MODEL ANSWERS

Write your name here

Surname	Other names

Pearson Edexcel Level 3 GCE

Centre Number | Candidate Number

Further Mathematics

Advanced Subsidiary
Paper 1: Core Pure Mathematics

Monday 14 May 2018 – Afternoon
Time: 1 hour 40 minutes

Paper Reference
8FM0/01

You must have:
Mathematical Formulae and Statistical Tables, calculator

Total Marks

Candidates may use any calculator allowed by the regulations of the Joint Council for Qualifications. Calculators must not have the facility for symbolic algebra manipulation, differentiation and integration, or have retrievable mathematical formulae stored in them.

Instructions

- Use **black** ink or ball-point pen.
- If pencil is used for diagrams/sketches/graphs it must be dark (HB or B).
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions and ensure that your answers to parts of questions are clearly labelled.
- Answer the questions in the spaces provided – *there may be more space than you need.*
- You should show sufficient working to make your methods clear. Answers without working may not gain full credit.
- Answers should be given to three significant figures unless otherwise stated.

Information

- A booklet 'Mathematical Formulae and Statistical Tables' is provided.
- There are 9 questions in this question paper. The total mark for this paper is 80.
- The marks for **each** question are shown in brackets – *use this as a guide as to how much time to spend on each question.*

Advice

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.

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Pearson

Answer ALL questions. Write your answers in the spaces provided.

1.

$$\mathbf{M} = \begin{pmatrix} 2 & 1 & -3 \\ 4 & -2 & 1 \\ 3 & 5 & -2 \end{pmatrix}$$

(a) Find $\mathbf{M}^{-1}$ giving each element in exact form.

(2)

(b) Solve the simultaneous equations

$$2x + y - 3z = -4$$
$$4x - 2y + z = 9$$
$$3x + 5y - 2z = 5$$

(2)

(c) Interpret the answer to part (b) geometrically.

(1)

a) By Calculator:

$$M^{-1} = \frac{1}{69}\begin{pmatrix} 1 & 13 & 5 \\ -11 & -5 & 14 \\ -26 & 7 & 8 \end{pmatrix}$$

b) $$\begin{pmatrix} 2 & 1 & -3 \\ 4 & -2 & 1 \\ 3 & 5 & -2 \end{pmatrix}\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} -4 \\ 9 \\ 5 \end{pmatrix}$$

$$\therefore \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 2 & 1 & -3 \\ 4 & -2 & 1 \\ 3 & 5 & -2 \end{pmatrix}^{-1}\begin{pmatrix} -4 \\ 9 \\ 5 \end{pmatrix}$$

$$= \begin{pmatrix} 2 \\ 1 \\ 3 \end{pmatrix}$$

c) The coordinates of the point where all three planes meet.

2. The cubic equation

$$z^3 - 3z^2 + z + 5 = 0$$

has roots α, β and γ.

Without solving the equation, find the cubic equation whose roots are $(2\alpha + 1)$, $(2\beta + 1)$ and $(2\gamma + 1)$, giving your answer in the form $w^3 + pw^2 + qw + r = 0$, where p, q and r are integers to be found.

(5)

$$z^3 - 3z^2 + z + 5 = 0$$

let $w = 2z + 1$

$$\frac{w-1}{2} = z$$

substituting:

$$\Rightarrow \left(\frac{w-1}{2}\right)^3 - 3\left(\frac{w-1}{2}\right)^2 + \left(\frac{w-1}{2}\right) + 5 = 0$$

$$\Rightarrow \frac{1}{8}(w^3 - 3w^2 + 3w - 1) - \frac{3}{4}(w^2 - 2w + 1) + \frac{1}{2}(w - 1) + 5 = 0$$

$\times 8$

$$\Rightarrow w^3 - 3w^2 + 3w - 1 - 6(w^2 - 2w + 1) + 4(w - 1) + 40 = 0$$

$$\Rightarrow w^3 - 9w^2 + 3w + 12w + 4w - 1 - 6 - 4 + 40 = 0$$

$$\Rightarrow \boxed{w^3 - 9w^2 + 19w + 29 = 0}$$

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3. (a) Shade on an Argand diagram the set of points

$$\{z \in \mathbb{C} : |z - 1 - \mathrm{i}| \leqslant 3\} \cap \left\{z \in \mathbb{C} : \frac{\pi}{4} \leqslant \arg(z - 2) \leqslant \frac{3\pi}{4}\right\}$$

