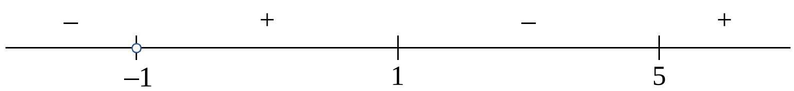
2019 H2 Maths Prelim Paper 1
Solution and Comments

Qn	Solution	Comments
1	$\dfrac{12}{x+1}-(7-x)=\dfrac{12+(x-7)(x+1)}{x+1}$ $=\dfrac{x^2-6x+5}{x+1}$	
	$\dfrac{12}{x+1}\le 7-x$ $\dfrac{x^2-6x+5}{x+1}\le 0$ $\dfrac{(x-1)(x-5)}{x+1}\le 0$  $x<-1$ or $1\le x\le 5$	
2i	$\dfrac{\mathrm{d}}{\mathrm{d}x}\tan^{-1}(x^2)=\dfrac{2x}{1+(x^2)^2}$ $=\dfrac{2x}{1+x^4}$	
ey2ii	$\int_0^1 x\tan^{-1}(x^2)\,\mathrm{d}x=\left[\dfrac{x^2}{2}\tan^{-1}(x^2)\right]_0^1-\int_0^1\dfrac{x^2}{2}\left(\dfrac{2x}{1+x^4}\right)\mathrm{d}x$ $=\dfrac{1}{2}\left(\dfrac{\pi}{4}\right)-\left[\dfrac{1}{4}\ln(1+x^4)\right]_0^1$ $=\dfrac{\pi}{8}-\dfrac{1}{4}\ln 2$	
3i	$\dfrac{\mathrm{d}}{\mathrm{d}x}(3x^2 2^x)=3(x^2 2^x\ln 2+2^{x+1}x)$ $=3x2^x(x\ln 2+2)$	
3ii	At $x=1$, gradient = $6(\ln 2+2)$ $y=6$ Equation of tangent: $y-6=6(\ln 2+2)(x-1)$ $y=6x(\ln 2+2)-6\ln 2-6$	

