AQA

Please write clearly in block capitals.

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

Surname StemUp Model Solution

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Candidate signature _____

# A-level MATHEMATICS

## Paper 2

Wednesday 12 June 2019 Morning 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 require extra space, use an AQA supplementary answer book; do **not** use the space provided for a different question.
- 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 |
| 1 | |
| 2 | |
| 3 | |
| 4 | |
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| **TOTAL** | |

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## Section A

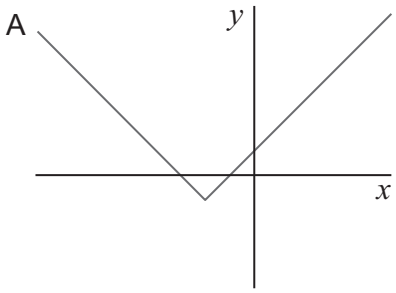
Answer **all** questions in the spaces provided.

**1** Identify the graph of $y = 1 - |x + 2|$ from the options below.

Tick (✓) **one** box.

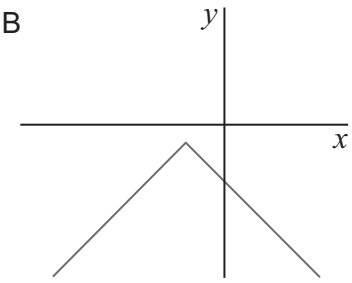
**[1 mark]**

A



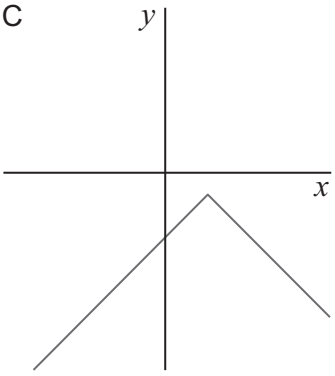

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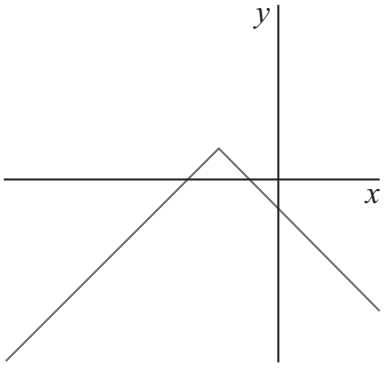

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**2** Simplify $\sqrt{a^{\frac{2}{3}} \times a^{\frac{2}{5}}}$

Circle your answer.

**[1 mark]**

$a^{\frac{2}{15}}$ $a^{\frac{4}{15}}$ $a^{\frac{8}{15}}$ $a^{\frac{16}{15}}$

**3** Each of these functions has domain $x \in \mathbb{R}$

Which function does **not** have an inverse?

Circle your answer.

**[1 mark]**

$f(x) = x^3$ $f(x) = 2x + 1$ $f(x) = x^2$ $f(x) = e^x$

**Turn over for the next question**

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**4** $x^2 + bx + c$ and $x^2 + dx + e$ have a common factor $(x + 2)$

Show that $2(d - b) = e - c$

Fully justify your answer.

**[4 marks]**

$(x + 2)$ is a factor of both, so by the factor theorem each quadratic equals zero when $x = -2$:

$(-2)^2 + b(-2) + c = 0 \Rightarrow 4 - 2b + c = 0$

$(-2)^2 + d(-2) + e = 0 \Rightarrow 4 - 2d + e = 0$

Both expressions equal zero, so

$4 - 2b + c = 4 - 2d + e$

$2d - 2b = e - c$

$\therefore 2(d - b) = e - c$ as required

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**5** Solve the differential equation

$$\frac{dt}{dx} = \frac{\ln x}{x^2 t} \qquad \text{for } x > 0$$

given $x = 1$ when $t = 2$

Write your answer in the form $t^2 = f(x)$

**[7 marks]**

Separating the variables:

$\int t\,dt = \int \frac{\ln x}{x^2}\,dx$

$\frac{t^2}{2} = \int x^{-2} \ln x\,dx$

By parts: $u = \ln x$, $u' = \frac{1}{x}$; $v' = x^{-2}$, $v = -x^{-1} = -\frac{1}{x}$

$\int x^{-2} \ln x\,dx = -\frac{\ln x}{x} - \int \frac{1}{x} \times \left(-\frac{1}{x}\right) dx$

