Oxford Cambridge and RSA

GCE

Further Mathematics A

Y545/01: Additional Pure Mathematics

A Level

Mark Scheme for June 2022

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This mark scheme is published as an aid to teachers and students, to indicate the requirements of the examination. It shows the basis on which marks were awarded by examiners. It does not indicate the details of the discussions which took place at an examiners' meeting before marking commenced.

All examiners are instructed that alternative correct answers and unexpected approaches in candidates' scripts must be given marks that fairly reflect the relevant knowledge and skills demonstrated.

Mark schemes should be read in conjunction with the published question papers and the report on the examination.

Text Instructions

1. Annotations and abbreviations

Annotation in RM assessor	Meaning
✓and ✗	
BOD	Benefit of doubt
FT	Follow through
ISW	Ignore subsequent working
M0, M1	Method mark awarded 0, 1
A0, A1	Accuracy mark awarded 0, 1
B0, B1	Independent mark awarded 0, 1
SC	Special case
^	Omission sign
MR	Misread
BP	Blank Page
Seen	
Highlighting	
Other abbreviations in mark scheme	**Meaning**
dep*	Mark dependent on a previous mark, indicated by *. The * may be omitted if only one previous M mark
cao	Correct answer only
oe	Or equivalent
rot	Rounded or truncated
soi	Seen or implied
www	Without wrong working
AG	Answer given
awrt	Anything which rounds to
BC	By Calculator
DR	This question included the instruction: In this question you must show detailed reasoning.

2. Subject-specific Marking Instructions for A Level Mathematics A

a Annotations must be used during your marking. For a response awarded zero (or full) marks a single appropriate annotation (cross, tick, M0 or ^) is sufficient, but not required.

For responses that are not awarded either 0 or full marks, you must make it clear how you have arrived at the mark you have awarded and all responses must have enough annotation for a reviewer to decide if the mark awarded is correct without having to mark it independently.

It is vital that you annotate standardisation scripts fully to show how the marks have been awarded.

Award NR (No Response)

- if there is nothing written at all in the answer space and no attempt elsewhere in the script
- OR if there is a comment which does not in any way relate to the question (e.g. 'can't do', 'don't know')
- OR if there is a mark (e.g. a dash, a question mark, a picture) which isn't an attempt at the question.

Note: Award 0 marks only for an attempt that earns no credit (including copying out the question).

If a candidate uses the answer space for one question to answer another, for example using the space for 8(b) to answer 8(a), then give benefit of doubt unless it is ambiguous for which part it is intended.

b An element of professional judgement is required in the marking of any written paper. Remember that the mark scheme is designed to assist in marking incorrect solutions. Correct solutions leading to correct answers are awarded full marks but work must not always be judged on the answer alone, and answers that are given in the question, especially, must be validly obtained; key steps in the working must always be looked at and anything unfamiliar must be investigated thoroughly. Correct but unfamiliar or unexpected methods are often signalled by a correct result following an apparently incorrect method. Such work must be carefully assessed. When a candidate adopts a method which does not correspond to the mark scheme, escalate the question to your Team Leader who will decide on a course of action with the Principal Examiner.
If you are in any doubt whatsoever you should contact your Team Leader.

c The following types of marks are available.

M
A suitable method has been selected and *applied* in a manner which shows that the method is essentially understood. Method marks are not usually lost for numerical errors, algebraic slips or errors in units. However, it is not usually sufficient for a candidate just to indicate an intention of using some method or just to quote a formula; the formula or idea must be applied to the specific problem in hand, e.g. by substituting the relevant quantities into the formula. In some cases the nature of the errors allowed for the award of an M mark may be specified.
A method mark may usually be implied by a correct answer unless the question includes the DR statement, the command words "Determine" or "Show that", or some other indication that the method must be given explicitly.

A
Accuracy mark, awarded for a correct answer or intermediate step correctly obtained. Accuracy marks cannot be given unless the associated Method mark is earned (or implied). Therefore M0 A1 cannot ever be awarded.

B
Mark for a correct result or statement independent of Method marks.

