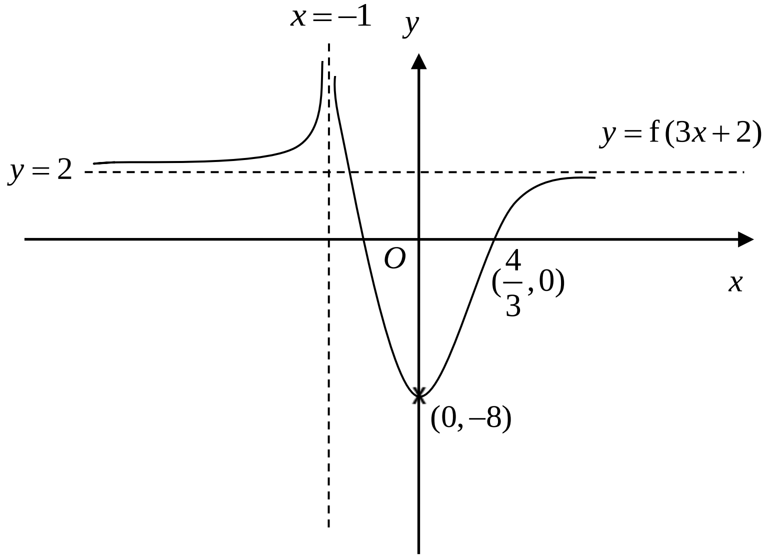
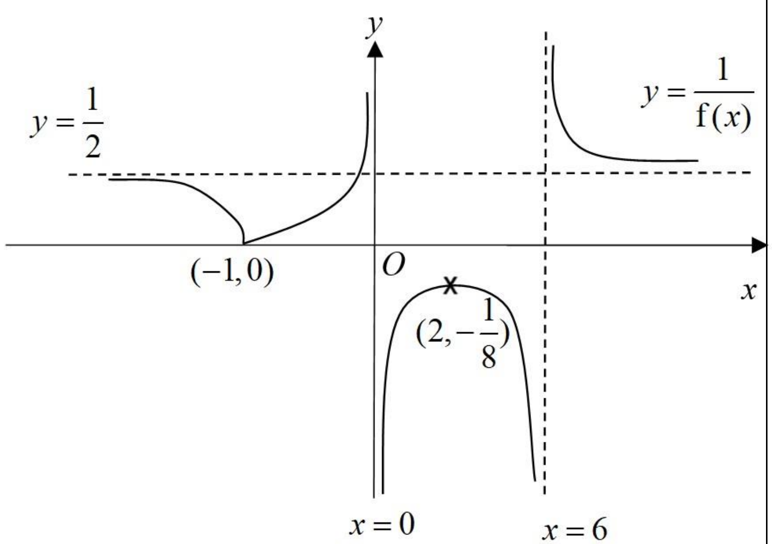
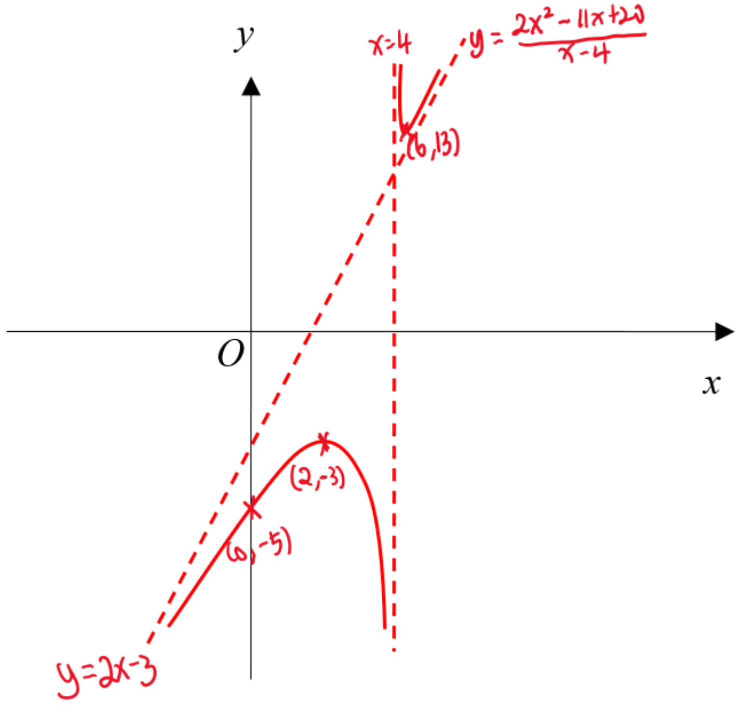
2024 JC1 H2 MATH

