Calculus An Applied Approach 10th edition Larson Solutions Manual

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C H A P T E R 2
Differentiation

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CHAPTER 2
Differentiation

Section 2.1 The Derivative and the Slope of a Graph

Skills Warm Up

1. $P(3, 1)$, $Q(3, 6)$

$m = \dfrac{6-1}{3-3}$; m is undefined.

$x = 3$

2. $P(2, 2)$, $Q = (-5, 2)$

$m = \dfrac{2-2}{-5-2} = 0$

$y - 2 = 0(x - 2)$

$y = 2$

3. $P(1, 5)$, $Q(4, -1)$

$m = \dfrac{-1-5}{4-1} = \dfrac{-6}{3} = -2$

$y - 5 = -2(x - 1)$

$y - 5 = -2x + 2$

$y = -2x + 7$

4. $P(3, 5)$, $Q(-1, -7)$

$m = \dfrac{-7-5}{-1-3} = \dfrac{-12}{-4} = 3$

$y - 5 = 3(x - 3)$

$y = 3x - 4$

5. $\displaystyle\lim_{\Delta x \to 0} \frac{2x\Delta x + (\Delta x)^2}{\Delta x} = \lim_{\Delta x \to 0} \frac{\Delta x(2x + \Delta x)}{\Delta x}$

$\displaystyle = \lim_{\Delta x \to 0} 2x + \Delta x$

$= 2x$

6. $\displaystyle\lim_{\Delta x \to 0} \frac{3x^2\Delta x + 3x(\Delta x)^2 + (\Delta x)^3}{\Delta x}$

$\displaystyle = \lim_{\Delta x \to 0} \frac{\Delta x\left[3x^2 + 3x\Delta x + (\Delta x)^2\right]}{\Delta x}$

$\displaystyle = \lim_{\Delta x \to 0} 3x^2 + 3x\Delta x + (\Delta x)^2$

$= 3x^2$

7. $\displaystyle\lim_{\Delta x \to 0} \frac{1}{x(x + \Delta x)} = \frac{1}{x^2}$

8. $\displaystyle\lim_{\Delta x \to 0} \frac{(x + \Delta x)^2 - x^2}{\Delta x}$

$\displaystyle = \lim_{\Delta x \to 0} \frac{x^2 + 2x\Delta x + (\Delta x)^2 - x^2}{\Delta x}$

$\displaystyle = \lim_{\Delta x \to 0} \frac{2x\Delta x + (\Delta x)^2}{\Delta x}$

$\displaystyle = \lim_{\Delta x \to 0} \frac{\Delta x(2x + \Delta x)}{\Delta x}$

$= 2x$

9. $f(x) = 3x$

Domain: $(-\infty, \infty)$

10. $f(x) = \dfrac{1}{x-1}$

Domain: $(-\infty, 1) \cup (1, \infty)$

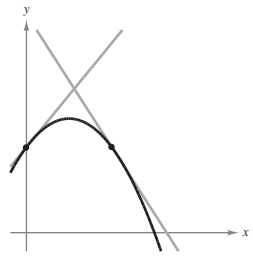
11. $f(x) = \frac{1}{5}x^3 - 2x^2 + \frac{1}{3}x - 1$

Domain: $(-\infty, \infty)$

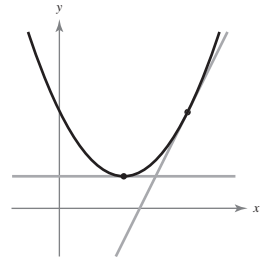
12. $f(x) = \dfrac{6x}{x^3 + x}$

Domain: $(-\infty, 0) \cup (0, \infty)$

1.



2.



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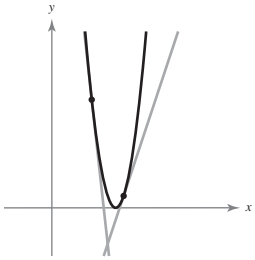
3.



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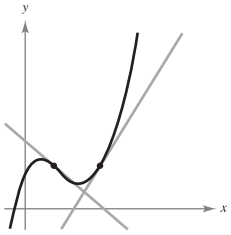

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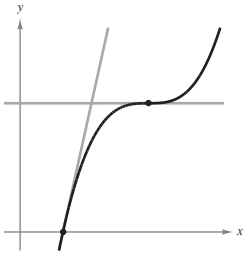
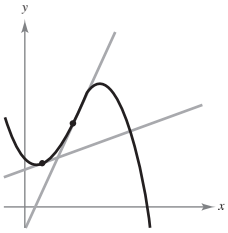


6.



7. The slope is $m = 1$.

8. The slope is $m = \frac{4}{3}$.

9. The slope is $m = 0$.

10. The slope is $m = \frac{1}{4}$.

11. The slope is $m = -\frac{1}{3}$.

12. The slope is $m = -3$.

13. 2009: $m \approx 118$

2011: $m \approx 375$

The slope is the rate of change in millions of dollars per year of revenue for the years 2009 and 2011 for Under Armour.

14. 2010: $m \approx 500$

2012: $m \approx 500$

The slope is the rate of change in millions of dollars per year of sales for the years 2010 and 2012 for Fossil.

15. $t = 3: m \approx 8$

$t = 7: m \approx 1$

$t = 10: m \approx -10$

The slope is the rate of change of the average temperature in degrees Fahrenheit per month in Bland, Virginia, for March, July, and October.

16. (a) At t_1, $f'(t_1) > g'(t_1)$, so the runner given by f is running faster.

(b) At t_2, $g'(t_2) > f'(t_2)$, so the runner given by g is running faster. The runner given by f has traveled farther.

(c) At t_3, the runners are at the same location, but the runner given by g is running faster.

(d) The runner given by g will finish first because that runner finishes the distance at a lesser value of t.

17. $f(x) = -1$ at $(0, -1)$

$$\begin{aligned} m_{\text{sec}} &= \frac{f(0 + \Delta x) - f(0)}{\Delta x} \\ &= \frac{-1 - (-1)}{\Delta x} \\ &= \frac{0}{\Delta x} \\ &= 0 \end{aligned}$$

$$m = \lim_{\Delta x \to 0} m_{\text{sec}} = \lim_{\Delta x \to 0} 0 = 0$$

18. $f(x) = 6$ at $(-2, 6)$

$$\begin{aligned} m_{\text{sec}} &= \frac{f(-2 + \Delta x) - f(-2)}{\Delta x} \\ &= \frac{6 - 6}{\Delta x} \\ &= \frac{0}{\Delta x} \\ &= 0 \end{aligned}$$

$$m = \lim_{\Delta x \to 0} m_{\text{sec}} = \lim_{\Delta x \to 0} 0 = 0$$

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19. $f(x) = 13 - 4x$ at $(3, 1)$

$$m_{\text{sec}} = \frac{f(3 + \Delta x) - f(3)}{\Delta x}$$
$$= \frac{\left[13 - 4(3 + \Delta x)\right] - 1}{\Delta x}$$
$$= \frac{13 - 12 - 4\Delta x - 1}{\Delta x}$$
$$= \frac{-4\Delta x}{\Delta x}$$
$$= -4$$
$$m = \lim_{\Delta x \to 0} m_{\text{sec}} = \lim_{\Delta x \to 0} (-4) = -4$$

20. $f(x) = 6x + 3$ at $(1, 9)$

$$m_{\text{sec}} = \frac{f(1 + \Delta x) - f(1)}{\Delta x}$$
$$= \frac{\left[6(1 + \Delta x) + 3\right] - 9}{\Delta x}$$
$$= \frac{6 + 6\Delta x + 3 - 9}{\Delta x}$$
$$= \frac{6\Delta x}{\Delta x}$$
$$= 6$$
$$m = \lim_{\Delta x \to 0} m_{\text{sec}} = \lim_{\Delta x \to 0} 6 = 6$$

21. $f(x) = 2x^2 - 3$ at $(2, 5)$

$$m_{\text{sec}} = \frac{f(2 + \Delta x) - f(2)}{\Delta x}$$
$$= \frac{\left[2(2 + \Delta x)^2 - 3\right] - 5}{\Delta x}$$
$$= \frac{\left[2\left(4 + 4\Delta x + (\Delta x)^2\right) - 3\right] - 5}{\Delta x}$$
$$= \frac{\left[8 + 8\Delta x + 2(\Delta x)^2 - 3\right] - 5}{\Delta x}$$
$$= \frac{2\Delta x(4 + \Delta x)}{\Delta x}$$
$$= 2(4 + \Delta x)$$
$$m = \lim_{\Delta x \to 0} m_{\text{sec}} = \lim_{\Delta x \to 0} \left(2(4 + \Delta x)\right) = 8$$

22. $f(x) = 11 - x^2$ at $(3, 2)$

$$m_{\text{sec}} = \frac{f(3 + \Delta x) - f(3)}{\Delta x}$$
$$= \frac{11 - (3 + \Delta x)^2 - \left[11 - (3)^2\right]}{\Delta x}$$
$$= \frac{11 - \left(9 + 6\Delta x + \Delta x^2\right) - 2}{\Delta x}$$
$$= \frac{11 - 9 - 6\Delta x + (\Delta x)^2 - 2}{\Delta x}$$
$$= \frac{-6\Delta x - (\Delta x)^2}{\Delta x}$$
$$= \frac{\Delta x(-6 - \Delta x)}{\Delta x}$$
$$= -6 - \Delta x$$
$$m = \lim_{\Delta x \to 0} m_{\text{sec}} = \lim_{\Delta x \to 0} (-6 - \Delta x) = -6$$

23. $f(x) = x^3 - 4x$ at $(-1, 3)$

$$m_{\text{sec}} = \frac{f(-1 + \Delta x) - f(-1)}{\Delta x}$$
$$= \frac{(-1 + \Delta x)^3 - 4(-1 + \Delta x) - \left[(-1)^3 - 4(-1)\right]}{\Delta x}$$
$$= \frac{-1 + 3\Delta x - 3(\Delta x)^2 + (\Delta x)^3 + 4 - 4\Delta x - 3}{\Delta x}$$
$$= \frac{-\Delta x - 3(\Delta x)^2 + (\Delta x)^3}{\Delta x}$$
$$= \frac{\Delta x\left(-1 - 3\Delta x + (\Delta x)^2\right)}{\Delta x}$$
$$= -1 - 3\Delta x + (\Delta x)^2$$
$$m = \lim_{\Delta x \to 0} m_{\text{sec}} = \lim_{\Delta x \to 0} \left(-1 - 3\Delta x + (\Delta x)^2\right) = -1$$

24. $f(x) = 7x - x^3$ at $(-3, 6)$

$$m_{\text{sec}} = \frac{f(-3 + \Delta x) - f(-3)}{\Delta x}$$
$$= \frac{7(-3 + \Delta x) - (-3 + \Delta x)^3 - \left[7(-3) - (-3)^3\right]}{\Delta x}$$
$$= \frac{-21 + 7\Delta x - \left(-27 + 27\Delta x - 9(\Delta x)^2 + (\Delta x)^3\right) - 6}{\Delta x}$$
$$= \frac{-20\Delta x + 9(\Delta x)^2 - (\Delta x)^3}{\Delta x}$$
$$= \frac{\Delta x\left(-20 + 9\Delta x - (\Delta x)^2\right)}{\Delta x}$$
$$= -20 + 9\Delta x - (\Delta x)^2$$
$$m = \lim_{\Delta x \to 0} m_{\text{sec}} = \lim_{\Delta x \to 0} \left(-20 + 9\Delta x - (\Delta x)^2\right) = -20$$

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25. $f(x) = 2\sqrt{x}$ at $(4, 4)$

$$\begin{aligned} m_{\text{sec}} &= \frac{f(4+\Delta x) - f(4)}{\Delta x} \\ &= \frac{2\sqrt{4+\Delta x} - 2\sqrt{4}}{\Delta x} \\ &= \frac{2\sqrt{4+\Delta x} - 4}{\Delta x} \cdot \frac{2\sqrt{4+\Delta x} + 4}{2\sqrt{4+\Delta x} + 4} \\ &= \frac{4(4+\Delta x) - 16}{\Delta x\left(2\sqrt{4+\Delta x} + 4\right)} \\ &= \frac{16 + 4\Delta x - 16}{\Delta x\left(2\sqrt{4+\Delta x} + 4\right)} \\ &= \frac{4\Delta x}{\Delta x\left(2\sqrt{4+\Delta x} + 4\right)} \\ &= \frac{4}{2\sqrt{4+\Delta x} + 4} \end{aligned}$$

$$\begin{aligned} m = \lim_{\Delta x \to 0} m_{\text{sec}} &= \lim_{\Delta x \to 0} \frac{4}{2\sqrt{4+\Delta x} + 4} \\ &= \frac{4}{2\sqrt{4} + 4} = \frac{1}{2} \end{aligned}$$

26. $f(x) = \sqrt{x+1}$ at $(8, 3)$

$$\begin{aligned} m_{\text{sec}} &= \frac{f(8+\Delta x) - f(8)}{\Delta x} \\ &= \frac{\sqrt{8+\Delta x+1} - \sqrt{8+1}}{\Delta x} \\ &= \frac{\sqrt{9+\Delta x} - 3}{\Delta x} \\ &= \frac{\sqrt{9+\Delta x} - 3}{\Delta x} \cdot \frac{\sqrt{9+\Delta x} + 3}{\sqrt{9+\Delta x} + 3} \\ &= \frac{9 + \Delta x - 9}{\Delta x\left(\sqrt{9+\Delta x} + 3\right)} \\ &= \frac{\Delta x}{\Delta x\left(\sqrt{9+\Delta x} + 3\right)} \\ &= \frac{1}{\sqrt{9+\Delta x} + 3} \end{aligned}$$

$$\begin{aligned} m &= \lim_{\Delta x \to 0} m_{\text{sec}} \\ &= \lim_{\Delta x \to 0} \frac{1}{\sqrt{9+\Delta x} + 3} \\ &= \frac{1}{\sqrt{9} + 3} \\ &= \frac{1}{6} \end{aligned}$$

27. $f(x) = 3$

$$\begin{aligned} f'(x) &= \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{3 - 3}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{0}{\Delta x} \\ &= \lim_{\Delta x \to 0} 0 \\ &= 0 \end{aligned}$$

28. $f(x) = -2$

$$\begin{aligned} f'(x) &= \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{-2 - (-2)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{0}{\Delta x} \\ &= \lim_{\Delta x \to 0} 0 \\ &= 0 \end{aligned}$$

29. $f(x) = -5x$

$$\begin{aligned} f'(x) &= \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{-5(x+\Delta x) - (-5x)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{-5x - 5\Delta x + 5x}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{-5\Delta x}{\Delta x} \\ &= \lim_{\Delta x \to 0} -5 \\ &= -5 \end{aligned}$$

30. $f(x) = 4x + 1$

$$\begin{aligned} f'(x) &= \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{4(x+\Delta x) + 1 - (4x+1)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{4x + 4\Delta x + 1 - 4x - 1}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{4\Delta x}{\Delta x} \\ &= \lim_{\Delta x \to 0} 4 \\ &= 4 \end{aligned}$$

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31. $g(s) = \frac{1}{3}s + 2$

$$\begin{aligned} g'(s) &= \lim_{\Delta s \to 0} \frac{g(s + \Delta s) - g(s)}{\Delta s} \\ &= \lim_{\Delta s \to 0} \frac{\frac{1}{3}(s + \Delta s) + 2 - \left(\frac{1}{3}s + 2\right)}{\Delta s} \\ &= \lim_{\Delta s \to 0} \frac{\frac{1}{3}s + \frac{1}{3}\Delta s + 2 - \frac{1}{3}s - 2}{\Delta s} \\ &= \lim_{\Delta s \to 0} \frac{\frac{1}{3}\Delta s}{\Delta s} \\ &= \lim_{\Delta s \to 0} \frac{1}{3} \\ &= \frac{1}{3} \end{aligned}$$

32. $h(t) = 6 - \frac{1}{2}t$

$$\begin{aligned} h'(t) &= \lim_{\Delta t \to 0} \frac{h(t + \Delta t) - h(t)}{\Delta t} \\ &= \lim_{\Delta t \to 0} \frac{6 - \frac{1}{2}(t + \Delta t) - \left(6 - \frac{1}{2}t\right)}{\Delta t} \\ &= \lim_{\Delta t \to 0} \frac{6 - \frac{1}{2}t - \frac{1}{2}\Delta t - 6 + \frac{1}{2}t}{\Delta t} \\ &= \lim_{\Delta t \to 0} \frac{-\frac{1}{2}\Delta t}{\Delta t} \\ &= \lim_{\Delta t \to 0} -\frac{1}{2} \\ &= -\frac{1}{2} \end{aligned}$$