$= -\frac{\ln x}{x} + \int \frac{1}{x^2}\,dx$

$= -\frac{\ln x}{x} - \frac{1}{x} + c$

$\frac{t^2}{2} = -\frac{\ln x}{x} - \frac{1}{x} + c$

$x = 1, t = 2$: $\frac{4}{2} = -\frac{\ln 1}{1} - \frac{1}{1} + c \Rightarrow 2 = 0 - 1 + c$

$c = 3$

$\frac{t^2}{2} = 3 - \frac{\ln x}{x} - \frac{1}{x}$

$t^2 = 6 - \frac{2 \ln x}{x} - \frac{2}{x}$

$t^2 = 6 - \frac{2(1 + \ln x)}{x}$

**Turn over for the next question**

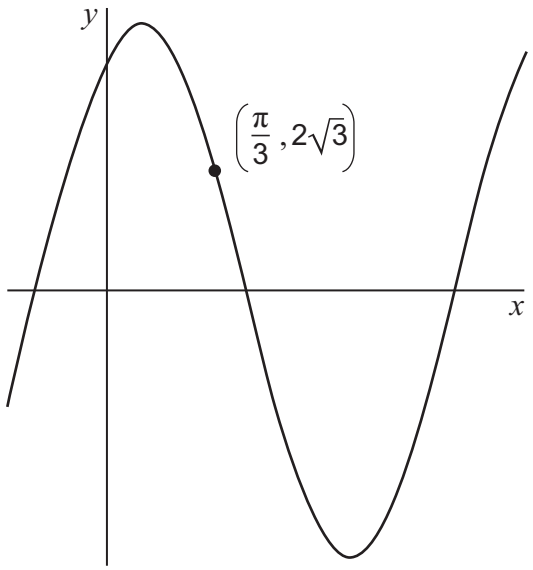
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**6** A curve has equation

$$y = a\sin x + b\cos x$$

where $a$ and $b$ are constants.

The maximum value of $y$ is 4 and the curve passes through the point $\left(\frac{\pi}{3}, 2\sqrt{3}\right)$ as shown in the diagram.




Find the exact values of $a$ and $b$.

**[6 marks]**

$a \sin x + b \cos x \equiv R \sin(x + \alpha) = R \cos\alpha \sin x + R \sin\alpha \cos x$

so $a = R\cos\alpha$, $b = R\sin\alpha$

Maximum value of y is R, so $R = 4$ $(a^2 + b^2 = 16)$

Through $\left(\frac{\pi}{3}, 2\sqrt{3}\right)$: $4\sin\left(\frac{\pi}{3} + \alpha\right) = 2\sqrt{3}$

$\sin\left(\frac{\pi}{3} + \alpha\right) = \frac{\sqrt{3}}{2} \Rightarrow \frac{\pi}{3} + \alpha = \frac{\pi}{3}$ or $\frac{2\pi}{3}$

$\alpha = 0$ or $\alpha = \frac{\pi}{3}$

$\alpha = 0$ gives $y = 4\sin x$, which is 0 when $x = 0$, but the curve crosses the y-axis above 0, so $\alpha = \frac{\pi}{3}$