(5)

The complex number w satisfies

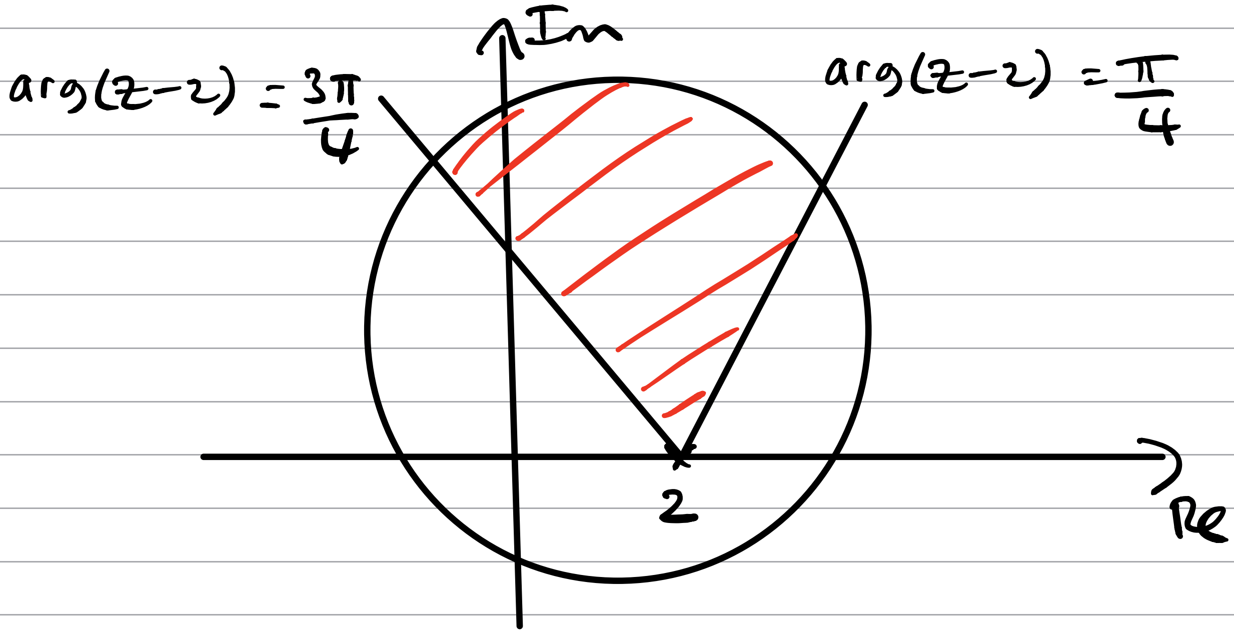
$$|w - 1 - \mathrm{i}| = 3 \text{ and } \arg(w - 2) = \frac{\pi}{4}$$

(b) Find, in simplest form, the exact value of $|w|^2$

(4)

• $|z-1-i| \leq 3$ is a circle with centre $(1,1)$ & radius 3.

• $\arg(z-2) = \alpha$ is a half-line starting at the point $(2+0i)$, making an angle α with the real axis.



b) finding cartesian eqn of $\arg(w-2) = \frac{\pi}{4}$:

passes through: $(2,0)$, gradient $= \tan\frac{\pi}{4} = 1$.

