Solutionbank
Edexcel AS and A Level Modular Mathematics

Exercise A, Question 1

Question:

Draw mapping diagrams and graphs for the following operations:

(a) ‘subtract 5’ on the set { 10 , 5 , 0 , − 5 , *x* {

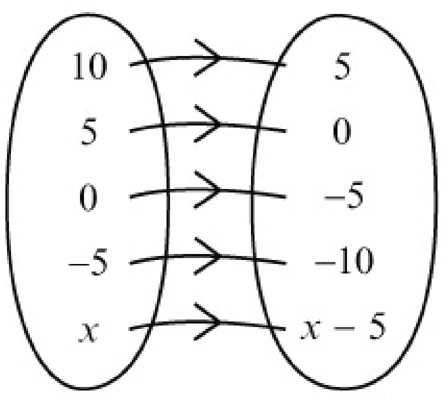
(b) ‘double and add 3’ on the set { − 2 , 2 , 4 , 6 , *x* {

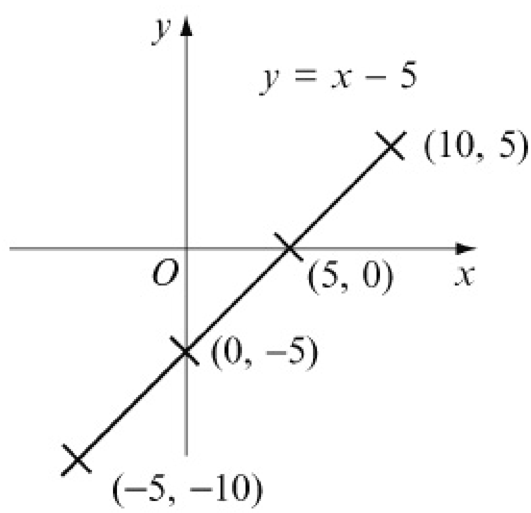
(c) ‘square and then subtract 1’ on the set { − 3 , − 1 , 0 , 1 , 3 , *x* {

(d) ‘the positive square root’ on the set { − 4 , 0 , 1 , 4 , 9 , *x* { .

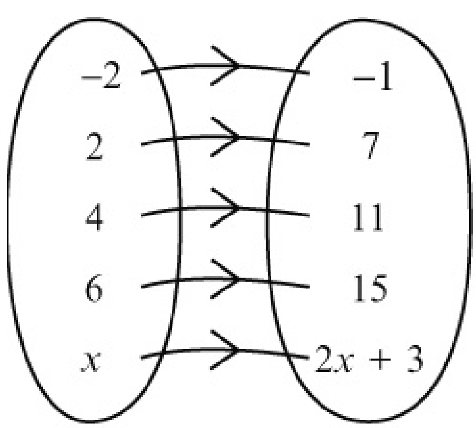
Solution:

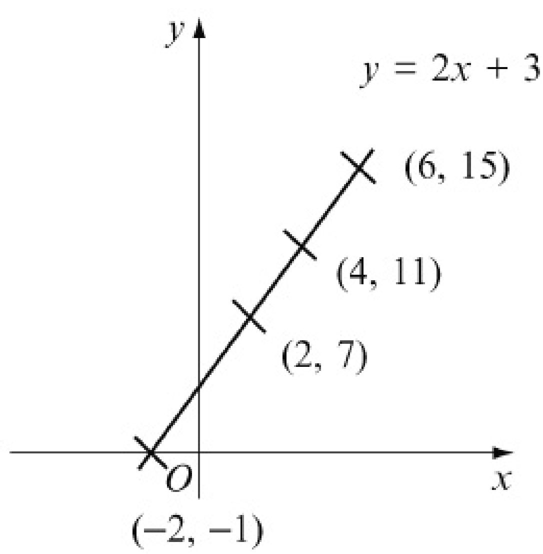
(a)



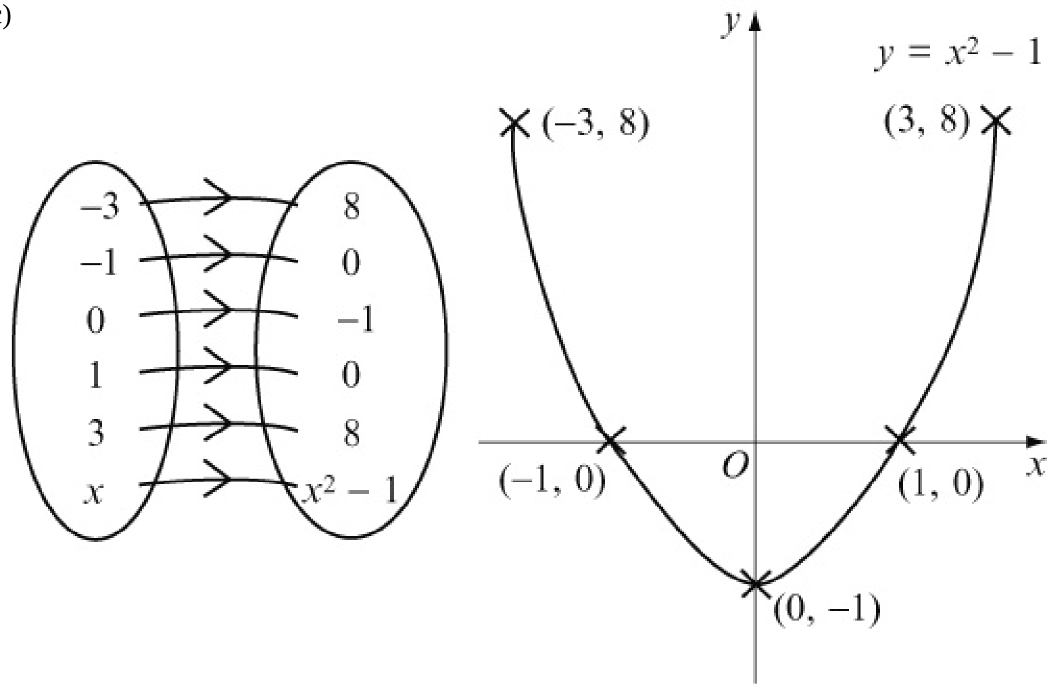


(b)

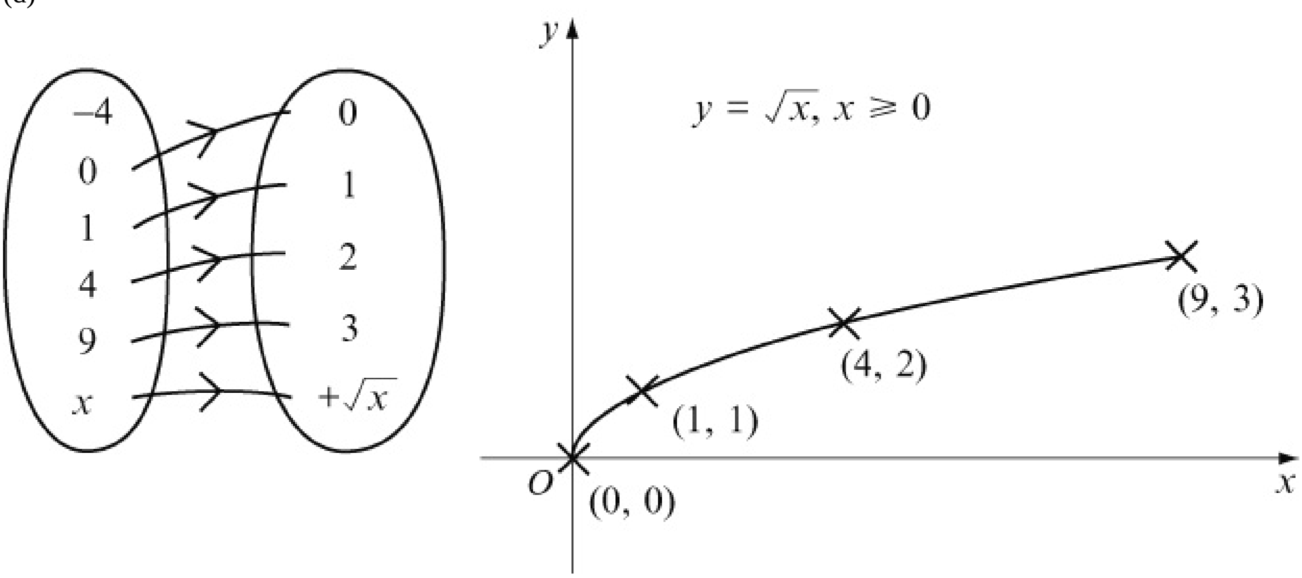




(c)



(d)



Note: You cannot take the square root of a negative number.

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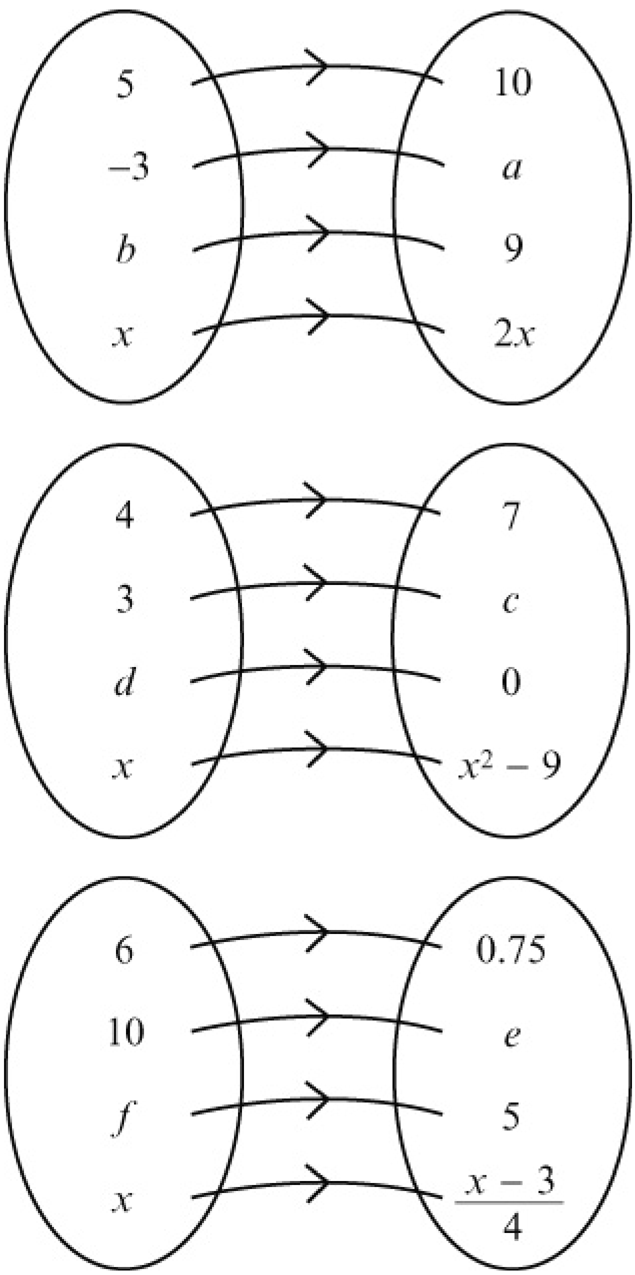
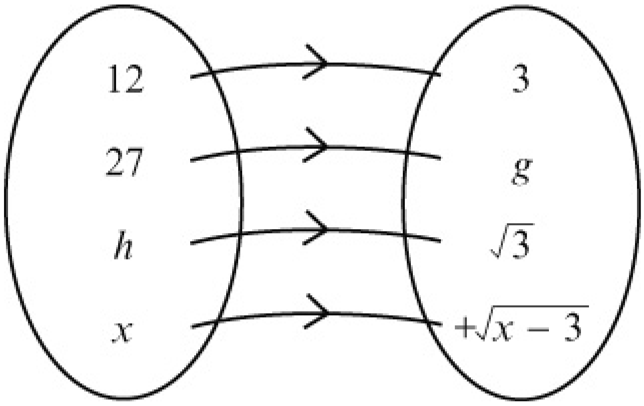
Exercise A, Question 2

Question:

Find the missing numbers ***a*** to ***h*** in the following mapping diagrams:





Solution:

$x \to 2x$ is 'doubling'
$-3 \to a$ so $a = -6$
$b \to 9$ so $b \times 2 = 9 \Rightarrow b = 4\frac{1}{2}$

$x \to x^2 - 9$ is 'squaring then subtracting 9'
$3 \to c$ so $c = 3^2 - 9 = 0$
$d \to 0$ so $d^2 - 9 = 0 \Rightarrow d^2 = 9 \Rightarrow d = \pm 3$

$x \to \frac{x-3}{4}$ is 'subtract 3, then divide by 4'
$10 \to e$ so $e = (10 - 3) \div 4 = 1.75$
$f \to 5$ so $\frac{f-3}{4} = 5 \Rightarrow f = 23$

$x \to +\sqrt{x-3}$ is 'subtract 3, then take the positive square root'
$27 \to g$ so $g = +\sqrt{27-3} = +\sqrt{24} = +2\sqrt{6}$
$h \to +\sqrt{3}$ so $\sqrt{h-3} = \sqrt{3} \Rightarrow h - 3 = 3 \Rightarrow h = 6$

So $a = -6$, $b = 4\frac{1}{2}$, $c = 0$, $d = \pm 3$, $e = 1.75$, $f = 23$, $g = 2\sqrt{6}$, $h = 6$

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Exercise B, Question 1

Question:

Find:

(a) f(3) where $f(x) = 5x + 1$

(b) $g(-2)$ where $g(x) = 3x^2 - 2$

(c) h(0) where $h : x \rightarrow 3^x$

(d) $j(-2)$ where $j : x \rightarrow 2^{-x}$

Solution:

(a) $f(x) = 5x + 1$
Substitute $x = 3 \Rightarrow f(3) = 5 \times 3 + 1 = 16$

(b) $g(x) = 3x^2 - 2$
Substitute $x = -2 \Rightarrow g(-2) = 3 \times (-2)^2 - 2 = 3 \times 4 - 2 = 10$

(c) $h(x) = 3^x$
Substitute $x = 0 \Rightarrow h(0) = 3^0 = 1$

(d) $j(x) = 2^{-x}$
Substitute $x = -2 \Rightarrow j(-2) = 2^{-(-2)} = 2^2 = 4$

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Exercise B, Question 2

Question:

Calculate the value(s) of a, b, c and d given that:

(a) $p(a) = 16$ where $p(x) = 3x - 2$

(b) $q(b) = 17$ where $q(x) = x^2 - 3$

(c) $r(c) = 34$ where $r(x) = 2(2^x) + 2$

(d) $s(d) = 0$ where $s(x) = x^2 + x - 6$

Solution:

(a) $p(x) = 3x - 2$
Substitute $x = a$ and $p(a) = 16$ then
$16 = 3a - 2$
$18 = 3a$
$a = 6$

(b) $q(x) = x^2 - 3$
Substitute $x = b$ and $q(b) = 17$ then
$17 = b^2 - 3$
$20 = b^2$
$b = \pm\sqrt{20}$
$b = \pm 2\sqrt{5}$

(c) $r(x) = 2 \times 2^x + 2$
Substitute $x = c$ and $r(c) = 34$ then
$34 = 2 \times 2^c + 2$
$32 = 2 \times 2^c$
$16 = 2^c$
$c = 4$

(d) $s(x) = x^2 + x - 6$
Substitute $x = d$ and $s(d) = 0$ then
$0 = d^2 + d - 6$
$0 = (d + 3)(d - 2)$
$d = 2, -3$

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Exercise B, Question 3

Question:

For the following functions
(i) sketch the graph of the function
(ii) state the range
(iii) describe if the function is one-to-one or many-to-one.

