AQA

Please write clearly in block capitals.

Centre number | | | | | | Candidate number | | | | |

Surname StemUp Model Solution

Forename(s) _____

Candidate signature _____

I declare this is my own work.

A-level MATHEMATICS

Paper 3

Tuesday 20 June 2023 Afternoon Time allowed: 2 hours

Materials
- You must have the AQA Formulae for A-level Mathematics booklet.
- You should have a graphical or scientific calculator that meets the requirements of the specification.

Instructions
- Use black ink or black ball-point pen. Pencil should only be used for drawing.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer each question in the space provided for that question.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- Do **not** write outside the box around each page or on blank pages.
- Show all necessary working; otherwise marks for method may be lost.
- Do all rough work in this book. Cross through any work that you do not want to be marked.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 100.

Advice
- Unless stated otherwise, you may quote formulae, without proof, from the booklet.
- You do not necessarily need to use all the space provided.

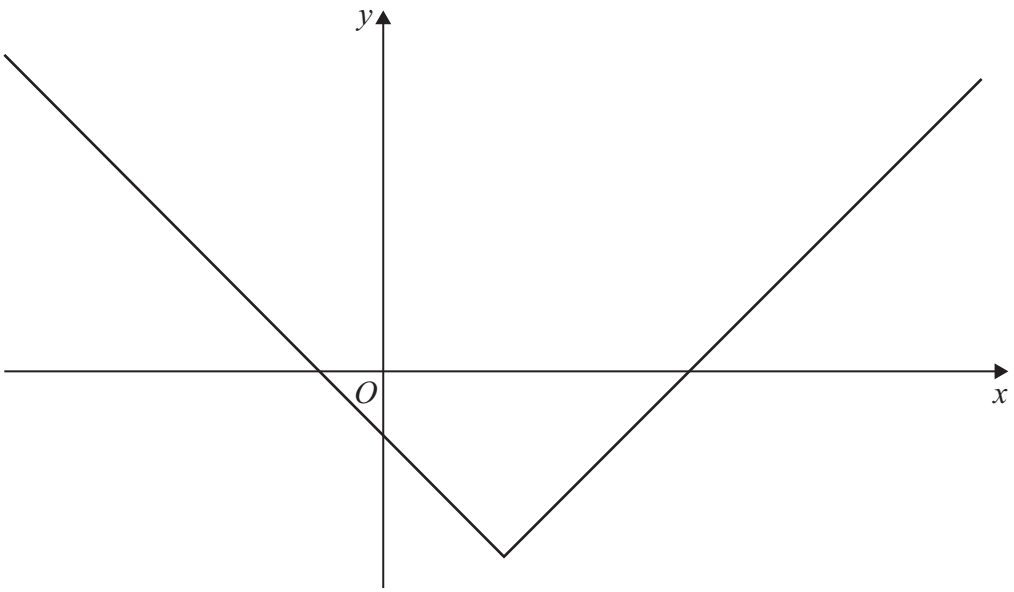
For Examiner's Use	
Question	Mark
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Section A

Answer **all** questions in the spaces provided.

1 The graph of $y = f(x)$ is shown below.



One of the four equations listed below is the equation of the graph $y = f(x)$

Identify which one is the correct equation of the graph.

Tick (✓) **one** box.

[1 mark]

$y = |x + 2| + 3$ ☐

$y = |x + 2| - 3$ ☐

$y = |x - 2| + 3$ ☐

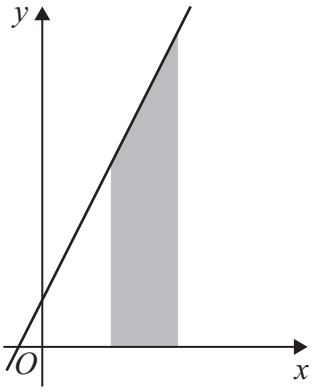
$y = |x - 2| - 3$ ☑

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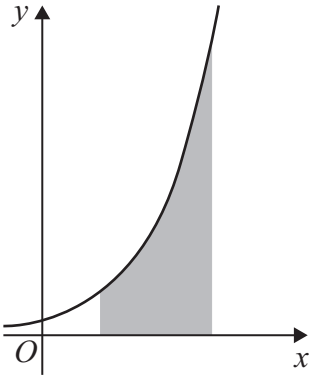
2 The trapezium rule is used to estimate the area of the shaded region in each of the graphs below.
Identify the graph for which the trapezium rule produces an overestimate.

