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Examiners' report

A LEVEL

FURTHER MATHEMATICS A

OCR Level 3 Advanced GCE in Further Mathematics A

H245

For first teaching in 2017

Y544/01 Summer 2025 series

Version 1

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Contents

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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. A selection of candidate responses is also provided. The reports will also explain aspects which 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/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 and the mark scheme can be downloaded from Teach Cambridge.

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Paper Y544 series overview

This is one of the optional papers for Further Mathematics. It assesses Discrete Mathematics through graphs and networks, algorithms, linear programming and the application of these to problems including critical path analysis and game theory.

Candidates who did well on this paper generally:	Candidates who did less well on this paper generally:
• worked neatly and ensured their working was clear where appropriate • explained their reasoning and showed their working • gave answers that were appropriate for the number of marks available.	• did not show their working • worked in a less clear way and misread their own letters or numerical values • did not use the algorithms given in the formulae booklet • relied on diagrams when a ruled answer space had been provided • were not able to make a substantial attempt at any question.

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Question 1 (a)

1 A coach operator offers sightseeing tours of a city. The sightseeing tour starts and ends at stop A, and there are tourist attractions at B, C, D, E, F and G. The table below shows the distances in metres that the coach must travel between each of the seven stops.

	A	B	C	D	E	F	G
A	–	120	100	230	260	150	200
B	120	–	180	210	200	250	280
C	100	180	–	235	190	170	270
D	230	210	235	–	170	185	210
E	260	200	190	170	–	210	270
F	150	250	170	185	210	–	195
G	200	280	270	210	270	195	–

The coach operator wants to find a route which starts and ends at A, visiting every tourist attraction once.

(a) State the standard network problem that they must solve. **[1]**

Most candidates identified this as being the travelling salesperson problem or finding a Hamiltonian cycle.

Question 1 (b)

(b) Use the nearest neighbour method to find an upper bound for the length of the coach operator's route starting at A. **[2]**

A few candidates did not apply the nearest neighbour method correctly, just choosing the nearest vertex even if it had already been visited.

Some candidates applied the method correctly to reach all the vertices, but did not close the cycle.

A few closed the cycle before every vertex had been visited.

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Question 1 (c)

(c) Beginning by removing stop A to reduce the network, use an algorithm to determine a lower bound for the length of the coach operator's route. **[4]**

The command word determine means that candidates need to show justification for their answer, for example listing the arcs in their minimum spanning tree for the reduced network.

Some candidates left vertex G out of their minimum spanning tree or used a nearest neighbour approach resulting in joining G using arc DG = 210 instead of FG = 195.

Some candidates thought that the two least weight arcs from A were AC and AF instead of AB and AC.

Question 1 (d)

(d) By referring to your lower bound, comment on the length of the route found by the nearest neighbour method. **[1]**

The comment needed to discuss the usefulness of the length of the route found by the nearest neighbour method, not just say that the length of the optimum tour is between the lower and upper bounds.

The nearest neighbour method gives a tour that solves the problem. Its length is an upper bound for the problem. For this network, the lower bound does not come from a tour, but the upper bound does give a relatively good tour length. The solution may or may not be the length of the shortest tour, however it is probably not worth spending time trying to improve it.

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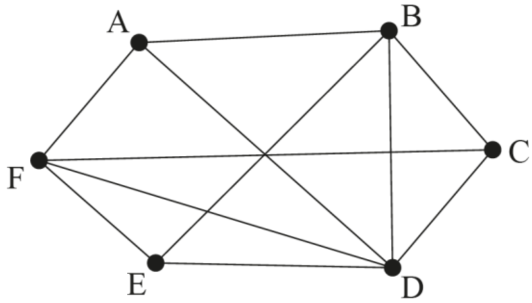
Question 2 (a) (i)

2 **(a)** Graph G is shown below



(i) Show that graph G is **not** bipartite. **[2]**

There are many ways to show this.

Several candidates used a colouring argument but they did not always say which vertex they had started from or explain how the colouring showed that the graph G is not bipartite.