$\therefore y = x - 2$ //

Cartesian eqn of circle: $(x-1)^2 + (y-1)^2 = 9$ //

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Question 3 continued

subbing $y = x - 2$ into circle :

$\Rightarrow (x-1)^2 + (x-3)^2 = 9$

$\Rightarrow x^2 - 2x + 1 + x^2 - 6x + 9 = 9$

$\Rightarrow 2x^2 - 8x + 1 = 0$

$\Rightarrow x = \dfrac{4 \pm \sqrt{14}}{2}$

we want the bigger value, so

$x = \dfrac{4 + \sqrt{14}}{2}$

$y = x - 2 = \dfrac{\sqrt{14}}{2}$ //

$\therefore w = \left(\dfrac{4+\sqrt{14}}{2}\right) + i\left(\dfrac{\sqrt{14}}{2}\right)$

$\Rightarrow |w|^2 = \left(\dfrac{4+\sqrt{14}}{2}\right)^2 + \left(\dfrac{\sqrt{14}}{2}\right)^2$

Question 3 continued

$$= \frac{16+14+8\sqrt{14}}{4} + \frac{14}{4}$$

$$= \frac{44+8\sqrt{14}}{4}$$

$$= \boxed{11+2\sqrt{14}}$$

4. Part of the mains water system for a housing estate consists of water pipes buried beneath the ground surface. The water pipes are modelled as straight line segments. One water pipe, W, is buried beneath a particular road. With respect to a fixed origin O, the road surface is modelled as a plane with equation $3x - 5y - 18z = 7$, and W passes through the points $A(-1, -1, -3)$ and $B(1, 2, -3)$. The units are in metres.

(a) Use the model to calculate the acute angle between W and the road surface.
(5)

A point $C(-1, -2, 0)$ lies on the road. A section of water pipe needs to be connected to W from C.

(b) Using the model, find, to the nearest cm, the shortest length of pipe needed to connect C to W.
(6)

a) road: $\mathbf{r} \cdot \underbrace{\begin{pmatrix} 3 \\ -5 \\ -18 \end{pmatrix}}_{\text{normal}} = 7$

$\overrightarrow{AB} = \begin{pmatrix} 1 \\ 2 \\ -3 \end{pmatrix} - \begin{pmatrix} -1 \\ -1 \\ -3 \end{pmatrix} = \begin{pmatrix} 2 \\ 3 \\ 0 \end{pmatrix}$ = dir. of W

$\therefore$ eqn of W: $\mathbf{r} = \begin{pmatrix} -1 \\ -1 \\ -3 \end{pmatrix} + \lambda \begin{pmatrix} 2 \\ 3 \\ 0 \end{pmatrix}$

angle between line & plane: $\sin\theta = \dfrac{\begin{pmatrix} 2 \\ 3 \\ 0 \end{pmatrix} \cdot \begin{pmatrix} 3 \\ -5 \\ -18 \end{pmatrix}}{\left|\begin{pmatrix} 2 \\ 3 \\ 0 \end{pmatrix}\right| \left|\begin{pmatrix} 3 \\ -5 \\ -18 \end{pmatrix}\right|}$

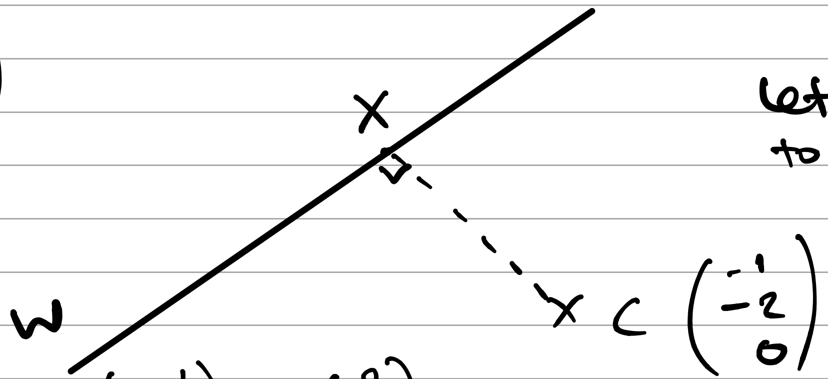
$= \dfrac{-9}{\sqrt{13} \cdot \sqrt{358}}$

Question 4 continued

$$\therefore \theta = \arcsin\left(\frac{-9}{\sqrt{13}\cdot\sqrt{358}}\right) = -7.58^\circ$$

