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Examiners' Report
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International Advanced Level in Pure Mathematics P3

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General Comments

While there were overall plenty of access points in this paper there were also some questions that challenged and proved good discriminators, in particular 1(a), 3(c), 4(b), 5, 6(ii), 7, 8 (especially (d)) and 9 (especially (b)). Even the strongest responses did not always gain full marks in all these parts, though were able to make progress in some of them.

The standard of work was good, but an over reliance on calculators was prevalent, even when warnings against calculator usage were given. Learners should be reminded to check these warnings and show that they understand the underlying mathematics of a problem when instructed to not rely on calculator technology and show all working. Question 8(d) was the question most affected by this.

Individual question reports

Question 1

Learners generally found this question accessible and were able to score marks throughout, although certain parts showed weaker responses, with part (a) and the final mark of part (b) eluding the majority.

Indeed, in part (a), learners often did not find the correct range for f. $f(x) \geq \ln 3$ was required. Some came quite close by writing $f(x) > \ln 3$, but more common was to give $f(x) > 3$, another value, or offer no answer at all.

Again, part (b) was not always fully correct and many did not include the domain, possibly not realising it was required. Learners should be reminded that a function consists of both rule and domain. The rest was well answered, and most learners correctly reached the expression for the rule of the inverse. Where domains were given, $x > 5$ and $x \neq 5$ were common incorrect answers.

Part (c) was again well answered and most learners reached $\mathrm{fg}(0) = \ln\frac{21}{4}$. The most common error was giving a decimal answer of awrt 1.7, though a few left it unsimplified or made errors during simplification.

In (d) again most learners successfully reached the answer $a = \frac{1}{2}\ln 5$ by realising that $\ln \mathrm{e}^4$ was simplified to 4 and then giving the correct manipulation to obtain $\mathrm{e}^{2a} = 5$. If this was achieved, rewriting in terms of natural logarithm was done well. Those learners who, when cross multiplying by $\mathrm{e}^{2a} + 2$, did not multiply the 2 by 4 ended with an expression $\mathrm{e}^{2a} = -1$. No further marks therefore could be gained due to the log of a negative number being undefined.

Most did this directly by using the functions f(*x*) and g(*x*) given in the question, and only very few used their answer to (c) and progressed via $\mathrm{g}^{-1}\mathrm{g}\left(\mathrm{e}^{2a}\right) = \mathrm{g}^{-1}\mathrm{f}\left(\sqrt{\mathrm{e}^4 - 3}\right)$. When proceeding this way some learners did not, however, manage to negotiate the required algebra, to reach the required answer, or did not give the answer as an exact expression.

Question 2

This question proved a good source of marks for all grades with the topic of iteration being well rehearsed. Most were able to score marks in all parts, although errors in algebra were common.

Most learners in part (a) were correctly able to find f(1) and f(2), rounded or truncated to an appropriate degree. Though learners have improved vastly on this in recent series, the main error was still to omit to state that the function was **continuous** over the [1,2] interval. A small proportion did not give any form of conclusion, while some made an error in one of the values. Some responses showed unsuccessful solution of the equation instead. A few only calculated the

value at one end of the interval, and a few used the incorrect interval – [0.5, 1.5] or similar. It was very rare to see a correct narrower interval used.

Regarding mentioning continuity, it appears that many responses include "continuous" (or one of its many spelling variants), but an understanding of its proper role is not demonstrated. For instance, it was not uncommon to see "there is a change in sign, therefore the function is continuous", or "change in sign so x is continuous / so the interval is continuous/ so data are continuous". There is no guarantee that such answers will continue to be accepted in future series, so learners should be reminded to correctly construct a conclusion to this type of problem.

In part (b), there was a large proportion of learners who could perform the algebra necessary to derive the iterative formula. Many were clear and accurate on this part with minor errors being the most common cause for loss of marks – omitting the cube root and just giving a square root in the final step being the most common. At lower grades, however, it was fairly common to see this part abandoned after a false start or not attempted altogether.

Regardless of progress in part (b), most learners were able to use the iteration formula correctly in part (c), but there were some rounding errors, particularly in x_3. However, some did not reach α, many stopping at 1.1812, or stopping at x_3 without any attempt at the root. Rounding errors (e.g. α = 1.1812) were not uncommon, and a further source of error in part (c) was to use the **square root** (rather than the cube root) in the iterative calculations.