Unless otherwise indicated, marks once gained cannot subsequently be lost, e.g. wrong working following a correct form of answer is ignored. Sometimes this is reinforced in the mark scheme by the abbreviation isw. However, this would not apply to a case where a candidate passes through the correct answer as part of a wrong argument.

d When a part of a question has two or more 'method' steps, the M marks are in principle independent unless the scheme specifically says otherwise; and similarly where there are several B marks allocated. (The notation 'dep*' is used to indicate that a particular mark is dependent on an earlier, asterisked, mark in the scheme.) Of course, in practice it may happen that when a candidate has once gone wrong in a part of a question, the work from there on is worthless so that no more marks can sensibly be given. On the other hand, when two or more steps are successfully run together by the candidate, the earlier marks are implied and full credit must be given.

e The abbreviation FT implies that the A or B mark indicated is allowed for work correctly following on from previously incorrect results. Otherwise, A and B marks are given for correct work only – differences in notation are of course permitted. A (accuracy) marks are not given for answers obtained from incorrect working. When A or B marks are awarded for work at an intermediate stage of a solution, there may be various alternatives that are equally acceptable. In such cases, what is acceptable will be detailed in the mark scheme. If this is not the case please, escalate the question to your Team Leader who will decide on a course of action with the Principal Examiner.
Sometimes the answer to one part of a question is used in a later part of the same question. In this case, A marks will often be 'follow through'. In such cases you must ensure that you refer back to the answer of the previous part question even if this is not shown within the image zone. You may find it easier to mark follow through questions candidate-by-candidate rather than question-by-question.

f We are usually quite flexible about the accuracy to which the final answer is expressed; over-specification is usually only penalised where the scheme explicitly says so.

- When a value **is given** in the paper only accept an answer correct to at least as many significant figures as the given value.
- When a value **is not given** in the paper accept any answer that agrees with the correct value to **3 s.f.** unless a different level of accuracy has been asked for in the question, or the mark scheme specifies an acceptable range.
  NB for Specification B (MEI) the rubric is not specific about the level of accuracy required, so this statement reads "2 s.f".

Follow through should be used so that only one mark in any question is lost for each distinct accuracy error.
Candidates using a value of 9.80, 9.81 or 10 for *g* should usually be penalised for any final accuracy marks which do not agree to the value found with 9.8 which is given in the rubric.

g Rules for replaced work and multiple attempts:

- If one attempt is clearly indicated as the one to mark, or only one is left uncrossed out, then mark that attempt and ignore the others.
- If more than one attempt is left not crossed out, then mark the last attempt unless it only repeats part of the first attempt or is substantially less complete.
- if a candidate crosses out all of their attempts, the assessor should attempt to mark the crossed out answer(s) as above and award marks appropriately.

h For a genuine misreading (of numbers or symbols) which is such that the object and the difficulty of the question remain unaltered, mark according to the scheme but following through from the candidate's data. A penalty is then applied; 1 mark is generally appropriate, though this may differ for some units. This is achieved by withholding one A or B mark in the question. Marks designated as cao may be awarded as long as there are no other errors.
If a candidate corrects the misread in a later part, do not continue to follow through. Note that a miscopy of the candidate's own working is not a misread but an accuracy error.

i If a calculator is used, some answers may be obtained with little or no working visible. Allow full marks for correct answers, provided that there is nothing in the wording of the question specifying that analytical methods are required such as the bold "In this question you must show detailed reasoning", or the command words "Show" or "Determine". Where an answer is wrong but there is some evidence of method, allow appropriate method marks. Wrong answers with no supporting method score zero. If in doubt, consult your Team Leader.

j If in any case the scheme operates with considerable unfairness consult your Team Leader.

Question			Answer	Marks	AO	Guidance
1	a		$\frac{\partial z}{\partial x} = \frac{1}{2}z^{-1}.-6x$ $\quad$ $\frac{\partial z}{\partial y} = \frac{1}{2}z^{-1}.-4y$	M1 A1	1.1 1.1	Attempt at partial differentiation (at least one case) $ax \times z^{-1}$ or $by \times z^{-1}$ At least one correct (any form)
			$\frac{\partial z}{\partial x} = -\frac{3x}{z} = -11$ and $\frac{\partial z}{\partial y} = -\frac{2y}{z} = \frac{16}{3}$	M1 A1	1.1 1.1	Substituting values into *their* partial derivatives to get numerical "gradients" (can be implied by a correct answer) Both correct
			Alternative method			
			$2z\frac{\partial z}{\partial x} = -6x$ $\quad$ $2z\frac{\partial z}{\partial y} = -4y$	M1 A1		Squaring and use of implicit differentiation (at least one case) At least one correct (any form)
			$\frac{\partial z}{\partial x} = -\frac{3x}{z} = -11$ and $\frac{\partial z}{\partial y} = -\frac{2y}{z} = \frac{16}{3}$	M1 A1		Substituting values to get numerical "gradients" Both correct
				[4]		
	b		$z - 3 = -11(x - 11) + \frac{16}{3}(y + 8)$	M1	1.1	Eqn. for tangent plane used Must have numerical "gradients" involved
			$\Rightarrow 33x - 16y + 3z = 500$	A1 **[2]**	1.1	**CAO** (any non-zero integer multiple)
2	a		If $h \mid 7n + 4$ and $h \mid 8n + 5$ then $h \mid 7(8n + 5) - 8(7n + 4)$	M1	2.1	A linear combination of the two numbers attempted
			i.e. $h \mid 3$	A1	1.1	Correct from choice of 7, –8 (or –7, 8)
			$\Rightarrow h = 1$ or 3	B1	2.2a	inclusion of either/both of $h = -1, -3$ → **B0**
			Alternative method			
			hcf(7*n*+4, 8*n*+5)=hcf(7*n*+4, *n*+1)=hcf(7(*n*+1)-(7*n*+4), *n*+1)	M1		
			hcf(3, *n*+1)	A1		
			$h = 1$ or 3	B1		
				[3]		

