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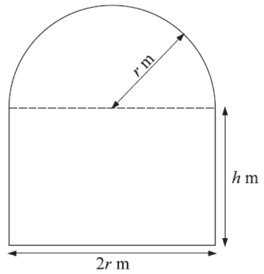
Differentiation

Q1

Differentiate $4x + \dfrac{6}{x^2}$ with respect to x. [2]

Q2

The diagram shows a glass window consisting of a rectangle of height h m and width $2r$ m and a semicircle of radius r m. The perimeter of the window is 8 m.



(i) Express h in terms of r. [2]

(ii) Show that the area of the window, A m^2, is given by

$$A = 8r - 2r^2 - \tfrac{1}{2}\pi r^2.$$ [2]

Given that r can vary,

(iii) find the value of r for which A has a stationary value, [4]

(iv) determine whether this stationary value is a maximum or a minimum. [2]

Q3

A curve is such that $\dfrac{dy}{dx} = 3x^2 - 4x + 1$. The curve passes through the point $(1, 5)$.

(i) Find the equation of the curve. [3]

(ii) Find the set of values of x for which the gradient of the curve is positive. [3]

Q4

A solid rectangular block has a base which measures $2x$ cm by x cm. The height of the block is y cm and the volume of the block is 72 cm^3.

(i) Express y in terms of x and show that the total surface area, A cm^2, of the block is given by

$$A = 4x^2 + \frac{216}{x}.$$ [3]

Given that x can vary,

(ii) find the value of x for which A has a stationary value, [3]

(iii) find this stationary value and determine whether it is a maximum or a minimum. [3]

Q5

A curve has equation $y = x^2 + \dfrac{2}{x}$.

(i) Write down expressions for $\dfrac{dy}{dx}$ and $\dfrac{d^2y}{dx^2}$. [3]

(ii) Find the coordinates of the stationary point on the curve and determine its nature. [4]

Q6

Find the gradient of the curve $y = \dfrac{12}{x^2 - 4x}$ at the point where $x = 3$. [4]

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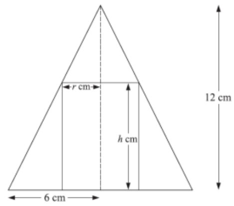
Q7

The diagram shows the cross-section of a hollow cone and a circular cylinder. The cone has radius 6 cm and height 12 cm, and the cylinder has radius r cm and height h cm. The cylinder just fits inside the cone with all of its upper edge touching the surface of the cone.



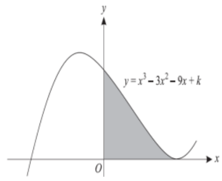
(i) Express h in terms of r and hence show that the volume, V cm^3, of the cylinder is given by

$$V = 12\pi r^2 - 2\pi r^3.$$ [3]

(ii) Given that r varies, find the stationary value of V. [4]

Q8

The diagram shows the curve $y = x^3 - 3x^2 - 9x + k$, where k is a constant. The curve has a minimum point on the x-axis.

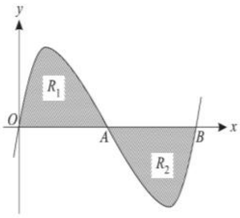


(i) Find the value of k. [4]

(ii) Find the coordinates of the maximum point of the curve. [1]

Q9

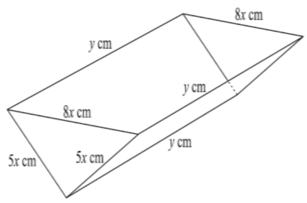
The diagram shows the curve $y = x(x - 1)(x - 2)$, which crosses the x-axis at the points $O\,(0, 0)$, $A\,(1, 0)$ and $B\,(2, 0)$.



(i) The tangents to the curve at the points A and B meet at the point C. Find the x-coordinate of C. [5]

Q10

The diagram shows an open container constructed out of 200 cm^2 of cardboard. The two vertical end pieces are isosceles triangles with sides $5x$ cm, $5x$ cm and $8x$ cm, and the two side pieces are rectangles of length y cm and width $5x$ cm, as shown. The open top is a horizontal rectangle.