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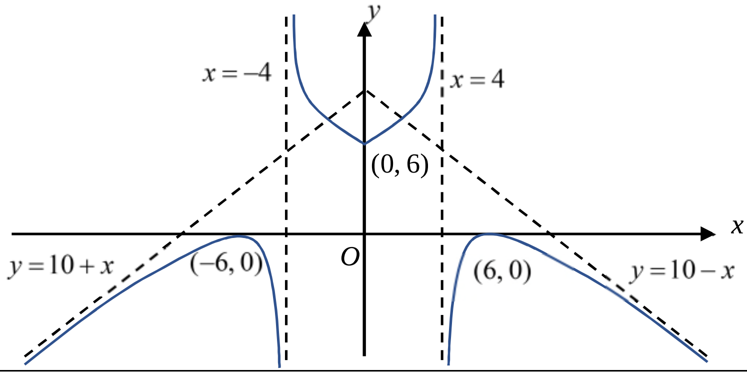
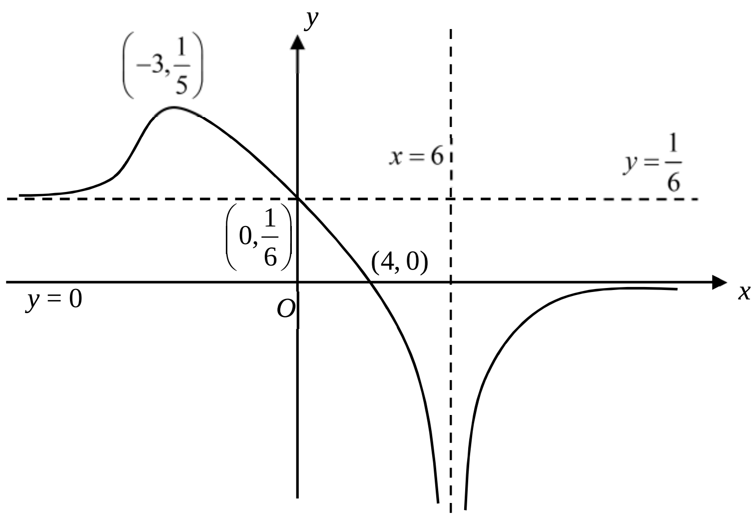
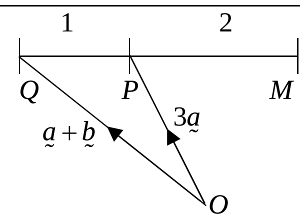
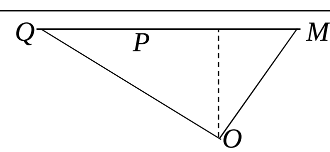
4i		
4ii		
5i	$\overrightarrow{OP} = \frac{2\overrightarrow{OQ} + \overrightarrow{OM}}{3}$ $\overrightarrow{OM} = 3\overrightarrow{OP} - 2\overrightarrow{OQ}$ $= 3(3\underset{\sim}{a}) - 2(\underset{\sim}{a} + \underset{\sim}{b})$ $= 7\underset{\sim}{a} - 2\underset{\sim}{b}$ 	
5ii	$\overrightarrow{PQ} \times \overrightarrow{OM} = (\underset{\sim}{a} + \underset{\sim}{b} - 3\underset{\sim}{a}) \times (7\underset{\sim}{a} - 2\underset{\sim}{b})$ $= (\underset{\sim}{b} - 2\underset{\sim}{a}) \times (7\underset{\sim}{a} - 2\underset{\sim}{b})$ $= 7\underset{\sim}{b} \times \underset{\sim}{a} - 2\underset{\sim}{b} \times \underset{\sim}{b} - 14\underset{\sim}{a} \times \underset{\sim}{a} + 4\underset{\sim}{a} \times \underset{\sim}{b}$ Since $\underset{\sim}{a} \times \underset{\sim}{a} = \underset{\sim}{b} \times \underset{\sim}{b} = \underset{\sim}{0}$ and $\underset{\sim}{a} \times \underset{\sim}{b} = -\underset{\sim}{b} \times \underset{\sim}{a}$, $\overrightarrow{PQ} \times \overrightarrow{OM} = 3\underset{\sim}{b} \times \underset{\sim}{a}$	
5iii	$\frac{\lvert \overrightarrow{PQ} \times \overrightarrow{OM} \rvert}{\lvert \overrightarrow{PQ} \rvert} = \left\lvert \overrightarrow{OM} \times \frac{\overrightarrow{PQ}}{\lvert \overrightarrow{PQ} \rvert} \right\rvert$  $\frac{\lvert \overrightarrow{PQ} \times \overrightarrow{OM} \rvert}{\lvert \overrightarrow{PQ} \rvert}$ is the shortest distance from *O* to line *PQ*.	

<table>
<tr><th>Qn</th><th>Solution</th><th>Comments</th></tr>
<tr><td>6i</td><td>

Let $y=\dfrac{12-3x}{x^2+4x-5}$ $\Rightarrow yx^2+(4y+3)x+(-5y-12)=0$

When x is real $\Rightarrow$ discriminant $\geqslant 0$

$\Rightarrow (4y+3)^2-4y(-5y-12)\geqslant 0$

$\Rightarrow 16y^2+24y+9+20y^2+48y\geqslant 0$

$\Rightarrow 36y^2+72y+9\geqslant 0$

$\Rightarrow 36(y+1.8660)(y+0.13397)\geqslant 0$

$+$ $-$ $+$

-1.8660 -0.13397

$y\leqslant -1.8660$ or $y\geqslant -0.13397$

$R_f=(-\infty,-1.87]\cup[-0.134,\infty)$

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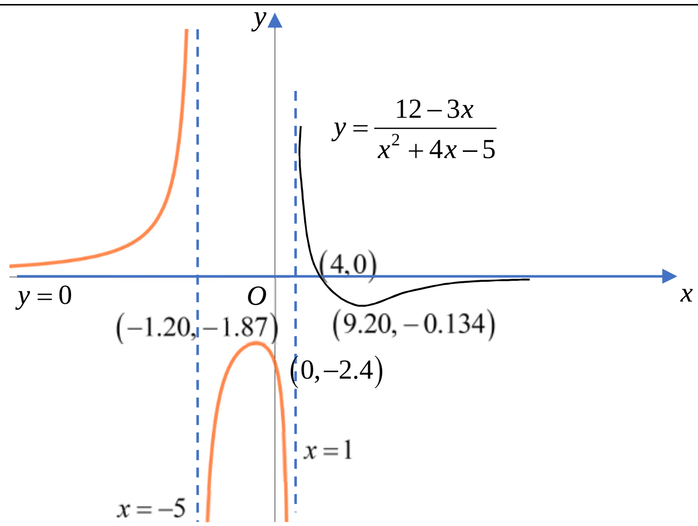
<tr><td>6ii</td><td>



