Please check the examination details below before entering your candidate information

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**Pearson Edexcel Level 3 GCE**

| Centre Number | Candidate Number |
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| | |

# Thursday 14 May 2020

Afternoon (Time: 1 hour 30 minutes) | Paper Reference **9FM0/02**

# Further Mathematics

## Advanced

## Paper 2: Core Pure Mathematics 2

**You must have:**
Mathematical Formulae and Statistical Tables (Green), calculator

Total Marks

**Candidates may use any calculator permitted by Pearson regulations. Calculators must not have the facility for algebraic 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.
- Inexact answers should be given to three significant figures unless otherwise stated.

## Information

- A booklet 'Mathematical Formulae and Statistical Tables' is provided.
- There are 7 questions in this question paper. The total mark for this paper is 75.
- 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.

*Turn over* ▶

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**1.** The curve $C$ has equation

$$y = 31\sinh x - 2\sinh 2x \qquad x \in \mathbb{R}$$

Determine, in terms of natural logarithms, the exact $x$ coordinates of the stationary points of $C$.

**(7)**

$\frac{dy}{dx} = 31\cosh x - 4\cosh 2x$

Stationary points: $31\cosh x - 4\cosh 2x = 0$

$31\cosh x - 4(2\cosh^2 x - 1) = 0$

$8\cosh^2 x - 31\cosh x - 4 = 0$

$(8\cosh x + 1)(\cosh x - 4) = 0$

$\cosh x = 4 \quad \text{or} \quad \cosh x = -\frac{1}{8}$

$\cosh x \geqslant 1$ for all real $x$, so $\cosh x = -\frac{1}{8}$ has no solutions.

$\cosh x = 4 \Rightarrow x = \pm\text{arcosh}\, 4 = \pm\ln(4 + \sqrt{(4^2 - 1)})$

$x = \ln(4 + \sqrt{15})$ and $x = -\ln(4 + \sqrt{15})$ $(= \ln(4 - \sqrt{15}))$

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**Question 1 continued**

**(Total for Question 1 is 7 marks)**

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**2.** In an Argand diagram, the points $A$ and $B$ are represented by the complex numbers $-3 + 2i$ and $5 - 4i$ respectively. The points $A$ and $B$ are the end points of a diameter of a circle $C$.

(a) Find the equation of $C$, giving your answer in the form

$$|z - a| = b \qquad a \in \mathbb{C},\ b \in \mathbb{R}$$

**(3)**

The circle $D$, with equation $|z - 2 - 3i| = 2$, intersects $C$ at the points representing the complex numbers $z_1$ and $z_2$

(b) Find the complex numbers $z_1$ and $z_2$

**(6)**

(a) Centre = midpoint of $AB = \left(\frac{-3+5}{2}, \frac{2-4}{2}\right) = (1, -1)$

Radius $r = \sqrt{((5-1)^2 + (-4+1)^2)} = \sqrt{(16+9)} = 5$

C: $|z - 1 + i| = 5$, i.e. $|z - (1 - i)| = 5$

(b) C: $(x-1)^2 + (y+1)^2 = 25 \Rightarrow x^2 - 2x + 1 + y^2 + 2y + 1 = 25$

D: $(x-2)^2 + (y-3)^2 = 4 \Rightarrow x^2 - 4x + 4 + y^2 - 6y + 9 = 4$

Subtracting: $2x + 8y - 11 = 21 \Rightarrow 2x + 8y = 32 \Rightarrow x = 16 - 4y$

Sub into D: $(16 - 4y)^2 - 4(16 - 4y) + 4 + y^2 - 6y + 9 = 4$

$256 - 128y + 16y^2 - 64 + 16y + y^2 - 6y + 9 = 0$

$17y^2 - 118y + 201 = 0$

$(17y - 67)(y - 3) = 0 \Rightarrow y = \frac{67}{17}$ or $y = 3$

$y = 3 \Rightarrow x = 16 - 12 = 4$

$y = \frac{67}{17} \Rightarrow x = 16 - \frac{268}{17} = \frac{4}{17}$

$z_1 = 4 + 3i$, $z_2 = \frac{4}{17} + \frac{67}{17}i$

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**Question 2 continued**

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**Question 2 continued**

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**Question 2 continued**

**(Total for Question 2 is 9 marks)**

**3.** A scientist is investigating the concentration of antibodies in the bloodstream of a patient following a vaccination.
The concentration of antibodies, $x$, measured in micrograms (μg) per millilitre (ml) of blood, is modelled by the differential equation

$$100\frac{\mathrm{d}^2x}{\mathrm{d}t^2} + 60\frac{\mathrm{d}x}{\mathrm{d}t} + 13x = 26$$

where $t$ is the number of weeks since the vaccination was given.