(i) Show that $y = \dfrac{200 - 24x^2}{10x}$. [3]

(ii) Show that the volume, V cm^3, of the container is given by $V = 240x - 28.8x^3$. [2]

Given that x can vary,

(iii) find the value of x for which V has a stationary value, [3]

(iv) determine whether it is a maximum or a minimum stationary value. [2]

Q11

The equation of a curve is $y = (2x - 3)^3 - 6x$.

(i) Express $\dfrac{dy}{dx}$ and $\dfrac{d^2y}{dx^2}$ in terms of x. [3]

(ii) Find the x-coordinates of the two stationary points and determine the nature of each stationary point. [5]

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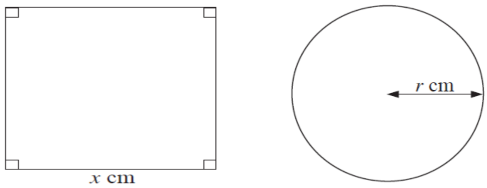
Q12

The equation of a curve is $y = 2x + \dfrac{8}{x^2}$.

(i) Obtain expressions for $\dfrac{dy}{dx}$ and $\dfrac{d^2y}{dx^2}$. [3]

(ii) Find the coordinates of the stationary point on the curve and determine the nature of the stationary point. [3]

Q13



A wire, 80 cm long, is cut into two pieces. One piece is bent to form a square of side x cm and the other piece is bent to form a circle of radius r cm (see diagram). The total area of the square and the circle is A cm^2.

(i) Show that $A = \dfrac{(\pi + 4)x^2 - 160x + 1600}{\pi}$. [4]

(ii) Given that x and r can vary, find the value of x for which A has a stationary value. [4]

Q14

The equation of a curve is $y = \dfrac{12}{x^2 + 3}$.

(i) Obtain an expression for $\dfrac{dy}{dx}$. [2]

(ii) Find the equation of the normal to the curve at the point $P(1, 3)$. [3]

(iii) A point is moving along the curve in such a way that the x-coordinate is increasing at a constant rate of 0.012 units per second. Find the rate of change of the y-coordinate as the point passes through P. [2]

Q15

A curve is such that $\dfrac{dy}{dx} = 3x^{\frac{1}{2}} - 6$ and the point $(9, 2)$ lies on the curve.

(i) Find the equation of the curve. [4]

(ii) Find the x-coordinate of the stationary point on the curve and determine the nature of the stationary point. [3]

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Q16

A solid rectangular block has a square base of side x cm. The height of the block is h cm and the total surface area of the block is $96\,\text{cm}^2$.

(i) Express h in terms of x and show that the volume, $V\,\text{cm}^3$, of the block is given by

$$V = 24x - \tfrac{1}{2}x^3.$$ [3]

Given that x can vary,

(ii) find the stationary value of V, [3]

(iii) determine whether this stationary value is a maximum or a minimum. [2]

Q17

The equation of a curve is $y = \frac{1}{6}(2x-3)^3 - 4x$.

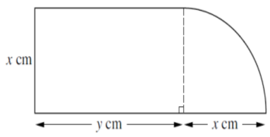
(i) Find $\frac{dy}{dx}$. [3]

(ii) Find the equation of the tangent to the curve at the point where the curve intersects the y-axis. [3]

(iii) Find the set of values of x for which $\frac{1}{6}(2x-3)^3 - 4x$ is an increasing function of x. [3]

Q18

The diagram shows a metal plate consisting of a rectangle with sides x cm and y cm and a quarter-circle of radius x cm. The perimeter of the plate is 60 cm.



(i) Express y in terms of x. [2]

(ii) Show that the area of the plate, $A\,\text{cm}^2$, is given by $A = 30x - x^2$. [2]

Given that x can vary,

(iii) find the value of x at which A is stationary, [2]

(iv) find this stationary value of A, and determine whether it is a maximum or a minimum value. [2]

Q19

The length, x metres, of a Green Anaconda snake which is t years old is given approximately by the formula

$$x = 0.7\sqrt{(2t-1)},$$

where $1 \leqslant t \leqslant 10$. Using this formula, find

(i) $\frac{dx}{dt}$, [2]

(ii) the rate of growth of a Green Anaconda snake which is 5 years old. [2]

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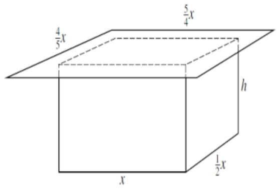
Q20

The diagram shows an open rectangular tank of height h metres covered with a lid. The base of the tank has sides of length x metres and $\frac{1}{2}x$ metres and the lid is a rectangle with sides of length $\frac{5}{4}x$ metres and $\frac{4}{5}x$ metres. When full the tank holds $4\,\text{m}^3$ of water. The material from which the tank is made is of negligible thickness. The external surface area of the tank together with the area of the top of the lid is $A\,\text{m}^2$.