Question			Answer	Marks	AO	Guidance
	b		$7n + 4 \equiv 0 \pmod 3$ $\Rightarrow n \equiv 2 \pmod 3$	**M1** **A1** **[2]**	3.1a 1.1	Solving attempt at this, or $8n + 5 \equiv 0 \pmod 3$, or both (if a list is given, at least $n = 2, 5, 8$ seen and no errors) Condone $n \equiv -1 \pmod 3$ instead
3			$\phi^1 = 1.\phi + 0 = (F_1)\phi + (F_0)$ so result true for $n = 1$ Assuming that $\phi^k = (F_k)\phi + (F_{k-1})$ … … it follows that $\phi^{k+1} = \phi((F_k)\phi + (F_{k-1}))$ $= (F_k)(\phi + 1) + (F_{k-1})\phi$ $=$ $(F_k + F_{k-1})\phi + (F_k) = (F_{k+1})\phi + F_k$ and result is also true for $n = k + 1$ Since true for $n = 1$ and (true for $n = k \Rightarrow$ true for $n = k + 1$), the result follows for all $n \geq 1$ by induction	**B1** **M1** **M1** **M1** **A1*** **A1dep** **[6]**	2.5 1.2 1.1a 3.1a 2.2a 2.4	Induction hypothesis explicitly stated (so "assume the result is true for $n = k$" does not suffice without a clear indication as to what it is that is being assumed) Attempt at ϕ^{k+1} with explicit use of induction hypothesis Use of result for $n = 2$ or from known property of ϕ (e.g. from the auxiliary equation of the Fib. sequence) or by direct calculation $(k + 1)^{th}$ case established clearly from use of the defining Fibonacci sequence property Explanation of the inductive logic (can only be awarded if the result has actually been proven).

Question			Answer	Marks	AO	Guidance
4	a	i	"odds – evens" = (1 + 8 + 4 + 7) – (5 + 2 + 5 + 8) = 0 Since result is a multiple of 11, so is N	**M1** **A1** **[2]**	1.1 2.4	Shown (**or** via 1 – 5 + 8 – 2 + 4 – 5 + 7 – 8 = 0) Explanation (not just "since answer = 0")
		ii	If 7 | N and 7 | 70 (e.g.) then 7 | N – 70 etc. N = 15 824 5**7**8 N_1 = **15** 824 508 N_2 = 01 **8**24 50**8** **given to here** N_3 = 01 1**24** **50**1 (e.g. from here) N_4 = 0**1 1**03 **0** **11** N_5 = 00 **40**0 **20**4 N_6 = 00 0**50** 0**64** N_7 = 00 00**1 0**01 (may note here that 1001 = 7×11×13) N_8 = 00 000 **30**1 N_9 = 00 000 021 N_{10} = 00 000 000	**B1** **B1** **[2]**	2.3 1.1	**or** equivalent including in words only, e.g. "a sum of multiples of 7 is a multiple of 7" Convincingly showing that the process ultimately yields a zero. Leading zeros not required, no specific notation required. Condone stopping at $N_r < 500$, provided $N_r \equiv 0$ (mod 7) shown A minimalist approach might go from N_2 = **18** **24** **50** **8** to (say) N_3 = 04 03 01 1 etc. (i.e. several steps at once)
		iii	Since 7 | 11×1 438 598 and hcf(7, 11) = 1 then 7 | 1 438 598	**B1** **[1]**	1.2	i.e. by *Euclid's lemma*
	b	i	$\frac{N}{101} = 156\ 678\ \frac{100}{101}$ a = 156 678 and b = 100	**M1** **A1** **[2]**	1.1 1.1	Division attempt (may be implied by correct answers)
		ii	$M = N^2 \equiv (-1)^2 \equiv 1$ (mod 101)	**B1** **[1]**	1.1	Must use their result in (b)(i)
		iii	The order of N mod 101 is 2	**B1** **[1]**	2.2a	