Question 3

This question on modelling using logs and exponential functions was generally well answered in parts (a) and (b), but learners appeared to find differentiating correctly and making progress in part (c) more challenging.

In (a) learners generally correctly found the gradient of the given straight line and used it to find $\log_{10} V = 0.05t + 2$. A few learners obtained the answer by substituting the given points in and solving simultaneous equations in *m* and c. Some used incorrect variables in their answer which prevented scoring of the final mark.

Part (b) was also well attempted and most obtained $V = 100 \times 1.12^t$ either by removing logs from their answer to (a) or by writing $\log_{10} V = \log_{10} a + t \log_{10} b$ and obtaining separate equations for *a* and *b*. A few learners used incorrect exponential work writing $V = 10^2 + 10^{0.05t}$ (though were allowed some marks if they recovered to the correct equation) and again sometimes incorrect variables were used. Also, a number of learners gave their values of *a* and *b* without writing out the full equation of the model, which was required by the question, and this resulted in the the final mark in (b) not being given.

Part (c) saw weaker responses as a number of learners did not demonstrate that they knew the correct approach for differentiating $V = 100 \times 1.12^t$. Attempts like $\frac{\mathrm{d}V}{\mathrm{d}t} = 100t \times 1.12^{t-1}$ often appeared and some learners did not attempt differentiation simple setting *V* = 50. Some were able to achieve the correct form, but with the incorrect coefficient, so were able to access the method marks, but not the accuracy in this part. Those who did achieve a correct form often also knew the correct method to proceed and were able to set $\frac{\mathrm{d}V}{\mathrm{d}t} = A \times 1.12^t$ equal to 50 and generally used correct log work to solve to find *T*. If the derivative was fully correct this usually proceeded to a correct answer, though the question required that the final answer be given to the nearest integer and some learners gave answers such as 12.8 rather than the required answer of 13, which prevented attainment of the final mark.

Question 4

This question provided some discrimination with part (a) being well answered by the majority, but many learners did not work out how to find the minimum value from the expression in part (b). Only a few learners appeared completely unsure of how to approach this question .

Most learners scored full marks in part (a), finding $R = 2\sqrt{3}$ (oe) and the angle, α to be $\frac{\pi}{3}$. Some errors were made with the angle, yielding $\frac{\pi}{6}$, while very occasionally, α was given as 1.03 (or some other rational approximation). Another error was to omit to state f(x) in the form required, $\sqrt{12}\sin\left(2x - \frac{\pi}{3}\right)$, instead just stating the values found, though not fully answering the question. Working in degrees was also seen a few times, but most responses were in the correct units of radians.

Part (b) was much more challenging for many; for a **minimum** value of g(x), a **maximum** value for its denominator was needed, but errors occurred with many taking the minimum for f(3x) to use in the expression. As well as this, some omitted the R when applying the maximum of f(3x), giving 1 + 4√3 as the denominator, or immediately trying to evaluate on a calculator giving a decimal with no method shown. So even though simplification of the expression was not required, many did not access the B mark, and consequently many also did not gain the next two marks as they were not processing the maximum for f(3x) but the minimum.

Even among those who understood the maximum for f(3x) was required, responses in (b)(ii) was mixed, with many not applying the 3x transformation correctly to their answer, either omitting the 3 entirely, multiplying both terms be 3, or in some cases dividing terms by 3. Those who set up the correct equation would usually go on to solve correctly, though even in this minority some made errors in rearranging and did not score the A mark.

Question 5

This question on exponential modelling and differentiation showed strong responses, although errors sometimes occurred, mainly in the attempt at differentiation, or in the numerical work towards the end.

For (a) most learners successfully substituted $t = 0$ into the equation of the model to obtain $N = 200$, although some incorrectly used $19 + e^0 = 19$ in the numerator.

In (b) learners usually made an attempt at differentiation using the quotient rule. A few learners rewrote the model as $N = 4000e^{0.1t}\left(19 + e^{0.2t}\right)^{-1}$ before attempting the product rule. Either way many attempts were completely successful or just contained minor errors. A minority of learners made incorrect attempts at differentiating by, for example, just differentiating the numerator and denominator, and then made no further progress in the question. Occasional instances of numerator the wrong way round or neglecting to square the denominator were seen, but were not common.

