

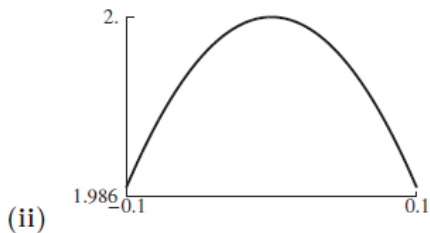
Limits and Continuity

Exercise Set 1.1

1. (a) 0 (b) 0 (c) 0 (d) 0
2. (a) 2 (b) 2 (c) 2 (d) 2
3. (a) -1 (b) 3 (c) does not exist (d) 1
4. (a) 2 (b) 0 (c) does not exist (d) 2
5. (a) 0 (b) 0 (c) 0 (d) 3
6. (a) 1 (b) 1 (c) 1 (d) 0
7. (a) $-\infty$ (b) $-\infty$ (c) $-\infty$ (d) 1
8. (a) $+\infty$ (b) $+\infty$ (c) $+\infty$ (d) can not be found from graph
9. (a) 1 (b) $-\infty$ (c) does not exist (d) -2
10. (a) $+\infty$ (b) 1 (c) does not exist (d) 2

11. (i)

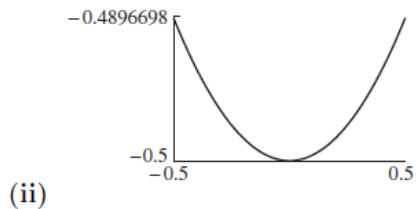
| | | | | | |
|-----------|-----------|-----------|-----------|-----------|-----------|
| -0.1 | -0.01 | -0.001 | 0.001 | 0.01 | 0.1 |
| 1.9866933 | 1.9998667 | 1.9999987 | 1.9999987 | 1.9998667 | 1.9866933 |



The limit appears to be 2.

12. (i)

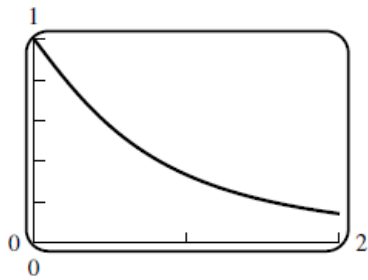
| | | | | | |
|--------------|--------------|--------------|--------------|--------------|--------------|
| -0.5 | -0.05 | -0.005 | 0.005 | 0.05 | 0.5 |
| -0.489669752 | -0.499895842 | -0.499998958 | -0.499998958 | -0.499895842 | -0.489669752 |



The limit appears to be $-1/2$.

13. (a)

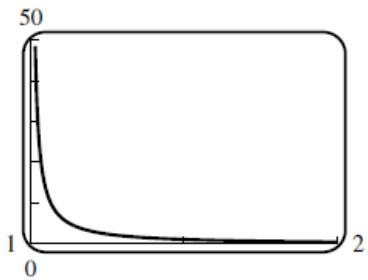
| | | | | | | | | | |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 2 | 1.5 | 1.1 | 1.01 | 1.001 | 0 | 0.5 | 0.9 | 0.99 | 0.999 |
| 0.1429 | 0.2105 | 0.3021 | 0.3300 | 0.3330 | 1.0000 | 0.5714 | 0.3690 | 0.3367 | 0.3337 |



The limit is $1/3$.

(b)

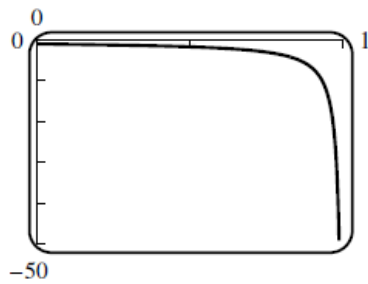
| | | | | | |
|--------|--------|-------|-------|-------|--------|
| 2 | 1.5 | 1.1 | 1.01 | 1.001 | 1.0001 |
| 0.4286 | 1.0526 | 6.344 | 66.33 | 666.3 | 6666.3 |



The limit is $+\infty$.

(c)

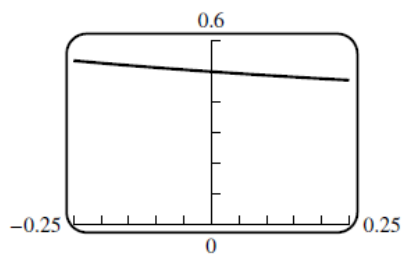
| | | | | | |
|----|---------|---------|---------|--------|---------|
| 0 | 0.5 | 0.9 | 0.99 | 0.999 | 0.9999 |
| -1 | -1.7143 | -7.0111 | -67.001 | -667.0 | -6667.0 |



The limit is $-\infty$.

14. (a)

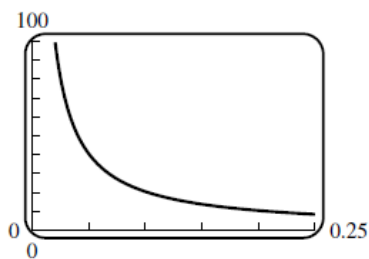
| | | | | | | | |
|--------|--------|--------|---------|--------|--------|--------|--------|
| -0.25 | -0.1 | -0.001 | -0.0001 | 0.0001 | 0.001 | 0.1 | 0.25 |
| 0.5359 | 0.5132 | 0.5001 | 0.5000 | 0.5000 | 0.4999 | 0.4881 | 0.4721 |



The limit is $1/2$.

(b)

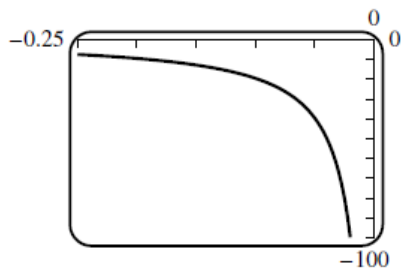
| | | | |
|--------|--------|--------|--------|
| 0.25 | 0.1 | 0.001 | 0.0001 |
| 8.4721 | 20.488 | 2000.5 | 20001 |



The limit is $+\infty$.

(c)

| | | | |
|---------|---------|---------|---------|
| -0.25 | -0.1 | -0.001 | -0.0001 |
| -7.4641 | -19.487 | -1999.5 | -20000 |

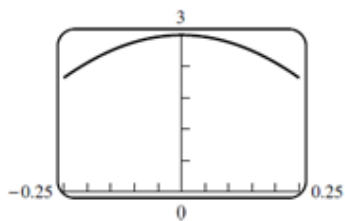


The limit is $-\infty$.

15.

(a)

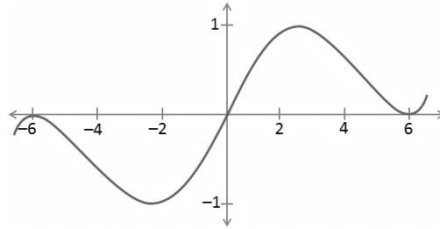
| | | | | | | | |
|--------|--------|--------|---------|--------|--------|--------|--------|
| -0.25 | -0.1 | -0.001 | -0.0001 | 0.0001 | 0.001 | 0.1 | 0.25 |
| 2.7266 | 2.9552 | 3.0000 | 3.0000 | 3.0000 | 3.0000 | 2.9552 | 2.7266 |



The limit is 3.

(b)

| | | | | | | | |
|--------|----------|----------|----------|---------------------|---------|---------|---------|
| x | -0.2 | -0.1 | -0.01 | 0 | 0.01 | 0.1 | 0.2 |
| $f(x)$ | -0.09967 | -0.04996 | -0.00500 | $f(x)$ approaches 0 | 0.00500 | 0.04996 | 0.09967 |

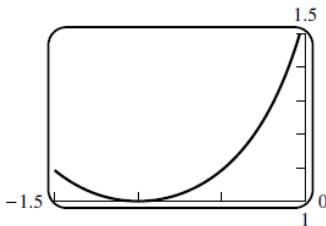


The limit is 0.

16.

(a)

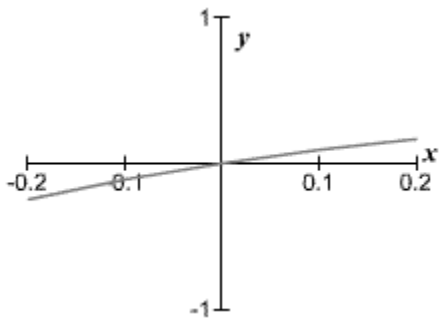
| | | | | | | | | |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 0 | -0.5 | -0.9 | -0.99 | -0.999 | -1.5 | -1.1 | -1.01 | -1.001 |
| 1.5574 | 1.0926 | 1.0033 | 1.0000 | 1.0000 | 1.0926 | 1.0033 | 1.0000 | 1.0000 |



The limit is 1.

(b)

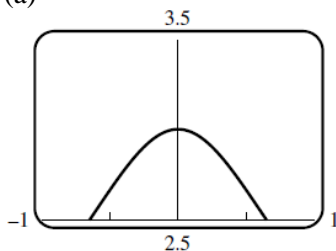
| | | | | | | | |
|--------|----------|----------|----------|---------------------|---------|---------|---------|
| x | -0.2 | -0.1 | -0.01 | 0 | 0.01 | 0.1 | 0.2 |
| $f(x)$ | -0.24918 | -0.11097 | -0.01011 | $f(x)$ approaches 0 | 0.00990 | 0.09073 | 0.16518 |



The limit is 0.

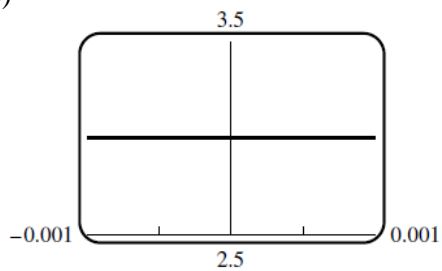
17. False; define $f(x) = x$ for $x \neq a$ and $f(a) = a + 1$. Then $\lim_{x \rightarrow a} f(x) = a \neq f(a) = a + 1$.
18. True; by 1.1.3.
19. False; define $f(x) = 0$ for $x < 0$ and $f(x) = x + 1$ for $x \geq 0$. Then the left and right limits exist but are unequal.
20. False; define $f(x) = 1/x$ for $x > 0$ and $f(0) = 2$.
27. $m_{\text{sec}} = \frac{3x^2 - 12}{x - 2} = 3(x + 2)$ which gets close to 12 as x gets close to 2, thus $y - 12 = 12(x - 2)$ or $y = 12x - 12$.
28. $m_{\text{sec}} = \frac{3x^2 - 27}{x - 3} = 3(x + 3)$ which gets close to 18 as x gets close to 3, thus $y - 27 = 18(x - 3)$ or $y = 18x - 27$.
29. $m_{\text{sec}} = \frac{x^3 - 8}{x - 2} = x^2 + 2x + 4$ which gets close to 12 as x gets close to 2, thus $y - 8 = 12(x - 2)$ or $y = 12x - 16$.
30. $m_{\text{sec}} = \frac{x^3 - 27}{x - 3} = x^2 + 3x + 9$ which gets close to 27 as x gets close to 3, thus $y - 27 = 27(x - 3)$ or $y = 27x - 54$.
31. (a) The length of the rod while at rest.
 (b) The limit is zero. The length of the rod approaches zero as its speed approaches c .
32. (a) The mass of the object while at rest.
 (b) The limiting mass as the velocity approaches the speed of light; the mass is unbounded.

33. (a)



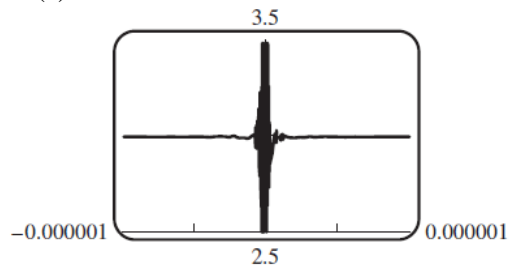
The limit appears to be 3.

(b)



The limit appears to be 3.

(c)



The limit does not exist.

Exercise Set 1.2

1.

(a) By Theorem 1.2.2, this limit is $2 + 2 \cdot (-4) = -6$.

(b) By Theorem 1.2.2, this limit is $0 - 3 \cdot (-4) + 1 = 13$.

(c) By Theorem 1.2.2, this limit is $2 \cdot (-4) = -8$.

(d) By Theorem 1.2.2, this limit is $(-4)^4 = 256$.

(e) By Theorem 1.2.2, this limit is $\sqrt[3]{6+2} = 2$.

(f) By Theorem 1.2.2, this limit is $\frac{3}{-4} = -\frac{3}{4}$.

-
2. (a) By Theorem 1.2.2, this limit is $0 + 0 = 0$.
- (b) The limit doesn't exist because $\lim f$ doesn't exist and $\lim g$ does.
- (c) By Theorem 1.2.2, this limit is $-2 + 2 = 0$.
- (d) By Theorem 1.2.2, this limit is $1 + 2 = 3$.
- (e) By Theorem 1.2.2, this limit is $0/(1 + 0) = 0$.
- (f) The limit doesn't exist because the denominator tends to zero but the numerator doesn't.
- (g) The limit doesn't exist because $\sqrt{f(x)}$ is not defined for $0 < x < 2$.
- (h) By Theorem 1.2.2, this limit is $\sqrt{1} = 1$.

3. By Theorem 1.2.3, this limit is $3 \cdot 2 \cdot 4 = 24$.

4. By Theorem 1.2.3, this limit is $2^3 - 3 \cdot 2^2 + 9 \cdot 2 = 14$.

5. For $x \neq 1$, $\frac{x^3 - x^2}{x - 1} = x^2$, so $\lim_{x \rightarrow 1} \frac{x^3 - x^2}{x - 1} = 1$.

6. By Theorem 1.2.4, this limit is, $\lim_{x \rightarrow 0} \frac{6 \times 0 - 9}{0^3 - 12 \times 0 + 4} = -\frac{9}{4}$.

7. After simplification, $\frac{x^3 - 1}{x - 1} = x^2 + x + 1$ and the limit is $1^2 + 1 + 1 = 3$.

8. After simplification, $\frac{t^3 + 8}{t + 2} = t^2 - 2t + 4$, and the limit is $(-3)^2 - 2 \cdot (-3) + 4 = 19$.

9. After simplification, $\frac{x^2 + 7x + 6}{x^2 - 3x - 4} = \frac{x + 6}{x - 4}$, and the limit is $\frac{-1 + 6}{-1 - 4} = \frac{5}{-5} = -1$.

10. After simplification, $\frac{x^2 - 4x + 4}{x^2 + 2x - 8} = \frac{x - 2}{x + 4}$, and the limit is $\frac{2 - 2}{2 + 4} = 0$.

11. After simplification, $\frac{3x^2 + 2x - 1}{x + 1} = 3x - 1$, and the limit is $3 \cdot (-1) - 1 = -4$.

12. After simplification, $\frac{3x^2 - x - 2}{4x^2 - x - 3} = \frac{3x + 2}{4x + 3}$, and the limit is $\frac{3 \cdot 1 + 2}{4 \cdot 1 + 3} = \frac{5}{7}$.

13. After simplification, $\frac{t^3 + 3t^2 - 12t + 4}{t^3 - 4t} = \frac{t^2 + 5t - 2}{t^2 + 2t}$, and the limit is $\frac{3^2 + 5 \cdot 3 - 2}{3^2 + 2 \cdot 3} = \frac{22}{15}$.

14. After simplification, $\frac{t^3 + t^2 - 5t + 3}{t^3 - 3t + 2} = \frac{t + 3}{t + 2}$, and the limit is $\frac{2 + 3}{2 + 2} = \frac{5}{4}$.

15. The limit is $+\infty$.

16. The limit is $-\infty$.

17. The limit does not exist.

18. The limit is $+\infty$.

19. The limit is $-\infty$.

20. The limit does not exist.

21.: The limit is $+\infty$.

22. The limit is $-\infty$.

23. The limit does not exist.

24. The limit is $-\infty$.

25. The limit is $+\infty$.

26. The limit does not exist.

27. The limit is $+\infty$.

28. The limit is $+\infty$.

29. After simplification, $\frac{x - 4}{\sqrt{x} - 2} = \sqrt{x} + 2$, and the limit is $\sqrt{4} + 2 = 4$.

30. After simplification, $\frac{25 - y}{5 - \sqrt{y}} = 5 + \sqrt{y}$, and the limit is $5 + \sqrt{25} = 10$.

31. (a) 2 (b) 2 (c) 2

32. (a) Does not exist (b) 1 (c) 6

33. True, by Theorem 1.2.2.

34. False; e.g. $\lim_{x \rightarrow 0} \frac{x^2}{x} = 0$.

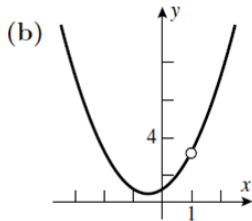
35. False; e.g. $f(x) = 2x$, $g(x) = x$, so $\lim_{x \rightarrow 0} f(x) = \lim_{x \rightarrow 0} g(x) = 0$, but $\lim_{x \rightarrow 0} f(x)/g(x) = 2$.

36. True, by Theorem 1.2.4.

37. After simplification, $\lim_{x \rightarrow 0} \frac{\sqrt{1+x}-1}{x} = \lim_{x \rightarrow 0} \frac{1}{\sqrt{1+x}+1} = 0.5$.

38. $\frac{\sqrt{x^2+4}-2}{x^2} \cdot \frac{\sqrt{x^2+4}+2}{\sqrt{x^2+4}+2} = \frac{x^2}{x^2(\sqrt{x^2+4}+2)} = \frac{1}{\sqrt{x^2+4}+2}$, so $\lim_{x \rightarrow 0} \frac{\sqrt{x^2+4}-2}{x^2} = \lim_{x \rightarrow 0} \frac{1}{\sqrt{x^2+4}+2} = \frac{1}{4}$.

39. (a) After simplification, $\frac{x^3-1}{x-1} = x^2+x+1$, and the limit is 3.



40. (a) After simplification, $\frac{x^2-25}{x+5} = x-5$ and the limit is -10 , so we need that $k = -10$.

(b) On its domain (all real numbers), $f(x) = x - 5$.

41. (a) Theorem 1.2.2 doesn't apply; moreover one cannot subtract infinities.

(b) $\lim_{x \rightarrow 0^+} \left(\frac{1}{x} - \frac{1}{x^2} \right) = \lim_{x \rightarrow 0^+} \left(\frac{x-1}{x^2} \right) = -\infty$.

42. (a) Theorem 1.2.2 assumes that L_1 and L_2 are real numbers, not infinities. It is in general not true that " $\infty \cdot 0 = 0$ ".