The easiest way to show that graph G is not bipartite is to identify three vertices that are each directly connected to the other two (for example A, D, F) and then explain that these cannot be put into two sets without having a pair in one set that have an arc between them.

Some candidates assumed that they were being asked to show that the graph was not the bipartite graph $K_{3,3}$ when it could have been $K_{2,4}$ or $K_{5,1}$ for example.

Question 2 (a) (ii)

(ii) Use Kuratowski's Theorem to show that graph G is **not** planar. **[3]**

A few candidates tried to used Euler's formula despite being instructed to use Kuratowski's Theorem.

Some candidates assumed that they had shown that $K_{3,3}$ is not a subgraph in part (a)(i), rather than that the graph *G* (in its entirety) is not bipartite and went on to try to explain how to use contraction to form K_5 as a subgraph. However, K_5 has 5 vertices so only one vertex could be combined with another by contraction and that could not deal with both A and C (neither of which are directly connected to E). Contraction involves contracting two vertices into one so that any arc incident with the original two vertices is incident with the contracted vertex.

The specification refers to a subgraph that is a subdivision of $K_{3,3}$ or K_5, but often no subdivision is required and all that is needed is to show that the graph contains a subgraph that is $K_{3,3}$ or K_5. Subdivision is inserting a vertex of degree 2 into an arc, so, for example, the subgraph may not be K_5 but would be if a vertex that is joined to only two others is contracted into one of them.

In this case graph *G* contains $K_{3,3}$ as a subgraph. The sets forming the $K_{3,3}$ subgraph should be written out, not deduced from a diagram.

By removing the arcs BD and DF a subgraph is formed that can be represented as $K_{3,3}$ using the two sets {A, C, E} and {B, D, F}, so $K_{3,3}$ is a subgraph of *G* and hence, by Kuratowski's Theorem, *G* is non-planar.

Question 2 (a) (iii)

(iii) Determine whether graph G is simply connected. **[1]**

Most candidates realised that graph *G* is simply connected, but some did not explain how they knew this.

For a graph to be simply connected it must be both simple and connected. In a simple graph there is at most one arc directly joining any two vertices (no repeated arcs) and no vertex is directly joined to itself (no 'loops').

Some candidates used the term 'loop' to mean 'cycle', rather than an arc that joins a vertex to itself.

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Question 2 (b) (i)

(b) The adjacency matrix for a digraph H is shown below

To

From	J	K	L	M	N	O
J	0	1	1	0	1	0
K	2	0	1	1	0	0
L	1	1	0	1	1	1
M	0	0	1	1	0	1
N	1	0	1	0	0	1
O	0	1	0	1	1	0

(i) Write down the indegree and outdegree of node L. **[2]**

This question part was usually correct.

Question 2 (b) (ii)

(ii) Determine whether digraph H is simply connected. **[1]**

A few candidates explained why H is not complete instead of simply connected.

Some claimed that the graph was not connected but, although the arcs are directed, it is possible to travel from any node to any other node.

To show that the graph is not simple it is sufficient to find a counterexample. This could be identifying that there is a repeated arc from K to J or that there is a (directed) loop from M to itself.

Some candidates thought that the table needed to be symmetric about the lead diagonal and some thought that the directed arcs each way between two nodes (for example L and M) made a repeated arc, rather than, essentially, being equivalent to a single undirected arc.

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Question 3 (a)

3 Hiro uses a sorting algorithm to sort the heights in cm of 8 people into **ascending** order.

At the end of the first pass through the algorithm, Hiro ends up with the list below:

142 165 152 135 171 154 172 182

(a) If Hiro used the **shuttle sort** algorithm, write down the possibilities for the original list. **[1]**

Several correct answers to this question part were seen.

Some candidates only gave one possibility, usually realising that swapping the first two values in the given list gave a possible original list but not saying that the given list was also a possibility.

Question 3 (b)

Hiro actually used the **bubble sort** algorithm starting at the left-hand side.

