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IGCSE_Maths

Algebra_2
Revision

SP-20	M-20	S-20	W-19

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Functions

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1(a) $f(x) = 4x+3$ $\qquad g(x) = 5x-4$

$fg(x) = 20x + p$

find the value of p. ---[2]

Solution: $fg(x) = f(g(x)) = f(5x-4)$

$= 4(5x-4)+3$ $\qquad [\because f(x) = 4x+3)$

$= 20x-16+3$

$\therefore f(g(x)) = 20x-13$ —①

Give $fg(x) = 20x+p$ —②

from ① and ② $\underline{p=-13}$ ✓.

(b) $h(x) = \frac{5x-1}{3}$

Find $h^{-1}(x)$. ---[3]

Solution: $h(x) = \frac{5x-1}{3} = y$ (let)

$\Rightarrow 3y = 5x-1$

Interchange x and y

$\Rightarrow 3x = 5y-1$

$\Rightarrow 5y = 3x+1$

$\Rightarrow y = \frac{3x+1}{3}$

$\Rightarrow \underline{h^{-1}(x) = \frac{3x+1}{3}}$ ✓ $\qquad$ [S-20/21/Q14]

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2 $f(x) = 3x-5$ $\qquad g(x) = 2^x$

(a) Find $fg(3)$ ---[2]

Solution: $fg(3) = f(g(3))$ $\qquad \because g(x) = 2^x$

$= f(2^3) = f(8)$

$= 3\times8-5$ $\qquad \because f(x) = 3x-5$

$= 24-5 = 19$ ✓

(b) Find $f^{-1}(x)$. ---[2]

Given $f(x) = 3x-5 = y$ (let)

Interchange x & y $\Rightarrow 3y-5 = x$

$y = \frac{x+5}{3}$ $\qquad$ [W-19/21/Q24]

$\Rightarrow f^{-1}(x) = \underline{\frac{x+5}{3}}$ ✓

3. $f(x) = 2x+1 \qquad g(x) = x^2+4 \qquad h(x) = 2^x$

(a) Solve the equation $f(x) = g(1)$ ...[2]

(b) Find $f^{-1}(x)$ ...[2]

(c) Find $gf(x)$ in its simplest form. ...[3]

(d) Solve the equation $h^{-1}(x) = 0.5$ ...[1]

(e) $\frac{1}{h(x)} = 2^{kx}$,

write down the value of k. $\boxed{SP\text{-}20/04/Q7}$ ...[1]

<u>Solution:</u> (a) Solve $f(x) = g(1)$

$\Rightarrow 2x+1 = 1^2+4 \qquad \because g(x) = x^2+4$

$\Rightarrow 2x = 4 \Rightarrow \underline{x = 2}$ ✓

(b) $f(x) = 2x+1 = y$ (let)

Interchange x and y

$2y+1 = x$

$\Rightarrow y = \frac{x-1}{2} \Rightarrow \underline{f^{-1}(x) = \frac{x-1}{2}}$ ✓

(c) $gf(x) = g(f(x))$

$= g(2x+1)$

$= (2x+1)^2+4 \qquad \because g(x) = x^2+4$

$= 4x^2+4x+1+4$

$= \underline{4x^2+4x+5}$ ✓

(d) Solve the equation $h^{-1}(x) = 0.5$

$\Rightarrow x = h(0.5)$

$= 2^{0.5} \qquad \because h(x) = 2^x$

$= 2^{\frac{1}{2}} = \underline{\sqrt{2}}$ ✓

(e) $\frac{1}{h(x)} = 2^{kx}$

$\Rightarrow \frac{1}{2^x} = 2^{kx}$

$\Rightarrow 2^{-x} = 2^{kx} \Rightarrow kx = -x$

$\Rightarrow \underline{k = -1}$ ✓

4. $f(x) = 4x-1$ $\quad g(x) = x^2$ $\quad h(x) = 3^{-x}$

(a) Find in its simplest form:

(i) $f(x-3)$ ...[1]

(ii) $g(5x)$ ...[1]

(b) Find $f^{-1}(x)$ ...[1]

(c) Find the value of $hh(1)$, correct to 4 significant figures. ...[3]

(d) (i) Show that $g(3x-2) - h(-3)$ can be written as $9x^2 - 12x - 23$ ...[2]