(b) $\frac{1}{x} - \frac{2}{x^2+2x} = \frac{x^2}{x(x^2+2x)} = \frac{1}{x+2}$ for $x \neq 0$, so that $\lim_{x \rightarrow 0} \left(\frac{1}{x} - \frac{2}{x^2+2x} \right) = \frac{1}{2}$.

43. For $x \neq 1$, $\frac{1}{x-1} - \frac{a}{x^2-1} = \frac{x+1-a}{x^2-1}$ and for this to have a limit it is necessary that $\lim_{x \rightarrow 1} (x+1-a) = 0$, i.e. $a = 2$. For this value, $\frac{1}{x-1} - \frac{2}{x^2-1} = \frac{x+1-2}{x^2-1} = \frac{x-1}{x^2-1} = \frac{1}{x+1}$ and $\lim_{x \rightarrow 1} \frac{1}{x+1} = \frac{1}{2}$.

44. (a) For small x , $1/x^2$ is much bigger than $\pm 1/x$.

(b) $\frac{1}{x} + \frac{1}{x^2} = \frac{x+1}{x^2}$. Since the numerator has limit 1 and x^2 tends to zero from the right, the limit is $+\infty$.

45. The left and/or right limits could be plus or minus infinity; or the limit could exist, or equal any preassigned real number. For example, let $q(x) = x - x_0$ and let $p(x) = a(x - x_0)^n$ where n takes on the values 0, 1, 2.

46. If on the contrary $\lim_{x \rightarrow a} g(x)$ did exist then by Theorem 1.2.2 so would $\lim_{x \rightarrow a} [f(x) + g(x)]$, and that would be a contradiction.

47. Clearly, $g(x) = [f(x) + g(x)] - f(x)$. By Theorem 1.2.2, $\lim_{x \rightarrow a} [f(x) + g(x)] - \lim_{x \rightarrow a} f(x) = \lim_{x \rightarrow a} [f(x) + g(x) - f(x)] = \lim_{x \rightarrow a} g(x)$.

48. By Theorem 1.2.2, $\lim_{x \rightarrow a} f(x) = \left(\lim_{x \rightarrow a} \frac{f(x)}{g(x)} \right) \lim_{x \rightarrow a} g(x) = \left(\lim_{x \rightarrow a} \frac{f(x)}{g(x)} \right) \cdot 0 = 0$, since $\lim_{x \rightarrow a} \frac{f(x)}{g(x)}$ exists.

Exercise Set 1.3

1. (a) $-\infty$ (b) $+\infty$

2. (a) 2 (b) 0

3. (a) 0 (b) -1

4. (a) does not exist (b) 0

5. (a) $3 + 5 \cdot (-5) = -22$ (b) $0 - 4 \cdot (-5) + 1 = 21$ (c) $3 \cdot (-5) = -15$ (d) $(-5)^2 = 25$

(e) $\sqrt[3]{5+3} = 2$ (f) $\frac{5}{-5} = -1$ (g) 0

(h) The limit doesn't exist because the denominator tends to zero but the numerator doesn't.

6. (a) $2 \cdot 7 - (-6) = 20$ (b) $7 \cdot 7 + 6 \cdot (-6) = 13$ (c) $+\infty$ (d) $-\infty$ (e) $\sqrt[3]{-42}$

(f) $-6/7$ (g) 7 (h) $-7/12$

7.

| | | | | | | |
|------|----------|----------|----------|----------|----------|-----------|
| x | 10 | 100 | 1000 | 10,000 | 100,000 | 1,000,000 |
| f(x) | 1.165343 | 1.015139 | 1.001501 | 1.000150 | 1.000015 | 1.0000015 |

The limit appears to be 1.

8.

| | | | | | | |
|------|-----------|-----------|-----------|-----------|-----------|------------|
| x | -10 | -100 | -1000 | -10,000 | -100,000 | -1,000,000 |
| f(x) | -0.862439 | -0.985136 | -0.998501 | -0.999850 | -0.999985 | -0.9999985 |

The limit appears to be -1 .

9. The limit is $+\infty$, by the highest degree term.

10. The limit is $-\infty$, by the highest degree term.

11. The limit is $+\infty$.

12. The limit is $+\infty$.

13. The limit is $3/2$, by the highest degree terms.

14. The limit is $5/2$, by the highest degree terms.

15. The limit is 0, by the highest degree terms.

-
16. The limit is 0, by the highest degree terms.
17. The limit is 0, by the highest degree terms.
18. The limit is $4/3$, by the highest degree terms.
19. The limit is $-\infty$, by the highest degree terms.
20. The limit is $-\infty$, by the highest degree terms.
21. The limit is $-1/5$, by the highest degree terms.
22. The limit is $5/7$, by the highest degree terms.
23. The limit is $\sqrt[3]{-9/8} = -\sqrt[3]{9}/2$, by the highest degree terms.
24. The limit is $\sqrt[3]{4/5}$, by the highest degree terms.

25. $\frac{\sqrt{7x^2-3}}{x+3} = \frac{\sqrt{7-\frac{3}{x^2}}}{-1-\frac{3}{x}}$ when $x < 0$. The limit is $-\sqrt{7}$.

26. $\frac{\sqrt{7x^2-3}}{x+3} = \frac{\sqrt{7-\frac{3}{x^2}}}{1+\frac{3}{x}}$ when $x > 0$. The limit is $\sqrt{7}$.

27. $\frac{2-y}{\sqrt{5+8y^2}} = \frac{-\frac{2}{y}+1}{\sqrt{\frac{5}{y^2}+8}}$ when $y < 0$. The limit is $1/\sqrt{8}$.

28. $\frac{2-y}{\sqrt{5+8y^2}} = \frac{\frac{2}{y}-1}{\sqrt{\frac{5}{y^2}+8}}$ when $y > 0$. The limit is $-1/\sqrt{8}$.

29. $\frac{\sqrt{5x^4+x}}{x^2-9} = \frac{\sqrt{5+\frac{1}{x^3}}}{1-\frac{9}{x^2}}$ when $x < 0$. The limit is $\sqrt{5}$.

30. $\frac{\sqrt{5x^4+x}}{x^2-9} = \frac{\sqrt{5+\frac{1}{x^3}}}{1-\frac{9}{x^2}}$ when $x > 0$. The limit is $\sqrt{5}$.

31. $\lim_{x \rightarrow \infty} \left(\sqrt{x^2+6} - x \right) \frac{\sqrt{x^2+6}+x}{\sqrt{x^2+6}+x} = \lim_{x \rightarrow \infty} \frac{6}{\sqrt{x^2+6}+x} = 0$, by the highest degree terms.

32. $\lim_{x \rightarrow +\infty} \left(\sqrt{x^2-5x} - x \right) \frac{\sqrt{x^2-5x}+x}{\sqrt{x^2-5x}+x} = \lim_{x \rightarrow +\infty} \frac{-5x}{\sqrt{x^2-5x}+x} = -5/2$, by the highest degree terms.

33. False. If $x/2 > 100$, then $100x < x^2/2$, $x^2 - 100x > x^2/2$, so the limit is $+\infty$.

34. False; $y = 0$ is a horizontal asymptote for the curve $y = e^x$ yet $\lim_{x \rightarrow +\infty} e^x$ does not exist.

35. True: for example $f(x) = \sin x/x$ crosses the x -axis infinitely many times at $x = n\pi, n = 1, 2, \dots$

36. False: if the asymptote is $y = 0$, then $\lim_{x \rightarrow \pm\infty} p(x)/q(x) = 0$, and clearly the degree of $p(x)$ is strictly less than the degree of $q(x)$. If the asymptote is $y = L \neq 0$, then $\lim_{x \rightarrow \pm\infty} p(x)/q(x) = L$ and the degrees must be equal.

37. It appears that $\lim_{t \rightarrow +\infty} n(t) = +\infty$, and $\lim_{t \rightarrow +\infty} e(t) = c$.

38. (a) It is the initial temperature of the potato (400° F).

(b) It is the ambient temperature, i.e. the temperature of the room.

39. (a) $+\infty$ (b) $-5/6$, by the highest degree terms.

40. (a) 0 (b) -8 , by the highest degree terms.

41. $\lim_{x \rightarrow -\infty} p(x) = +\infty$. When n is even, $\lim_{x \rightarrow +\infty} p(x) = +\infty$; when n is odd, $\lim_{x \rightarrow +\infty} p(x) = -\infty$.

42. (a) $p(x) = 2x, q(x) = x$ (b) $p(x) = x, q(x) = x^2$. (c) $p(x) = x^2, q(x) = x$.

(d) $p(x) = x+4, q(x) = x$

43. (a) No. (b) Yes, $\tan x$ and $\sec x$ at $x = n\pi + \pi/2$ and $\cot x$ and $\csc x$ at $x = n\pi, n = 0, \pm 1, \pm 2, \dots$

44. If $m > n$ the limit is zero. If $m = n$ the limit is c_m/d_m . If $n > m$ the limit is $+\infty$ if $c_n d_m > 0$ and $-\infty$ if $c_n d_m < 0$.

45. (a) If $f(t) \rightarrow +\infty$ (resp. $f(t) \rightarrow -\infty$) then $f(t)$ can be made arbitrarily large (resp. small) by taking t large enough. But by considering the values $g(x)$ where $g(x) > t$, we see that $f(g(x))$ has the limit $+\infty$ too (resp. limit $-\infty$). If $f(t)$ has the limit L as $t \rightarrow +\infty$ the values $f(t)$ can be made arbitrarily close to L by taking t large enough. But if x is large enough then $g(x) > t$ and hence $f(g(x))$ is also arbitrarily close to L .

(b) For $\lim_{x \rightarrow -\infty}$ the same argument holds with the substitution "x decreases without bound" instead of "x increases without bound". For $\lim_{x \rightarrow c^-}$ substitute "x close enough to c, $x < c$ ", etc.

46. (a) If $f(t) \rightarrow +\infty$ (resp. $f(t) \rightarrow -\infty$) then $f(t)$ can be made arbitrarily large (resp. small) by taking t small enough. But by considering the values $g(x)$ where $g(x) < t$, we see that $f(g(x))$ has the limit $+\infty$ too (resp. limit $-\infty$). If $f(t)$ has the limit L as $t \rightarrow -\infty$ the values $f(t)$ can be made arbitrarily close to L by taking t small enough. But if x is large enough then $g(x) < t$ and hence $f(g(x))$ is also arbitrarily close to L .

(b) For $\lim_{x \rightarrow -\infty}$ the same argument holds with the substitution "x decreases without bound" instead of "x increases without bound". For $\lim_{x \rightarrow c^-}$ substitute "x close enough to c, $x < c$ ", etc.

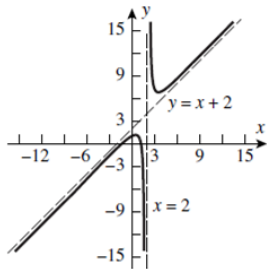
47. $t = 1/x, \lim_{t \rightarrow +\infty} f(t) = +\infty.$

48. $t = 1/x, \lim_{t \rightarrow -\infty} f(t) = 0.$

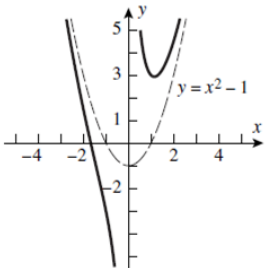
49. $t = \cot x, \lim_{t \rightarrow +\infty} f(t) = +\infty.$

50. $t = \cot x, \lim_{t \rightarrow -\infty} f(t) = 0.$

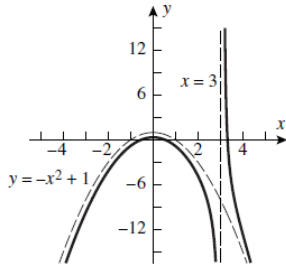
51. After a long division, $f(x) = x + 2 + \frac{2}{x-2}$, so $\lim_{x \rightarrow \pm\infty} (f(x) - (x+2)) = 0$ and $f(x)$ is asymptotic to $y = x + 2$. The only vertical asymptote is at $x = 2$.



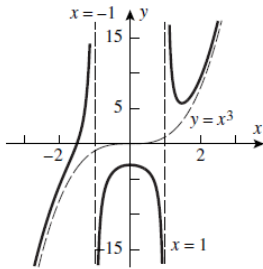
52. After a simplification, $f(x) = x^2 - 1 + \frac{3}{x}$, so $\lim_{x \rightarrow \pm\infty} (f(x) - (x^2 - 1)) = 0$ and $f(x)$ is asymptotic to $y = x^2 - 1$. The only vertical asymptote is at $x = 0$.



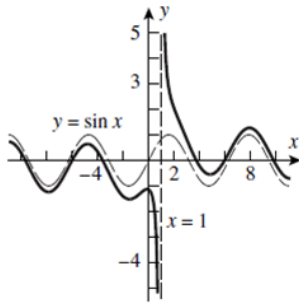
53. After a long division, $f(x) = -x^2 + 1 + \frac{2}{x-3}$, so $\lim_{x \rightarrow \pm\infty} (f(x) - (-x^2 + 1)) = 0$ and $f(x)$ is asymptotic to $y = -x^2 + 1$. The only vertical asymptote is at $x = 3$.



54. After a long division, $f(x) = x^3 + \frac{3}{2(x-1)} - \frac{3}{2(x+1)}$, so $\lim_{x \rightarrow \pm\infty} (f(x) - x^3) = 0$ and $f(x)$ is asymptotic to $y = x^3$. The vertical asymptotes are at $x = \pm 1$.



55. $\lim_{x \rightarrow \pm\infty} (f(x) - \sin x) = 0$ so $f(x)$ is asymptotic to $y = \sin x$. The only vertical asymptote is at $x = 1$.



Exercise Set 1.4

- (a) $|f(x) - f(0)| = |x + 2 - 2| = |x| < 0.1$ if and only if $|x| < 0.1$.

(b) $|f(x) - f(3)| = |(4x - 5) - 7| = 4|x - 3| < 0.1$ if and only if $|x - 3| < (0.1)/4 = 0.025$.

(c) $|f(x) - f(4)| = |x^2 - 16| < \epsilon$ if $|x - 4| < \delta$. We get $f(x) = 16 + \epsilon = 16.001$ at $x = 4.000124998$, which corresponds to $\delta = 0.000124998$; and $f(x) = 16 - \epsilon = 15.999$ at $x = 3.999874998$, for which $\delta = 0.000125002$. Use the smaller δ : thus $|f(x) - 16| < \epsilon$ provided $|x - 4| < 0.000125$ (to six decimals).
- (a) $|f(x) - f(0)| = |4x + 3 - 3| = 4|x| < 0.1$ if and only if $|x| < 0.025$.

(b) $|f(x) - f(0)| = |4x + 3 - 3| = 4|x| < 0.01$ if and only if $|x| < 0.0025$.

(c) $|f(x) - f(0)| = |4x + 3 - 3| = 4|x| < 0.0012$ if and only if $|x| < 0.0003$.

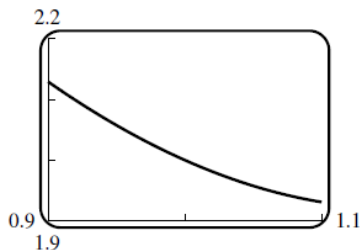
3. (a) $x_0 = (1.95)^2 = 3.8025, x_1 = (2.05)^2 = 4.2025$.

(b) $\delta = \min(|4 - 3.8025|, |4 - 4.2025|) = 0.1975$.

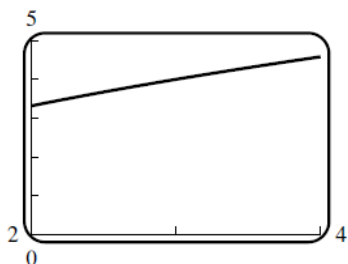
4. (a) $x_0 = 1/(1.1) = 0.909090\dots, x_1 = 1/(0.9) = 1.111111\dots$

(b) $\delta = \min(|1 - 0.909090|, |1 - 1.111111|) = 0.090909\dots$

5. $|(x^3 - 4x + 5) - 2| < 0.05$ is equivalent to $-0.05 < (x^3 - 4x + 5) - 2 < 0.05$, which means $1.95 < x^3 - 4x + 5 < 2.05$. Now $x^3 - 4x + 5 = 1.95$ at $x = 1.0616$, and $x^3 - 4x + 5 = 2.05$ at $x = 0.9558$. So $\delta = \min(1.0616 - 1, 1 - 0.9558) = 0.0442$.



6. $\sqrt{5x + 1} = 3.5$ at $x = 2.25, \sqrt{5x + 1} = 4.5$ at $x = 3.85$, so $\delta = \min(3 - 2.25, 3.85 - 3) = 0.75$.



7. With the TRACE feature of a calculator, we discover that (to five decimal places) (0.87000, 1.80274) and (1.13000, 2.19301) belong to the graph. Set $x_0 = 0.87$ and $x_1 = 1.13$. Since the graph of $f(x)$ rises from left to right, we see that if $x_0 < x < x_1$ then $1.80274 < f(x) < 2.19301$, and therefore $1.8 < f(x) < 2.2$. So we can take $\delta = 0.13$.

8. From a calculator plot we conjecture that $\lim_{x \rightarrow 0} f(x) = 2$. Using the TRACE feature we see that the points $(\pm 0.2, 1.94709)$ belong to the graph. Thus if $-0.2 < x < 0.2$, then $1.95 < f(x) \leq 2$ and hence $|f(x) - L| < 0.05 < 0.1 = \epsilon$.

9. $|2x - 8| = 2|x - 4| < 0.5$ when $|x - 4| < 0.5/2 = 0.25 = \delta$.

10. $|(5x - 2) - 13| = 5|x - 3| < 0.2$ when $|x - 3| < 0.2/5 = 0.04 = \delta$.

11. If $x \neq 4$, then $\left| \frac{x^2 - 16}{x - 4} - 8 \right| = \left| \frac{x^2 - 16 - 8x + 32}{x - 4} \right| = \left| \frac{x^2 - 8x + 16}{x - 4} \right| = |x - 4| < 0.05$ when $|x - 4| < 0.05 = \delta$.

12. If $x \neq -1/2$, then $\left| \frac{4x^2 - 1}{2x + 1} - (-2) \right| = \left| \frac{4x^2 - 1 + 4x + 2}{2x + 1} \right| = \left| \frac{4x^2 + 4x + 1}{2x + 1} \right| = |2x + 1| = 2 \left| x - \left(-\frac{1}{2} \right) \right| < 0.01$

when $\left| x - \left(-\frac{1}{2} \right) \right| < 0.005 = \delta$.

