VCE® Mathematical Methods

Unit 3 and 4 Practice Written Examination 1

SOLUTIONS

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Solution Pathway

Question 1 (3 marks)

$Let\ f: R \to R, f(x) = 2x^2 e^{-x}$

a. Find $f'(x)$. Express $f'(x)$ in a form that contains no negative signs in the exponent(s).

2 marks

Product rule.

Let $y = f(x)$

Let $u = 2x^2, \quad v = e^{-x}$

$\therefore \frac{du}{dx} = 4x, \quad \frac{dv}{dx} = -e^{-x}$

$\frac{dy}{dx} = u\frac{dv}{dx} + v\frac{du}{dx}$

$= 2x^2 \times -e^{-x} + e^{-x} \times 4x$

$= \frac{4x}{e^x} - \frac{2x^2}{e^x}$

$= \frac{4x - 2x^2}{e^x}$

1 mark for correct substitution into an appropriate rule.
1 mark for correct derivative.

b. Hence, determine $f'(1)$. **1 mark**

$f'(1) = \frac{4-2}{e^1}$

$= \frac{2}{e}$

1 mark for correct value of $f'(1)$.

Question 2 (3 marks)

Solve the equation:

$3 \sin sin\,(x)\ + 2(cos(x))^2 = 3,\ \ x \in [0, 2\pi]$

$3 \sin sin\,(x)\ + 2(1 - (sin(x))^2) = 3$

$3 \sin sin\,(x)\ + 2 - 2(\sin sin\,(x)\,)^2 = 3$

$2(\sin sin\,(x)\,)^2 - 3 \sin sin\,(x)\ + 1 = 0$

Let $a = \sin(x)$

$\therefore 2a^2 - 3a + 1 = 0$

$(2a - 1)(a - 1) = 0$

$a = \frac{1}{2},\ a = 1$

$\sin sin\,(x)\ = \frac{1}{2}, \quad \sin sin\,(x)\ = 1$

$x = \frac{\pi}{6},\ x = \frac{\pi}{2}$

Consider domain of $[0,\ 2\pi]$

$\sin(x) > 0$ in second quadrant.

$\therefore x = \frac{5\pi}{6}$

The solutions are therefore $x = \frac{\pi}{6}, x = \frac{\pi}{2}, x = \frac{5\pi}{6}$

1 mark for a valid approach to solving equation (e.g., quadratic substitution).
2 marks for correct solutions (solution to $\sin(x) = 1$ and solutions to $\sin(x) = ½$).

Question 3 (2 marks)

$f(x) = 4\cos cos\,(x) - 1$

Consider dilation from y-axis. This is parallel to x-axis.

$Dilation\ Factor\ (DF) = \frac{1}{n}$

$\therefore n = \frac{1}{DF}$

$= \frac{1}{2}$

$f(x) = 4\cos cos\left(\frac{x}{2}\right) - 1$

Consider translation of π units in the positive direction of the x-axis

$f(x) = 4\cos cos\left(\frac{1}{2}(x - \pi)\right) - 1$

Consider reflection about the x-axis.

$f(x) =- \left(4\cos cos\left(\frac{1}{2}(x - \pi)\right) - 1\right)$

$=- 4\cos cos\left(\frac{1}{2}(x - \pi)\right) + 1$

1 mark for correct value of n in the final equation.
1 mark for correct equation resulting from transformations.

Question 4 (6 marks)

Consider $f(x) = \frac{ax-bx^2}{\sqrt{x}}$, $a, b \in R\backslash\{0\}$

a. Show that the x-intercept of $f(x)$ is located at $x = \frac{a}{b}$ **1 mark**

Solve $f(x) = 0$ for x.

$\frac{ax-bx^2}{\sqrt{x}} = 0$

$ax - bx^2 = 0$

$x(a - bx) = 0$

$\therefore x = 0,\ a - bx = 0$

$x = 0,\ x = \frac{a}{b}$

However, x cannot equal 0, since at $x = 0$ $f(x)$ would be undefined.