(ii) Use the quadratic formula to solve $9x^2 - 12x - 23 = 0$ ...[4]

(e) Find x when $f(61) = h(x)$ $\boxed{M\text{-}20/42/Q10}$ ...[2]

Solution (a) (i) $f(x-3) = 4(x-3) - 1$ $\quad \because f(x) = 4x-1$

$= 4x - 12 - 1 = \underline{4x - 13}$ ✓

a(ii) $g(5x) = (5x)^2$

$= \underline{25x^2}$ ✓ $\quad \because g(x) = x^2$

(b) $f(x) = 4x - 1 = y$ (let)

Interchange x and $y \Rightarrow 4y - 1 = x$

$\Rightarrow y = \frac{x+1}{4} \Rightarrow \underline{f^{-1}(x) = \frac{x+1}{4}}$ ✓

(c) $hh(1) = h(h(1)) = h(3^{-1})$ $\quad \because h(x) = 3^{-x}$

$= h\left(\frac{1}{3}\right) = 3^{-\frac{1}{3}} = \frac{1}{3^{1/3}} = \frac{1}{1.44225} = \underline{0.6933}$ ✓

(d) (i) $g(3x-2) - h(-3) = (3x-2)^2 - 3^{-(-3)}$

$= 9x^2 - 12x + 4 - 27 = \underline{9x^2 - 12x - 23}$ ✓

(ii) $9x^2 - 12x - 23 = 0$ $\quad a = 9, b = -12, c = -23$

$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ $\quad b^2 - 4ac = (-12) - 4 \times 9 \times (-23) = 972$

$= \frac{12 \pm \sqrt{972}}{2 \times 9}$

$= \frac{12 \pm 31.17}{18}$

$= \frac{43.17}{18}, -\frac{19.17}{18}$

$= \underline{2.34}; \underline{-1.07}$ ✓

(e) $f(61) = h(x)$

$\Rightarrow 4 \times 61 - 1 = 3^{-x}$

$\Rightarrow 3^{-x} = 243 = 3^5$

$\Rightarrow -x = 5$

$\Rightarrow \underline{x = -5}$ ✓

5. $f(x) = 3x+2$ $g(x) = x^2+1$ $h(x) = 4^x$

(a) Find $h(4)$ ---[1]

(b) Find $fg(1)$ ---[2]

(c) Find $gf(x)$ in the form ax^2+bx+c ---[3]

(d) Find x when $f(x) = g(7)$ ---[2]

(e) Find $f^{-1}(x)$ ---[2]

(f) Find $\frac{g(x)}{f(x)} + x$ Giving your answer as a single fraction in terms of x ---[3]

(g) Find x when $h^{-1}(x) = 2$ ---[1]

[S-20/42/Q6]

Solution (a) $h(4) = 4^4 = \underline{256}$ ✓ $(\because h(x) = 4^x)$

(b) $fg(1) = f(g(1))$ $(\because g(x) = x^2+1)$

$= f(1^2+1) = f(2)$

$= 3\times2+2 = \underline{8}$ ✓ $(\because f(x) = 3x+2)$

(c) $gf(x) = g(f(x)) = g(3x+2)$

$= (3x+2)^2+1 = 9x^2+12x+4+1$

$= \underline{9x^2+12x+5}$ ✓

(d) $f(x) = g(7) \Rightarrow 3x+2 = 7^2+1$

$\Rightarrow 3x+2 = 50 \Rightarrow 3x = 48$

$\Rightarrow \underline{x = 16}$ ✓

(e) $f(x) = 3x+2 = y$ (let)

Interchang. x and y $\Rightarrow 3y+2 = x$

$\Rightarrow y = \frac{x-2}{3}$

$\Rightarrow \underline{f^{-1}(x) = \frac{x-2}{3}}$ ✓

(f) $\frac{g(x)}{f(x)} + x = \frac{x^2+1}{3x+2} + x$

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

$= \underline{\frac{4x^2+2x+1}{3x+2}}$ ✓

(g) $h^{-1}(x) = 2 \Rightarrow h(2) = x$

$\Rightarrow 4^2 = x$ $\because h(x) = 4^x$

$\Rightarrow \underline{x = 16}$ ✓

6. $f(x) = 7x-4$ $\quad g(x) = \frac{2x}{x-3}, x \neq 3,$ $\quad h(x) = x^2$

(a) Find $g(6)$ ---[1]