Tick (✓) **one** box.

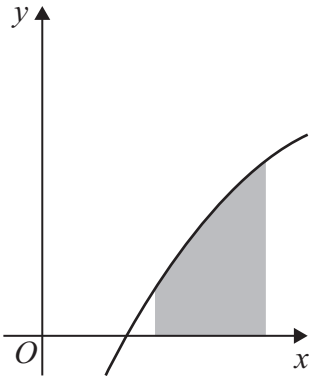
[1 mark]



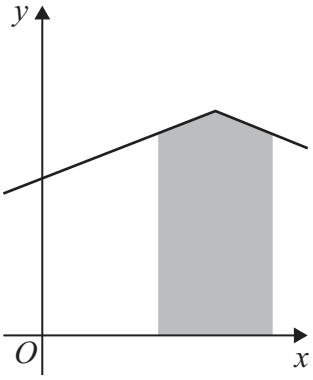
☐



☑



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3 A curve with equation $y = f(x)$ passes through the point (3, 7)

Given that $f'(3) = 0$ find the equation of the normal to the curve at (3, 7)

Circle your answer.

[1 mark]

$y = \frac{7}{3}x$ $\quad$ $y = 0$ $\quad$ $x = 3$ $\quad$ $x = 7$

4 Express

$$\frac{5 - \sqrt[3]{x}}{x^2}$$

in the form

$$5x^p - x^q$$

where p and q are constants.

[2 marks]

$\frac{5 - x^{1/3}}{x^2} = 5x^{-2} - x^{1/3} \times x^{-2}$

$= 5x^{-2} - x^{1/3 - 2}$

$= 5x^{-2} - x^{-5/3}$

so $p = -2$ and $q = -\frac{5}{3}$

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5 A curve has equation $y = 3e^{2x}$

Find the gradient of the curve at the point where $y = 10$

[3 marks]

$y = 3e^{2x} \Rightarrow \frac{dy}{dx} = 2 \times 3e^{2x} = 6e^{2x}$

$\frac{dy}{dx} = 2 \times (3e^{2x}) = 2y$

When $y = 10$: $3e^{2x} = 10 \Rightarrow x = \frac{1}{2} \ln\frac{10}{3} = 0.6019...$

$\frac{dy}{dx} = 2 \times 10$

Gradient = 20

Turn over for the next question

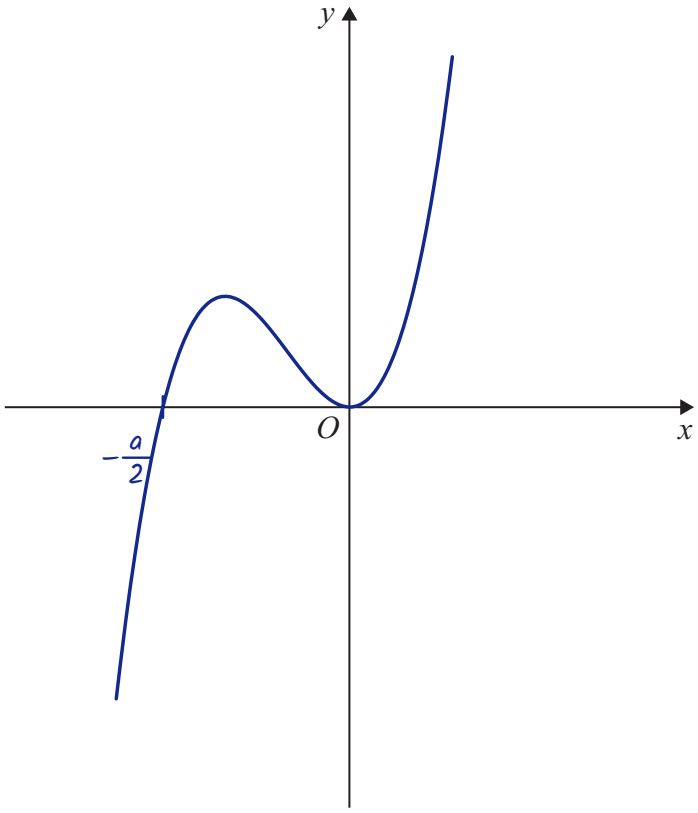
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6 (a) Sketch the curve with equation

$$y = x^2(2x + a)$$

where $a > 0$

[3 marks]