33. $f(x) = 4x^2 - 5x$

$$\begin{aligned} f'(x) &= \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{\left[4(x + \Delta x)^2 - 5(x + \Delta x)\right] - \left(4x^2 - 5x\right)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{\left[4\left(x^2 + 2x\Delta x + (\Delta x)^2\right) - 5x - 5\Delta x\right] - 4x^2 + 5x}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{4x^2 + 8x\Delta x + 4(\Delta x)^2 - 5x - 5\Delta x - 4x^2 + 5x}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{4\Delta x\left(2x + \Delta x - \frac{5}{4}\right)}{\Delta x} \\ &= \lim_{\Delta x \to 0} 4\left(2x + \Delta x - \frac{5}{4}\right) = 8x - 5 \end{aligned}$$

34. $f(x) = 2x^2 + 7x$

$$\begin{aligned} f'(x) &= \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{\left[2(x + \Delta x)^2 + 7(x + \Delta x)\right] - \left(2x^2 + 7x\right)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{\left[2\left(x^2 + 2x\Delta x + (\Delta x)^2\right) + 7x + 7\Delta x\right] - 2x^2 - 7x}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{2x^2 + 4x\Delta x + 2(\Delta x)^2 + 7x + 7\Delta x - 2x^2 - 7x}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{2\Delta x\left(2x + \Delta x + \frac{7}{2}\right)}{\Delta x} \\ &= \lim_{\Delta x \to 0} 2\left(2x + \Delta x + \frac{7}{2}\right) = 4x + 7 \end{aligned}$$

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35. $h(t) = \sqrt{t-3}$

$$\begin{aligned}
h'(t) &= \lim_{\Delta t \to 0} \frac{h(t+\Delta t) - h(t)}{t} \\
&= \lim_{\Delta t \to 0} \frac{\sqrt{t+\Delta t-3} - \sqrt{t-3}}{\Delta t} \\
&= \lim_{\Delta t \to 0} \frac{\sqrt{t+\Delta t-3} - \sqrt{t-3}}{\Delta t} \cdot \frac{\sqrt{t+\Delta t-3} + \sqrt{t-3}}{\sqrt{t+\Delta t-3} + \sqrt{t-3}} \\
&= \lim_{\Delta t \to 0} \frac{t+\Delta t-3-(t-3)}{\Delta t\left(\sqrt{t+\Delta t-3} + \sqrt{t-3}\right)} \\
&= \lim_{\Delta t \to 0} \frac{\Delta t}{\Delta t\left(\sqrt{t+\Delta t-3} + \sqrt{t-3}\right)} \\
&= \lim_{\Delta t \to 0} \frac{1}{\sqrt{t+\Delta t-3} + \sqrt{t-3}} \\
&= \frac{1}{2\sqrt{t-13}} \\
&= \frac{\sqrt{t-3}}{2(t-3)}
\end{aligned}$$

36. $f(x) = \sqrt{x+2}$

$$\begin{aligned}
f'(x) &= \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\sqrt{x+\Delta x+2} - \sqrt{x+2}}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\sqrt{x+\Delta x+2} - \sqrt{x+2}}{\Delta x} \cdot \frac{\sqrt{x+\Delta x+2} + \sqrt{x+2}}{\sqrt{x+\Delta x+2} + \sqrt{x+2}} \\
&= \lim_{\Delta x \to 0} \frac{x+\Delta x+2-(x+2)}{\Delta x\left(\sqrt{x+\Delta x+2} + \sqrt{x+2}\right)} \\
&= \lim_{\Delta x \to 0} \frac{\Delta x}{\Delta x\left(\sqrt{x+\Delta x+2} + \sqrt{x+2}\right)} \\
&= \lim_{\Delta x \to 0} \frac{1}{\sqrt{x+\Delta x+2} + \sqrt{x+2}} \\
&= \frac{1}{2\sqrt{x+2}}
\end{aligned}$$

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37. $f(t) = t^3 - 12t$

$$\begin{aligned}
f'(t) &= \lim_{\Delta t \to 0} \frac{f(t + \Delta t) - f(t)}{\Delta t} \\
&= \lim_{\Delta t \to 0} \frac{(t + \Delta t)^3 - 12(t + \Delta t) - (t^3 - 12t)}{\Delta t} \\
&= \lim_{\Delta t \to 0} \frac{t^3 + 3t^2\Delta t + 3t(\Delta t)^2 + (\Delta t)^3 - 12t - 12\Delta t - t^3 + 12t}{\Delta t} \\
&= \lim_{\Delta t \to 0} \frac{3t^2\Delta t + 3t(\Delta t)^2 + (\Delta t)^3 - 12\Delta t}{\Delta t} \\
&= \lim_{\Delta t \to 0} \frac{\Delta t\left(3t^2 + 3t\Delta t + (\Delta t)^2 - 12\right)}{\Delta t} \\
&= \lim_{\Delta t \to 0} \left(3t^2 + 3t\Delta t + (\Delta t)^2 - 12\right) \\
&= 3t^2 - 12
\end{aligned}$$

38. $f(t) = t^3 + t^2$

$$\begin{aligned}
f'(t) &= \lim_{\Delta t \to 0} \frac{f(t + \Delta t) - f(t)}{\Delta t} \\
&= \lim_{\Delta t \to 0} \frac{(t + \Delta t)^3 + (t + \Delta t)^2 - (t^3 + t^2)}{\Delta t} \\
&= \lim_{\Delta t \to 0} \frac{t^3 + 3t^2\Delta t + 3t(\Delta t)^2 + (\Delta t)^3 + t^2 + 2t\Delta t + (\Delta t)^2 - t^3 - t^2}{\Delta t} \\
&= \lim_{\Delta t \to 0} \frac{3t^2\Delta t + 3t(\Delta t)^2 + (\Delta t)^3 + 2t\Delta t + (\Delta t)^2}{\Delta t} \\
&= \lim_{\Delta t \to 0} \frac{\Delta t\left(3t^2 + 3t\Delta t + (\Delta t)^2 + 2t + \Delta t\right)}{\Delta t} \\
&= \lim_{\Delta t \to 0} \left(3t^2 + 3t\Delta t + (\Delta t)^2 + 2t + \Delta t\right) \\
&= 3t^2 + 2t
\end{aligned}$$

39. $f(x) = \dfrac{1}{x + 2}$

$$\begin{aligned}
f'(x) &= \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\dfrac{1}{x + \Delta x + 2} - \dfrac{1}{x + 2}}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\dfrac{1}{x + \Delta x + 2} \cdot \dfrac{x + 2}{x + 2} - \dfrac{1}{x + 2} \cdot \dfrac{x + \Delta x + 2}{x + \Delta x + 2}}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\dfrac{x + 2 - (x + \Delta x + 2)}{(x + \Delta x + 2)(x + 2)}}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{-\Delta x}{\Delta x(x + \Delta x + 2)(x + 2)} \\
&= \lim_{\Delta x \to 0} \frac{-1}{(x + \Delta x + 2)(x + 2)} \\
&= -\frac{1}{(x + 2)^2}
\end{aligned}$$

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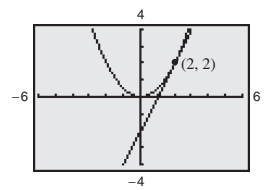
40. $g(s) = \dfrac{1}{s-4}$

$$\begin{aligned}
g'(s) &= \lim_{\Delta s \to 0} \frac{g(s+\Delta s) - g(s)}{\Delta s} \\
&= \lim_{\Delta s \to 0} \frac{\dfrac{1}{s+\Delta s-4} - \dfrac{1}{s-4}}{\Delta s} \\
&= \lim_{\Delta s \to 0} \frac{\dfrac{s-4-(s+\Delta s-4)}{(s+\Delta s-4)(s-4)}}{\Delta s} \\
&= \lim_{\Delta s \to 0} \frac{\dfrac{s-4-(s+\Delta s-4)}{(s+\Delta s-4)(s-4)}}{(s+\Delta s-4)(s-4)} \cdot \frac{1}{\Delta s} \\
&= \lim_{\Delta s \to 0} \frac{-\Delta s}{\Delta s(s+\Delta s-4)(s-4)} \\
&= \lim_{\Delta s \to 0} \frac{-1}{(s+\Delta s-4)(s-4)} \\
&= -\frac{1}{(s-4)^2}
\end{aligned}$$

41. $f(x) = \frac{1}{2}x^2$ at $(2, 2)$

$$\begin{aligned}
f'(x) &= \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\frac{1}{2}(x+\Delta x)^2 - \frac{1}{2}x^2}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\frac{1}{2}\left(x^2 + 2x\Delta x + (\Delta x)^2\right) - \frac{1}{2}x^2}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{x\Delta x + (\Delta x)^2}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\Delta x(x+\Delta x)}{\Delta x} \\
&= \lim_{\Delta x \to 0} (x+\Delta x) \\
&= x
\end{aligned}$$

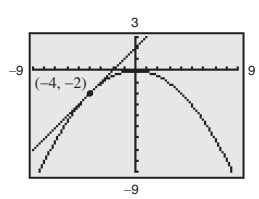
$$\begin{aligned}
m &= f'(2) = 2 \\
y - 2 &= 2(x-2) \\
y &= 2x - 2
\end{aligned}$$



42. $f(x) = -\frac{1}{8}x^2$ at $(-4, -2)$

$$\begin{aligned}
f'(x) &= \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{-\frac{1}{8}(x+\Delta x)^2 - \left(-\frac{1}{8}x^2\right)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{-\frac{1}{8}\left(x^2 + 2x\Delta x + (\Delta x)^2\right) + \frac{1}{8}x^2}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{-\frac{1}{8}x^2 - \frac{1}{4}x\Delta x - \frac{1}{8}(\Delta x)^2 + \frac{1}{8}x^2}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{-\frac{1}{4}x\Delta x - \frac{1}{8}(\Delta x)^2}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\Delta x\left(-\frac{1}{4}x - \frac{1}{8}\Delta x\right)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \left(-\frac{1}{4}x - \frac{1}{8}\Delta x\right) \\
&= -\frac{1}{4}x
\end{aligned}$$

$$\begin{aligned}
m &= f'(-4) = -\tfrac{1}{4}(-4) = 1 \\
y - (-2) &= 1[x - (-4)] \\
y + 2 &= x + 4 \\
y &= x + 2
\end{aligned}$$



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43. $f(x) = (x-1)^2$ at $(-2, 9)$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{(x+\Delta x-1)^2 - (x-1)^2}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{x^2 + 2x\Delta x - 2x + (\Delta x)^2 - 2\Delta x + 1 - x^2 + 2x - 1}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{2x\Delta x + (\Delta x)^2 - 2\Delta x}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\Delta x(2x + \Delta x - 2)}{\Delta x}$$

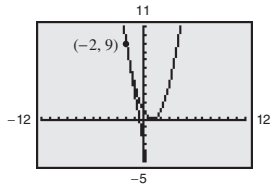
$$= \lim_{\Delta x \to 0} (2x + \Delta x - 2)$$

$$= 2x - 2$$

$$m = f'(-2) = 2(-2) - 2 = -6$$

$$y - 9 = -6[x - (-2)]$$

$$y = -6x - 3$$



44. $f(x) = 2x^2 - 5$ at $(-1, -3)$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{2(x+\Delta x)^2 - 5 - (2x^2 - 5)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{2x^2 + 4x\Delta x + 2(\Delta x)^2 - 5 - 2x^2 + 5}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{4x\Delta x + 2(\Delta x)^2}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\Delta x(4x + 2\Delta x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} (4x + 2\Delta x)$$

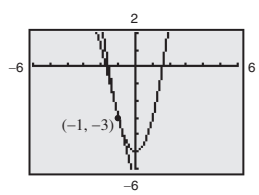
$$= 4x$$

$$m = f'(-1) = 4(-1) = -4$$

$$y - (-3) = -4(x - (-1))$$

$$y + 3 = -4x - 4$$

$$y = -4x - 7$$



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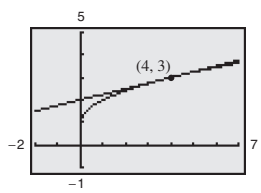
45. $f(x) = \sqrt{x} + 1$ at $(4, 3)$

$$\begin{aligned}
f'(x) &= \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\sqrt{x + \Delta x} + 1 - \left(\sqrt{x} + 1\right)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\sqrt{x + \Delta x} - \sqrt{x}}{\Delta x} \cdot \frac{\sqrt{x + \Delta x} + \sqrt{x}}{\sqrt{x + \Delta x} + \sqrt{x}} \\
&= \lim_{\Delta x \to 0} \frac{x + \Delta x - x}{\Delta x\left(\sqrt{x + \Delta x} + \sqrt{x}\right)} \\
&= \lim_{\Delta x \to 0} \frac{\Delta x}{\Delta x\left(\sqrt{x + \Delta x} + \sqrt{x}\right)} \\
&= \lim_{\Delta x \to 0} \frac{1}{\sqrt{x + \Delta x} + \sqrt{x}} \\
&= \frac{1}{2\sqrt{x}}
\end{aligned}$$

$$m = f'(4) = \frac{1}{2\sqrt{4}} = \frac{1}{4}$$

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

$$y = \frac{1}{4}x + 2$$



46. $f(x) = \sqrt{x + 3}$ at $(6, 3)$

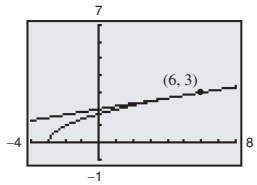
$$\begin{aligned}
f'(x) &= \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\sqrt{x + \Delta x + 3} - \sqrt{x + 3}}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\sqrt{x + \Delta x + 3} - \sqrt{x + 3}}{\Delta x} \cdot \frac{\sqrt{x + \Delta x + 3} + \sqrt{x + 3}}{\sqrt{x + \Delta x + 3} + \sqrt{x + 3}} \\
&= \lim_{\Delta x \to 0} \frac{x + \Delta x + 3 - (x + 3)}{\Delta x\left(\sqrt{x + \Delta x + 3} + \sqrt{x + 3}\right)} \\
&= \lim_{\Delta x \to 0} \frac{\Delta x}{\Delta x\left(\sqrt{x + \Delta x + 3} + \sqrt{x + 3}\right)} \\
&= \lim_{\Delta x \to 0} \frac{1}{\sqrt{x + \Delta x + 3} + \sqrt{x + 3}} \\
&= \frac{1}{2\sqrt{x + 3}} \\
&= \frac{\sqrt{x + 3}}{2(x + 3)}
\end{aligned}$$

$$m = f'(6) = \frac{1}{2\sqrt{6 + 3}} = \frac{1}{6}$$

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

$$y - 3 = \frac{1}{6}x - 1$$

$$y = \frac{1}{6}x + 2$$



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47. $f(x) = \dfrac{1}{5x}$ at $\left(-\dfrac{1}{5}, -1\right)$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\dfrac{1}{5(x + \Delta x)} - \dfrac{1}{5x}}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\dfrac{x - (x + \Delta x)}{5x(x + \Delta x)}}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{x - (x + \Delta x)}{5x(x + \Delta x)} \cdot \frac{1}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{-\Delta x}{5x \cdot \Delta x \cdot (x + \Delta x)}$$

$$= \lim_{\Delta x \to 0} \frac{-1}{5x(x + \Delta x)}$$

$$= -\frac{1}{5x^2}$$

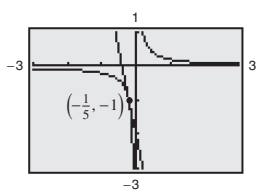
$$m = f'\left(-\frac{1}{5}\right) = -\frac{1}{5\left(-\frac{1}{5}\right)^2} = -\frac{1}{5\left(\frac{1}{25}\right)} = -5$$

$$y - (-1) = -5\left(x - \left(-\frac{1}{5}\right)\right)$$

$$y + 1 = -5\left(x + \frac{1}{5}\right)$$

$$y + 1 = -5x - 1$$

$$y = -5x - 2$$



48. $f(x) = \dfrac{1}{x - 3}$ at $(2, -1)$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\dfrac{1}{x + \Delta x - 3} - \dfrac{1}{x - 3}}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\dfrac{1}{x + \Delta x - 3} \cdot \dfrac{x - 3}{x - 3} - \dfrac{1}{x - 3} \cdot \dfrac{x + \Delta x - 3}{x + \Delta x - 3}}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\dfrac{x - 3 - (x + \Delta x - 3)}{(x + \Delta x - 3)(x - 3)}}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{-\Delta x}{(x + \Delta x - 3)(x - 3)\Delta x}$$