$a = 4\cos\frac{\pi}{3} = 4 \times \frac{1}{2} = 2$

$b = 4\sin\frac{\pi}{3} = 4 \times \frac{\sqrt{3}}{2} = 2\sqrt{3}$

$a = 2$, $b = 2\sqrt{3}$

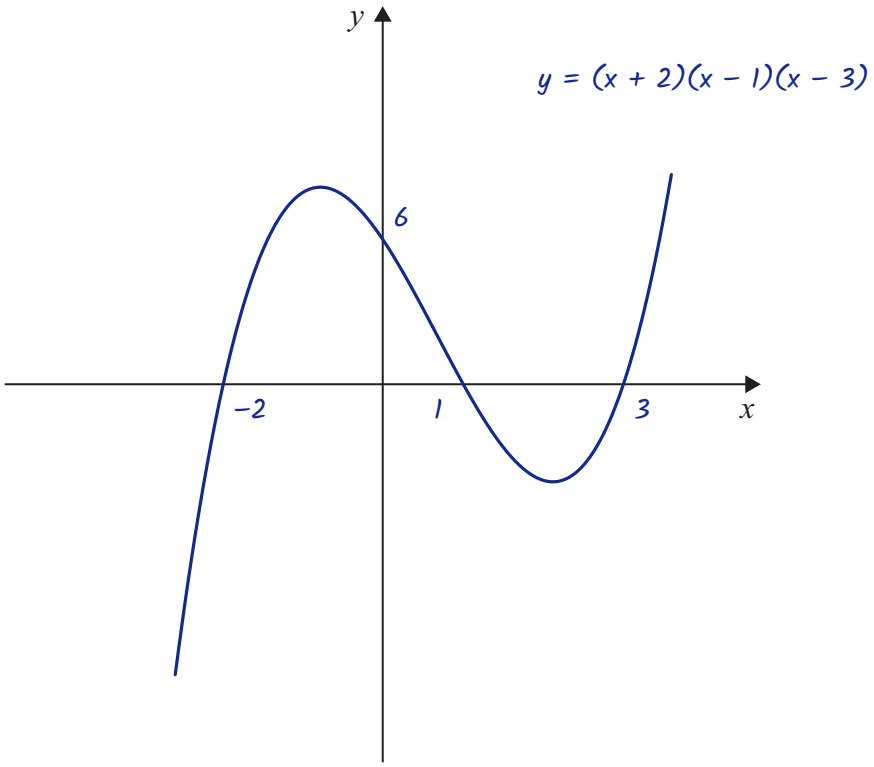
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**7 (a)** Sketch the graph of any cubic function that has **both** three distinct real roots **and** a positive coefficient of $x^3$

**[2 marks]**




**7 (b)** The function $\mathrm{f}(x)$ is defined by

$$\mathrm{f}(x) = x^3 + 3px^2 + q$$

where $p$ and $q$ are constants and $p > 0$

**7 (b) (i)** Show that there is a turning point where the curve crosses the $y$-axis.

**[3 marks]**

f'(x) = 3x² + 6px

At a turning point f'(x) = 0 :

3x² + 6px = 0

3x(x + 2p) = 0

x = 0 or x = −2p

One root is x = 0, so there is a turning point at x = 0, i.e. at

(0, q), which is where the curve crosses the y-axis.

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**7 (b) (ii)** The equation $f(x) = 0$ has three distinct real roots.

By considering the positions of the turning points find, in terms of $p$, the range of possible values of $q$.

**[5 marks]**

$f'(x) = 6x + 6p$

$f'(0) = 6p > 0$ since $p > 0$, so $x = 0$ is a minimum

$f'(-2p) = -12p + 6p = -6p < 0$, so $x = -2p$ is a maximum

$f(0) = q$

$f(-2p) = (-2p)^3 + 3p(-2p)^2 + q$

$= -8p^3 + 12p^3 + q = 4p^3 + q$

For three distinct real roots, the maximum (on the left) must be above the x-axis and the minimum must be below the x-axis:

$4p^3 + q > 0$ and $q < 0$

$q > -4p^3$ and $q < 0$

$-4p^3 < q < 0$

**Turn over for the next question**

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**8** Theresa bought a house on 2 January 1970 for £8000.

The house was valued by a local estate agent on the same date every 10 years up to 2010.

The valuations are shown in the following table.

| **Year** | 1970 | 1980 | 1990 | 2000 | 2010 |
|---|---|---|---|---|---|
| **Valuation price** | £8 000 | £19 000 | £36 000 | £82 000 | £205 000 |

The valuation price of the house can be modelled by the equation

$$V = pq^t$$

where $V$ pounds is the valuation price $t$ years after 2 January 1970 and $p$ and $q$ are constants.