(a) Find a general solution of the differential equation.

**(4)**

Initially,

- there are no antibodies in the bloodstream of the patient
- the concentration of antibodies is estimated to be increasing at 10 μg/ml per week

(b) Find, according to the model, the maximum concentration of antibodies in the bloodstream of the patient after the vaccination.

**(8)**

A second dose of the vaccine has to be given to try to ensure that it is fully effective.
It is only safe to give the second dose if the concentration of antibodies in the bloodstream of the patient is less than 5 μg/ml.

(c) Determine whether, according to the model, it is safe to give the second dose of the vaccine to the patient exactly 10 weeks after the first dose.

**(2)**

(a) Auxiliary equation: $100m^2 + 60m + 13 = 0$

$$m = \frac{-60 \pm \sqrt{(3600 - 5200)}}{200} = \frac{-60 \pm 40i}{200} = -0.3 \pm 0.2i$$

CF: $x = e^{-0.3t}(A\cos 0.2t + B\sin 0.2t)$

PI: $x = \lambda \Rightarrow 13\lambda = 26 \Rightarrow \lambda = 2$

GS: $x = e^{-0.3t}(A\cos 0.2t + B\sin 0.2t) + 2$

(b) $t = 0, x = 0$: $0 = A + 2 \Rightarrow A = -2$

$$\frac{dx}{dt} = -0.3e^{-0.3t}(A\cos 0.2t + B\sin 0.2t) + e^{-0.3t}(-0.2A\sin 0.2t + 0.2B\cos 0.2t)$$

$t = 0, \frac{dx}{dt} = 10$: $10 = -0.3A + 0.2B = 0.6 + 0.2B \Rightarrow B = 47$

$$x = e^{-0.3t}(47\sin 0.2t - 2\cos 0.2t) + 2$$

$$\frac{dx}{dt} = -0.3e^{-0.3t}(47\sin 0.2t - 2\cos 0.2t) + e^{-0.3t}(9.4\cos 0.2t + 0.4\sin 0.2t)$$

$$= e^{-0.3t}(10\cos 0.2t - 13.7\sin 0.2t)$$

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**Question 3 continued**

Maximum when $\frac{dx}{dt} = 0$: $10 \cos 0.2t = 13.7 \sin 0.2t$

$\tan 0.2t = \frac{10}{13.7} = \frac{100}{137} \Rightarrow 0.2t = 0.63053... \Rightarrow t = 3.1526...$ weeks

$x = e^{-0.3 \times 3.1526...}(47 \sin(0.63053...) - 2 \cos(0.63053...)) + 2$

$= 0.38837... \times 26.0945... + 2 = 12.134...$

Maximum concentration = 12.1 μg/ml (3 s.f.)

(c) $t = 10$: $x = e^{-3}(47 \sin 2 - 2 \cos 2) + 2 = 4.169...$ μg/ml

$4.17 < 5$, so according to the model it is safe to give the second dose 10 weeks after the first dose.

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**Question 3 continued**

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**Question 3 continued**

**(Total for Question 3 is 14 marks)**

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**4.** (a) Use de Moivre's theorem to prove that

$$\sin 7\theta = 7\sin\theta - 56\sin^3\theta + 112\sin^5\theta - 64\sin^7\theta$$

**(5)**

(b) Hence find the distinct roots of the equation

$$1 + 7x - 56x^3 + 112x^5 - 64x^7 = 0$$

**(5)**

giving your answer to 3 decimal places where appropriate.

(a) Let $c = \cos\theta$, $s = \sin\theta$. By de Moivre: $\cos 7\theta + i\sin 7\theta = (c + is)^7$

$(c + is)^7 = c^7 + 7c^6(is) + 21c^5(is)^2 + 35c^4(is)^3 + 35c^3(is)^4$

$\quad + 21c^2(is)^5 + 7c(is)^6 + (is)^7$

Imaginary parts: $i\sin 7\theta = 7c^6is + 35c^4i^3s^3 + 21c^2i^5s^5 + i^7s^7$

$\sin 7\theta = 7c^6s - 35c^4s^3 + 21c^2s^5 - s^7$

$= 7(1 - s^2)^3s - 35(1 - s^2)^2s^3 + 21(1 - s^2)s^5 - s^7$

$= 7s(1 - 3s^2 + 3s^4 - s^6) - 35s^3(1 - 2s^2 + s^4) + 21s^5 - 21s^7 - s^7$

$= 7s - 21s^3 + 21s^5 - 7s^7 - 35s^3 + 70s^5 - 35s^7 + 21s^5 - 21s^7 - s^7$

$= 7s - 56s^3 + 112s^5 - 64s^7$

$\therefore \sin 7\theta = 7\sin\theta - 56\sin^3\theta + 112\sin^5\theta - 64\sin^7\theta$