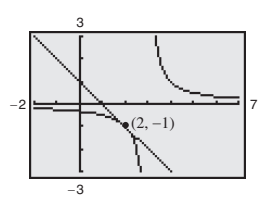
$$= \lim_{\Delta x \to 0} \frac{-1}{(x + \Delta x - 3)(x - 3)} = -\frac{1}{(x - 3)^2}$$

$$m = f'(2) = -\frac{1}{(2 - 3)^2} = -1$$

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

$$y + 1 = -x + 2$$

$$y = -x + 1$$



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49. $f(x) = -\frac{1}{4}x^2$

$$\begin{aligned} f'(x) &= \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{-\frac{1}{4}(x+\Delta x)^2 - \left(-\frac{1}{4}x^2\right)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{-\frac{1}{4}x^2 - \frac{1}{2}x\Delta x - \frac{1}{4}(\Delta x)^2 + \frac{1}{4}x^2}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{-\frac{1}{2}x\Delta x - \frac{1}{4}(\Delta x)^2}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{\Delta x\left(-\frac{1}{2}x - \frac{1}{4}\Delta x\right)}{\Delta x} \\ &= \lim_{\Delta x \to 0}\left(-\frac{1}{2}x - \frac{1}{4}\Delta x\right) \\ &= -\frac{1}{2}x \end{aligned}$$

Since the slope of the given line is -1,

$$\begin{aligned} -\tfrac{1}{2}x &= -1 \\ x &= 2 \text{ and } f(2) = -1. \end{aligned}$$

At the point $(2, -1)$, the tangent line parallel to

$$\begin{aligned} x + y = 0 \text{ is } y - (-1) &= -1(x - 2) \\ y &= -x + 1. \end{aligned}$$

50. $f(x) = x^2 - 7$

$$\begin{aligned} f'(x) &= \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{\left[(x+\Delta x)^2 - 7\right] - \left(x^2 - 7\right)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{x^2 + 2x\Delta x + (\Delta x)^2 - 7 - x^2 + 7}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{\Delta x(2x + \Delta x)}{\Delta x} \\ &= \lim_{\Delta x \to 0} (2x + \Delta x) = 2x \end{aligned}$$

Since the slope of the given line is -2,

$$\begin{aligned} 2x &= -2 \\ x &= -1 \text{ and } f(-1) = -6. \end{aligned}$$

At the point $(-1, -6)$, the tangent line parallel to

$$\begin{aligned} 2x + y = 0 \text{ is } y - (-6) &= -2(x - (-1)) \\ y &= -2x - 8. \end{aligned}$$

51. $f(x) = -\frac{1}{3}x^3$

$$\begin{aligned} f'(x) &= \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{-\frac{1}{3}(x+\Delta x)^3 - \left(-\frac{1}{3}x^3\right)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{-\frac{1}{3}\left(x^3 + 3x^2\Delta x + 3x(\Delta x)^2 + (\Delta x)^3\right) + \frac{1}{3}x^3}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{-\frac{1}{3}x^3 - x^2\Delta x - x(\Delta x)^2 - \frac{1}{3}(\Delta x)^3 + \frac{1}{3}x^3}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{\Delta x\left(-x^2 - x\Delta x - \frac{1}{3}(\Delta x)^2\right)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \left(-x^2 - x\Delta x - \tfrac{1}{3}(\Delta x)^2\right) = -x^2 \end{aligned}$$

Since the slope of the given line is -9,

$$\begin{aligned} -x^2 &= -9 \\ x^2 &= 9 \\ x &= \pm 3 \text{ and } f(3) = -9 \text{ and } f(-3) = 9. \end{aligned}$$

At the point $(3, -9)$, the tangent line parallel to $9x + y - 6 = 0$ is

$$\begin{aligned} y - (-9) &= -9(x - 3) \\ y &= -9x + 18. \end{aligned}$$

At the point $(-3, 9)$, the tangent line parallel to $9x + y - 6 = 0$ is

$$\begin{aligned} y - 9 &= -9(x - (-3)) \\ y &= -9x - 18. \end{aligned}$$

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52. $f(x) = x^3 + 2$

$$\begin{aligned} f'(x) &= \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{(x + \Delta x)^3 + 2 - (x^3 + 2)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{x^3 + 3x^2\Delta x + 3x(\Delta x)^2 + (\Delta x)^3 + 2 - x^3 - 2}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{3x^2\Delta x + 3(\Delta x)^2 + (\Delta x)^3}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{\Delta x\left(3x^2 + 3x\Delta x + (\Delta x)^2\right)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \left(3x^2 + 3x\Delta x + (\Delta x)^2\right) \\ &= 3x^2 \end{aligned}$$

The slope of the given line is

$$\begin{aligned} 3x - y - 4 &= 0 \\ y &= 3x - 4 \\ m &= 3. \end{aligned}$$

$$\begin{aligned} 3x^2 &= 3 \\ x^2 &= 1 \\ x &= \pm 1 \\ x &= 1 \text{ and } f(1) = 3 \\ x &= -1 \text{ and } f(-1) = 1 \end{aligned}$$

At the point $(1, 3)$, the tangent line parallel to $3x - y - 4 = 0$ is

$$\begin{aligned} y - 3 &= 3(x - 1) \\ y - 3 &= 3x - 3 \\ y &= 3x. \end{aligned}$$

At the point $(-1, 1)$, the tangent line parallel to $3x - y - 4 = 0$ is

$$\begin{aligned} y - 1 &= 3(x - (-1)) \\ y - 1 &= 3(x + 1) \\ y - 1 &= 3x + 3 \\ y &= 3x + 4. \end{aligned}$$

53. y is differentiable for all $x \neq -3$.

At $(-3, 0)$, the graph has a node.

54. y is differentiable for all $x \neq \pm 3$.

At $(\pm 3, 0)$, the graph has a cusp.

55. y is differentiable for all $x \neq -\frac{1}{2}$.

At $\left(-\frac{1}{2}, 0\right)$, the graph has a vertical tangent line.

56. y is differentiable for all $x > 1$.

The derivative does not exist at endpoints.

57. y is differentiable for all $x \neq \pm 2$.

The function is not defined at $x = \pm 2$.

58. y is differentiable for all $x \neq 0$.

The function is discontinuous at $x = 0$.

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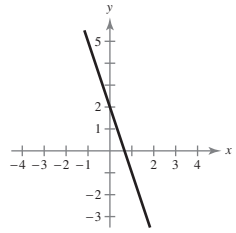
59. Since $f'(x) = -3$ for all x, f is a line of the form

$f(x) = -3x + b.$

$f(0) = 2$, so $2 = (-3)(0) + b$, or $b = 2.$

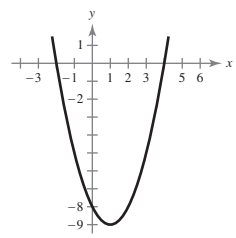
Thus, $f(x) = -3x + 2.$



60. Sample answer: Since $f(-2) = f(4) = 0$, $(x + 2)(x - 4) = 0.$

A function with these zeros is $f(x) = x^2 - 2x - 8.$

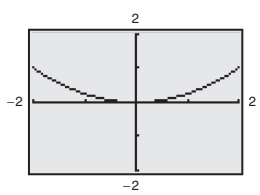
$$\begin{aligned}
\text{Then } f'(x) &= \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\left[(x + \Delta x)^2 - 2(x + \Delta x) - 8\right] - \left(x^2 - 2x - 8\right)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{x^2 + 2x\Delta x + (\Delta x)^2 - 2x - 2\Delta x - 8 - x^2 + 2x + 8}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{2x\Delta x + (\Delta x)^2 - 2\Delta x}{\Delta x} \\
&= \lim_{\Delta x \to 0} 2x + \Delta x - 2 \\
&= 2x - 2.
\end{aligned}$$



So $f'(1) = 2(1) - 2 = 0.$ Sketching $f(x)$ shows that

$f'(x) < 0$ for $x < 1$ and $f'(0) > 0$ for $x > 1.$

61.



x	-2	$-\frac{3}{2}$	-1	$-\frac{1}{2}$	0	$\frac{1}{2}$	1	$\frac{3}{2}$	2
$f(x)$	1	0.5625	0.25	0.0625	0	0.0625	0.25	0.5625	1
$f'(x)$	-1	-0.75	-0.5	-0.25	0	0.25	0.5	0.75	1

Analytically, the slope of $f(x) = \frac{1}{4}x^2$ is

$$\begin{aligned}
m &= \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\frac{1}{4}(x + \Delta x)^2 - \frac{1}{4}x^2}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\frac{1}{4}\left[x^2 + 2x(\Delta x)^2 + (\Delta x)^2\right] - \frac{1}{4}x^2}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\frac{1}{4}x^2 + \frac{1}{2}x\Delta x + \frac{1}{4}(\Delta x)^2 - \frac{1}{4}x^2}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\frac{1}{2}x\Delta x + \frac{1}{4}(\Delta x)^2}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\Delta x\left(\frac{1}{2}x\Delta x + \frac{1}{4}\Delta x\right)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \left(\frac{1}{2}x + \frac{1}{4}\Delta x\right) \\
&= \frac{1}{2}x.
\end{aligned}$$

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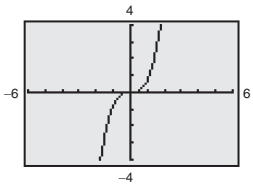
62.

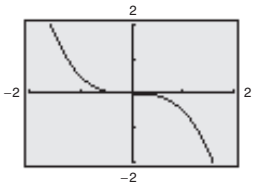


x	-2	$-\frac{3}{2}$	-1	$-\frac{1}{2}$	0	$\frac{1}{2}$	1	$\frac{3}{2}$	2
$f(x)$	-6	-2.53	-0.75	-0.1	0	0.1	0.75	2.53	6
$f'(x)$	9	5.0625	2.25	0.5625	0	0.5625	2.25	5.0625	9

Analytically, the slope of $f(x) = \frac{3}{4}x^3$ is

$$\begin{aligned}
m &= \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\frac{3}{4}(x + \Delta x)^3 - \frac{3}{4}x^3}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\frac{3}{4}\left(x^3 + 3x^2\Delta x + 3x(\Delta x)^2 + (\Delta x)^3\right) - \frac{3}{4}x^3}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\frac{3}{4}x^3 + \frac{9}{4}x^2\Delta x + \frac{9}{4}x(\Delta x)^2 + \frac{3}{4}(\Delta x)^3 - \frac{3}{4}x^3}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\frac{9}{4}x^2\Delta x + \frac{9}{4}x(\Delta x)^2 + \frac{3}{4}x(\Delta x)^3}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{\Delta x\left(\frac{9}{4}x^2 + \frac{9}{4}x\Delta x + \frac{3}{4}(\Delta x)^2\right)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \left(\frac{9}{4}x^2 + \frac{9}{4}x\Delta x + \frac{3}{4}(\Delta x)^2\right) \\
&= \frac{9}{4}x^2.
\end{aligned}$$

63.



x	-2	$-\frac{3}{2}$	-1	$-\frac{1}{2}$	0	$\frac{1}{2}$	1	$\frac{3}{2}$	2
$f(x)$	4	1.6875	0.5	0.0625	0	-0.0625	-0.5	-1.6875	-4
$f'(x)$	-6	-3.375	-1.5	-0.375	0	-0.375	-1.5	-3.375	-6

Analytically, the slope of $f(x) = -\frac{1}{2}x^3$ is

$$\begin{aligned}
m &= \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{-\frac{1}{2}(x + \Delta x)^3 + \frac{1}{2}x^3}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{-\frac{1}{2}\left[x^3 + 3x^2\Delta x + 3x(\Delta x)^2 + (\Delta x)^3\right] + \frac{1}{2}x^3}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{-\frac{1}{2}\left[3x^2\Delta x + 3x(\Delta x)^2 + (\Delta x)^3\right]}{\Delta x} \\
&= \lim_{\Delta x \to 0} -\frac{1}{2}\left[3x^2 + 3x(\Delta x) + (\Delta x)^2\right] \\
&= -\frac{3}{2}x^2.
\end{aligned}$$

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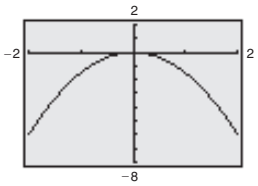
64.



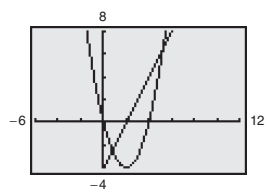
x	-2	$-\frac{3}{2}$	-1	$-\frac{1}{2}$	0	$\frac{1}{2}$	1	$\frac{3}{2}$	2
$f(x)$	-6	-3.375	-1.5	-0.375	0	-0.375	-1.5	-3.375	-6
$f'(x)$	6	4.5	3	1.5	0	-1.5	-3	-4.5	-6

Analytically, the slope of $f(x) = -\frac{3}{2}x^2$ is

$$\begin{aligned}
m &= \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{-\frac{3}{2}(x + \Delta x)^2 - \left(-\frac{3}{2}x^2\right)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{-\frac{3}{2}\left[x^2 + 2x\Delta x + (\Delta x)^2\right] + \frac{3}{2}x^2}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{-\frac{3}{2}\left[2x\Delta x + (\Delta x)^2\right]}{\Delta x} \\
&= \lim_{\Delta x \to 0} -\frac{3}{2}(2x + \Delta x) \\
&= -3x.
\end{aligned}$$

65.

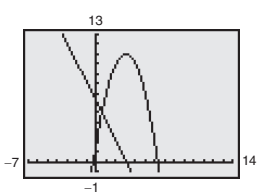
$$\begin{aligned}
f'(x) &= \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{(x + \Delta x)^2 - 4(x + \Delta x) - (x^2 - 4x)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{2x\Delta x + (\Delta x)^2 - 4\Delta x}{\Delta x} \\
&= \lim_{\Delta x \to 0} (2x + \Delta x - 4) \\
&= 2x - 4
\end{aligned}$$



The x-intercept of the derivative indicates a point of horizontal tangency for f.

66.

$$\begin{aligned}
f'(x) &= \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x} = \lim_{\Delta x \to 0} \frac{2 + 6(x + \Delta x) - (x + \Delta x)^2 - (2 + 6x - x^2)}{\Delta x} \\
&= \lim_{\Delta x \to 0} \frac{6\Delta x - 2x\Delta x - (\Delta x)^2}{\Delta x} = \lim_{\Delta x \to 0} (6 - 2x - \Delta x) = 6 - 2x
\end{aligned}$$



The x-intercept of the derivative indicates a point of horizontal tangency for f.

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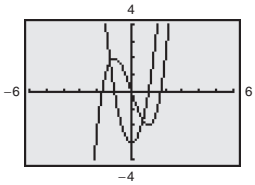
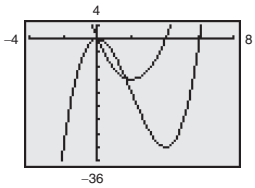
67. $$\begin{aligned} f'(x) &= \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{(x + \Delta x)^3 - 3(x + \Delta x) - (x^3 - 3x)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{x^3 + 3x^2\Delta x + 3x(\Delta x)^2 + (\Delta x)^3 - 3x - 3\Delta x - x^3 + 3x}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{3x^2\Delta x + 3x(\Delta x)^2 + (\Delta x)^3 - 3\Delta x}{\Delta x} \\ &= \lim_{\Delta x \to 0} \left(3x^2 + 3x\Delta x + (\Delta x)^2 - 3\right) \\ &= 3x^2 - 3 \end{aligned}$$



The x-intercepts of the derivative indicate points of horizontal tangency for f.

68. $$\begin{aligned} f'(x) &= \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{(x + \Delta x)^3 - 6(x + \Delta x)^2 - (x^3 - 6x^2)}{\Delta x} \\ &= \lim_{\Delta x \to 0} \frac{x^3 - 3x^2\Delta x + 3x(\Delta x)^2 + (\Delta x)^3 - 6\left(x^2 + 2x\Delta x + (\Delta x)^2\right) - x^3 + 6x^2}{\Delta x} \\ &= \lim_{\Delta x \to 0} \left(3x^2 + 3x\Delta x + (\Delta x)^2 - 12x - 6\Delta x\right) \\ &= 3x^2 - 12x \end{aligned}$$



The x-intercepts of the derivative indicate points of horizontal tangency for f.

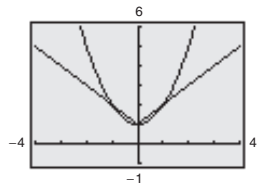
69. True. The slope of the graph is given by $f'(x) = 2x$, which is different for each different x value.

70. False. $f(x) = |x|$ is continuous, but not differentiable at $x = 0$.

71. True. See page 122.

72. True. See page 115.

73. The graph of $f(x) = x^2 + 1$ is smooth at (0, 1), but the graph of $g(x) = |x| + 1$ has a node at (0, 1). The function g is not differentiable at (0, 1).