(b) Find $fg(4)$ ---[2]

(c) Find $fh(x)$ --[1]

(d) Find $\frac{f(x)}{2} + g(x)$, Give your answer as a single fraction-[3]

(e) Find the value of x when $f(x+2) = -11$ --[2]

(f) Find the value of p that satisfy $h(p) = p$. --[2]

------ S-20/43/Q11

Solution (a) $g(6) = \frac{2\times 6}{6-3} = \frac{12}{3} = \underline{4}$ ✓ $\left(\because g(x) = \frac{2x}{x-3}\right)$

(b) $fg(4) = f(g(4)) = f\left(\frac{2\times 4}{4-3}\right) = f(8)$

$= 7\times 8 - 4$ $\quad (\because f(x) = 7x-4)$

$= 56-4 = \underline{52}$ ✓

(c) $fh(x) = f(x^2) = \underline{7x^2-4}$ ✓

(d) $\frac{f(x)}{2} + g(x) = \frac{7x-4}{2} + \frac{2x}{x-3}$

$= \frac{(7x-4)(x-3)+2x\times 2}{2(x-3)}$

$= \frac{7x^2-21x-4x+12+4x}{2(x-3)} = \underline{\frac{7x^2-21x+12}{2(x-3)}}$ ✓

(e) $f(x+2) = -11$

$\Rightarrow 7(x+2)-4 = -11 \Rightarrow 7x+14-4 = -11$

$\Rightarrow 7x = -11-10$

$\Rightarrow x = -\frac{21}{7} = -3$

$\therefore \underline{x = -3}$ ✓

(f) $h(p) = p$

$\Rightarrow p^2 = p$ $\quad (\because h(x) = x^2)$

$\Rightarrow p^2 - p = 0$

$\Rightarrow p(p-1) = 0$

$\Rightarrow p = 0$ or $p-1 = 0$

$\Rightarrow \underline{p = 0 \text{ or } p = 1}$ ✓

7. $f(x) = 7 - 2x$ $\quad g(x) = \frac{10}{x}, x \neq 0$ $\quad h(x) = 27^x$

(a) Find (i) $f(-3)$ --- [1]

(ii) $hg(30)$ --- [2]

(iii) $f^{-1}(x)$ --- [2]

(b) Solve $g(2x+1) = 4$ --- [3]

(c) Simplify, giving your answer as a single fraction: $\frac{1}{f(x)} + g(x)$ -- [3]

(d) Find $h^{-1}(19683)$ -- [1]

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Solve (a) (i) $f(-3) = 7 - 2(-3)$ $\quad (\because f(x) = 7 - 2x)$

$= 7 + 6 = \underline{13}$ ✓

(ii) $hg(30)$

$= h\left(\frac{10}{30}\right) = h\left(\frac{1}{3}\right)$ $\quad \left(\because g(x) = \frac{10}{x}\right)$

$= 27^{1/3}$ $\quad (\because h(x) = 27^x)$

$= (3^3)^{1/3} = 3^{3 \times \frac{1}{3}} = \underline{3}$ ✓

(b) $g(2x+1) = 4$

$\Rightarrow \frac{10}{2x+1} = 4 \Rightarrow 4(2x+1) = 10$

$\Rightarrow 2x + 1 = \frac{10}{4} \Rightarrow 2x = \frac{5}{2} - 1 = \frac{3}{2}$

$\Rightarrow x = \frac{3}{4} = \underline{0.75}$ ✓

(c) $\frac{1}{f(x)} + g(x) = \frac{1}{7-2x} + \frac{10}{x}$

$= \frac{x + 10(7-2x)}{x(7-2x)} = \frac{x + 70 - 20x}{x(7-2x)}$

$= \underline{\frac{70 - 19x}{x(7-2x)}}$ ✓

(d) $h^{-1}(19683) = x$ (let)

$\Rightarrow h(x) = 19683$

$\Rightarrow 27^x = 19683$

$\Rightarrow 27^x = 27^3$

$\Rightarrow x = 3$

$\therefore h^{-1}(19683) = \underline{3}$ ✓

8. $f(x) = 2x-3$ $g(x) = 9-x^2$ $h(x) = 3^x$

(a) Find (i) $f(4)$ --[1]