6 (b) The polynomial $\mathrm{p}(x)$ is given by

$$\mathrm{p}(x) = x^2(2x + a) + 36$$

6 (b) (i) It is given that $x + 3$ is a factor of $\mathrm{p}(x)$

Use the factor theorem to show $a = 2$

[2 marks]

$x + 3$ is a factor $\Rightarrow$ $p(-3) = 0$

$p(-3) = (-3)^2(2(-3) + a) + 36 = 0$

$9(a - 6) + 36 = 0$

$9a - 54 + 36 = 0$

$9a - 18 = 0$

$\therefore \ a = 2$

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6 (b) (ii) State the transformation which maps the curve with equation

$$y = x^2(2x + 2)$$

onto the curve with equation

$$y = x^2(2x + 2) + 36$$

[2 marks]

Translation by the vector $\begin{pmatrix} 0 \\ 36 \end{pmatrix}$

(i.e. 36 units in the positive y-direction)

6 (b) (iii) The polynomial $x^2(2x + 2) + 36$ can be written as $(x + 3)(2x^2 + bx + c)$

Without finding the values of b and c, use your answers to parts **(a)** and **(b)(ii)** to explain why

$$b^2 < 8c$$

[2 marks]

From (a), $y = x^2(2x + 2)$ has a minimum point at (0, 0) and its maximum is only just above the x-axis. Translating up by 36 moves the minimum to (0, 36), so the new curve crosses the x-axis only once, at $x = -3$.

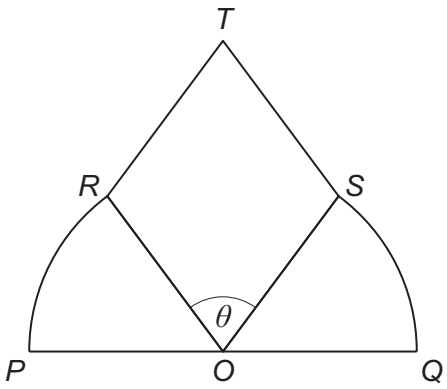
So $(x + 3)(2x^2 + bx + c) = 0$ has only one real root, $x = -3$, and $2x^2 + bx + c = 0$ has no real roots $\Rightarrow$ discriminant < 0

$b^2 - 4(2)(c) < 0 \Rightarrow b^2 - 8c < 0 \Rightarrow b^2 < 8c$

Turn over for the next question

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7 A new design for a company logo is to be made from two sectors of a circle, *ORP* and *OQS*, and a rhombus *OSTR*, as shown in the diagram below.



The points *P*, *O* and *Q* lie on a straight line and the angle *ROS* is θ radians.

A large copy of the logo, with $PQ = 5$ metres, is to be put on a wall.

7 (a) Show that the area of the logo, A square metres, is given by

$$A = \frac{25}{8}(\pi - \theta + 2\sin\theta)$$

[4 marks]

$r = PQ \div 2 = 2.5$ m. Angle ROP + angle SOQ $= \pi - \theta$

Area of both sectors $= \frac{1}{2} r^2(\pi - \theta) = \frac{1}{2}(2.5)^2(\pi - \theta) = \frac{25}{8}(\pi - \theta)$

OR = OS = 2.5 (radii), so the rhombus is two triangles with angle θ

Area of rhombus OSTR $= 2 \times \frac{1}{2}(2.5)(2.5)\sin\theta = (2.5)^2 \sin\theta = \frac{25}{4}\sin\theta$

$A = \frac{25}{8}(\pi - \theta) + \frac{25}{4}\sin\theta$

$A = \frac{25}{8}(\pi - \theta) + \frac{25}{8} \times 2\sin\theta$

$A = \frac{25}{8}(\pi - \theta + 2\sin\theta)$ as required

Do not write outside the box

7 (b) (i) Show that the maximum value of A occurs when $\theta = \frac{\pi}{3}$

Fully justify your answer.