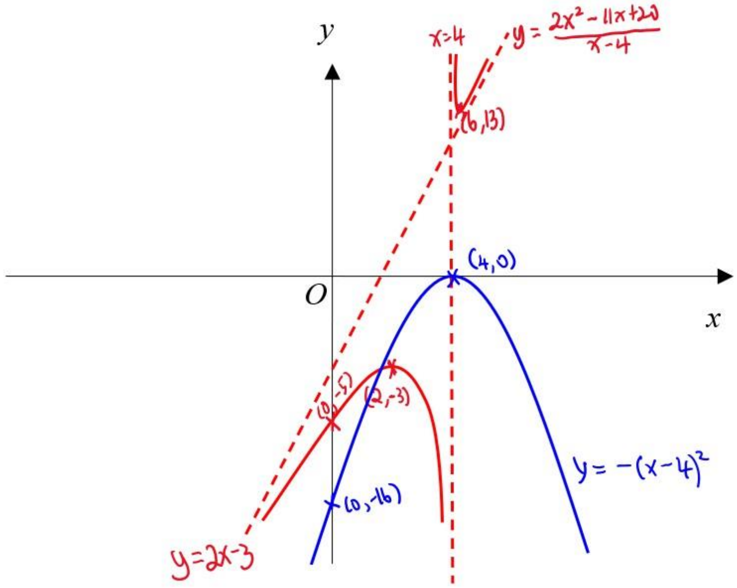
1	Solution [5] Solving system of linear equations	
	$y=\frac{a}{x^2}+\frac{b}{x}+c$ Substitute $\left(-2,-\frac{11}{2}\right)$ $\Rightarrow \frac{a}{4}-\frac{b}{2}+c=-\frac{11}{2}$ $\Rightarrow a-2b+4c=-22$ ---(1) $\frac{\mathrm{d}y}{\mathrm{d}x}=-\frac{2a}{x^3}-\frac{b}{x^2}$ When $x=1, \frac{\mathrm{d}y}{\mathrm{d}x}=0$ $\Rightarrow -2a-b=0$ $\Rightarrow 2a+b=0$ ---(2) When $x=2, \frac{\mathrm{d}y}{\mathrm{d}x}=-\frac{3}{2}$ $\Rightarrow -\frac{a}{4}-\frac{b}{4}=-\frac{3}{2}$ $\Rightarrow a+b=6$ ---(3) Solving (1), (2) and (3), from GC, $a=-6,\ b=12,\ c=2$ Equation of C is $y=-\frac{6}{x^2}+\frac{12}{x}+2$	

2	Solution [5] Transformation of graphs	
(i)		
(b)		

3	Solution [5] Solving inequalities	
(i)	$\dfrac{9}{x^2-5} > -1$ $\dfrac{9}{x^2-5} + 1 > 0$ $\dfrac{x^2+4}{x^2-5} > 0$ Since $x^2+4>0$ as $x^2 \geq 0$, hence $x^2-5>0$ $\left(x+\sqrt{5}\right)\left(x-\sqrt{5}\right)>0$ $+ \qquad - \qquad +$ $-\sqrt{5} \qquad \sqrt{5}$ $x<-\sqrt{5}$ or $x>\sqrt{5}$	
(b)	Replacing x with e^x, $\dfrac{9}{e^{2x}-5} > -1$ Using result in (i), $e^x < -\sqrt{5}$ or $e^x > \sqrt{5}$ (Reject as $e^x > 0$ for all real x) $\quad x > \ln\left(\sqrt{5}\right)$ $x > \dfrac{1}{2}\ln 5$ Therefore $x > \dfrac{1}{2}\ln 5$.	

4	Solution [6] Sigma Notation	
(a)	$\sum_{r=n}^{2n}(r+1)^3 = \sum_{k=n+1}^{2n+1} k^3$ $= \sum_{k=1}^{2n+1} k^3 - \sum_{k=1}^{n} k^3$ $= \frac{1}{4}(2n+1)^2(2n+2)^2 - \frac{1}{4}n^2(n+1)^2$ $= (n+1)^2(2n+1)^2 - \frac{1}{4}n^2(n+1)^2$ $= \frac{1}{4}(n+1)^2\left[4(2n+1)^2 - n^2\right]$ Therefore $a = 4$	
(b)	$1^3 + 3^3 + \ldots + (2k-1)^3 = \sum_{r=1}^{2k} r^3 - \sum_{r=1}^{k}(2r)^3$ $= \sum_{r=1}^{2k} r^3 - 8\sum_{r=1}^{k} r^3$ $= \frac{1}{4}(2k)^2(2k+1)^2 - \frac{1}{4}(8)(k)^2(k+1)^2$ $= (k)^2(2k+1)^2 - 2(k)^2(k+1)^2$ $= (k)^2(2k^2-1)$ $= 2k^4 - k^2$	