(a) $m(x) = 3x + 2$

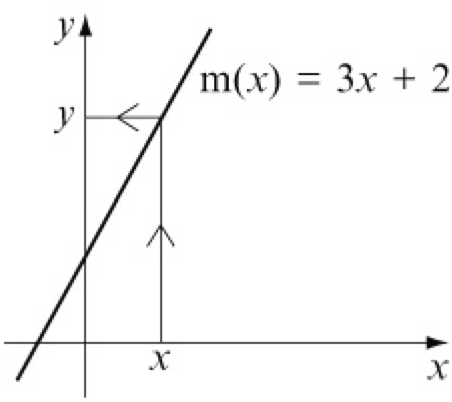
(b) $n(x) = x^2 + 5$

(c) $p(x) = \sin(x)$

(d) $q(x) = x^3$

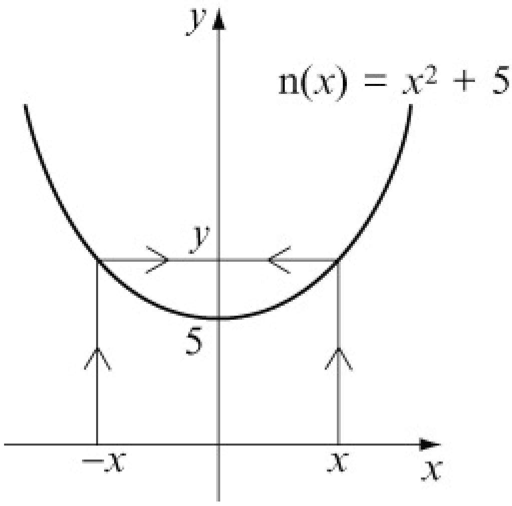
Solution:

(a) $m(x) = 3x + 2$
(i)



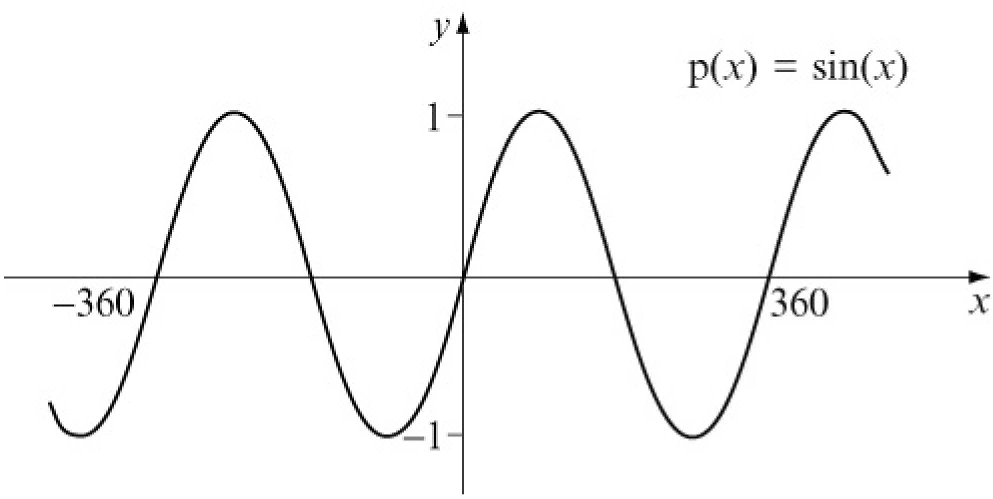
(ii) Range of $m(x)$ is $-\infty < m(x) < \infty$
or $m(x) \in \mathbb{R}$ (all of the real numbers)
(iii) Function is one-to-one

(b) $n(x) = x^2 + 5$
(i)



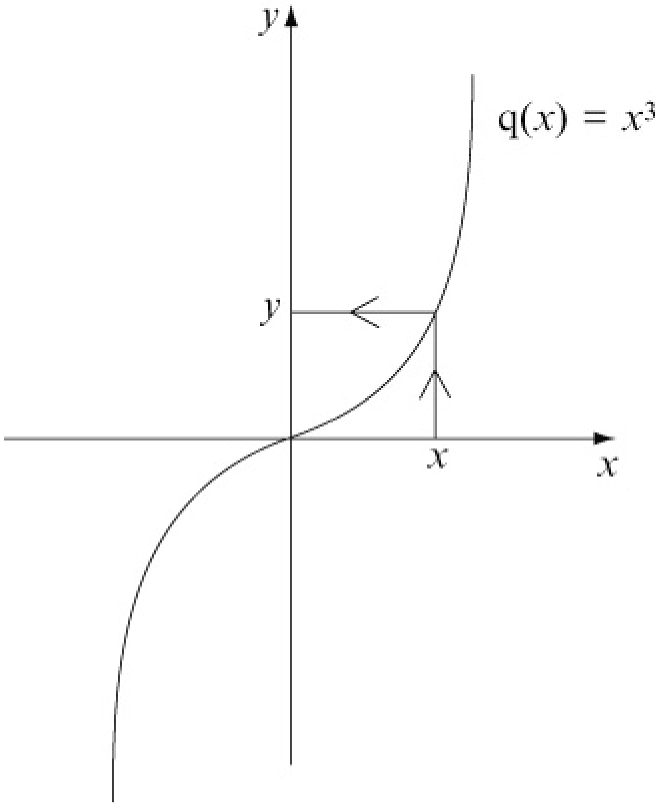
(ii) Range of $n(x)$ is $n(x) \geq 5$
(iii) Function is many-to-one

(c) $p(x) = \sin(x)$
(i)



(ii) Range of $p(x)$ is $-1 \leq p(x) \leq 1$
(iii) Function is many-to-one

(d) $q(x) = x^3$
(i)



(ii) Range of $q(x)$ is $-\infty < q(x) < \infty$ or $q(x) \in \mathbb{R}$

(iii) Function is one-to-one

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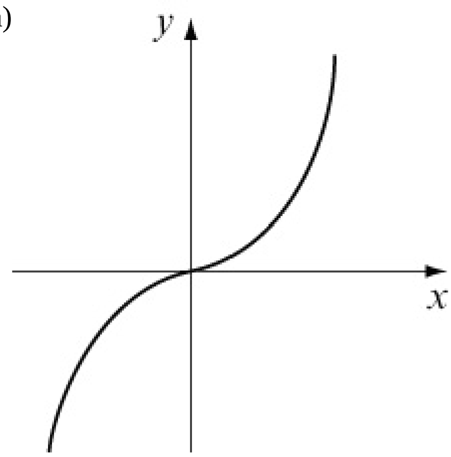
Exercise B, Question 4

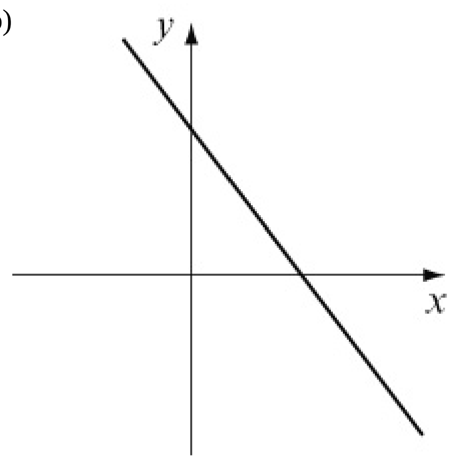
Question:

State whether or not the following graphs represent functions. Give reasons for your answers and describe the type of function.

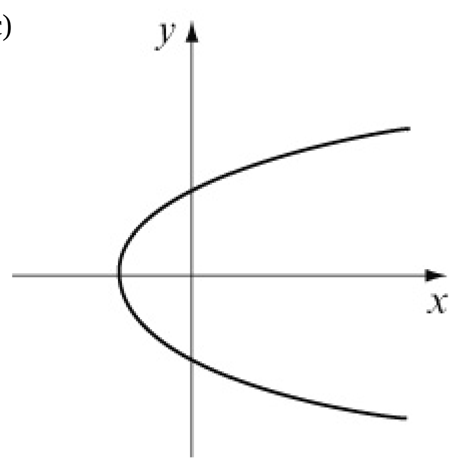
(a)



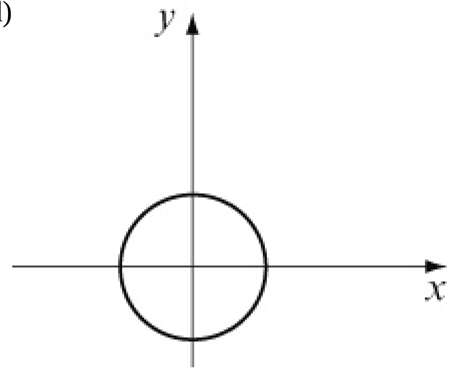
(b)



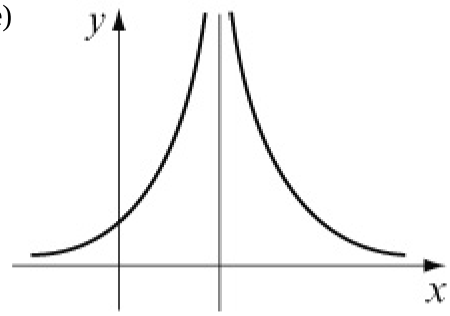
(c)



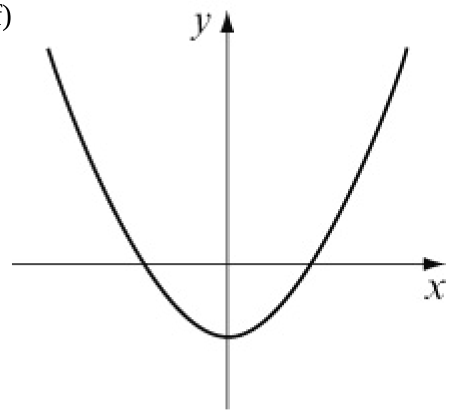
(d)



(e)

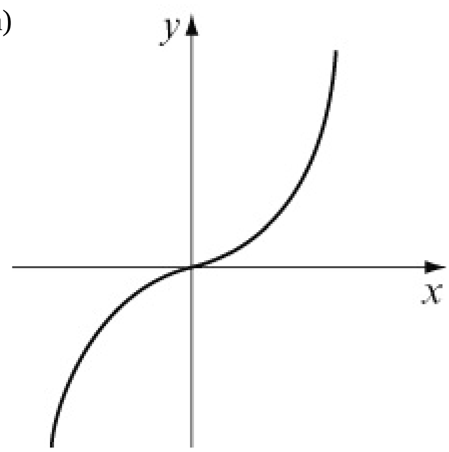


(f)



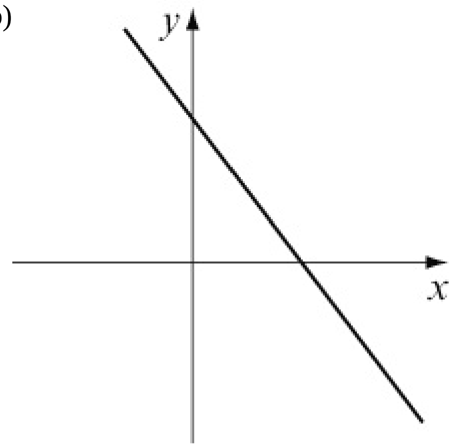
Solution:

(a)



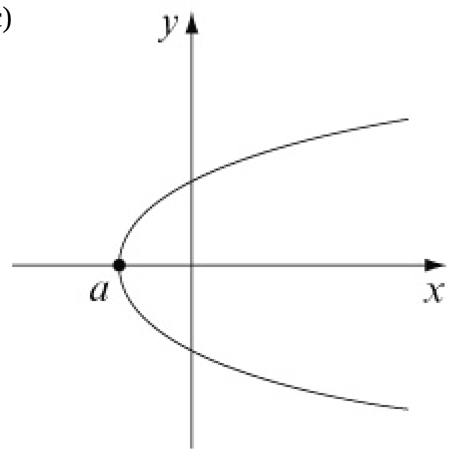
One-to-one function

(b)



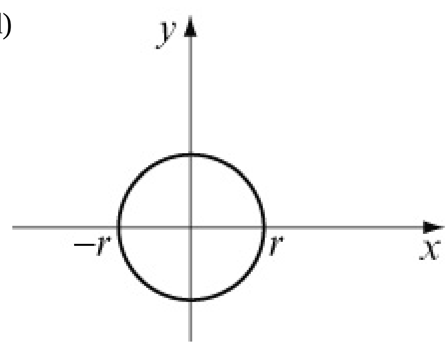
One-to-one function

(c)



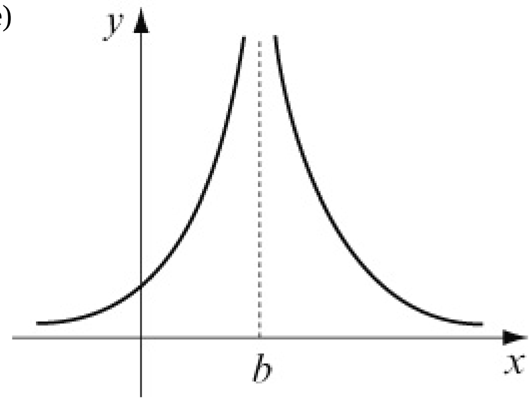
Not a function.
The values left of $x = a$ do not get mapped anywhere.
The values right of $x = a$ get mapped to two values of y.

(d)



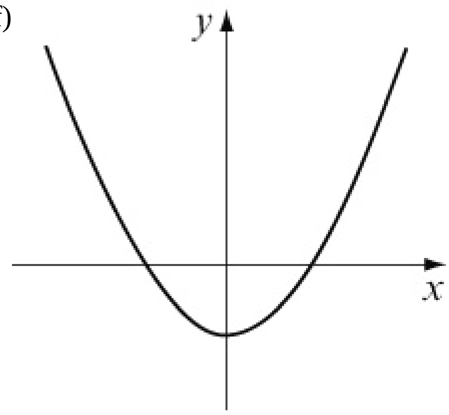
Not a function. Similar to part (c).
Values of x between $-r$ and $+r$ get mapped to two values of y.
Values outside this don't get mapped anywhere.

(e)



Not a function. The value $x = b$ doesn't get mapped anywhere.

(f)



Many-to-one function. Two values of x get mapped to the same value of y.

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Exercise C, Question 1

Question:

The functions below are defined for the discrete domains.
(i) Represent each function on a mapping diagram, writing down the elements in the range.
(ii) State if the function is one-to-one or many-to-one.

(a) $f(x) = 2x + 1$ for the domain $\{x = 1, 2, 3, 4, 5\}$.

(b) $g(x) = +\sqrt{x}$ for the domain $\{x = 1, 4, 9, 16, 25, 36\}$.

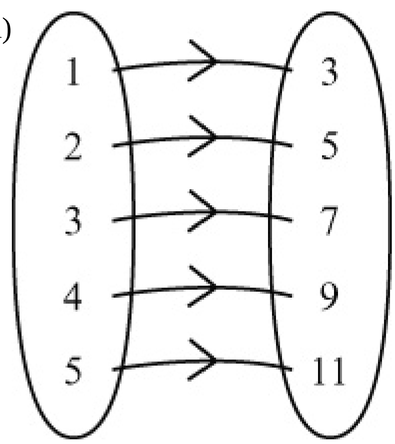
(c) $h(x) = x^2$ for the domain $\{x = -2, -1, 0, 1, 2\}$.

(d) $j(x) = \frac{2}{x}$ for the domain $\{x = 1, 2, 3, 4, 5\}$.

Solution:

(a) $f(x) = 2x + 1$ ‘Double and add 1’

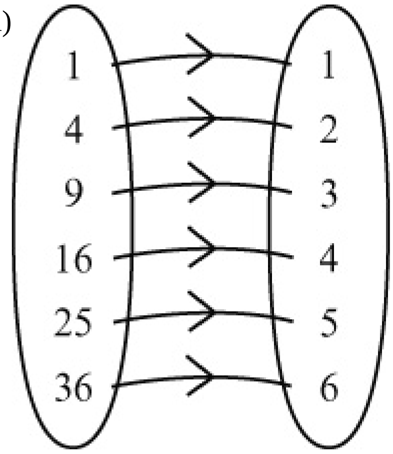
(i)



(ii) One-to-one function

(b) $g(x) = +\sqrt{x}$ ‘The positive square root’

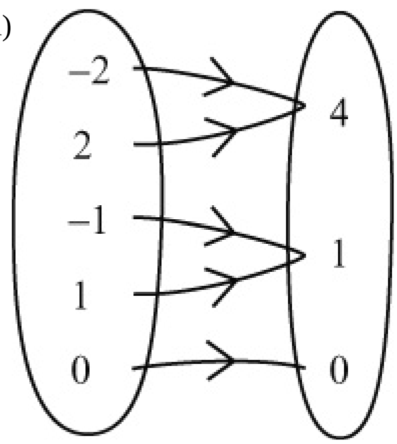
(i)



(ii) One-to-one function

(c) $h(x) = x^2$ ‘Square the numbers in the domain’

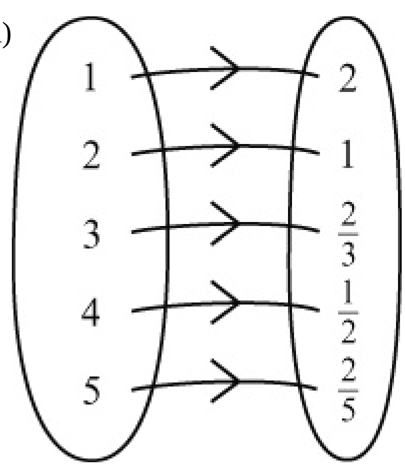
(i)



(ii) Many-to-one function

(d) $j(x) = \frac{2}{x}$ ‘2 divided by numbers in the domain’

(i)



(ii) One-to-one function

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Exercise C, Question 2

Question:

The functions below are defined for continuous domains.
(i) Represent each function on a graph.
(ii) State the range of the function.
(iii) State if the function is one-to-one or many-to-one.