**8 (a)** Show that $V = pq^t$ can be written as $\log_{10} V = \log_{10} p + t \log_{10} q$

**[2 marks]**

$V = pq^t$

$\log_{10} V = \log_{10} (pq^t)$

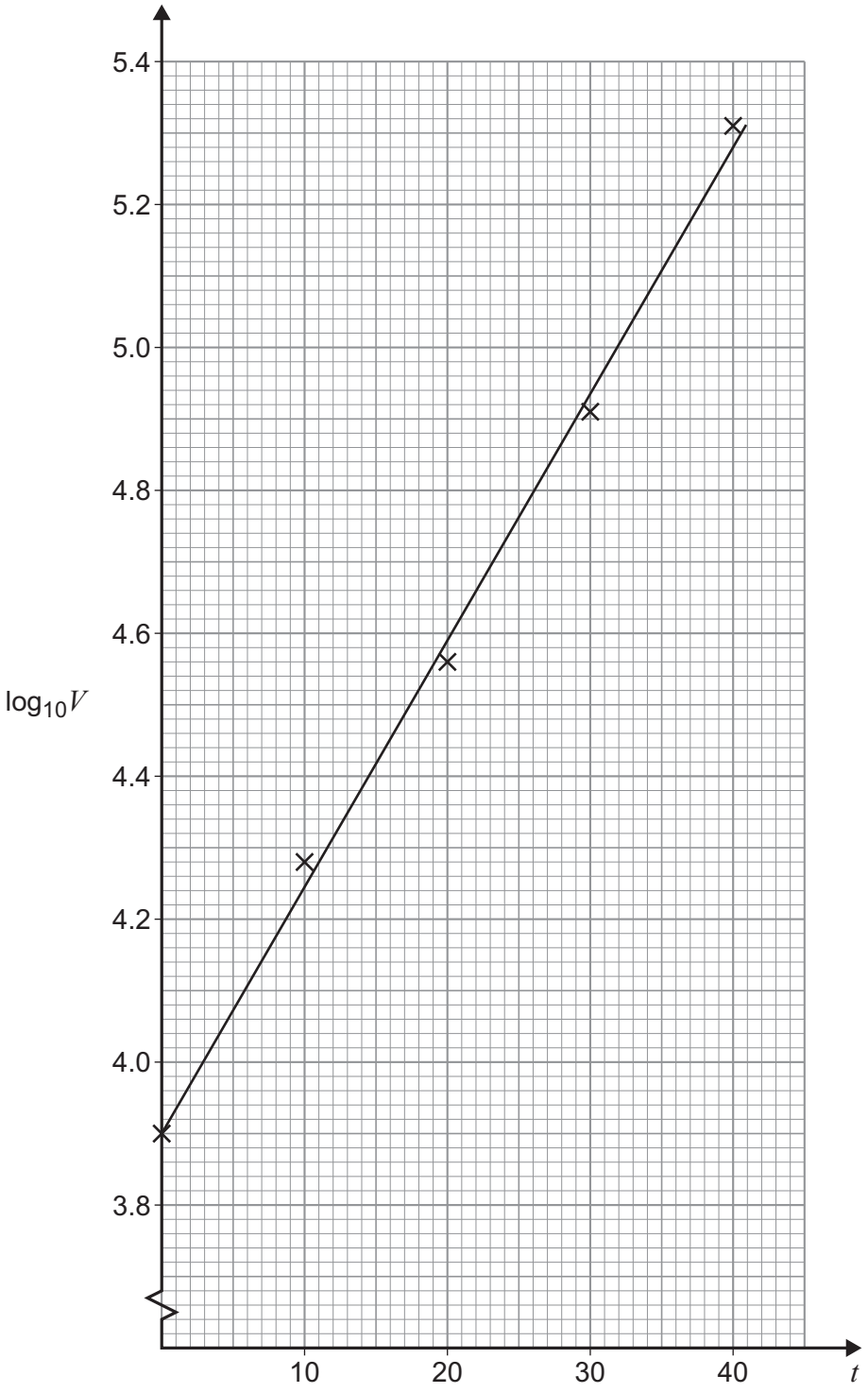
$\log_{10} V = \log_{10} p + \log_{10} q^t$

$\log_{10} V = \log_{10} p + t \log_{10} q$ as required

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**8 (b)** The values in the table of $\log_{10} V$ against $t$ have been plotted and a line of best fit has been drawn on the graph below.

| $t$ | 0 | 10 | 20 | 30 | 40 |
|---|---|---|---|---|---|
| $\log_{10} V$ | 3.90 | 4.28 | 4.56 | 4.91 | 5.31 |




**Question 8 continues on the next page**

**Turn over ▶**

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Using the given line of best fit, find estimates for the values of $p$ and $q$.

Give your answers correct to three significant figures.

**[4 marks]**

Intercept of the line of best fit: $\log_{10} p = 3.90$

$p = 10^{3.90} = 7943.28...$

Gradient: $\log_{10} q = \frac{5.28 - 3.90}{40 - 0} = \frac{1.38}{40} = 0.0345$

$q = 10^{0.0345} = 1.08267...$

$p = 7940$ (3 s.f.)

$q = 1.08$ (3 s.f.)

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**8 (c)** Determine the year in which Theresa's house will first be worth half a million pounds.