Question			Answer	Marks	AO	Guidance
5	a		$\overrightarrow{OA} \times \overrightarrow{OB} = \mathbf{0}$ requires OA // OB … … and (3 –8 …) can never be a multiple of (1 2 …)	M1 A1 [2]	2.1 2.4	Clear use of this result (parallellism) Properly explained
	b	i	$(3\mathbf{i} - 8\mathbf{j} + t\mathbf{k}) \times (\mathbf{i} + 2\mathbf{j} - 2\mathbf{k}) = (16 - 2t)\mathbf{i} + (6 + t)\mathbf{j} + 14\mathbf{k}$ Area $\Delta OAB = \frac{1}{2}\lvert\text{their Vector Product}\rvert$ $= \frac{1}{2}\sqrt{5t^2 - 52t + 488}$	M1 A1 M1 A1 [4]	1.1 1.1 1.1 1.1	Either of the **i**- or **j**- components correct All correct Attempted (must have t's involved) $\frac{1}{2}\sqrt{(16-2t)^2 + (6+t)^2 + 14^2}$ is fine here
		ii	Differentiating their answer, or by completing the square $t = 5.2$	M1 A1 [2]	3.1a 1.1	Leading to a linear equation of the form $at + b = 0$ with non-zero a and b

Question			Answer	Marks	AO	Guidance
6	a		$A_{n+1} = 0.96A_n + 40$ and $A_0 = 1000$	B1 [1]	3.3	or $A_n = 0.96A_{n-1} + 40$ and $A_0 = 1000$
	b	i	80, i.e. 8% of adults lost linked to the 0.92 (noting that the 1000 and 40 remain the same as before) $A_{n+1} = 0.92A_n + 40$ and $A_0 = 1000$	B1 [1]	2.1	**AG**
		ii	PS from $A_{n+1} = A_n = a$ is $A_n = 500$ CS is $A_n = C \times 0.92^n$ Soln. from GS: $A_n = C \times 0.92^n + 500$ with $A_0 = 1000$ $A_n = 500 \times 0.92^n + 500$	B1 B1 M1 A1 [4]	1.1 1.1 1.1 1.1	
		iii	A_n decreases, stabilising at a constant 500 i.e. $A_n \to 500$	B1 [1]	3.4	Not required to say "monotonic decreasing", since only *long-term* behaviour asked-for

Question			Answer	Marks	AO	Guidance
	c	i	PS is $A_n = 250$	B1	1.1	May be implied by following answer
			General solution is of the form $A_n = D \times \alpha^n + E \times \beta^n +$ "250" where α and β are positive and less than 1	M1	3.1a	Accept statement that α and β are both positive and less than 1
			Hence both α^n and $\beta^n \to 0$	A1	2.4	If calculated, α and β must be correct Note that $\alpha = \frac{1}{2}(0.9+\sqrt{0.41}) = 0.77$ and $\beta = \frac{1}{2}(0.9-\sqrt{0.41}) = 0.13$ ($D = 375 + \frac{665}{2\sqrt{0.41}} \approx 894.27776$ and $E = 375 - \frac{665}{2\sqrt{0.41}} \approx -144.27776$)
			$A_n \to$ '250'	A1	1.1	**FT** from PS
				[4]		**SC1** $X = 0.9X - 0.1X + 50$, so $X = 250$ **B1M1A0A1** is possible
		ii	$A_{n+1} = \text{INT}(0.9A_n - 0.1A_{n-1} + 50)$	B1 [1]	3.5c	(Note that this gives $A_n \to 249$)

