of large pies that can be made.

- Your reasoning should be in the form of words, calculations or algebra.
- You must check that your solution is feasible. **[6]**

This was an unstructured problem-solving task that could be approached in several ways. Most candidates were able to attempt at least a partial solution and several achieved full credit. Some candidates did not check that their solution was feasible (or did not say what value of x, y and z they were checking).

There were, broadly, five different approaches used to answer this question:

Method 1: An algebraic approach, as in part (c), using $x + y = z$ to eliminate one variable from the pastry and filling constraints and get two inequalities in the remaining two variables. This led to maximum values (for x) of 5.86 and 3.91, so the maximum number of large pies is 3. They then needed to check that this is feasible, by putting either $x = 3$, $y = 0$, $z = 3$ or $x = 3$, $y = 1$, $z = 4$ through the constraints.

Method 2: Explaining, as in part (c), that the best case is when 0 medium pies are made, so $y = 0$ and $x = z$. This again led to the maximum values (for x) of 5.86 and 3.91, which then proceeds as above.

Method 3: Trying to set the problem up as a simplex tableau in which the objective is to maximise $P = x$. Usually this was only partially successful because of the equality constraint. The constraint $x + y = z$ needed to be written as the two inequalities $x + y \leq z$ and $x + y \geq z$, which can then be written as $x + y - z + \text{slack} = 0$ and $-x - y + z + \text{slack} = 0$ to give two rows in the simplex. Candidates who did this achieved the optimum at $x = 3.91$, $y = 0$, $z = 3.91$ and the remainder of the answer followed as above.

Method 4: Using branch-and-bound, which is appropriate since this is an integer programming problem. The working to deal with the branches was then as above.

Method 5: Starting with $x = 5$ (since there is only enough filling for 5 large pies) and showing that this is impossible, then reducing x by 1 and checking again until a feasible solution was achieved. This method was used by several candidates, but was also the least successful approach because candidates usually just gave a lot of number work and left out some of the details of their reasoning.

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