[6 marks]

$A = \frac{25}{8}(\pi - \theta + 2\sin\theta)$

$\frac{dA}{d\theta} = \frac{25}{8}(-1 + 2\cos\theta)$

Maximum (stationary point) occurs when $\frac{dA}{d\theta} = 0$

$\frac{25}{8}(-1 + 2\cos\theta) = 0 \Rightarrow \cos\theta = \frac{1}{2}$

$\theta = \cos^{-1}\frac{1}{2} = \frac{\pi}{3} \quad (0 < \theta < \pi)$

$\frac{d^2A}{d\theta^2} = \frac{25}{8}(-2\sin\theta) = -\frac{25}{4}\sin\theta$

When $\theta = \frac{\pi}{3}$: $\frac{d^2A}{d\theta^2} = -\frac{25}{4} \times \frac{\sqrt{3}}{2} = -\frac{25\sqrt{3}}{8} = -5.41... < 0$

Second derivative is negative, so A has a maximum when $\theta = \frac{\pi}{3}$

Question 7 continues on the next page

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7 (b) (ii) Find the exact maximum value of A

[2 marks]

$A = \frac{25}{8}\left(\pi - \frac{\pi}{3} + 2\sin\frac{\pi}{3}\right)$

$= \frac{25}{8}\left(\frac{2\pi}{3} + 2 \times \frac{\sqrt{3}}{2}\right) = \frac{25}{8}\left(\frac{2\pi}{3} + \sqrt{3}\right)$

Maximum $A = \frac{25\pi}{12} + \frac{25\sqrt{3}}{8}$ m^2 $(= 11.96\ m^2)$

7 (c) Without further calculation, state how your answers to parts **(b)(i)** and **(b)(ii)** would change if PQ were increased to 10 metres.

[2 marks]

The angle θ for the maximum would be the same: $\theta = \frac{\pi}{3}$

The lengths double, so the maximum area would be quadrupled ($\times 4$):

maximum $A = 4 \times \frac{25}{8}\left(\frac{2\pi}{3} + \sqrt{3}\right) = \frac{25\pi}{3} + \frac{25\sqrt{3}}{2}$ m^2

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Turn over for the next question

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8 Use the substitution $u = x^5 + 2$ to show that

$$\int_0^1 \frac{x^9}{(x^5+2)^3}\,\mathrm{d}x = \frac{1}{180}$$

[7 marks]

$u = x^5 + 2 \Rightarrow \frac{du}{dx} = 5x^4 \Rightarrow dx = \frac{du}{5x^4}$

Limits: $x = 0 \Rightarrow u = 2$; $x = 1 \Rightarrow u = 3$; also $x^5 = u - 2$

$\int_0^1 \frac{x^9}{(x^5+2)^3}\,dx = \int_2^3 \frac{x^9}{u^3} \times \frac{1}{5x^4}\,du$

$= \int_2^3 \frac{x^5}{5u^3}\,du = \int_2^3 \frac{u-2}{5u^3}\,du$

$= \frac{1}{5}\int_2^3 (u^{-2} - 2u^{-3})\,du$

$= \frac{1}{5}\left[-u^{-1} + u^{-2}\right]_2^3$

$= \frac{1}{5}\left[-\frac{1}{u} + \frac{1}{u^2}\right]_2^3$

$= \frac{1}{5}\left[\left(-\frac{1}{3} + \frac{1}{9}\right) - \left(-\frac{1}{2} + \frac{1}{4}\right)\right]$