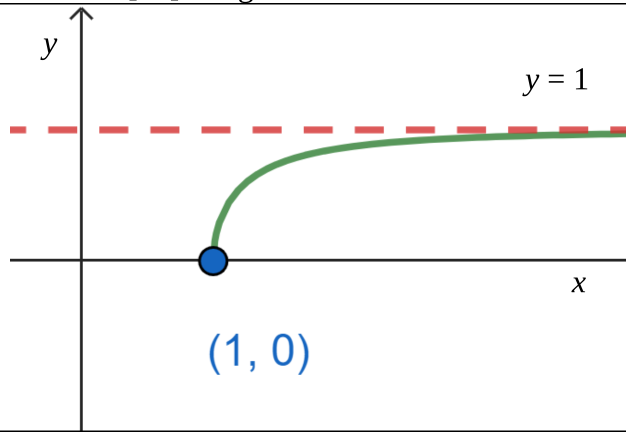
5	Solution [8] Graphing techniques	
(i)	Since C has asymptote $x=4 \Rightarrow b=-4$ <u>Method 1</u> $y=2x-3+\frac{k}{x-4}=\frac{(2x-3)(x-4)+k}{x-4}$, where k is a constant By comparing $y=\frac{2x^2+ax+20}{x-4}=\frac{2x^2-11x+(k+12)}{x-4}$, we obtain $a=-11$.	
	<u>Method 2</u> By long division, $y=\frac{2x^2+ax+20}{x-4}=2x+a+8+\frac{4a+52}{x-4}$ By comparing $y=2x-3=2x+a+8$, we obtain $a=-11$.	
(b) (i)	When $a=-11,\ b=-4,\ y=\frac{2x^2-11x+20}{x-4}$ 	
(iii)	$2x^2+ax+20=-(x+b)^3$ $\frac{2x^2+ax+20}{x+b}=-(x+b)^2$ ---(1)	

	 There is 1 intersect between the graph of C and $y=-(x-4)^2$, implying 1 real root for equation (1).	

6	Solution [8] Integration Techniques	
(a) (i)	$\int \frac{x^3}{1+x^4}\,\mathrm{d}x = \frac{1}{4}\int \frac{4x^3}{1+x^4}\,\mathrm{d}x$ $= \frac{1}{4}\ln\left(1+x^4\right)+c$	
(a) (ii)	$\int \frac{x}{1+x^4}\,\mathrm{d}x = \frac{1}{2}\int \frac{2x}{1+\left(x^2\right)^2}\,\mathrm{d}x$ $= \frac{1}{2}\tan^{-1}x^2 + c$	
(b)	$\int x\tan^{-1}x^2\ \mathrm{d}x$ $= \left(\tan^{-1}x^2\right)\left(\frac{1}{2}x^2\right) - \int \left(\frac{1}{2}x^2\right)\left(\frac{(2x)}{1+x^4}\right)\mathrm{d}x$ $= \left(\frac{1}{2}x^2\right)\tan^{-1}x^2 - \int \frac{x^3}{1+x^4}\,\mathrm{d}x$ $= \left(\frac{1}{2}x^2\right)\tan^{-1}x^2 - \frac{1}{4}\int \frac{4x^3}{1+x^4}\,\mathrm{d}x$ $= \left(\frac{1}{2}x^2\right)\tan^{-1}x^2 - \frac{1}{4}\ln\left(1+x^4\right)+c$	