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Section 2.2 Some Rules for Differentiation

Skills Warm Up

1. (a) $2x^2,\ x = 2$

$2(2^2) = 2(4) = 8$

(b) $(5x)^2,\ x = 2$

$[5(2)]^2 = 10^2 = 100$

(c) $6x^{-2},\ x = 2$

$6(2)^{-2} = 6\left(\frac{1}{4}\right) = \frac{3}{2}$

2. (a) $\dfrac{1}{(3x)^2},\ x = 2$

$\dfrac{1}{[3(2)]^2} = \dfrac{1}{6^2} = \dfrac{1}{36}$

(b) $\dfrac{1}{4x^3},\ x = 2$

$\dfrac{1}{4(2^3)} = \dfrac{1}{4(8)} = \dfrac{1}{32}$

(c) $\dfrac{(2x)^{-3}}{4x^{-2}},\ x = 2$

$\dfrac{[2(2)]^{-3}}{4(2)^{-2}} = \dfrac{4^{-3}}{4(2)^{-2}} = \dfrac{2^2}{4(4^3)} = \dfrac{1}{64}$

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

4. $\frac{1}{2}(3)x^2 - \frac{3}{2}x^{1/2} = \frac{3}{2}x^2 - \frac{3}{2}\sqrt{x} = \frac{3}{2}x^{1/2}(x^{3/2} - 1)$

5. $\left(\dfrac{1}{4}\right)x^{-3/4} = \dfrac{1}{4x^{3/4}}$

6. $\dfrac{1}{3}(3)x^2 - 2\left(\dfrac{1}{2}\right)x^{-1/2} + \dfrac{1}{3}x^{-2/3} = x^2 - x^{-1/2} + \dfrac{1}{3}x^{-2/3}$

$= x^2 - \dfrac{1}{\sqrt{x}} + \dfrac{1}{3\sqrt[3]{x^2}}$

7. $3x^2 + 2x = 0$

$x(3x + 2) = 0$

$x = 0$

$3x + 2 = 0 \rightarrow x = -\frac{2}{3}$

8. $x^3 - x = 0$

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

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

$x = 0$

$x + 1 = 0 \rightarrow x = -1$

$x - 1 = 0 \rightarrow x = 1$

9. $x^2 + 8x - 20 = 0$

$(x + 10)(x - 2) = 0$

$x + 10 = 0 \rightarrow x = -10$

$x - 2 = 0 \rightarrow x = 2$

10. $3x^2 - 10x + 8 = 0$

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

$3x - 4 = 0 \rightarrow x = \frac{4}{3}$

$x - 2 = 0 \rightarrow x = 2$

1. $y = 3$

$y' = 0$

2. $f(x) = -8$

$f'(x) = 0$

3. $y = x^5$

$y' = 5x^4$

4. $f(x) = \dfrac{1}{x^6} = x^{-6}$

$f'(x) = -6x^{-7} = -\dfrac{6}{x^7}$

5. $h(x) = 3x^3$

$h'(x) = 9x^2$

6. $h(x) = 6x^5$

$h'(x) = 30x^4$

7. $y = \dfrac{5x^4}{3}$

$y' = \dfrac{20}{6}x^3 = \dfrac{10}{3}x^3$

8. $g(t) = \dfrac{3t^2}{4}$

$g'(t) = \dfrac{3}{2}t$

9. $f(x) = 4x$

$f'(x) = 4$

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10. $g(x) = \frac{x}{3} = \frac{1}{3}x$

$g'(x) = \frac{1}{3}$

11. $y = 8 - x^3$

$y = -3x^2$

12. $y = t^2 - 6$

$y' = 2t$

13. $f(x) = 4x^2 - 3x$

$f'(x) = 8x - 3$

14. $g(x) = 3x^2 + 5x^3$

$g'(x) = 6x + 15x^2 = 15x^2 + 6x$

15. $f(t) = -3t^2 + 2t - 4$

$f'(t) = -6t + 2$

16. $y = 7x^3 - 9x^2 + 8$

$y' = 21x^2 - 18x$

17. $s(t) = 4t^4 - 2t + t + 3$

$s'(t) = 16t^2 - 4t + 1$

18. $y = 2x^3 - x^2 + 3x - 1$

$y' = 6x^2 - 2x + 3$

19. $g(x) = x^{2/3}$

$g'(x) = \frac{2}{3}x^{-1/3} = \frac{2}{3x^{1/3}}$

20. $h(x) = x^{5/2}$

$h'(x) = \frac{5}{2}x^{3/2}$

21. $y = 4t^{4/3}$

$y' = 4\left(\frac{4}{3}\right)t^{1/3} = \frac{16}{3}t^{1/3}$

22. $f(x) = 10x^{1/6}$

$f'(x) = \frac{5}{3}x^{-5/6} = \frac{5}{3x^{5/6}} = \frac{5}{3\sqrt[6]{x^5}}$

23. $y = 4x^{-2} + 2x^2$

$y' = -8x^{-3} + 4x^1 = -\frac{8}{x^3} + 4x$

24. $s(t) = 8t^{-4} + t$

$s'(t) = 8\left(-4t^{-6}\right) + 1 = -\frac{32}{t^6} + 1$

	Function	*Rewrite*	*Differentiate*	*Simplify*
25.	$y = \frac{2}{7x^4}$	$y = \frac{2}{7}x^{-4}$	$y' = \frac{-8}{7}x^{-5}$	$y' = -\frac{8}{7x^5}$
26.	$y = \frac{2}{3x^2}$	$y = \frac{2}{3}x^{-2}$	$y' = -\frac{4}{3}x^{-3}$	$y' = -\frac{4}{3x^3}$
27.	$y = \frac{1}{(4x)^3}$	$y = \frac{1}{64}x^{-3}$	$y' = -\frac{3}{64}x^{-4}$	$y' = -\frac{3}{64x^4}$
28.	$y = \frac{\pi}{(2x)^6}$	$y = \frac{\pi}{64}x^{-6}$	$y' = -\frac{6\pi}{64}x^{-7}$	$y' = -\frac{3\pi}{32x^7}$
29.	$y = \frac{4}{(2x)^{-5}}$	$y = 128x^5$	$y' = 128(5)x^4$	$y' = 640x^4$
30.	$y = \frac{4x}{x^{-3}}$	$y = 4x^4$	$y' = 4(4)x^3$	$y' = 16x^3$
31.	$y = 6\sqrt{x}$	$y = 6x^{1/2}$	$y' = 6\left(\frac{1}{2}\right)x^{-1/2}$	$y' = \frac{3}{\sqrt{x}}$
32.	$y = \frac{3\sqrt{x}}{4}$	$y = \frac{3}{4}x^{1/2}$	$y' = \frac{3}{4}\left(\frac{1}{2}\right)x^{-1/2}$	$y' = \frac{3}{8\sqrt{x}}$

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	Function	*Rewrite*	*Differentiate*	*Simplify*
33.	$y = \dfrac{1}{7\sqrt[6]{x}}$	$y = \dfrac{1}{7}x^{-1/6}$	$y' = \dfrac{1}{7}\left(-\dfrac{1}{6}\right)x^{-7/6}$	$y' = -\dfrac{1}{42\sqrt[6]{x^7}}$
34.	$y = \dfrac{3}{2\sqrt[4]{x^3}}$	$y = \dfrac{3}{2}x^{-3/4}$	$y' = \dfrac{3}{2}\left(-\dfrac{3}{4}\right)x^{-7/4}$	$y' = -\dfrac{9}{8\sqrt[4]{x^7}}$
35.	$y = \sqrt[5]{8x}$	$y = (8x)^{1/5} = 8^{1/5}x^{1/5}$	$y' = 8^{1/5}\left(\dfrac{1}{5}x^{-4/5}\right)$	$y' = 8^{1/5}\dfrac{1}{5x^{4/5}} = \dfrac{\sqrt[5]{8}}{5\sqrt[5]{x^4}} = \dfrac{\sqrt[5]{8}}{5x}$
36.	$y = \sqrt[3]{6x^2}$	$y = \sqrt[3]{6}(x)^{2/3}$	$y' = \sqrt[3]{6}\left(\dfrac{2}{3}\right)x^{-1/3}$	$y' = \dfrac{2\sqrt[3]{6}}{3\sqrt[3]{x}}$

37. $y = x^{3/2}$

$y' = \frac{3}{2}x^{1/2}$

At the point $(1, 1)$, $y' = \frac{3}{2}(1)^{1/2} = \frac{3}{2} = m.$

38. $y = x^{-1}$

$y' = x^{-2} = -\dfrac{1}{x^2}$

At the point $\left(\dfrac{3}{4}, \dfrac{4}{3}\right)$, $y' = -\dfrac{1}{\left(\frac{3}{4}\right)^2} = -\dfrac{16}{9} = m.$

39. $f(t) = t^{-4}$

$f'(t) = -4t^{-5} = -\dfrac{4}{t^5}$

At the point

$\left(\dfrac{1}{2}, 16\right)$, $f'\left(\dfrac{1}{2}\right) = -\dfrac{4}{\left(\frac{1}{2}\right)^5} = -\dfrac{4}{\frac{1}{32}} = -128 = m.$

40. $f(x) = x^{-1/3}$

$f'(x) = -\dfrac{1}{3}x^{-4/3} = -\dfrac{1}{3x^{4/3}}$

At the point $\left(8, \dfrac{1}{2}\right)$, $f'(8) = -\dfrac{1}{3(8)^{4/3}} = -\dfrac{1}{48} = m.$

41. $f(x) = 2x^3 + 8x^2 - x - 4$

$f'(x) = 6x^2 + 16x - 1$

At the point

$(-1, 3)$, $f'(-1) = 6(-1)^2 + 16(-1) - 1 = -11 = m.$

42. $f(x) = x^4 - 2x^3 + 5x^2 - 7x$

$f'(x) = 4x^3 - 6x^2 + 10x - 7$

At the point

$(-1, 15)$, $f'(-1) = 4(-1)^3 - 6(-1)^2 + 10(-1) - 7$

$= -4 - 6 - 10 - 7 = -27 = m.$

43. $f(x) = -\frac{1}{2}x(1 + x^2) = -\frac{1}{2}x - \frac{1}{2}x^3$

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

$f'(1) = -\frac{1}{2} - \frac{3}{2} = -2$

44. $f(x) = 3(5 - x)^2 = 75 - 30x + 3x^2$

$f'(x) = -30 + 6x$

$f'(5) = -30 + (6)(5) = 0$

45. (a) $y = -2x^4 + 5x^2 - 3$

$y' = -8x^3 + 10x$

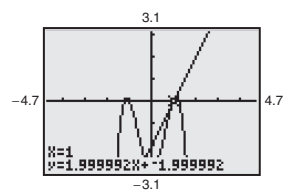
$m = y'(1) = -8 + 10 = 2$

The equation of the tangent line is

$y - 0 = 2(x - 1)$

$y = 2x - 2.$

(b) and (c)



46. (a) $y = x^3 + x + 4$

$y' = 3x^2 + 1$

$m = y'(-2) = 3(-2)^2 + 1 = 13$

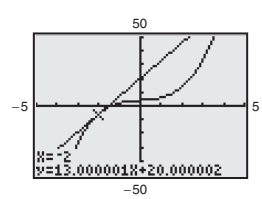
The equation of the tangent line is

$y - (-6) = 13[x - (-2)]$

$y + 6 = 13x + 26$

$y = 13x + 20.$

(b) and (c)



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47. (a) $f(x) = \sqrt[3]{x} + \sqrt[5]{x} = x^{1/3} + x^{1/5}$

$$f'(x) = \frac{1}{3}x^{-2/3} + \frac{1}{5}x^{-4/5} = \frac{1}{3x^{2/3}} + \frac{1}{5x^{4/5}}$$

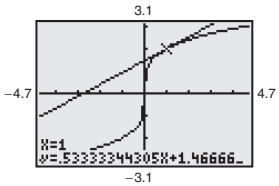
$$m = f'(1) = \frac{1}{3} + \frac{1}{5} = \frac{8}{15}$$

The equation of the tangent line is

$$y - 2 = \frac{8}{15}(x - 1)$$

$$y = \frac{8}{15}x + \frac{22}{15}.$$

(b) and (c)



48. (a) $f(x) = \dfrac{1}{\sqrt[3]{x^2}} - x = x^{-2/3} - x$

$$f'(x) = -\frac{2}{3}x^{-5/3} - 1$$

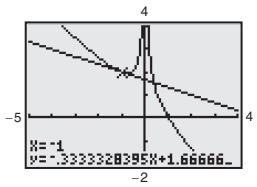
$$m = f'(-1) = \frac{2}{3} - 1 = -\frac{1}{3}$$

The equation of the tangent line is

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

$$y = -\tfrac{1}{3}x + \tfrac{5}{3}.$$

(b) and (c)



49. (a) $y = 3x\left(x^2 - \dfrac{2}{x}\right)$

$$y = 3x^3 - 6$$

$$y' = 9x^2$$

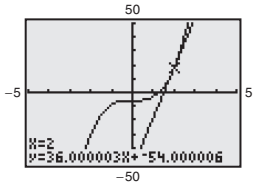
$$m = y' = 9(2)^2 = 36$$

The equation of the tangent line is

$$y - 18 = 36(x - 2)$$

$$y = 36x - 54.$$

(b) and (c)



50. (a) $y = (2x + 1)^2$

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

$$y' = 8x + 4$$

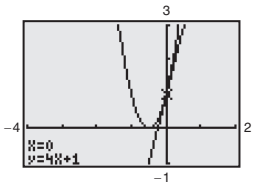
$$m = y' = 8(0) + 4 = 4$$

The equation of the tangent line is

$$y - 1 = 4(x - 0)$$

$$y = 4x + 1.$$

(b) and (c)



51. $f(x) = x^2 - 4x^{-1} - 3x^{-2}$

$$f'(x) = 2x + 4x^{-2} + 6x^{-3} = 2x + \frac{4}{x^2} + \frac{6}{x^3}$$

52. $f(x) = 6x^2 - 5x^{-2} + 7x^{-3}$

$$f'(x) = 12x + 10x^{-3} - 21x^{-4} = 12x + \frac{10}{x^3} - \frac{21}{x^4}$$

53. $f(x) = x^2 - 2x - \dfrac{2}{x^4} = x^2 - 2x - 2x^{-4}$

$$f'(x) = 2x - 2 + 8x^{-5} = 2x - 2 + \frac{8}{x^5}$$

54. $f(x) = x^2 + 4x + \dfrac{1}{x} = x^2 + 4x + x^{-1}$

$$f'(x) = 2x + 4 - x^{-2} = 2x + 4 - \frac{1}{x^2}$$

55. $f(x) = x^{4/5} + x$

$$f'(x) = \frac{4}{5}x^{-1/5} + 1 = \frac{4}{5x^{1/5}} + 1$$

56. $f(x) = x^{1/3} - 1$

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

57. $f(x) = x(x^2 + 1) = x^3 + x$

$$f'(x) = 3x^2 + 1$$

58. $f(x) = (x^2 + 2x)(x + 1) = x^3 + 3x^2 + 2x$

$$f'(x) = 3x^2 + 6x + 2$$

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59. $f(x) = \dfrac{2x^3 - 4x^2 + 3}{x^2} = 2x - 4 + 3x^{-2}$

$f'(x) = 2 - 6x^{-3} = 2 - \dfrac{6}{x^3} = \dfrac{2x^3 - 6}{x^3} = \dfrac{2(x^3 - 3)}{x^3}$

60. $f(x) = \dfrac{2x^2 - 3x + 1}{x} = 2x - 3 + x^{-1}$

$f'(x) = 2 - x^{-2} = 2 - \dfrac{1}{x^2} = \dfrac{2x^2 - 1}{x^2}$

61. $f(x) = \dfrac{4x^3 - 3x^2 + 2x + 5}{x^2} = 4x - 3 + 2x^{-1} + 5x^{-2}$

$f'(x) = 4 - 2x^{-2} - 10x^{-3} = 4 - \dfrac{2}{x^2} - \dfrac{10}{x^3} = \dfrac{4x^3 - 2x - 10}{x^3}$

62. $f(x) = \dfrac{-6x^3 + 3x^2 - 2x + 1}{x} = -6x^2 + 3x - 2 + x^{-1}$

$f'(x) = -12x + 3 - x^{-2} = -12x + 3 - \dfrac{1}{x^2}$

63. $y = x^4 - 2x + 3$

$y' = 4x^3 - 4x = 4x(x^2 - 1) = 0$ when $x = 0, \pm 1$

If $x = \pm 1$, then $y = (\pm 1)^4 - 2(\pm 1)^2 + 3 = 2$.