(ii) $hg(3)$ --[2]

(iii) $g(2x)$ in its simplest form. ---[1]

(iv) $fg(x)$ in its simplest form. --[2]

(b) Find $f^{-1}(x)$ ---[2]

(c) Find x when $5f(x)=3$ --[2]

(d) Solve the equation $gf(x)=-16$ ---[4]

(e) Find x when $h^{-1}(x)=-2$ --[1]

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Solution: (a) (i) $f(4) = 2\times 4-3 = \underline{5}$ ✓ $(\because f(x) = 2x-3)$

(ii) $hg(3) = h(9-3^2)$ $(\because g(x) = 9-x^2)$

$= h(0) = 3^0 = \underline{1}$ ✓

(iii) $g(2x) = 9-(2x)^2$

$= \underline{9-4x^2}$ ✓

(iv) $fg(x) = f(g(x)) = f(9-x^2) = 2(9-x^2)-3$

$= 18-2x^2-3 = \underline{15-2x^2}$ ✓

(b) $f(x) = 2x-3 = y$ (let)

Interchange x and y $\Rightarrow 2y-3 = x$

$\Rightarrow y = \frac{x+3}{2} \Rightarrow f^{-1}(x) = \underline{\frac{x+3}{2}}$ ✓

(c) $5f(x) = 3 \Rightarrow 5(2x-3) = 3$

$\Rightarrow 10x-15 = 3 \Rightarrow 10x = 18 \Rightarrow x = \frac{18}{10} = \underline{1.8}$ ✓

(d) $gf(x) = -16 \Rightarrow g[2x-3] = -16$

$\Rightarrow 9-(2x-3)^2 = -16$

$\Rightarrow 9-(4x^2-12x+9) = -16 \Rightarrow 9-4x^2+12x-9+16 = 0$

$\Rightarrow 4x^2-12x-16 = 0$

$\Rightarrow x^2-3x-4 = 0$

$\Rightarrow x^2-4x+x-4 = 0 \Rightarrow x(x-4)+(x-4) = 0 \Rightarrow (x-4)(x+1) = 0$

$\Rightarrow \underline{x = 4 \text{ and } -1}$ ✓

(e) $h^{-1}(x) = -2 \Rightarrow h(-2) = x$

$\Rightarrow 3^{-2} = x \Rightarrow x = \frac{1}{3^2} = \frac{1}{9}$

$\therefore \underline{x = \frac{1}{9}}$ ✓

Derived Functions

9. A curve has equation $y = x^3 - 6x^2 + 16$

(a) Find the coordinates of the two turning points. ---[6]

(b) Determine whether each of the turning points is a maximum or a minimum. Give reasons for your answers. ---[3]

SP-20/04/Q11

Solution: $y = x^3 - 6x^2 + 16$ —— ①

$\left[\because \frac{d}{dx}x^n = nx^{n-1} \text{ and } \frac{d}{dx}c = 0 \right]$

$\frac{dy}{dx} = 3x^2 - 6 \times 2x + 0$

$= 3x^2 - 12x$ —— ②

or $\frac{dy}{dx} = 3x(x-4)$

for any turning point $\frac{dy}{dx} = 0$

from ② $3x(x-4) = 0$

$\Rightarrow x = 0$ or $x = 4$

from ① $x = 0, y = 16$, $(0,16)$ ✓

$x = 4$, $y = 4^3 - 6 \times 4^2 + 16 = -16 \Rightarrow (4,-16)$ ✓

$\therefore$ Turning points are $(0,16)$ and $(4,-16)$ ✓

Now to check the max/min at turning points.

First derivative Test

(i) at $(0,16)$ from ②

Take $-1 < 0 \Rightarrow \left(\frac{dy}{dx}\right)_{x=-1} = 3(-1)(-1-4) = +15 > 0$

and $1 > 0 \Rightarrow \left(\frac{dy}{dx}\right)_{x=1} = 3 \times 1(1-4) = -9 < 0$

$\frac{dy}{dx}$ changes sign at $(0,16)$ from $+$ to $-$ve $\Rightarrow$ Max at $(0,16)$.