7	Solution [9] Functions	
(a)	Let $y=6x-x^2-2,\ x\le -1$ $y=-x^2+6x-2$ $y=-\left(x^2-6x+2\right)$ $y=-\left[\left(x-3\right)^2-9+2\right]$ $y=7-\left(x-3\right)^2$ $\left(x-3\right)^2=7-y$ $x-3=\pm\sqrt{7-y}$ $x=3\pm\sqrt{7-y}$ $x=3-\sqrt{7-y}$ (reject $x=3+\sqrt{7-y}$ as $x\le -1$) $D_{f^{-1}}=R_f=(-\infty,-9]$ $f^{-1}:x\mapsto 3-\sqrt{7-x},x\in\mathbb{R},x\le -9$	
(b) (i)	$g^2(x)=\dfrac{a\left(\frac{ax}{x-a}\right)}{\left(\frac{ax}{x-a}\right)-a}$ $=\dfrac{\frac{a^2x}{x-a}}{\frac{ax-a(x-a)}{x-a}}$ $=\dfrac{a^2x}{ax-ax+a^2}$ $=\dfrac{a^2x}{a^2}$ $=x$	
(ii)	$g^2(x)=x$ $g^{-1}\left[g^2(x)\right]=g^{-1}(x)$ $g^{-1}\left[g(g(x))\right]=g^{-1}(x)$ $g(x)=g^{-1}(x)$ (Shown)	
(iii)	For fg^{-1} to exist, $R_{g^{-1}}\subseteq D_f$. Since $R_{g^{-1}}=D_g=(-\infty,a)$ and $D_f=(-\infty,-1]$,	

	$\therefore a \le -1$ Alternatively, from (ii), since $g(x) = g^{-1}(x)$, Since $R_{g^{-1}} = R_g = (-\infty, a)$ and $D_f = (-\infty, -1]$ $\therefore a \le -1$	

8	Solution [10] Integration	
(a)		

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<td>(ii)</td>
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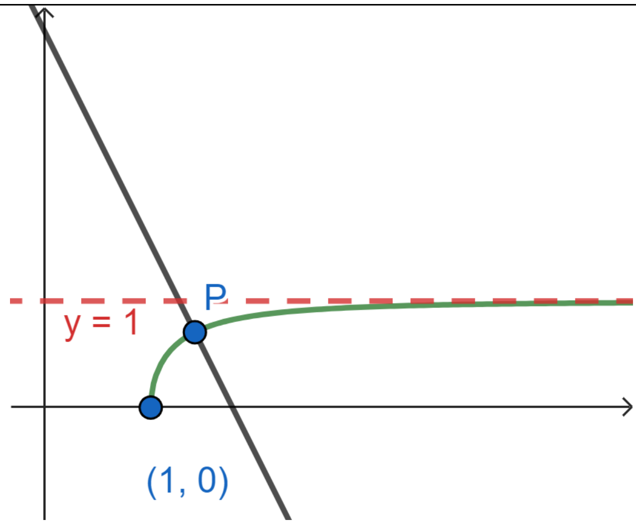

$y=\frac{1}{x}\sqrt{x^2-1}=\frac{\left(x^2-1\right)^{\frac{1}{2}}}{x}$

$\frac{\mathrm{d}y}{\mathrm{d}x}=\frac{(x)\left(\frac{1}{2}\right)\left(x^2-1\right)^{\frac{-1}{2}}(2x)-\left(x^2-1\right)^{\frac{1}{2}}}{x^2}=\frac{1}{x^2\sqrt{x^2-1}}$

When $x=\sqrt{2}$,

$\left.\frac{\mathrm{d}y}{\mathrm{d}x}\right|_{x=\sqrt{2}}=\frac{1}{2}$ *(This value can be obtained via GC)*

Equation of normal:

$y-\frac{1}{\sqrt{2}}=(-2)\left(x-\sqrt{2}\right)$

$y=-2x+\frac{5}{\sqrt{2}}$

Alternatively

$y=\frac{1}{x}\sqrt{x^2-1}=\sqrt{\frac{x^2-1}{x^2}}=\sqrt{1-\frac{1}{x^2}}$

$\frac{\mathrm{d}y}{\mathrm{d}x}=\left(\frac{1}{2}\right)\left(1-\frac{1}{x^2}\right)^{\frac{-1}{2}}\left(\frac{2}{x^3}\right)$

$\frac{\mathrm{d}y}{\mathrm{d}x}=\left(\frac{1}{2}\right)\left(\frac{x^2}{x^2-1}\right)^{\frac{1}{2}}\left(\frac{2}{x^3}\right)$