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<tr><td>6iii</td><td>

$y=\dfrac{12-3x}{(x-1)(x+5)}$

Stretch parallel to the y-axis with x-axis invariant with factor $\dfrac{1}{3}$:

$y=\dfrac{4-x}{(x-1)(x+5)}$

Translate in the positive x-direction by 5 units:

$y=\dfrac{4-(x-5)}{(x-5-1)(x-5+5)}$ ie. $y=\dfrac{9-x}{(x-6)(x)}$

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7	$\sin^{-1} y = \ln(1+x)$ $\frac{1}{\sqrt{1-y^2}}\frac{\mathrm{d}y}{\mathrm{d}x} = \frac{1}{1+x}$ $(1+x)\frac{\mathrm{d}y}{\mathrm{d}x} = \sqrt{1-y^2}$	
7i	$(1+x)\frac{\mathrm{d}y}{\mathrm{d}x} = \sqrt{1-y^2}$ $\frac{\mathrm{d}y}{\mathrm{d}x} + (1+x)\frac{\mathrm{d}^2y}{\mathrm{d}x^2} = -\frac{y}{\sqrt{1-y^2}}\left(\frac{\mathrm{d}y}{\mathrm{d}x}\right)$ When $x = 0$, $y = 0$, $\frac{\mathrm{d}y}{\mathrm{d}x} = 1$, $\frac{\mathrm{d}^2y}{\mathrm{d}x^2} = -\frac{\mathrm{d}y}{\mathrm{d}x} = -1$ $y = 0 + x - \frac{1}{2!}x^2 + \ldots \approx x - \frac{1}{2}x^2$	
7ii	$\sin^{-1} y = \ln(1+x)$ $y = \sin(\ln(1+x)) \approx x - \frac{1}{2}x^2$ $\int \frac{\sin(\ln(1+x))}{x}\,\mathrm{d}x \approx \int \left(1 - \frac{1}{2}x\right)\mathrm{d}x$ $= x - \frac{x^2}{4} + C$ $\int_0^{0.5} \frac{\sin(\ln(1+x))}{x}\,\mathrm{d}x \approx \left[x - \frac{x^2}{4}\right]_0^{0.5}$ $= 0.4375$	
8i	The sum of the numbers in the first row: $\frac{8}{2}[2a_1 + 7d] = 58 \Rightarrow 4a_1 + 14d = 29$ ------- (1) The sum of the numbers in the third column: $a_3, a_{11}, a_{19}, \cdots, a_{59}$ are in arithmetic progression with common difference 8*d*. $a_3 + a_{11} + a_{19} + \cdots + a_{59} = \frac{8}{2}[2(a_1 + 2d) + 7(8d)] = 376$ $\Rightarrow a_1 + 30d = 47$ ------- (2) By GC, $a_1 = 2$, $d = 1.5$	
8ii	Sum to infinity $= 2 \Rightarrow \frac{a}{1-r} = 2$ -------------- (1) Sum of the terms from the 4th term to 9th term: $\frac{ar^3(1-r^6)}{1-r} = -\frac{63}{256}$ -------- (2) Sub (1) into (2):	