(or 7.58°)

b)



let X = closest point to C. Then $\overrightarrow{CX} \perp W$

$$r = \begin{pmatrix}-1\\-1\\-3\end{pmatrix} + \lambda\begin{pmatrix}2\\3\\0\end{pmatrix}$$

$$X = \begin{pmatrix}-1+2\lambda\\-1+3\lambda\\-3\end{pmatrix} \quad \therefore \overrightarrow{CX} = \begin{pmatrix}-1+2\lambda\\-1+3\lambda\\-3\end{pmatrix} - \begin{pmatrix}-1\\-2\\0\end{pmatrix}$$

$$= \begin{pmatrix}2\lambda\\1+3\lambda\\-3\end{pmatrix}$$

but $\overrightarrow{CX}$ is perpendicular to the line.

$$\Rightarrow \begin{pmatrix}2\lambda\\1+3\lambda\\-3\end{pmatrix} \cdot \begin{pmatrix}2\\3\\0\end{pmatrix} = 0$$

$$\Rightarrow 4\lambda + 9\lambda + 3 = 0$$

$$\Rightarrow \lambda = -3/13$$

Turn over

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Question 4 continued

$$\therefore \overrightarrow{CX} = \begin{pmatrix} -6/13 \\ 1 - 9/13 \\ -3 \end{pmatrix}$$

$$= \begin{pmatrix} -6/13 \\ 4/13 \\ -3 \end{pmatrix}$$

$$\therefore |\overrightarrow{CX}| = \sqrt{\left(\frac{-6}{13}\right)^2 + \left(\frac{4}{13}\right)^2 + (-3)^2}$$

$$= \sqrt{\frac{121}{13}} = \boxed{3.05\text{m}}$$

(3sf)

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5.

$$\mathbf{A} = \begin{pmatrix} -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ \frac{\sqrt{3}}{2} & -\frac{1}{2} \end{pmatrix}$$

(a) Describe fully the single geometrical transformation U represented by the matrix **A**.

(3)

The transformation V, represented by the 2×2 matrix **B**, is a reflection in the line $y = -x$

(b) Write down the matrix **B**.

(1)

Given that U followed by V is the transformation T, which is represented by the matrix **C**,

(c) find the matrix **C**.

(2)

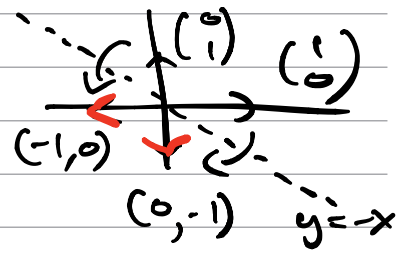
(d) Show that there is a real number k for which the point $(1, k)$ is invariant under T.

(4)

a) Rotation $120°$ Anti-clockwise about O.

(This is simply the rotation matrix with $\theta = 120°$)

b) $B = \begin{pmatrix} 0 & -1 \\ -1 & 0 \end{pmatrix}$



c) $T = VU = \begin{pmatrix} 0 & -1 \\ -1 & 0 \end{pmatrix}\begin{pmatrix} -\frac{1}{2} & -\sqrt{3}/2 \\ \sqrt{3}/2 & -\frac{1}{2} \end{pmatrix}$

$$= \boxed{\begin{pmatrix} -\frac{\sqrt{3}}{2} & \frac{1}{2} \\ \frac{1}{2} & \frac{\sqrt{3}}{2} \end{pmatrix}}$$

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Question 5 continued

d) $(1,k)$ invariant $\iff \begin{pmatrix} -\frac{\sqrt{3}}{2} & \frac{1}{2} \\ \frac{1}{2} & \frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} 1 \\ k \end{pmatrix} = \begin{pmatrix} 1 \\ k \end{pmatrix}$

$$\left.\begin{aligned} -\frac{\sqrt{3}}{2}(1) + \frac{1}{2}(k) &= 1 \\ (\times 2): \quad -\sqrt{3} + k &= 2 \\ \therefore k &= 2+\sqrt{3} \end{aligned}\right\}$$ multiplying 1st row

to check this is correct, multiply out the 2nd row:

$$\frac{1}{2}(1) + \frac{\sqrt{3}}{2}(k) = k$$

$$(\times 2): \quad 1 + \sqrt{3}k = 2k$$

$$k(2-\sqrt{3}) = 1$$

$$k = \frac{1}{2-\sqrt{3}} = \boxed{2+\sqrt{3}} \checkmark$$

6. (a) Use the standard results for $\sum_{r=1}^{n} r^2$ and $\sum_{r=1}^{n} r$ to show that

$$\sum_{r=1}^{n} (3r-2)^2 = \frac{1}{2}n\left[6n^2 - 3n - 1\right]$$

for all positive integers n.