**[3 marks]**

$V = 7940 \times 1.08^t$ , $V = 500\,000$

$1.08^t = \frac{500\,000}{7940} = 62.972...$

$t = \frac{\log_{10} 62.972...}{\log_{10} 1.08} = 53.82...$

$1970 + 53.82... = 2023.8...$

The house will first be worth half a million pounds during 2023

**8 (d)** Explain whether your answer to part **(c)** is likely to be reliable.

**[2 marks]**

Not reliable: 2023 is outside the range of the data (1970 to 2010),

so this is extrapolation. House prices may not continue to grow

in the same way indefinitely, e.g. prices could fall in a market crash.

**Turn over for the next question**

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**9 (a)** Show that the first two terms of the binomial expansion of $\sqrt{4-2x^2}$ are

$$2-\frac{x^2}{2}$$

**[2 marks]**

$\sqrt{(4-2x^2)} = (4-2x^2)^{1/2} = 4^{1/2}(1-\frac{x^2}{2})^{1/2} = 2(1-\frac{x^2}{2})^{1/2}$

$\approx 2(1+\frac{1}{2}(-\frac{x^2}{2})+\ldots)$

$= 2(1-\frac{x^2}{4})$

$= 2-\frac{x^2}{2}$ as required

**9 (b)** State the range of values of $x$ for which the expansion found in part **(a)** is valid.

**[2 marks]**

Valid for $|-\frac{x^2}{2}| < 1 \Rightarrow x^2 < 2$

$|x| < \sqrt{2}$, i.e. $-\sqrt{2} < x < \sqrt{2}$

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**9 (c)** Hence, find an approximation for

$$\int_0^{0.4} \sqrt{\cos x}\, \mathrm{d}x$$

giving your answer to five decimal places.

Fully justify your answer.

**[4 marks]**

0.4 radians is small, so $\cos x \approx 1 - \frac{x^2}{2}$ for $0 \leq x \leq 0.4$

$\sqrt{(\cos x)} \approx \sqrt{(1 - \frac{x^2}{2})} = \frac{1}{2}\sqrt{(4 - 2x^2)}$

$\approx \frac{1}{2}(2 - \frac{x^2}{2}) = 1 - \frac{x^2}{4}$ using part (a)

$\int_0^{0.4} \sqrt{(\cos x)}\, dx \approx \int_0^{0.4} (1 - \frac{x^2}{4})\, dx$

$= [x - \frac{x^3}{12}]_0^{0.4}$

$= 0.4 - \frac{0.4^3}{12} - 0$

$= 0.394666...$

$\approx 0.39467$ (5 d.p.)

**9 (d)** A student decides to use this method to find an approximation for

$$\int_0^{1.4} \sqrt{\cos x}\, \mathrm{d}x$$

Explain why this may not be a suitable method.

**[1 mark]**

1.4 radians is not a small angle, so the approximation $\cos x \approx 1 - \frac{1}{2}x^2$ is not valid over this interval.