$\frac{\mathrm{d}y}{\mathrm{d}x}=\frac{1}{x^2\sqrt{x^2-1}}$

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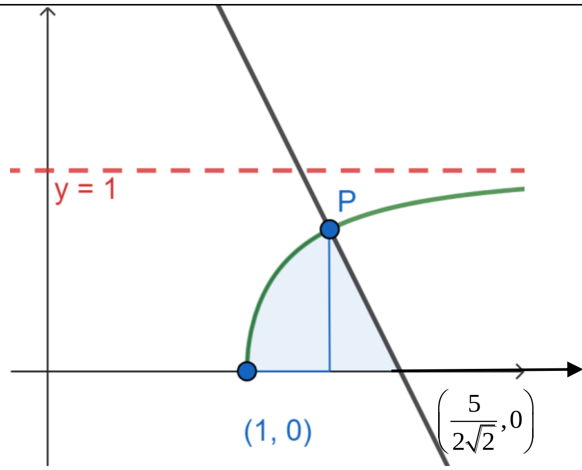
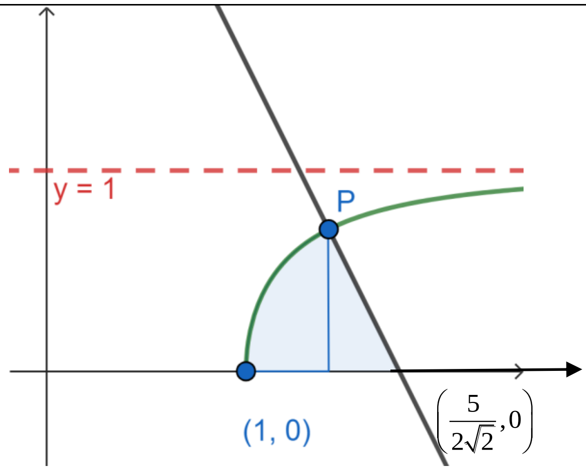
(iii)	 Area $= \int_{1}^{\sqrt{2}} \frac{1}{x}\sqrt{x^2-1}\,\mathrm{d}x$ $= \int_{0}^{\frac{\pi}{4}} \frac{1}{\sec\theta}\sqrt{\sec^2\theta-1}\,\sec\theta\tan\theta\,\mathrm{d}\theta$ $= \int_{0}^{\frac{\pi}{4}} \tan^2\theta\,\mathrm{d}\theta$ $= \int_{0}^{\frac{\pi}{4}} \sec^2\theta-1\,\mathrm{d}\theta$ $= \left[\tan\theta-\theta\right]_{0}^{\frac{\pi}{4}}$ $= 1-\frac{\pi}{4}$ units^2 $x = \sec\theta$ $\frac{\mathrm{d}x}{\mathrm{d}\theta} = \sec\theta\tan\theta$ When $x = 1$, $\theta = 0$ When $x = \sqrt{2}$, $\theta = \frac{\pi}{4}$	

(iv)	 Area $= \int_1^{\sqrt{2}} \frac{1}{x}\sqrt{x^2-1}\,dx + \frac{1}{2}\left(\frac{5}{2\sqrt{2}}-\sqrt{2}\right)\left(\frac{1}{\sqrt{2}}\right)$ $= \left[1-\frac{\pi}{4}\right]+\frac{1}{2}\left(\frac{1}{2\sqrt{2}}\right)\left(\frac{1}{\sqrt{2}}\right)$ $= \left[1-\frac{\pi}{4}\right]+\frac{1}{8}$ $= \frac{9}{8}-\frac{\pi}{4}$ $= \frac{9-2\pi}{8}$ units^2	

9	Solution [10] AP, GP contextual question	
(a)	$S_n = \frac{n}{2}[2a+(n-1)d]$ $= \frac{77}{2}\left[2(1250)+(77-1)(12)\right]$ $= 131\ 362$ The theoretical maximum amount of waste that the landfill can contain is 131 362 tonnes.	
(b) (i)	$S_n = \frac{a(1-r^n)}{1-r}$ $= \frac{1500(1-0.98^n)}{1-0.98}$ <u>Method 1</u> $\frac{1500(1-0.98^n)}{1-0.98} > 50\ 000$ $1500(1-0.98^n) > 1000$ $1-0.98^n > \frac{2}{3}$ $0.98^n < \frac{1}{3}$ $n > \frac{\ln\left(\frac{1}{3}\right)}{\ln(0.98)}$ $n > 54.4$ (3 s.f.) <u>Method 2</u> $\frac{1500(1-0.98^n)}{1-0.98} > 50\ 000$ By GC, <table><tr><td>n</td><td>$\frac{1500(1-0.98^n)}{1-0.98}$</td></tr><tr><td>54</td><td>49 808 < 50 000</td></tr><tr><td>55</td><td>50 311 > 50 000</td></tr></table> Thus least $n = 55$ and the least number of years is 55.	

<table>
<tr><td>(b)
(ii)</td><td>Method 1
$S_\infty = \frac{a}{1-r}$
$= \frac{1500}{1-0.98}$
$= 75\ 000$

Method 2
As $n \to \infty$, $\frac{1500\left(1-0.98^n\right)}{1-0.98} \to \frac{1500}{1-0.98} = 75\ 000$

Yes, the plant can cope with the total amount of waste of 75 000 tonnes to be incinerated.</td><td></td></tr>
<tr><td>(c)</td><td>In the nth year from 2014, amount of waste deposited in landfill is $1250+(n-1)(12)$.
In the nth year from 2014, amount of waste incinerated is $1500\left(0.98\right)^{n-1}$.