(5)

(b) Hence find any values of n for which

$$\sum_{r=5}^{n} (3r-2)^2 + 103\sum_{r=1}^{28} r\cos\left(\frac{r\pi}{2}\right) = 3n^3$$

(5)

a) $\sum_{r=1}^{n} (3r-2)^2 = \sum_{r=1}^{n} 9r^2 - 12r + 4$

$= 9\sum_{r=1}^{n} r^2 - 12\sum_{r=1}^{n} r + 4\sum_{r=1}^{n} 1$

$= 9\left(\frac{1}{6}n(n+1)(2n+1)\right) - 12\left(\frac{n}{2}(n+1)\right) + 4n$

$= \frac{n}{2}\left[3(n+1)(2n+1) - 12(n+1) + 8\right]$

$= \frac{n}{2}\left[3(2n^2+3n+1) - 12n - 4\right]$

$= \frac{n}{2}\left[6n^2 + 9n + 3 - 12n - 4\right]$

$= \frac{n}{2}\left[6n^2 - 3n - 1\right]$ //

(as required)

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Question 6 continued

b) $\sum_{r=5}^{n}(3r-2)^2 + 103\sum_{r=1}^{28} r\cos\left(\frac{r\pi}{2}\right) = 3n^3$

$$\sum_{r=5}^{n}(3r-2)^2 = \sum_{r=1}^{n}(3r-2)^2 - \sum_{r=1}^{4}(3r-2)^2$$

$$= \frac{n}{2}(6n^2-3n-1) - \frac{4}{2}\left(6(4)^2-3(4)-1\right)$$

$$= 3n^3 - \frac{3n^2}{2} - \frac{n}{2} - 166 \;//$$

now looking at $\sum_{r=1}^{28} r\cos\left(\frac{r\pi}{2}\right)$ ...

notice that when r is odd, $\cos\left(\frac{r\pi}{2}\right) = 0$.

so this sum follows a pattern:

$$\begin{array}{ccccccccc} r=1 & r=2 & r=3 & r=4 & r=5 & r=6 & \ldots & r=28 \\ 0 & -2+ & 0+ & 4+ & 0 & -6 & \ldots & +28 \end{array}$$

adding up all such terms manually:

$$\sum_{r=1}^{28} r\cos\left(\frac{r\pi}{2}\right) = 14 \;//$$

Question 6 continued

back to the given equation:

$$\sum_{r=5}^{n}(3r-2)^2 + 103\sum_{r=1}^{28} r\cos\left(\frac{r\pi}{2}\right) = 3n^3$$

$$\cancel{3n^3} - \frac{3n^2}{2} - \frac{n}{2} - 166 + 103(14) = \cancel{3n^3}$$

$$-\frac{3}{2}n^2 - \frac{1}{2}n + 1276 = 0$$

Quadratic Formula: $\boxed{n = 29}$ //

$\cancel{\left(n = -\frac{88}{3}\right)}$ reject. $n \in \mathbb{Z}^+$

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7.

$$f(z) = z^3 + z^2 + pz + q$$

where p and q are real constants.

The equation $f(z) = 0$ has roots z_1, z_2 and z_3
When plotted on an Argand diagram, the points representing z_1, z_2 and z_3 form the vertices of a triangle of area 35

Given that $z_1 = 3$, find the values of p and q.