(b) Complete the second and third passes using the bubble sort algorithm.
You should show the list that results at the end of each pass. **[2]**

The majority of candidates showed that they knew how to carry out passes of bubble sort, with only a few using shuttle sort.

Most wrote the correct lists at the end of the second and third passes, but some repeated the given list after the first pass and then found the list after the second pass, and a few gave the lists after the third and fourth passes.

Question 3 (c)

In total, Hiro needed 5 passes to complete the bubble sort algorithm.

In total, the **shuttle sort** algorithm would take 12 comparisons to sort the original list into ascending order.

(c) Using the total number of comparisons for each algorithm, compare the efficiency of bubble sort and shuttle sort for sorting the heights of the 8 people. **[3]**

Some candidates claimed that there were 7 comparisons in each of 5 passes so 35 in total. Bubble sort is given in the formulae booklet, where it says that the length of the list reduces with each pass, until either there is a pass in which no swaps occur or the reduced list has length 1.

Some candidates compared the number of passes, despite the question saying to use the number of comparisons.

A few candidates tried to discuss the efficiencies in the general case, rather than for this specific case.

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Question 3 (d)

(d) It takes a computer $\mathbf{2.4 \times 10^{-3}}$ **seconds** to sort a list of 300 numbers into ascending order using the bubble sort algorithm.

Find the approximate length of a list the computer could sort in 1 minute. Give your answer to **1** significant figure. **[2]**

Often answered correctly, although some candidates achieved the answer 47434 but then did not round this to 1 sf as asked in the question.

Some candidates did not use the fact that the algorithm is $O(n^2)$.

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Question 4 (a) (i)

4 The table shows the activities involved in a project, together with the immediate predecessors and the duration of each activity in hours.

Activity	Immediate Predecessors	Duration (hours)
A	–	5
B	–	4
C	A	3
D	B	3
E	D	2
F	B	5
G	C, E	2
H	D	5
I	G	3
J	C, E, H	1
K	D, F	2

(a) **(i)** By constructing an activity network for the project, determine the minimum time in which the project can be completed. **[5]**

Diagrams should be large enough that labels and values are legible, while leaving enough space for a second attempt if an error is made. Ideally diagrams should be drawn horizontally across the page, not rotated. If a second attempt is made, the incorrect or incomplete attempt should be crossed through.

Most candidates used activity on arc with directed arcs, although some missed the direction on at least one arc. Some candidates had multiple start events and/or multiple end events. Several had extra dummy activities.

The early event times and late event times should either be shown at the vertices or given as a list or table with the events labelled. If using the box notation it is usual to give the EET in the first (left hand or upper) box and the LET in the second (right hand or lower) box.

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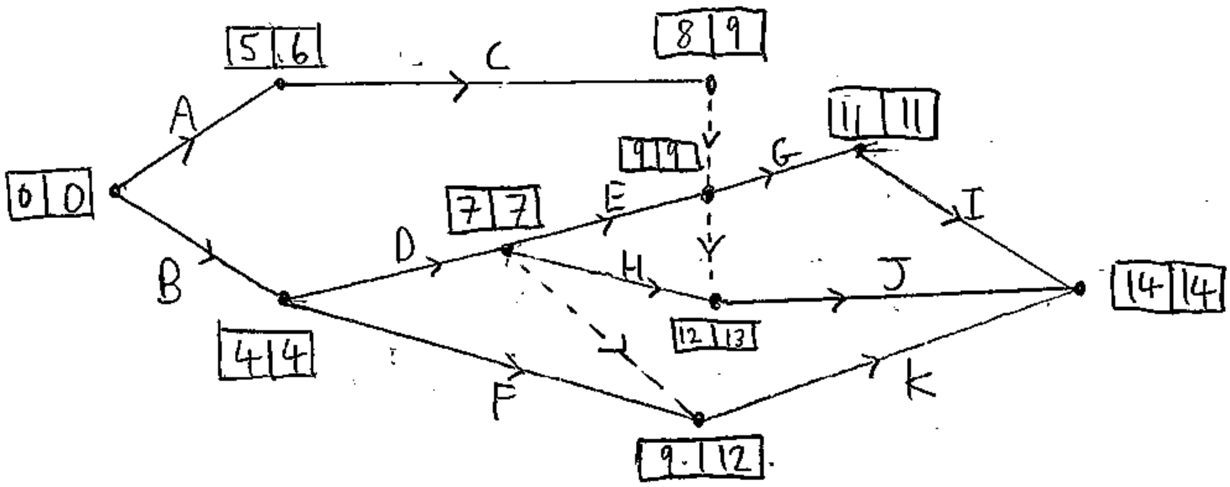
Exemplar 1