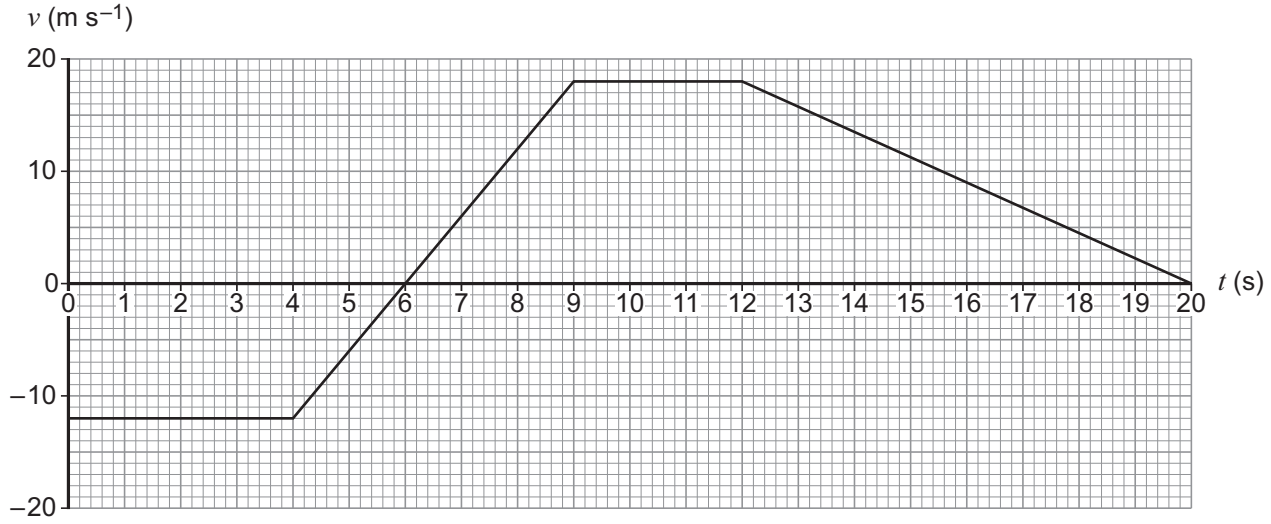
**Turn over for Section B**

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## Section B

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

**10** The diagram below shows a velocity-time graph for a particle moving with velocity $v\,\text{m s}^{-1}$ at time $t$ seconds.




Which statement is correct?

Tick (✓) **one** box.

**[1 mark]**

The particle was stationary for $9 \leq t \leq 12$ ☐

The particle was decelerating for $12 \leq t \leq 20$ ☑

The particle had a displacement of zero when $t = 6$ ☐

The particle's speed when $t = 4$ was $-12\,\text{m s}^{-1}$ ☐

Do not write outside the box

**11** A wooden crate rests on a rough horizontal surface.

The coefficient of friction between the crate and the surface is 0.6

A forward force acts on the crate, parallel to the surface.

When this force is 600 N, the crate is on the point of moving.

Find the weight of the crate.

Circle your answer.

**[1 mark]**

(1000 N) 100 kg 360 N 36 kg

**12** A particle, under the action of two constant forces, is moving across a perfectly smooth horizontal surface at a constant speed of $10\,\text{m}\,\text{s}^{-1}$

The first force acting on the particle is $(400\mathbf{i} + 180\mathbf{j})$ N.

The second force acting on the particle is $(p\mathbf{i} - 180\mathbf{j})$ N.

Find the value of $p$.

Circle your answer.

**[1 mark]**

($-400$) $-390$ 390 400

**Turn over for the next question**

Do not write outside the box

**13** In a school experiment, a particle, of mass $m$ kilograms, is released from rest at a point $h$ metres above the ground.

At the instant it reaches the ground, the particle has velocity $v\,\text{m}\,\text{s}^{-1}$

**13 (a)** Show that

$$v = \sqrt{2gh}$$

**[2 marks]**

Constant acceleration: $u = 0$, $s = h$, $a = g$, final velocity $v$

$v^2 = u^2 + 2as$

$v^2 = 0^2 + 2gh = 2gh$

$v = \sqrt{(2gh)}$ as required $(v > 0)$

**13 (b)** A student correctly used $h = 18$ and measured $v$ as 20

The student's teacher claims that the machine measuring the velocity must have been faulty.

Determine if the teacher's claim is correct.

Fully justify your answer.

**[3 marks]**

Using $g = 9.8$ and $h = 18$ :

$v = \sqrt{(2 \times 9.8 \times 18)} = \sqrt{352.8} = 18.78...$

$v \approx 18.8\ \text{m s}^{-1}$

$18.8 < 20$, so the measured value of 20 m $s^{-1}$ is too large.

The teacher's claim is correct: the machine must be faulty.

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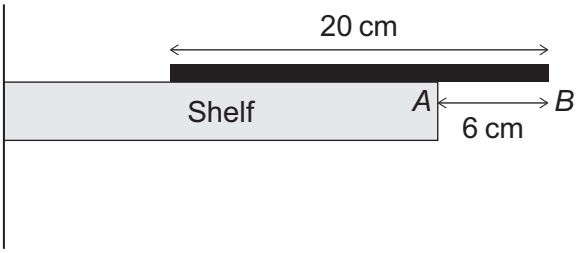
**Turn over for the next question**

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**14** A metal rod, of mass $m$ kilograms and length 20 cm, lies at rest on a horizontal shelf.

The end of the rod, *B*, extends 6 cm beyond the edge of the shelf, *A*, as shown in the diagram below.




**14 (a)** The rod is in equilibrium when an object of mass 0.28 kilograms hangs from the midpoint of *AB*.

Show that $m = 0.21$

**[3 marks]**

Rod uniform: weight mg acts at its midpoint, 10 cm from B,

i.e. 4 cm from A (on the shelf side).