$= \frac{1}{5}\left[-\frac{2}{9} + \frac{1}{4}\right]$

$= \frac{1}{5} \times \frac{1}{36}$

$= \frac{1}{180}$ as required

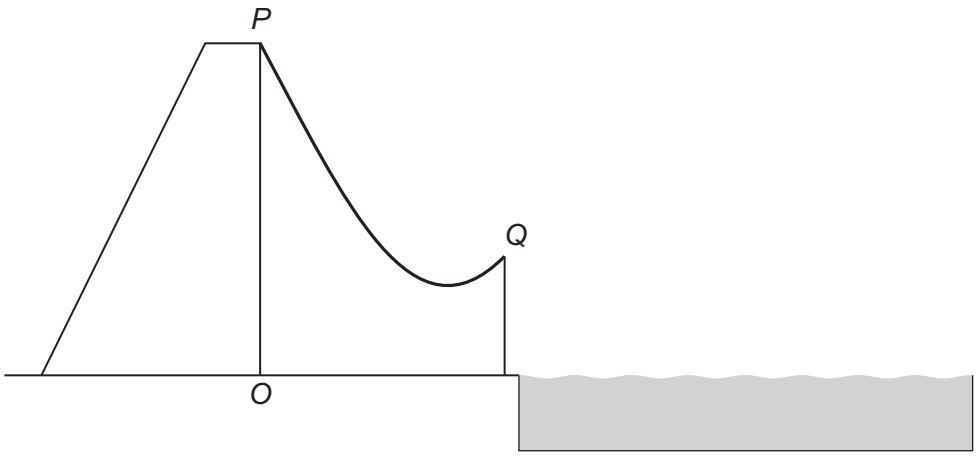
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Turn over for the next question

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9 A water slide is the shape of a curve PQ as shown in **Figure 1** below.

Figure 1



The curve can be modelled by the parametric equations

$$x = t - \frac{1}{t} + 4.8$$

$$y = t + \frac{2}{t}$$

where $0.2 \leq t \leq 3$

The horizontal distance from O is x metres.

The vertical distance above the point O at ground level is y metres.

P is the point where $t = 0.2$ and Q is the point where $t = 3$

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9 (a) To make sure speeds are safe at Q, the difference in height between P and Q must be less than 7 metres.

Show that the slide meets this safety requirement.

[3 marks]

At P, $t = 0.2$: $y = 0.2 + \frac{2}{0.2} = 0.2 + 10 = 10.2$

At Q, $t = 3$: $y = 3 + \frac{2}{3} = \frac{11}{3} = 3.666...$

Difference in height $= 10.2 - \frac{11}{3} = 6.533...$ m

$6.53 < 7$, so the slide meets the safety requirement.

9 (b) (i) Find an expression for $\frac{\mathrm{d}y}{\mathrm{d}x}$ in terms of t

[3 marks]

$x = t - t^{-1} + 4.8 \Rightarrow \frac{dx}{dt} = 1 + t^{-2}$

$y = t + 2t^{-1} \Rightarrow \frac{dy}{dt} = 1 - 2t^{-2}$

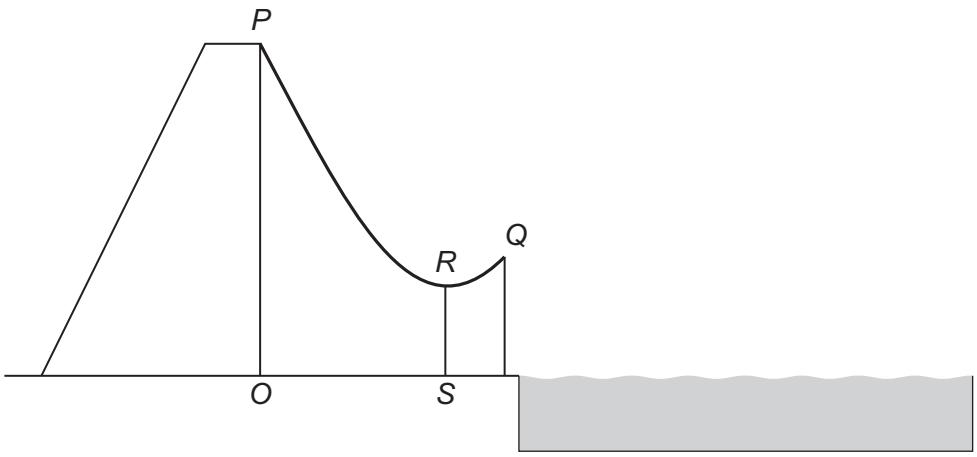
$\frac{dy}{dx} = \frac{dy}{dt} \times \frac{dt}{dx} = \frac{1 - 2t^{-2}}{1 + t^{-2}} = \frac{t^2 - 2}{t^2 + 1}$

Question 9 continues on the next page

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9 (b) (ii) A vertical support, *RS*, is to be added between the ground and the lowest point on the slide as shown in **Figure 2** below.