(b) Let $x = \sin\theta$: $1 + 7x - 56x^3 + 112x^5 - 64x^7 = 1 + \sin 7\theta = 0$

$\Rightarrow \sin 7\theta = -1$

$7\theta = -\frac{5\pi}{2}, -\frac{\pi}{2}, \frac{3\pi}{2}, \frac{7\pi}{2}, \ldots$

$\theta = -\frac{5\pi}{14}, -\frac{\pi}{14}, \frac{3\pi}{14}, \frac{\pi}{2}, \ldots$

(other values of $\theta$ give repeated values of $\sin\theta$)

$x = \sin\left(-\frac{5\pi}{14}\right) = -0.90096\ldots = -0.901$

$x = \sin\left(-\frac{\pi}{14}\right) = -0.22252\ldots = -0.223$

$x = \sin\frac{3\pi}{14} = 0.62348\ldots = 0.623$

$x = \sin\frac{\pi}{2} = 1$

Distinct roots: $x = -0.901,\ -0.223,\ 0.623,\ 1$

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**Question 4 continued**

**Question 4 continued**

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**Question 4 continued**

**(Total for Question 4 is 10 marks)**

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**5.** (a) $y = \tan^{-1} x$

Assuming the derivative of $\tan x$, prove that

$$\frac{dy}{dx} = \frac{1}{1+x^2}$$

**(3)**

$$f(x) = x\tan^{-1} 4x$$

(b) Show that

$$\int f(x)\,dx = Ax^2 \tan^{-1} 4x + Bx + C\tan^{-1} 4x + k$$

where $k$ is an arbitrary constant and $A$, $B$ and $C$ are constants to be determined.

**(5)**

(c) Hence find, in exact form, the mean value of $f(x)$ over the interval $\left[0, \frac{\sqrt{3}}{4}\right]$

**(2)**

(a) $y = \tan^{-1}x \Rightarrow \tan y = x$

Differentiate w.r.t. x: $\sec^2 y \frac{dy}{dx} = 1$

$\frac{dy}{dx} = \frac{1}{\sec^2 y} = \frac{1}{1+\tan^2 y} = \frac{1}{1+x^2}$

(b) $\frac{d}{dx}(\tan^{-1}4x) = \frac{4}{1+(4x)^2} = \frac{4}{1+16x^2}$

By parts: $u = \tan^{-1}4x$, $\frac{dv}{dx} = x \Rightarrow v = \frac{x^2}{2}$

$\int x\tan^{-1}4x\,dx = \frac{x^2}{2}\tan^{-1}4x - \int \frac{x^2}{2} \times \frac{4}{1+16x^2}\,dx$

$= \frac{x^2}{2}\tan^{-1}4x - \frac{1}{8}\int \frac{16x^2+1-1}{1+16x^2}\,dx$

$= \frac{x^2}{2}\tan^{-1}4x - \frac{1}{8}\int \left(1 - \frac{1}{1+16x^2}\right)dx$

$= \frac{x^2}{2}\tan^{-1}4x - \frac{1}{8}x + \frac{1}{8}\times\frac{1}{4}\tan^{-1}4x + k$

$= \frac{1}{2}x^2\tan^{-1}4x - \frac{1}{8}x + \frac{1}{32}\tan^{-1}4x + k$

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**Question 5 continued**

$A = \frac{1}{2}$, $B = -\frac{1}{8}$, $C = \frac{1}{32}$

(c) Mean value $= \frac{1}{(\sqrt{3}/4) - 0} \left[ \frac{x^2}{2} \tan^{-1} 4x - \frac{x}{8} + \frac{1}{32} \tan^{-1} 4x \right]_0^{\sqrt{3}/4}$

$\tan^{-1}\left(4 \times \frac{\sqrt{3}}{4}\right) = \tan^{-1}\sqrt{3} = \frac{\pi}{3}$

$= \frac{4}{\sqrt{3}} \left( \frac{3}{32} \times \frac{\pi}{3} - \frac{1}{8} \times \frac{\sqrt{3}}{4} + \frac{1}{32} \times \frac{\pi}{3} - 0 \right)$

$= \frac{4}{\sqrt{3}} \left( \frac{\pi}{24} - \frac{\sqrt{3}}{32} \right) = \frac{\pi}{6\sqrt{3}} - \frac{1}{8}$