$\therefore x - intercept\ at\ x = \frac{a}{b}$

1 mark for a valid approach to show x-intercept at $x = \frac{a}{b}$.

b. Determine the x-coordinate of the turning point of $f(x)$ in terms of a and b. **2 marks**

$f(x) = \frac{ax-bx^2}{\sqrt{x}}$

$= ax^{\frac{1}{2}} - bx^{\frac{3}{2}}$

$f'(x) = \frac{1}{2}ax^{-\frac{1}{2}} - \frac{3}{2}bx^{\frac{1}{2}}$

Solve $f'(x) = 0$ for x.

$\frac{1}{2}ax^{-\frac{1}{2}} - \frac{3}{2}bx^{\frac{1}{2}} = 0$

$\frac{\frac{1}{2}ax^{-\frac{1}{2}} - \frac{3}{2}bx^{\frac{1}{2}}}{\frac{1}{2}x^{-\frac{1}{2}}} = \frac{0}{\frac{1}{2}x^{-\frac{1}{2}}}$

$a - 3bx = 0$

$x = \frac{a}{3b}$

1 mark for correct expression for $f'(x)$.
1 mark for correct solution to $f'(x) = 0$ and hence correct x-coordinate.

c. **Let $a = 3$ and $b = 1$. Determine the value of x such that the gradient of $f(x)$ at this value is equal to the gradient of that line that passes through the turning point of $f(x)$ and the x-intercept located at $x = \frac{a}{b}$.** **3 marks**

Determine gradient of line passing through x-intercept and turning point.

$m = \frac{y_2 - y_1}{x_2 - x_1}$

$= \frac{f\left(\frac{a}{3b}\right) - 0}{\frac{a}{3b} - \frac{a}{b}}$

$= \frac{f\left(\frac{a}{3b}\right)}{\frac{-2a}{3b}}$

$= \frac{f\left(\frac{a}{3b}\right)}{\frac{-2a}{3b}}$

$= -\frac{3f\left(\frac{a}{3b}\right)b}{2a}$

$= -\frac{3\left(\frac{a\left(\frac{a}{3b}\right) - b\left(\frac{a}{3b}\right)^2}{\sqrt{\frac{a}{3b}}}\right)b}{2a}$

At $a = 3$ and $b = 1$

$m = -\frac{3(3-1)}{2}$

$= -1$

Determine where $m = -1$ on $f(x)$
Solve $f'(x) = -1$ for x

$\frac{a}{2\sqrt{x}} - \frac{3b}{2}\sqrt{x} = -1$

Given $a = 3$, $b = 1$

$\frac{3}{2\sqrt{x}} - \frac{3}{2}\sqrt{x} = -1$

$3 - 3x = -2\sqrt{x}$

$3x - 2\sqrt{x} - 3 = 0$

Let $a = \sqrt{x}$

$3a^2 - 2a - 3 = 0$

$a = \frac{2\pm\sqrt{4-(4\times3\times-3)}}{2\times3}$

$= \frac{2\pm\sqrt{40}}{6}$

$= \frac{2\pm\sqrt{10}}{6}$

$= \frac{1\pm\sqrt{10}}{3}$

$\therefore \sqrt{x} = \frac{1\pm\sqrt{10}}{3}$

$\therefore x = \left(\frac{1+\sqrt{10}}{3}\right)^2 or\ x = \left(\frac{1-\sqrt{10}}{3}\right)^2$

$x = \frac{11+2\sqrt{10}}{9} \quad or\ x = \frac{11-2\sqrt{10}}{9}$

But the *x*-value must be between that of the turning point and the x-intercept of $f(x)$, which in this situation is between $x = 1$ and $x = 3$.

Since $\sqrt{10}\sim 3$

$x\sim\frac{11+6}{9} \quad or\ \ x\sim\frac{11-6}{9}$

$x\sim\frac{17}{9}\ or\ x\sim\frac{5}{9}$

$x = \frac{11+2\sqrt{10}}{9}$

1 mark for determination of gradient of line that passes through turning point and x-intercept.
1 mark for a valid approach for solving $f'(x)$=-1 for x.
1 mark for correct value of x.