Figure 2



Find the length of *RS*

[4 marks]

Lowest point R where $\frac{dy}{dx} = 0$: $1 - 2t^{-2} = 0$

$t^2 = 2 \Rightarrow t = \sqrt{2}$ (= 1.414..., which lies in $0.2 \leq t \leq 3$)

$y = \sqrt{2} + \frac{2}{\sqrt{2}} = \sqrt{2} + \sqrt{2} = 2\sqrt{2}$

Length of RS = $2\sqrt{2}$ = 2.828... = 2.83 metres

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9 (b) (iii) Find the acute angle the slide makes with the horizontal at Q

Give your answer to the nearest degree.

[2 marks]

At Q, $t = 3$: $\frac{dy}{dx} = \frac{9-2}{9+1} = \frac{7}{10} = 0.7$

$\tan \alpha = 0.7 \Rightarrow \alpha = \tan^{-1}(0.7) = 34.99...°$

Acute angle $= 35°$

END OF SECTION A

TURN OVER FOR SECTION B

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Section B

Answer **all** questions in the spaces provided.

10 Which of the following is **not** a possible value for a product moment correlation coefficient?

Circle your answer.

[1 mark]

$-\frac{6}{5}$ $-\frac{3}{5}$ 0 1

11 A and B are mutually exclusive events.

Which one of the following statements must be correct?

Tick (✓) **one** box.

[1 mark]

$P(A \cup B) = P(A) \times P(B)$ ☐

$P(A \cup B) = P(A) - P(B)$ ☐

$P(A \cap B) = 0$ ✓

$P(A \cap B) = 1$ ☐

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Turn over for the next question

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12 It is known that, on average, 40% of the drivers who take their driving test at a local test centre pass their driving test.

Each day 32 drivers take their driving test at this centre.

The number of drivers who pass their test on a particular day can be modelled by the distribution B (32, 0.4)

12 (a) State one assumption, in context, required for this distribution to be used.

[1 mark]

The probability of a driver passing the test is constant (0.4)

for every driver, and drivers pass their tests independently.

12 (b) Find the probability that exactly 7 of the drivers on a particular day pass their test.

[1 mark]

$X \sim B(32, 0.4)$

$P(X = 7) = 0.01567... = 0.0157$

12 (c) Find the probability that, at most, 16 of the drivers on a particular day pass their test.

[1 mark]

$P(X \leq 16) = 0.90803... = 0.908$

12 (d) Find the probability that more than 12 of the drivers on a particular day pass their test.

[2 marks]

$P(X > 12) = P(X \geq 13) = 1 - P(X \leq 12)$

$= 1 - 0.46180...$

$= 0.538$

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12 (e) Find the mean number of drivers per day who pass their test.

[1 mark]

Mean = $np = 32 \times 0.4 = 12.8$

12 (f) Find the standard deviation of the number of drivers per day who pass their test.

[2 marks]

Variance = $np(1 - p) = 32 \times 0.4 \times 0.6 = 7.68$

Standard deviation = $\sqrt{7.68} = 2.7712...$

Standard deviation = 2.77

Turn over for the next question

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13 There are two types of coins in a money box:

- 20% are bronze coins
- 80% are silver coins

Craig takes out a coin at random and places it back in the money box.

Craig then takes out a second coin at random.

13 (a) Find the probability that both coins were of the same type.

[2 marks]

$P(\text{both bronze}) = 0.2 \times 0.2 = 0.04$

$P(\text{both silver}) = 0.8 \times 0.8 = 0.64$

$P(\text{both same type}) = 0.04 + 0.64 = 0.68$

13 (b) Find the probability that both coins are bronze, given that at least one of the coins is bronze.

[2 marks]

$P(\text{at least one bronze}) = 1 - P(\text{both silver}) = 1 - 0.64 = 0.36$

$P(\text{both bronze} \mid \text{at least one bronze}) = \frac{P(\text{both bronze})}{P(\text{at least one bronze})}$

$= \frac{0.04}{0.36} = \frac{1}{9}$

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Turn over for the next question

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14 The mass of aluminium cans recycled each day in a city may be modelled by a normal distribution with mean 24 500 kg and standard deviation 5 200 kg.