13. Assume $\delta \leq 1$. Then, $-1 < x - 3 < 1$ means $2 < x < 4$ and then

$$|x^3 - 27| = |(x-3)(x^2 + 3x + 9)| < 37|x-3|, \text{ so we choose } \delta = 0.001/37.$$

14. Assume $\delta \leq 1$. Then, $-1 < x - 4 < 1$ means $3 < x < 5$ and then $|\sqrt{x} - 2| = \frac{|x-4|}{\sqrt{x}+2} < \frac{|x-4|}{\sqrt{3}+2}$, so we can

choose $\delta = 0.1 \cdot (\sqrt{3} + 2)$.

15. Assume $\delta \leq 1$. Then, $-1 < x - 10 < 1$ means $9 < x < 11$ and then $\left| \frac{1}{x} - \frac{1}{10} \right| = \frac{|x-10|}{10x} < \frac{|x-10|}{90}$, so we

can choose $\delta = 0.05 \cdot 90 = 4.5$.

16. $||x| - 0| = |x| < 0.02$ when $|x - 0| < 0.02 = \delta$.

17. Let $\varepsilon > 0$ be given. Then $|f(x) - 4| = |4 - 4| = 0 < \varepsilon$ regardless of x , and hence any $\delta > 0$ will work.

18. Let $\varepsilon > 0$ be given. Then, $|(x+1) - 5| = |x-4| < \varepsilon$ provided $\delta = \varepsilon$ (although any smaller δ would work).

19. $|3x - 9| = 3|x-3| < \varepsilon$ if $|x-3| < \varepsilon/3$, $\delta = \varepsilon/3$.

20. $|7x + 5 + 9| = 7|x+2| < \varepsilon$ if $|x - (-2)| < \varepsilon/7$, $\delta = \varepsilon/7$.

21. $\left| \frac{4x^2 + x}{x} - 1 \right| = |4x + 1 - 1| = |4x| < \varepsilon$ if $|x| < \varepsilon/4$, $\delta = \varepsilon/4$.

22. $\left| \frac{x^2 - 25}{x+5} - (-10) \right| = |x+5| < \varepsilon$ if $|x+5| < \varepsilon$, $\delta = \varepsilon$.

23. $|f(x) - 3| = |x+4-3| = |x+1| < \varepsilon$ if $0 < |x+1| < \varepsilon$, $\delta = \varepsilon$.

24. $|11 - 2x - 7| = 2|x-2| < \varepsilon$ if $0 < |x-2| < \varepsilon/2$, $\delta = \varepsilon/2$.

25. If $\epsilon > 0$ is given, then take $\delta = \epsilon$; if $|x - 0| = |x| < \delta$, then $|x - 0| = |x| < \epsilon$.
26. If $x < 2$ then $|f(x) - 5| = |9 - 2x - 5| = 2|x - 2| < \epsilon$ if $|x - 2| < \epsilon/2$, $\delta_1 = \epsilon/2$. If $x > 2$ then $|f(x) - 5| = |3x - 1 - 5| = 3|x - 2| < \epsilon$ if $|x - 2| < \epsilon/3$, $\delta_2 = \epsilon/3$. Now let $\delta = \min(\delta_1, \delta_2)$ then for any x with $|x - 2| < \delta$, $|f(x) - 5| < \epsilon$.
27. For the first part, let $\epsilon > 0$. Then there exists $\delta > 0$ such that if $a < x < a + \delta$ then $|f(x) - L| < \epsilon$. For the left limit replace $a < x < a + \delta$ with $a - \delta < x < a$.
28. (a) Given $\epsilon > 0$ there exists $\delta > 0$ such that if $0 < |x - a| < \delta$ then $||f(x) - L| - 0| < \epsilon$, or $|f(x) - L| < \epsilon$.
 (b) From part (a) it follows that $|f(x) - L| < \epsilon$ is the defining condition for each of the two limits, so the two limit statements are equivalent.
29. (a) $|(3x^2 + 2x - 20 - 300)| = |3x^2 + 2x - 320| = |(3x + 32)(x - 10)| = |3x + 32| \cdot |x - 10|$.
 (b) If $|x - 10| < 1$ then $|3x + 32| < 65$, since clearly $x < 11$.
 (c) $\delta = \min(1, \epsilon/65)$; $|3x + 32| \cdot |x - 10| < 65 \cdot |x - 10| < 65 \cdot \epsilon/65 = \epsilon$.
30. (a) $\left| \frac{28}{3x+1} - 4 \right| = \left| \frac{28 - 12x - 4}{3x+1} \right| = \left| \frac{-12x + 24}{3x+1} \right| = \left| \frac{12}{3x+1} \right| \cdot |x - 2|$.
 (b) If $|x - 2| < 4$ then $-2 < x < 6$, so x can be very close to $-1/3$, hence $\left| \frac{12}{3x+1} \right|$ is not bounded.
 (c) If $|x - 2| < 1$ then $1 < x < 3$ and $3x + 1 > 4$, so $\left| \frac{12}{3x+1} \right| < \frac{12}{4} = 3$.
 (d) $\delta = \min(1, \epsilon/3)$; $\left| \frac{12}{3x+1} \right| \cdot |x - 2| < 3 \cdot |x - 2| < 3 \cdot \epsilon/3 = \epsilon$.
31. If $\delta < 1$ then $|2x^2 - 2| = 2|x - 1||x + 1| < 6|x - 1| < \epsilon$ if $|x - 1| < \epsilon/6$, so $\delta = \min(1, \epsilon/6)$.
32. If $\delta < 1$ then $|x^2 + x - 12| = |x + 4| \cdot |x - 3| < 5|x - 3| < \epsilon$ if $|x - 3| < \epsilon/5$, so $\delta = \min(1, \epsilon/5)$.
33. If $\delta < 1/2$ and $|x - (-2)| < \delta$ then $-5/2 < x < -3/2$, $x + 1 < -1/2$, $|x + 1| > 1/2$; then
 $\left| \frac{1}{x+1} - (-1) \right| = \frac{|x+2|}{|x+1|} < 2|x+2| < \epsilon$ if $|x+2| < \epsilon/2$, so $\delta = \min(1/2, \epsilon/2)$.
34. If $\delta < 1/4$ and $|x - (1/2)| < \delta$ then $\left| \frac{2x+3}{x} - 8 \right| = \frac{|6x-3|}{|x|} < \frac{6|x - (1/2)|}{1/4} = 24|x - (1/2)| < \epsilon$ if $|x - (1/2)| < \epsilon/24$,
 so $\delta = \min(1/4, \epsilon/24)$.
35. $|\sqrt{x} - 2| = \left| (\sqrt{x} - 2) \frac{\sqrt{x} + 2}{\sqrt{x} + 2} \right| = \left| \frac{x - 4}{\sqrt{x} + 2} \right| < \frac{1}{2}|x - 4| < \epsilon$ if $|x - 4| < 2\epsilon$, so $\delta = \min(2\epsilon, 4)$.

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36. If $\delta < 1$ and $|x - 2| < \delta$ then $|x| < 3$ and $x^2 + 2x + 4 < 9 + 6 + 4 = 19$, so $|x^3 - 8| = |x - 2| \cdot |x^2 + 2x + 4| < 19\delta < \epsilon$ if $\delta = \min(\epsilon/19, 1)$.
37. Let $\epsilon > 0$ be given and take $\delta = \epsilon$. If $|x| < \delta$, then $|f(x) - 0| = 0 < \epsilon$ if x is rational, and $|f(x) - 0| = |x| < \delta = \epsilon$ if x is irrational.
38. If the limit did exist, then for $\epsilon = 1/2$ there would exist $\delta > 0$ such that if $|x| < \delta$ then $|f(x) - L| < 1/2$. Some of the x -values are rational, for which $|L| < 1/2$; some are irrational, for which $|1 - L| < 1/2$. But $1 = |1| = L + (1 - L) < 1/2 + 1/2$, or $1 < 1$, a contradiction. Hence the limit cannot exist.
39. (a) We have to solve the equation $1/N^2 = 0.1$ here, so $N = \sqrt{10}$.
- (b) This will happen when $N/(N + 1) = 0.99$, so $N = 99$.
- (c) Because the function $1/x^3$ approaches 0 from below when $x \rightarrow -\infty$, we have to solve the equation $1/N^3 = -0.001$, and $N = -10$.
- (d) The function $x/(x + 1)$ approaches 1 from above when $x \rightarrow -\infty$, so we have to solve the equation $N/(N + 1) = 1.01$. We obtain $N = -101$.
40. (a) $N = \sqrt{10}$ (b) $N = \sqrt{100} = 10$ (c) $N = \sqrt{1000}$
41. (a) $\frac{x_1^2}{1 + x_1^2} = 1 - \epsilon$, $x_1 = -\sqrt{\frac{1 - \epsilon}{\epsilon}}$; $\frac{x_2^2}{1 + x_2^2} = 1 - \epsilon$, $x_2 = \sqrt{\frac{1 - \epsilon}{\epsilon}}$
- (b) $N = \sqrt{\frac{1 - \epsilon}{\epsilon}}$ (c) $N = -\sqrt{\frac{1 - \epsilon}{\epsilon}}$
42. (a) $x_1 = -1/\epsilon^3$; $x_2 = 1/\epsilon^3$ (b) $N = 1/\epsilon^3$ (c) $N = -1/\epsilon^3$
43. $\frac{1}{x^2} < 0.0001$ if $|x| > 100$, $N = 100$.
44. $\frac{1}{x + 2} < 0.004$ if $|x + 2| > 250$, $x > 248$, $N = 248$.
45. $\left| \frac{x}{x + 1} - 1 \right| = \left| \frac{1}{x + 1} \right| < 0.01$ if $|x + 1| > 100$, $x > 99$, $N = 99$.
46. $\left| \frac{4x - 5}{2x + 5} - 2 \right| = \left| \frac{15}{2x + 5} \right| < 0.1$ if $|2x + 5| > 150$, $2x > 145$, $N = 72.5$.
47. $\left| \frac{1}{x + 2} - 0 \right| < 0.002$ if $|x + 2| > 500$, $-x - 2 > 500$, $x < -502$, $N = -502$.
48. $\left| \frac{1}{x^2} \right| < 0.0025$ if $|x| > 20$, $-x > 20$, $x < -20$, $N = -20$.

49. $\left| \frac{4x-5}{2x+5} - 2 \right| = \left| \frac{15}{2x+5} \right| < 0.1$ if $|2x+5| > 150$, $-2x-5 > 150$, $2x < -155$, $x < -77.5$, $N = -77.5$.

50. $\left| \frac{x}{x+1} - 1 \right| = \left| \frac{1}{x+1} \right| < 0.005$ if $|x+1| > 200$, $-x-1 > 200$, $x < -201$, $N = -201$.

51. $\left| \frac{1}{x^2} \right| < \epsilon$ if $|x| > \frac{1}{\sqrt{\epsilon}}$, so $N = \frac{1}{\sqrt{\epsilon}}$.

52. $\left| \frac{1}{x+3} \right| < \epsilon$ if $|x+3| > \frac{1}{\epsilon}$, that is when $x+3 > \frac{1}{\epsilon}$, or $x > \frac{1}{\epsilon} - 3$, so $N = \frac{1}{\epsilon} - 3$.

53. $\left| \frac{4x-5}{2x+5} - 2 \right| = \left| \frac{15}{2x+5} \right| < \epsilon$ if $|2x+5| > \frac{15}{\epsilon}$, that is when $-2x-5 > \frac{15}{\epsilon}$, which means $2x < -\frac{15}{\epsilon} - 5$, or $x < -\frac{15}{2\epsilon} - \frac{5}{2}$, so $N = -\frac{5}{2} - \frac{15}{2\epsilon}$.

54. $\left| \frac{-x}{x-1} + 1 \right| = \left| \frac{1}{x-1} \right| < \epsilon$ if $|x-1| > \frac{1}{\epsilon}$, that is when $-x+1 > \frac{1}{\epsilon}$, or $x < 1 - \frac{1}{\epsilon}$, so $N = 1 - \frac{1}{\epsilon}$.

55. $\left| \frac{4\sqrt{x}}{\sqrt{x}-1} - 4 \right| = \left| \frac{4}{\sqrt{x}-1} \right| < \epsilon$ if $|\sqrt{x}-1| > \frac{4}{\epsilon}$, that is when $\sqrt{x} > 1 + \frac{4}{\epsilon}$, or $x > \left(1 + \frac{4}{\epsilon}\right)^2$, so $N = \left(1 + \frac{4}{\epsilon}\right)^2$.

56. $\left| \frac{\sqrt[3]{x}}{\sqrt[3]{x}+2} - 1 \right| = \left| \frac{-2}{\sqrt[3]{x}+2} \right| < \epsilon$ if $\sqrt[3]{x}+2 < -\frac{2}{\epsilon}$, i.e. when $\sqrt[3]{x} < -2 - \frac{2}{\epsilon}$, or $x < \left(-2 - \frac{2}{\epsilon}\right)^3$, so $N = \left(-2 - \frac{2}{\epsilon}\right)^3$.

57. (a) $\frac{1}{x^2} > 100$ if $|x| < \frac{1}{10}$ (b) $\frac{1}{|x-1|} > 1000$ if $|x-1| < \frac{1}{1000}$

(c) $\frac{-1}{(x-3)^2} < -1000$ if $|x-3| < \frac{1}{10\sqrt{10}}$ (d) $-\frac{1}{x^4} < -10000$ if $x^4 < \frac{1}{10000}$, $|x| < \frac{1}{10}$

58. (a) $\frac{1}{(x-1)^2} > 10$ if and only if $|x-1| < \frac{1}{\sqrt{10}}$

(b) $\frac{1}{(x-1)^2} > 1000$ if and only if $|x-1| < \frac{1}{10\sqrt{10}}$

(c) $\frac{1}{(x-1)^2} > 100000$ if and only if $|x-1| < \frac{1}{100\sqrt{10}}$

59. If $M > 0$ then $\frac{1}{(x-5)^2} > M$ when $0 < (x-5)^2 < \frac{1}{M}$, or $0 < |x-5| < \frac{1}{\sqrt{M}}$, so $\delta = \frac{1}{\sqrt{M}}$.

60. If $M < 0$ then $\frac{-1}{(x-5)^2} < M$ when $0 < (x-5)^2 < -\frac{1}{M}$, or $0 < |x-5| < \frac{1}{\sqrt{-M}}$, so $\delta = \frac{1}{\sqrt{-M}}$.

61. If $M > 0$ then $\frac{1}{|x|} > M$ when $0 < |x| < \frac{1}{M}$, so $\delta = \frac{1}{M}$.

62. If $M > 0$ then $\frac{1}{|x-2|} > M$ when $0 < |x-2| < \frac{1}{M}$, so $\delta = \frac{1}{M}$.

63. If $M < 0$ then $-\frac{1}{x^8} < M$ when $0 < x^8 < -\frac{1}{M}$, or $|x| < \frac{1}{(-M)^{1/8}}$, so $\delta = \frac{1}{(-M)^{1/8}}$.

64. If $M > 0$ then $\frac{1}{x^8} > M$ when $0 < x^8 < \frac{1}{M}$, or $|x| < \frac{1}{M^{1/8}}$, so $\delta = \frac{1}{M^{1/8}}$.

65. If $x > 3$, then $|x+1-4| = |x-3| = x-3 < \varepsilon$ if $3 < x < 3+\varepsilon$, so $\delta = \varepsilon$.

66. If $x < 2$, then $|3x+2-8| = |3x-6| = 3|x-2| = 3(2-x) < \varepsilon$ if $2-x < \varepsilon/3$, or $2-\varepsilon/3 < x < 2$, so $\delta = \varepsilon/3$.

67. If $x > 6$, then $\sqrt{x-6} < \varepsilon$ if $x-6 < \varepsilon^2$, or $6 < x < 6+\varepsilon^2$, so $\delta = \varepsilon^2$.

68. If $x < 0$ then $\sqrt{-x/2} < \varepsilon$ if $-x/2 < \varepsilon^2$, or $-2\varepsilon^2 < x < 0$, so $\delta = 2\varepsilon^2$.

69. If $x > 2$ then $|f(x) - 2| = |x - 2| = x - 2 < \varepsilon$ if $2 < x < 2 + \varepsilon$, so $\delta = \varepsilon$.

70. If $x < 2$ then $|f(x) - 6| = |3x - 6| = 3|x - 2| = 3(2 - x) < \varepsilon$ if $2 - x < \varepsilon/3$, or $2 - \varepsilon/3 < x < 2$, so $\delta = \varepsilon/3$.

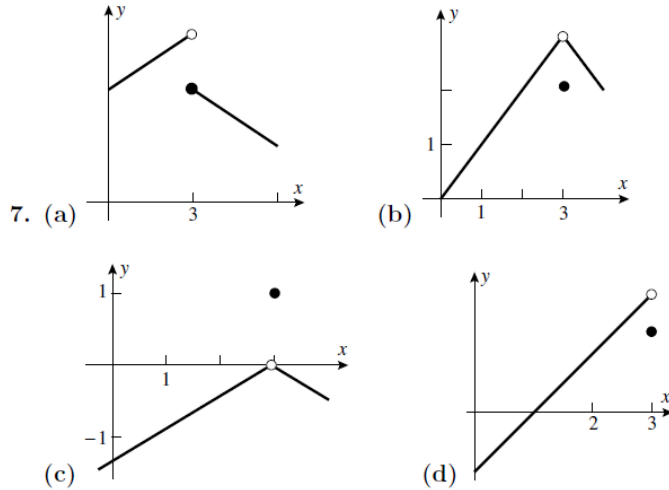
71. (a) Definition: For every $M < 0$ there corresponds a $\delta > 0$ such that if $1 < x < 1 + \delta$ then $f(x) < M$. In our case we want $\frac{1}{1-x} < M$, i.e. $1-x > \frac{1}{M}$, or $x < 1 - \frac{1}{M}$, so we can choose $\delta = -\frac{1}{M}$.

(b) Definition: For every $M > 0$ there corresponds a $\delta > 0$ such that if $1 - \delta < x < 1$ then $f(x) > M$. In our case we want $\frac{1}{1-x} > M$, i.e. $1-x < \frac{1}{M}$, or $x > 1 - \frac{1}{M}$, so we can choose $\delta = \frac{1}{M}$.