Object at midpoint of AB: 3 cm from A, beyond the shelf.

Rod on the point of tipping, so the reaction acts at A.

Moments about A: $mg \times 0.04 = 0.28g \times 0.03$

$0.04m = 0.0084$

$m = \frac{0.0084}{0.04} = 0.21$ as required

Do not write outside the box

**14 (b)** The object of mass 0.28 kilograms is removed.

A number, $n$, of identical objects, each of mass 0.048 kg, are hung from the rod all at a distance of 1 cm from $B$.

Find the maximum value of $n$ such that the rod remains horizontal.

**[4 marks]**

Objects 1 cm from B, so 6 − 1 = 5 cm from A.

Rod remains horizontal while the moment of the objects about A does not exceed the moment of the rod's weight about A:

Moments about A: $0.048g \times n \times 0.05 \leq 0.21g \times 0.04$

$0.0024n \leq 0.0084$

$n \leq \frac{0.0084}{0.0024} = 3.5$

n must be a whole number, so maximum n = 3

**14 (c)** State one assumption you have made about the rod.

**[1 mark]**

The rod is uniform (its weight acts at its midpoint).

**Turn over for the next question**

Do not write outside the box

**15** Four buoys on the surface of a large, calm lake are located at $A$, $B$, $C$ and $D$ with position vectors given by

$$\overrightarrow{OA} = \begin{bmatrix} 410 \\ 710 \end{bmatrix}, \overrightarrow{OB} = \begin{bmatrix} -210 \\ 530 \end{bmatrix}, \overrightarrow{OC} = \begin{bmatrix} -340 \\ -310 \end{bmatrix} \text{ and } \overrightarrow{OD} = \begin{bmatrix} 590 \\ -40 \end{bmatrix}$$

All values are in metres.

**15 (a)** Prove that the quadrilateral $ABCD$ is a trapezium but **not** a parallelogram.

**[5 marks]**

$AB = OB - OA = \begin{bmatrix} -620 \\ -180 \end{bmatrix}$ $\quad CD = OD - OC = \begin{bmatrix} 930 \\ 270 \end{bmatrix}$

$CD = -1.5\,AB$ , so AB and CD are parallel,

and $|CD| = 1.5|AB|$ , so AB and CD are not equal in length.

$BC = OC - OB = \begin{bmatrix} -130 \\ -840 \end{bmatrix}$ $\quad DA = OA - OD = \begin{bmatrix} -180 \\ 750 \end{bmatrix}$

$\frac{-130}{-180} = \frac{13}{18}$ but $\frac{-840}{750} = -\frac{28}{25}$ , so $BC \neq k\,DA$

so BC and DA are not parallel.

ABCD has one pair of parallel sides (AB and CD), so ABCD is a

trapezium. The other pair of sides (BC and DA) are not parallel

(and $AB \neq CD$ in length), so ABCD is not a parallelogram.

Do not write outside the box

**15 (b)** A speed boat travels directly from $B$ to $C$ at a constant speed in 50 seconds.

Find the speed of the boat between $B$ and $C$.

**[4 marks]**

$BC = \begin{bmatrix} -130 \\ -840 \end{bmatrix}$ (displacement in 50 s)

$|BC| = \sqrt{((-130)^2 + (-840)^2)}$

$= \sqrt{722\,500} = 850$ m

$\text{Speed} = \frac{850}{50} = 17$

Speed = 17 m $s^{-1}$

**Turn over for the next question**

Do not write outside the box

**16** An elite athlete runs in a straight line to complete a 100-metre race.

During the race, the athlete's velocity, $v\,\text{m s}^{-1}$, may be modelled by

$$v = 11.71 - 11.68e^{-0.9t} - 0.03e^{0.3t}$$

where $t$ is the time, in seconds, after the starting pistol is fired.

**16 (a)** Find the maximum value of $v$, giving your answer to one decimal place.

Fully justify your answer.