14 (a) State the probability that the mass of aluminium cans recycled on any given day is **not** equal to 24 500 kg.

[1 mark]

Probability = 1

14 (b) To reduce costs, the city's council decides to collect aluminium cans for recycling less frequently.

Following the decision, it was found that over a 24-day period a total mass of 641 520 kg of aluminium cans was recycled.

It can be assumed that the distribution of the mass of aluminium cans recycled is still normal with standard deviation 5 200 kg, and that the 24-day period can be regarded as a random sample.

Investigate, at the 5% level of significance, whether the mean daily mass of aluminium cans recycled has **changed**.

[7 marks]

H_0: $\mu = 24\,500$ H_1: $\mu \neq 24\,500$ (two-tailed, 5% level)

where μ is the mean daily mass of aluminium cans recycled (kg)

Sample mean $\bar{x} = \frac{641\,520}{24} = 26\,730$

Under H_0: $\bar{X} \sim N(24\,500, \frac{5200^2}{24})$ i.e. variance = 1 126 666.7

Standard error = $\frac{5200}{\sqrt{24}} = 1061.4...$

$P(\bar{X} \geq 26\,730) = 0.01782... = 0.0178$

(test statistic $z = \frac{26\,730 - 24\,500}{5200 \div \sqrt{24}} = 2.10...$)

Two-tailed, so compare with 0.025: $0.0178 < 0.025$

(equivalently $2.10 > 1.96$)

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The result is significant, so reject H_0

There is sufficient evidence at the 5% level of significance to suggest that the mean daily mass of aluminium cans recycled has changed.

14 (c) A member of the council claims that if a different sample of 24 days had been used the hypothesis test in part **(b)** would have given the same result.

Comment on the validity of this claim.

[2 marks]

A different sample of 24 days would probably have a different sample mean, so the test statistic (p-value) could be different. The result of the test could therefore be different (H_0 might not be rejected), so the claim is not valid: it could be wrong.

Turn over for the next question

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15 (a) A random sample of eight cars was selected from the Large Data Set.

The masses of these cars, in kilograms, were as follows.

950 989 1247 1415 1506 1680 1833 2040

It is given that, for the population of cars in the Large Data Set:

$$\text{lower quartile} = 1167$$

$$\text{median} = 1393$$

$$\text{upper quartile} = 1570$$

15 (a) (i) It was decided to remove any of the masses which fall outside the following interval.

$$\text{median} - 1.5\times \text{interquartile range} \leq \text{mass} \leq \text{median} + 1.5\times \text{interquartile range}$$

Show that only one of the eight masses in the sample should be removed.

[3 marks]

IQR = 1570 − 1167 = 403

Lower limit = 1393 − 1.5 × 403 = 1393 − 604.5 = 788.5

Upper limit = 1393 + 1.5 × 403 = 1393 + 604.5 = 1997.5

Interval: 788.5 ≤ mass ≤ 1997.5

Smallest mass 950 > 788.5, so no mass is removed at the lower end.

950, 989, 1247, 1415, 1506, 1680, 1833 all lie in the interval.

2040 > 1997.5, so 2040 kg is outside the interval.

∴ only one mass, 2040 kg, should be removed.

15 (a) (ii) Write down the statistical name for the mass that should be removed in part **(a)(i)**.

[1 mark]

Outlier

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15 (b) The table shows the probability distribution of the number of previous owners, N, for a sample of cars taken from the Large Data Set.

n	0	1	2	3	4	5	6 or more
$\mathbf{P}(N = n)$	0.14	0.37	0.9k	0.25	0.4k	1.7k	0

Find the value of $P(1 \leq N < 5)$

[4 marks]

$\Sigma P(N = n) = 1$:

$0.14 + 0.37 + 0.9k + 0.25 + 0.4k + 1.7k + 0 = 1$

$0.76 + 3k = 1$

$3k = 0.24 \Rightarrow k = 0.08$

$P(1 \leq N < 5) = P(N = 1) + P(N = 2) + P(N = 3) + P(N = 4)$

$= 0.37 + 0.9(0.08) + 0.25 + 0.4(0.08)$

$= 0.37 + 0.072 + 0.25 + 0.032$

$P(1 \leq N < 5) = 0.724$

Question 15 continues on the next page

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15 (c) An expert team is investigating whether there have been any changes in CO_2 emissions from all cars taken from the Large Data Set.