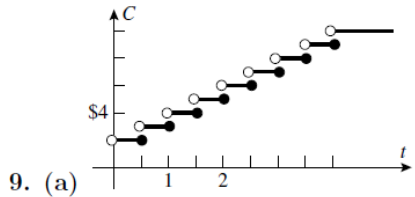
72. (a) Definition: For every $M > 0$ there corresponds a $\delta > 0$ such that if $0 < x < \delta$ then $f(x) > M$. In our case we want $\frac{1}{x} > M$, i.e. $x < \frac{1}{M}$, so take $\delta = \frac{1}{M}$.
- (b) Definition: For every $M < 0$ there corresponds a $\delta > 0$ such that if $-\delta < x < 0$ then $f(x) < M$. In our case we want $\frac{1}{x} < M$, i.e. $x > \frac{1}{M}$, so take $\delta = -\frac{1}{M}$.
73. (a) Given any $M > 0$, there corresponds an $N > 0$ such that if $x > N$ then $f(x) > M$, i.e. $x + 1 > M$, or $x > M - 1$, so $N = M - 1$.
- (b) Given any $M < 0$, there corresponds an $N < 0$ such that if $x < N$ then $f(x) < M$, i.e. $x + 1 < M$, or $x < M - 1$, so $N = M - 1$.
74. (a) Given any $M > 0$, there corresponds an $N > 0$ such that if $x > N$ then $f(x) > M$, i.e. $x^2 - 3 > M$, or $x > \sqrt{M + 3}$, so $N = \sqrt{M + 3}$.
- (b) Given any $M < 0$, there corresponds an $N < 0$ such that if $x < N$ then $f(x) < M$, i.e. $x^3 + 5 < M$, or $x < (M - 5)^{1/3}$, so $N = (M - 5)^{1/3}$.
75. (a) $\frac{3.0}{7.5} = 0.4$ (amperes) (b) $[0.3947, 0.4054]$ (c) $\left[\frac{3}{7.5 + \delta}, \frac{3}{7.5 - \delta} \right]$ (d) 0.0187
- (e) It approaches infinity.

Exercise Set 1.5

1. (a) No: $\lim_{x \rightarrow 2} f(x)$ does not exist. (b) No: $\lim_{x \rightarrow 2} f(x)$ does not exist. (c) No: $\lim_{x \rightarrow 2^-} f(x) \neq f(2)$.
- (d) Yes. (e) Yes. (f) Yes.
2. (a) No: $\lim_{x \rightarrow 2} f(x) \neq f(2)$. (b) No: $\lim_{x \rightarrow 2} f(x) \neq f(2)$. (c) No: $\lim_{x \rightarrow 2^-} f(x) \neq f(2)$.
- (d) Yes. (e) No: $\lim_{x \rightarrow 2^+} f(x) \neq f(2)$. (f) Yes.
3. (a) No: $f(1)$ and $f(3)$ are not defined. (b) Yes. (c) No: $f(1)$ is not defined.
- (d) Yes. (e) No: $f(3)$ is not defined. (f) Yes.
4. (a) No: $f(3)$ is not defined. (b) Yes. (c) Yes.
- (d) Yes. (e) No: $f(3)$ is not defined. (f) Yes.
5. (a) No. (b) No. (c) No. (d) Yes. (e) Yes. (f) No. (g) Yes.
6. (a) No. (b) No. (c) No. (d) No. (e) Yes. (f) Yes. (g) Yes.



8. The discontinuities probably correspond to the times when the patient takes the medication. We see a jump in the concentration values here, which are followed by continuously decreasing concentration values as the medication is being absorbed.



(b) One second could cost you one dollar.

10. (a) Not continuous, since the values are integers.

(b) Continuous.

(c) Not continuous, again, the values are integers (if we measure them in cents).

(d) Continuous.

11. None, this is a continuous function on the real numbers.

12. None, this is a continuous function on the real numbers.

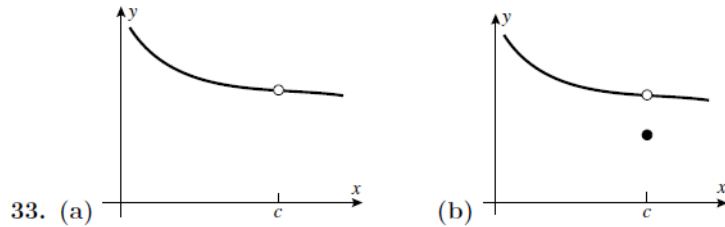
13. The function is not continuous at $x = 6$.

14. None, this is a continuous function on the real numbers.

-
15. The function is not continuous at $x=1/2$ and $x=0$.
16. The function is not continuous at $x = \frac{1}{7}(-3 \pm \sqrt{37})$.
17. The function is not continuous at $x=0$ and $x=-4$.
18. The function is not continuous at $x=0$ and $x=3$.
19. The function is not continuous at $x=-4$ and $x=4$.
20. The function is not continuous at $x=0$, $x=-1$, and $x=1$.
21. None, this is a continuous function on the real numbers. $f(x) = 2x + 3$ is continuous on $x < 4$ and $f(x) = 7 + \frac{16}{x}$ is continuous on $4 < x$; $\lim_{x \rightarrow 4^-} f(x) = \lim_{x \rightarrow 4^+} f(x) = f(4) = 11$ so f is continuous at $x = 4$.
22. The function is not continuous at $x = 1$, as $\lim_{x \rightarrow 1} f(x)$ does not exist.
23. True; by Theorem 1.5.5.
24. False; e.g. $f(x) = 1$ if $x \neq 3$, $f(3) = -1$.
25. False; e.g. $f(x) = g(x) = 2$ if $x \neq 3$, $f(3) = 1$, $g(3) = 3$.
26. False; e.g. $f(x) = g(x) = 2$ if $x \neq 3$, $f(3) = 1$, $g(3) = 4$.
27. True; use Theorem 1.5.3 with $g(x) = \sqrt{f(x)}$.
28. Generally, this statement is false because $\sqrt{f(x)}$ might not even be defined. If we suppose that $f(c)$ is nonnegative, and $f(x)$ is also nonnegative on some interval $(c - \alpha, c + \alpha)$, then the statement is true. If $f(c) = 0$ then given $\epsilon > 0$ there exists $\delta > 0$ such that whenever $|x - c| < \delta$, $0 \leq f(x) < \epsilon^2$. Then $|\sqrt{f(x)}| < \epsilon$ and \sqrt{f} is continuous at $x = c$. If $f(c) \neq 0$ then given $\epsilon > 0$ there corresponds $\delta > 0$ such that whenever $|x - c| < \delta$, $|f(x) - f(c)| < \epsilon\sqrt{f(c)}$. Then $|\sqrt{f(x)} - \sqrt{f(c)}| = \frac{|f(x) - f(c)|}{|\sqrt{f(x)} + \sqrt{f(c)}|} \leq \frac{|f(x) - f(c)|}{\sqrt{f(c)}} < \epsilon$.
29. (a) f is continuous for $x < 1$, and for $x > 1$; $\lim_{x \rightarrow 1^-} f(x) = 5$, $\lim_{x \rightarrow 1^+} f(x) = k$, so if $k = 5$ then f is continuous for all x .
- (b) f is continuous for $x < 2$, and for $x > 2$; $\lim_{x \rightarrow 2^-} f(x) = 4k$, $\lim_{x \rightarrow 2^+} f(x) = 4 + k$, so if $4k = 4 + k$, $k = 4/3$ then f is continuous for all x .
30. (a) f is continuous for $x < 3$, and for $x > 3$; $\lim_{x \rightarrow 3^-} f(x) = k/9$, $\lim_{x \rightarrow 3^+} f(x) = 0$, so if $k = 0$ then f is continuous for all x .
- (b) f is continuous for $x < 0$, and for $x > 0$; $\lim_{x \rightarrow 0^-} f(x)$ doesn't exist unless $k = 0$, and if so then $\lim_{x \rightarrow 0^-} f(x) = 0$; $\lim_{x \rightarrow 0^+} f(x) = 9$, so there is no k value which makes the function continuous everywhere.

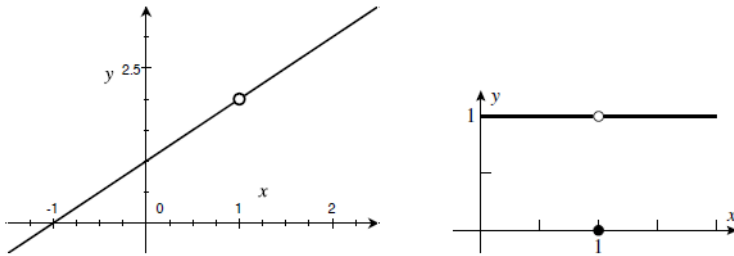
31. f is continuous for $x < -1$, $-1 < x < 2$ and $x > 2$; $\lim_{x \rightarrow -1^-} f(x) = 4$, $\lim_{x \rightarrow -1^+} f(x) = k$, so $k = 4$ is required. Next, $\lim_{x \rightarrow 2^-} f(x) = 3m + k = 3m + 4$, $\lim_{x \rightarrow 2^+} f(x) = 9$, so $3m + 4 = 9$, $m = 5/3$ and f is continuous everywhere if $k = 4$ and $m = 5/3$.

32. (a) No, f is not defined at $x = 2$. (b) No, f is not defined for $x \leq 2$. (c) Yes. (d) No, see (b).



33. (a) $f(c) = \lim_{x \rightarrow c} f(x)$

(b) $\lim_{x \rightarrow 1} f(x) = 2$, $\lim_{x \rightarrow 1} g(x) = 1$.



(c) Define $f(1) = 2$ and redefine $g(1) = 1$.

35. (a) $x = 0$, $\lim_{x \rightarrow 0^-} f(x) = -1 \neq +1 = \lim_{x \rightarrow 0^+} f(x)$ so the discontinuity is not removable.

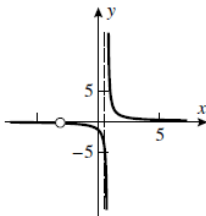
(b) $x = -3$; define $f(-3) = -3 = \lim_{x \rightarrow -3} f(x)$, then the discontinuity is removable.

(c) f is undefined at $x = \pm 2$; at $x = 2$, $\lim_{x \rightarrow 2} f(x) = 1$, so define $f(2) = 1$ and f becomes continuous there; at $x = -2$, $\lim_{x \rightarrow -2} f(x)$ does not exist, so the discontinuity is not removable.

36. (a) f is not defined at $x = 2$; $\lim_{x \rightarrow 2} f(x) = \lim_{x \rightarrow 2} \frac{x+2}{x^2+2x+4} = \frac{1}{3}$, so define $f(2) = \frac{1}{3}$ and f becomes continuous there.

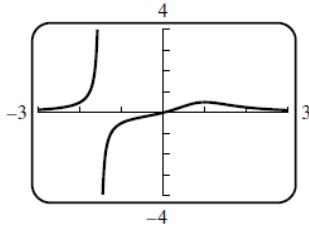
(b) $\lim_{x \rightarrow 2^-} f(x) = 1 \neq 4 = \lim_{x \rightarrow 2^+} f(x)$, so f has a nonremovable discontinuity at $x = 2$.

(c) $\lim_{x \rightarrow 1} f(x) = 8 \neq f(1)$, so f has a removable discontinuity at $x = 1$.



37. (a) Discontinuity at $x = 1/2$, not removable; at $x = -3$, removable.

(b) $2x^2 + 5x - 3 = (2x - 1)(x + 3)$



38. (a) There appears to be one discontinuity near $x = -1.52$.

(b) One discontinuity at $x \approx -1.52$.

39. Write $f(x) = x^{3/5} = (x^3)^{1/5}$ as the composition (Theorem 1.5.6) of the two continuous functions $g(x) = x^3$ and $h(x) = x^{1/5}$; it is thus continuous.

40. $x^4 + 7x^2 + 1 \geq 1 > 0$, thus $f(x)$ is the composition of the polynomial $x^4 + 7x^2 + 1$, the square root \sqrt{x} , and the function $1/x$ and is therefore continuous by Theorem 1.5.6.

41. Since f and g are continuous at $x = c$ we know that $\lim_{x \rightarrow c} f(x) = f(c)$ and $\lim_{x \rightarrow c} g(x) = g(c)$. In the following we use Theorem 1.2.2.

(a) $f(c) + g(c) = \lim_{x \rightarrow c} f(x) + \lim_{x \rightarrow c} g(x) = \lim_{x \rightarrow c} (f(x) + g(x))$ so $f + g$ is continuous at $x = c$.

(b) Same as (a) except the $+$ sign becomes a $-$ sign.

(c) $f(c)g(c) = \lim_{x \rightarrow c} f(x) \lim_{x \rightarrow c} g(x) = \lim_{x \rightarrow c} f(x)g(x)$ so fg is continuous at $x = c$.

42. A rational function is the quotient $f(x)/g(x)$ of two polynomials $f(x)$ and $g(x)$. By Theorem 1.5.2 f and g are continuous everywhere; by Theorem 1.5.3 f/g is continuous except when $g(x) = 0$.

43. (a) Let $h = x - c$, $x = h + c$. Then by Theorem 1.5.5, $\lim_{h \rightarrow 0} f(h + c) = f(\lim_{h \rightarrow 0} (h + c)) = f(c)$.

(b) With $g(h) = f(c + h)$, $\lim_{h \rightarrow 0} g(h) = \lim_{h \rightarrow 0} f(c + h) = f(c) = g(0)$, so $g(h)$ is continuous at $h = 0$. That is, $f(c + h)$ is continuous at $h = 0$, so f is continuous at $x = c$.

44. The function $h(x) = f(x) - g(x)$ is continuous on the interval $[a, b]$, and satisfies $h(a) > 0$, $h(b) < 0$. The Intermediate Value Theorem or Theorem 1.5.9 tells us that there is at least one solution of the equation on this interval $h(x) = 0$, i.e. $f(x) = g(x)$.

45. Of course such a function must be discontinuous. Let $f(x) = 1$ on $0 \leq x < 1$, and $f(x) = -1$ on $1 \leq x \leq 2$.

46. (a) (i) No. (ii) Yes. (b) (i) No. (ii) No. (c) (i) No. (ii) No.

47. If $f(x) = x^4 + x^3 + x^2 - 2x - 2$, then $f(-1) = 1$, $f(1) = -1$. The Intermediate-Value Theorem gives us the result.

48. Since $\lim_{x \rightarrow -\infty} p(x) = -\infty$ and $\lim_{x \rightarrow +\infty} p(x) = +\infty$ (or vice versa, if the leading coefficient of p is negative), it follows that for $M = -1$ there corresponds $N_1 < 0$, and for $M = 1$ there is $N_2 > 0$, such that $p(x) < -1$ for $x < N_1$ and $p(x) > 1$ for $x > N_2$. We choose $x_1 < N_1$ and $x_2 > N_2$ and use Theorem 1.5.9 on the interval $[x_1, x_2]$ to show the existence of a solution of $p(x) = 0$.

49. For the negative root, use intervals on the x -axis as follows: $[-2, -1]$; since $f(-1.3) < 0$ and $f(-1.2) > 0$, the midpoint $x = -1.25$ of $[-1.3, -1.2]$ is the required approximation of the root. For the positive root use the interval $[0, 1]$; since $f(0.7) < 0$ and $f(0.8) > 0$, the midpoint $x = 0.75$ of $[0.7, 0.8]$ is the required approximation.

50. For the negative root, use intervals on the x -axis as follows: $[-2, -1]$; since $f(-1.7) < 0$ and $f(-1.6) > 0$, use the interval $[-1.7, -1.6]$. Since $f(-1.61) < 0$ and $f(-1.60) > 0$ the midpoint $x = -1.605$ of $[-1.61, -1.60]$ is the required approximation of the root. For the positive root use the interval $[1, 2]$; since $f(1.3) > 0$ and $f(1.4) < 0$, use the interval $[1.3, 1.4]$. Since $f(1.37) > 0$ and $f(1.38) < 0$, the midpoint $x = 1.375$ of $[1.37, 1.38]$ is the required approximation.

51. For the positive root, use intervals on the x -axis as follows: $[2; 3]$; since $f(2.6) < 0$ and $f(2.7) > 0$, use the interval $[2.6, 2.7]$. Since $f(2.64) < 0$ and $f(2.65) > 0$, the midpoint $x = 2.645$ of $[2.64, 2.65]$ is the required approximation of the root.

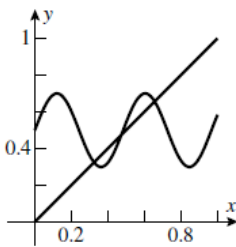
52. Assume the locations along the track are numbered with increasing $x \geq 0$. Let $T_S(x)$ denote the time during the sprint when the runner is located at point $x, 0 \leq x \leq 100$. Let $T_J(x)$ denote the time when the runner is at the point x on the return jog, measured so that $T_J(100) = 0$. Then $T_S(0) = 0, T_S(100) > 0, T_J(100) = 0, T_J(0) > 0$, so that Exercise 44 applies and there exists an x_0 such that $T_S(x_0) = T_J(x_0)$.

53. Consider the function $f(\theta) = T(\theta + \pi) - T(\theta)$. Note that T has period 2π , $T(\theta + 2\pi) = T(\theta)$, so that $f(\theta + \pi) = T(\theta + 2\pi) - T(\theta + \pi) = -(T(\theta + \pi) - T(\theta)) = -f(\theta)$. Now if $f(\theta) \equiv 0$, then the statement follows. Otherwise, there exists θ such that $f(\theta) \neq 0$ and then $f(\theta + \pi)$ has an opposite sign, and thus there is a t_0 between θ and $\theta + \pi$ such that $f(t_0) = 0$ and the statement follows.

54. Let the ellipse be contained between the horizontal lines $y = a$ and $y = b$, where $a < b$. The expression $|f(z_1) - f(z_2)|$ expresses the area of the ellipse that lies between the vertical lines $x = z_1$ and $x = z_2$, and thus $|f(z_1) - f(z_2)| \leq (b - a)|z_1 - z_2|$. Thus for a given $\epsilon > 0$ there corresponds $\delta = \epsilon/(b - a)$, such that if $|z_1 - z_2| < \delta$, then $|f(z_1) - f(z_2)| \leq (b - a)|z_1 - z_2| < (b - a)\delta = \epsilon$ which proves that f is a continuous function.

55. Since R and L are arbitrary, we can introduce coordinates so that L is the x -axis. Let $f(z)$ be as in Exercise 54. Then for large z , $f(z) = \text{area of ellipse}$, and for small z , $f(z) = 0$. By the Intermediate Value Theorem there is a z_1 such that $f(z_1) = \text{half of the area of the ellipse}$.

56. (a)



(b) Let $g(x) = x - f(x)$. Then $g(x)$ is continuous, $g(1) \geq 0$ and $g(0) \leq 0$; by the Intermediate Value Theorem there is a solution c in $[0, 1]$ of $g(c) = 0$, which means $f(c) = c$.