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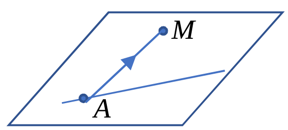
	$2r^3\left(1-r^6\right)=-\dfrac{63}{256}$ $\Rightarrow 512r^3-512r^9=-63$ $\Rightarrow 512r^9-512r^3-63=0$ From the GC, $r=1.02(\text{NA})$, -0.977 or -0.5 as $-1<r<1$ for the sum to infinity to exist.	
9i	Coefficients of equation are real $\Rightarrow b+\sqrt{2}\mathrm{i}$ is also a root. $z^3-az-66=\left(z-b+\sqrt{2}\mathrm{i}\right)\left(z-b-\sqrt{2}\mathrm{i}\right)\left(z+k\right)$ $=\left[(z-b)^2-\left(\sqrt{2}\mathrm{i}\right)^2\right]\left(z+k\right)$ $=\left(z^2-2bz+b^2+2\right)\left(z+k\right)$ $=z^3+\left(-2b+k\right)z^2+\left(b^2+2-2bk\right)z+k\left(b^2+2\right)$ Comparing coefficients of z^2, z and constant: $-2b+k=0$ $\left(b^2+2\right)-2kb=-a$ $k\left(b^2+2\right)=-66$ Solving the equations, $k=2b \quad \Rightarrow 2b\left(b^2+2\right)=-66 \qquad \Rightarrow b=-3$ **Alternatively** Substitute $z=b-\sqrt{2}\mathrm{i}$ $\left(b-\sqrt{2}\mathrm{i}\right)^3-a\left(b-\sqrt{2}\mathrm{i}\right)-66=0$ $b^3+3b^2\left(-\sqrt{2}\mathrm{i}\right)+3b\left(-\sqrt{2}\mathrm{i}\right)^2+\left(-\sqrt{2}\mathrm{i}\right)^3-ab+\sqrt{2}a\mathrm{i}-66=0$ Comparing real and imaginary parts $b^3-6b-ab-66 = 0 \quad --(1)$ $-3\sqrt{2}b^2+2\sqrt{2}+\sqrt{2}a = 0 \quad --(2)$ From (2): $a=3b^2-2--(3)$ Substitute (3) into (1): $b^3-6b-b\left(3b^2-2\right)-66=0$ $2b^3+4b+66=0$ $b=-3$ $b=-3\Rightarrow a=25$ $\dfrac{w}{w^*}=\dfrac{-3-\sqrt{2}\mathrm{i}}{-3+\sqrt{2}\mathrm{i}}\times\dfrac{-3-\sqrt{2}\mathrm{i}}{-3-\sqrt{2}\mathrm{i}}=\dfrac{7+6\sqrt{2}\mathrm{i}}{11}$	

Qn	Solution	Comments
9ii	w is a root $\Rightarrow w^3 - aw - 66 = 0 \quad \Rightarrow aw + 66 = w^3 \Rightarrow aw^2 + 66w = w^4$ $w^4 = \left(re^{i\theta}\right)^4 = r^4 e^{i(4\theta)}$ $\therefore \left\|aw^2 + 66w\right\| = \left\|w^4\right\| = r^4$ $\arg\left(aw^2 + 66w\right) = \arg\left(r^4 e^{i(4\theta)}\right)$ $-\pi < \theta < -\frac{3\pi}{4} \quad \Rightarrow -4\pi < 4\theta < -3\pi \qquad \Rightarrow 0 < 4\theta + 4\pi < \pi$ $\therefore \arg\left(aw^2 + 66w\right) = 4\theta + 4\pi$	
10i	Equation of l_1 is $\underset{\sim}{r} = \begin{pmatrix} 7 \\ 0 \\ -2 \end{pmatrix} + s\begin{pmatrix} 1 \\ 3 \\ -2 \end{pmatrix}, s \in \mathbb{R}$ $\begin{pmatrix} 1 \\ 3 \\ -2 \end{pmatrix} \cdot \begin{pmatrix} 4 \\ -2 \\ -1 \end{pmatrix} = 4 - 6 + 2 = 0$ $\therefore$ line l_1 is perpendicular to normal vector of π. $\therefore$ line l_1 is parallel to π. $\begin{pmatrix} 7 \\ 0 \\ -2 \end{pmatrix} \cdot \begin{pmatrix} 4 \\ -2 \\ -1 \end{pmatrix} = 28 + 0 + 2 = 30$ $\therefore (7, 0, -2)$ is in π. Thus, l_1 is in π.	
10ii	Let $A(7, 0, -2)$.  $\overrightarrow{AM} = \begin{pmatrix} 6 \\ -5 \\ 11 \end{pmatrix} - \begin{pmatrix} 7 \\ 0 \\ -2 \end{pmatrix} = \begin{pmatrix} -1 \\ -5 \\ 13 \end{pmatrix}$ normal vector of plane $= \begin{pmatrix} -1 \\ -5 \\ 13 \end{pmatrix} \times \begin{pmatrix} 1 \\ 3 \\ -2 \end{pmatrix} = \begin{pmatrix} -29 \\ 11 \\ 2 \end{pmatrix}$ $\begin{pmatrix} 7 \\ 0 \\ -2 \end{pmatrix} \cdot \begin{pmatrix} -29 \\ 11 \\ 2 \end{pmatrix} = -207$ Cartesian equation of the plane is $-29x + 11y + 2z = -207$	
10iii	Since N is a point on l_1, $\overrightarrow{ON} = \begin{pmatrix} 7 \\ 0 \\ -2 \end{pmatrix} + s\begin{pmatrix} 1 \\ 3 \\ -2 \end{pmatrix}$, for some $s \in \mathbb{R}$	