Question 5 (3 marks)

A function has the equation $g(x) = e^{2x} - e^{x},\ x \in R$. A graph of $g(x)$ is shown below.

a. **Let $h(x) = g(x),\quad x \in [a, \infty)$. What is the minimum value of a for which $h^{-1}(x)$ the inverse of $h(x)$ is defined?** **1 mark**

For $h^{-1}(x)$ to be defined $h(x)$ must pass the horizontal line test. The minimum value of a for which $h(x)$ is defined will therefore be the *x*-coordinate of the turning point.

Solve $g'(x) = 0\ for\ x$

$x =- (2)$

$\therefore a =- (2)$

1 mark for correct value of a.

b. **Hence determine the equation of $h^{-1}(x)$** **2 marks**

$y = e^{2x} - e^{x}$

Let $x = y$ and $y = x$

$x = e^{2y} - e^{y}$

Rearrange to make y the subject.

$x = \left(e^{y}\right)^{2} - e^{y}$

Complete the square.

$x = \left(e^{y} - \frac{1}{2}\right)^{2} - \frac{1}{4}$

$\left(e^{y} - \frac{1}{2}\right)^{2} = x + \frac{1}{4}$

$e^{y} - \frac{1}{2} = \pm\sqrt{x + \frac{1}{4}}$

There are two solutions here. The point (0, 0) must be on $h^{-1}(x)$.

$\therefore e^{y} = \frac{1}{2} + \sqrt{x + \frac{1}{4}}$

$y = \left(\frac{1}{2} + \sqrt{x + \frac{1}{4}}\right)$

$\therefore h^{-1}(x) = \left(\frac{1}{2} + \sqrt{x + \frac{1}{4}}\right)$

1 mark for a valid approach for determining the inverse.
1 mark for the correct inverse.

Question 6 (8 marks)

a. The probability that Ralph arrives at class on time is 0.25. The teacher said that if he was not on time for at least two out of the next three mornings, he would have to make up the time at lunch.

(i) If Ralph decided to keep with his normal routine, what is the probability that he will be making up time at lunch? 1 mark

Let X be a random variable corresponding the number of times Ralph arrives on time. To meet the condition required to make up time at lunch he would need to be on time 0 or 1 times in the next three mornings.

$\Pr Pr\ (X \leq 1)\ = \Pr Pr\ (X\ =\ 1)\ +\ Pr(X\ =\ 0)$

$\Pr Pr\ (X \leq 1)\ = 3\left(\frac{3}{4} \times \frac{3}{4} \times \frac{1}{4}\right) + \left(\frac{3}{4} \times \frac{3}{4} \times \frac{3}{4}\right)$

$= \frac{27}{64} + \frac{27}{64}$

$= \frac{27}{32}$

1 mark for the correct probability.

(ii) If Ralph was on time for at least one of the mornings, what is the probability that he will be making up time at lunch? 1 mark

If Ralph was on time for at least one morning then, $X \geq 1$.

$$\Pr Pr\ (X \geq 1) = \frac{Pr(X \leq 1 \cap X \geq 1)}{Pr(X \geq 1)}$$

$$= \frac{Pr(X=1)}{Pr(X \geq 1)}$$

$$= \frac{\frac{27}{64}}{1 - \left(\frac{3}{4} \times \frac{3}{4} \times \frac{3}{4}\right)}$$

$$= \frac{\frac{27}{64}}{\frac{37}{64}}$$

$$= \frac{27}{37}$$

The probability that he will be making up time is 27/37.

1 mark for the correct probability.

b. Ralph completes logic puzzles. The time required, in minutes, for him to complete a puzzle can be modelled by the random variable, X, with probability density function given by:

$$f(x) = \{\frac{1}{h\sqrt{x}} - k, \quad 1 \leq x \leq a\ 0, \qquad elsewhere$$

The probability that Ralph takes between 4 and 9 minutes is $\frac{3}{8}$ while the probability that it takes between 1 and 4 minutes is $\frac{5}{8}$

(i) What is the shortest possible time that Ralph can complete a puzzle? 1 mark

The shortest possible time is 1 minute.

1 mark for the correct value for the shortest possible time.