57. For $x \geq 0$, f is increasing and so is one-to one. It is continuous everywhere and thus by Theorem 1.5.7 it has an inverse defined on its range $[3, +\infty)$ which is continuous there.

$$58. L = h(0) = h\left(\lim_{x \rightarrow 0} f^{-1}(x)\right) = \lim_{x \rightarrow 0} h(f^{-1}(x)) = \lim_{x \rightarrow 0} \frac{f(f^{-1}(x))}{f^{-1}(x)} = \lim_{x \rightarrow 0} \frac{x}{f^{-1}(x)}.$$

Exercise Set 1.6

1. This is a composition of continuous functions, so it is continuous everywhere.

2. Discontinuity at $x = \pi/2$.

3. Discontinuities at $x = n\pi, n = 0, \pm 1, \pm 2, \dots$

4. Discontinuities at $x = \frac{\pi}{2} + n\pi, n = 0, \pm 1, \pm 2, \dots$

5. Discontinuities at $x = n\pi, n = 0, \pm 1, \pm 2, \dots$

6. Continuous everywhere.

7. Discontinuities at $x = 2n\pi + \frac{\pi}{3}$ and $x = 2n\pi + \frac{2\pi}{3}, n = 0, \pm 1, \pm 2, \dots$

8. Discontinuities at $x = n\pi + \frac{\pi}{2}, n = 0, \pm 1, \pm 2, \dots$

9. (a) $f(x) = \sin x, g(x) = x^3 + 7x + 1$. (b) $f(x) = |x|, g(x) = \sin x$.
(c) $f(x) = x^3, g(x) = \cos(x + 2)$.

10. (a) $f(x) = |x|, g(x) = 4 + \sin 2x$. (b) $f(x) = \sin x, g(x) = \sin x$.
(c) $f(x) = x^5 - 2x^3 + 1, g(x) = \cos x$.

11. $\lim_{x \rightarrow +\infty} 2 \cos\left(\frac{1}{x}\right) = 2 \lim_{x \rightarrow +\infty} \cos \frac{1}{x} = 2 \cos 0 = 2$.

12. $\lim_{x \rightarrow +\infty} \sin\left(\frac{\pi x}{2 + 3x}\right) = \sin \lim_{x \rightarrow +\infty} \frac{\pi x}{2 + 3x} = \sin\left(\frac{\pi}{3}\right) = \frac{\sqrt{3}}{2}$.

13. $\lim_{\theta \rightarrow 0} \frac{\sin 5\theta}{\theta} = 5 \lim_{\theta \rightarrow 0} \frac{\sin 5\theta}{5\theta} = 5$

14. $\lim_{h \rightarrow 0} \frac{\sin h}{4h} = \frac{1}{4} \lim_{h \rightarrow 0} \frac{\sin h}{h} = \frac{1}{4}$.

15. $\lim_{x \rightarrow 0} \frac{2x^2 - 3\sin x}{x} = \lim_{x \rightarrow 0} 2x - 3 \lim_{x \rightarrow 0} \frac{\sin x}{x} = -3$.

16. $\frac{2 - \cos 5x - \cos 7x}{x} = \frac{1 - \cos 5x}{x} + \frac{1 - \cos 7x}{x}$

Note that $\frac{1 - \cos 5x}{x} = \frac{1 - \cos 5x}{x} \cdot \frac{1 + \cos 5x}{1 + \cos 5x} = \frac{\sin^2 5x}{x(1 + \cos 5x)} = \frac{\sin 5x}{x} \cdot \frac{\sin 5x}{1 + \cos 5x}$

Thus,

$$\lim_{x \rightarrow 0} \frac{2 - \cos 5x - \cos 7x}{x} = \lim_{x \rightarrow 0} \frac{\sin 5x}{x} \cdot \frac{\sin 5x}{1 + \cos 5x} + \lim_{x \rightarrow 0} \frac{\sin 7x}{x} \cdot \frac{\sin 7x}{1 + \cos 7x}$$

$$= 5 \cdot 0 + 7 \cdot 0 = 0.$$

$$17. \lim_{\theta \rightarrow 0^+} \frac{\sin \theta}{\theta^3} = \left(\lim_{\theta \rightarrow 0^+} \frac{1}{\theta^2} \right) \lim_{\theta \rightarrow 0^+} \frac{\sin \theta}{\theta} = +\infty.$$

$$18. \lim_{\theta \rightarrow 0} \frac{2 \sin^2 \theta}{\theta} = 2 \left(\lim_{\theta \rightarrow 0} \sin \theta \right) \lim_{\theta \rightarrow 0} \frac{\sin \theta}{\theta} = 0.$$

$$19. \frac{\tan 5x}{\sin 4x} = \frac{5}{4 \cos 5x} \cdot \frac{\sin 5x}{5x} \cdot \frac{4x}{\sin 4x}$$

$$\text{So, } \lim_{x \rightarrow 0} \frac{\tan 5x}{\sin 4x} = \frac{5}{4 \cdot 1} \cdot 1 \cdot 1 = \frac{5}{4}.$$

$$20. \frac{\sin 3x}{\sin 9x} = \frac{3}{9} \cdot \frac{\sin 3x}{3x} \cdot \frac{9x}{\sin 9x}$$

$$\text{So, } \lim_{x \rightarrow 0} \frac{\sin 3x}{\sin 9x} = \frac{3}{9} \cdot 1 \cdot 1 = \frac{1}{3}.$$

$$21. \lim_{x \rightarrow 0^+} \frac{\sin x}{\sqrt[3]{x}} = \lim_{x \rightarrow 0^+} x^{2/3} \times \frac{\sin x}{x} = \lim_{x \rightarrow 0^+} x^{2/3} \times \lim_{x \rightarrow 0^+} \frac{\sin x}{x} = 0 \cdot 1 = 0.$$

$$22. \lim_{x \rightarrow 0} \frac{\sin^2 x}{10x^2} = \frac{1}{10} \left(\lim_{x \rightarrow 0} \frac{\sin x}{x} \right)^2 = \frac{1}{10}$$

$$23. \lim_{x \rightarrow 0} \frac{\sin x^2}{2x} = \frac{1}{2} \left(\lim_{x \rightarrow 0} x \right) \left(\lim_{x \rightarrow 0} \frac{\sin x^2}{x^2} \right) = 0.$$

$$24. \lim_{h \rightarrow 0} \frac{2 \sin h}{1 - \cos h} = 2 \frac{\sin h}{1 - \cos h} \cdot \frac{1 + \cos h}{1 + \cos h} = \frac{2 \sin h (1 + \cos h)}{1 - \cos^2 h} = 2 \frac{1 + \cos h}{\sin h};$$

this implies that $\lim_{h \rightarrow 0^+}$ is $+\infty$, and $\lim_{h \rightarrow 0^-}$ is $-\infty$, therefore the limit does not exist.

$$25. \frac{2t^2}{1 - \cos^2 t} = 2 \left(\frac{t}{\sin t} \right)^2$$

$$\text{So, } 2 \lim_{t \rightarrow 0} \frac{t^2}{1 - \cos^2 t} = 2.$$

$$26. \cos(\pi - x) = \cos(\pi) \cos x + \sin(\pi) \sin x = -\cos x$$

$$\text{So, } \lim_{x \rightarrow 0} \frac{x}{\cos(\pi - x)} = 0.$$

$$27. 2 \frac{\theta^2}{1-\cos \theta} \cdot \frac{1+\cos \theta}{1+\cos \theta} = 2 \frac{\theta^2(1+\cos \theta)}{1-\cos^2 \theta} = 2 \left(\frac{\theta}{\sin \theta} \right)^2 (1+\cos \theta)$$

$$\text{So, } 2 \lim_{\theta \rightarrow 0} \frac{\theta^2}{1-\cos \theta} = 2 \cdot (1)^2 \cdot 2 = 4.$$

$$28. \frac{1-\cos h}{\cos^2 3h-1} \cdot \frac{1+\cos h}{1+\cos h} = \frac{\sin^2 h}{-\sin^2 3h} \cdot \frac{1}{1+\cos h}$$

$$\text{So, } \lim_{h \rightarrow 0} \frac{1-\cos h}{\cos^2 3h-1} = \lim_{h \rightarrow 0} \frac{\sin^2 h}{-\sin^2 3h} \cdot \frac{1}{1+\cos h} = -\left(\frac{1}{3}\right)^2 \cdot \frac{1}{2} = -\frac{1}{18}.$$

$$29. \lim_{x \rightarrow 0^+} \sin\left(\frac{2}{x}\right) = \lim_{t \rightarrow +\infty} \sin 2t, \text{ so the limit does not exist.}$$

$$30. \frac{\tan 2x^2 + \sin^2 4x}{x^2} = \frac{2}{\cos 2x^2} \frac{\sin 2x^2}{2x^2} + \frac{16 \sin^2 4x}{(4x)^2}$$

$$\text{So, } \lim_{x \rightarrow 0} \frac{2}{\cos 2x^2} \lim_{x \rightarrow 0} \frac{\sin 2x^2}{2x^2} + 16 \lim_{x \rightarrow 0} \left(\frac{\sin 4x}{4x}\right)^2 = 2 + 16 = 18.$$

31.

$$\lim_{\theta \rightarrow 0} \tan\left(\frac{1-\cos \theta}{\theta}\right) = \tan\left(\lim_{\theta \rightarrow 0} \frac{1-\cos \theta}{\theta}\right) = \tan\left(\lim_{\theta \rightarrow 0} \frac{1-\cos^2 \theta}{\theta(1+\cos \theta)}\right) = \tan\left(\lim_{\theta \rightarrow 0} \frac{\sin \theta}{\theta} \cdot \frac{\sin \theta}{(1+\cos \theta)}\right) = 0.$$

$$32. \text{ If } x \neq 0, \text{ then } \frac{3x - \sin(kx)}{x} = 3 - k \frac{\sin(kx)}{kx}, \text{ so the limit is } 3 - k.$$

33. (a)

| | | | | | | |
|--------|---------|----------|----------|----------|----------|----------|
| x | 3 | 3.5 | 3.9 | 4.1 | 4.5 | 5 |
| $f(x)$ | 0.12021 | 0.127847 | 0.126371 | 0.123251 | 0.112806 | 0.093497 |

The limit appears to be 0.125.

$$(b) \text{ Let } t = x - 4. \text{ Then } t \rightarrow 0 \text{ as } x \rightarrow 4 \text{ and } \lim_{x \rightarrow 4} \frac{\sin(x-4)}{x^2-16} = \lim_{x \rightarrow 4} \frac{1}{x+4} \lim_{t \rightarrow 0} \frac{\sin t}{t} = \frac{1}{8} \cdot 1 = \frac{1}{8}.$$

34.

| | | | | | | |
|--------|-----------|-----------|-----------|-----------|-----------|-----------|
| x | -4.1 | -4.01 | -4.001 | -3.999 | -3.99 | -3.9 |
| $f(x)$ | -3.050586 | -3.009546 | -3.000995 | -2.998996 | -2.989555 | -2.859522 |

The limit appears to be -3 .

(b) Let $t = (x+4)(x+1)$. Then $t \rightarrow 0$ as $x \rightarrow -4$, and

$$\lim_{x \rightarrow -4} \frac{\sin[(x+4)(x+1)]}{x+4} = \lim_{x \rightarrow -4} (x+1) \lim_{t \rightarrow 0} \frac{\sin t}{t} = -3 \cdot 1 = -3 \text{ by the Substitution Principle.}$$

35. True: let $\varepsilon > 0$ and $\delta = \varepsilon$. Then if $|x - (-1)| = |x+1| < \delta$ then $|f(x) + 10| < \varepsilon$.

36. True; from the proof of Theorem 1.6.3 we have $\tan x \geq x \geq \sin x$ for $0 < x < \pi/2$, and the desired inequalities follow immediately.

37. True; the functions $f(x) = x$, $g(x) = \sin x$, and $h(x) = 1/x$ are continuous everywhere except possibly at $x = 0$, so by Theorem 1.5.6 the given function is continuous everywhere except possibly at $x = 0$. We prove that

$\lim_{x \rightarrow 0} x \sin(1/x) = 0$. Let $\epsilon > 0$. Then with $\delta = \epsilon$, if $|x| < \delta$ then $|x \sin(1/x)| \leq |x| < \delta = \epsilon$, and hence f is continuous everywhere.

38. True; by the Squeezing Theorem 1.6.4 $|\lim_{x \rightarrow 0} xf(x)| \leq M \lim_{x \rightarrow 0} |x| = 0$ and $\left| \lim_{x \rightarrow +\infty} \frac{f(x)}{x} \right| \leq M \lim_{x \rightarrow +\infty} \frac{1}{x} = 0$.

39. (a) The student calculated x in degrees rather than radians.

(b) $\sin x^\circ = \sin t$ where x° is measured in degrees, t is measured in radians and $t = \frac{\pi x^\circ}{180}$. Thus $\lim_{x^\circ \rightarrow 0} \frac{\sin x^\circ}{x^\circ} = \lim_{t \rightarrow 0} \frac{\sin t}{(180t/\pi)} = \frac{\pi}{180}$.

40. Denote θ by x in accordance with Figure 1.6.4. Let P have coordinates $(\cos x, \sin x)$ and Q coordinates $(1, 0)$ so that $c^2(x) = (1 - \cos x)^2 + \sin^2 x = 2(1 - \cos x)$. Since $s = r\theta = 1 \cdot x = x$ we have $\lim_{x \rightarrow 0^+} \frac{c^2(x)}{s^2(x)} = \lim_{x \rightarrow 0^+} 2 \frac{1 - \cos x}{x^2} = \lim_{x \rightarrow 0^+} 2 \frac{1 - \cos x}{x^2} \cdot \frac{1 + \cos x}{1 + \cos x} = \lim_{x \rightarrow 0^+} \left(\frac{\sin x}{x} \right)^2 \frac{2}{1 + \cos x} = 1$.

41. $\lim_{x \rightarrow 0^-} f(x) = k \lim_{x \rightarrow 0} \frac{\sin kx}{kx \cos kx} = k$, $\lim_{x \rightarrow 0^+} f(x) = 4k^2$, so $k = 4k^2$, and the non-zero solution is $k = \frac{1}{4}$.

42. No; $\sin x/|x|$ has unequal one-sided limits (+1 and -1).

43. (a) $\lim_{t \rightarrow 0^+} \frac{\sin t}{t} = 1$.

(b) $\lim_{t \rightarrow 0^-} \frac{2 - 2 \cos t}{t} = 0$.

(c) $\sin \pi - t = \sin t$, so $\lim_{x \rightarrow \pi} \frac{\pi - x}{\sin x} = \lim_{t \rightarrow 0} \frac{t}{\sin t} = 1$.

44. Let $t = \frac{\pi}{2} - \frac{\pi}{x}$. Then

$$\cos\left(\frac{\pi}{2} - t\right) = \sin t, \text{ so } \lim_{x \rightarrow 2} \frac{2 \cos(\pi/x)}{x-2} = 2 \lim_{t \rightarrow 0} \frac{(\pi-2t) \sin t}{4t} = 2 \lim_{t \rightarrow 0} \frac{(\pi-2t)}{4} \lim_{t \rightarrow 0} \frac{\sin t}{t} = \frac{\pi}{2}.$$

45. Let $t = x - 1$;

$$3 \sin(\pi x) = 3 \sin(\pi t + \pi) = -3 \sin \pi t; \text{ and } \lim_{x \rightarrow 1} \frac{3 \sin(\pi x)}{x-1} = -3 \lim_{t \rightarrow 0} \frac{\sin \pi t}{t} = -3\pi.$$

46. Let $t = x - \frac{\pi}{4}$

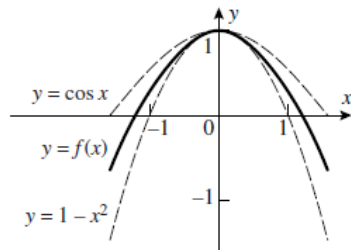
$$\tan x - 1 = \frac{2 \sin t}{\cos t - \sin t}; \lim_{x \rightarrow \pi/4} \frac{\frac{1}{2}(\tan x - 1)}{x - \frac{\pi}{4}} = \frac{1}{2} \lim_{t \rightarrow 0} \frac{2 \sin t}{t(\cos t - \sin t)} = 1.$$

47. $-|x| \leq x \cos\left(\frac{50\pi}{x}\right) \leq |x|$, which gives the desired result.

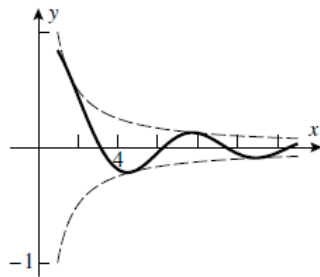
48. $-x^2 \leq x^2 \sin\left(\frac{50\pi}{\sqrt[3]{x}}\right) \leq x^2$, which gives the desired result.

49. Since $\lim_{x \rightarrow 0} \sin(1/x)$ does not exist, no conclusions can be drawn.

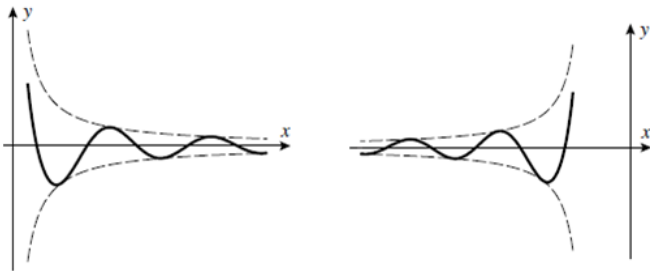
50. $\lim_{x \rightarrow 0} f(x) = 1$ by the Squeezing Theorem.



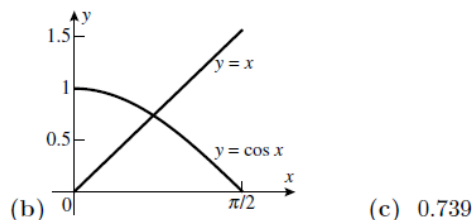
51. $\lim_{x \rightarrow +\infty} f(x) = 0$ by the Squeezing Theorem.



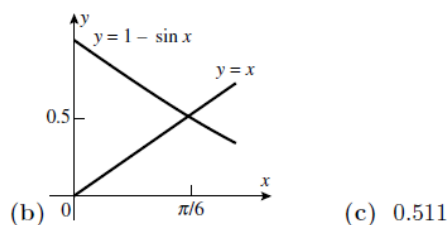
52.