(a) $m(x) = 3x + 2$ for the domain $\{ x > 0 \{$.

(b) $n(x) = x^2 + 5$ for the domain $\{ x \geq 2 \{$.

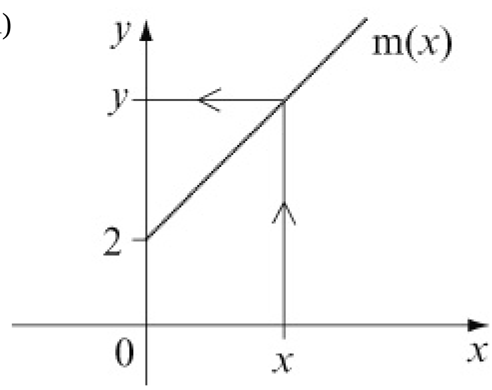
(c) $p(x) = 2\sin x$ for the domain $\{ 0 \leq x \leq 180 \{$.

(d) $q(x) = +\sqrt{x+2}$ for the domain $\{ x \geq -2 \{$.

Solution:

(a) $m(x) = 3x + 2$ for $x > 0$

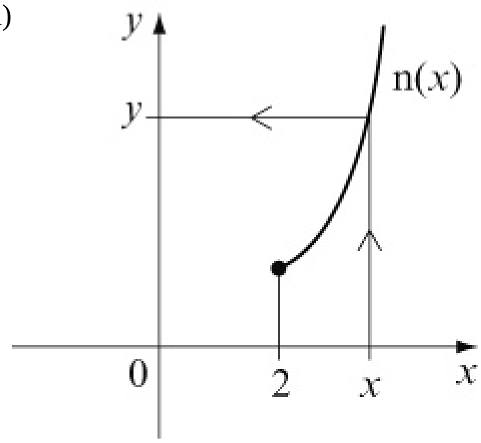
(i)



$3x + 2$ is a linear function of gradient 3 passing through 2 on the y axis.
(ii) $x = 0$ does not exist in the domain
So range is $m(x) > 3 \times 0 + 2 \Rightarrow m(x) > 2$
(iii) $m(x)$ is a one-to-one function

(b) $n(x) = x^2 + 5$ for $x \geq 2$

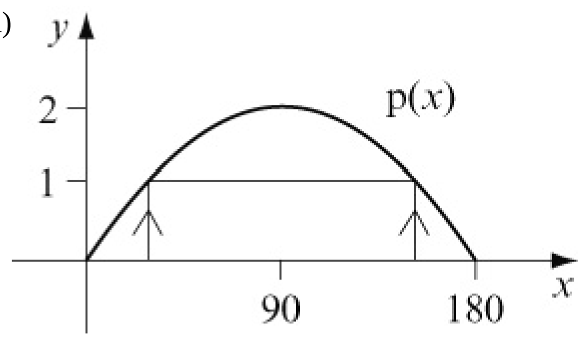
(i)



$x^2 + 5$ is a parabola with minimum point at $(0, 5)$.
The domain however is only values bigger than or equal to 2.
(ii) $x = 2$ exists in the domain
So range is $n(x) \geq 2^2 + 5 \Rightarrow n(x) \geq 9$
(iii) $n(x)$ is a one-to-one function

(c) $p(x) = 2\sin x$ for $0 \leq x \leq 180$

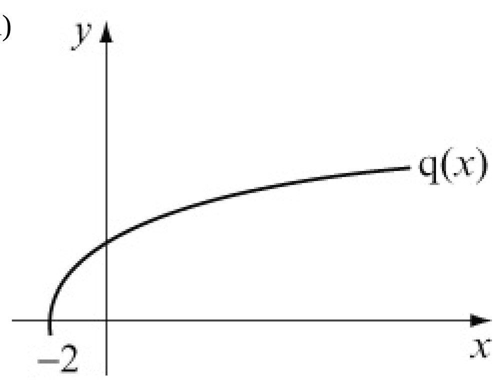
(i)



$2\sin x$ has the same shape as $\sin x$ except that it has been stretched by a factor of 2 parallel to the y axis.
(ii) Range of p(x) is $0 \leq p(x) \leq 2$
(iii) The function is many-to-one

(d) $q(x) = +\sqrt{x+2}$ for $x \geq -2$

(i)



$\sqrt{x+2}$ is the $\sqrt{x}$ graph translated 2 units to the left.
(ii) The range of q(x) is $q(x) \geq 0$
(iii) The function is one-to-one

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Exercise C, Question 3

Question:

The mappings f(x) and g(x) are defined by

$$f(x) = \begin{cases} 4 - x & x < 4 \\ x^2 + 9 & x \geq 4 \end{cases}$$

$$g(x) = \begin{cases} 4 - x & x < 4 \\ x^2 + 9 & x > 4 \end{cases}$$

Explain why f(x) is a function and g(x) is not.
Sketch the function f(x) and find

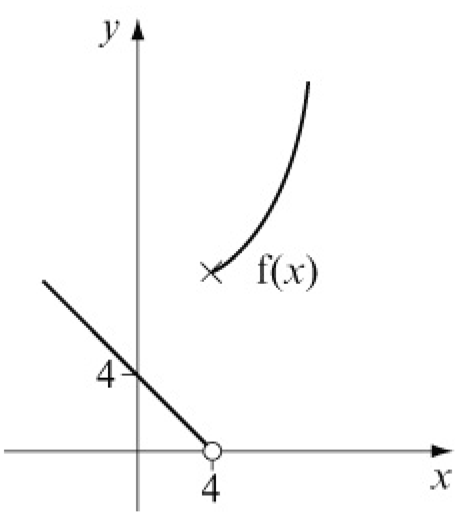
(a) f(3)

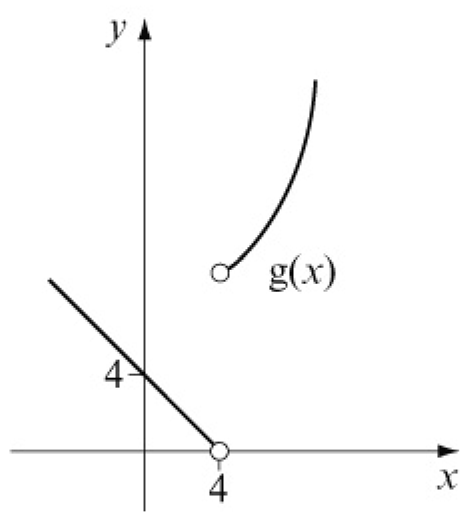
(b) f(10)

(c) the value(s) of a such that $f(a) = 90$.

Solution:

$4 - x$ is a linear function of gradient -1 passing through 4 on the y axis.
$x^2 + 9$ is a $\cup$ -shaped quadratic
At $x = 4$ $4 - x = 0$ and $x^2 + 9 = 25$



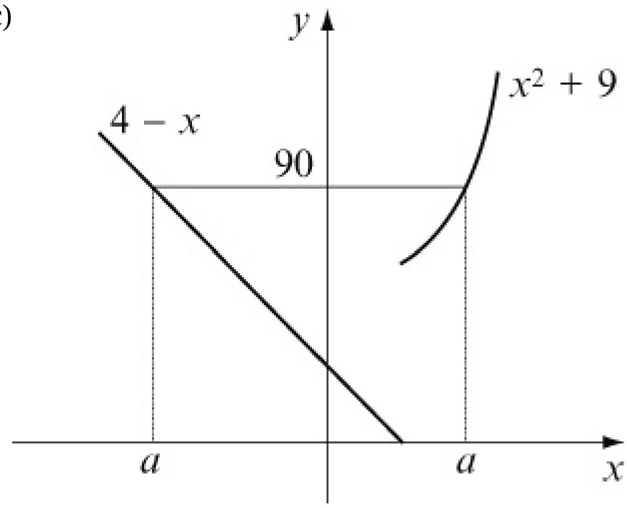


g(x) is not a function because the element 4 of the domain does not get mapped anywhere.
In f(x) it gets mapped to 25.

(a) $f(3) = 4 - 3 = 1$ (Use $4 - x$ as $3 < 4$)

(b) $f(10) = 10^2 + 9 = 109$ (Use $x^2 + 9$ as $10 > 4$)

(c)



The negative value of a is where $4 - a = 90 \Rightarrow a = -86$

The positive value of a is where

$a^2 + 9 = 90$

$a^2 = 81$

$a = \pm 9$

$a = 9$

The values of a are -86 and 9.

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Exercise C, Question 4

Question:

The function s(x) is defined by

$$s(x) = \begin{cases} x^2 - 6 & x < 0 \\ 10 - x & x \geq 0 \end{cases}$$

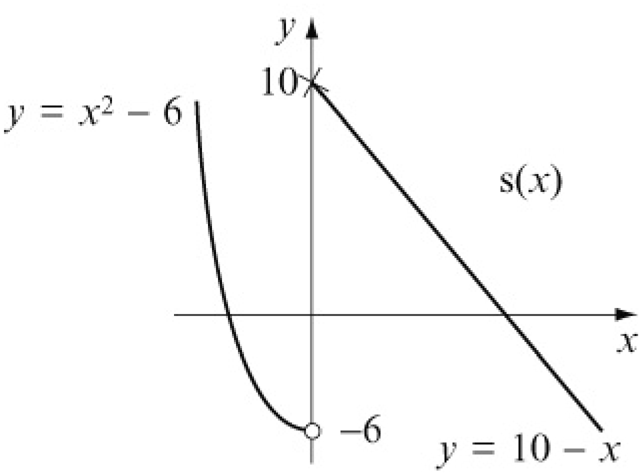
(a) Sketch s(x).

(b) Find the value(s) of a such that $s(a) = 43$.

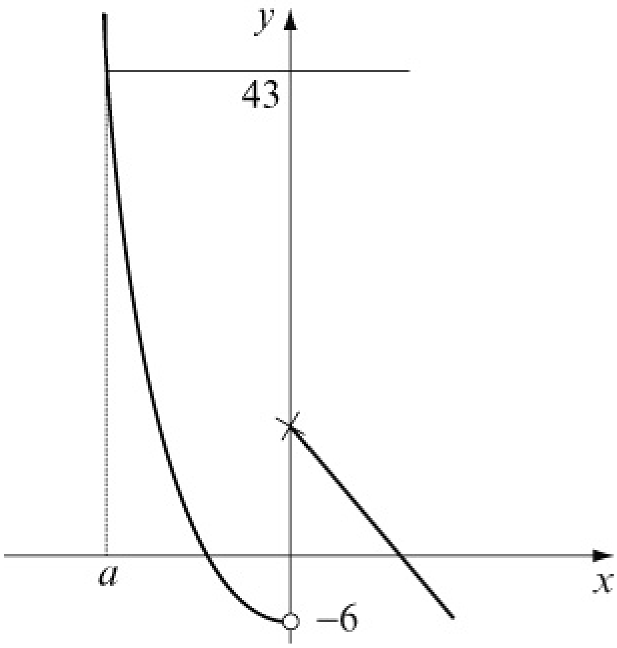
(c) Find the values of the domain that get mapped to themselves in the range.

Solution:

(a) $x^2 - 6$ is a $\cup$ -shaped quadratic with a minimum value of $(0, -6)$.
$10 - x$ is a linear function with gradient -1 passing through 10 on the y axis.



(b) There is only one value of a such that $s(a) = 43$ (see graph).



$s(a) = 43$

$a^2 - 6 = 43$

$a^2 = 49$

$a = \pm 7$

Value is negative so $a = -7$

(c) If value gets mapped to itself then $s(b) = b$

For $10 - x$ part

$10 - b = b$

$\Rightarrow \quad 10 = 2b$

$\Rightarrow \quad b = 5$

Check. $s(5) = 10 - 5 = 5$✓

For $x^2 - 6$ part

$b^2 - 6 = b$

$\Rightarrow \quad b^2 - b - 6 = 0$

$\Rightarrow \quad (b - 3)(b + 2) = 0$

$\Rightarrow \quad b = 3, -2$

b must be negative

$\Rightarrow \quad b = -2$

Check. $s(-2) = (-2)^2 - 6 = 4 - 6 = -2$✓

Values that get mapped to themselves are -2 and 5.

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Exercise C, Question 5

Question:

The function g(*x*) is defined by $g(x) = cx + d$ where *c* and *d* are constants to be found. Given $g(3) = 10$ and $g(8) = 12$ find the values of *c* and *d*.

Solution:

$g(x) = cx + d$

$g(3) = 10 \Rightarrow c \times 3 + d = 10$

$g(8) = 12 \Rightarrow c \times 8 + d = 12$

$3c + d = 10$ ①

$8c + d = 12$ ②

② − ①: $5c = 2$ $(\div 5)$

$\Rightarrow c = 0.4$

Substitute $c = 0.4$ into ①:

$3 \times 0.4 + d = 10$

$1.2 + d = 10$

$d = 8.8$

Hence $g(x) = 0.4x + 8.8$

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Exercise C, Question 6

Question:

The function f(x) is defined by $f(x) = ax^3 + bx - 5$ where a and b are constants to be found. Given that $f(1) = -4$ and $f(2) = 9$, find the values of the constants a and b.

Solution:

$f(x) = ax^3 + bx - 5$

$f(1) = -4 \quad \Rightarrow \quad a \times 1^3 + b \times 1 - 5 = -4$

$\Rightarrow \quad a + b - 5 = -4$

$\Rightarrow \quad a + b = 1 \quad ①$

$f(2) = 9 \quad \Rightarrow \quad a \times 2^3 + b \times 2 - 5 = 9$

$\Rightarrow \quad 8a + 2b - 5 = 9$

$\Rightarrow \quad 8a + 2b = 14$

$\Rightarrow \quad 4a + b = 7 \quad ②$

② − ①: $3a = 6$

$\Rightarrow \quad a = 2$

Substitute $a = 2$ in ①:

$2 + b = 1$

$b = -1$

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Exercise C, Question 7

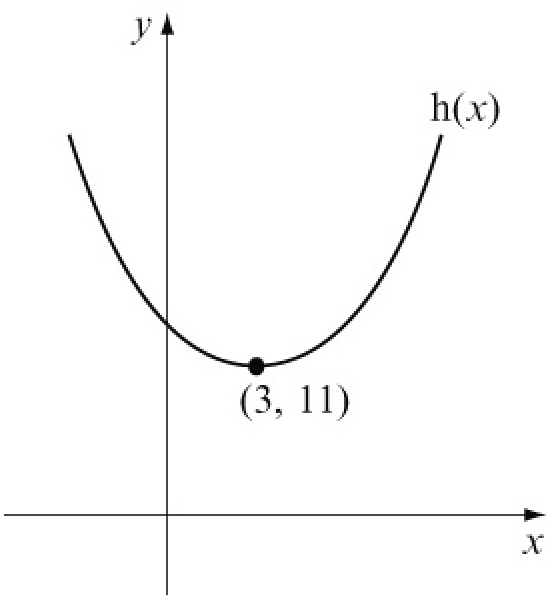
Question:

The function h(x) is defined by $h(x) = x^2 - 6x + 20 \{ x \geq a \}$. Given that h($x$) is a one-to-one function find the smallest possible value of the constant a.

Solution:

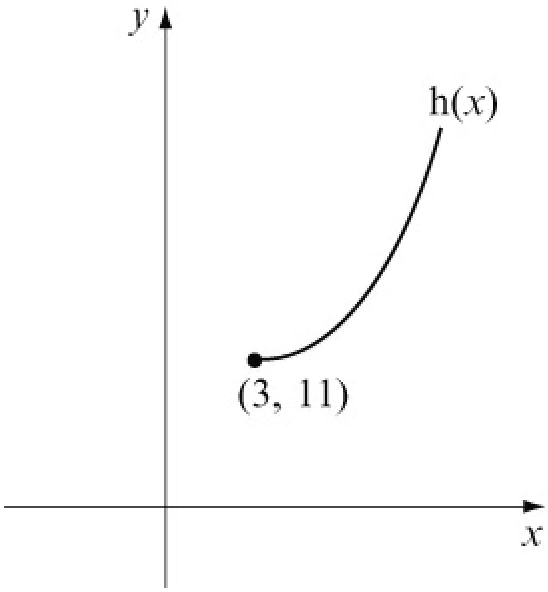
$h(x) = x^2 - 6x + 20 = (x - 3)^2 - 9 + 20 = (x - 3)^2 + 11$

This is a $\cup$ -shaped quadratic with minimum point at (3, 11).