(7)

$f(3) = 0 : \quad 3^3 + 3^2 + 3p + q = 0$

$3p + q = -36$ —— (1)

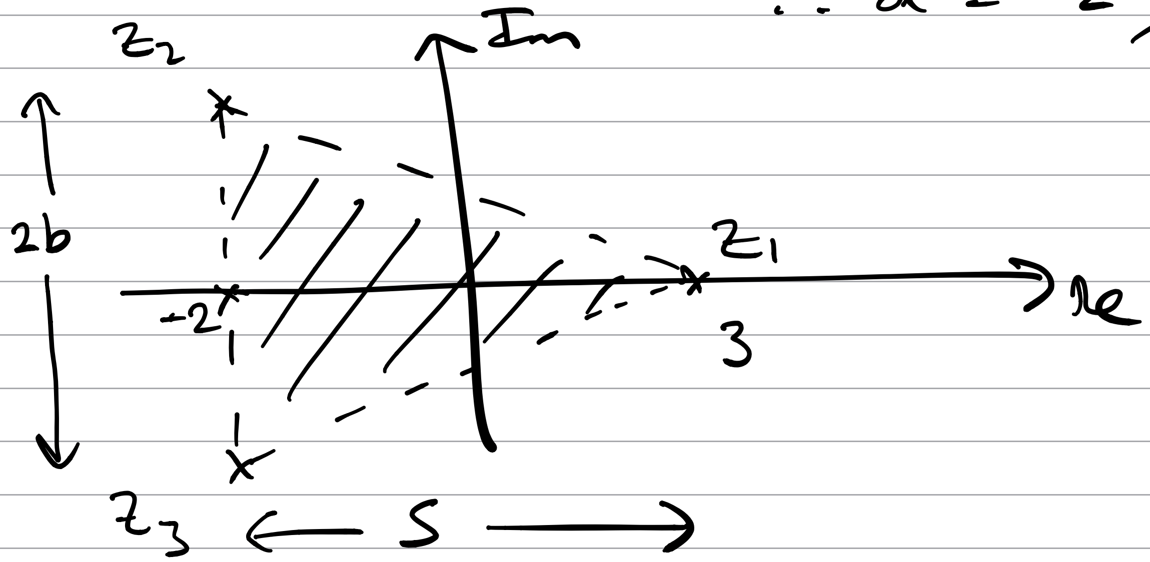
let $z_2, z_3 = a \pm bi$.

Sum of roots : $3 + (a+bi) + (a-bi) = -1$

$\sum \alpha = \frac{-b}{a} = -1 \quad \therefore \quad 3 + 2a = -1$

$2a = -4$

$\therefore a = -2$



Area $= \frac{1}{2} bh = \frac{1}{2}(2b)(5) = 35$

$\therefore b = \frac{35}{5} = 7$

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Question 7 continued

$\therefore z_2 = -2 + 7i$

$z_3 = -2 - 7i$

to find p, q now :

$\alpha\beta\gamma = -\frac{d}{a} \Rightarrow (3)(-2+7i)(-2-7i) = \frac{-q}{1}$

$\therefore q = -3(4 - 49i^2)$

$\boxed{q = -159}$

from (1) : $3p + q = -36$

$\therefore p = \frac{-36 - (-159)}{3}$

$\boxed{p = 41}$

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Question 7 continued

8. (i) Prove by induction that for $n \in \mathbb{Z}^+$

$$\begin{pmatrix} 5 & -8 \\ 2 & -3 \end{pmatrix}^n = \begin{pmatrix} 4n+1 & -8n \\ 2n & 1-4n \end{pmatrix}$$

(6)

(ii) Prove by induction that for $n \in \mathbb{Z}^+$

$$f(n) = 4^{n+1} + 5^{2n-1}$$

is divisible by 21

(6)

a) when $n=1$: LHS $= \begin{pmatrix} 5 & -8 \\ 2 & -3 \end{pmatrix}$

RHS $= \begin{pmatrix} 4+1 & -8(1) \\ 2(1) & 1-4(1) \end{pmatrix} = \begin{pmatrix} 5 & -8 \\ 2 & -3 \end{pmatrix}$

= LHS ✓

$\therefore$ true for $n=1$.

assume true for $n=k$.