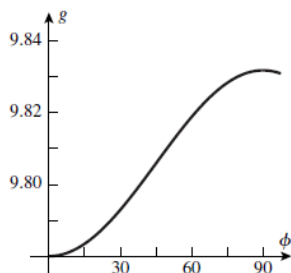
53. (a) Let $f(x) = x - \cos x$; $f(0) = -1$, $f(\pi/2) = \pi/2$. By the IVT there must be a solution of $f(x) = 0$.



54. (a) $f(x) = x + \sin x - 1$; $f(0) = -1$, $f(\pi/6) = \pi/6 - 1/2 > 0$. By the IVT there must be a solution of $f(x) = 0$ in the interval.



55. (a) Gravity is strongest at the poles and weakest at the equator.



(b) Let $g(\phi)$ be the given function. Then $g(38) < 9.8$ and $g(39) > 9.8$, so by the Intermediate Value Theorem there is a value c between 38 and 39 for which $g(c) = 9.8$ exactly.

Exercise Set 1.7

1. $\sin^{-1} u$ is continuous for $-1 \leq u \leq 1$, so $-1 \leq 2x \leq 1$, or $-1/2 \leq x \leq 1/2$.

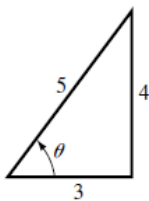
2. $\cos^{-1} u$ is continuous for $-1 \leq u \leq 1$, so $0 \leq \sqrt{3x} \leq 1$, or $0 \leq x \leq 1/3$.

3. \sqrt{u} is continuous for $0 \leq u$, so $0 \leq \tan^{-1} x$ or $x \geq 0$; $x^2 - 4 \neq 0$ thus the function is continuous for $0 \leq x < 2$ and $x > 2$.

4. $\sin^{-1} u$ is continuous for $-1 \leq u \leq 1$, so $-1 \leq \frac{1}{2x} \leq 1$, thus $x \leq -\frac{1}{2}$ or $x \geq \frac{1}{2}$. The function is continuous

on $\left(-\infty, -\frac{1}{2}\right) \cup \left(\frac{1}{2}, \infty\right)$.

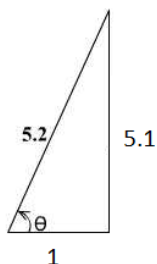
5. $\tan \theta = 4/3$, $0 < \theta < \pi/2$; use the triangle shown to get $\sin \theta = 4/5$, $\cos \theta = 3/5$, $\cot \theta = 3/4$, $\sec \theta = 5/3$, $\csc \theta = 5/4$.



6. $\sec \theta = 5.2$, $0 < \theta < \pi/2$; use the triangle shown to get

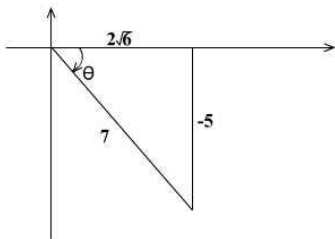
$$\sin \theta = \frac{5.1}{5.2} = \frac{51}{52}; \quad \cos \theta = \frac{1}{5.2} = \frac{5}{26}; \quad \tan \theta = \frac{5.1}{1} = \frac{51}{10}; \quad \cot \theta = \frac{1}{5.1} = \frac{10}{51}$$

$$\csc \theta = \frac{5.2}{5.1} = \frac{52}{51}.$$

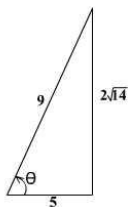


7. (a) $0 \leq x \leq \pi$ (b) $-1 \leq x \leq 1$ (c) $-\pi/2 < x < \pi/2$ (d) $-\infty < x < +\infty$

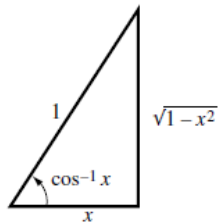
8. Let $\theta = \sin^{-1}(-5/7)$; then $\sin \theta = -5/7$, $-\pi/2 < \theta < 0$ and (see figure) $\sec \theta = 7/2\sqrt{6}$.



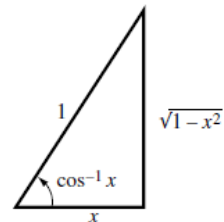
9. Let $\theta = \cos^{-1}(5/9)$; $\sin 2\theta = 2 \sin \theta \cos \theta = 2(2\sqrt{14}/9)(5/9) = 20\sqrt{14}/81$.



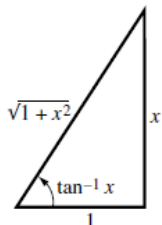
10. (a) $\sin(\cos^{-1} x) = \sqrt{1-x^2}$



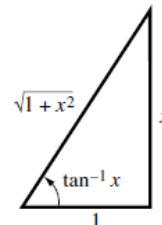
(b) $\tan(\cos^{-1} x) = \frac{\sqrt{1-x^2}}{x}$



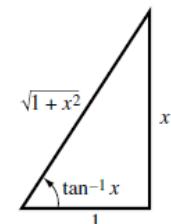
(c) $\csc(\tan^{-1} x) = \frac{\sqrt{1+x^2}}{x}$



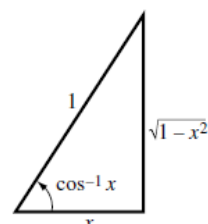
(d) $\sin(\tan^{-1} x) = \frac{x}{\sqrt{1+x^2}}$



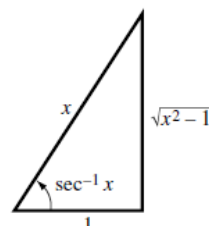
11. (a) $\cos(\tan^{-1} x) = \frac{1}{\sqrt{1+x^2}}$



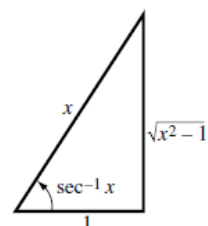
(b) $\tan(\cos^{-1} x) = \frac{\sqrt{1-x^2}}{x}$



(c) $\sin(\sec^{-1} x) = \frac{\sqrt{x^2-1}}{x}$

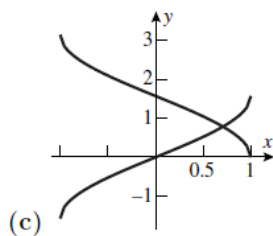
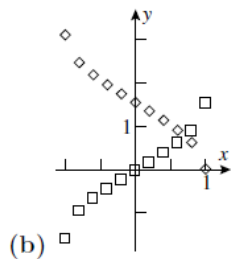


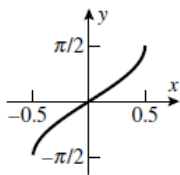
(d) $\cot(\sec^{-1} x) = \frac{1}{\sqrt{x^2-1}}$



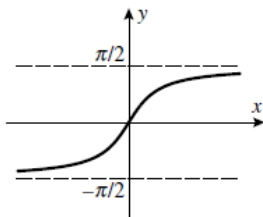
12. (a)

| | | | | | | | | | | | |
|---------------|-------|-------|-------|-------|-------|------|------|------|------|------|------|
| x | -1.00 | -0.80 | -0.60 | -0.40 | -0.20 | 0.00 | 0.20 | 0.40 | 0.60 | 0.80 | 1.00 |
| $\sin^{-1} x$ | -1.57 | -0.93 | -0.64 | -0.41 | -0.20 | 0.00 | 0.20 | 0.41 | 0.64 | 0.93 | 1.57 |
| $\cos^{-1} x$ | 3.14 | 2.50 | 2.21 | 1.98 | 1.77 | 1.57 | 1.37 | 1.16 | 0.93 | 0.64 | 0.00 |





13. (a)



(b)

14. $8^2 = 4^2 + 6^2 - 2(4)(6) \cos \theta$, $\cos \theta = -\frac{1}{4}$, $\theta = \cos^{-1}\left(-\frac{1}{4}\right) \approx 104^\circ$.

15.

(a) $x = \pi - \sin^{-1}(0.42) \approx 2.7081$ rad.

(b) $\theta = 180^\circ + \sin^{-1}(0.61) \approx 217.6^\circ$.

16.

(a) $x = \pi + \cos^{-1}(0.80) \approx 3.7851$ rad.

(b) $\theta = -\cos^{-1}(0.23) \approx -76.7^\circ$.

17.

(a) $\sin^{-1}(\sin^{-1} 0.30) \approx \sin^{-1}(0.3047) \approx 0.3096$, $\sin^{-1} 0.9 > 1$, so it is not in the domain of $\sin^{-1} x$.

(b) $-1 \leq \sin^{-1} x \leq 1$ is necessary, or $-0.841471 \leq x \leq 0.841471$.

18. $\sin 2\theta = gR/v^2 = (9.8)(18)/(15)^2 = 0.784$, $2\theta = \sin^{-1} 0.784$ or $2\theta = 180^\circ - \sin^{-1} 0.784$ so $\theta = \frac{1}{2} \sin^{-1} 0.784 \approx 26^\circ$ or $\theta = 90^\circ - \frac{1}{2} \sin^{-1} 0.784 \approx 64^\circ$.

The ball will have a lower parabolic trajectory for $\theta = 26^\circ$ and hence will result in the shorter time of flight.

19. $\lim_{x \rightarrow +\infty} \sin^{-1}\left(\frac{x}{1+2x}\right) = \sin^{-1}\left(\lim_{x \rightarrow +\infty} \frac{x}{1+2x}\right) = \sin^{-1}\left(\frac{1}{2}\right) = \frac{\pi}{6}$.

20. $\lim_{x \rightarrow +\infty} \cos(\tan^{-1} x) = \cos(\lim_{x \rightarrow +\infty} \tan^{-1} x) = \cos(\pi/2) = 0$.

21. False; the range of \sin^{-1} is $[-\pi/2, \pi/2]$, so the equation is only true for x in this range.

22. False; it is the interval $-\pi/2 \leq x \leq \pi/2$.

23. False; the line $y = \pi/2$ is a horizontal asymptote as $x \rightarrow \infty$ and as $x \rightarrow -\infty$.

24. Let $g(x) = f^{-1}(x)$ and $h(x) = f(x)/x$ when $x \neq 0$ and $h(0) = L$. Then $\lim_{x \rightarrow 0} h(x) = L = h(0)$, so h is continuous at $x = 0$. Apply Theorem 1.5.5 to $h \circ g$ to obtain that on the one hand $h(g(0)) = L$, and on the other $h(g(x)) = \frac{f(g(x))}{g(x)}$, $x \neq 0$, and $\lim_{x \rightarrow 0} h(g(x)) = h(g(0))$. Since $f(g(x)) = x$ and $g = f^{-1}$ this shows that $\lim_{x \rightarrow 0} \frac{x}{f^{-1}(x)} = L$.

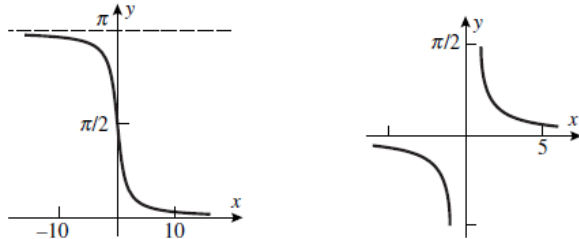
25. $\lim_{x \rightarrow 0} \frac{x/2}{\sin^{-1} x/2} = \lim_{x \rightarrow 0} \frac{\sin x/2}{x/2} = 1$.

26. $\tan(\tan^{-1} 3x) = 3x$, so $\lim_{x \rightarrow 0} \frac{\tan^{-1} 3x}{3x} = \lim_{x \rightarrow 0} \frac{3x}{\tan 3x} = (\lim_{x \rightarrow 0} \cos 3x) \lim_{x \rightarrow 0} \frac{3x}{\sin 3x} = 1 \cdot 1 = 1$.

27. $7 \lim_{x \rightarrow 0} \frac{\sin^{-1} 7x}{7x} = 7 \lim_{x \rightarrow 0} \frac{7x}{\sin 7x} = 7$.

28. $\lim_{x \rightarrow -1} \frac{1}{x-1} \frac{\sin^{-1}(x+1)}{x+1} = -\frac{1}{2} \lim_{x \rightarrow -1} \frac{x+1}{\sin x+1} = -\frac{1}{2}$.

29. (a)



(b) The domain of $\cot^{-1} x$ is $(-\infty, +\infty)$, the range is $(0, \pi)$; the domain of $\csc^{-1} x$ is $(-\infty, -1] \cup [1, +\infty)$, the range is $[-\pi/2, 0) \cup (0, \pi/2]$.

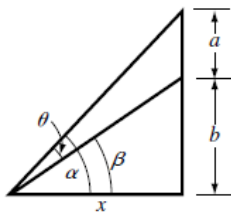
30. (a) $y = \cot^{-1} x$; if $x > 0$ then $0 < y < \pi/2$ and $x = \cot y$, $\tan y = 1/x$, $y = \tan^{-1}(1/x)$; if $x < 0$ then $\pi/2 < y < \pi$ and $x = \cot y = \cot(y - \pi)$, $\tan(y - \pi) = 1/x$, $y = \pi + \tan^{-1} \frac{1}{x}$.

(b) $y = \sec^{-1} x$, $x = \sec y$, $\cos y = 1/x$, $y = \cos^{-1}(1/x)$.

(c) $y = \csc^{-1} x$, $x = \csc y$, $\sin y = 1/x$, $y = \sin^{-1}(1/x)$.

31. (a) 21.8° (b) 33.6° (c) 25.8°

32. $\theta = \alpha - \beta$, $\cot \alpha = \frac{x}{a+b}$ and $\cot \beta = \frac{x}{b}$ so $\theta = \cot^{-1} \frac{x}{a+b} - \cot^{-1} \left(\frac{x}{b} \right)$.



33. (a) If $\gamma = 90^\circ$, then $\sin \gamma = 1$, $\sqrt{1 - \sin^2 \phi \sin^2 \gamma} = \sqrt{1 - \sin^2 \phi} = \cos \phi$, $D = \tan \phi \tan \lambda = (\tan 23.45^\circ)(\tan 65^\circ) \approx 0.93023374$ so $h \approx 21.1$ hours.

(b) If $\gamma = 270^\circ$, then $\sin \gamma = -1$, $D = -\tan \phi \tan \lambda \approx -0.93023374$ so $h \approx 2.9$ hours.

34. (b) $\theta = \sin^{-1} \frac{R}{R+h} = \sin^{-1} \frac{6378}{26378} \approx 13.9^\circ$.

35. $y = 0$ when $x^2 = \frac{6000v^2}{g}$, $x = 10v\sqrt{\frac{60}{g}} = 1250\sqrt{30}$ for $v = 500$ and $g = 32$;

$$\tan \theta = 3000/1250\sqrt{30}, \theta = \tan^{-1} 2.4/\sqrt{30} \approx 24^\circ.$$

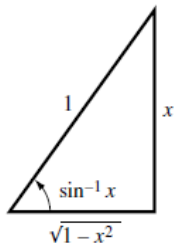
36. (a) Let $\theta = \sin^{-1}(-x)$ then $\sin \theta = -x$, $-\pi/2 \leq \theta \leq \pi/2$. But $\sin(-\theta) = -\sin \theta$ and $-\pi/2 \leq -\theta \leq \pi/2$ so $\sin(-\theta) = -(-x) = x$, $-\theta = \sin^{-1} x$, $\theta = -\sin^{-1} x$.

(b) Proof is similar to that in part (a).

37. (a) Let $\theta = \cos^{-1}(-x)$ then $\cos \theta = -x$, $0 \leq \theta \leq \pi$. But $\cos(\pi - \theta) = -\cos \theta$ and $0 \leq \pi - \theta \leq \pi$ so $\cos(\pi - \theta) = x$, $\pi - \theta = \cos^{-1} x$, $\theta = \pi - \cos^{-1} x$.

(b) Let $\theta = \sec^{-1}(-x)$ for $x \geq 1$; then $\sec \theta = -x$ and $\pi/2 < \theta \leq \pi$. So $0 \leq \pi - \theta < \pi/2$ and $\pi - \theta = \sec^{-1} \sec(\pi - \theta) = \sec^{-1}(-\sec \theta) = \sec^{-1} x$, or $\sec^{-1}(-x) = \pi - \sec^{-1} x$.

38. (a) $\sin^{-1} x = \tan^{-1} \frac{x}{\sqrt{1-x^2}}$ (see figure).



(b) $\sin^{-1} x + \cos^{-1} x = \pi/2$; $\cos^{-1} x = \pi/2 - \sin^{-1} x = \pi/2 - \tan^{-1} \frac{x}{\sqrt{1-x^2}}$.

39. $\tan(\alpha + \beta) = \frac{\tan \alpha + \tan \beta}{1 - \tan \alpha \tan \beta}$,

$$\tan(\tan^{-1} x + \tan^{-1} y) = \frac{\tan(\tan^{-1} x) + \tan(\tan^{-1} y)}{1 - \tan(\tan^{-1} x) \tan(\tan^{-1} y)} = \frac{x + y}{1 - xy}$$

so $\tan^{-1} x + \tan^{-1} y = \tan^{-1} \frac{x + y}{1 - xy}$.

40. (a) $\tan^{-1} \frac{1}{2} + \tan^{-1} \frac{1}{3} = \tan^{-1} \frac{1/2 + 1/3}{1 - (1/2)(1/3)} = \tan^{-1} 1 = \pi/4$.

(b) $2 \tan^{-1} \frac{1}{3} = \tan^{-1} \frac{1}{3} + \tan^{-1} \frac{1}{3} = \tan^{-1} \frac{1/3 + 1/3}{1 - (1/3)(1/3)} = \tan^{-1} \frac{3}{4}$,

$$2 \tan^{-1} \frac{1}{3} + \tan^{-1} \frac{1}{7} = \tan^{-1} \frac{3}{4} + \tan^{-1} \frac{1}{7} = \tan^{-1} \frac{3/4 + 1/7}{1 - (3/4)(1/7)} = \tan^{-1} 1 = \pi/4.$$

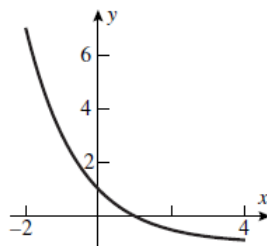
41. $\sin(\sec^{-1} x) = \sin(\cos^{-1}(1/x)) = \sqrt{1 - \left(\frac{1}{x}\right)^2} = \frac{\sqrt{x^2 - 1}}{|x|}$.