(ii) Determine the values of the parameters h and k. **3 marks**

$\int_4^9 \left(\frac{1}{h\sqrt{x}} - k\right)dx = \frac{3}{8}$

$\left[\frac{2}{h}\sqrt{x} - kx\right]_4^9 = \frac{3}{8}$

$\left(\frac{6}{h} - 9k\right) - \left(\frac{4}{h} - 4k\right) = \frac{3}{8}$

$\frac{2}{h} - 5k = \frac{3}{8}$ 1.

$\int_1^4 \left(\frac{1}{h\sqrt{x}} - k\right)dx = \frac{5}{8}$

$\left[\frac{2}{h}\sqrt{x} - kx\right]_1^4 = \frac{5}{8}$

$\left(\frac{4}{h} - 4k\right) - \left(\frac{2}{h} - k\right) = \frac{5}{8}$

$\frac{2}{h} - 3k = \frac{5}{8}$ 2.

2. – 1. To eliminate h.

$2k = \frac{1}{4}$

$k = \frac{1}{8}$

$\frac{2}{h} - 3k = \frac{5}{8}$

$\frac{2}{h} - \frac{3}{8} = \frac{5}{8}$

$\frac{2}{h} = 1$

$h = 2$

The parameters are $h = 2$ and $k = 1/8$.

1 mark for correct substitution of given information to form 2 equations.
1 mark for correct value of h.
1 mark for correct value of k.

(ii) Hence determine the value of a in $f(x)$ **2 marks**

$\int_1^a \frac{1}{2\sqrt{x}} - \frac{1}{8}dx = 1$

$\left[\sqrt{x} - \frac{1}{8}x\right]_1^a = 1$

$\left(\sqrt{a} - \frac{a}{8}\right) - \left(1 - \frac{1}{8}\right) = 1$

$\sqrt{a} - \frac{a}{8} = \frac{15}{8}$

$8\sqrt{a} - a = 15$

$8\sqrt{a} = 15 + a$

$64a = 225 + 30a + a^2$

$a^2 - 34a + 225 = 0$

$(a - 25)(a - 9) = 0$

$a = 25 \ or \ a = 9$

$a = 9 \ since \ if \ a = 25 \ there \ would \ be \ value \ of \ f(x) < 0$

1 mark for a valid definite integral.
1 mark for correct value of a.

Question 7 (5 marks)

Gertrude, a Year 12 student, wanted to improve the menu of the school's canteen. She planned to survey the students about their preference for hot snacks. A presurvey indicated that 14 out of the 20 students surveyed prefer the hot snacks currently offered.

Z is a standard normal random variable such that:

$$\Pr Pr\ (Z \le 1.2816)\ =\ 0.90\ and\ \Pr Pr\ (Z \le 1.6449)\ =\ 0.95$$

a. What is the value of $\hat{p}$? Express your answer as simplified fraction. 1 mark

$\hat{p} = \frac{14}{20} = \frac{7}{10}$

1 mark for correct value of $\hat{p}$ expressed as a simplified fraction.

b. Gertrude decided to sample 100 students from across the school for her survey. Using the information provided, write an expression for the 90% confidence interval.2 marks

$$90\%\ Confidence\ Interval\ = \left(\hat{p} - Z\sqrt{\frac{\hat{p}(1-\hat{p})}{n}}, \hat{p} + Z\sqrt{\frac{\hat{p}(1-\hat{p})}{n}}\right)$$

For a 90% Confidence interval, $Z = 1.6499$.

$$\therefore 90\%\ Confidence\ Interval\ = \left(\frac{7}{10} - 1.6499\sqrt{\frac{\frac{7}{10}\left(1-\frac{7}{10}\right)}{100}}, \frac{7}{10} + 1.6499\sqrt{\frac{\frac{7}{10}\left(1-\frac{7}{10}\right)}{100}}\right)$$

$$= \left(\frac{7}{10} - 1.6499\sqrt{\frac{21}{10000}}, \frac{7}{10} + 1.6499\sqrt{\frac{21}{10000}}\right)$$

$$= \left(\frac{7}{10} - 1.6499\frac{\sqrt{21}}{100}, \frac{7}{10} + 1.6499\frac{\sqrt{21}}{100}\right)$$