(ii) at $(4,-16)$ or at $x = 4$ from ②

Take $3 < 4 \Rightarrow \left(\frac{dy}{dx}\right)_{x=3} = 3 \times 3 \times (3-4) = -9 < 0$

and $5 > 4 \Rightarrow \left(\frac{dy}{dx}\right)_{x=5} = 3 \times 5 \times (5-4) = 15 > 0$

$\therefore \frac{dy}{dx}$ changes sign from $-$ve to $+$ at $(4,-16)$ has Minimum.

Alternatively:

Second derivative test:

Diff ②

$\frac{d^2y}{dx^2} = 6x - 12$ —— ③

$\left(\frac{d^2y}{dx^2}\right)_{x=0} = 0 - 12 < 0$

Max at $(0,16)$ ✓

Again: from ③

$\left(\frac{d^2y}{dx^2}\right)_{x=4} = 6 \times 4 - 12 = 12 > 0$ is $+$

$\therefore$ Min. at $(4,-16)$

10. A curve has equation $y = x^3 - 3x + 4$

(a) Work out the coordinates of the two stationary points. ---[5]

(b) determine whether each stationary point is a maximum or a minimum, Give reason for your answers. ---[3]

[M-20/42/Q 11]

<u>Solution:</u> $y = x^3 - 3x + 4$ ——① $\left(\because \frac{d}{dx}x^n = nx^{n-1}\right)$

$\frac{dy}{dx} = 3x^2 - 3$ ——②

diff ② $\frac{d^2y}{dx^2} = 6x$ ——③ $\left(\because \frac{d^2y}{dx^2} = \frac{d}{dx}\left(\frac{dy}{dx}\right)\right)$

(a) For stationary points $\frac{dy}{dx} = 0$

$\Rightarrow 3x^2 - 3 = 0$ from ②

$3(x^2-1) = 0 \Rightarrow 3(x-1)(x+1) = 0$

$\Rightarrow x = 1$ or $x = -1$

from ① $x = 1, y = 1 - 3 + 4 = 2 \Rightarrow (1, 2)$

$x = -1, y = -1 + 3 + 4 = 6 \Rightarrow (-1, 6)$

$\therefore$ Stationary points are <u>(1,2) and (-1,6)</u> ✓

(b) <u>To Check Max/Min. Using second derivative test:</u>

at (1,2) from ③

$\left(\frac{d^2y}{dx^2}\right)_{x=1} = 6 \times 1 = 6 > 0$ $\therefore$ <u>Minimum at (1,2)</u> ✓

and at (-1,6)

$\left(\frac{d^2y}{dx^2}\right)_{x=-1} = 6 \times (-1) = -6 < 0$ $\therefore$ <u>Max. at (-1, 6)</u> ✓

9. A curve has the equation $y = x^3 + 8x^2 + 5x$

(i) Work out the coordinates of the two turning points. --- [6]

(ii) Determine whether each of the turning points is a maximum or a minimum. Give reasons for your answers. --- [3]

[S-20/41/Q10(b)]

Solution: $y = x^3 + 8x^2 + 5x$ —— ①

diff. $\frac{dy}{dx} = 3x^2 + 16x + 5$ —— ②

diff ② $\frac{d^2y}{dx^2} = 6x + 16$ —— ③.

(i) For any turning point $\frac{dy}{dx} = 0$

from ① $\Rightarrow 3x^2 + 16x + 5 = 0$

$3x^2 + 15x + x + 5 = 0$

$3x(x+5) + 1(x+5) = 0$

$(x+5)(3x+1) = 0$

$\Rightarrow (x+5) = 0$ or $3x+1 = 0 \Rightarrow x = -5, x = -\frac{1}{3}$

from ① $x = -5, y = (-5)^3 + 8(-5)^2 + 5(-5) = 50, (-5, 50)$ ✓

$x = -\frac{1}{3}, y = (-\frac{1}{3})^3 + 8(-\frac{1}{3})^2 + 5(-\frac{1}{3}) = -\frac{22}{27}, (-\frac{1}{3}, -\frac{22}{27})$

$\therefore$ Two turning points are $(-5, 50)$ and $(-\frac{1}{3}, -\frac{22}{27})$ ✓

(ii) To check the Max/Min.