This is a many-to-one function.

For h(x) to be one-to-one, $x \geq 3$



Hence smallest value of a is 3.

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Exercise D, Question 1

Question:

Given the functions $f(x) = 4x + 1$, $g(x) = x^2 - 4$ and $h(x) = \frac{1}{x}$, find expressions for the functions:

(a) $fg(x)$

(b) $gf(x)$

(c) $gh(x)$

(d) $fh(x)$

(e) $f^2(x)$

Solution:

(a) $fg(x) = f(x^2 - 4) = 4(x^2 - 4) + 1 = 4x^2 - 15$

(b) $gf(x) = g(4x + 1) = (4x + 1)^2 - 4 = 16x^2 + 8x - 3$

(c) $gh(x) = g\left(\frac{1}{x}\right) = \left(\frac{1}{x}\right)^2 - 4 = \frac{1}{x^2} - 4$

(d) $fh(x) = f\left(\frac{1}{x}\right) = 4 \times \left(\frac{1}{x}\right) + 1 = \frac{4}{x} + 1$

(e) $f^2(x) = ff(x) = f(4x + 1) = 4(4x + 1) + 1 = 16x + 5$

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Exercise D, Question 2

Question:

For the following functions f(x) and g(x), find the composite functions fg(x) and gf(x). In each case find a suitable domain and the corresponding range when

(a) $f(x) = x - 1$, $g(x) = x^2$

(b) $f(x) = x - 3$, $g(x) = +\sqrt{x}$

(c) $f(x) = 2^x$, $g(x) = x + 3$

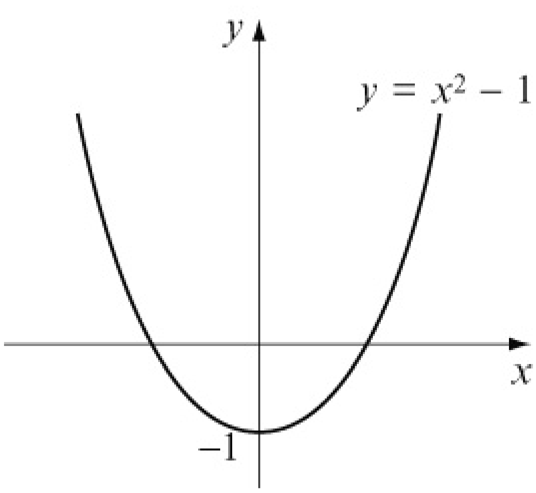
Solution:

(a) $f(x) = x - 1$, $g(x) = x^2$

$fg(x) = f(x^2) = x^2 - 1$

Domain $x \in \mathbb{R}$

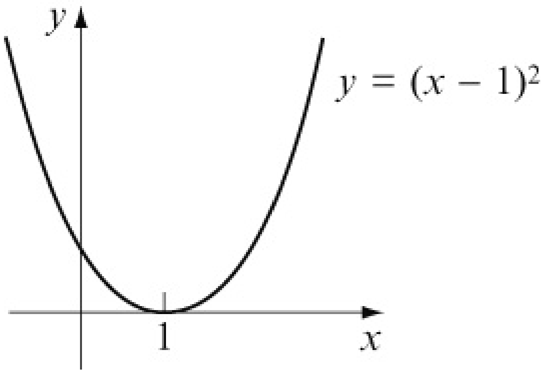
Range $fg(x) \geq -1$



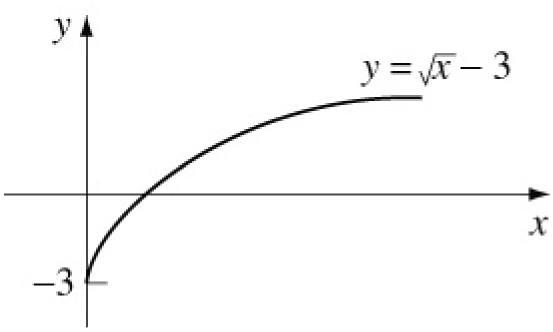
$gf(x) = g(x - 1) = (x - 1)^2$

Domain $x \in \mathbb{R}$

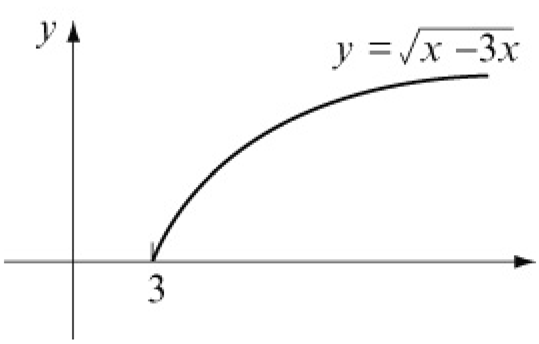
Range $gf(x) \geq 0$



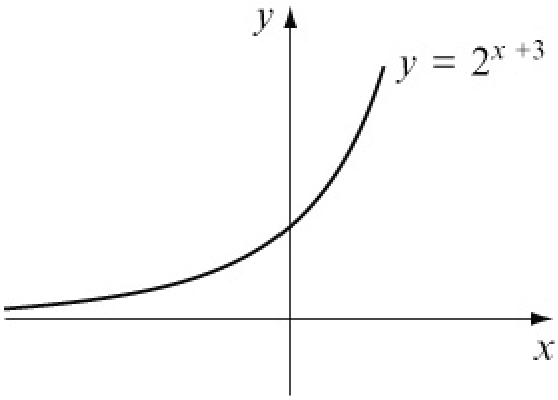
(b) $f(x) = x - 3$, $g(x) = +\sqrt{x}$
$fg(x) = f(+\sqrt{x}) = \sqrt{x} - 3$
Domain $x \geq 0$
(It will not be defined for negative numbers)
Range $fg(x) \geq -3$



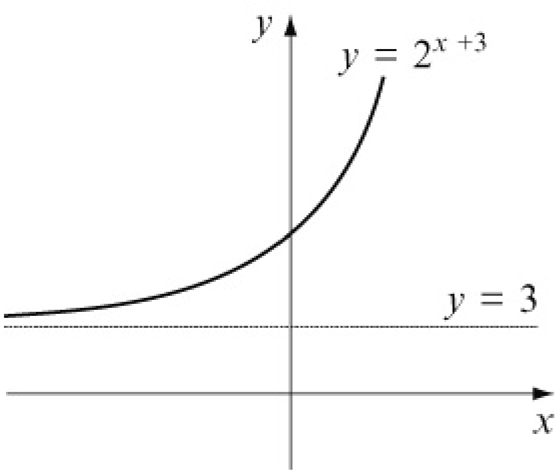
$gf(x) = g(x - 3) = \sqrt{x - 3}$
Domain $x \geq 3$
Range $gf(x) \geq 0$



(c) $f(x) = 2^x$, $g(x) = x + 3$
$fg(x) = f(x + 3) = 2^{x + 3}$
Domain $x \in \mathbb{R}$
Range $fg(x) > 0$



gf (x) = g (2^x) = $2^x + 3$
Domain $x \in \mathbb{R}$
Range gf (x) > 3



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Exercise D, Question 3

Question:

If $f(x) = 3x - 2$ and $g(x) = x^2$, find the number(s) a such that $fg(a) = gf(a)$.

Solution:

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

$fg(x) = f(x^2) = 3x^2 - 2$

$gf(x) = g(3x - 2) = (3x - 2)^2$

If $fg(a) = gf(a)$

$3a^2 - 2 = (3a - 2)^2$

$3a^2 - 2 = 9a^2 - 12a + 4$

$0 = 6a^2 - 12a + 6$

$0 = a^2 - 2a + 1$

$0 = (a - 1)^2$

Hence $a = 1$

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Exercise D, Question 4

Question:

Given that $s(x) = \frac{1}{x-2}$ and $t(x) = 3x + 4$ find the number m such that $ts(m) = 16$.

Solution:

$s(x) = \frac{1}{x-2}$, $t(x) = 3x + 4$

$ts(x) = t\left(\frac{1}{x-2}\right) = 3 \times \left(\frac{1}{x-2}\right) + 4 = \frac{3}{x-2} + 4$

If $ts(m) = 16$

$\frac{3}{m-2} + 4 = 16 \qquad (-4)$

$\frac{3}{m-2} = 12 \qquad [\times (m-2)]$

$3 = 12(m-2) \qquad (\div 12)$

$\frac{3}{12} = m - 2$

$0.25 = m - 2$

$m = 2.25$

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Exercise D, Question 5

Question:

The functions l(x), m(x), n(x) and p(x) are defined by $l(x) = 2x + 1$, $m(x) = x^2 - 1$, $n(x) = \frac{1}{x+5}$ and $p(x) = x^3$. Find in terms of l, m, n and p the functions:

(a) $4x + 3$

(b) $4x^2 + 4x$

(c) $\frac{1}{x^2 + 4}$

(d) $\frac{2}{x+5} + 1$

(e) $(x^2 - 1)^3$

(f) $2x^2 - 1$

(g) x^{27}

Solution:

(a) $4x + 3 = 2(2x + 1) + 1 = 2\,l(x) + 1 = ll(x)$ [or $l^2(x)$]

(b) $4x^2 + 4x = (2x + 1)^2 - 1 = [l(x)]^2 - 1 = ml(x)$

(c) $\frac{1}{x^2 + 4} = \frac{1}{(x^2 - 1) + 5} = \frac{1}{m(x) + 5} = nm(x)$

(d) $\frac{2}{x+5} + 1 = 2 \times \frac{1}{x+5} + 1 = 2\,n(x) + 1 = ln(x)$

(e) $(x^2 - 1)^3 = [m(x)]^3 = pm(x)$

(f) $2x^2 - 1 = 2(x^2 - 1) + 1 = 2\,m(x) + 1 = lm(x)$

(g) $x^{27} = [(x^3)^3]^3 = \{ [p (x)]^3 \{^3 = [pp (x)]^3 = ppp (x)$
$= p^3 (x)$

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Exercise D, Question 6

Question:

If $\mathrm{m}(x) = 2x + 3$ and $\mathrm{n}(x) = \frac{x-3}{2}$, prove that $\mathrm{mn}(x) = x$.

Solution:

$\mathrm{m}(x) = 2x + 3$, $\mathrm{n}(x) = \frac{x-3}{2}$

$$\mathrm{mn}(x) = \mathrm{m}\left(\frac{x-3}{2}\right) = \not{2}\left(\frac{x-3}{\not{2}}\right) + 3 = x - 3 + 3 = x$$

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Exercise D, Question 7

Question:

If $s(x) = \frac{3}{x+1}$ and $t(x) = \frac{3-x}{x}$, prove that $st(x) = x$.

Solution:

$s(x) = \frac{3}{x+1}$, $t(x) = \frac{3-x}{x}$

$$\begin{aligned} st(x) &= s\left(\frac{3-x}{x}\right) \\ &= \frac{3}{\frac{3-x}{x}+1} \begin{matrix} \times x \\ \times x \end{matrix} \\ &= \frac{3x}{3-x+x} \\ &= \frac{\cancel{3}x}{\cancel{3}} \\ &= x \end{aligned}$$

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Exercise D, Question 8

Question:

If $f(x) = \frac{1}{x+1}$, prove that $f^2(x) = \frac{x+1}{x+2}$. Hence find an expression for $f^3(x)$.

Solution:

$f(x) = \frac{1}{x+1}$

$$\begin{aligned} ff(x) &= f\left(\frac{1}{x+1}\right) \\ &= \frac{1}{\frac{1}{x+1}+1} \begin{matrix}\times(x+1)\\ \times(x+1)\end{matrix} \\ &= \frac{x+1}{1+x+1} \\ &= \frac{x+1}{x+2} \end{aligned}$$

$$\begin{aligned} f^3(x) = f[f^2(x)] &= f\left(\frac{x+1}{x+2}\right) \\ &= \frac{1}{\frac{x+1}{x+2}+1} \begin{matrix}\times(x+2)\\ \times(x+2)\end{matrix} \\ &= \frac{x+2}{x+1+x+2} \\ &= \frac{x+2}{2x+3} \end{aligned}$$

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Exercise E, Question 1

Question:

For the following functions f(x), sketch the graphs of f(x) and $f^{-1}(x)$ on the same set of axes. Determine also the equation of $f^{-1}(x)$.

(a) $f(x) = 2x + 3 \quad \{ x \in \mathbb{R} \{$

(b) $f(x) = \frac{x}{2} \quad \left\{ x \in \mathbb{R} \right\}$

(c) $f(x) = \frac{1}{x} \quad \left\{ x \in \mathbb{R}, \quad x \neq 0 \right\}$

(d) $f(x) = 4 - x \quad \{ x \in \mathbb{R} \{$

(e) $f(x) = x^2 + 2 \quad \{ x \in \mathbb{R}, \quad x \geq 0 \{$

(f) $f(x) = x^3 \quad \{ x \in \mathbb{R} \{$

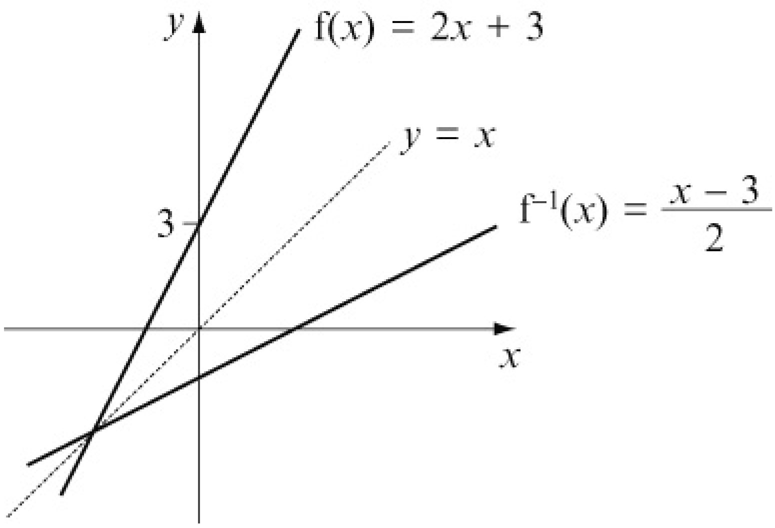
Solution:

(a) If $y = 2x + 3$

$y - 3 = 2x$

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

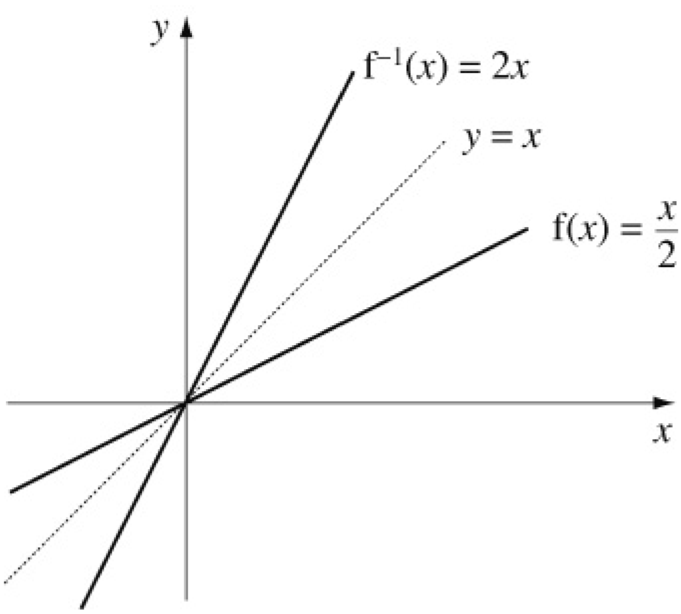
Hence $f^{-1}(x) = \frac{x - 3}{2}$



(b) If $y = \frac{x}{2}$

$2y = x$

Hence $f^{-1}(x) = 2x$



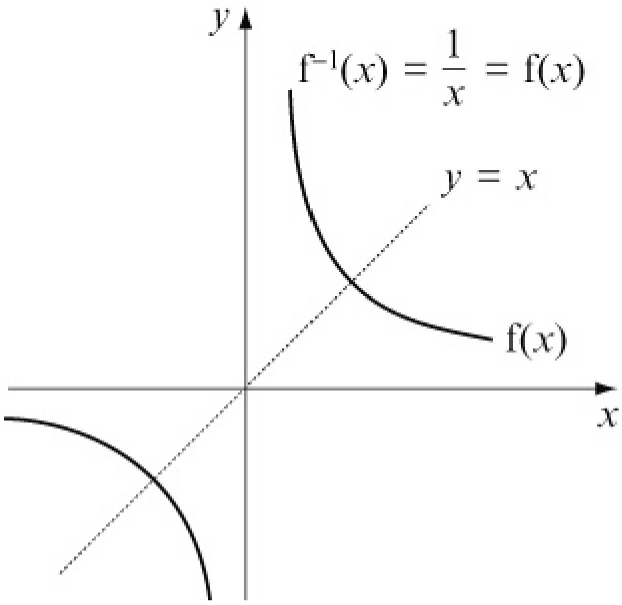
(c) If $y = \frac{1}{x}$

$yx = 1$

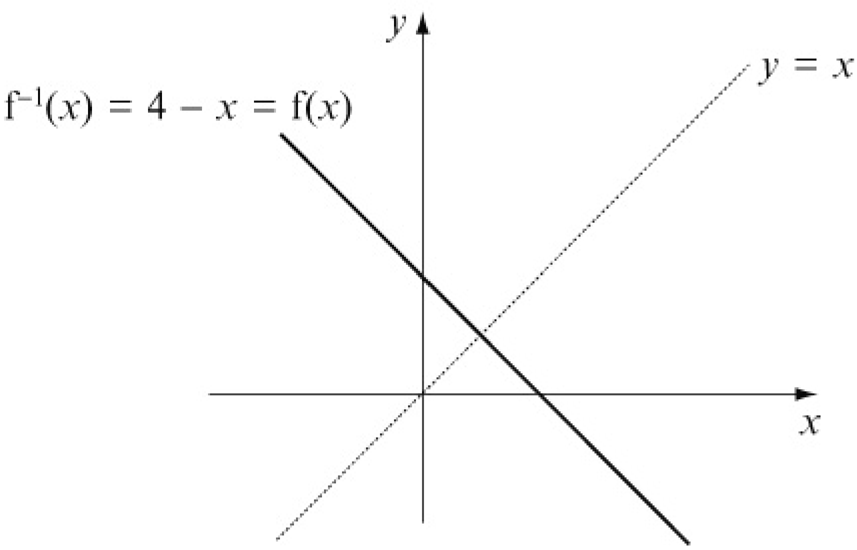
$x = \frac{1}{y}$

Hence $f^{-1}(x) = \frac{1}{x}$

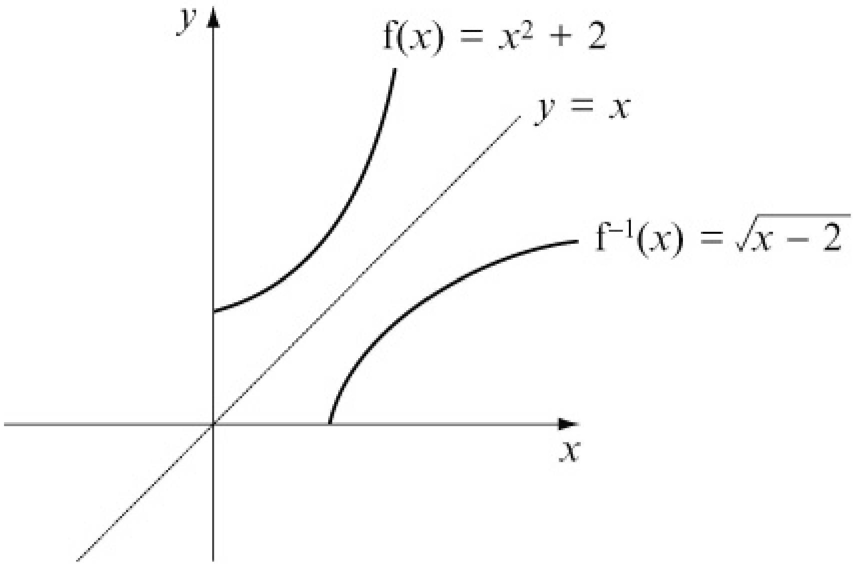
Note that the inverse to the function is identical to the function.



(d) If $y = 4 - x$
$x + y = 4$
$x = 4 - y$
Hence $f^{-1}(x) = 4 - x$
Note that the inverse to the function is identical to the function.



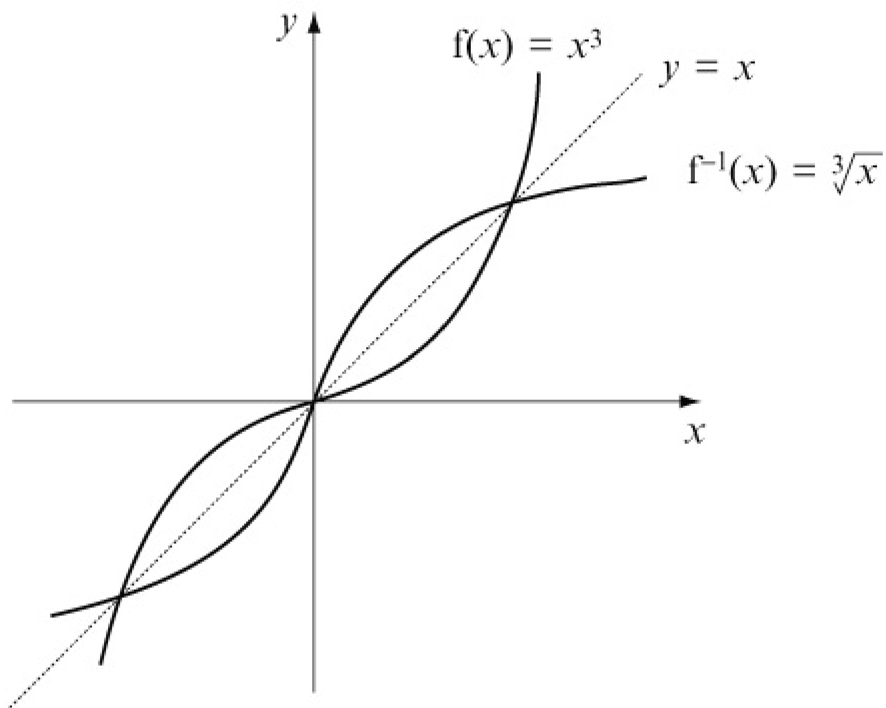
(e) If $y = x^2 + 2$
$y - 2 = x^2$
$\sqrt{y - 2} = x$
Hence $f^{-1}(x) = \sqrt{x - 2}$



(f) If $y = x^3$

$\sqrt[3]{y} = x$

Hence $f^{-1}(x) = \sqrt[3]{x}$



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Exercise E, Question 2

Question:

Determine which of the functions in Question 1 are self inverses. (That is to say the function and its inverse are identical.)

Solution:

Look back at Question 1.

1(c) $f(x) = \frac{1}{x}$ and

1(d) $f(x) = 4 - x$

are both identical to their inverses.

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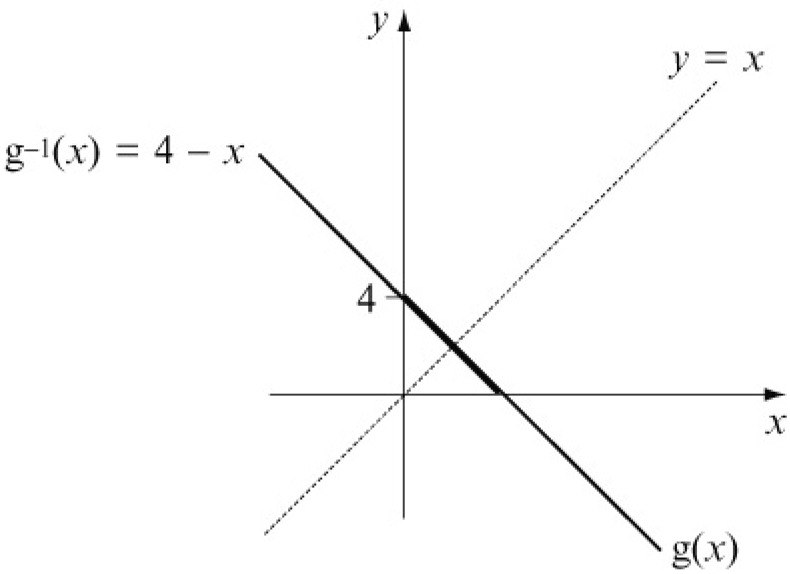
Exercise E, Question 3

Question:

Explain why the function $g(x) = 4 - x \{ x \in \mathbb{R}, x > 0 \{$ is not identical to its inverse.

Solution:



$g(x) = 4 - x$
has domain $x > 0$
and range $g(x) < 4$
Hence $g^{-1}(x) = 4 - x$
has domain $x < 4$
and range $g^{-1}(x) > 0$
Although g(x) and $g^{-1}(x)$ have identical equations they act on different numbers and so are not identical. See graph.

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Exercise E, Question 4

Question:

For the following functions g(x), sketch the graphs of g(x) and $g^{-1}(x)$ on the same set of axes. Determine the equation of $g^{-1}(x)$, taking care with its domain.

(a) $g(x) = \frac{1}{x} \quad \left\{ x \in \mathbb{R}, x \geq 3 \right\}$

(b) $g(x) = 2x - 1 \quad \{ x \in \mathbb{R}, x \geq 0 \{$

(c) $g(x) = \frac{3}{x-2} \quad \left\{ x \in \mathbb{R}, x > 2 \right\}$

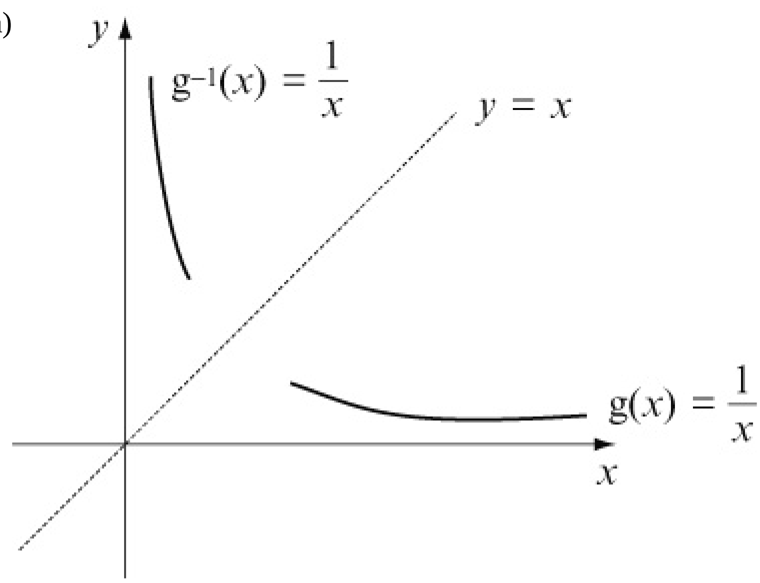
(d) $g(x) = \sqrt{x-3} \quad \{ x \in \mathbb{R}, x \geq 7 \{$

(e) $g(x) = x^2 + 2 \quad \{ x \in \mathbb{R}, x > 4 \{$

(f) $g(x) = x^3 - 8 \quad \{ x \in \mathbb{R}, x \leq 2 \{$

Solution:

(a)



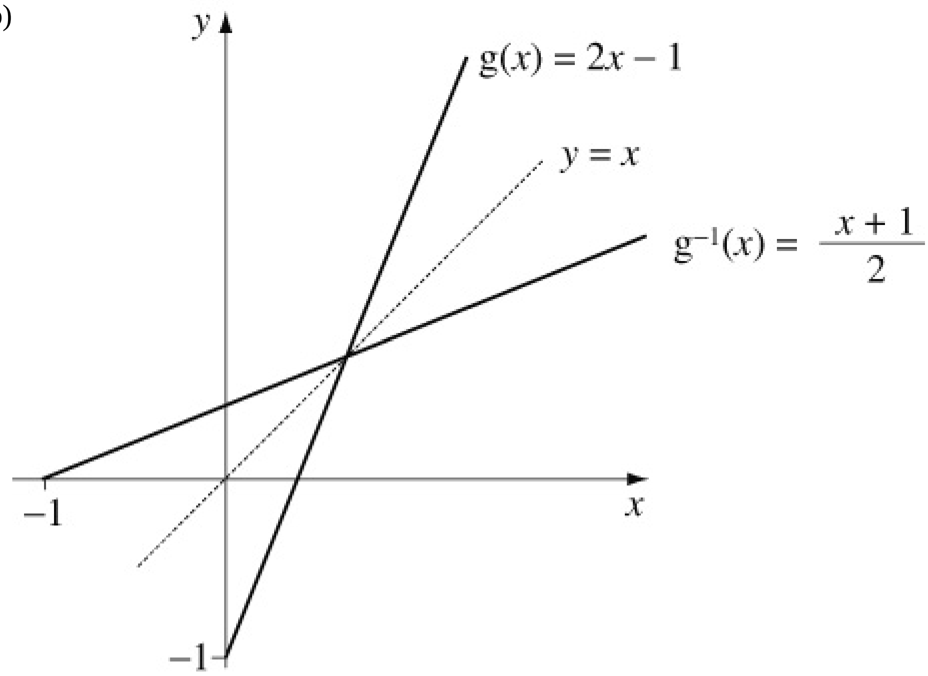
$$g(x) = \frac{1}{x} \left\{ x \in \mathbb{R}, \ x \geq 3 \right\}$$

has range $g(x) \in \mathbb{R}, \ 0 < g(x) \leq \frac{1}{3}$

Changing the subject of the formula gives

$$g^{-1}(x) = \frac{1}{x} \left\{ x \in \mathbb{R}, \ 0 < x \leq \frac{1}{3} \right\}$$

(b)



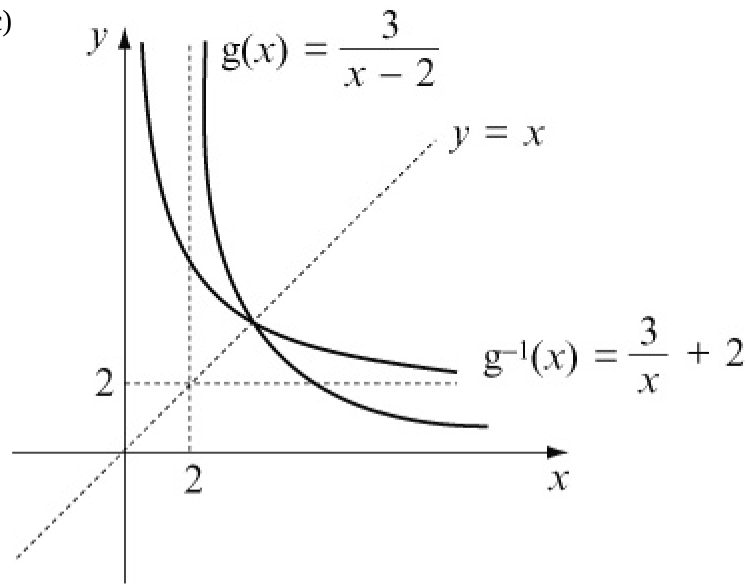
$g(x) = 2x - 1 \ \{ x \in \mathbb{R}, \ x \geq 0 \{$

has range $g(x) \in \mathbb{R}, \ g(x) \geq -1$

Changing the subject of the formula gives

$$g^{-1}(x) = \frac{x+1}{2} \left\{ x \in \mathbb{R}, \ x \geq -1 \right\}$$

(c)