1 mark for correct value of Z.
1 mark for a valid confidence interval.

c. If instead a sample of 200 students was used in Part b, by what scale factor would the width of the confidence interval change? Would its width increase or decrease? 2 marks

If $n = 200$,

$$\therefore 90\%\ Confidence\ Interval = \left(\frac{7}{10} - 1.6499\sqrt{\frac{21}{20000}}, \frac{7}{10} + 1.6499\sqrt{\frac{21}{20000}}\right)$$

$$= \left(\frac{7}{10} - 1.6499\frac{\sqrt{21}}{100\sqrt{2}}, \frac{7}{10} + 1.6499\frac{\sqrt{21}}{100\sqrt{2}}\right)$$

The width, $w_{n=100}$, of the confidence interval when $n = 100$ is,

$$w_{n=100} = 2\times1.6499\frac{\sqrt{21}}{100}$$

$$= 1.6499\frac{\sqrt{21}}{50}$$

The width, $w_{n=200}$, of the confidence interval when $n = 200$ is,

$$w_{n=200} = 2\times1.6499\frac{\sqrt{21}}{100\sqrt{2}}$$

$$= 1.6499\frac{\sqrt{21}}{50\sqrt{2}}$$

There, the ratio of $w_{n=200}$ to $w_{n=100}$ is:

$$\frac{1.6499\frac{\sqrt{21}}{50\sqrt{2}}}{1.6499\frac{\sqrt{21}}{50}}$$

$$= \frac{1}{\sqrt{2}}$$

Thus, if the value of n was increased from 100 to 200, the width of the confidence interval would decrease. The scale factor is $\frac{1}{\sqrt{2}}$.

1 mark for correct scale factor.
1 mark for explicit statement about whether the width of the confidence interval would increase or decrease.

Question 8 (4 marks)

The average daily maximum temperature, T, throughout the year for a particular town can be modelled by the equation:

$$T(t) = a cos(bt) + c, \quad a, b, c \in R$$

Where t is time in months and $t = 0$ corresponds to 1st January and $t = 1$ corresponds to the first of February and so on.

a. Determine the value of b in the model. **1 mark**

Since t is in months and there are 12 months in a year, the period is 12.

$P = \frac{2\pi}{n}$

$\therefore n = \frac{2\pi}{P}$

$= \frac{2\pi}{12}$

$= \frac{\pi}{6}$

$\therefore b = \frac{\pi}{6}$

1 mark for correct value of **b**.

b. Given that on the 1st of March, the average daily maximum temperature is 26°C, while on the 1st of September the average daily maximum temperature is 14°C, determine the values of the other parameters in the model. **2 marks**

Consider 1st of March information, $n = 2$:

$26 = a \cos cos\left(\frac{\pi}{6}\times 2\right) + c$

$26 = a \cos cos\left(\frac{\pi}{3}\right) + c$

$26 = \frac{a}{2} + c \qquad 1.$

Consider 1st of September information, $n = 8$:

$$14 = a\cos cos\left(\frac{\pi}{6}\times 8\right) + c$$

$$14 = a\cos cos\left(\frac{4\pi}{3}\right) + c$$

$$14 = -\frac{a}{2} + c \qquad 2.$$

Add 1. And 2. To eliminate a.

$$40 = 2c$$

$$c = 20$$

$$\therefore 14 = -\frac{a}{2} + 20$$

$$-6 = -\frac{a}{2}$$

$$a = 12$$

The other model parameters are $a = 12,\ c = 20$.

1 mark for correct value of a.
1 mark for correct value of c.

c. Hence, what is the average daily maximum temperature on the 1st of May? 1 mark

$$T(t) = 12\cos cos\left(\frac{\pi t}{6}\right) + 20$$

On 1st May, $t = 4$.

$$T(4) = 12\cos cos\left(\frac{2\pi}{3}\right) + 20$$

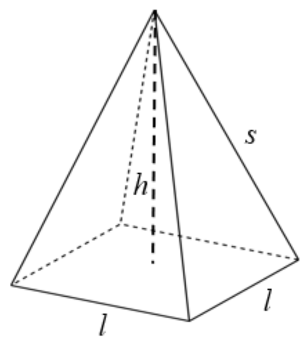
$$= (20 - 6)^{o}C$$

$$= 14^{o}C$$

1 mark for the correct temperature.