at $(-5, 50)$ from ③ $\left(\frac{d^2y}{dx^2}\right)_{x=-5} = 6(-5) + 15 = -15 < 0$ Max. ✓

at $(-\frac{1}{3}, -\frac{22}{27}) \rightarrow \left(\frac{d^2y}{dx^2}\right)_{x=-\frac{1}{3}} = 6 \cdot (-\frac{1}{3}) + 15 = 13 > 0$ Min ✓

$\therefore$ $(-5, 50)$ is Maximum. ✓

$(-\frac{1}{3}, -\frac{22}{27})$ is Minimum. ✓

10.(a) $y = x^4 - 4x^3$

(i) Find the value of y when $x = -1$. ---[2]

(ii) Find two stationary points on the graph of $y = x^4 - 4x^3$ ---[6]

(b) $y = x^p + 2x^q$

$\frac{dy}{dx} = 11x^{10} + 10x^4$, where $\frac{dy}{dx}$ is the desired function.

Find the value of p and the value of q. ---[2]

S-20/42/Q10

Solution: $y = x^4 - 4x^3$ —— ①

(i) for $x = -1$, $y = (-1)^4 - 4(-1)^3 = 1 - 4(-1) = \underline{5}$ ✓

(ii) diff ①

$$\frac{dy}{dx} = 4x^3 - 12x^2 \text{ —— ②}$$

for any turning point $\frac{dy}{dx} = 0$

$\therefore$ from ② $4x^3 - 12x^2 = 0$

$\Rightarrow 4x^2(x-3) = 0 \Rightarrow x = 0,\ x = 3$

from ① $x = 0$, $y = 0$ and $x = 3$, $y = 3^4 - 4 \times 3^3 = 81 - 108 = -27$

$\therefore$ the two turning points are $\underline{(0,0) \text{ and } (3,-27)}$ ✓

(b) $y = x^p + 2x^q$ —— ③

diff ③ $\frac{dy}{dx} = px^{p-1} + 2qx^{q-1}$ —— ④

and given $\frac{dy}{dx} = 11x^{10} + 10x^4$ —— ⑤

Comparing ④ and ⑤ $\Rightarrow$ $p = 11$ ✓

and $q - 1 = 4$ (or $2q = 10$)

$q = 5$ ✓

$\therefore$ $\underline{p = 11 \text{ and } q = 5}$ ✓

11. A curve has equation $y = 4x^3 - 3x + 3$
(i) Find the coordinates of the two stationary points. --[5]
(ii) Determine whether each of the stationary points is a maximum or a minimum. Give reasons for your answers. --[3]
[S-20/43/Q12(a)]

Solution: $y = 4x^3 - 3x + 3$ —— ①

diff ① $\frac{dy}{dx} = 12x^2 - 3$ —— ②

diff ② $\frac{d^2y}{dx^2} = 24x$ —— ③

(i) for any stationary point $\frac{dy}{dx} = 0$

fm ② $\Rightarrow 12x^2 - 3 = 0$

$3(4x^2 - 1) = 0$

$3(2x-1)(2x+1) = 0$

$\Rightarrow x = \frac{1}{2}$ or $x = -\frac{1}{2}$

from ① $x = \frac{1}{2}$, $y = 4(\frac{1}{2})^3 - 3\times\frac{1}{2} + 3 = 2$ $\therefore (\frac{1}{2}, 2)$ ✓

and $x = -\frac{1}{2}$, $y = 4(-\frac{1}{2})^3 - 3(-\frac{1}{2}) + 3 = 4$ $\therefore (-\frac{1}{2}, 4)$ ✓

$\therefore$ turning points are; $(\frac{1}{2}, 2)$ and $(-\frac{1}{2}, 4)$ ✓

(ii) To Check Max/Min.

at $(\frac{1}{2}, 2)$ from ③ $\left(\frac{d^2y}{dx^2}\right)_{x=\frac{1}{2}} = 24\times\frac{1}{2} = 12 > 0$ $\therefore$ Min

and at $(-\frac{1}{2}, 4)$ from ③ $\left(\frac{d^2y}{dx^2}\right)_{x=-\frac{1}{2}} = 24\times\left(-\frac{1}{2}\right) = -12 < 0$ Max

$\therefore (\frac{1}{2}, 2)$ is a Minimum ✓

and $(-\frac{1}{2}, 4)$ is a Maximum ✓