Question			Answer	Marks	AO	Guidance
7	a		$3t\sqrt{16+t^2}$	**B1** **[1]**	1.1	
	b		$I_n = \int t^{n-1}.t\sqrt{16+t^2}\ \mathrm{d}t =$ $a\,t^{n-1}(16+t^2)^{3/2} - b\int (n-1)t^{n-2}(16+t^2)^{3/2}\ \mathrm{d}t$	**M1**	3.1a	Use of integration by parts, with appropriate splitting, so that **(a)**'s result can be used
			$a=b=1/3$	**A1**	1.1	1st stage all correct
			$3I_n = t^{n-1}\left(16+t^2\right)^{3/2} - (n-1)\int t^{n-2}.\left(16+t^2\right)\sqrt{16+t^2}\ \mathrm{d}t$	**M1***	3.1a	Splitting $(16+t^2)^{3/2}$ in the integral appropriately
			$= t^{n-1}\left(16+t^2\right)^{3/2} - (n-1)\left(16I_{n-2} + I_n\right)$	**M1dep**	2.1	Integral(s) correctly expressed in terms of I's
			$\Rightarrow (n+2)\,I_n = (125\times 3^{n-1}) - 16(n-1)\,I_{n-2}$	**A1** **[5]**	2.2a	**AG cao** (showing correct substitution of limits at some point)
	c		$\dot{x} = \mp t^4\sin t + 4t^3\cos t$ or $\dot{y} = \pm t^4\cos t + 4t^3\sin t$	**M1***	1.1	Attempt at differentiation using the *Product rule*
			$\left(\dot{x}\right)^2 + \left(\dot{y}\right)^2 = \left(t^8\sin^2 t - 8t^7\sin t\cos t + 16t^6\cos^2 t\right)$ $+ (t^8\cos^2 t + 8t^7\sin t\cos t + 16t^6\sin^2 t)$	**A1**	1.1	
			$L = \int\sqrt{t^8+16t^6}\ \mathrm{d}t$	**M1dep**	1.1	Use of arc-length formula with their $\left(\dot{x}\right)^2 + \left(\dot{y}\right)^2$
			$= \int_0^3 t^3\sqrt{t^2+16}\ \mathrm{d}t = I_3$	**A1** **[4]**	1.1	**AG** www, including limits (note that $I_3 = 94\frac{13}{15}$)

Question			Answer	Marks	AO	Guidance
8	a		Inverses pair up (even number) and there is one identity element Since total is even, there must be an odd number of self-inverse elements	**M1** **A1** **[2]**	2.1 2.2a	Parity argument involving inverse pairs
	b		Consider xy and its inverse, also xy. Now $xy = (xy)^{-1}$ $= y^{-1}x^{-1} = yx$ ($\Rightarrow$ abelian)	**M1** **A1** **[2]**	3.1a 1.1	Must be stated or derived **NB** No need to include statements about the identity
	c		By considering the product of any two of elements a, b, c … … gives one of d, e of order 3	**M1** **A1** **[2]**	2.1 2.2a	It must be noted that these elements are self-inverse (or of order 2) Correct example from the Cayley table must be given and the contradiction concluded
	d		Assume that all (non-identity) elements of G are self-inverse/have order 2 Then H is a group ($\cong$ the Klein group of order 4) and hence a subgroup of G (*Lagrange's theorem* states that) $o(H) \mid o(G)$ But $4 \nmid (4n + 2)$ giving the required $\Rightarrow\Leftarrow$	**B1** **B1*** **M1** **A1dep** **[4]**	2.1 2.2a 2.4 1.1	 Longer proofs that H is a group may involve $xy = yx$ (by part **b**) so that H is closed, etc. Consideration of *Lagrange's theorem*

Question			Answer	Marks	AO	Guidance
9	a		$\frac{\partial z}{\partial x} = 8x + 4y + 6$ and $\frac{\partial z}{\partial y} = 4x + 2y + 3$	**M1** **A1** **[2]**	1.1 1.1	Both first partial derivatives attempted Both correct
	b		Considering z as a function of $2x + y$	**M1**	3.1a	
			$z = (2x + y)^2 + a(2x + y) + b$	**M1**	3.2a	a and b non-zero constants
			a=3 and b=k	**A1**	2.1	
			For S always lying above the x-y plane $z > 0$ $t = 2x + y$ so $z = t^2 + 3t + k$ (> 0) soi	**B1**	1.1	
			Discriminant of $t^2 + 3t + k$ <0	**M1**	3.1a	Or completing the square $\left(t + \frac{3}{2}\right)^2 + c$ (This implies the first two M1) and stating $c > 0$
			Discriminant=9-4k	**A1**	1.1	If completing the square, $\left(t + \frac{3}{2}\right)^2 - \frac{9}{4} + k$ This implies the first A1
			$k > \frac{9}{4}$ so least integer k is 3	**B1**	2.4	**SC1** k=3 with no evidence
			Alternative method			
			$8x + 4y + 6 = 0$ and/or $4x + 2y + 3 = 0$	**M1**		
			$x = -\frac{3}{4} - \frac{1}{2}y$ or $y = -2x - \frac{3}{2}$	**M1**		
			Substituting either into z	**M1**		

Question			Answer	Marks	AO	Guidance
			Correct substitution	A1		
			$-\frac{9}{4}+k$	A1		seen
			For S always lying above the x-y plane $z > 0$	B1		Must justify that a minimum value of z occurs when $4x + 2y + 3 = 0$ (eg through a sketch)
			$\Rightarrow\ k > \frac{9}{4}$ so least integer k is 3	B1		
				[7]		

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