Question 9 (6 marks)

The frame (base and sloped edges) for a square-based pyramid is to be constructed from 4 m of wire. A diagram of the pyramid is shown below.



As can be seen in the diagram, the base of the pyramid has dimensions of $l \times l$, and the sloping edges have length s. The height of the apex of the pyramid above the centre of the base is h.

a. Express s in terms of l. **1 mark**

Frame Perimeter, FP, = 4 m

$FP = 4l + 4s$

$4 = 4l + 4s$

$s = 1 - l$

1 mark for a valid equation relating s to l.

b. The volume of a pyramid is equal to one third of the area of the base multiplied by the height. The volume contained within the wire-framed pyramid is to be maximised. Show that the volume, V, can be determined using the formula: **2 marks**

$$V = \frac{1}{3}\sqrt{\frac{1}{2}l^6 - 2l^5 + l^4}$$

$V = \frac{1}{3}bh$

Need h in terms of l. Use Pythagoras' theorem.

$h^2 = s^2 - \left(\frac{l}{\sqrt{2}}\right)^2$

Where $\frac{l}{\sqrt{2}}$ is the distance from a base corner to the centre of the base, determined using Pythagoras' theorem.

$$h = \sqrt{(1 - l)^2 - \frac{1}{2}l^2}$$

$$= \sqrt{\frac{1}{2}l^2 - 2l + 1}$$

$$V = \frac{1}{3}bh$$

$$V = \frac{1}{3}l^2\sqrt{\frac{1}{2}l^2 - 2l + 1}$$

$$= \frac{1}{3}\sqrt{\frac{1}{2}l^6 - 2l^5 + l^4}$$

1 mark for a valid expression for h in terms of l.
1 mark for substitution of formula terms and simplification.

c. Determine the dimensions of the frame (values of l and s) that will result in the maximum volume. **3 marks**

$$V = \frac{1}{3}\sqrt{\frac{1}{2}l^6 - 2l^5 + l^4}$$

$Let\ u = \frac{1}{2}l^6 - 2l^5 + l^4$ $\qquad$ $V = \frac{1}{3}\sqrt{u}$

$\frac{du}{dl} = 3l^5 - 10l^4 + 4l^3$ $\qquad$ $\frac{dV}{du} = \frac{1}{6\sqrt{u}}$

$$\frac{dV}{dl} = \frac{dV}{du} \times \frac{du}{dl}$$

$$= \frac{1}{6\sqrt{u}} \times \left(3l^5 - 10l^4 + 4l^3\right)$$

$$= \frac{3l^5 - 10l^4 + 4l^3}{6\sqrt{\frac{1}{2}l^6 - 2l^5 + l^4}}$$

$Solve\ \frac{dV}{dl} = 0$

$\frac{3l^5-10l^4+4l^3}{6\sqrt{\frac{1}{2}l^6-2l^5+l^4}} = 0$

$3l^5 - 10l^4 + 4l^3 = 0$

$3l^2 - 10l + 4 = 0$

$l = \frac{-b\pm\sqrt{b^2-4ac}}{2a}$

$= \frac{10\pm\sqrt{100-(4\times3\times4)}}{6}$

$= \frac{10\pm\sqrt{52}}{6}$

$= \frac{10\pm2\sqrt{13}}{6}$

$= \frac{5\pm\sqrt{13}}{3}$

But if $s = 1 - l$ and $s > 0$, then $l < 1$.

$\therefore l = \frac{5-\sqrt{13}}{3}$

$s = 1 - l$

$\therefore s = 1 - \frac{5-\sqrt{13}}{3}$

$= \frac{\sqrt{13}-2}{3}$

The dimensions that provide the largest volume are:

$l = \frac{5-\sqrt{13}}{3}m\ and\ s = \frac{\sqrt{13}-2}{3}\ m$

1 mark for a valid derivative
1 mark for solving derivative = 0 with respect to l.
1 mark for correct value of s.