ie $\begin{pmatrix} 5 & -8 \\ 2 & -3 \end{pmatrix}^k = \begin{pmatrix} 4k+1 & -8k \\ 2k & 1-4k \end{pmatrix}$

Consider $n=k+1$:

$$\begin{pmatrix} 5 & -8 \\ 2 & -3 \end{pmatrix}^{k+1} = \begin{pmatrix} 5 & -8 \\ 2 & -3 \end{pmatrix}^k \begin{pmatrix} 5 & -8 \\ 2 & -3 \end{pmatrix}$$

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Question 8 continued

$$= \begin{pmatrix} 4k+1 & -8k \\ 2k & 1-4k \end{pmatrix} \begin{pmatrix} 5 & -8 \\ 2 & -3 \end{pmatrix}$$

$$= \begin{pmatrix} 5(4k+1)-16k & -8(4k+1)+24k \\ 10k+2-8k & -16k-3+12k \end{pmatrix}$$

$$= \begin{pmatrix} 4k+5 & -8k+8 \\ 2k+2 & -4k-3 \end{pmatrix}$$

$$= \begin{pmatrix} 4(k+1)+1 & -8(k+1) \\ 2(k+1) & 1-4(k+1) \end{pmatrix}$$

$\therefore$ true for $n=k+1$.

- we have proved the statement true for $n=1$
- we have shown it to be true for $n=k+1$ when assumed true for $n=k$
- $\therefore$ By Mathematical Induction it is true for all $n \in \mathbb{Z}^+$.

$f(n) = 4^{n+1} + 5^{2n-1}$ (div 21)

Question 8 continued

b) $\underline{n=1}$: $4^2 + 5^1 = 21 = 21(1)$

$\therefore$ when $n=1$, $f(n)$ is divisible by 21.

assume true for $n=k$.

$f(k) = 4^{k+1} + 5^{2k-1}$ is divisible by 21.

consider $n=k+1$:

$f(k+1) = 4^{k+2} + 5^{2k+1}$

$= 4(4^{k+1}) + 5^2(5^{2k-1})$

factoring out $f(k)$

$= 25[4^{k+1} + 5^{2k-1}] - 21(4^{k+1})$

$= 25 f(k) - 21(4^{k+1})$

Div. by 21

Div by 21

$\therefore f(k+1)$ is divisible by 21.

Question 8 continued

- we have proved the statement true for $n=1$
- we have shown it to be true for $n=k+1$ when assumed true for $n=k$
- $\therefore$ By Mathematical Induction it is true for all $n \in \mathbb{Z}^+$.

(Total for Question 8 is 12 marks)

9.

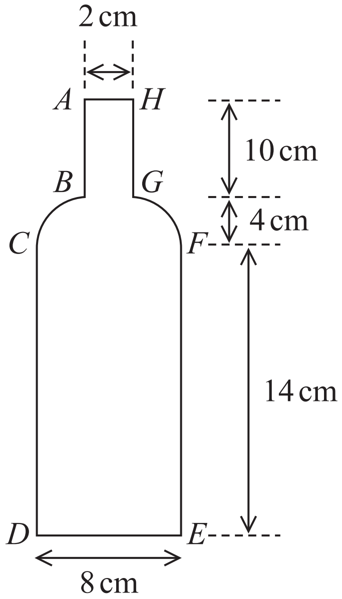


Figure 1

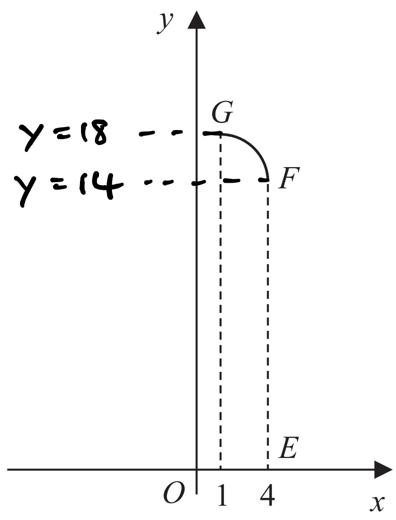


Figure 2

A mathematics student is modelling the profile of a glass bottle of water. Figure 1 shows a sketch of a central vertical cross-section *ABCDEFGHA* of the bottle with the measurements taken by the student.