Learners often progressed in part (c) by setting the numerator of their quotient rule attempt equal to zero and moved from expressions like $7600e^{0.1t} - 400e^{0.3t} = 0$ to $e^{0.2T} = 19$. There were some errors but generally work advanced correctly here.

In (d) learners again generally produced correct log work and solved $e^{0.2T} = 19$ to obtain a value of T that they substituted into the model to obtain N, though a significant number stopped at finding T and did not proceed to find N. A careful reading of the question is required to ensure the answer to the question posed is given. Sometimes, where further progress was attempted, learners incorrectly used $T = 19$ to find N.

Alternatively, learners used $e^{0.1t} = \sqrt{19}$ and substituted this directly into the equation of the model to find $N = \dfrac{4000\sqrt{19}}{19 + 19}$ without obtaining T first. Either way,

many successfully reached $N = 458$ or 459, although some lost the final mark for answers like $N = 458.8$, where they did not round their answer to an integer as required by the question. Some learners stopped when they found T, believing that this was the maximum number of squirrels.

Question 6

The integration was generally successfully completed in both parts of this question, but part (ii) did provide some challenge. Many did not heed k being an integer in otherwise correct solutions.

Most could differentiate correctly in part (i), certainly the majority knew the answer was of the form $\frac{\cdots}{2x^2+5}$, allowing for miscopies of the argument ($12x^2 + 5$ was relatively common) but some did not achieve the correct numerator. $2x$, 4 or just 1 were the most common incorrect numerators seen. There were a few who did not achieve a correct form at all, demonstrating an answer as a power of e, or another log expression.

For part (ii) many took the hint from part (i), or otherwise knew the correct form, and found the correct form of the integral, mostly successfully, though some did not get the constants correct. A small number tried to differentiate instead of integrating or did not form a log integral and so did not make further progress. Surprisingly many who integrated correctly did not reduce the fraction from $\frac{21}{6}$ to $\frac{7}{2}$ until much later, seeming to not detect the common factor of 3.

Following the finding of a suitable integral, the limits were substituted correctly in most cases, and most who reached this stage were able to combine log terms, equation to the 7 ln 8 and proceed to remove logs. Errors occurred in some weaker responses; some incorrect cancellation was seen or the power law was

not applied correctly to the ln 8 term, preventing the final three marks from being scored.

The route taken to simplify the inequality (or equality) formed was not always the most efficient in the cases suitable progress was made. Terms such as 8^7 or $\ln\left(\frac{3k^2+k}{3+k}\right)^{\frac{7}{2}}$ were quite often seen instead of first look to cancel 7s and cross-multiply the 2.

A fairly common algebraic error after reaching the fraction $\frac{3k^2+k}{3+k}$ was to incorrectly simplify it to k, mistakenly factorising the numerator or misreading the denominator. However, most were able to proceed to a correct quadratic, and were able to solve. Those who arrived at a correct inequality did not always remember that k was a whole number, so did not gain the final mark, typically giving 23.7 or the exact root $\frac{21+\sqrt{697}}{2}$ as the answer. It seems, few had read and absorbed the fact that k was an *integer* with $k > 1$, and so the inequality required a value of 23 for the value of k. Indeed, this proved to be a very good discriminating mark on the paper and shows the importance of a careful reading of the question.

Question 7

This question on differentiation and stationary values appeared to be challenging, with a lot of zero scores for the question, or many learners not progressing beyond the differentiation. The product rule with exponential term requiring a chain rule proved especially challenging. Many learners showed parts of the correct method of differentiation required but ended up scoring very few marks for not handling the exponential correctly. Most also knew that they needed to apply the discriminant in some way, but often did not have a suitable expression to use it on.

Many learners made a good attempt at the product rule and then advanced through the question. No such suitable attempt meant only the final M mark was possible and there were many incorrect attempts at the differentiation as well as the many good ones. Some learners attempted to rewrite the function, such as $y = 2x\mathrm{e}^{x^2}\mathrm{e}^{3kx}\mathrm{e}^{-2x}$ and then did not know how to proceed with three terms. Others did not use a product rule at all but took the product of the derivatives of the two terms, while again others had the correct method but did not achieve f(x) in the mark scheme as a quadratic function, instead yielding either a cubic or linear function.