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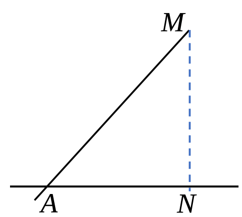
	$\overrightarrow{MN}\cdot\begin{pmatrix}1\\3\\-2\end{pmatrix}=0$ $\left[\left(\begin{pmatrix}7\\0\\-2\end{pmatrix}+s\begin{pmatrix}1\\3\\-2\end{pmatrix}\right)-\begin{pmatrix}6\\-5\\11\end{pmatrix}\right]\cdot\begin{pmatrix}1\\3\\-2\end{pmatrix}=0$ $\left[\begin{pmatrix}1\\5\\-13\end{pmatrix}+s\begin{pmatrix}1\\3\\-2\end{pmatrix}\right]\cdot\begin{pmatrix}1\\3\\-2\end{pmatrix}=0$ $42+14s=0$ $s=-3$ $\therefore\overrightarrow{ON}=\begin{pmatrix}7-3\\3(-3)\\-2-2(-3)\end{pmatrix}=\begin{pmatrix}4\\-9\\4\end{pmatrix}$ Alternatively, $\overrightarrow{AN}=\left(\overrightarrow{AM}\cdot\frac{1}{\sqrt{14}}\begin{pmatrix}1\\3\\-2\end{pmatrix}\right)\frac{1}{\sqrt{14}}\begin{pmatrix}1\\3\\-2\end{pmatrix}$ $=\frac{1}{14}\left(\left(\begin{pmatrix}6\\-5\\11\end{pmatrix}-\begin{pmatrix}7\\0\\-2\end{pmatrix}\right)\cdot\begin{pmatrix}1\\3\\-2\end{pmatrix}\right)\begin{pmatrix}1\\3\\-2\end{pmatrix}$ $=\frac{1}{14}\left(\begin{pmatrix}-1\\-5\\13\end{pmatrix}\cdot\begin{pmatrix}1\\3\\-2\end{pmatrix}\right)\begin{pmatrix}1\\3\\-2\end{pmatrix}$ $=\frac{-1-15-26}{14}\begin{pmatrix}1\\3\\-2\end{pmatrix}$ $=\begin{pmatrix}-3\\-9\\6\end{pmatrix}$  $\therefore\overrightarrow{ON}=\begin{pmatrix}7\\0\\-2\end{pmatrix}+\begin{pmatrix}-3\\-9\\6\end{pmatrix}=\begin{pmatrix}4\\-9\\4\end{pmatrix}$ Area of triangle = $\frac{1}{2}\left\|\overrightarrow{OM}\times\overrightarrow{ON}\right\|$ $=\frac{1}{2}\left\|\begin{pmatrix}6\\-5\\11\end{pmatrix}\times\begin{pmatrix}4\\-9\\4\end{pmatrix}\right\|$ $=\frac{1}{2}\left\|\begin{pmatrix}79\\20\\-34\end{pmatrix}\right\|$ $=44.2\text{ unit}^2$	
\10iv	Let θ be the angle between the normal of π and l_2. $\overrightarrow{MN}=\begin{pmatrix}4\\-9\\4\end{pmatrix}-\begin{pmatrix}6\\-5\\11\end{pmatrix}=\begin{pmatrix}-2\\-4\\-7\end{pmatrix}$	