Mean value $= \frac{\sqrt{3}}{18}\pi - \frac{1}{8}$ $\left( = \frac{\sqrt{3}}{72}(4\pi - 3\sqrt{3}) \right)$

**Question 5 continued**

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**Question 5 continued**

**(Total for Question 5 is 10 marks)**

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**6.**

$$\mathbf{M} = \begin{pmatrix} k & 5 & 7 \\ 1 & 1 & 1 \\ 2 & 1 & -1 \end{pmatrix} \quad \text{where } k \text{ is a constant}$$

(a) Given that $k \neq 4$, find, in terms of $k$, the inverse of the matrix $\mathbf{M}$.

**(4)**

(b) Find, in terms of $p$, the coordinates of the point where the following planes intersect.

$$\begin{aligned} 2x + 5y + 7z &= 1 \\ x + y + z &= p \\ 2x + y - z &= 2 \end{aligned}$$

**(3)**

(c) (i) Find the value of $q$ for which the following planes intersect in a straight line.

$$\begin{aligned} 4x + 5y + 7z &= 1 \\ x + y + z &= q \\ 2x + y - z &= 2 \end{aligned}$$

(ii) For this value of $q$, determine a vector equation for the line of intersection.

**(7)**

(a) $\det M = k(-1-1) - 5(-1-2) + 7(1-2) = -2k + 15 - 7 = 8 - 2k$

Minors: $\begin{pmatrix} -2 & -3 & -1 \\ -12 & -k-14 & k-10 \\ -2 & k-7 & k-5 \end{pmatrix}$

Cofactors: $\begin{pmatrix} -2 & 3 & -1 \\ 12 & -k-14 & 10-k \\ -2 & 7-k & k-5 \end{pmatrix}$

$M^{-1} = \frac{1}{8-2k}\begin{pmatrix} -2 & 12 & -2 \\ 3 & -k-14 & 7-k \\ -1 & 10-k & k-5 \end{pmatrix}$

(b) This is M with $k = 2$, so $\det M = 8 - 4 = 4$:

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \frac{1}{4}\begin{pmatrix} -2 & 12 & -2 \\ 3 & -16 & 5 \\ -1 & 8 & -3 \end{pmatrix}\begin{pmatrix} 1 \\ p \\ 2 \end{pmatrix} = \frac{1}{4}\begin{pmatrix} -2+12p-4 \\ 3-16p+10 \\ -1+8p-6 \end{pmatrix}$$

Point of intersection: $\left(\frac{12p-6}{4}, \frac{13-16p}{4}, \frac{8p-7}{4}\right)$

i.e. $\left(3p - \frac{3}{2}, \frac{13}{4} - 4p, 2p - \frac{7}{4}\right)$

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**Question 6 continued**

(c)(i) $k = 4$ so M is singular. Eliminate z:

(1) + 7 × (3): $4x + 5y + 7z + 14x + 7y - 7z = 1 + 14 \Rightarrow 18x + 12y = 15$

$\Rightarrow 6x + 4y = 5$

(2) + (3): $3x + 2y = q + 2 \Rightarrow 6x + 4y = 2q + 4$

For a line of intersection the equations must be consistent:

$2q + 4 = 5 \Rightarrow q = \frac{1}{2}$

(ii) Let $z = \lambda$: $4x + 5y = 1 - 7\lambda$ and $2x + y = 2 + \lambda$

$y = 2 + \lambda - 2x \Rightarrow 4x + 10 + 5\lambda - 10x = 1 - 7\lambda \Rightarrow 6x = 9 + 12\lambda$

$x = \frac{3}{2} + 2\lambda$, $y = 2 + \lambda - 3 - 4\lambda = -1 - 3\lambda$, $z = \lambda$

(check in $x + y + z$: $\frac{3}{2} + 2\lambda - 1 - 3\lambda + \lambda = \frac{1}{2} = q$ )

$$\mathbf{r} = \begin{pmatrix} 3/2 \\ -1 \\ 0 \end{pmatrix} + \lambda \begin{pmatrix} 2 \\ -3 \\ 1 \end{pmatrix} \quad \text{i.e. } \mathbf{r} = \frac{3}{2}\mathbf{i} - \mathbf{j} + \lambda(2\mathbf{i} - 3\mathbf{j} + \mathbf{k})$$