Also, some correct attempts included bracketing errors like $\frac{\mathrm{d}y}{\mathrm{d}x} = 2\mathrm{e}^{x^2+(3k-2)x} + 2x\left(2x+3k-2\mathrm{e}^{x^2+(3k-2)x}\right)$, which were not always recovered, although they were allowed to access the first M and gain some credit. Some learners attempted to rewrite the function as $\ln\frac{y}{2x} = x^2+(3k-2)x$ to reach a form where implicit differentiation could be used, but very few made progress this way.

Those who had made a valid attempt at differentiation were generally able to set their derivative equal to zero to reach a suitable quadratic in x, and then apply the discriminant to obtain a quadratic in k. The dependent method mark prevented some who had attempted a derivative equal to zero (but from an incorrect initial attempt at the derivative) from scoring one extra mark here.

Learners who navigated to finding an equation in k solved this quadratic using a variety of methods – often by calculator after expanding even despite the quadratic initially being in a completed square form. Of those who had a correct quadratic, the majority obtained the critical values $\frac{2\pm2\sqrt{2}}{3}$. However, many then chose the inside region for their critical values and thus did not gain the final two marks. A few were able to pick up the final M from earlier incorrect work (with no

prior marks scored), though, for showing the correct interpretation of their quadratic inequality as long as they had reached one.

The correct answer of $k < \frac{2-2\sqrt{2}}{3}$ or $k > \frac{2+2\sqrt{2}}{3}$ was reached by some learners, but it was probably the most rare final mark that was earned of any question on the paper. Some did not gain the final mark because they did not use exact values. Learners should be reminded to not over-rely on a calculator.

Question 8

This question showed mixed responses, with answers in part (a) gaining both marks as the given answer made it very difficult to distinguish a genuine from false answer, and in part (d) the over reliance on a calculator to solve the cubic despite the warning against calculator usage was prevalent. These parts did create some challenges for marking as well as for learners. Between, in parts (b) and (c), the work was generally very good.

Part (a) would have worked better without a fully given answer, with perhaps part (b) instead asking to show that $b = -8$ and to find a, or similar structure to give the aid for later parts. As it is, the given answer in part (a) was given by nearly all learners (some did not attempt it), but the working leading to it was not always clear.

Whilst acceptable solutions for part (a) were seen, many learners did not clearly indicate that the *left-hand* branch of the modulus function, viz. $y = a - 5x - b$, was required. Once this is established, substitution of $(-2, 25)$ yields the result to be shown, i.e. $a = 15 + b$, and this is what was intended for the question. However, though some did make this clear, it was much more common for learners to either substitute the coordinates into both branches, and then choose the one giving the required result, or to only ever write out clearly the equation with modulus in. Learners often then had a series of lines with crossed-out work and sign

corrections in their equation leading to the given answer, demonstrating backwards working after having initially chosen the incorrect starting equation.

In the former of these, the M mark was awarded on the basis that the learner knew what a modulus function does through considering the negative branch, but a clear choice of the correct solution was needed for both marks. This was often done through crossing out the work leading to the other equation, sometimes just by underlining or circling the correct one. This did not show a sufficient appreciation of the underlying mathematics, but both marks were awarded unless there was a clearly incorrect statement.

In the second case, where various corrections were made leading to the given solution, responses were unclear. It needed checking that at least one correct unsimplified line without modulus was seen before the answer to award the M and that everything was correct to award both. Again, this meant that despite many responses showing limited understanding of which branch was needed, some responses still ended up getting both marks. Though, some responses had no suitable equation prior to stating the given answer and so scored neither. Overall, it was challenging to distinguish between learners who knew exactly what to do and those who took a less direct approach to the answer.

Furthermore, there were many who felt the need to use the cubic to calculate the y value at $x = -2$, rather than simply use that it was given, again demonstrating limited understanding of the context of the question. However, marks were still able to be scored as the calculation was correct.

Part (b) was more straightforward to follow as most were able to substitute (2 , 9) into the positive branch, $y = a + 5x + b$, and proceed to solve with the given answer to part (a) and find the values of a and b. These were correct in the majority of cases, though a few did make errors when solving to get either one or both incorrect. There were a few cases of attempting both branches here as well, though less commonly than in part (a), and usually the correct solutions were then

selected, meaning full marks were scored. It is likely that in some cases the selection of correct roots was chosen due to use of a graphical calculator, which was not actually prohibited for this part.

Having found values for a and b in part (b), the vast majority proceeded to score at least one mark in part (c) for finding the coordinates of the vertex, and if a and b were correct, usually both marks were scored. Again, it was likely some learners used a calculator to help with these, but the answers generally followed the results of part (b). A few did omit this part, and some made sign errors (neglecting to realise from the sketch that we can see what quadrant the vertex is in), but these were rarities.