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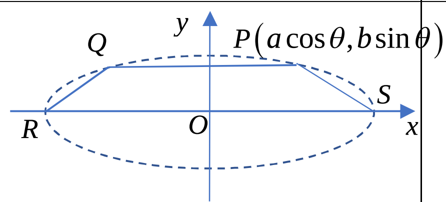
	$\cos\theta = \dfrac{\begin{pmatrix}-2\\-4\\-7\end{pmatrix}\cdot\begin{pmatrix}4\\-2\\-1\end{pmatrix}}{\sqrt{69}\sqrt{21}} = \dfrac{7}{\sqrt{69}\sqrt{21}}$ $\theta = 79.403°$ Acute angle between π and $l_2 =$ $90° - 79.403° = 10.6°$	
11i	Given the curve $\dfrac{x^2}{a^2}+\dfrac{y^2}{b^2}=1$,  LHS $= \dfrac{(a\cos\theta)^2}{a^2}+\dfrac{(b\sin\theta)^2}{b^2}$ $=\cos^2\theta+\sin^2\theta$ $=1=$ RHS $P(a\cos\theta,\ b\sin\theta)$ lies on the curve. Q is $(-a\cos\theta,\ b\sin\theta)$. [by symmetry in the y-axis]	
11ii	V = cylinder + 2 identical cones $=\pi(b\sin\theta)^2(2a\cos\theta)+2*\dfrac{1}{3}\pi(b\sin\theta)^2(a-a\cos\theta)$ $=\dfrac{2}{3}\pi b^2\sin^2\theta(3a\cos\theta+a-a\cos\theta)$ $=\dfrac{2}{3}\pi ab^2\sin^2\theta(2\cos\theta+1)$ $\therefore k=\dfrac{2}{3}ab^2$	
11iii	At $\theta=\theta_1$, $\dfrac{dV}{d\theta}=0$ $\dfrac{dV}{d\theta}=\dfrac{2}{3}\pi ab^2\left[\sin^2\theta(-2\sin\theta)+(2\cos\theta+1)(2\sin\theta\cos\theta)\right]=0$ $\sin\theta\left(-2\sin^2\theta+2\cos\theta+4\cos^2\theta\right)=0$ $\sin\theta=0$ or $-2(1-\cos^2\theta)+2\cos\theta+4\cos^2\theta=0$ $\left(\text{NA since } 0<\theta<\dfrac{\pi}{2}\right)$ $6\cos^2\theta+2\cos\theta-2=0$ $3\cos^2\theta+\cos\theta-1=0$ (shown) $\cos\theta=0.43425, -0.76759\left(\text{NA } \because 0<\theta<\dfrac{\pi}{2}\right)$ $\Rightarrow\theta_1=1.1216\approx1.12$ $\dfrac{dV}{d\theta}=\dfrac{2}{3}\pi ab^2\left[-2\sin^3\theta+(2\cos\theta+1)\sin2\theta\right]$ $\dfrac{d^2V}{d\theta^2}=\dfrac{2}{3}\pi ab^2\left[-6\sin^2\theta\cos\theta+(-2\sin\theta)\sin2\theta\right.$ $\left.+2\cos2\theta(2\cos\theta+1)\right]$	