The function has horizontal tangent lines at the points $(0, 3)$, $(1, 2)$, and $(-1, 2)$.

64. $y = x^3 + 3x^2$

$y' = 3x^2 + 6x = 3x(x + 2) = 0$ when $x = 0, -2$.

The function has horizontal tangent lines at the points $(0, 0)$ and $(-2, 4)$.

65. $y = \frac{1}{2}x^2 + 5x$

$y' = x + 5 = 0$ when $x = -5$.

The function has a horizontal tangent line at the point $\left(-5, -\frac{25}{2}\right)$.

66. $y = x^2 + 2x$

$y' = 2x + 2 = 0$ when $x = -1$.

The function has a horizontal tangent line at the point $(-1, -1)$.

67. $y = x^2 + 3$

$y' = 2x$

Set $y' = 4$.

$2x = 4$

$x = 2$

If $x = 2$, $y = (2)^2 + 3 = 7 \rightarrow (2, 7)$.

The graph of $y = x^2 + 3$ has a tangent line with slope $m = 4$ at the point $(2, 7)$.

68. $y = x^2 + 2x$

$y' = 2x + 2$

Set $y' = 10$.

$2x + 2 = 10$

$x = 4$

If $x = 4$, $y = (4)^2 + 2(4) = 24 \rightarrow (4, 24)$.

The graph of $y = x^2 + 2x$ has a tangent line with slope $m = 10$ at the point $(4, 24)$.

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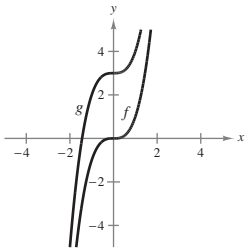
69. (a)



(b) $f'(x) = g'(x) = 3x^2$

$f'(1) = g'(1) = 3$

(c) Tangent line to f at $x = 1$:

$f(1) = 1$

$y - 1 = 3(x - 1)$

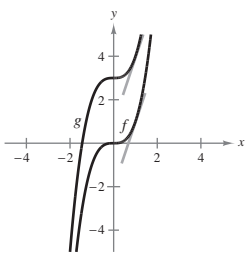
$y = 3x - 2$

Tangent line to g at $x = 1$:

$g(1) = 4$

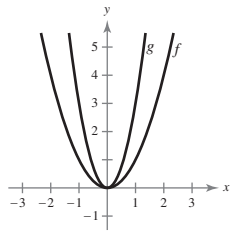
$y - 4 = 3(x - 1)$

$y = 3x + 1$



(d) f' and g' are the same.

70. (a)



(b) $f'(x) = 2x$

$f'(1) = 2$

$g'(x) = 6x$

$g'(1) = 6$

(c) Tangent line to f at $x = 1$:

$f(1) = 1$

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

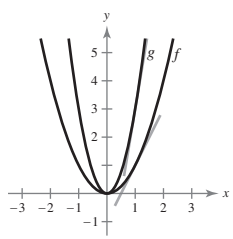
$y = 2x - 1$

Tangent line to g at $x = 1$:

$g(1) = 3$

$y - 3 = 6(x - 1)$

$y = 6x - 3$



(d) g' is 3 times f'.

71. If $g(x) = f(x) + 6$, then $g'(x) = f'(x)$ because the derivative of a constant is 0, $g'(x) = f'(x)$.

72. If $g(x) = 2f(x)$, then $g'(x) = 2f'(x)$ because of the Constant Multiple Rule.

73. If $g(x) = -5f(x)$, then $g'(x) = -5f'(x)$ because of the Constant Multiple Rule.

74. If $g(x) = 3f(x) - 1$, then $g'(x) = 3f'(x)$ because of the Constant Multiple Rule and the derivative of a constant is 0.

75. (a) $R = -4.1685t^3 + 175.037^2 - 1950.88t + 7265.3$

$R' = -12.5055t^2 + 350.074t - 1950.88$

2009: $R'(9) = -12.5055(9)^2 + 350.074(9) - 1950.88 \approx \$186.8$ million per year

2011: $R'(11) = -12.5055(11)^2 + 350.074(1) - 1950.88 \approx \$386.8$ million per year

(b) These results are close to the estimates in Exercise 13 in Section 2.1.

(c) The slope of the graph at time t is the rate at which sales are increasing in millions of dollars per year.

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76. (a) $R = -2.67538t^4 + 94.0568t^3 - 1155.203t^2 + 6002.42t - 9794.2$

$R' = -10.70152t^3 + 282.1704t^2 - 2310.406t + 6002.42$

2010: $R'(10) = -10.70152(10)^3 + 282.1704(10)^2 - 2310.406(10) + 6002 \approx \$413.88$ million per year

2012: $R'(12) = -10.70152(12)^3 + 282.1704(12)^2 - 2310.406(12) + 6002 \approx \$417.86$ million per year

(b) These results are close to the estimates in Exercise 14 in Section 2.1.

(c) The slope of the graph at time t is the rate at which sales are increasing in millions of dollars per year.

77. (a) More men and women seem to suffer from migraines between 30 and 40 years old. More females than males suffer from migraines. Fewer people whose income is greater than or equal to \$30,000 suffer from migraines than people whose income is less than \$10,000.

(b) The derivatives are positive up to approximately 37 years old and negative after about 37 years of age. The percent of adults suffering from migraines increases up to about 37 years old, then decreases. The units of the derivative are percent of adults suffering from migraines per year.

78. (a) The attendance rate for football games, $g'(t)$, is greater at game 1.

(b) The attendance rate for basketball games, $f'(t)$, is greater than the rate for football games, $g'(t)$, at game 3.

(c) The attendance rate for basketball games, $f'(t)$, is greater than the rate for football games, $g'(t)$, at game 4. In addition, the attendance rate for football games is decreasing at game 4.

(d) At game 5, the attendance rate for football continues to increase, while the attendance rate for basketball continues to decrease.

79. $C = 7.75x + 500$

$C' = 7.75$, which equals the variable cost.

80. $C = 150x + 7000$

$P = R - C$

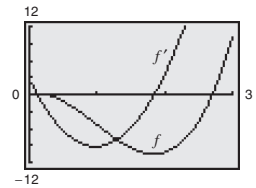
$P = 500x - (150x + 7000)$

$P = 350x - 7000$

$P' = 350$, which equals the profit on each dinner sold.

81. $f(x) = 4.1x^3 - 12x^2 + 2.5x$

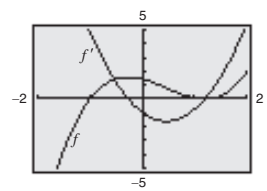
$f'(x) = 12.3x^2 - 24x + 2.5$



f has horizontal tangents at $(0.110, 0.135)$ and $(1.841, -10.486)$.

82. $f(x) = x^3 - 1.4x^2 - 0.96x + 1.44$

$f'(x) = 3x^2 - 2.8x - 0.96$



f has horizontal tangents at $(1.2, 0)$ and $(-0.267, 1.577)$.

83. False. Let $f(x) = x$ and $g(x) = x + 1$.

Then $f'(x) = g'(x) = 1$, but $f(x) \neq g(x)$.

84. True. c is a constant.

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Section 2.3 Rates of Change: Velocity and Marginals

Skills Warm Up

1. $\dfrac{-63-(-105)}{21-7} = \dfrac{42}{14}$
$= 3$

2. $\dfrac{-43-35}{6-(-7)} = \dfrac{-78}{13}$
$= -6$

3. $\dfrac{24-33}{9-6} = \dfrac{-9}{3} = -3$

4. $\dfrac{40-16}{18-8} = \dfrac{24}{10} = \dfrac{12}{5}$

5. $y = 4x^2 - 2x + 7$
$y' = 8x - 2$

6. $s = -2t^3 + 8t^2 - 7t$
$s' = -6t^2 + 16t - 7$

7. $s = -16t^2 + 24t + 30$
$s' = -32t + 24$

8. $y = -16x^2 + 54x + 70$
$y' = -32x + 54$

9. $A = \frac{1}{10}\left(-2r^3 + 3r^2 + 5r\right)$
$A' = \frac{1}{10}\left(-6r^2 + 6r + 5\right)$
$A' = -\frac{3}{5}r^2 + \frac{3}{5}r + \frac{1}{2}$

10. $y = \frac{1}{9}\left(6x^3 - 18x^2 + 63x - 15\right)$
$y' = \frac{1}{9}\left(18x^2 - 36x + 63\right)$
$y' = 2x^2 - 4x + 7$

11. $y = 12x - \dfrac{x^2}{5000}$
$y' = 12 - \dfrac{2x}{5000}$
$y' = 12 - \dfrac{x}{2500}$

12. $y = 138 + 74x - \dfrac{x^3}{10{,}000}$
$y' = 74 - \dfrac{3x^2}{10{,}000}$

1. (a) 1980–1986: $\dfrac{120-63}{6-0} = \$9.5$ billion/yr

(b) 1986–1992: $\dfrac{165-120}{12-6} = \$7.5$ billion/yr

(c) 1992–1998: $\dfrac{226-165}{18-12} \approx \$10.2$ billion/yr

(d) 1998–2004: $\dfrac{305-226}{24-18} \approx \$13.2$ billion/yr

(e) 2004–2010: $\dfrac{408-305}{30-24} \approx \$17.2$ billion/yr

(f) 1980–2012: $\dfrac{453-63}{32-0} \approx \$12.2$ billion/yr

(g) 1990–2012: $\dfrac{453-152}{32-10} \approx \$13.7$ billion/yr

(h) 2000–2012: $\dfrac{453-269}{32-20} \approx \$15.3$ billion/yr

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2. (a) Imports:

1980–1990: $\dfrac{495 - 245}{10 - 0} = \$25$ billion/yr

(b) Exports:

1980–1990: $\dfrac{394 - 226}{10 - 0} = \$16.8$ billion/yr

(c) Imports:

1990–2000: $\dfrac{1218 - 495}{20 - 10} \approx \$72.3$ billion/yr

(d) Exports:

1990–2000: $\dfrac{782 - 394}{20 - 10} = \$38.8$ billion/yr

(e) Imports:

2000–2010: $\dfrac{1560 - 1218}{29 - 20} = \$38.0$ billion/yr

(f) Exports:

2000–2010: $\dfrac{1056 - 782}{29 - 20} = \$30.4$ billion/yr

(g) Imports:

1980–2013: $\dfrac{2268 - 245}{33 - 0} \approx \$61.3$ billion/yr

(h) Exports:

1980–2013: $\dfrac{1580 - 226}{33 - 0} \approx \$41.0$ billion/yr

3. $f(t) = 3t + 5; [1, 2]$

Average rate of change:

$$\frac{\Delta y}{\Delta t} = \frac{f(2) - f(1)}{2 - 1} = \frac{11 - 8}{1} = 3$$

$$f'(t) = 3$$

Instantaneous rates of change: $f'(1) = 3,\ f'(2) = 3$

4. $h(x) = 7 - 2x; [1, 3]$

Average rate of change:

$$\frac{\Delta h}{\Delta t} = \frac{h(3) - h(1)}{3 - 1} = \frac{1 - 5}{2} = -2$$

$$h'(t) = -2$$

Instantaneous rates of change: $h(1) = -2,\ h(3) = -2$

5. $h(x) = x^2 - 4x + 2; [-2, 2]$

Average rate of change:

$$\frac{\Delta h}{\Delta x} = \frac{h(2) - h(-2)}{2 - (-2)} = \frac{-2 - 14}{4} = -4$$

$$h'(x) = 2x - 4$$

Instantaneous rates of change: $h'(-2) = -8,\ h'(2) = 0$

6. $f(x) = -x^2 - 6x - 5; [-3, 1]$

Average rate of change:

$$\frac{\Delta f}{\Delta x} = \frac{f(1) - f(-3)}{1 - (-3)} = \frac{-12 - 4}{4} = -4$$

$$f'(x) = -2x - 6$$

Instantaneous rates of change: $f'(-3) = 0,\ f'(1) = -8$

7. $f(x) = 3x^{4/3}; [1, 8]$

Average rate of change:

$$\frac{\Delta y}{\Delta x} = \frac{f(8) - f(1)}{8 - 1} = \frac{48 - 3}{7} = \frac{45}{7}$$

$$f'(x) = 4x^{1/3}$$

Instantaneous rates of change: $f'(1) = 4,\ f'(8) = 8$

8. $f(x) = x^{3/2}; [1, 4]$

Average rate of change:

$$\frac{\Delta y}{\Delta x} = \frac{f(4) - f(1)}{4 - 1} = \frac{8 - 1}{3} = \frac{7}{3}$$

$$f'(x) = \frac{3}{2}x^{1/2}$$

Instantaneous rates of change: $f'(1) = \dfrac{3}{2},\ f'(4) = 3$

9. $f(x) = \dfrac{1}{x}; [1, 5]$

Average rate of change:

$$\frac{\Delta y}{\Delta x} = \frac{f(5) - f(1)}{5 - 1} = \frac{\frac{1}{5} - 1}{3} = \frac{-\frac{4}{5}}{4} = -\frac{1}{5}$$

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

Instantaneous rates of change:

$$f'(1) = -1,\ f'(5) = -\frac{1}{25}$$

10. $f(x) = \dfrac{1}{\sqrt{x}}; [1, 9]$

Average rate of change:

$$\frac{\Delta y}{\Delta x} = \frac{f(9) - f(1)}{9 - 1} = \frac{\frac{1}{3} - 1}{8} = \frac{-\frac{2}{3}}{4} = -\frac{1}{6}$$

$$f'(x) = \frac{1}{2x^{3/2}}$$

Instantaneous rates of change:

$$f'(1) = -\frac{1}{2},\ f'(9) = \frac{1}{54}$$

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11. $f(t) = t^4 - 2t^2; [-2, -1]$

Average rate of change:

$$\frac{\Delta y}{\Delta x} = \frac{f(-1) - f(-2)}{-1 - (-2)} = \frac{-1 - 8}{1} = -9$$

$$f'(t) = 4t^3 - 4t$$

Instantaneous rates of change:

$$f'(-2) = -24,\ f'(-1) = 0$$

12. $g(x) = x^3 - 1; [-1, 1]$

Average rate of change:

$$\frac{\Delta y}{\Delta x} = \frac{g(1) - g(-1)}{1 - (-1)} = \frac{0 - (-2)}{2} = 1$$

$$g'(x) = 3x^2$$

Instantaneous rates of change:

$$g'(-1) = 3,\ g'(1) = 3$$

13. (a) $\approx \dfrac{0 - 1400}{3} \approx -467$

The number of visitors to the park is decreasing at an average rate of 467 people per month from September to December.

(b) Answers will vary. Sample answer: $[4, 11]$

Both the instantaneous rate of change at $t = 8$ and the average rate of change on $[4, 11]$ are about zero.

14. (a) $\dfrac{\Delta M}{\Delta t} = \dfrac{800 - 200}{3 - 1} = \dfrac{600}{2} = 300 \text{ mg/hr}$

(b) Answers will vary. Sample answer: $[2, 5]$

Both the instantaneous rate of change at $t = 4$ and the average rate of change on $[2, 5]$ is about zero.

15. $s = -16t^2 + 30t + 250$

Instantaneous: $v(t) = s'(t) = -32t + 30$

(a) Average: $[0, 1]$:

$$\frac{s(1) - s(0)}{1 - 0} = \frac{264 - 250}{1} = 14 \text{ ft/sec}$$

$$v(0) = s'(0) = 30 \text{ ft/sec}$$

$$v(1) = s'(1) = -2 \text{ ft/sec}$$

(b) Average: $[1, 2]$:

$$\frac{s(2) - s(1)}{2 - 1} = \frac{246 - 264}{1} = -18 \text{ ft/sec}$$

$$v(1) = s'(1) = -2 \text{ ft/sec}$$

$$v(2) = s'(2) = -34 \text{ ft/sec}$$

(c) Average: $[2, 3]$:

$$\frac{s(3) - s(2)}{3 - 2} = \frac{196 - 246}{1} = -50 \text{ ft/sec}$$

$$v(2) = s'(2) = -34 \text{ ft/sec}$$

$$v(3) = s'(3) = -66 \text{ ft/sec}$$

(d) Average: $[3, 4]$:

$$\frac{s(4) - s(3)}{4 - 3} = \frac{114 - 196}{1} = -82 \text{ ft/sec}$$

$$v(3) = s'(3) = -66 \text{ ft/sec}$$

$$v(4) = s'(4) = -98 \text{ ft/sec}$$

16. (a) $H'(v) = 33\left[10\left(\frac{1}{2}v^{-1/2}\right) - 1\right] = 33\left[\frac{5}{\sqrt{v}} - 1\right]$

Rate of change of heat loss with respect to wind speed.