This candidate has an extra dummy activity after activity C. Otherwise it is correct.

The minimum completion time of 14 hours is given on the answer line at the end of the answer space..

Question 4 (a) (ii)

(ii) State the critical activities. **[1]**

Many candidates found the critical activities, even when their activity network was not entirely correct.

Question 4 (b)

(b) Calculate the interfering float for each non-critical activity. **[3]**

Several candidates knew how to calculate the total float as (LET (tail) – EET (head) – duration, the independent float as max{EET (tail) – LET (head) – duration, 0} and the interfering float from total float = independent float + interfering float.

Some candidates gave various calculations but did not say which type of float they represented.

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Exemplar 2

Inteferring Float = Total float − independent float

	Total	independent	inteferring
A	1	0	1
C	1	−1	0
F	3	2	1
H	1	0	1
J	1	0	1
K	3	0	3

Inteferring float: A = 1, C = 0, F = 1, H = 1, J = 1, K = 3

This candidate has set their work out clearly but has given a negative independent float at C and also made an error in their calculation at F.

The candidate had used an extra dummy activity so their EET at the tail of C was 8, which gave EET (tail) – LET (head) – duration = 8 – 6 – 3 = -1 but they had given this as the independent float instead of max{ EET (tail) – LET (head) – duration, 0} = 0.

Question 4 (c)

Each activity requires one worker. When an activity is started it must be completed without interruption.

(c) Use the diagram in the Printed Answer Booklet to determine the minimum number of workers needed to complete the project in the minimum completion time.

Each column in the diagram represents 1 hour. For each worker, write the letter of the activity they are doing in each box, or leave the box blank if the worker is resting for that hour. You may not need to use all the rows or columns in the table. **[3]**

Many correct schedules, and some that were correct apart from not using the float on H and J to shift them to happen after A and C (to reduce the number of workers needed).

A few candidates exceeded the minimum project completion time, often by putting J or K after I.

A small number of candidates split an activity, often activity H, across two workers (with one starting it and the other finishing it) and some had at least one activity with the wrong duration.

Some candidates used the first two workers to complete activities B, D, E, G, I and A, C, H, J but then had the third worker starting activity F at time 0, or other precedence errors such as starting G before C had finished.

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Question 4 (d)

(d) Activity C takes an additional t hours, but all other timings are unchanged.

Determine the range of values of t that result in an increase in the minimum project completion time. **[2]**

Some candidates worried about whether the number of workers available was an additional restriction, but the stem for part (d) only says that 'Each activity requires one worker. When an activity is started it must be completed without interruption.'

Candidates needed to either use the float of activity C or consider the duration that would make it become critical to deduce that any value of $t > 1$ would increase the minimum project completion time.

Some candidates thought that t needed to be integer-valued, but time is a continuous variable, and a few thought that t was the new duration of activity C rather than the increase.

Question 5 (a)

5 The table below shows the pay-off for Player A in a two-person zero-sum game between Player A and Player B. Each player has three options; P, Q and R represent the options for Player A and X, Y and Z represent the options for player B.

	X	Y	Z
P	1	2	−1
Q	3	0	2
R	−1	4	−2

(a) Write down the maximum possible pay-off to Player B if Player A plays option P. **[1]**

This question part was usually correct, although a few candidates did not remember that the pay-offs to player B are the negatives of the values in the table.