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	When $\theta_1 = 1.1216$, $\dfrac{\mathrm{d}^2V}{\mathrm{d}\theta^2} = -3.90\pi ab^2$ Since a and b are positive, $\dfrac{\mathrm{d}^2V}{\mathrm{d}\theta^2} < 0$ Hence, θ_1 gives a maximum value of V.	
11iv	$\text{Volume} = \pi\int_{a\cos\left(\frac{\pi}{6}\right)}^{a} y^2 \ \mathrm{d}x$ $= \pi\int_{\frac{\sqrt{3}}{2}a}^{a} b^2\left(1-\dfrac{x^2}{a^2}\right)\mathrm{d}x$ $= \pi b^2\int_{\frac{\sqrt{3}}{2}a}^{a} \left(1-\dfrac{x^2}{a^2}\right)\mathrm{d}x$ $= \pi b^2\left[x-\dfrac{x^3}{3a^2}\right]_{\frac{\sqrt{3}}{2}a}^{a}$ $= \pi b^2\left\{\left(a-\dfrac{a^3}{3a^2}\right)-\left(\dfrac{\sqrt{3}}{2}a-\dfrac{3\sqrt{3}a^3}{24a^2}\right)\right\}$ $= \pi ab^2\left(\dfrac{2}{3}-\dfrac{3\sqrt{3}}{8}\right)$ (**or** $0.0171\pi ab^2$)	
12i	$\dfrac{\mathrm{d}v}{\mathrm{d}t} = 10-0.001v^2 = \dfrac{10000-v^2}{1000}$ $\Rightarrow \int \dfrac{1}{10000-v^2}\mathrm{d}v = \int \dfrac{1}{1000}\mathrm{d}t$ $\Rightarrow \dfrac{1}{200}\ln\left\|\dfrac{100+v}{100-v}\right\| = \dfrac{t}{1000}+d$ $\Rightarrow \ln\left\|\dfrac{100+v}{100-v}\right\| = \dfrac{t}{5}+d'$ $\Rightarrow \left\|\dfrac{100+v}{100-v}\right\| = C\mathrm{e}^{\frac{t}{5}}$ $\Rightarrow \dfrac{100+v}{100-v} = D\mathrm{e}^{\frac{t}{5}}$ $t=0, v=0 \Rightarrow D=1$ $\dfrac{100+v}{100-v} = \mathrm{e}^{\frac{t}{5}} \Rightarrow 100+v = \mathrm{e}^{\frac{t}{5}}(100-v) \Rightarrow v\left(\mathrm{e}^{\frac{t}{5}}+1\right) = 100\mathrm{e}^{\frac{t}{5}}-100$ $v = 100\left(\dfrac{\mathrm{e}^{\frac{t}{5}}-1}{\mathrm{e}^{\frac{t}{5}}+1}\right)$ (shown)	
12ii	Method 1: $v = 100\left(\dfrac{\mathrm{e}^{\frac{t}{5}}-1}{\mathrm{e}^{\frac{t}{5}}+1}\right) = 100\left(1-\dfrac{2}{\mathrm{e}^{\frac{t}{5}}+1}\right)$	

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	When $t \to \infty$, $\dfrac{1}{e^{\frac{t}{5}}+1} \to 0$, $v \to 100$ $\therefore v_0 = 100$ Method 2: $v = 100\left(\dfrac{e^{\frac{t}{5}}-1}{e^{\frac{t}{5}}+1}\right) = 100\left(\dfrac{e^{\frac{t}{5}}\left(1-e^{-\frac{t}{5}}\right)}{e^{\frac{t}{5}}\left(1+e^{-\frac{t}{5}}\right)}\right)$ When $t \to \infty$, $e^{-\frac{t}{5}} \to 0$, $v \to 100$ $\therefore v_0 = 100$ Method 3: When $t \to \infty$, $\dfrac{1}{e^{\frac{t}{5}}+1} \to 0$, $v \to 100$ $\therefore v_0 = 100$ $v = 100\left(\dfrac{e^{\frac{t}{5}}-1}{e^{\frac{t}{5}}+1}\right) \to 100\left(\dfrac{e^{\frac{t}{5}}}{e^{\frac{t}{5}}}\right)$ $v \to 100$ $\therefore v_0 = 100$	
12iii	$\dfrac{dv}{dt} = \dfrac{dv}{dx}\dfrac{dx}{dt}$ $\Rightarrow 10 - 0.001v^2 = \dfrac{dv}{dx}(v)$ $\Rightarrow \int 1\,dx = \int \dfrac{v}{10-0.001v^2}dv = \int \dfrac{1000v}{10000-v^2}dv$ $\Rightarrow -500\int \dfrac{-2v}{10000-v^2}dv = x + c$ $\Rightarrow \ln\left\|10000-v^2\right\| = -\dfrac{x}{500} + c'$ $\Rightarrow \left\|10000-v^2\right\| = Ae^{-\frac{x}{500}}$ $\Rightarrow 10000 - v^2 = Be^{-\frac{x}{500}}$ $x = 0, v = 0 \Rightarrow B = 10000$ $10000 - v^2 = 10000e^{-\frac{x}{500}}$ $v^2 = 10000 - 10000e^{-\frac{x}{500}}$ $v \geqslant 0$ $\Rightarrow v = 100\sqrt{1-e^{-\frac{x}{500}}}$ (shown)	
12iv	When $t = 5, v = 100\left(\dfrac{e-1}{e+1}\right) = 46.2117$ When $v = 46.2117, 46.2117 = 100\sqrt{1-e^{-\frac{x}{500}}}$ $\therefore x = 120.11$ The required distance is 120.11 m.	

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