Finally, in part (d) most learners made a good start, forming the cubic equation. Although, some chose the incorrect branch of the modulus graph and so were not able to gain the dependent marks. Some did not make any attempt, but most did and mostly were successful in achieving some marks. With an incorrect initial equation set up, only the final M mark was subsequently available, though many did achieve this mark who had started from the incorrect branch initially.

The biggest challenge for learners in this part, that prevented attainment of 3 marks, was not acknowledging the warning in the question that calculators were not to be relied on. This warning indicates there are clues in the question as to how to solve the equation that the learner is expected to understand. Yet many, after setting up the cubic, simply stated the roots from a calculator solution, or immediately wrote down a fully factorised form without an intermediate quadratic factor. Even among some who did show factorisation, some factored out $(3x + 2)$ directly, presumably having used their calculators first to finding the root they needed, as this was not immediately apparent like the $(x + 2)$ factor is. Although use of calculators to solve quadratics it acceptable in most places on papers, learners should be reminded to adhere to instructions where they are told a calculator solution is not acceptable or else they will not gain full marks. Some did justify the work by using the factor theorem to determine the root first, but

even then, it is possible they were first using the root due to having used a graphical calculator.

Responses that recognised ($x + 2$) was a factor and proceeded to factor out to find a quadratic factor were awarded marks, but some learners proceeded to use their calculator to solve the quadratic anyway, losing just one mark in such instances. The algebra in factorisation and/or division was generally very good, with only a few making errors who attempted it.

The mark scheme allowed the final two marks to those who had solved the cubic by calculator, if they proceeded to find the y coordinate and so obtain the correct solutions. There were a few who omitted to do this final step, giving just the x coordinate for Q, but most learners did realise both coordinates were needed, even if they had found the x coordinate by calculator. Those who started from the wrong branch at the start were able to access the method mark for remembering to find both if they did so.

Question 9

Learners found this trigonometry question to be demanding throughout, yet with some accessible marks available in part (c) for those who attempted this question.

In (a) many learners gained the first mark for using $4\sin\theta\cos\theta = 2\sin 2\theta$ but this was often the only mark scored in this part. Those who did make progress usually employed $\sin^2\theta = \frac{1}{2}(1-\cos 2\theta)$ and $\cot 2\theta = \frac{\cos 2\theta}{\sin 2\theta}$ to rewrite the expression in the required form. Many, however, after using identities that introduced $\sin\theta, \cos\theta$ or $\tan\theta$ did not reach an expression in just $\sin 2\theta$ and $\cos 2\theta$ even when they did, errors were common. A common approach was to use $\sin^2\theta = 1-\cos^2\theta$ and this rarely led to a correct answer. Some learners attempted other

approaches often writing $\cot 2\theta = \frac{1}{\tan 2\theta}$ and using a double angle formula for $\tan 2\theta$ but these also rarely made any progress. Another common mistake was to multiply the expression through by $\sin 2\theta$ too early, although the marks may have been gained under isw by this stage. A few lost the multiple 6 in an otherwise correct expression.

For (b) most learners realised that they needed to use their answer from (a) and substituted this in on the right-hand side of the given equation. Incorrect work in (a) then often meant that they could not advance any further. Those who had the correct answer to (a) often managed to multiply through by $\sin 2\theta$ and then subtract $3\cos 2\theta$ from both sides before using $\cos^2 2\theta = 1 - \sin^2 2\theta$ to reach the required result. Some learners omitted the '= 0' from their final answer which prevented the final mark from being scored. Some did not use their answer to (a) but repeated the work again, with varying degrees of success.

Part (c) was attempted by most, regardless of attempts at (a) and (b). Most learners used the result from (b) and found a suitable way of finding a solution to the quadratic, and then used $\sin^{-1}\frac{1}{5}$ and divided by 2 to obtain a value for *x*. Rounding errors were then common, and many learners did not obtain the second required answers of 84.2. Common incorrect answers were 84.25 and 84.3. Some learners also worked in radians but final answers in degrees were required. A number of learners also did not use a correct method to find their second solution and incorrect attempts like $x = \frac{180 - 5.8}{2}$ and $x = \frac{180 + 11.54}{2}$ were fairly common.