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Question 5 (b)

(b) Determine whether or not the game is stable. **[4]**

Candidates should show the row minima and column maxima as well as either identifying the row maximin (max of the row minima) and column minimax (min of the column maxima), or equivalent, or identifying the play-safe strategies Q and Z. The values of the play-safe strategies (or the minimax and maximin, the 'least worst' values) 0 and 2 are not equal so the game is not stable.

Some candidates calculated row maxima and column minima, which was wrong.

Some candidates used Nash Equilibrium here, but this was not appropriate here as it was asked in part (c).

Assessment for learning

'Determine' is a command word and means that justification should be given for any results.

More information about these can be found in section 2b of the specification. OCR has also produced blogs and a poster to support teachers.

Question 5 (c)

(c) Show that there are no Nash Equilibrium points for the game. **[2]**

Working was sometimes done on the table in part (b), if part of the answer to a question is in a different answer space this needs to be stated.

When candidates worked on a table their answers were sometimes quite difficult to see, it is better to list the Nash Equilibrium cells. The best outcomes for A for each of B's choices (the cell that gives the maximum in each column) are (Q, X), (R, Y) and (Q, Z). The best outcomes for B for each of A's choices (the cell that gives the best for B in each row) are (P, Z), (Q, Y) and (R, Z). No cell appears in both lists so there is no Nash Equilibrium.

Candidates who chased 'regrets' missed out either (Q, X) or (P, Z) and so they had not identified both sets of cells.

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Question 5 (d)

(d) The entry in one cell in the zero-sum game above can be **increased** so that there is a Nash Equilibrium point.

- Identify the cell that should be chosen.
- Write down the smallest value that it could take. **[2]**

Several candidates did not know how to identify the appropriate cell. Those who did recognise that increasing the value of cell (Q, Y) was the only way to make cell (Q, Z) best for B in row Q (or equivalent using the values of the play-safe strategies) did not always appreciate that making the values of (Q, Y) and (Q, Z) equal was enough.

Question 5 (e)

(e) Show that the original game can be reduced to a game with a 3×2 pay-off matrix using dominance. **[1]**

Most candidates realised that they needed to compare the values in columns X and Z. Showing the actual comparisons is the easiest way to do this.

Because the pay-offs for B are the negatives of the values in the table, this meant that Z dominates X and column X could be deleted.

Question 5 (f) (i)

The entry in cell (Q,Y) in the reduced game is changed to a number **less than -4**. This new number is denoted by m.
You are given that the value of the reduced game to Player B with this change is 0.4.

(f) (i) Determine the optimal mixed strategy for Player B. **[6]**

Some responses given were disorganised and difficult to follow or had several restarts with no indication of what was intended to be the working leading to their answer.

Most candidates worked with a reduced table, having deleted a column and changed cell (Q, Y) to *m* (or -*m* if the table had been switched to show pay-offs for B). A few candidates increased the table by a constant to remove negatives (as if they were setting up a linear programming formulation), but the most negative value is *m*, and this is not necessary for a graphical solution.

With just two choices for B, the minimum expected value for A when each of P, Q, R is played can be given algebraically in terms of *m* and a single unknown probability.

At this point, the fact that the optimum value to B is 0.4 should have led to the appropriate equation and hence the optimal value for the unknown probability. Some candidates just solved pairs of their expressions with no reference to the optimum value 0.4, or used 0.4 when they should have been using -0.4 (because they were still using the table of pay-offs for A).

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Question 5 (f) (ii)

(ii) Find the corresponding value of m. **[1]**

Candidates who had a substantially correct answer to part (f) (i) were usually able to find the correct value.

Question 6 (a)

6 A furniture company makes three types of wardrobes.

Each **Type A** wardrobe requires 4 hours of machine time, 6 hours of craftsman time and 2 hours of finishing time.

Each **Type B** wardrobe requires 3 hours of machine time, 5 hours of craftsman time and 11 hours of finishing time.