(b) $H'(2) = 33\left[\frac{5}{\sqrt{2}} - 1\right]$

$$\approx 83.673 \frac{\text{kcal/m}^2\text{/hr}}{\text{m/sec}}$$

$$= 83.673 \frac{\text{kcal}}{\text{m}^3} \cdot \frac{\text{sec}}{\text{hr}}$$

$$= 83.673 \frac{\text{kcal}}{\text{m}^3} \cdot \frac{1}{3600}$$

$$= 0.023 \text{ kcal/m}^3$$

$H'(5) = 33\left[\frac{5}{\sqrt{5}} - 1\right]$

$$\approx 40.790 \frac{\text{kcal/m}^2\text{/hr}}{\text{m/sec}}$$

$$= 40.790 \frac{\text{kcal}}{\text{m}^3} \cdot \frac{\text{sec}}{\text{hr}}$$

$$= 40.790 \frac{\text{kcal}}{\text{m}^3} \cdot \frac{1}{3600}$$

$$= 0.11 \text{ kcal/m}^3$$

17. $s = -16t^2 + 555$

(a) Average velocity $= \dfrac{s(3) - s(2)}{3 - 2}$

$$= \frac{411 - 491}{1}$$

$$= -80 \text{ ft/sec}$$

(b) $v = s'(t) = -32t,\ v(2) = -64 \text{ ft/sec},$

$v(3) = -96 \text{ ft/sec}$

(c) $s = -16t^2 + 555 = 0$

$$16t^2 = 555$$

$$t^2 = \frac{555}{16}$$

$$t \approx 5.89 \text{ seconds}$$

(d) $v(5.89) \approx -188.5 \text{ ft/sec}$

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18. (a) $s(t) = -16t^2 - 18t + 210$

$v(t) = s'(t) = -32t - 18$

(b) $[1, 2]$: $\dfrac{s(2) - s(1)}{2 - 1} = \dfrac{110 - 176}{1} = -66$ ft/sec

(c) $v(1) = -50$ ft/sec

$v(2) = -82$ ft/sec

(d) Set $s(t) = 0$.

$-16t^2 - 18t + 210 = 0$

$$t = -\frac{(-18) \pm \sqrt{(-18)^2 - 4(-16)(210)}}{2(-16)} = \frac{18 \pm \sqrt{13{,}764}}{-32} \approx 3.10 \text{ sec}$$

(e) $v(3.10) = -117.2$ ft/sec

19. $C = 205{,}000 + 9800x$

$\dfrac{dC}{dx} = 9800$

20. $C = 150{,}000 + 7x^3$

$\dfrac{dC}{dx} = 21x^2$

21. $C = 55{,}000 + 470x - 0.25x^2,\ 0 \le x \le 940$

$\dfrac{dC}{dx} = 470 - 0.5x$

22. $C = 100\left(9 + 3\sqrt{x}\right)$

$\dfrac{dC}{dx} = 100\left[0 + 3\left(\dfrac{1}{2}x^{-1/2}\right)\right] = \dfrac{150}{\sqrt{x}}$

23. $R = 50x - 0.5x^2$

$\dfrac{dR}{dx} = 50 - x$

24. $R = 30x - x^2$

$\dfrac{dR}{dx} = 30 - 2x$

25. $R = -6x^3 + 8x^2 + 200x$

$\dfrac{dR}{dx} = -18x^2 + 16x + 200$

26. $R = 50\left(20x - x^{3/2}\right)$

$\dfrac{dR}{dx} = 50\left[20 - \dfrac{3}{2}x^{1/2}\right] = 1000 - 75\sqrt{x}$

27. $P = -2x^2 + 72x - 145$

$\dfrac{dP}{dx} = -4x + 72$

28. $P = -0.25x^2 + 2000x - 1{,}250{,}000$

$\dfrac{dP}{dx} = -0.5x + 2000$

29. $P = 0.0013x^3 + 12x$

$\dfrac{dP}{dx} = 0.0039x^2 + 12$

30. $P = -0.5x^3 + 30x^2 - 164.25x - 1000$

$\dfrac{dP}{dx} = -1.5x^2 + 60x - 164.25$

31. $C = 3.6\sqrt{x} + 500$

(a) $C'(x) = 1.8/\sqrt{x}$

$C'(9) = \$0.60$ per unit.

(b) $C(10) - C(9) \approx \$0.584$

(c) The answers are close.

32. $R = 2x\left(900 + 32x - x^2\right)$

(a) $R = 1800x + 64x^2 - 2x^3$

$R'(x) = 1800 + 128x - 6x^2$

$R'(14) = \$2416$

(b) $R(15) - R(14) = 2(15)\left[900 + 32(15) - 15^2\right] - 2(14)\left[900 + 32(14) - 14^2\right]$

$= 34{,}650 - 32{,}256 = \$2394$

(c) The answers are close.

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33. $P = -0.04x^2 + 25x - 1500$

(a) $\dfrac{dP}{dx} = -0.08x + 25 = P'(x)$

$P'(150) = \$13$

(b) $\dfrac{\Delta P}{\Delta x} = \dfrac{P(151) - P(150)}{151 - 150} = \dfrac{1362.96 - 1350}{1} = \$12.96$

(c) The results are close.

34. $P = 36{,}000 + 2048\sqrt{x} - \dfrac{1}{8x^2}, 150 \le x \le 275$

$$\frac{dP}{dx} = 2048\left(\frac{1}{2}x^{-1/2}\right) - \frac{1}{8}\left(-2x^{-3}\right)$$

$$= \frac{1024}{\sqrt{x}} + \frac{1}{4x^3}$$

(a) When $x = 150$, $\dfrac{dP}{dx} \approx \$83.61$.

(b) When $x = 175$, $\dfrac{dP}{dx} \approx \$77.41$.

(c) When $x = 200$, $\dfrac{dP}{dx} \approx \$72.41$.

(d) When $x = 225$, $\dfrac{dP}{dx} \approx \$68.27$.

(e) When $x = 250$, $\dfrac{dP}{dx} \approx \$64.76$.

(f) When $x = 275$, $\dfrac{dP}{dx} \approx \$61.75$.

35. $P = 1.73t^2 + 190.6t + 16{,}994$

(a) $P(0) = 16{,}994$ thousand people

$P(3) = 17{,}581.37$ thousand people

$P(6) = 18{,}199.88$ thousand people

$P(9) = 18{,}849.53$ thousand people

$P(12) = 19{,}530.32$ thousand people

$P(15) = 20{,}242.25$ thousand people

$P(18) = 20{,}985.32$ thousand people

$P(21) = 21{,}759.53$ thousand people

The population is increasing from 1990 to 2011.

(b) $\dfrac{dP}{dt} = P'(t) = 3.46t + 190.6$

$\dfrac{dP}{dt}$ represents the population growth rate.

(c) $P'(0) = 190.6$ thousand people per year

$P'(3) = 200.98$ thousand people per year

$P'(6) = 211.36$ thousand people per year

$P'(9) = 221.74$ thousand people per year

$P'(12) = 232.12$ thousand people per year

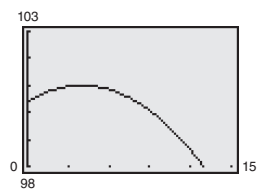
$P'(15) = 242.5$ thousand people per year

$P'(18) = 252.88$ thousand people per year

$P'(21) = 263.26$ thousand people per year

The rate of growth is increasing.

36. (a)



(b) For $t < 4$, the slopes are positive, and the fever is increasing. For $t > 4$, the slopes are negative, and the fever is decreasing.

(c) $T(0) = 100.4°\text{F}$

$T'(4) = 101°\text{F}$

$T(8) = 100.4°\text{F}$

$T(12) = 98.6°\text{F}$

(d) $\dfrac{dT}{dt} = -0.075t + 0.3$; the rate of change of temperature with respect to time

(e) $T'(0) = 0.3°\text{F}$ per hour

$T'(4) = 0°\text{F}$ per hour

$T'(8) = -0.3°\text{F}$ per hour

$T(12) = -0.6°\text{F}$ per hour

For $0 \le t < 4$, the rate of change of the temperature is positive; therefore, the temperature is increasing. For $4 < t \le 12$, the rate of change of the temperature is decreasing; therefore, the temperature is decreasing back to a normal temperature of $98.6°\text{F}$.

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37. (a) $TR = -10Q^2 + 160Q$

(b) $(TR)' = MR = -20Q + 160$

(c)

Q	0	2	4	6	8	10
Model	160	120	80	40	0	−40
Table	–	130	90	50	10	−30

38. (a) $R = xp = x(5 - 0.001x) = 5x - 0.001x^2$

(b) $P = R - C = (5x - 0.001x^2) - (35 + 1.5x)$

$= -0.001x^2 + 3.5x - 35$

(c) $\dfrac{dR}{dx} = 5 - 0.002x$

$\dfrac{dP}{dx} = 3.5 - 0.002x$

x	600	1200	1800	2400	3000
dR/dx	3.8	2.6	1.4	0.2	−1.0
dP/dx	2.3	1.1	−0.1	−1.3	−2.5
P	1705	2725	3025	2605	1465

39. (a) $(400, 1.75), (500, 1.50)$

$$\text{Slope} = \frac{1.50 - 1.75}{500 - 400} = -0.0025$$

$$p - 1.75 = -0.0025(x - 400)$$

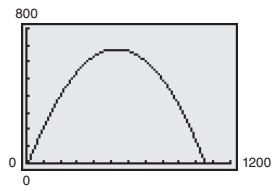
$$p = -0.0025x + 2.75$$

$$P = R - C = xp - c$$

$$= x(-0.0025x + 2.75) - (0.1x + 25)$$

$$= -0.0025x^2 + 2.65x - 25$$

(b)



At $x = 300$, P has a positive slope.

At $x = 530$, P has a 0 slope.

At $x = 700$, P has a negative slope.

(c) $P'(x) = -0.005x + 2.65$

$P'(300) = \$1.15$ per unit

$P'(530) = \$0$ per unit

$P'(700) = -\$.85$ per unit

40. $(36{,}000, 30), (32{,}000, 35)$

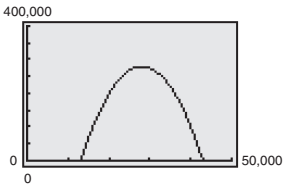
$$\text{Slope} = \frac{35 - 30}{32{,}000 - 36{,}000} = -\frac{5}{4000} = \frac{1}{800}$$

$$p - 30 = -\frac{1}{800}(x - 36{,}000)$$

$$p = -\frac{1}{800}x + 75 \text{ (demand function)}$$

(a) $P = R - C = xp - C = x\left(-\dfrac{1}{800}x + 75\right) - (5x + 700{,}000) = -\dfrac{1}{800}x^2 + 70x - 700{,}000$

(b)



At $x = 18{,}000$, P has a positive slope.

At $x = 28{,}000$, P has a 0 slope.

At $x = 36{,}000$, P has a negative slope.

(c) $P'(x) = -\dfrac{1}{400}x + 70$

$P'(18{,}000) = \$25$ per ticket

$P'(28{,}000) = \$0$ per ticket

$P'(36{,}000) = -\$20$ per ticket

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41. (a) $C(x) = \left(\dfrac{15{,}000 \text{ mi}}{\text{yr}}\right)\left(\dfrac{1 \text{ gal}}{x \text{ mi}}\right)\left(\dfrac{2.60 \text{ dollars}}{1 \text{ gal}}\right)$

$C(x) = \dfrac{39{,}000}{x}\,\dfrac{\text{dollars}}{\text{yr}}$

(b) $\dfrac{dC}{dx} = -\dfrac{39{,}000}{x^2}\,\dfrac{\frac{\text{dollars}}{\text{yr}}}{\text{mpg}}$

The marginal cost is the change of savings for a 1-mile per gallon increase in fuel efficiency.

(c)

x	10	15	20	25	30	35	40
C	3900	2600	1950	1560	1300	1114.29	975
dC/dx	−390	−173.33	−97.5	−62.4	−43.33	−31.84	−24.38

(d) The driver who gets 15 miles per gallon would benefit more than the driver who gets 35 miles per gallon. The value of dC/dx is a greater savings for $x = 15$ than for $x = 35$.

42. (a) $f'(2.959)$ is the rate of change of the number of gallons of gasoline sold when the price is $\$2.959/\text{gallon}$.

(b) In general, it should be negative. Demand tends to decrease as price increases. Answers will vary.

43. (a) Average rate of change from 2000 to 2013: $\dfrac{\Delta p}{\Delta t} = \dfrac{16{,}576.66 - 10{,}786.85}{13 - 0} \approx \$445.37/\text{yr}$

(b) Average rate of change from 2003 to 2007: $\dfrac{\Delta p}{\Delta t} = \dfrac{13{,}264.82 - 10{,}453.92}{7 - 3} \approx \$702.73/\text{yr}$

So, the instantaneous rate of change for 2005 is $p'(5) \approx \$702.73/\text{yr}$.

(c) Average rate of change from 2004 to 2006: $\dfrac{\Delta p}{\Delta t} = \dfrac{12{,}463.15 - 10{,}783.01}{6 - 4} \approx \$840.07/\text{yr}$

So, the instantaneous rate of change for 2005 is $p'(5) \approx \$840.07/\text{yr}$.

(d) The average rate of change from 2004 to 2006 is a better estimate because the data is closer to the years in question.

44. Answers will vary. *Sample answer:*
The rate of growth in the lag phase is relatively slow when compared with the rapid growth in the acceleration phase. The population grows slower in the deceleration phase, and there is no growth at equilibrium. These changes could be explained by food supply or seasonal growth.

Section 2.4 The Product and Quotient Rules

Skills Warm Up

1. $$\begin{aligned}(x^2+1)(2) + (2x+7)(2x) &= 2x^2 + 2 + 4x^2 + 14x \\ &= 6x^2 + 14x + 2 \\ &= 2(3x^2 + 7x + 1)\end{aligned}$$

2. $$\begin{aligned}(2x - x^3)(8x) + (4x^2)(2 - 3x^2) &= 16x^2 - 8x^4 + 8x^2 - 12x^4 \\ &= 24x^2 - 20x^4 \\ &= 4x^2(6 - 5x^2)\end{aligned}$$

3. $x(4)(x^2+2)^3(2x) + (x^2+4)(1) = 8x^2(x^2+2)^3(x^2+4)$

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Skills Warm Up —*continued*—

4. $x^2(2)(2x+1)(2) + (2x+1)^4(2x) = 4x^2(2x+1) + 2x(2x+1)^4$

$= 2x(2x+1)\left[2x + (2x+1)^3\right]$

5. $\dfrac{(2x+7)(5) - (5x+6)(2)}{(2x+7)^2} = \dfrac{10x + 35 - 10x - 12}{(2x+7)^2}$

$= \dfrac{23}{(2x+7)^2}$

6. $\dfrac{(x^2-4)(2x+1) - (x^2+x)(2x)}{(x^2-4)^2} = \dfrac{2x^3 + x^2 - 8x - 4 - 2x^3 - 2x^2}{(x^2-4)^2}$

$= \dfrac{-x^2 - 8x - 4}{(x^2-4)^2}$

7. $\dfrac{(x^2+1)(2) - (2x+1)(2x)}{(x^2+1)^2} = \dfrac{2x^2 + 2 - 4x^2 - 2x}{(x^2+1)^2}$

$= \dfrac{-2x^2 - 2x + 2}{(x^2+1)^2}$

$= \dfrac{-2(x^2 + x - 1)}{(x^2+1)^2}$

8. $\dfrac{(1-x^4)(4) - (4x-1)(-4x^3)}{(1-x^4)^2} = \dfrac{4 - 4x^4 + 16x^4 - 4x^3}{(1-x^4)^2}$

$= \dfrac{12x^4 - 4x^3 + 4}{(1-x^4)^2}$

$= \dfrac{4(3x^4 - x^3 + 1)}{(1-x^4)^2}$

9. $(x^{-1} + x)(2) + (2x-3)(-x^{-2} + 1) = 2x^{-1} + 2x + (-2x^{-1} + 2x + 3x^{-2} - 3)$

$= 4x + 3x^{-2} - 3$

$= 4x + \dfrac{3}{x^2} - 3$

$= \dfrac{4x^3 - 3x^2 + 3}{x^2}$

10. $\dfrac{(1-x^{-1})(1) - (x-4)(x^{-2})}{(1-x^{-1})^2} = \left(\dfrac{1 - x^{-1} - x^{-1} + 4x^{-2}}{1 - 2x^{-1} + x^{-2}}\right)\left(\dfrac{x^2}{x^2}\right)$

$= \dfrac{x^2 - 2x + 4}{x^2 - 2x + 1}$

$= \dfrac{x^2 - 2x + 4}{(x-1)^2}$

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Skills Warm Up —*continued*—