Exercise Set 1.8

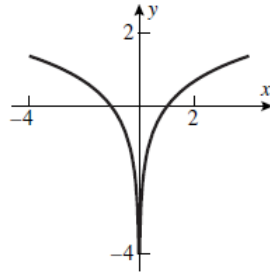
1. (a) -9 (b) 9 (c) $1/9$
2. (a) $1/16$ (b) 64 (c) $1/3$
3. (a) 5.6115 (b) 0.0341
4. (a) 1.5157 (b) 0.9381
5. (a) $\log_2 1/64 = \log_2 2^{-6} = -6$ (b) $\log_2 \left(\frac{1}{32}\right) = \log_2 2^{-5} = -5$
(c) $\log_4 4 = 1$ (d) $\log_9 3 = \log_9 9^{1/2} = 1/2$
6. (a) $\log_{10} 0.00001 = \log_{10} 10^{-5} = -5$ (b) $\log_{10} 10^4 = 4$
(c) $\ln e^3 = 3$ (d) $\ln \sqrt{e} = \ln e^{1/2} = 1/2$
7. (a) 1.4393 (b) -0.3011
8. (a) -0.9208 (b) 1.1447
9. (a) $3 \ln a + \frac{1}{2} \ln b + \frac{1}{2} \ln c = 3r + \frac{s}{2} + t/2.$
(b) $\ln b - 3 \ln a - \ln c = s - 3r - t.$
10. (a) $\frac{1}{3} \ln c - \ln a - 2 \ln b = \frac{t}{3} - r - 2s.$
(b) $\frac{1}{2} (\ln a + 3 \ln b - 2 \ln c) = r/2 + 3s/2 - t.$
11. (a) $1 + \log x + \frac{1}{2} \log(x + 3)$ (b) $2 \ln|x| + 3 \ln(\sin x) - \frac{1}{2} \ln(x^2 + 1)$
12. (a) $\frac{1}{3} \log|x + 2| - \log|\cos 7x|$ when $x < -2$ and $\cos 7x < 0$ or when $x > -2$ and $\cos 7x > 0.$
(b) $\frac{1}{2} \ln(x^2 + 1) - \frac{1}{2} \ln(x^3 + 5).$
13. $\log \frac{2^5(16)}{3} = \log(512/3).$
14. $\log \sqrt{x} - \log(\sin^3 3x) + \log 100 = \log \frac{100\sqrt{x}}{\sin^3 3x}.$
15. $\ln \frac{\sqrt[3]{x}(x+2)^2}{\cos x}.$
16. $1 + x = 10^2 = 100, x = 99.$

17. $\sqrt{x} = 10^{-2} = 0.01, x = 0.0001.$
18. $x^2 = e^6, x = \pm e^3.$
19. $\frac{1}{x} = e^{-3}, x = e^3.$
20. $x = 9.$
21. $2x = 10, x = 5.$
22. $\ln 4x - \ln x^6 = \ln 8, \ln \frac{4}{x^5} = \ln 8, \frac{4}{x^5} = 8, x^5 = \frac{1}{2}, x = 1/\sqrt[5]{2}.$
23. $\ln 2x^2 = \ln 4, 2x^2 = 4, x^2 = 2, x = \sqrt{2}$ (we discard $-\sqrt{2}$ because it does not satisfy the original equation).
24. $\ln 5^x = \ln 2, x \ln 5 = \ln 2, x = \frac{\ln 2}{\ln 5}.$
25. $\ln 5^{-2x} = \ln 6, -2x \ln 5 = \ln 6, x = -\frac{\ln 6}{2 \ln 5}.$
26. $e^{-2x} = 7/3, -2x = \ln(7/3), x = -\frac{1}{2} \ln(7/3).$
27. $e^{3x} = 5/2, 3x = \ln(5/2), x = \frac{1}{3} \ln(5/2).$
28. $e^x(1 - 4x) = 0$, so $e^x = 0$ impossible, or $1 - 4x = 0; x = 1/4.$
29. $e^{-x}(x + 3) = 0$, so $e^{-x} = 0$ impossible, or $x + 3 = 0; x = -3.$
30. With $u = e^{-x}$, the equation becomes $u^2 - 3u = -2$, so $(u - 1)(u - 2) = u^2 - 3u + 2 = 0$, and $u = 1$ or 2 . Hence $x = -\ln(u)$ gives $x = 0$ or $x = -\ln 2$.

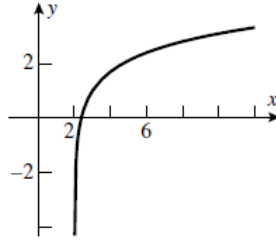
31. (a) Domain: all x ; range: $y > -1$.



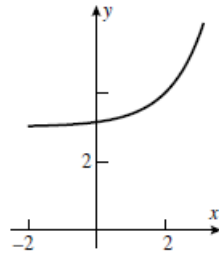
- (b) Domain: $x \neq 0$; range: all y .



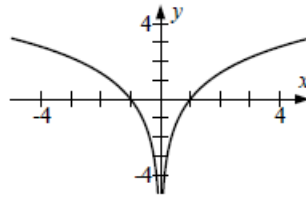
32. (a) Domain: $x > 2$; range: all y .



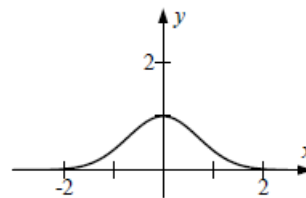
(b) Domain: all x ; range: $y > 3$.



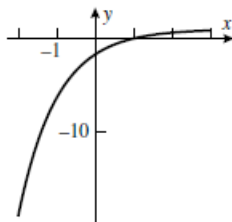
33. (a) Domain: $x \neq 0$; range: all y .



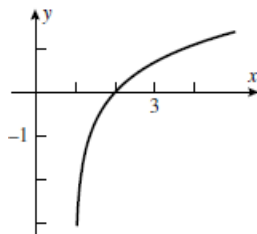
(b) Domain: all x ; range: $0 < y \leq 1$.



34. (a) Domain: all x ; range: $y < 1$.



(b) Domain: $x > 1$; range: all y .



35. False. The graph of an exponential function passes through $(0, 1)$, but the graph of $y = x^3$ does not.

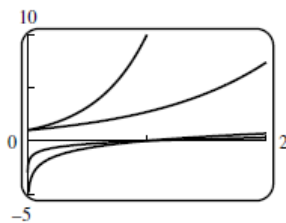
36. True. For any $b > 0$, $b^0 = 1$.

37. True, by definition.

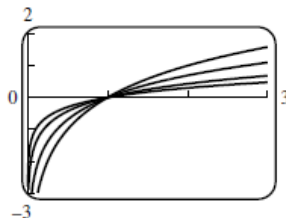
38. False. The domain is the interval $x > 0$.

39. $\log_2 7.35 = (\log 7.35)/(\log 2) = (\ln 7.35)/(\ln 2) \approx 2.8777$; $\log_5 0.6 = (\log 0.6)/(\log 5) = (\ln 0.6)/(\ln 5) \approx -0.3174$.

40.



41.



42.

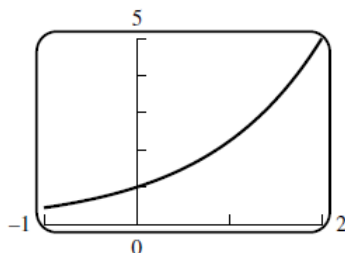
(a) Let $X = \log_b x$ and $Y = \log_a x$. Then $b^X = x$ and $a^Y = x$ so $a^Y = b^X$, or $a^{Y/X} = b$, which means $\log_a b = Y/X$. Substituting for Y and X yields $\frac{\log_a x}{\log_b x} = \log_a b$, $\log_b x = \frac{\log_a x}{\log_a b}$.

(b) Let $x = a$ to get $\log_b a = (\log_a a) / (\log_a b) = 1 / (\log_a b)$ so $(\log_a b)(\log_b a) = 1$. Now $(\log_2 81)(\log_3 64) = (\log_2 [3^4])(\log_3 [2^6]) = (4 \log_2 3)(6 \log_3 2) = 24 (\log_2 3)(\log_3 2) = 24$.

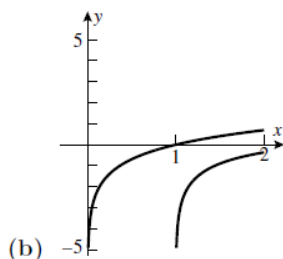
43. $x \approx 1.47099$ and $x \approx 7.85707$.

44. $x \approx \pm 0.836382$

45. (a) No, the curve passes through the origin. (b) $y = (\sqrt[4]{2})^x$ (c) $y = 2^{-x} = (1/2)^x$ (d) $y = (\sqrt{5})^x$



46. (a) As $x \rightarrow +\infty$ the function grows very slowly, but it is always increasing and tends to $+\infty$. As $x \rightarrow 1^+$ the function tends to $-\infty$.



47. $\log(1/2) < 0$ so $3 \log(1/2) < 2 \log(1/2)$.

48. Let $x = \log_b a$ and $y = \log_b c$, so $a = b^x$ and $c = b^y$.

First, $ac = b^x b^y = b^{x+y}$ or equivalently, $\log_b(ac) = x + y = \log_b a + \log_b c$.

Second, $a/c = b^x / b^y = b^{x-y}$ or equivalently, $\log_b(a/c) = x - y = \log_b a - \log_b c$.

Next, $a^r = (b^x)^r = b^{rx}$ or equivalently, $\log_b a^r = rx = r \log_b a$.

Finally, $1/c = 1/b^y = b^{-y}$ or equivalently, $\log_b(1/c) = -y = -\log_b c$.

49. $\lim_{x \rightarrow -\infty} \frac{1 - e^x}{1 + e^x} = \frac{1 - 0}{1 + 0} = 1$.

50. Divide the numerator and denominator by e^x : $\lim_{x \rightarrow +\infty} \frac{1 - e^x}{1 + e^x} = \lim_{x \rightarrow +\infty} \frac{e^{-x} - 1}{e^{-x} + 1} = \frac{0 - 1}{0 + 1} = -1$.

51. Divide the numerator and denominator by e^x : $\lim_{x \rightarrow +\infty} \frac{1 + e^{-2x}}{1 - e^{-2x}} = \frac{1 + 0}{1 - 0} = 1$.

52. Divide the numerator and denominator by e^{-x} : $\lim_{x \rightarrow -\infty} \frac{e^{2x} + 1}{e^{2x} - 1} = \frac{0 + 1}{0 - 1} = -1$.

53. The limit is $-\infty$.

54. The limit is $+\infty$.

55. $\frac{x+1}{x} = 1 + \frac{1}{x}$, so $\lim_{x \rightarrow +\infty} \frac{(x+1)^x}{x^x} = e$ from Figure 1.3.4.

56. $\left(1 + \frac{1}{x}\right)^{-x} = \frac{1}{\left(1 + \frac{1}{x}\right)^x}$, so the limit is e^{-1} .

57. $t = 1/x$, $\lim_{t \rightarrow +\infty} f(t) = +\infty$.

58. $t = 1/x$, $\lim_{t \rightarrow -\infty} f(t) = 0$.

59. $t = \csc x$, $\lim_{t \rightarrow +\infty} f(t) = +\infty$.

60. $t = \csc x$, $\lim_{t \rightarrow -\infty} f(t) = 0$.

61. Let $t = \ln x$. Then t also tends to $+\infty$, and $\frac{\ln 3x}{\ln 4x} = \frac{t + \ln 3}{t + \ln 4}$, so the limit is 1.

62. With $t = x - 1$, $[\ln(x^2 - 1) - \ln(x + 1)] = \ln(x + 1) + \ln(x - 1) - \ln(x + 1) = \ln t$, so the limit is $+\infty$.

63. Set $t = -x$, then get $\lim_{t \rightarrow -\infty} \left(1 + \frac{1}{t}\right)^t = e$ by Figure 1.3.4.

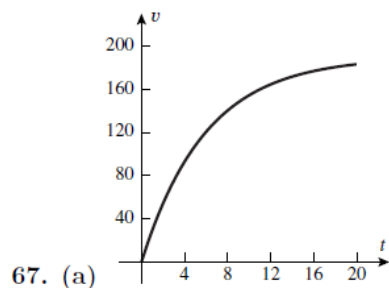
64. With $t = x/3$, $\lim_{x \rightarrow +\infty} \left(1 + \frac{3}{x}\right)^x = \left(\lim_{t \rightarrow +\infty} [1 + 1/t]^t\right)^3 = e^3$.

65. From the hint, $\lim_{x \rightarrow +\infty} b^x = \lim_{x \rightarrow +\infty} e^{(\ln b)x} = \begin{cases} 0 & \text{if } b < 1, \\ 1 & \text{if } b = 1, \\ +\infty & \text{if } b > 1. \end{cases}$

66. It suffices by Theorem 1.1.3 to show that the left and right limits at zero are equal to e .

(a) $\lim_{x \rightarrow +\infty} (1+x)^{1/x} = \lim_{t \rightarrow 0^+} (1+1/t)^t = e$.

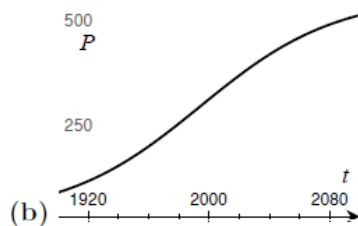
(b) $\lim_{x \rightarrow -\infty} (1+x)^{1/x} = \lim_{t \rightarrow 0^-} (1+1/t)^t = e$.



(b) $\lim_{t \rightarrow \infty} v = 190 \left(1 - \lim_{t \rightarrow \infty} e^{-0.168t}\right) = 190$, so the asymptote is $v = c = 190$ ft/sec.

(c) Due to air resistance (and other factors) this is the maximum speed that a sky diver can attain.

68. (a) $p(1990) = 525/(1 + 1.1) = 250$ (million).



(c) $\lim_{t \rightarrow \infty} p(t) = \frac{525}{1 + 1.1 \lim_{t \rightarrow \infty} e^{-0.02225(t-1990)}} = 525$ (million).

(d) The population becomes stable at this number.

69. (a)

| | | | | | | |
|--------------------------|--------|--------|--------|---------|----------|-----------|
| n | 2 | 3 | 4 | 5 | 6 | 7 |
| $1 + 10^{-n}$ | 1.01 | 1.001 | 1.0001 | 1.00001 | 1.000001 | 1.0000001 |
| $1 + 10^n$ | 101 | 1001 | 10001 | 100001 | 1000001 | 10000001 |
| $(1 + 10^{-n})^{1+10^n}$ | 2.7319 | 2.7196 | 2.7184 | 2.7183 | 2.71828 | 2.718282 |

The limit appears to be e .

(b) This is evident from the lower left term in the chart in part (a).

(c) The exponents are being multiplied by a , so the result is e^a .

70. (a) $f(-x) = \left(1 - \frac{1}{x}\right)^{-x} = \left(\frac{x-1}{x}\right)^{-x} = \left(\frac{x}{x-1}\right)^x$, $f(x-1) = \left(\frac{x}{x-1}\right)^{x-1} = \left(\frac{x-1}{x}\right) f(-x)$.

(b) $\lim_{x \rightarrow -\infty} \left(1 + \frac{1}{x}\right)^x = \lim_{x \rightarrow +\infty} f(-x) = \left[\lim_{x \rightarrow +\infty} \frac{x}{x-1} \right] \lim_{x \rightarrow +\infty} f(x-1) = \lim_{x \rightarrow +\infty} f(x-1) = e$.

71. $75e^{-t/125} = 12$, $t = -125 \ln(12/75) = 125 \ln(25/4) \approx 229$ days.

72. (a) If $t = 0$, then $Q = 12$ grams.

(b) $Q = 12e^{-0.055(4)} = 12e^{-0.22} \approx 9.63$ grams.

(c) $12e^{-0.055t} = 6$, $e^{-0.055t} = 0.5$, $t = -(\ln 0.5)/(0.055) \approx 12.6$ hours.

73. (a) 7.4; basic (b) 4.2; acidic (c) 6.4; acidic (d) 5.9; acidic

74. (a) $\log[H^+] = -2.44$, $[H^+] = 10^{-2.44} \approx 3.6 \times 10^{-3}$ mol/L

(b) $\log[H^+] = -8.06$, $[H^+] = 10^{-8.06} \approx 8.7 \times 10^{-9}$ mol/L

75. (a) 140 dB; damage (b) 100 dB; damage (c) 80 dB; no damage (d) 75 dB; no damage

76. Suppose that $I_1 = 4I_2$ and $\beta_1 = 10\log_{10} I_1/I_0$, $\beta_2 = 10\log_{10} I_2/I_0$. Then $I_1/I_0 = 4I_2/I_0$, $\log_{10} I_1/I_0 = \log_{10} 4I_2/I_0 = \log_{10} 4 + \log_{10} I_2/I_0$, $\beta_1 = 10\log_{10} 4 + \beta_2$, $\beta_1 - \beta_2 = 10\log_{10} 4 \approx 6.02$ dB.

77. Let I_A and I_B be the intensities of the automobile and blender, respectively. Then $\log_{10}(I_A/I_0) = 7$ and $\log_{10}(I_B/I_0) = 9.7$ and $I_A = 10^7 I_0$ and $I_B = 10^{9.7} I_0$, so $I_B/I_A \approx 500$.

78. First we solve $120 = 10\log(I/I_0)$ to find the intensity of the original sound:

$I = 10^{120/10} I_0 = 10^{12} \cdot 10^{-12} = 1 \text{ W/m}^2$. Hence the intensity of the n 'th echo is $(3/4)^n \text{ W/m}^2$ and its decibel level is $10\log\left[\frac{(3/4)^n}{10^{-12}}\right] = 10[n\log(3/4) + 12]$. Setting this equal to 10 gives $n = -\frac{11}{\log(3/4)} \approx 88$. So the first 88 echos can be heard.

79. (a) $\log E = 4.4 + 1.5(7.8) = 16.1$, $E = 10^{16.1} \approx 1.26 \times 10^{16} \text{ J}$.

(b) Let M_1 and M_2 be the magnitudes of earthquakes with energies of E and $10E$, respectively. Then $1.5(M_2 - M_1) = \log(10E) - \log E = \log 10 = 1$, $M_2 - M_1 = 1/1.5 = 2/3 \approx 0.67$.

80. Let E_1 and E_2 be the energies of earthquakes with magnitudes M and $M + 1$, respectively. Then $\log E_2 - \log E_1 = \log(E_2/E_1) = 1.5$, $E_2/E_1 = 10^{1.5} \approx 31.6$.

Chapter 1 Review Exercises

1. (a) 1 (b) Does not exist. (c) Does not exist. (d) 1 (e) 3 (f) 0 (g) 0
(h) 2 (i) 1/2

2. (a)

| | | | | | | |
|--------|----------|----------|----------|----------|----------|----------|
| x | 3.00001 | 3.0001 | 3.001 | 3.01 | 3.1 | 3.5 |
| $f(x)$ | 0.166666 | 0.166664 | 0.166639 | 0.166389 | 0.163934 | 0.153846 |

For $x \neq 3$, $f(x) = \frac{1}{x+3}$, so the limit is $1/6$.