$1250+(n-1)(12) > 1500\left(0.98\right)^{n-1}$
$1250+(n-1)(12) - 1500\left(0.98\right)^{n-1} > 0$
By GC, $n > 7.17$

By GC,
<table><tr><td>n</td><td>$1250+(n-1)(12)-1500\left(0.98\right)^{n-1}$</td></tr><tr><td>7</td><td>–6.764 < 0</td></tr><tr><td>8</td><td>31.812 > 0</td></tr></table>
Thus $n=8$ and it is the 8th year after the year 2014 that the amount of waste deposited in the landfill first exceeds the amount of waste incenerated in the incineration plant.</td><td></td></tr>
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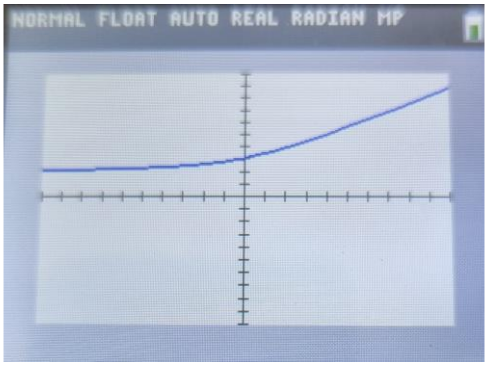
10	Solution [10] Maclaurin series	
(a) (i)	$y=\ln(2+\sin 2x)$ $e^y=2+\sin 2x$ Differentiate w.r.t. x: $e^y\frac{dy}{dx}=2\cos 2x$ ---(1) Differentiate w.r.t. x: $e^y\frac{d^2y}{dx^2}+e^y\left(\frac{dy}{dx}\right)^2=-4\sin 2x$ $e^y\left(\frac{d^2y}{dx^2}+\left(\frac{dy}{dx}\right)^2\right)+4\sin 2x=0$ ---(2)	
	<u>Alternative method</u> $y=\ln(2+\sin 2x)$ Differentiate w.r.t. x: $\frac{dy}{dx}=\frac{2\cos 2x}{2+\sin 2x}$ Differentiate w.r.t. x: $\frac{d^2y}{dx^2}=\frac{-4\sin 2x(2+\sin 2x)-2\cos 2x(2\cos 2x)}{(2+\sin 2x)^2}$ $=\frac{-4\sin 2x}{2+\sin 2x}-\left(\frac{2\cos 2x}{2+\sin 2x}\right)^2$ $=\frac{-4\sin 2x}{e^y}-\left(\frac{dy}{dx}\right)^2$ $e^y\frac{d^2y}{dx^2}=-4\sin 2x-e^y\left(\frac{dy}{dx}\right)^2$ $e^y\frac{d^2y}{dx^2}+e^y\left(\frac{dy}{dx}\right)^2+4\sin 2x=0$ $e^y\left(\frac{d^2y}{dx^2}+\left(\frac{dy}{dx}\right)^2\right)+4\sin 2x=0$	

(a) (ii)	Differentiate implicitly w.r.t. x: $e^y \frac{d^3y}{dx^3} + e^y\left(\frac{dy}{dx}\right)\left(\frac{d^2y}{dx^2}\right) + 2e^y\left(\frac{dy}{dx}\right)\left(\frac{d^2y}{dx^2}\right) + e^y\left(\frac{dy}{dx}\right)^3 + 8\cos 2x = 0$ When $x = 0$, $y = \ln 2$, $\frac{dy}{dx} = 1$, $\frac{d^2y}{dx^2} = -1$, $\frac{d^3y}{dx^3} = -2$, $y = \ln 2 + x + \frac{-1}{2!}x^2 + \frac{-2}{3!}x^3 + ...$ $y \approx \ln 2 + x - \frac{1}{2}x^2 - \frac{1}{3}x^3$ (up to x^3 term)	
(a) (iii)	$\ln(2+\sin 2x) = \ln 2 + x - \frac{1}{2}x^2 - \frac{1}{3}x^3 + ...$ Differentiate w.r.t. x: $\frac{2\cos 2x}{2+\sin 2x} = 1 - x - x^2$ (up to x^2 term)	
(b)	$\frac{2\cos 2x}{2+\sin 2x} \approx 2\left(1 - \frac{(2x)^2}{2}\right)(2+2x)^{-1}$ $\approx 2(1-2x^2)(2)^{-1}(1+x)^{-1}$ $\approx (1-2x^2)\left(1 - x + \frac{(-1)(-2)}{2!}(-x)^2\right)$ $= (1-2x^2)(1-x+x^2)$ $= 1 - x + x^2 - 2x^2 + ...$ $= 1 - x - x^2$ (up to x^2 term)	