$g(x) = \frac{3}{x-2} \quad \left\{ x \in \mathbb{R},\ x > 2 \right\}$

has range $g(x) \in \mathbb{R},\ g(x) > 0$

Changing the subject of the formula gives

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

$y(x-2) = 3$

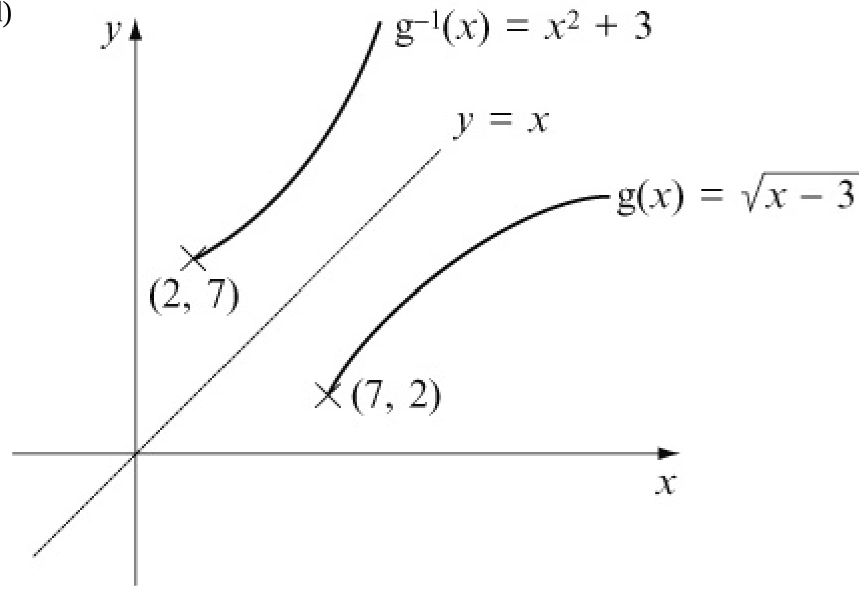
$x - 2 = \frac{3}{y}$

$x = \frac{3}{y} + 2 \qquad \left(\text{or } \frac{3+2y}{y} \right)$

Hence $g^{-1}(x) = \frac{3}{x} + 2 \qquad \left(\text{or } \frac{3+2x}{x} \right)$

$\{ x \in \mathbb{R},\ x > 0 \{$

(d)



$g(x) = \sqrt{x-3}$ $\{ x \in \mathbb{R}, \ x \geq 7 \{$

has range $g(x) \in \mathbb{R}, \ g(x) \geq 2$

Changing the subject of the formula gives

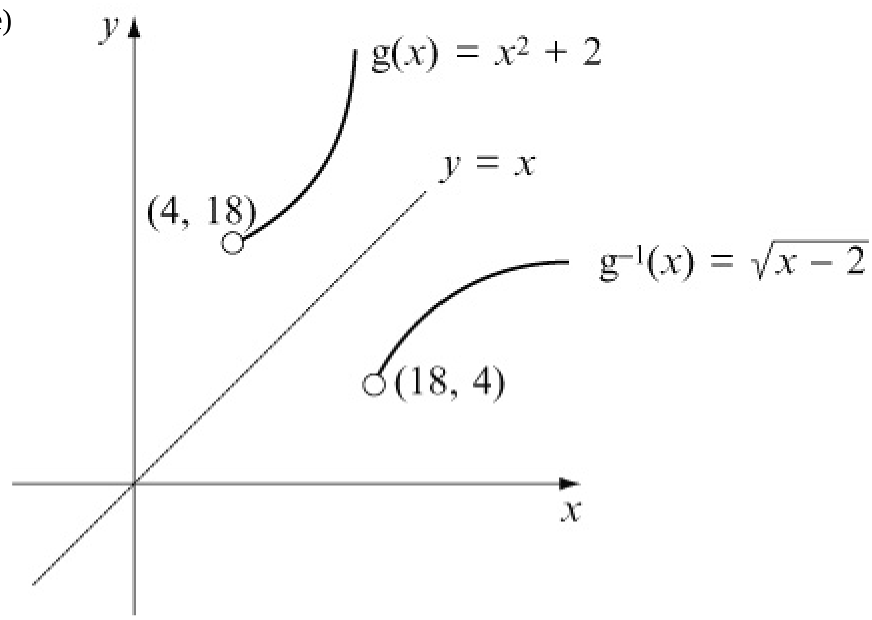
$y = \sqrt{x-3}$

$y^2 = x - 3$

$x = y^2 + 3$

Hence $g^{-1}(x) = x^2 + 3$ with domain $x \in \mathbb{R}, \ x \geq 2$

(e)



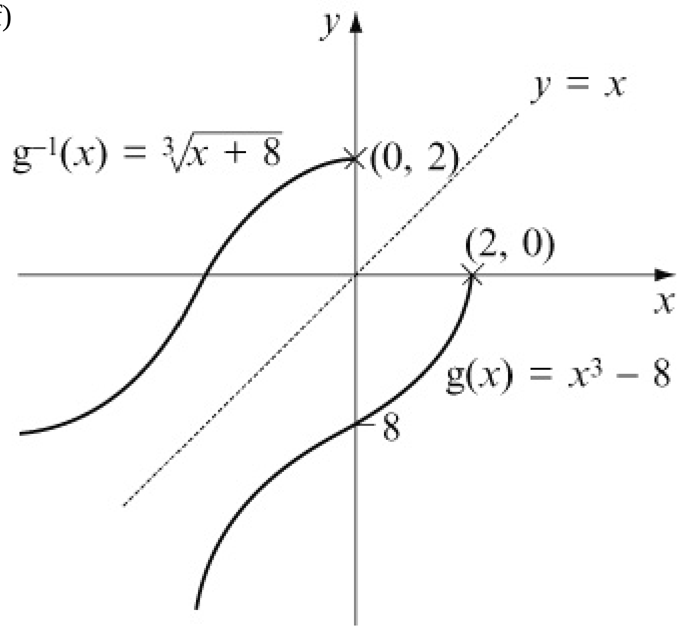
$g(x) = x^2 + 2$ $\{ x \in \mathbb{R}, \ x > 4 \{$

has range $g(x) \in \mathbb{R}, \ g(x) > 18$

Changing the subject of the formula gives

$g^{-1}(x) = \sqrt{x-2}$ with domain $x \in \mathbb{R}, \ x > 18$

(f)



$g(x) = x^3 - 8 \quad \{ x \in \mathbb{R}, \ x \leq 2 \{$

has range $g(x) \in \mathbb{R}, g(x) \leq 0$

Changing the subject of the formula gives

$y = x^3 - 8$

$y + 8 = x^3$

$\sqrt[3]{y+8} = x$

Hence $g^{-1}(x) = \sqrt[3]{x+8}$ with domain $x \in \mathbb{R}, \ x \leq 0$

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Exercise E, Question 5

Question:

The function m(x) is defined by $m(x) = x^2 + 4x + 9 \{ x \in \mathbb{R}, x > a \{$ for some constant a. If $m^{-1}(x)$ exists, state the least value of a and hence determine the equation of $m^{-1}(x)$. State its domain.

Solution:

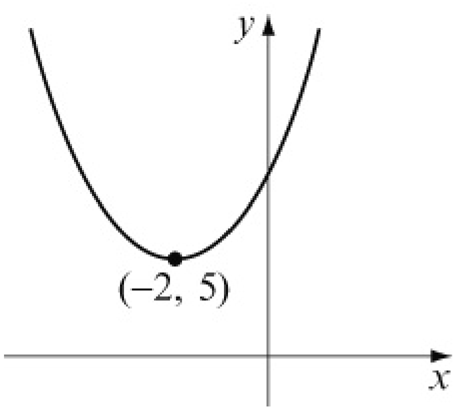
$m(x) = x^2 + 4x + 9 \{ x \in \mathbb{R}, x > a \{$.

Let $y = x^2 + 4x + 9$

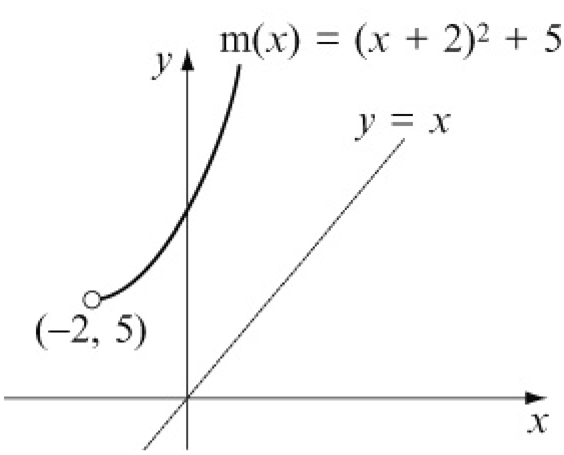
$y = (x + 2)^2 - 4 + 9$

$y = (x + 2)^2 + 5$

This has a minimum value of $(-2, 5)$.



For m(x) to have an inverse it must be one-to-one.
Hence the least value of a is -2.



m(x) would have a range of $\mathrm{m}(x) \in \mathbb{R}, \mathrm{m}(x) > 5$
Changing the subject of the formula gives

$y = (x+2)^2 + 5$

$y - 5 = (x+2)^2$

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

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

Hence $\mathrm{m}^{-1}(x) = \sqrt{x-5} - 2$ with domain $x \in \mathbb{R}, x > 5$

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Exercise E, Question 6

Question:

Determine $t^{-1}(x)$ if the function t(x) is defined by $t(x) = x^2 - 6x + 5$ $\{x \in \mathbb{R}, \ x \geq 5\{$.

Solution:

$t(x) = x^2 - 6x + 5$ $\{x \in \mathbb{R}, \ x \geq 5\{$

Let $y = x^2 - 6x + 5$ (complete the square)

$y = (x-3)^2 - 9 + 5$

$y = (x-3)^2 - 4$

This has a minimum point at $(3, -4)$.

Note. Since $x \geq 5$ is the domain, t(x) is a one-to-one function.

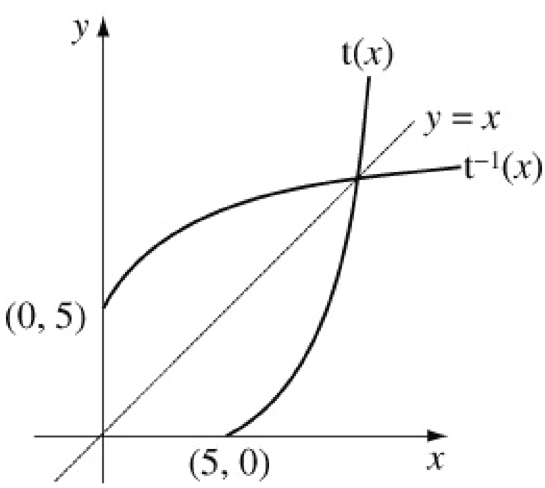
Change the subject of the formula to find $t^{-1}(x)$:

$y = (x-3)^2 - 4$

$y + 4 = (x-3)^2$

$\sqrt{y+4} = x - 3$

$\sqrt{y+4} + 3 = x$



$t(x) = x^2 - 6x + 5$ $\{x \in \mathbb{R}, \ x \geq 5\{$

has range $t(x) \in \mathbb{R}, \ t(x) \geq 0$

So $t^{-1}(x) = \sqrt{x+4} + 3$ and has domain $x \in \mathbb{R}, \ x \geq 0$

Solutionbank
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Exercise E, Question 7

Question:

The function h(*x*) is defined by $h(x) = \frac{2x+1}{x-2} \left\{ x \in \mathbb{R},\ x \neq 2 \right\}$.

(a) What happens to the function as *x* approaches 2?

(b) Find $h^{-1}(3)$.

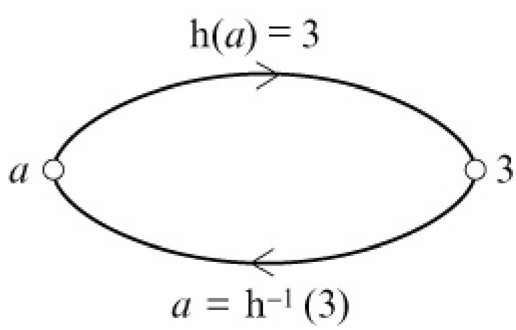
(c) Find $h^{-1}(x)$, stating clearly its domain.

(d) Find the elements of the domain that get mapped to themselves by the function.

Solution:

(a) As $x \to 2$ $h(x) \to \frac{5}{0}$ and hence $h(x) \to \infty$

(b) To find $h^{-1}(3)$ we can find what element of the domain gets mapped to 3.



So $h(a) = 3$

$\frac{2a+1}{a-2} = 3$

$2a + 1 = 3a - 6$

$7 = a$

So $h^{-1}(3) = 7$

(c) Let $y = \frac{2x+1}{x-2}$ and find *x* as a function of *y*.

$y(x-2) = 2x+1$
$yx - 2y = 2x + 1$
$yx - 2x = 2y + 1$
$x(y-2) = 2y+1$
$x = \frac{2y+1}{y-2}$

So $h^{-1}(x) = \frac{2x+1}{x-2} \quad \left\{ x \in \mathbb{R},\ x \neq 2 \right\}$

Hence the inverse function has exactly the same equation as the function. **But** the elements don't get mapped to themselves, see part (b).

(d) For elements to get mapped to themselves

$h(b) = b$

$\frac{2b+1}{b-2} = b$

$2b + 1 = b(b-2)$

$2b + 1 = b^2 - 2b$

$0 = b^2 - 4b - 1$

$b = \frac{4 \pm \sqrt{16+4}}{2} = \frac{4 \pm \sqrt{20}}{2} = \frac{4 \pm 2\sqrt{5}}{2} = 2 \pm \sqrt{5}$

The elements $2 + \sqrt{5}$ and $2 - \sqrt{5}$ get mapped to themselves by the function.

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Exercise E, Question 8

Question:

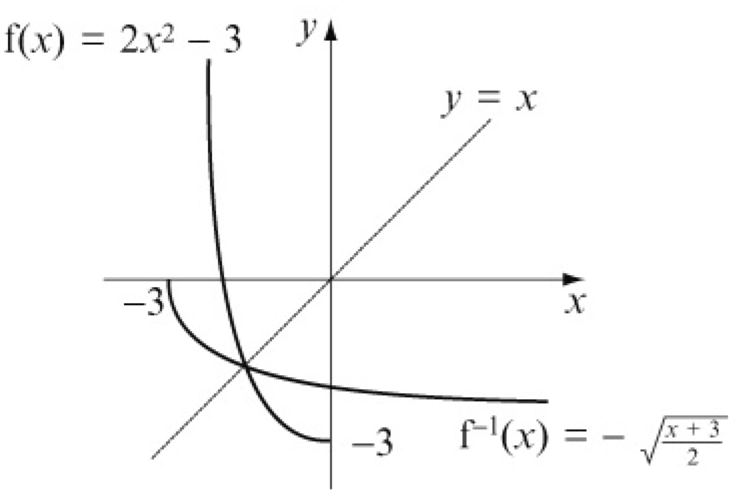
The function $f(x)$ is defined by $f(x) = 2x^2 - 3 \quad \{ x \in \mathbb{R}, \ x < 0 \{$.
Determine

(a) $f^{-1}(x)$ clearly stating its domain

(b) the values of a for which $f(a) = f^{-1}(a)$.

Solution:

(a) Let $y = 2x^2 - 3$
$y + 3 = 2x^2$
$\frac{y + 3}{2} = x^2$
$\sqrt{\frac{y + 3}{2}} = x$
The domain of $f^{-1}(x)$ is the range of $f(x)$.
$f(x) = 2x^2 - 3 \quad \{ x \in \mathbb{R}, \ x < 0 \{$
has range $f(x) > -3$
Hence $f^{-1}(x)$ must be the **negative** square root
$f^{-1}(x) = -\sqrt{\frac{x + 3}{2}}$ has domain $x \in \mathbb{R}, \ x > -3$



(b) If $f(a) = f^{-1}(a)$ then a is negative (see graph).
Solve $f(a) = a$

$2a^2 - 3 = a$

$2a^2 - a - 3 = 0$

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

$a = \frac{3}{2}, -1$

Therefore $a = -1$

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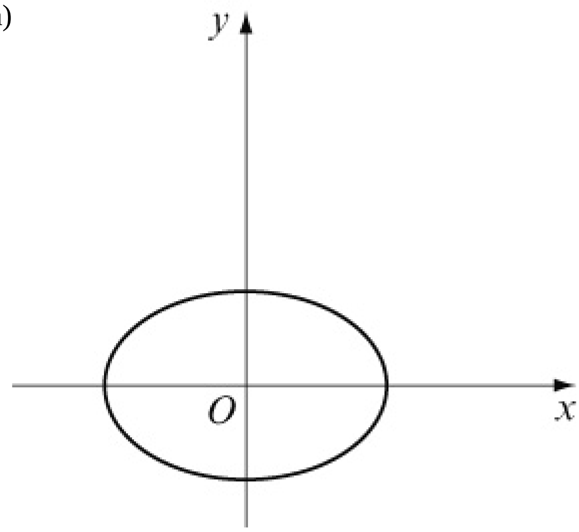
Exercise F, Question 1

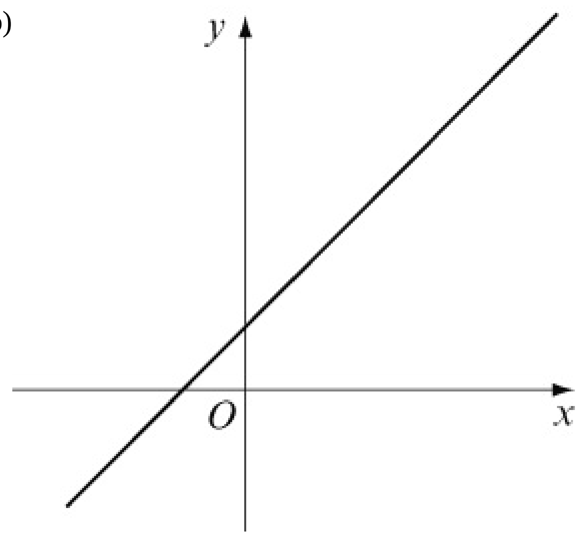
Question:

Categorise the following as
(i) not a function
(ii) a one-to-one function
(iii) a many-to-one function.