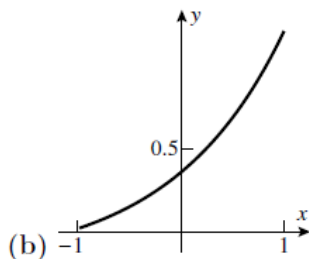
(b)

| | | | | | | |
|--------|-----------|-----------|-----------|-----------|-----------|-----------|
| x | -0.01 | -0.001 | -0.0001 | 0.0001 | 0.001 | 0.01 |
| $f(x)$ | 4.0021347 | 4.0000213 | 4.0000002 | 4.0000002 | 4.0000213 | 4.0021347 |

Use $\frac{\tan 4x}{x} = \frac{\sin 4x}{x \cos 4x} = \frac{4}{\cos 4x} \cdot \frac{\sin 4x}{4x}$; the limit is 4.

3. (a)

| | | | | | | |
|--------|-------|--------|---------|--------|-------|-------|
| x | -0.01 | -0.001 | -0.0001 | 0.0001 | 0.001 | 0.01 |
| $f(x)$ | 0.402 | 0.405 | 0.405 | 0.406 | 0.406 | 0.409 |



4.

| | | | | | | |
|--------|-------|-------|-------|-------|-------|-------|
| x | 2.9 | 2.99 | 2.999 | 3.001 | 3.01 | 3.1 |
| $f(x)$ | 5.357 | 5.526 | 5.543 | 5.547 | 5.564 | 5.742 |

5. The limit is $\lim_{x \rightarrow -1} \frac{(-1)^3 - (-1)^2}{-1 - 2} = \frac{2}{3}$.

6. By Theorem 1.2.4, this limit is $(3^2 - 2 \cdot 3)/(3 + 1) = 3/4$.

7. If $x \neq -3$, then $\frac{4x+12}{x^2+4x+3} = \frac{4}{x+1}$ with limit -2.

8. The limit is $-\infty$.

9. By the highest degree terms, the limit is $\frac{2^5}{3} = \frac{32}{3}$.

10. After simplification, $\frac{\sqrt{x^2+4}-2}{x} = \frac{x}{\sqrt{x^2+4}+2}$, and the limit is 0.

11. (a) $y = 0$. (b) None. (c) $y = 2$.

12. (a) $\sqrt{5}$, no limit, $\sqrt{10}$, $\sqrt{10}$, no limit, $+\infty$, no limit.

(b) -1, +1, -1, -1, no limit, -1, +1

13. If $x \neq 0$, then $\frac{\sin 5x}{\tan 5x} = \cos 5x$, and the limit is 1.

14. If $x \neq 0$, then $\frac{2x \sin x}{1 - \cos x} \cdot \frac{1 + \cos x}{1 + \cos x} = \frac{2x}{\sin x} (1 + \cos x)$, so the limit is 4.

15. $\lim_{x \rightarrow 0} \frac{\sin^2(kx)}{x} = \lim_{x \rightarrow 0} k^2 x \left(\frac{\sin(kx)}{kx} \right)^2 = 0$.

16. $\lim_{x \rightarrow 0} \frac{\tan ax}{\sin bx} = \lim_{x \rightarrow 0} \frac{a \sin ax}{b} \frac{1}{ax} \frac{bx}{\cos ax \sin bx} = a/b.$

17. As $t \rightarrow \pi/2^+$, $\tan t \rightarrow -\infty$, so the limit in question is 0.

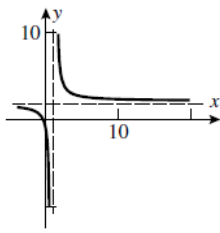
18. $\ln(2 \sin \theta \cos \theta) - \ln \tan \theta = \ln 2 + 2 \ln \cos \theta$, so the limit is $\ln 2$.

19. $\left(1 + \frac{4}{x}\right)^{-x} = \left[\left(1 + \frac{4}{x}\right)^{x/4}\right]^{-4}$, so the limit is e^{-4} .

20. $\left(1 + \frac{a}{x}\right)^{bx} = \left[\left(1 + \frac{a}{x}\right)^{x/a}\right]^{(ab)}$, so the limit is e^{ab} .

21. For $n = 4$: \$2435.19; for $n = 12$: \$2451.36; for $n = 365$: \$2459.33; for $n \rightarrow +\infty$: \$2459.60.

23. (a) $f(x) = 2x/(x-1)$.



(b)

24. Given any window of height 2ϵ centered at the point $x = a, y = L$ there exists a width 2δ such that the window of width 2δ and height 2ϵ contains all points of the graph of the function for x in that interval.

25. (a) $\lim_{x \rightarrow 2} f(x) = 5.$

(b) $\delta = (2/3) \cdot (0.048/8) = 0.004.$

26. $\delta \approx 0.07747$ (use a graphing utility).

27.

(a) $|4x - 7 - 1| < 0.01$ means $4|x - 2| < 0.01$, or $|x - 2| < 0.0025$, so $\delta = 0.0025$.

(b) $\left|\frac{4x^2 - 9}{2x - 3} - 6\right| < 0.03$ means $|2x + 3 - 6| < 0.03$, or $|x - 1.5| < 0.015$, so $\delta = 0.015$.

(c) $|x^2 - 16| < 0.001$; if $\delta < 1$ then $|x + 4| < 9$ if $|x - 4| < 1$; then $|x^2 - 16| = |x - 4||x + 4| \leq 9|x - 4| < 0.001$ provided $|x - 4| < 0.001/9 = 1/9000$, take $\delta = 1/9000$, then $|x^2 - 16| < 9|x - 4| < 9(1/9000) = 1/1000 = 0.001$.

28. (a) Given $\varepsilon > 0$ then $|4x - 11 - 1| < \varepsilon$ provided $|x - 3| < \varepsilon/4$, take $\delta = \varepsilon/4$.

(b) Given $\varepsilon > 0$ the inequality $\left| \frac{4x^2 - 9}{2x - 3} - 6 \right| < \varepsilon$ holds if $|2x + 3 - 6| < \varepsilon$, or $|x - 1.5| < \varepsilon/2$, take $\delta = \varepsilon/2$.

29. Let $\varepsilon = f(x_0)/2 > 0$; then there corresponds a $\delta > 0$ such that if $|x - x_0| < \delta$ then $|f(x) - f(x_0)| < \varepsilon$, $-\varepsilon < f(x) - f(x_0) < \varepsilon$, $f(x) > f(x_0) - \varepsilon = f(x_0)/2 > 0$, for $x_0 - \delta < x < x_0 + \delta$.

30. (a)

| | | | | | | |
|--------|------|------|-------|--------|---------|----------|
| x | 1.1 | 1.01 | 1.001 | 1.0001 | 1.00001 | 1.000001 |
| $f(x)$ | 0.49 | 0.54 | 0.540 | 0.5403 | 0.54030 | 0.54030 |

(b) $\cos 1$

31. (a) f is not defined at $x = \pm 5$, continuous elsewhere.

(b) None; continuous everywhere.

(c) f is not defined at $x = 0$ and $x = -3$, continuous elsewhere.

32. (a) Continuous everywhere except $x = \pm 5$.

(b) Defined and continuous for $x \leq -1$, $x \geq 1$.

(c) Defined and continuous for $x > 0$.

33. For $x < 2$ f is a polynomial and is continuous; for $x > 2$ f is a polynomial and is continuous. At $x = 2$, $f(2) = -13 \neq 13 = \lim_{x \rightarrow 2^+} f(x)$, so f is not continuous there.

35. $f(x) = -1$ for $a \leq x < \frac{a+b}{2}$ and $f(x) = 1$ for $\frac{a+b}{2} \leq x \leq b$; f does not take the value 0.

36. If, on the contrary, $f(x_0) < 0$ for some x_0 in $[0, 1]$, then by the Intermediate Value Theorem we would have a solution of $f(x) = 0$ in $[0, x_0]$, contrary to the hypothesis.

37. $f(-6) = 185$, $f(0) = -1$, $f(2) = 65$; apply Theorem 1.5.8 twice, once on $[-6, 0]$ and once on $[0, 2]$.

38. (a) $x = f(y) = (e^y)^3 + 1$; $f^{-1}(x) = y = \ln \sqrt[3]{x-1} = \frac{1}{3} \ln(x-1)$

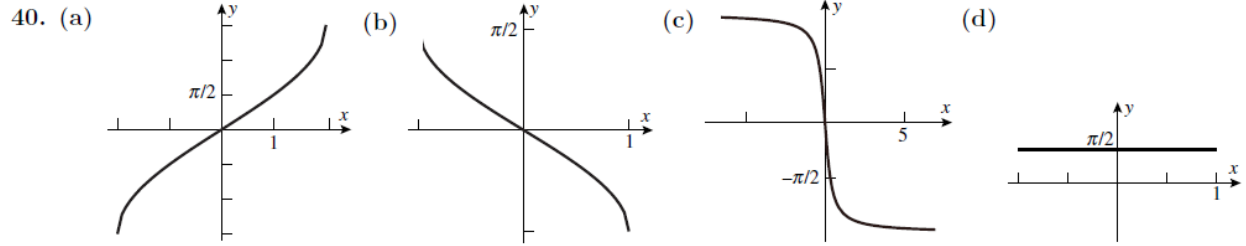
(b) $x = f(y) = \sin\left(\frac{1-2y}{y}\right)$; $f^{-1}(x) = y = \frac{1}{2 + \sin^{-1} x}$.

(c) $x = \frac{1}{1 + 3 \tan^{-1} y}$; $y = \tan\left(\frac{1-x}{3x}\right)$. The range of f consists of all $x < \frac{-2}{3\pi - 2}$ or $x > \frac{2}{3\pi + 2}$, so this is also the domain of f^{-1} . Hence $f^{-1}(x) = \tan\left(\frac{1-x}{3x}\right)$, $x < \frac{-2}{3\pi - 2}$ or $x > \frac{2}{3\pi + 2}$.

39. Draw right triangles of sides 5, 12, 13, and 3, 4, 5. Then $\sin[\cos^{-1}(4/5)] = 3/5$, $\sin[\cos^{-1}(5/13)] = 12/13$, $\cos[\sin^{-1}(4/5)] = 3/5$, and $\cos[\sin^{-1}(5/13)] = 12/13$.

(a) $\cos[\cos^{-1}(4/5) + \sin^{-1}(5/13)] = \cos(\cos^{-1}(4/5))\cos(\sin^{-1}(5/13)) - \sin(\cos^{-1}(4/5))\sin(\sin^{-1}(5/13)) = \frac{4}{5} \frac{12}{13} - \frac{3}{5} \frac{5}{13} = \frac{33}{65}$.

(b) $\sin[\sin^{-1}(4/5) + \cos^{-1}(5/13)] = \sin(\sin^{-1}(4/5))\cos(\cos^{-1}(5/13)) + \cos(\sin^{-1}(4/5))\sin(\cos^{-1}(5/13)) = \frac{4}{5} \frac{5}{13} + \frac{3}{5} \frac{12}{13} = \frac{56}{65}$.

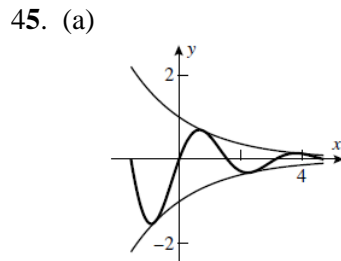


41. $y = 5 \text{ ft} = 60 \text{ in}$, so $60 = \log x$, $x = 10^{60} \text{ in} \approx 1.58 \times 10^{55} \text{ mi}$.

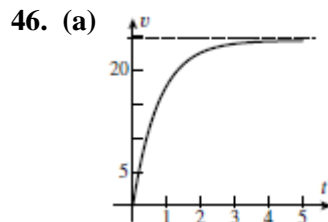
42. $y = 100 \text{ mi} = 12 \times 5280 \times 100 \text{ in}$, so $x = \log y = \log 12 + \log 5280 + \log 100 \approx 6.8018 \text{ in}$.

43. $3 \ln(e^{2x}(e^x)^3) + 2 \exp(\ln 1) = 3 \ln e^{2x} + 3 \ln(e^x)^3 + 2 \cdot 1 = 3(2x) + (3 \cdot 3)x + 2 = 15x + 2$.

44. $Y = \ln(Ce^{kt}) = \ln C + \ln e^{kt} = \ln C + kt$, a line with slope k and Y -intercept $\ln C$.

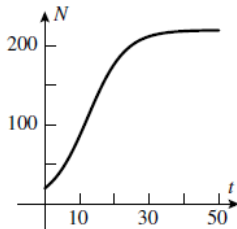


(b) The curve $y = e^{-x/2} \sin 2x$ has x -intercepts at $x = -\pi/2, 0, \pi/2, \pi, 3\pi/2$. It intersects the curve $y = e^{-x/2}$ at $x = \pi/4, 5\pi/4$ and it intersects the curve $y = -e^{-x/2}$ at $x = -\pi/4, 3\pi/4$.



- (b) As t gets larger, the velocity v grows towards 24.61 ft/s.
- (c) For large t the velocity approaches $c = 24.61$.
- (d) No; but it comes very close (arbitrarily close).
- (e) $0.96 = 1 - e^{-1.3t}$, $t = 2.476$ s.

47. (a)



- (b) $N = 80$ when $t = 9.35$ yrs.
- (c) 220 sheep.

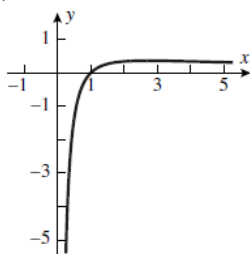
48. (a) The potato is done in the interval $27.65 < t < 32.71$.

(b) The oven temperature is always 400° F, so the difference between the oven temperature and the potato temperature is $D = 400 - T$. Initially $D = 325$, so solve $D = 75 + 325/2 = 237.5$ for t , so $t \approx 22.76$ min.

49. (a) The function $\ln x - x^{0.2}$ is negative at $x = 1$ and positive at $x = 4$, so by the intermediate value theorem it is zero somewhere in between.

- (b) $x = 3.654$ and 332105.108 .

50. (a)

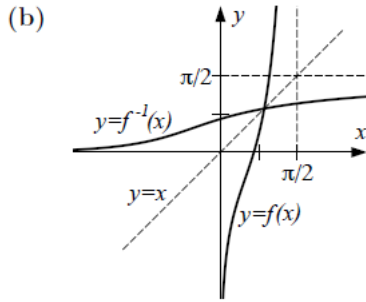


If $x^k = e^x$ then $k \ln x = x$, or $\frac{\ln x}{x} = \frac{1}{k}$. The steps are reversible.

(b) By zooming it is seen that the maximum value of y is approximately 0.368 (actually, $1/e$), so there are two distinct solutions of $x^k = e^x$ whenever $k > e$.

- (c) $x \approx 1.155, 26.093$.

51. (a) The functions x^2 and $\tan x$ are positive and increasing on the indicated interval, so their product $x^2 \tan x$ is also increasing there. So is $\ln x$; hence the sum $f(x) = x^2 \tan x + \ln x$ is increasing, and it has an inverse.



The asymptotes for $f(x)$ are $x = 0, x = \pi/2$. The asymptotes for $f^{-1}(x)$ are $y = 0, y = \pi/2$.

Chapter 1 Making Connections

- Let $P(x, x^2)$ be an arbitrary point on the curve, let $Q(-x, x^2)$ be its reflection through the y -axis, let $O(0, 0)$ be the origin. The perpendicular bisector of the line which connects P with O meets the y -axis at a point $C(0, \lambda(x))$, whose ordinate is as yet unknown. A segment of the bisector is also the altitude of the triangle $\triangle OPC$ which is isosceles, so that $CP = CO$.

Using the symmetrically opposing point Q in the second quadrant, we see that $\overline{OP} = \overline{OQ}$ too, and thus C is equidistant from the three points O, P, Q and is thus the center of the unique circle that passes through the three points.

- Let R be the midpoint of the line segment connecting P and O , so that $R(x/2, x^2/2)$. We start with the Pythagorean Theorem $\overline{OC}^2 = \overline{OR}^2 + \overline{CR}^2$, or $\lambda^2 = (x/2)^2 + (x^2/2)^2 + (x/2)^2 + (\lambda - x^2/2)^2$. Solving for λ we obtain $\lambda x^2 = (x^2 + x^4)/2, \lambda = 1/2 + x^2/2$.
- Replace the parabola with the general curve $y = f(x)$ which passes through $P(x, f(x))$ and $S(0, f(0))$. Let the perpendicular bisector of the line through S and P meet the y -axis at $C(0, \lambda)$, and let $R(x/2, (f(x) - \lambda)/2)$ be the midpoint of P and S . By the Pythagorean Theorem, $\overline{CS}^2 = \overline{RS}^2 + \overline{CR}^2$, or $(\lambda - f(0))^2 = x^2/4 + \left[\frac{f(x) + f(0)}{2} - f(0) \right]^2 + x^2/4 + \left[\frac{f(x) + f(0)}{2} - \lambda \right]^2$, which yields $\lambda = \frac{1}{2} \left[f(0) + f(x) + \frac{x^2}{f(x) - f(0)} \right]$.

4. (a) $f(0) = 0, C(x) = \frac{1}{8} + 2x^2, x^2 + (y - \frac{1}{8})^2 = (\frac{1}{8})^2$.

(b) $f(0) = 0, C(x) = \frac{1}{2}(\sec x + x^2), x^2 + (y - \frac{1}{2})^2 = (\frac{1}{2})^2$.

(c) $f(0) = 0, C(x) = \frac{1}{2} \frac{x^2 + |x|^2}{|x|}, x^2 + y^2 = 0$ (not a circle).

(d) $f(0) = 0, C(x) = \frac{1}{2} \frac{x(1 + \sin^2 x)}{\sin x}, x^2 + (y - \frac{1}{2})^2 = (\frac{1}{2})^2$.

(e) $f(0) = 1, C(x) = \frac{1}{2} \frac{x^2 - \sin^2 x}{\cos x - 1}, x^2 + y^2 = 1$.

(f) $f(0) = 0, C(x) = \frac{1}{2g(x)} + \frac{x^2 g(x)}{2}, x^2 + (y - \frac{1}{2g(0)})^2 = (\frac{1}{2g(0)})^2$.

(g) $f(0) = 0, C(x) = \frac{1}{2} \frac{1+x^6}{x^2}$, limit does not exist, osculating circle does not exist.