**[8 marks]**

$\frac{dv}{dt} = -11.68 \times (-0.9)e^{-0.9t} - 0.03 \times 0.3e^{0.3t}$

$\frac{dv}{dt} = 10.512e^{-0.9t} - 0.009e^{0.3t}$

Maximum v occurs at a stationary point, where $\frac{dv}{dt} = 0$ :

$10.512e^{-0.9t} - 0.009e^{0.3t} = 0$

$e^{1.2t} = \frac{10.512}{0.009} = 1168$

$1.2t = \ln 1168 \quad \Rightarrow \quad t = 5.8858...$

$v = 11.71 - 11.68e^{-0.9 \times 5.8858...} - 0.03e^{0.3 \times 5.8858...}$

$v = 11.476...$

$\frac{d^2v}{dt^2} = -9.4608e^{-0.9t} - 0.0027e^{0.3t}$

At $t = 5.8858...$ : $\frac{d^2v}{dt^2} = -0.0631... < 0$ , so this is a maximum

(it is the only stationary point, so it is the maximum value of v)

Maximum v = 11.5 m $s^{-1}$ (1 d.p.)

Do not write outside the box

**16 (b)** Find an expression for the distance run in terms of $t$.

**[6 marks]**

$s = \int v\,dt = \int (11.71 - 11.68e^{-0.9t} - 0.03e^{0.3t})\,dt$

$s = 11.71t + \frac{11.68}{0.9}e^{-0.9t} - \frac{0.03}{0.3}e^{0.3t} + c$

$s = 11.71t + 12.978e^{-0.9t} - 0.1e^{0.3t} + c$

Initial conditions: $s = 0$ when $t = 0$

$0 = 0 + 12.978 - 0.1 + c$

$c = -12.878$

Distance:

$s = 11.71t + 12.978e^{-0.9t} - 0.1e^{0.3t} - 12.878$

**Question 16 continues on the next page**

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**16 (c)** The athlete's actual time for this race is 9.8 seconds.

Comment on the accuracy of the model.

**[2 marks]**

$t = 9.8$ : $s = 11.71(9.8) + 12.978e^{-8.82} - 0.1e^{2.94} - 12.878$

$s = 99.99$ m

The model predicts the athlete runs 99.99 m in 9.8 s, which is very close to 100 m, so the model is accurate.

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**Turn over for the next question**

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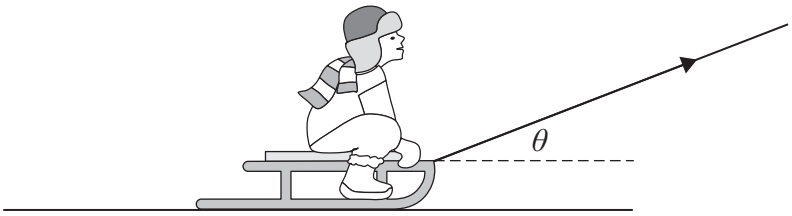
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**17** Lizzie is sat securely on a wooden sledge.

The combined mass of Lizzie and the sledge is $M$ kilograms.

The sledge is being pulled forward in a straight line along a horizontal surface by means of a light inextensible rope, which is attached to the front of the sledge.

This rope stays inclined at an acute angle $\theta$ above the horizontal and remains taut as the sledge moves forward.




The sledge remains in contact with the surface throughout.

The coefficient of friction between the sledge and the surface is $\mu$ and there are no other resistance forces.

Lizzie and the sledge move forward with constant acceleration, $a\,\text{m s}^{-2}$

The tension in the rope is a constant $T$ Newtons.

**17 (a)** Show that

$$T = \frac{M(a + \mu g)}{\cos\theta + \mu \sin\theta}$$

**[7 marks]**

Resolving vertically: $R + T\sin\theta = Mg \Rightarrow R = Mg - T\sin\theta$

N2L horizontally: $T\cos\theta - F = Ma$

The sledge is sliding, so friction is limiting: $F = \mu R$

$T\cos\theta - \mu R = Ma$

$T\cos\theta - \mu(Mg - T\sin\theta) = Ma$

$T\cos\theta + \mu T\sin\theta = Ma + \mu Mg$

$T(\cos\theta + \mu\sin\theta) = M(a + \mu g)$

$T = \dfrac{M(a + \mu g)}{\cos\theta + \mu\sin\theta}$ as required

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**17 (b)** It is known that when $M = 30$, $\theta = 30°$, and $T = 40$, the sledge remains at rest.

Lizzie uses these values with the relationship formed in part **(a)** to find the value for $\mu$

Explain why her value for $\mu$ may be incorrect.

**[2 marks]**

*The sledge is at rest, so friction may not be at its limiting value: $F \leq \mu R$, not necessarily $F = \mu R$. The relationship in (a) uses $F = \mu R$, so it may not be valid here and her $\mu$ may be wrong.*

**END OF QUESTIONS**

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