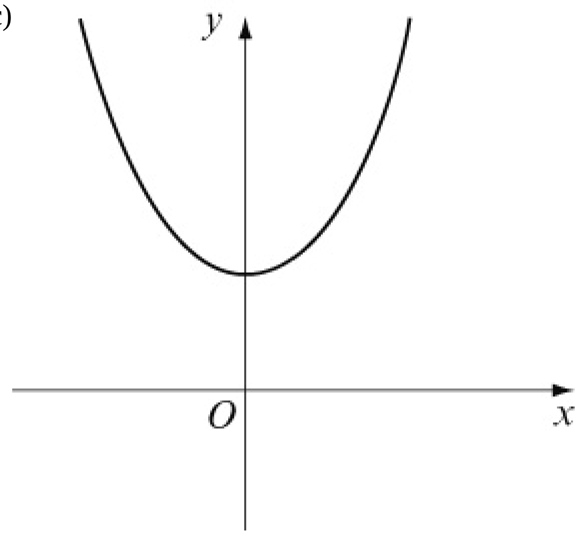
(a)



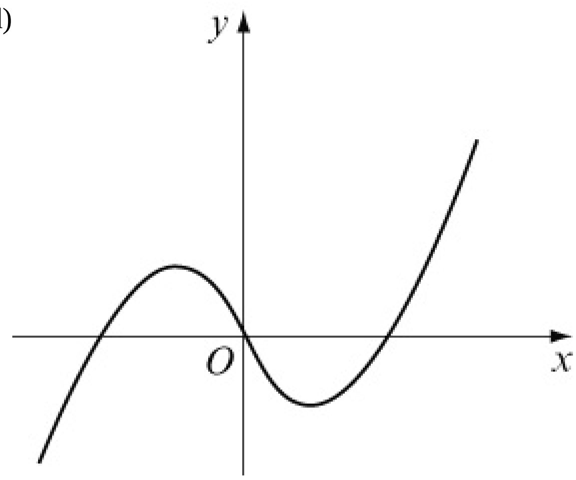
(b)



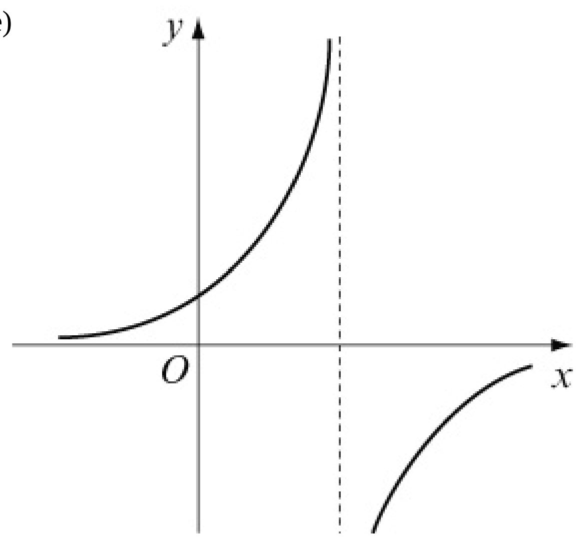
(c)



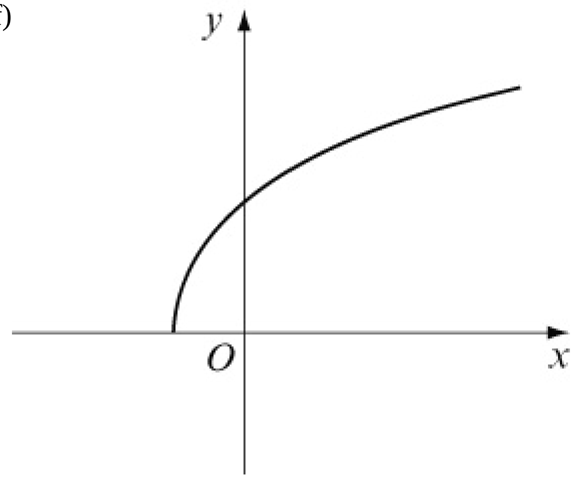
(d)



(e)

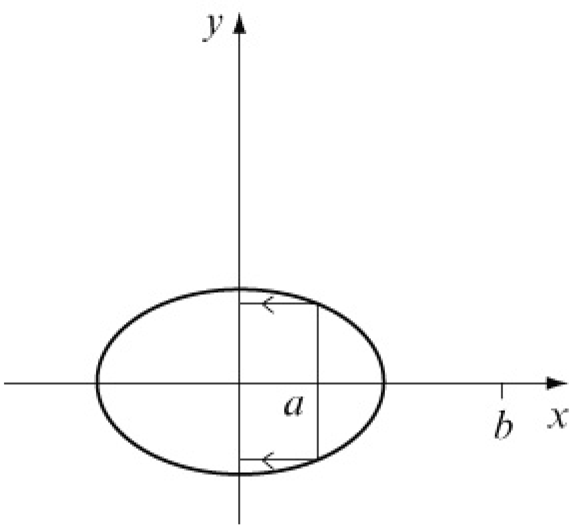


(f)



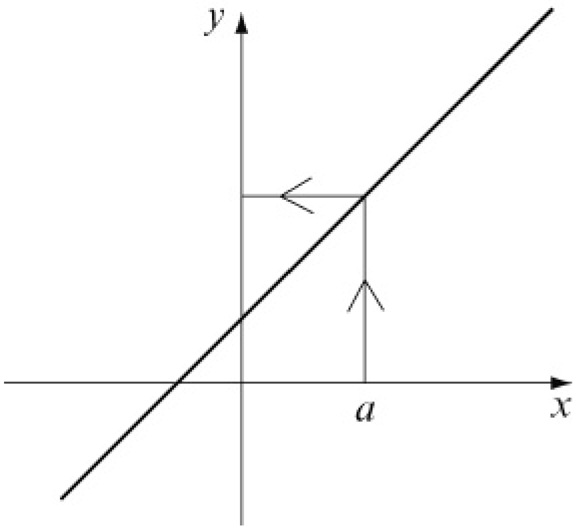
Solution:

(a) not a function

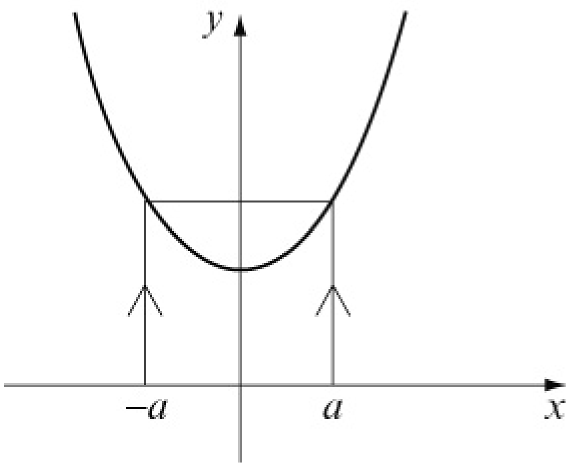


x value *a* gets mapped to two values of *y*.
x value *b* gets mapped to no values

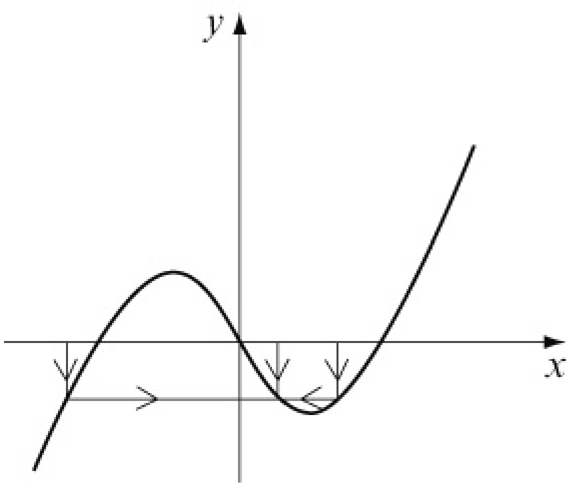
(b) one-to-one function



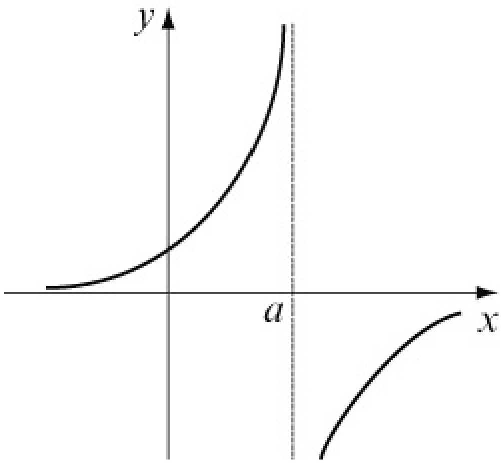
(c) many-to-one function



(d) many-to-one function

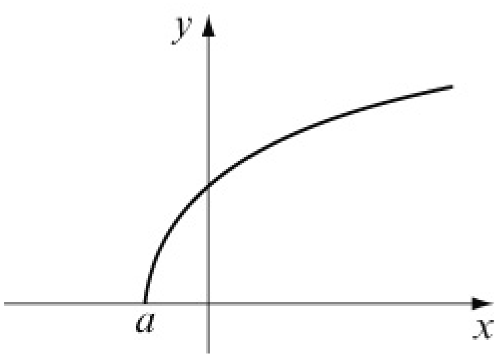


(e) not a function



x value *a* doesn't get mapped to any value of *y*.
It could be redefined as a function if the domain is said to exclude point *a*.

(f) not a function



x values less than *a* don't get mapped anywhere.
Again we could define the domain to be $x \geq a$ and then it would be a function.

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Exercise F, Question 2

Question:

The following functions f(x), g(x) and h(x) are defined by

$f(x) = 4(x-2) \quad \{x \in \mathbb{R}, x \geq 0\{$

$g(x) = x^3 + 1 \quad \{x \in \mathbb{R}\{$

$h(x) = 3^x \quad \{x \in \mathbb{R}\{$

(a) Find f(7), g(3) and $h(-2)$.

(b) Find the range of f(x) and the range of g(x).

(c) Find $g^{-1}(x)$.

(d) Find the composite function fg(x).

(e) Solve $gh(a) = 244$.

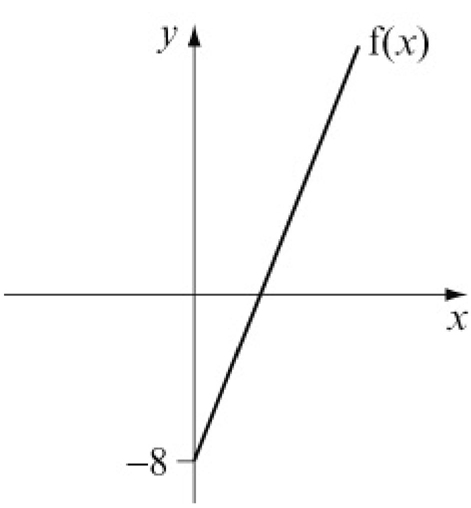
Solution:

(a) $f(7) = 4(7-2) = 4 \times 5 = 20$

$g(3) = 3^3 + 1 = 27 + 1 = 28$

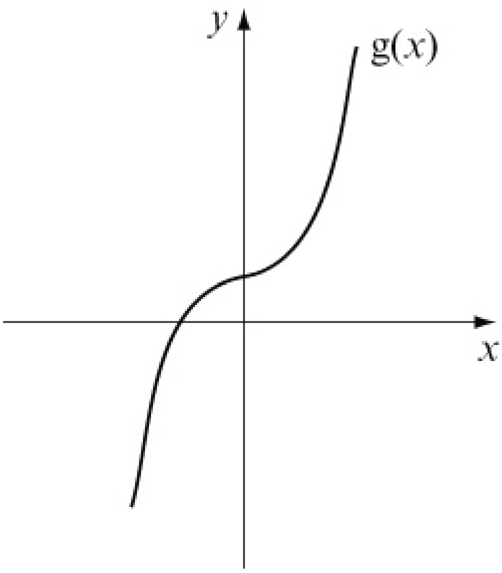
$h(-2) = 3^{-2} = \frac{1}{3^2} = \frac{1}{9}$

(b) $f(x) = 4(x-2) = 4x - 8$
This is a straight line with gradient 4 and intercept -8.
The domain tells us that $x \geq 0$.



The range of f(x) is $f(x) \in \mathbb{R}, f(x) \geq -8$

$g(x) = x^3 + 1$



The range of g(x) is $g(x) \in \mathbb{R}$

(c) Let $y = x^3 + 1$ (change the subject of the formula)

$y - 1 = x^3$

$\sqrt[3]{y-1} = x$

Hence $g^{-1}(x) = \sqrt[3]{x-1}$ $\{ x \in \mathbb{R} \{$

(d) $fg(x) = f(x^3 + 1) = 4(x^3 + 1 - 2) = 4(x^3 - 1)$

(e) Find gh(x) first.

$gh(x) = g(3^x) = (3^x)^3 + 1 = 3^{3x} + 1$

If $gh(a) = 244$

$3^{3a} + 1 = 244$

$3^{3a} = 243$

$3^{3a} = 3^5$

$3a = 5$

$a = \frac{5}{3}$

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Exercise F, Question 3

Question:

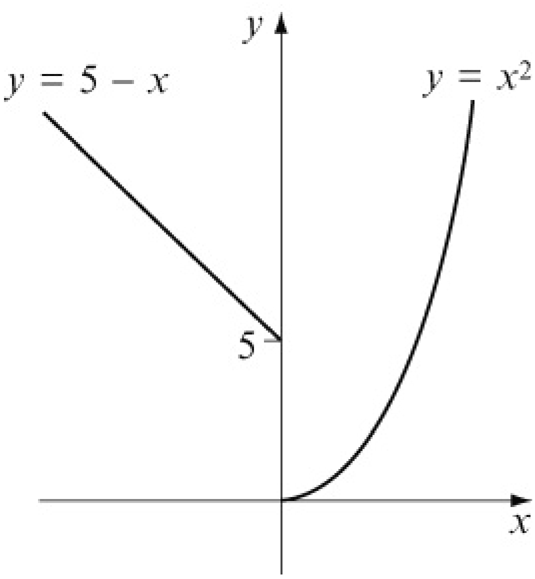
The function n(x) is defined by

$$n(x) = \begin{cases} 5 - x & x \leq 0 \\ x^2 & x > 0 \end{cases}$$

(a) Find $n(-3)$ and n(3).

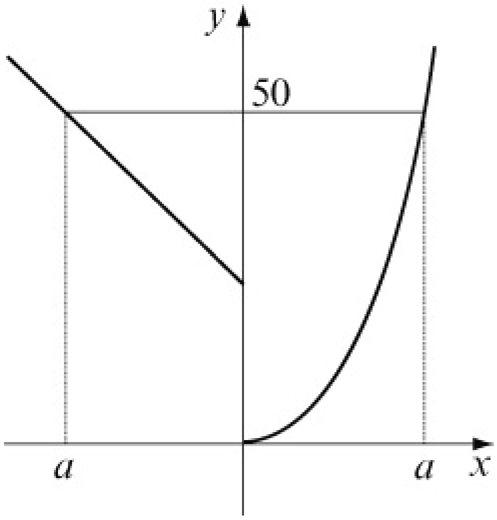
(b) Find the value(s) of a such that $n(a) = 50$.