11. $f(x) = 3x^2 - x + 4$

$f'(x) = 6x - 1$

$f'(2) = 6(2) - 1$

$= 12 - 1$

$= 11$

12. $f(x) = -x^3 + x^2 + 8x$

$f'(x) = -3x^2 + 2x + 8$

$f'(2) = -3(2^2) + 2(2) + 8$

$= -3(4) + 4 + 8$

$= 0$

13. $f(x) = \dfrac{2}{7x} = \dfrac{2}{7}x^{-1}$

$f'(x) = -\dfrac{2}{7}x^{-2} = -\dfrac{2}{7x^2}$

$f'(2) = -\dfrac{2}{7(2)^2}$

$= -\dfrac{1}{14}$

14. $f(x) = x^2 - \dfrac{1}{x^2}$

$f'(x) = 2x + \dfrac{2}{x^3}$

$f'(2) = 2(2) + \dfrac{2}{2^3}$

$= 4 + \dfrac{2}{8}$

$= 4 + \dfrac{1}{4}$

$= \dfrac{17}{4}$

1. $f(x) = (2x - 3)(1 - 5x)$

$f'(x) = (2x - 3)(-5) + (1 - 5x)(2)$

$= -10x + 15 + 2 - 10x$

$= -20x + 17$

2. $g(x) = (4x - 7)(3x + 1)$

$g'(x) = (4x - 7)(3) + (3x + 1)(4)$

$= 12x - 21 + 12x + 4$

$= 24x - 17$

3. $f(x) = (6x - x^2)(4 + 3x)$

$f'(x) = (6x - x^2)(3) + (4 + 3x)(6 - 2x)$

$= 18x - 3x^2 + 24 - 8x + 18x - 6x^2$

$= -9x^2 + 28x + 24$

4. $f(x) = (5x - x^3)(2x + 9)$

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

$= 10x - 2x^3 + 10 - 6x^3 + 45 - 27x^2$

$= -8x^3 - 27x^2 + 20x + 45$

5. $f(x) = x(x^2 + 3)$

$f'(x) = x(2x) + (x^2 + 3)(1)$

$= 2x^2 + x^2 + 3$

$= 3x^2 + 3$

6. $f(x) = x^2(3x^3 - 1)$

$f'(x) = x^2(9x^2) + (3x^3 - 1)(2x)$

$= 9x^4 + 6x^4 - 2x$

$= 15x^4 - 2x$

7. $h(x) = \left(\dfrac{2}{x} - 3\right)(x^2 + 7) = (2x^{-1} - 3)(x^2 + 7)$

$h'(x) = (2x^{-1} - 3)(2x) + (x^2 + 7)(-2x^{-2})$

$= 4 - 6x - 2 - 14x^{-2}$

$= -6x + 2 - \dfrac{14}{x^2}$

8. $f(x) = (3 - x)\left(\dfrac{4}{x^2} - 5\right) = (3 - x)(4x^{-2} - 5)$

$f'(x) = (3 - x)(-8x^{-3}) + (4x^{-2} - 5)(-1)$

$= -24x^{-3} + 8x^{-2} - 4x^{-2} + 5$

$= -\dfrac{24}{x^3} + \dfrac{4}{x^2} + 5$

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9. $g(x) = (x^2 - 4x + 3)(x - 2)$

$$g'(x) = (x^2 - 4x + 3)(1) + (x - 2)(2x - 4)$$
$$= x^2 - 4x + 3 + 2x^2 - 4x - 4x + 8$$
$$= 3x^2 - 12x + 11$$

10. $g(x) = (x^2 - 2x + 1)(x^3 - 1)$

$$g'(x) = (x^2 - 2x + 1)(3x^2) + (x^3 - 1)(2x - 2)$$
$$= 3x^4 - 6x^3 + 3x^2 + 2x^4 - 2x^3 - 2x + 2$$
$$= 5x^4 - 8x^3 + 3x^2 - 2x + 2$$

11. $h(x) = \dfrac{x}{x - 5}$

$$h'(x) = \frac{(x - 5)(1) - x(1)}{(x - 5)^2} = \frac{x - 5 - x}{(x - 5)^2} = -\frac{5}{(x - 5)^2}$$

12. $h(x) = \dfrac{x^2}{x + 3}$

$$h'(x) = \frac{(x + 3)(2x) - x^2(1)}{(x + 3)^2}$$
$$= \frac{2x^2 + 6x - x^2}{(x + 3)^2}$$
$$= \frac{x^2 + 6x}{(x + 3)^2}$$

13. $f(t) = \dfrac{2t^2 - 3}{3t + 1}$

$$f'(t) = \frac{(3t + 1)(4t) - (2t^2 - 3)(3)}{(3t + 1)^2}$$
$$= \frac{12t^2 + 4t - 6t^2 + 9}{(3t + 1)^2}$$
$$= \frac{6t^2 + 4t + 9}{(3t + 1)^2}$$

14. $f(x) = \dfrac{7x + 3}{4x - 9}$

$$f'(x) = \frac{(4x - 9)(7) - (7x + 3)(4)}{(4x - 9)^2}$$
$$= \frac{28x - 63 - 28x - 12}{(x - 1)^2}$$
$$= -\frac{75}{(4x - 9)^2}$$

15. $f(t) = \dfrac{t + 6}{t^2 - 8}$

$$f'(t) = \frac{(t^2 - 8)(1) - (t + 6)(2t)}{(t^2 - 8)^2}$$
$$= \frac{t^2 - 8t - 2t^2 - 12t}{(t^2 - 8)^2}$$
$$= \frac{-t^2 - 12t - 8}{(t^2 - 8)^2}$$

16. $g(x) = \dfrac{4x - 5}{x^2 - 1}$

$$g'(x) = \frac{(x^2 - 1)(4) - (4x - 5)(2x)}{(x^2 - 1)^2}$$
$$= \frac{4x^2 - 4 - 8x^2 + 10x}{(x^2 - 1)^2}$$
$$= \frac{-4x^2 + 10x - 4}{(x^2 - 1)^2}$$

17. $f(x) = \dfrac{x^2 + 6x + 5}{2x - 1}$

$$f'(x) = \frac{(2x - 1)(2x + 6) - (x^2 + 6x + 5)(2)}{(2x - 1)^2}$$
$$= \frac{4x^2 + 12x - 2x - 6 - 2x^2 - 12x - 10}{(2x - 1)^2}$$
$$= \frac{2x^2 - 2x - 16}{(2x - 1)^2}$$

18. $f(x) = \dfrac{4x^2 - x + 2}{3 - 4x}$

$$f'(x) = \frac{(3 - 4x)(8x - 1) - (4x^2 - x + 2)(-4)}{(3 - 4x)^2}$$
$$= \frac{24x - 3 - 32x^2 + 4x + 16x^2 - 4x + 8}{(3 - 4x)^2}$$
$$= \frac{-16x^2 + 24x + 5}{(3 - 4x)^2}$$

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19. $f(x) = \dfrac{6 + 2x^{-1}}{3x - 1}$

$$f'(x) = \frac{(3x-1)(-2x^{-2}) - (6 + 2x^{-1})(3)}{(3x-1)^2}$$
$$= \frac{-6x^{-1} + 2x^{-2} - 18 - 6x^{-1}}{(3x-1)^2}$$
$$= \frac{2x^{-2} - 12x^{-1} - 18}{(3x-1)^2}$$
$$= \frac{\dfrac{2}{x^2} - \dfrac{12}{x} - 18}{(3x-1)^2} = \frac{2 - 12x - 18x^2}{x^2(3x-1)^2}$$

20. $f(x) = \dfrac{5 - x^{-2}}{x + 2}$

$$f'(x) = \frac{(x+2)(2x^{-3}) - (5 - x^{-2})(1)}{x + 2}$$
$$= \frac{2x^{-2} + 4x^{-3} - 5 + x^{-2}}{(x+2)^2}$$
$$= \frac{4x^{-3} + 3x^{-2} - 5}{(x+2)^2}$$
$$= \frac{\dfrac{4}{x^3} + \dfrac{3}{x^2} - 5}{(x+2)^2}$$
$$= \frac{4 + 2x - 5x^3}{x^3(x+2)^2}$$

	Function	*Rewrite*	*Differentiate*	*Simplify*
21.	$f(x) = \dfrac{x^3 + 6x}{3}$	$f(x) = \dfrac{1}{3}x^3 + 2x$	$f'(x) = x^2 + 2$	$f'(x) = x^2 + 2$
22.	$f(x) = \dfrac{x^3 + 2x^2}{10}$	$f(x) = \dfrac{1}{10}x^3 + \dfrac{1}{5}x^2$	$f'(x) = \dfrac{3}{10}x^2 + \dfrac{2}{5}x$	$f'(x) = \dfrac{3}{10}x^2 + \dfrac{2}{5}x$
23.	$y = \dfrac{7x^2}{5}$	$y = \dfrac{7}{5}x^2$	$y' = \dfrac{7}{5} \cdot 2x$	$y' = \dfrac{14}{5}x$
24.	$y = \dfrac{2x^4}{9}$	$y = \dfrac{2}{9}x^4$	$y' = \dfrac{2}{9} \cdot 4x^3$	$y' = \dfrac{8}{9}x^3$
25.	$y = \dfrac{7}{3x^3}$	$y = \dfrac{7}{3}x^{-3}$	$y' = -7x^{-4}$	$y' = -\dfrac{7}{x^4}$
26.	$y = \dfrac{4}{5x^2}$	$y = \dfrac{4}{5}x^{-2}$	$y' = -\dfrac{8}{5}x^{-3}$	$y' = -\dfrac{8}{5x^3}$
27.	$y = \dfrac{4x^2 - 3x}{8\sqrt{x}}$	$y = \dfrac{1}{2}x^{3/2} - \dfrac{3}{8}x^{1/2},\ x \neq 0$	$y' = \dfrac{3}{4}x^{1/2} - \dfrac{3}{16}x^{-1/2}$	$y' = \dfrac{3}{4}\sqrt{x} - \dfrac{3}{16\sqrt{x}}$
28.	$y = \dfrac{5(3x^2 + 2x)}{6\sqrt[3]{x}}$	$y = \dfrac{5}{2}x^{5/3} + \dfrac{5}{3}x^{5/3},\ x \neq 0$	$y' = \dfrac{25}{6}x^{2/3} + \dfrac{10}{9}x^{-1/3},\ x \neq 0$	$y' = \dfrac{25}{6}\sqrt[3]{x^2} + \dfrac{10}{9\sqrt[3]{x}}$
29.	$y = \dfrac{x^2 - 4x + 3}{2(x - 1)}$	$y = \dfrac{1}{2}(x - 3),\ x \neq 1$	$y' = \dfrac{1}{2}(1),\ x \neq 1$	$y' = \dfrac{1}{2},\ x \neq 1$
30.	$y = \dfrac{x^2 - 4}{4(x + 2)}$	$y = \dfrac{1}{4}(x - 2),\ x \neq -2$	$y' = \dfrac{1}{4}(1),\ x \neq -2$	$y' = \dfrac{1}{4},\ x \neq -2$

31. $f'(x) = (x^3 - 3x)(4x + 3) + (3x^2 - 3)(2x^2 + 3x + 5)$

$$= 4x^4 + 3x^3 - 12x^2 - 9x + 6x^4 + 9x^3 + 9x^2 - 9x - 15$$
$$= 10x^4 + 12x^3 - 3x^2 - 18x - 15$$

Product Rule and Simple Power Rule

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32. $h'(t) = (t^5 - 1)(8t - 7) + (5t^4)(4t^2 - 7t - 3)$

$= 8t^6 - 7t^5 - 8t + 7 + 20t^6 - 35t^5 - 15t^4$

$= 28t^6 - 42t^5 - 15t^4 - 8t + 7$

Product Rule and Simple Power Rule

33. $h(t) = \frac{1}{3}(6t - 4)$

$h'(t) = \frac{1}{3}(6) = 2$

Constant Multiple and Simple Power Rules

34. $f(x) = \frac{1}{2}(3x - 8)$

$f'(x) = \frac{1}{2}(3) = \frac{3}{2}$

Constant Multiple and Simple Power Rules

35. $f'(x) = \dfrac{(x^2 - 1)(3x^2 + 3) - (x^3 + 3x + 2)(2x)}{(x^2 - 1)^2}$

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

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

Quotient Rule and Simple Power Rule

36. $f(x) = \dfrac{2x^3 - 4x^2 - 9}{x^3 - 5}$

$f'(x) = \dfrac{(x^3 - 5)(3x^2 - 8x) - (2x^3 - 4x^2 - 9)(3x^2)}{(x^3 - 5)^2}$

$= \dfrac{3x^5 - 8x^4 - 15x^2 + 40x - 6x^5 + 12x^4 - 27x^2}{(x^3 - 5)^2}$

$= \dfrac{-3x^5 + 4x^4 - 42x^2 + 40x}{(x^3 - 5)^2}$

Quotient Rule and Simple Power Rule

37. $f(x) = \dfrac{x^2 - x - 20}{x + 4} = \dfrac{(x - 5)(x + 4)}{(x + 4)} = x - 5,\ x \neq -4$

$f'(x) = 1$

Simple Power Rule

38. $h(t) = \dfrac{3t^2 + 22t + 7}{t + 7} = \dfrac{(3t + 1)(1 + 7)}{t + 7} = 3t + 1,\ t \neq -7$

$h'(t) = 3,\ t \neq -7$

Simple Power Rule

39. $g(t) = (2t^3 - 1)^2 = (2t^3 - 1)(2t^3 - 1)$

$g'(t) = (2t^3 - 1)(6t^2) + (2t^3 - 1)(6t^2)$

$= 12t^2(2t^3 - 1)$

Product Rule and Simple Power Rule

40. $f(x) = (4x^3 - 2x - 3)^2 = (4x^3 - 2x - 3)(4x^3 - 2x - 3)$

$f'(x) = (4x^3 - 2x - 3)(12x^2 - 2) + (4x^3 - 2x - 3)(12x^2 - 2)$

$= 48x^5 - 24x^3 - 36x^2 - 8x^3 + 4x + 6 + 48x^5 - 24x^3 - 36x^2 - 8x^3 + 4x + 6$

$= 96x^5 - 48x^3 - 72x^2 - 16x^3 + 8x + 12$

Product Rule and Simple Power Rule

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41. $g(s) = \dfrac{s^2 - 2s + 5}{\sqrt{s}} = \dfrac{s^2 - 2s + 5}{s^{1/2}}$

$$g'(s) = \frac{s^{1/2}(2s - 2) - \left(s^2 - 2s + 5\right)\left(\frac{1}{2}s^{-1/2}\right)}{s}$$

$$= \frac{2s^{3/2} - 2s^{1/2} - \frac{1}{2}s^{3/2} + s^{1/2} - \frac{5}{2}s^{-1/2}}{s}$$

$$= \frac{3}{2}s^{1/2} - s^{-1/2} - \frac{5}{2}s^{-3/2} = \frac{3s^2 - 2s - 5}{2s^{3/2}}$$