**Question 6 continued**

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**Question 6 continued**

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**7.**

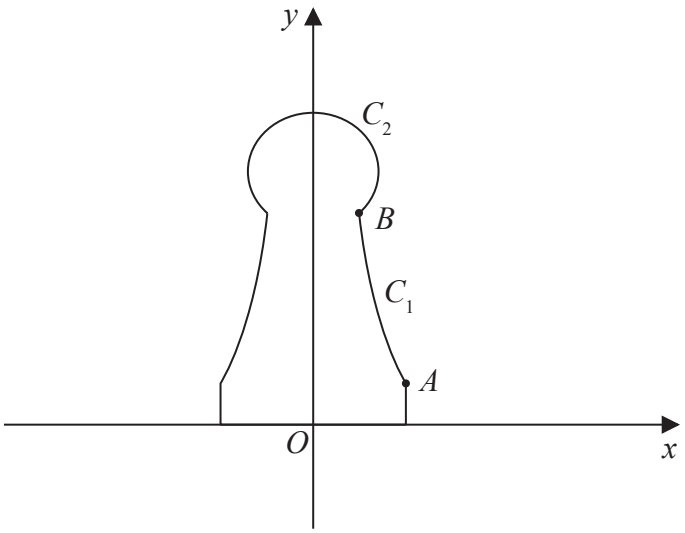



**Figure 1**

A student wants to make plastic chess pieces using a 3D printer. Figure 1 shows the central vertical cross-section of the student's design for one chess piece. The plastic chess piece is formed by rotating the region bounded by the $y$-axis, the $x$-axis, the line with equation $x = 1$, the curve $C_1$ and the curve $C_2$ through 360° about the $y$-axis.

The point $A$ has coordinates (1, 0.5) and the point $B$ has coordinates (0.5, 2.5) where the units are centimetres.

The curve $C_1$ is modelled by the equation

$$x = \frac{a}{y + b} \qquad 0.5 \leqslant y \leqslant 2.5$$

(a) Determine the value of $a$ and the value of $b$ according to the model.

**(2)**

The curve $C_2$ is modelled to be an arc of the circle with centre (0, 3).

(b) Use calculus to determine the volume of plastic required to make the chess piece according to the model.

**(9)**

(a) $A(1, 0.5)$: $1 = \frac{a}{0.5 + b}$ $B(0.5, 2.5)$: $0.5 = \frac{a}{2.5 + b}$

$a = 0.5 + b$ and $a = 1.25 + 0.5b \Rightarrow 0.5b = 0.75$

$b = 1.5$, $a = 2$

(b) Volume from $C_1$ $(0.5 \leqslant y \leqslant 2.5)$:

$V_1 = \pi \int_{0.5}^{2.5} x^2 \, dy = \pi \int_{0.5}^{2.5} \left( \frac{2}{y + 1.5} \right)^2 dy = 4\pi \int_{0.5}^{2.5} (y + 1.5)^{-2} \, dy$

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**Question 7 continued**

$= 4\pi \left[ -(y + 1.5)^{-1} \right]_{0.5}^{2.5} \quad = 4\pi \left( -\frac{1}{4} + \frac{1}{2} \right) = \pi$

$C_2$: circle centre (0, 3) through B(0.5, 2.5): $r^2 = 0.5^2 + (2.5 - 3)^2 = 0.5$

$x^2 + (y - 3)^2 = 0.5$ ; top of piece at $y = 3 + \frac{1}{\sqrt{2}}$

$V_2 = \pi \int_{2.5}^{3 + 1/\sqrt{2}} x^2 \, dy = \pi \int_{2.5}^{3 + 1/\sqrt{2}} (0.5 - (y - 3)^2) \, dy$

$= \pi \left[ 0.5y - \frac{1}{3}(y - 3)^3 \right]_{2.5}^{3 + 1/\sqrt{2}}$

$= \pi \left[ \left( \frac{3}{2} + \frac{1}{2\sqrt{2}} - \frac{1}{3} \times \frac{1}{2\sqrt{2}} \right) - \left( 1.25 + \frac{1}{24} \right) \right]$

$= \pi \left( \frac{5}{24} + \frac{\sqrt{2}}{6} \right)$

Cylinder base ($0 \leq y \leq 0.5$, radius 1): $V_3 = \pi \times 1^2 \times 0.5 = \frac{\pi}{2}$

Total $V = \pi + \pi\left( \frac{5}{24} + \frac{\sqrt{2}}{6} \right) + \frac{\pi}{2} = \pi\left( \frac{41}{24} + \frac{\sqrt{2}}{6} \right)$

$= 6.1073...$

Volume of plastic $\approx 6.11\ cm^3$

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**Question 7 continued**

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**Question 7 continued**

**(Total for Question 7 is 11 marks)**

**TOTAL FOR PAPER IS 75 MARKS**

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