11	Solution [12] Tangent & Rate of change	
(a)	$C:\ x=\dfrac{3}{\theta}-\theta,\quad y=\dfrac{2}{\theta}+2,\quad$ where $\theta>0$ 	
(b)	$x=\dfrac{3}{\theta}-\theta$ $\dfrac{dx}{d\theta}=\dfrac{-3}{\theta^2}-1=\dfrac{-3-\theta^2}{\theta^2}$ $\dfrac{d\theta}{dt}=\dfrac{d\theta}{dx}.\dfrac{dx}{dt}=-\dfrac{\theta^2}{3+\theta^2}\cdot 10$ At $(2,4)$, $\quad \dfrac{3}{\theta}-\theta=2 \quad$ and $\quad \dfrac{2}{\theta}+2=4$ $\theta^2+2\theta-3=0$ $\theta=-3$ or 1 and $\theta=1$ $\because \theta=1$ $\dfrac{d\theta}{dt}=-\dfrac{(1)^2}{3+(1)^2}.10=-\dfrac{5}{2}$ units s^{-1}	
(c) (i)	$y=\dfrac{2}{\theta}+2$ $\dfrac{dy}{d\theta}=-\dfrac{2}{\theta^2}$ $\dfrac{dy}{dx}=\dfrac{-\dfrac{2}{\theta^2}}{\dfrac{-3-\theta^2}{\theta^2}}$ $=\dfrac{-2}{\theta^2}\times\dfrac{\theta^2}{-3-\theta^2}$ $=\dfrac{2}{3+\theta^2}$	

	When $\theta = 1 \Rightarrow \frac{\mathrm{d}y}{\mathrm{d}x} = \frac{1}{2}$, $x = 2$ and $y = 4$. $y - 4 = \frac{1}{2}(x - 2)$ $y = \frac{1}{2}x + 3$ The tangent at point *P* is $y = \frac{1}{2}x + 3$.	
(c) (ii)	$y - 4 = \frac{1}{2}(x - 2)$ ---(1) Substitute $x = \frac{3}{\theta} - \theta,\ y = \frac{2}{\theta} + 2$ into (1): $\frac{2}{\theta} + 2 - 4 = \frac{1}{2}\left(\frac{3}{\theta} - \theta - 2\right)$ $\frac{2 - 2\theta}{\theta} = \frac{3 - \theta^2 - 2\theta}{2\theta}$ $4 - 4\theta = 3 - \theta^2 - 2\theta$ $\theta^2 - 2\theta + 1 = 0$ $(\theta - 1)^2 = 0$ $\theta = 1$ which corresponds to *P*. Alternatively, $\theta^2 - 2\theta + 1 = 0$ $b^2 - 4ac = (-2)^2 - 4(1)(1) = 0$ This implies that the equation $\theta^2 - 2\theta + 1 = 0$ has two equal and real roots, which is $\theta = 1$. Hence the tangent will not meet the curve again.	
(c) (iii)	Tangent to *C* at point *P*, gradient is $\frac{1}{2}$ Tangent to *C* at point *M*, gradient is $\frac{2}{3 + \theta^2} = \frac{2}{3 + (2)^2}$ $= \frac{2}{7}$ Therefore, Normal to *C* at point *M* has gradient $-\frac{7}{2}$.	

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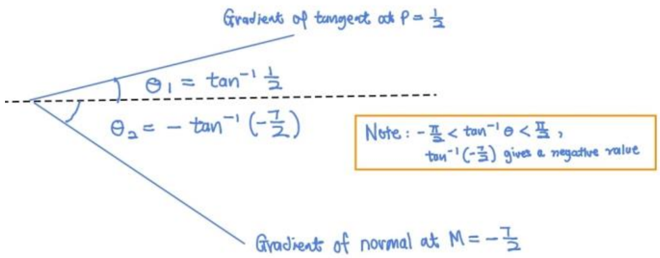
<tr><td></td><td>