The horizontal cross-section between *CF* and *DE* is a circle of diameter 8 cm and the horizontal cross-section between *BG* and *AH* is a circle of diameter 2 cm.

The student thinks that the curve *GF* could be modelled as a curve with equation

$$y = ax^2 + b \qquad 1 \leqslant x \leqslant 4$$

where *a* and *b* are constants and *O* is the fixed origin, as shown in Figure 2.

(a) Find the value of *a* and the value of *b* according to the model. **(2)**

(b) Use the model to find the volume of water that the bottle can contain. **(7)**

(c) State a limitation of the model. **(1)**

The label on the bottle states that the bottle holds approximately 750 cm³ of water.

(d) Use this information and your answer to part (b) to evaluate the model, explaining your reasoning. **(1)**

a) $x=1, y=18$ $\qquad$ $x=4, y=14$

$\Rightarrow 18 = a(1) + b$ $\qquad$ $\Rightarrow 14 = a(16) + b$

(1) $\qquad$ (2)

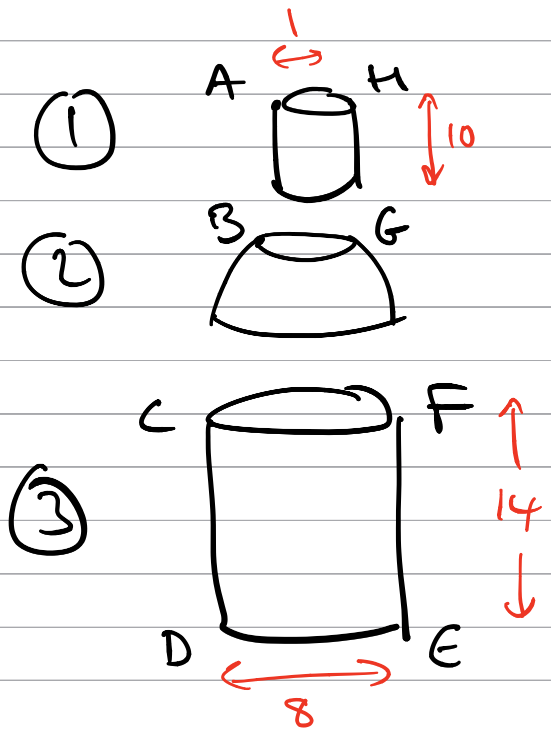
P 5 8 3 0 2 A 0 3 2 3 6

Question 9 continued

$① - ② : \quad 4 = -15a \quad \therefore a = -\frac{4}{15}$ //

So $b = 18 - \left(-\frac{4}{15}\right) = \frac{274}{15} = b$ //

b)



Volume $= ① + ② + ③$

$① : \quad V = \pi r^2 h = \pi (1)^2 (10) = 10\pi$

$③ : \quad V = \pi r^2 h = \pi (4)^2 (14) = 224\pi$

$② : \quad V = \pi \int_1^4 x^2 \, dy$

$y = -\frac{4}{15}x^2 + \frac{274}{15}$

$\therefore \frac{274 - 15y}{4} = x^2$

Question 9 continued

$$\therefore V_{②} = \frac{\pi}{4}\int_{14}^{18} 274 - 15y \, dy$$

$$= \frac{\pi}{4}\left[274y - \frac{15y^2}{2}\right]_{14}^{18}$$

$$= \frac{\pi}{4}\left[2502 - 2366\right] = 34\pi$$

$$\therefore \text{Volume total} = 10\pi + 224\pi + 34\pi$$

$$= 268\pi = \boxed{842 \text{ cm}^3}$$

(3sf)

c) · The curve may not be suitable to model the bottle.

(Any sensible comment regarding the simplified shape will do.)

d) $842 > 750$

$$\%\text{ error} = \left(\frac{842 - 750}{750}\right) \times 100 = 12.3\%$$

Large % error, $842 > 750$ $\therefore$ this isn't a good model.

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