Solution:



$y = 5 - x$ is a straight line with gradient -1 passing through 5 on the y axis.
$y = x^2$ is a $\cup$ -shaped quadratic passing through (0, 0).
(a) $n(-3) = 5 - (-3) = 5 + 3 = 8$
$n(3) = 3^2 = 9$

(b) There are two values of a.



The negative value of a is where

$5 - a = 50$

$a = 5 - 50$

$a = -45$

The positive value of a is where

$a^2 = 50$

$a = \sqrt{50}$

$a = 5\sqrt{2}$

The values of a such that $n(a) = 50$ are -45 and $+5\sqrt{2}$.

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Exercise F, Question 4

Question:

The function g(x) is defined as $g(x) = 2x + 7 \; \{x \in \mathbb{R}, \; x \geq 0\}$.

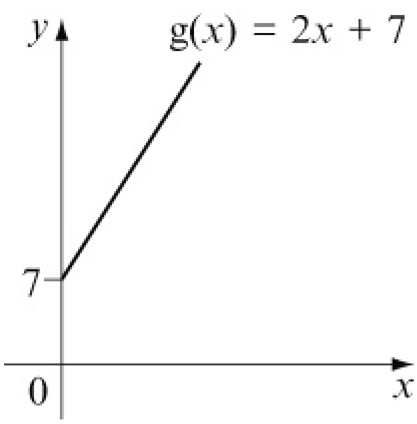
(a) Sketch g(x) and find the range.

(b) Determine $g^{-1}(x)$, stating its domain.

(c) Sketch $g^{-1}(x)$ on the same axes as g(x), stating the relationship between the two graphs.

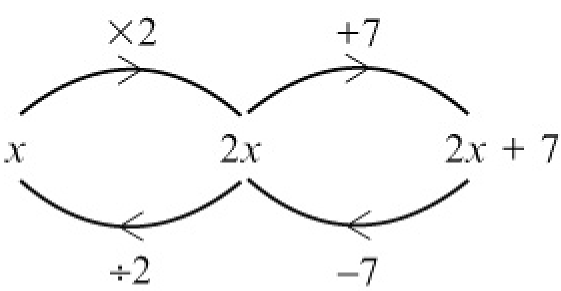
Solution:

(a) $y = 2x + 7$ is a straight line of gradient 2 passing through 7 on the y axis.
The domain is given as $x \geq 0$.



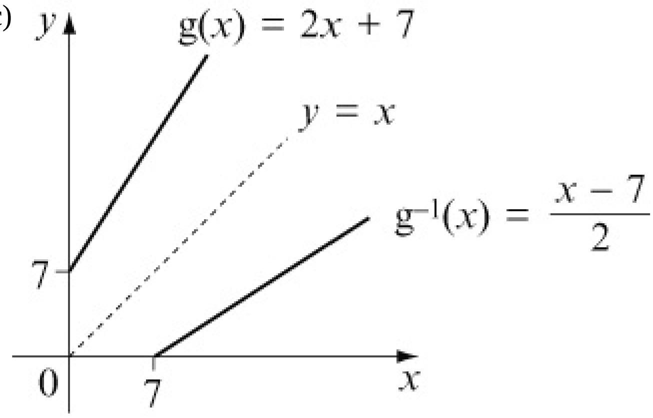
Hence the range is $g(x) \geq 7$

(b) The domain of the inverse function is $x \geq 7$.
To find the equation of the inverse function use a flow chart.



$g^{-1}(x) = \frac{x-7}{2}$ and has domain $x \geq 7$

(c)



$g^{-1}(x)$ is the reflection of g(x) in the line $y = x$.

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Exercise F, Question 5

Question:

The functions f and g are defined by

$f : x \to 4x - 1 \quad \{ x \in \mathbb{R} \{$

$g : x \to \frac{3}{2x - 1} \quad \left\{ x \in \mathbb{R}, \quad x \neq \frac{1}{2} \right\}$

Find in its simplest form:

(a) the inverse function f^{-1}

(b) the composite function gf, stating its domain

(c) the values of x for which $2f(x) = g(x)$, giving your answers to 3 decimal places.

[E]

Solution:

(a) $f : x \to 4x - 1$

Let $y = 4x - 1$ and change the subject of the formula.

$\Rightarrow \quad y + 1 = 4x$

$\Rightarrow \quad x = \frac{y + 1}{4}$

Hence $f^{-1} : x \to \frac{x + 1}{4}$

(b) $gf(x) = g(4x - 1) = \frac{3}{2(4x - 1) - 1} = \frac{3}{8x - 3}$

Hence $gf : x \to \frac{3}{8x - 3}$

The domain would include all the real numbers apart from $x = \frac{3}{8}$(i.e. where $8x - 3 = 0$).

(c) If $2f(x) = g(x)$

$2 \times (4x - 1) = \frac{3}{2x - 1}$

$8x - 2 = \frac{3}{2x - 1}$

$(8x - 2)(2x - 1) = 3$

$16x^2 - 12x + 2 = 3$

$16x^2 - 12x - 1 = 0$

Use $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ with $a = 16$, $b = -12$ and $c = -1$.

Then $x = \frac{12 \pm \sqrt{144 + 64}}{32} = \frac{12 \pm \sqrt{208}}{32} = 0.826, \quad -0.076$

Values of x are -0.076 and 0.826

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Exercise F, Question 6

Question:

The function f(x) is defined by

$$f(x) = \begin{cases} -x & x \leq 1 \\ x - 2 & x > 1 \end{cases}$$

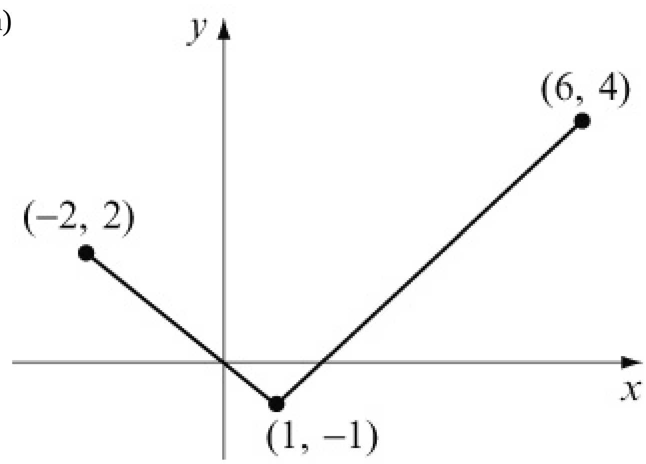
(a) Sketch the graph of f(x) for $-2 \leq x \leq 6$.

(b) Find the values of x for which $f(x) = -\frac{1}{2}$.

[E]

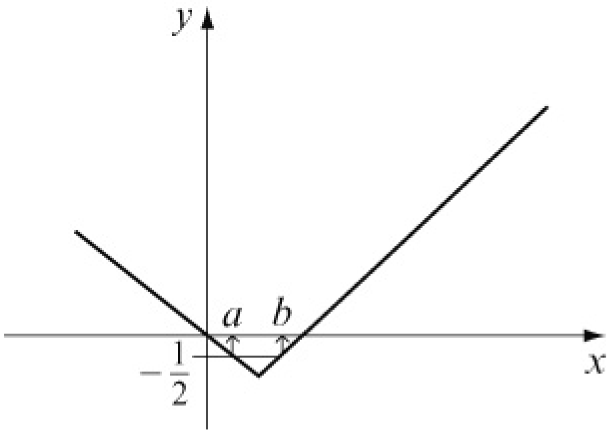
Solution:

(a)



For $x \leq 1$, $f(x) = -x$
This is a straight line of gradient -1.
At point $x = 1$, its y coordinate is -1.
For $x > 1$, $f(x) = x - 2$
This is a straight line of gradient $+1$.
At point $x = 1$, its y coordinate is also -1.
The graph is said to be **continuous**.

(b) There are two values at which $f(x) = -\frac{1}{2}$(see graph).



Point a is where

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

Point b is where

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

The values of x for which $f(x) = -\frac{1}{2}$ are $\frac{1}{2}$ and $1\frac{1}{2}$.

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Exercise F, Question 7

Question:

The function f is defined by

$$\mathrm{f} : x \to \frac{2x+3}{x-1} \quad \left\{ x \in \mathbb{R}, \quad x > 1 \right\}$$

(a) Find $\mathrm{f}^{-1}(x)$.

(b) Find (i) the range of $\mathrm{f}^{-1}(x)$
(ii) the domain of $\mathrm{f}^{-1}(x)$.

[E]

Solution:

(a) To find $\mathrm{f}^{-1}(x)$ change the subject of the formula.

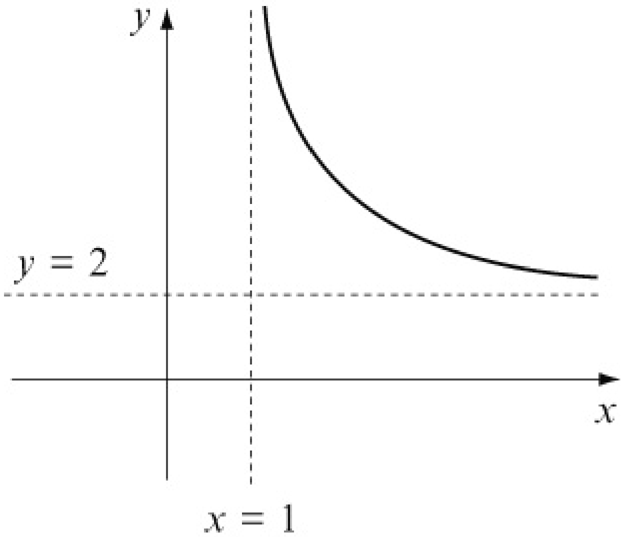
Let $y = \frac{2x+3}{x-1}$

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

Therefore $\mathrm{f}^{-1} : x \to \frac{x+3}{x-2}$

(b) f(x) has domain $\{ x \in \mathbb{R}, \quad x > 1 \{$ and range $\{ \mathrm{f}(x) \in \mathbb{R}, \quad \mathrm{f}(x) > 2$
$\{$

As $x \to \infty$, $y \to \frac{2x}{x} = 2$



So $f^{-1}(x)$ has domain $\{ x \in \mathbb{R}, \ x > 2 \{$ and range $\{ f^{-1}(x) \in \mathbb{R}, \ f^{-1}\left(x\right) > 1 \}$

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Exercise F, Question 8

Question:

The functions f and g are defined by

$$f : x \to \frac{x}{x-2} \quad \left\{ x \in \mathbb{R}, \quad x \neq 2 \right\}$$

$$g : x \to \frac{3}{x} \quad \left\{ x \in \mathbb{R}, \quad x \neq 0 \right\}$$

(a) Find an expression for $f^{-1}(x)$.

(b) Write down the range of $f^{-1}(x)$.

(c) Calculate gf(1.5).

(d) Use algebra to find the values of x for which $g(x) = f(x) + 4$.

[E]

Solution:

(a) To find $f^{-1}(x)$ change the subject of the formula.

Let $y = \frac{x}{x-2}$

$y(x-2) = x$
$yx - 2y = x$ (rearrange)
$yx - x = 2y$
$x(y-1) = 2y$

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

It must always be rewritten as a function in x:

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

(b) The range of $f^{-1}(x)$ is the domain of $f(x)$.
Hence range is $\{ f^{-1}(x) \in \mathbb{R}, \quad f^{-1}(x) \neq 2 \{$.

(c) $\text{gf}(1.5) = \text{g}\left(\frac{1.5}{1.5-2}\right) = \text{g}\left(\frac{1.5}{-0.5}\right) = \text{g}(-3) = \frac{3}{-3} = -1$

(d) If $\text{g}(x) = \text{f}(x) + 4$

$\frac{3}{x} = \frac{x}{x-2} + 4 \qquad \left[\times x\left(x-2\right)\right]$

$3(x-2) = x \times x + 4x(x-2)$

$3x - 6 = x^2 + 4x^2 - 8x$

$0 = 5x^2 - 11x + 6$

$0 = (5x-6)(x-1)$

$\Rightarrow \quad x = \frac{6}{5}, \quad 1$

The values of x for which $\text{g}(x) = \text{f}(x) + 4$ are $\frac{6}{5}$ and 1.

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Exercise F, Question 9

Question:

The functions f and g are given by

$$f : x \to \frac{x}{x^2-1} - \frac{1}{x+1} \quad \left\{ x \in \mathbb{R}, \quad x > 1 \right\}$$

$$g : x \to \frac{2}{x} \quad \left\{ x \in \mathbb{R}, \quad x > 0 \right\}$$

(a) Show that $f(x) = \frac{1}{(x-1)(x+1)}$.

(b) Find the range of $f(x)$.

(c) Solve $gf(x) = 70$.

[E]

Solution:

(a) $f(x) = \frac{x}{x^2-1} - \frac{1}{x+1}$

$$= \frac{x}{(x+1)(x-1)} - \frac{1}{(x+1)}$$

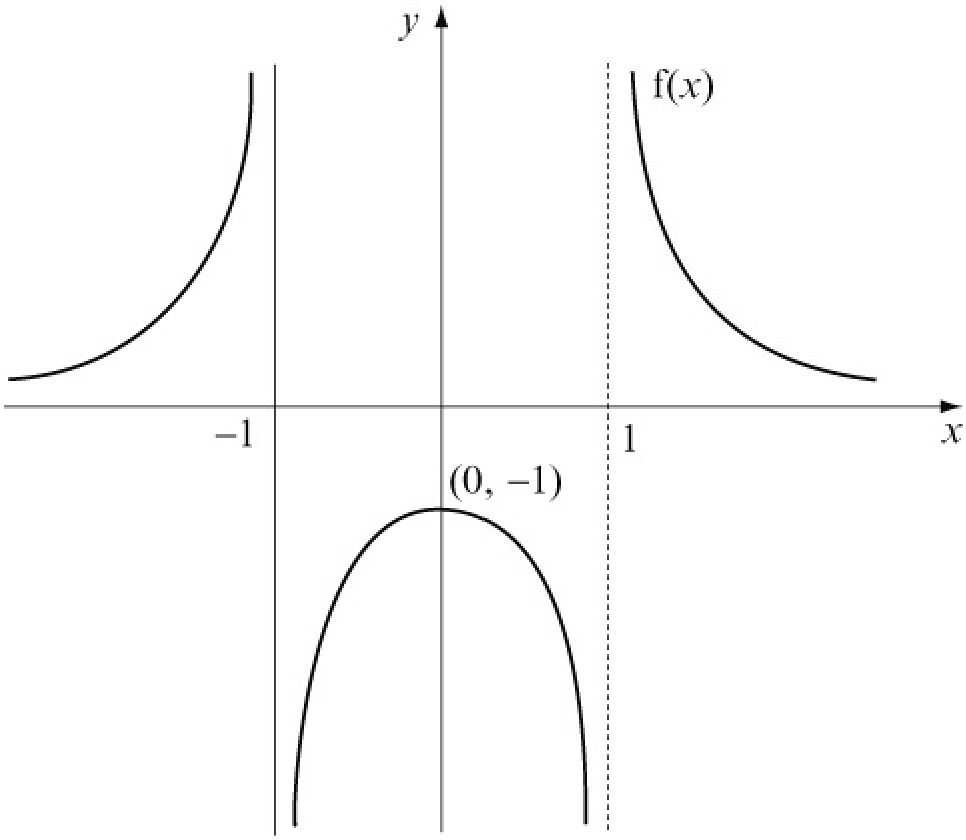
$$= \frac{x}{(x+1)(x-1)} - \frac{x-1}{(x+1)(x-1)}$$

$$= \frac{x-(x-1)}{(x+1)(x-1)}$$

$$= \frac{1}{(x+1)(x-1)}$$

(b) The range of $f(x)$ is the set of values that y take.

By using a graphical calculator we can see that $y = f(x)$ $\left\{ x \in \mathbb{R}, \quad x \neq -1, \quad x \neq 1 \right\}$ is a symmetrical graph about the y axis.



For $x > 1$, $f(x) > 0$

(c) $gf(x) = g\left[\frac{1}{(x-1)(x+1)}\right] = \frac{2}{\frac{1}{(x-1)(x+1)}} = 2 \times \frac{(x-1)(x+1)}{1} = 2\left(x-1\right)\left(x+1\right)$

If $gf(x) = 70$

$2(x-1)(x+1) = 70$

$(x-1)(x+1) = 35$

$x^2 - 1 = 35$

$x^2 = 36$

$x = \pm 6$