The team decided to collect a quota sample of 200 cars to reflect the different years and the different makes of cars in the Large Data Set.

15 (c) (i) Using your knowledge of the Large Data Set, explain how the team can collect this sample.

[2 marks]

The Large Data Set contains cars from two years (2002 and 2016) and five makes (BMW, Ford, Toyota, Vauxhall, Volkswagen): 10 groups. So the team selects 200 ÷ 10 = 20 cars of each of the five makes from each of the two years, choosing cars until each quota of 20 is filled.

15 (c) (ii) Describe **one disadvantage** of quota sampling.

[1 mark]

The sample is not random, so it could be biased (it may not be representative of the population).

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16 A farm supplies apples to a supermarket.

The diameters of the apples, D centimetres, are normally distributed with mean 6.5 and standard deviation 0.73

16 (a) (i) Find $P(D < 5.2)$

[1 mark]

$D \sim N(6.5, 0.73^2)$

$P(D < 5.2) = 0.03747... = 0.0375$

16 (a) (ii) Find $P(D > 7)$

[1 mark]

$P(D > 7) = 0.24669... = 0.2467$

16 (a) (iii) The supermarket only accepts apples with diameters between 5 cm and 8 cm.

Find the proportion of apples that the supermarket accepts.

[1 mark]

$P(5 < D < 8) = 0.96010... = 0.9601$

Do not write outside the box

16 (b) The farm also supplies plums to the supermarket.

These plums have diameters that are normally distributed.

It is found that 60% of these plums have a diameter less than 5.9 cm.

It is found that 20% of these plums have a diameter greater than 6.1 cm.

Find the mean and standard deviation of the diameter, in centimetres, of the plums supplied by the farm.

[6 marks]

Let $X \sim N(\mu, \sigma^2)$ be the diameter of a plum (cm).

$P(X < 5.9) = 0.6 \Rightarrow P\left(Z < \frac{5.9 - \mu}{\sigma}\right) = 0.6 \Rightarrow z = 0.2533...$

$P(X > 6.1) = 0.2 \Rightarrow P\left(Z < \frac{6.1 - \mu}{\sigma}\right) = 0.8 \Rightarrow z = 0.8416...$

$\frac{5.9 - \mu}{\sigma} = 0.2533 \Rightarrow 5.9 - \mu = 0.2533\sigma \quad (1)$

$\frac{6.1 - \mu}{\sigma} = 0.8416 \Rightarrow 6.1 - \mu = 0.8416\sigma \quad (2)$

$(2) - (1)$: $0.2 = 0.5883\sigma$

$\sigma = 0.2 \div 0.58827... = 0.33997...$

$\mu = 5.9 - 0.2533 \times 0.33997... = 5.8138...$

Mean = 5.81 cm, standard deviation = 0.340 cm

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17 A council found that 70% of its new local businesses made a profit in their first year.

The council introduced an incentive scheme for its residents to encourage the use of new local businesses.

At the end of the scheme, a random sample of 25 new local businesses was selected and it was found that 21 of them had made a profit in their first year.

Using a binomial distribution, investigate, at the 2.5% level of significance, whether there is evidence of an increase in the proportion of new local businesses making a profit in their first year.

[6 marks]

Let p = proportion of new local businesses making a profit in their first year.

H_0: $p = 0.7$ H_1: $p > 0.7$ (one-tailed, 2.5% level)

Under H_0: $X \sim B(25, 0.7)$

$P(X \geq 21) = 1 - P(X \leq 20)$

$= 1 - 0.90952...$

$= 0.0905$ (3 s.f.)

$0.0905 > 0.025$, so the result is not significant.

Do not reject H_0

There is insufficient evidence at the 2.5% level of significance to suggest that the proportion of new local businesses making a profit in their first year has increased.

END OF QUESTIONS

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