(i) Express h in terms of x and hence show that $A = \frac{3}{2}x^2 + \frac{24}{x}$. [5]

(ii) Given that x can vary, find the value of x for which A is a minimum, showing clearly that A is a minimum and not a maximum. [5]

Q21

A curve has equation $y = \frac{1}{x-3} + x$.

(i) Find $\frac{dy}{dx}$ and $\frac{d^2y}{dx^2}$. [2]

(ii) Find the coordinates of the maximum point A and the minimum point B on the curve. [5]

Q22

The volume of a spherical balloon is increasing at a constant rate of $50\,\text{cm}^3$ per second. Find the rate of increase of the radius when the radius is 10 cm. [Volume of a sphere = $\frac{4}{3}\pi r^3$.] [4]

Q23

The variables x, y and z can take only positive values and are such that

$$z = 3x + 2y \quad \text{and} \quad xy = 600.$$

(i) Show that $z = 3x + \frac{1200}{x}$. [1]

(ii) Find the stationary value of z and determine its nature. [6]

Q24

A curve is such that $\frac{dy}{dx} = \frac{3}{(1+2x)^2}$ and the point $(1, \frac{1}{2})$ lies on the curve.

(i) Find the equation of the curve. [4]

(ii) Find the set of values of x for which the gradient of the curve is less than $\frac{1}{3}$. [3]

Q25

A curve has equation $y = \frac{4}{3x-4}$ and $P\,(2, 2)$ is a point on the curve.

(i) Find the equation of the tangent to the curve at P. [4]

(ii) Find the angle that this tangent makes with the x-axis. [2]

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Q26

Differentiate $\dfrac{2x^3 + 5}{x}$ with respect to x. [3]

Q27

A curve is such that $\dfrac{dy}{dx} = \dfrac{2}{\sqrt{x}} - 1$ and $P(9, 5)$ is a point on the curve.

(i) Find the equation of the curve. [4]

(ii) Find the coordinates of the stationary point on the curve. [3]

(iii) Find an expression for $\dfrac{d^2y}{dx^2}$ and determine the nature of the stationary point. [2]

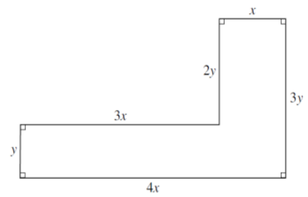
(iv) The normal to the curve at P makes an angle of $\tan^{-1} k$ with the positive x-axis. Find the value of k. [2]

Q28

A curve has equation $y = 3x^3 - 6x^2 + 4x + 2$. Show that the gradient of the curve is never negative. [3]

Q29

The diagram shows the dimensions in metres of an L-shaped garden. The perimeter of the garden is 48 m.



(i) Find an expression for y in terms of x. [1]

(ii) Given that the area of the garden is A m^2, show that $A = 48x - 8x^2$. [2]

(iii) Given that x can vary, find the maximum area of the garden, showing that this is a maximum value rather than a minimum value. [4]

Q30

A curve $y = f(x)$ has a stationary point at $P(3, -10)$. It is given that $f'(x) = 2x^2 + kx - 12$, where k is a constant.

(i) Show that $k = -2$ and hence find the x-coordinate of the other stationary point, Q. [4]

(ii) Find $f''(x)$ and determine the nature of each of the stationary points P and Q. [2]

(iii) Find $f(x)$. [4]

Q31

A watermelon is assumed to be spherical in shape while it is growing. Its mass, M kg, and radius, r cm, are related by the formula $M = kr^3$, where k is a constant. It is also assumed that the radius is increasing at a constant rate of 0.1 centimetres per day. On a particular day the radius is 10 cm and the mass is 3.2 kg. Find the value of k and the rate at which the mass is increasing on this day. [5]

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Answers:

Q1: $4 - 12x^{-3}$

Q2: (i) $h = 4 - r - \frac{1}{2}\pi r$ (ii) $8r - 2r^2 - \frac{1}{2}\pi r^2$ (iii) $\frac{dA}{dr} = 8 - 4r - \pi r, \ r = \frac{8}{4+\pi}$

(iv) $\frac{dA^2}{dr^2} = -4 - \pi \ (negative, so\ Maximum)$

Q3:

(i) $y = x^3 - 2x^2 + x \ \ (+c)$
(1,5) used to give c= 5

(ii) $3x^2 - 4x + 1 > 0$
$\rightarrow$ end values of 1 and $\frac{1}{3}$
$\rightarrow x < \frac{1}{3}$ and $x > 1$

Q4:

(i) $y = 72 \div (2x^2)$ or $36 \div x^2$
$A = 4x^2 + 6xy$
$\rightarrow A = 4x^2 + 216 \div x$

(ii) $dA/dx = 8x - 216 \div x^2$
$= 0$ when $8x^3 = 216$
$\rightarrow x = 3$

(iii) Stationary value = 108 cm²

$d^2A/dx^2 = 8 + 432 \div x^3$
$\rightarrow$ Positive when x=3 Minimum.

Q5:

(i) $dy/dx = 2x - 2/x^2$

$d^2y/dx^2 = 2 + 4/x^3$

(ii) $dy/dx = 0 \quad 2x - 2/x^2 = 0$
$\rightarrow x^3 = 1 \rightarrow x = 1, y = 3$

If $x = 1$, $d^2y/dx^2 > 0$, Minimum

Q6:

$y = \frac{12}{x^2 - 4x}$

$\frac{dy}{dx} = -12(x^2 - 4x)^{-2} \times (2x - 4)$

If $x = 3$, $\frac{dy}{dx} = -\frac{8}{3}$

Q7:

(i) Similar triangles or trig (tan = opp/hyp)
$\frac{6}{12} = \frac{r}{12 - h} \quad \rightarrow h = 12 - 2r$
$\rightarrow V = \pi r^2 h \rightarrow V = 12\pi r^2 - 2\pi r^3$

(ii) $dV/dr = 24\pi r - 6\pi r^2$

$= 0$ when $r = 4 \ \rightarrow V = 64\pi$ (or 201)

Q8

0. $y = x^3 - 3x^2 - 9x + k$

(i) $dy/dx = 3x^2 - 6x - 9$
$= 0$ when $x = 3$ or $x = -1$
$\rightarrow x = 3, y = 0 \ \rightarrow k = 27$

(ii) $x = -1 \ \rightarrow y = 32$

Q9:

(i) $y = x^3 - 3x^2 + 2x$
$\frac{dy}{dx} = 3x^2 - 6x + 2$
At A (1,0), $m = -1 \rightarrow y = -1(x - 1)$
At B (2,0), $m = 2 \rightarrow y = 2(x - 2)$
Sim equations $\rightarrow x = \frac{5}{3}$

Q10:

(i) Height = 3x
$10xy + \frac{1}{2}.8x.3x.2 = 200$
$\rightarrow y = \frac{200 - 24x^2}{10x}$

(ii) $V = \frac{1}{2}.8x.3xy = 240x - 28.8x^3$

(iii) $\frac{dV}{dx} = 240 - 86.4x^2$
$= 0$ when $x = 1⅔$

(iv) $\frac{d^2V}{dx^2} = -172.8x$
$\rightarrow$ −ve $\rightarrow$ Maximum

Q11:

8. $y = (2x - 3)^3 - 6x$

(i) $\frac{dy}{dx} = 3 \times (2x-3)^2 \times 2 \quad -6$

$\frac{d^2y}{dx^2} = 12 \times (2x-3) \times 2$

(ii) s.p $\rightarrow \frac{dy}{dx} = 0 \rightarrow (2x-3)^2 = 1$

$\rightarrow x = 2$ or $x = 1$

If x = 2, 2nd diff = +ve $\rightarrow$ MIN

If x = 1, 2nd diff = −ve $\rightarrow$ MAX

Q12

(i) $\frac{dy}{dx} = 2 - \frac{16}{x^3}$
$\frac{d^2y}{dx^2} = \frac{48}{x^4}$

(ii) $\frac{dy}{dx} = 0 \quad \rightarrow x = 2, y = 6.$
$\frac{d^2y}{dx^2}$ is +ve Minimum.