<u>Method 1</u>
$\tan^{-1}\left(\frac{1}{2}\right)-\tan^{-1}\left(-\frac{7}{2}\right)=100.6^\circ$
Required acute angle
$=180^\circ-100.6^\circ$
$=79.4^\circ$</td><td></td></tr>
<tr><td></td><td><u>Method 2</u>
Angle between the 2 lines
$=\tan^{-1}\left(\frac{1}{2}\right)+\tan^{-1}\left(\frac{7}{2}\right)=100.6^\circ$
Required acute angle
$=180^\circ-100.6^\circ$
$=79.4^\circ$</td><td></td></tr>
<tr><td>(d)</td><td>$C:\ x=\frac{3}{\theta}-\theta,\quad y=\frac{2}{\theta}+2,\quad \text{where } \theta>0$
After by a stretch with scale factor 2 in the x-direction, the equation of C becomes
$\frac{x}{2}=\frac{3}{\theta}-\theta,\quad y=\frac{2}{\theta}+2,\quad \text{where } \theta>0$
$x=\frac{6}{\theta}-2\theta,\quad y=\frac{2}{\theta}+2,\quad \text{where } \theta>0$
After by a reflection in the y-axis, the equation becomes
$-x=\frac{6}{\theta}-2\theta,\quad y=\frac{2}{\theta}+2,\quad \text{where } \theta>0$
$D:\ x=2\theta-\frac{6}{\theta},\quad y=\frac{2}{\theta}+2,\quad \text{where } \theta>0$

Alternatively,
After by a reflection in the y-axis, the equation becomes
$-x=\frac{3}{\theta}-\theta,\quad y=\frac{2}{\theta}+2,\quad \text{where } \theta>0$</td><td></td></tr>
</table>

	$x=\theta-\frac{3}{\theta}, \quad y=\frac{2}{\theta}+2, \quad \text{where } \theta>0$ After by a stretch with scale factor 2 in the *x*-direction, the equation of becomes $\frac{x}{2}=\theta-\frac{3}{\theta}, \quad y=\frac{2}{\theta}+2, \quad \text{where } \theta>0$ $D: \ x=2\theta-\frac{6}{\theta}, \quad y=\frac{2}{\theta}+2, \quad \text{where } \theta>0$	

12	Solution [12] Differential Equations	
(a) (i)	$\frac{\mathrm{d}v}{\mathrm{d}t}=c$	
(a) (ii)	$\frac{\mathrm{d}v}{\mathrm{d}t}=c$ $\int \mathrm{d}v=\int c\,\mathrm{d}t$ $v=ct+v_0$ Given that $c=10$, $v=10t+v_0$ When $t=0,\ v=0 \Rightarrow v_0=0$ Therefore $v=10t$. When $v=30 \Rightarrow 30=10t \Rightarrow t=3$ It will take 3 seconds for the velocity to reach 30 ms^{-1}	
(b) (i)	$\frac{\mathrm{d}v}{\mathrm{d}t}=10-k\sqrt{v}$ $\frac{\mathrm{d}v}{\mathrm{d}t}=0$ when $v=\frac{100}{k^2}$ $v=\frac{100}{k^2}$ is the constant velocity that the object moves eventually.	

(b)(ii)	Let $u=\sqrt{v}\Rightarrow v=u^2\Rightarrow \frac{\mathrm{d}v}{\mathrm{d}u}=2u$ $\frac{\mathrm{d}v}{\mathrm{d}t}=10-k\sqrt{v}$ $\frac{\mathrm{d}v}{\mathrm{d}u}\cdot\frac{\mathrm{d}u}{\mathrm{d}t}=10-ku$ $2u\frac{\mathrm{d}u}{\mathrm{d}t}=10-ku\ ----(*)$ $2\int\frac{u}{10-ku}\,\mathrm{d}u=\int\mathrm{d}t$ $2\int\frac{1}{k}\left(\frac{10}{10-ku}-1\right)\mathrm{d}u=\int\mathrm{d}t$ using given result Note: Given $\frac{ku}{10-ku}=\frac{10}{10-ku}-1$ where k is a constant $\int\frac{10}{10-ku}-1\ \mathrm{d}u=\frac{kt}{2}+C$ $-\frac{10}{k}\ln\lvert 10-ku\rvert-u=\frac{kt}{2}+C$ $u+\frac{10}{k}\ln\lvert 10-ku\rvert=-\frac{kt}{2}-C$ $\sqrt{v}+\frac{10}{k}\ln\lvert 10-k\sqrt{v}\rvert=-\frac{kt}{2}-C$ $2k\sqrt{v}+20\ln\lvert 10-k\sqrt{v}\rvert=A-k^2t,$ where $A=-2Ck$ (Shown)	