Each **Type C** wardrobe requires 5 hours of machine time, 4 hours of craftsman time and 4 hours of finishing time.

Each month, there is a maximum of 200 hours of machine time, 160 hours of craftsman time and 144 hours of finishing time.

The company makes **£16** profit on each **Type A** wardrobe, **£20** profit on each **Type B** wardrobe and **£14** profit on each **Type C** wardrobe. The company wants to make as much profit P as possible.

Let x, y and z denote the number of Type A, Type B and Type C wardrobes made each month.

(a) Write down the objective function for this problem. **[1]**

Some candidates used *a*, *b* and *c* as their variables; despite having *x*, *y* and *z* defined in the question.

'Max' (or equivalent) should be included as part of the objective function, unless the question has asked, for example, for 'an objective function P, to be maximised'.

Question 6 (b)

(b) Complete the table in the Printed Answer Booklet to represent the problem as an initial simplex tableau. You should use the first blank row for your objective function. **[5]**

Most candidates were able to set up an appropriate initial simplex tableau. This question part was accessible to many candidates, with very few not attempting to answer. The majority of candidates scored 5 marks here.

Question 6 (c) (i)

(c) **(i)** Show the calculations used to find the pivot element for the first iteration of the simplex algorithm. **[1]**

The specification point 7.07b says that, when choosing the pivot, the 'column with the most negative value in the objective row should be chosen, unless other specific instruction is given'.

Question 6 (c) (ii)

(ii) Carry out **one** iteration of the simplex algorithm. You should give each entry in exact form. **[3]**

Many candidates were able to perform the operations on their pivot row and column although some had used an unsuitable pivot choice that led to having negative entries in the RHS column.

Candidates should work with exact values, which in this case meant using fractions.

Question 6 (d)

Multiple iterations of the simplex algorithm are carried out until the objective function has been maximised. The final tableau is shown below.

	P	x	y	z	r	s	t	RHS
Row 1	1	0	5	0	0	2.25	1.25	540
Row 2	0	0	−8.5	0	1	−0.375	−0.875	k
Row 3	0	1	−1.5	0	0	0.25	−0.25	4
Row 4	0	0	3.5	1	0	−0.125	0.375	34

(d) Explain how the values in Row 1 indicate that the objective function has been maximised. **[1]**

Most candidates knew that when all the values in row 1 are non-negative the optimum has been achieved.

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Question 6 (e)

(e) Determine the value of k. **[2]**

The candidates who answered this part were usually able to read off the optimal values of *x*, *y* and *z*. Often they then substituted into the appropriate constraint (the machine time constraint from the original problem) to find the value of *k*.

Question 7 (a)

7 Charlie has a set of 100 cards.
On each card one of the integers from 1 to 100 is printed without any repeats.

(a) Use the inclusion-exclusion principle to determine how many of Charlie's cards show a number that is a multiple of 2, 3 or 5. **[3]**

Some candidates worked with probabilities instead of counting the number of cards of each type.

Several candidates were able to calculate the number of cards that were multiples of 2 and similarly for multiples of 5. Some did not round down to an integer when finding the number of cards that were multiples of 3.

A few candidates then used inclusion-exclusion for two events and said things like 'there are 50 cards with multiples of 2 and 33 with multiples of 3, but 16 of these have already been counted', this led to adding up lots of little bits rather than using inclusion-exclusion for three events.

Inclusion-exclusion for three events is in the specification under point 7.01k.

Question 7 (b)

Charlie then chooses one or more cards at random and arranges them next to each other to form a number with n digits where $n \geqslant 1$.

(b) Determine the total number of different arrangements of cards that will produce a 3-digit number. **[3]**

Some candidates did not count the number of cards with 1 digit, 2 digits and 3 digits correctly. Those who did were often able to write down appropriate calculations, although some used 9C3 instead of 9P3 and some counted, for example, the numbers made from 1 digit followed by 2 digits but did not include 2 digits followed by 1 digit.

It is easy for correct working to get lost in among incorrect work. Candidates should be encouraged to show the values being used in their final sum.

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