Q13:

(i) $4x + 2\pi r = 80$
$A = x^2 + \pi r^2$
$\rightarrow A = \frac{(\pi + 4)x^2 - 160x + 1600}{\pi}$

(ii) $\frac{dA}{dx} = \frac{2(\pi + 4)x - 160}{\pi}$
$= 0$ when $x = \frac{160}{2(\pi + 4)}$ or 11.2

Q14:

$y = \frac{12}{x^2 + 3}$

(i) $\frac{dy}{dx} = -12(x^2 + 3)^{-2} \times 2x$

(ii) At $x = 1$, $m = -\frac{3}{2}$
m of normal = ⅔
Eqn of normal
$y - 3 = \frac{2}{3}(x - 1)$

(iii) $\frac{dy}{dt} = \frac{dy}{dx} \times \frac{dx}{dt} = -\frac{3}{2} \times 0.012$
$\rightarrow -0.018$

Q15:

$\frac{dy}{dx} = 3\sqrt{x} - 6 \quad (9, 2)$

(i) $y = \frac{3x^{\frac{3}{2}}}{\frac{3}{2}} - 6x \, (+c)$

(9, 2) $2 = 54 - 54 + c$
$\rightarrow c = 2.$

(ii) $\frac{dy}{dx} = 0 \rightarrow x = 4$

$\frac{d^2y}{d^2x} = \frac{3x^{-\frac{1}{2}}}{2}$
$\rightarrow$ +ve (or ¾) Minimum

Q16:

(i) $4xh + 2x^2 = 96$
$\rightarrow h = \frac{24}{x} - \frac{x}{2}$
$V = x^2 h \ \rightarrow V = 24x - \frac{x^3}{2}.$

(ii) $\frac{dV}{dx} = 24 - \frac{3x^2}{2}$
$= 0$ when $x = 4$
$\rightarrow V = 64.$

(iii) $\frac{d^2V}{dx^2} = -3x \ \rightarrow$ Max.

Q17:

$y = \frac{1}{6}(2x - 3)^3 - 4x$

(i) $\frac{dy}{dx} = \frac{1}{6} \times 3 \times (2x - 3)^2 \times 2 - 4$

(ii) $x = 0, \ y = -\frac{27}{6},$
$y + \frac{27}{6} = 5x \ \rightarrow 2y + 9 = 10x$

(iii) $(2x - 3)^2 - 4 \ \ (> 0)$

$\rightarrow x = 2½$ or ½
$\rightarrow x > 2½, \ x < ½.$

Q18:

(i) $2x + 2y + \frac{\pi x}{2} = 60$

$\rightarrow y = 30 - x - \frac{\pi x}{4}$

(ii) $A = xy + \frac{\pi x^2}{4}$

$= x\,(30 - x - \frac{\pi x}{4}) + \frac{\pi x^2}{4}$

$= 30x - x^2$

(iii) $\frac{dA}{dx} = 30 - 2x$

$= 0$ when $x = 15$ cm

(iv) Max.

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Q19:

(i) $(k(2t-1))^{-1/2}$
$0.7(2t-1)^{-1/2}$

(ii) Sub $t=5$ into *their* deriv
0.23(3)

Q20: **(i)** $h=\frac{8}{x^2}$

$A=\frac{1}{2}x^2+2\times\frac{1}{2}xh+2xh+\frac{5}{4}x\times\frac{4}{5}x$

$A=(3/2)x^2+3xh$

$A=\frac{3}{2}x^2+3x\times\frac{8}{x^2}$

$A=\frac{3}{2}x^2+\frac{24}{x}$

(ii) $\frac{dA}{dx}=3x-\frac{24}{x^2}=0$

$x=2$

$\frac{d^2A}{dx^2}=3+\frac{48}{x^3}$

>0 when $x=2$ hence minimum

Q21:

(i) $\frac{dy}{dx}=\frac{-1}{(x-3)^2}+1$

$\frac{d^2y}{dx^2}=\frac{2}{(x-3)^3}$

(ii) $(x-3)^2=1\Rightarrow x-3=\pm1$

$x=4, 2$
$y=5, 1$

When $x=4$ $\frac{d^2y}{dx^2}>0\ (=2)\Rightarrow$ min

When $x=2$ $\frac{d^2y}{dx^2}<0\ (=-2)\Rightarrow$ max

Q22:

$\left(\frac{dv}{dr}=\right)4\pi r^2$

$=4\pi\times10^2$

$\frac{dr}{dt}=\frac{dv}{dt}\Big/\frac{dv}{dr}$ **OE used**

$\frac{50}{4\pi\times10^2}=\frac{1}{8\pi}$ or 0.0398

Q23:

(i) $z=3x+2\left(\frac{600}{x}\right)$ or $x\frac{(z-3x)}{2}=600$ OE

$\rightarrow$ **AG**

(ii) $\frac{dz}{dx}=3-\frac{1200}{x^2}$ or $\frac{dz}{dy}=2-\frac{1800}{y^2}$

$=0\rightarrow x=20$ or $=0\rightarrow y=30$

$z=60+\frac{120}{20}=120$

$\frac{d^2z}{dx^2}=\frac{2400}{x^3}$

$>0\Rightarrow$ minimum

Q24:

(i) $\frac{3(1+2x)^{-1}}{-1}+(c)$

$y=\frac{3(1+2x)^{-1}}{-2}+(c)$

Sub (1, (1/2))

$\frac{1}{2}=\frac{3}{-6}+c\Rightarrow c=1$

(ii) $(1+2x)^2(>)9$ or $4x^2+4x-8(>)0$ **OE**

1, −2

$x>1, x<-2$ ISW

Q25:

$y=\frac{4}{3x-4}$

(i) $\frac{dy}{dx}=-4(3x-4)^{-2}\quad\times\quad3$

If $x=2$, $m=-3$

Eqn of tangent $y-2=-3(x-2)$

(ii) $\tan\theta=\pm(-3)$

$\rightarrow\ \theta=\pm108.4^\circ$ (or $\pm71.6^\circ$)

or scalar product, $\tan\theta=y$-step $\div$ x-step
or use of tan $(A-B)$ M1A1 for each

Q26:

$y=\frac{2x^3+5}{x}=2x^2+\frac{5}{x}$

$d/dx=4x-\frac{5}{x^2}$ or $4x-5x^{-2}$

Q27:

$\frac{dy}{dx}=\frac{2}{\sqrt{x}}-1\quad P(9,5)$

(i) $y=4\sqrt{x}-x\,(+c)$
Uses (9, 5) in an integrated expression
$\rightarrow c=2$

(ii) $\frac{dy}{dx}=0\rightarrow x=4, y=6$

(iii) $\frac{d^2y}{d^2x}=-x^{\frac{-3}{2}}\rightarrow$ –ve $\rightarrow$ Max

(iv) $\frac{dy}{dx}=-\frac{1}{3}$ Perpendicular $m=3$

$\tan\theta=3$ Angle is $\tan^{-1}3$

$k=3$

Q28:

$\frac{\delta y}{\delta x}=9x^2-12x+4$

$(3x-2)^2\geq0$

Q29:

(i) $y=\frac{1}{6(48-8x)}$ oe

(ii) $A=4xy+2xy$ or $3xy+3xy=6xy$

$A=x(48-8x)=48x-8x^2$

(iii) $\frac{\delta A}{\delta x}=48-16x$

$A=72$ cao

$\frac{\delta^2A}{\delta x^2}=-16\ (<0)\Rightarrow$ Maximum

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Q30:

(i) $f'(3) = 0 \Rightarrow 18 + 3k - 12 = 0$
$k = -2$
$(x-3)(x+2) = 0$
$x = -2$, (Allow also $= 3$)

(ii) $f''(x) = 4x - 2$
$f''(3) > 0$ hence min at P
$f''(-2) < 0$ hence max at Q

(iii) $f(x) = \frac{2}{3}x^3 - x^2 - 12x \ (+c)$
Sub $(3,-10) \rightarrow -10 = 18 - 9 - 36 + c$
$c = 17$

Q31: $1000k = 3.2 \Rightarrow k = \frac{3.2}{1000}$ or $\frac{2}{625}$ or 0.0032 oe

$\left(\frac{dM}{dr}\right) = 3kr^2$

$\frac{dM}{dt} = \frac{dM}{dr} \times \frac{dr}{dt}$ **used** e.g. $3 \times k \times 10^2 \times 0.1$

0.096