Quotient Rule and Simple Power Rule

42. $f(x) = \dfrac{x^3 - 5x^2 - 6x}{\sqrt{x}} = \dfrac{x^3 - 5x^2 - 6x}{x^{1/2}}$

$$= x^{5/2} - 5x^{3/2} - 6x^{1/2}$$

$$f'(x) = \frac{5}{2}x^{3/2} - \frac{15}{2}x^{1/2} - 3x^{-1/2}$$

$$= \frac{5}{2}x^{3/2} - \frac{15}{2}x^{1/2} - \frac{3}{x^{1/2}}$$

$$= \frac{5x^2 - 15x - 6}{2x^{1/2}}$$

Constant Multiple and Simple Power Rules

43. $f(x) = \dfrac{(x - 2)(3x + 1)}{4x + 2} = \dfrac{3x^2 - 5x - 2}{4x + 2}$

$$f'(x) = \frac{(4x + 2)(6x - 5) - \left(3x^2 - 5x - 2\right)(4)}{(4x + 2)^2}$$

$$= \frac{24x^2 - 8x - 10 - 12x^2 + 20x + 8}{(4x + 2)^2}$$

$$= \frac{12x^2 + 12x - 2}{4(2x + 1)^2}$$

$$= \frac{2\left(6x^2 + 6x - 1\right)}{2(2x + 1)^2}$$

$$= \frac{6x^2 + 6x - 1}{2(2x + 1)^2}$$

Quotient Rule and Simple Power Rule

44. $f(x) = \dfrac{(x + 1)(2x - 7)}{2x + 1} = \dfrac{2x^2 - 5x - 7}{2x + 1}$

$$f'(x) = \frac{(2x + 1)(4x - 5) - \left(2x^2 - 5x - 7\right)(2)}{(2x + 1)^2}$$

$$= \frac{8x^2 - 6x - 5 - 4x^2 + 10x + 14}{(2x + 1)^2}$$

$$= \frac{4x^2 + 4x + 9}{(2x + 1)^2}$$

Quotient Rule and Simple Power Rule

45. $f(x) = (x + 4)(2x + 9)(x - 3)$

$$= \left(2x^2 + 17x + 36\right)(x - 3)$$

$$f'(x) = \left(2x^2 + 17x + 36\right)(1) + (x - 3)(4x + 17)$$

$$= \left(2x^2 + 17x + 36\right) + \left(4x^2 + 5x - 51\right)$$

$$= 6x^2 + 22x - 15$$

Product Rule and Simple Power Rule

46. $f(x) = \left(3x^3 + 4x\right)(x - 5)(x + 1)$

$$= \left(3x^3 + 4x\right)\left(x^2 - 4x - 5\right)$$

$$f'(x) = \left(3x^3 + 4x\right)(2x - 4) + \left(x^2 - 4x - 5\right)\left(9x^2 + 4\right)$$

$$= \left(6x^4 - 12x^3 + 8x^2 - 16x\right)$$

$$+ \left(9x^4 - 36x^3 - 41x^2 - 16x - 20\right)$$

$$= 15x^4 - 48x^3 - 33x^2 - 32x - 20$$

Product Rule and Simple Power Rule

47. $f(x) = (5x + 2)\left(x^2 + x\right)$

$$f'(x) = (5x + 2)(2x + 1) + \left(x^2 + x\right)(5)$$

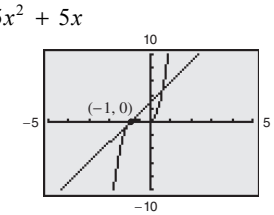
$$= 10x^2 + 9x + 2 + 5x^2 + 5x$$

$$= 15x^2 + 14x + 2$$

$$m = f'(-1) = 3$$

$$y - 0 = 3\left(x - (-1)\right)$$

$$y = 3x + 3$$



48. $f(x) = \left(x^2 - 1\right)\left(x^3 - 3x\right)$

$$f'(x) = \left(x^2 - 1\right)\left(3x^2 - 3\right) + \left(x^2 - 3x\right)(2x)$$

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

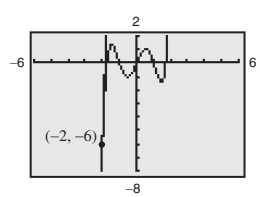
$$= 5x^4 - 12x^2 + 3$$

$$m = f'(-2) = 5(-2)^4 - 12(-2)^2 + 3 = 35$$

$$y - (-6) = 35\left(x - (-2)\right)$$

$$y + 6 = 35x + 70$$

$$y = 35x + 64$$



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49. $f(x) = x^3(x^2 - 4)$

$f'(x) = x^2(2x) + (x^2 - 4)(3x^2)$

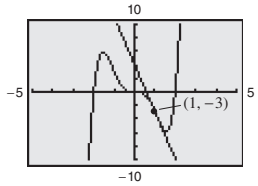
$= 2x^4 + 3x^4 - 12x^2$

$= 5x^4 - 12x^2$

$m = f'(1) = -7$

$y - (-3) = -7(x - 1)$

$y = -7x + 4$



50. $f(x) = \sqrt{x}(x - 3) = x^{1/2}(x - 3)$

$f'(x) = x^{1/2}(1) + (x - 3)\left(\frac{1}{2}x^{-1/2}\right)$

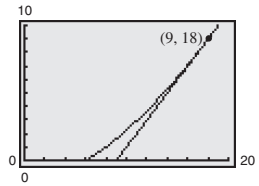
$= x^{1/2} + \frac{1}{2}x^{1/2} - \frac{3}{2}x^{-1/2}$

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

$m = f'(9) = \frac{3}{2}(9)^{1/2} - \frac{3}{2}(9)^{-1/2} = \frac{9}{2} - \frac{1}{2} = 4$

$y - 18 = 4(x - 9)$

$y = 4x - 18$



51. $f(x) = \dfrac{3x - 2}{x + 1}$

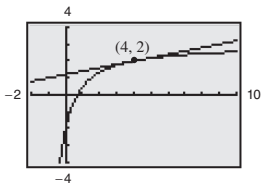
$f'(x) = \dfrac{(x + 1)(3) - (3x - 2)(1)}{(x + 1)^2} = \dfrac{3x + 3 - 3x + 2}{(x + 1)^2} = \dfrac{5}{(x + 1)^2}$

$f'(4) = \dfrac{1}{5}$

$y - 2 = \dfrac{1}{5}(x - 4)$

$y - 2 = \dfrac{1}{5}x - \dfrac{4}{5}$

$y = \dfrac{1}{5}x + \dfrac{6}{5}$

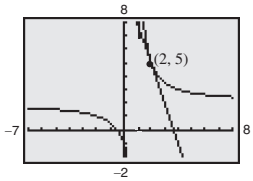


52. $f'(x) = \dfrac{(x - 1)2 - (2x + 1)}{(x - 1)^2} = \dfrac{-3}{(x - 1)^2}$

$f'(2) = -3$

$y - 5 = -3(x - 2)$

$y = -3x + 11$



53. $f(x) = \dfrac{(3x - 2)(6x + 5)}{2x - 3} = \dfrac{18x^2 + 3x - 10}{2x - 3}$

$f'(x) = \dfrac{(2x - 3)(36x + 3) - (18x^2 + 3x - 10)(2)}{(2x - 3)^2}$

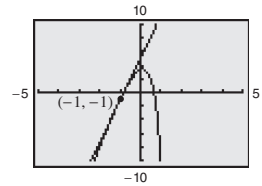
$= \dfrac{72x^2 - 102x - 9 - 36x^2 - 6x - 20}{(2x - 3)^2}$

$= \dfrac{36x^2 - 108x + 11}{(2x - 3)^2}$

$m = f'(-1) = \dfrac{36(-1)^2 - 108(-1) + 11}{(2(-1) - 3)^2} = \dfrac{31}{5}$

$y - (-1) = \dfrac{31}{5}(x - (-1))$

$y = \dfrac{31}{5}x + \dfrac{26}{5}$



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54. $f(x) = \dfrac{(x+2)(x^2+x)}{x-4} = \dfrac{x^3+3x^2+2x}{x-4}$

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

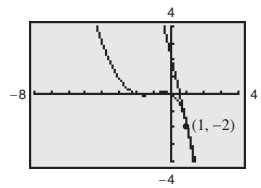
$$= \frac{3x^3-12x^2+6x^2-24x+2x-8-x^3-3x^2-2x}{(x-4)^2}$$

$$= \frac{2x^3-9x^2-24x-8}{(x-4)^2}$$

$$m = f'(1) = \frac{2(1)^3-9(1)^2-24(1)-8}{(1-4)^2} = -\frac{13}{3}$$

$$y-(-2) = -\frac{13}{3}(x-1)$$

$$y = \frac{13}{3}x + \frac{7}{3}$$



55. $f'(x) = \dfrac{(x-1)(2x)-x^2(1)}{(x-1)^2} = \dfrac{x^2-2x}{(x-1)^2}$

$f'(x) = 0$ when $x^2-2x = x(x-2) = 0$, which implies that $x = 0$ or $x = 2$. Thus, the horizontal tangent lines occur at $(0, 0)$ and $(2, 4)$.

56. $f'(x) = \dfrac{(x^2+1)(2x)-(x^2)(2x)}{(x^2+1)^2} = \dfrac{2x}{(x^2+1)^2}$

$f'(x) = 0$ when $2x = 0$, which implies that $x = 0$. Thus, the horizontal tangent line occurs at $(0, 0)$.

57. $f'(x) = \dfrac{(x^3+1)(4x^3)-x^4(3x^2)}{(x^3+1)^2} = \dfrac{x^6+4x^3}{(x^3+1)^2}$

$f'(x) = 0$ when $x^6+4x^3 = x^3(x^3+4) = 0$, which implies that $x = 0$ or $x = \sqrt[3]{-4}$. Thus, the horizontal tangent lines occur at $(0, 0)$ and $(\sqrt[3]{-4}, -2.117)$.

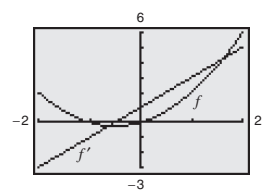
58. $f'(x) = \dfrac{(x^2+1)(4x^3)-(x^4+3)(2x)}{(x^2+1)^2}$

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

$f'(x) = 0$ when $2x(x^2+3)(x^2-1) = 0$, which implies that $x = 0$ or $x = \pm 1$. Thus, the horizontal tangent lines occur at $(0, 3)$, $(1, 2)$, and $(-1, 2)$.

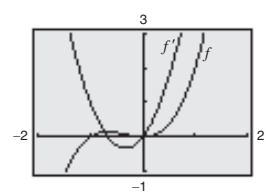
59. $f(x) = x(x+1) = x^2+x$

$f'(x) = 2x+1$



60. $f(x) = x^2(x+1) = x^3+x^2$

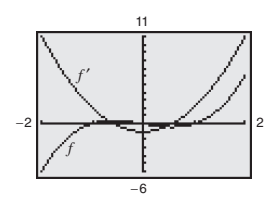
$f'(x) = 3x^2+2x = x(3x+2)$



61. $f(x) = x(x+1)(x-1)$

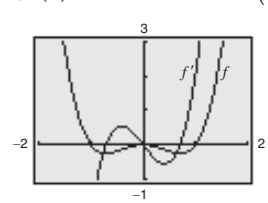
$= x^3-x$

$f'(x) = 3x^2-1$



62. $f(x) = x^2(x+1)(x-1) = x^4-x^2$

$f'(x) = 4x^3-2x = 2x(2x^2-1)$



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63. $x = 275\left(1 - \dfrac{3p}{5p+1}\right)$

$$\frac{dx}{dp} = -275\left[\frac{(5p+1)3 - (3p)(5)}{(5p+1)^2}\right] = -275\left[\frac{3}{(5p+1)^2}\right]$$

When $p = 4$, $\dfrac{dx}{dp} = -275\left[\dfrac{3}{(21)^2}\right] \approx -1.87$ units per dollar.

64. $\dfrac{dx}{dp} = 0 - 1 - \dfrac{(p+1)(2) - (2p)(1)}{(p+1)^2}$

$$= -1 - \frac{2}{(p+1)^2}$$

$$= \frac{-(p+1)^2 - 2}{(p+1)^2}$$

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

When $p = 3$, $\dfrac{dx}{dp} = \dfrac{-9 - 6 - 3}{16} \approx -1.13$ units per dollar.

65. $P' = 500\left[\dfrac{(50+t^2)(4) - (4t)(2t)}{(50+t^2)^2}\right] = 500\left[\dfrac{200 - 4t^2}{(50+t^2)^2}\right]$

When $t = 2$, $P' = 500\left[\dfrac{184}{(54)^2}\right] \approx 31.55$ bacteria/hour.

66. $\dfrac{dP}{dt} = \dfrac{50(t+2)(1) - (t+1750)(50)}{[50(t+2)]^2}$

$$= \frac{50[(t+2) - (t+1750)]}{2500(t+2)^2}$$

$$= \frac{-1748}{50(t+2)^2}$$

$$= \frac{-874}{25(t+2)^2}$$

(a) When $t = 1$, $\dfrac{dP}{dt} = \dfrac{-874}{225} \approx -3.88$ percent/day.

(b) When $t = 10$, $\dfrac{dP}{dt} = \dfrac{-874}{3600}$

$$= -\frac{437}{1800}$$

$$\approx -0.24 \text{ percent/day.}$$

67. $P = \dfrac{t^2 - t + 1}{t^2 + 1}$

$$P' = \frac{(t^2+1)(2t-1) - (t^2 - t + 1)(2t)}{(t^2+1)^2} = \frac{t^2 - 1}{(t^2+1)^2}$$

(a) $P'(0.5) = -0.480$/week

(b) $P'(2) = 0.120$/week

(c) $P'(8) = 0.015$/week

Each rate in parts (a), (b), and (c) is the rate at which the level of oxygen in the pond is changing at that particular time.

68. $T = 10\left(\dfrac{4t^2 + 16t + 75}{t^2 + 4t + 10}\right)$

Initial temperature: $T(0) = 75°\text{F}$

$$T'(t) = 10\left(\frac{(t^2 + 4t + 10)(8t + 16) - (4t^2 + 16t + 75)(2t + 4)}{(t^2 + 4t + 10)^2}\right) = \frac{-700(t+2)}{(t^2 + 4t + 10)^2}$$

(a) $T'(1) \approx -9.33°\text{F/hr}$

(b) $T'(3) \approx -3.64°\text{F/hr}$

(c) $T'(5) \approx -1.62°\text{F/hr}$

(d) $T'(10) \approx -0.37°\text{F/hr}$

Each rate in parts (a), (b), (c), and (d) is the rate at which the temperature of the food in the refrigerator is changing at that particular time.

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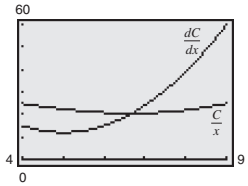
69. $C = x^3 - 15x^2 + 87x - 73,\ 4 \le x \le 9$

Marginal cost: $\dfrac{dC}{dx} = 3x^2 - 30x + 87$

Average cost: $\dfrac{C}{x} = x^2 - 15x + 87 - \dfrac{73}{x}$

(a)



(b) Point of intersection:

$$3x^2 - 30x + 87 = x^2 - 15x + 87 - \frac{73}{x}$$

$$2x^2 - 15x + \frac{73}{x} = 0$$

$$2x^3 - 15x^2 + 73 = 0$$

$$x \approx 6.683$$

When $x = 6.683$, $\dfrac{C}{x} = \dfrac{dC}{dx} \approx 20.50$.

Thus, the point of intersection is (6.683, 20.50). At this point average cost is at a minimum.

70. (a) As time passes, the percent of people aware of the product approaches approximately 95%.

(b) As time passes, the rate of change of the percent of people aware of the product approaches zero.

71. $C = 100\left(\dfrac{200}{x^2} + \dfrac{x}{x+30}\right),\ x \ge 1$

$$C' = 100\left[-2\left(200x^{-3}\right) + \frac{(x+30) - x}{(x+30)^2}\right]$$

$$= 100\left[-\frac{400}{x^3} + \frac{30}{(x+30)^2}\right]$$

(a) $C'(10) = 100\left(-\dfrac{400}{10^3} + \dfrac{30}{40^2}\right) = -38.125$

(b) $C'(15) \approx -10.37$

(c) $C'(20) \approx -3.8$

Increasing the order size reduces the cost per item. An order size of 2000 should be chosen since the cost per item is the smallest at $x = 20$.

72. (a) $P = ax^2 + bx + c$

When $x = 10$, $P = 50$: $50 = 100a + 10b + c$.

When $x = 12$, $P = 60$: $60 = 144a + 12b + c$.

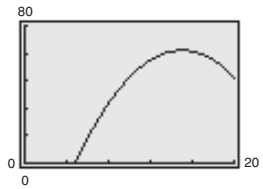
When $x = 14$, $P = 65$: $65 = 196a + 14b + c$.

Solving this system, we have

$a = -\frac{5}{8}$, $b = \frac{75}{4}$, and $c = -75$.

Thus, $P = -\frac{5}{8}x^2 + \frac{75}{4}x - 75$.

(b)



(c) Marginal profit: $P' = -\frac{5}{4}x + \frac{75}{4} = 0 \Rightarrow x = 15$

This is the maximum point on the graph of P, so selling 15 units will maximize the profit.

73. $f(x) = 2g(x) + h(x)$

$f'(x) = 2g'(x) + h'(x)$

$f'(2) = 2(-2) + 4 = 0$

74. $f(x) = 3 - g(x)$

$f'(x) = -g'(x)$

$f'(2) = -(-2) = 2$

75. $f(x) = g(x)h(x)$

$$f'(x) = g(x)h'(x) + h(x)g'(x)$$

$$f'(2) = g(2)h'(2) + h(2)g'(2)$$

$$= (3)(4) + (-1)(-2)$$

$$= 14$$

76. $f(x) = \dfrac{g(x)}{h(x)}$

$$f'(x) = \frac{h(x)g'(x) - g(x)h'(x)}{\left[h(x)\right]^2}$$

$$f'(2) = \frac{(-1)(-2) - (3)(4)}{(-1)^2} = -10$$

77. Answers will vary.

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Chapter 2 Quiz Yourself

1. $f(x) = 5x + 3$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{[5(x + \Delta x) + 3] - (5x + 3)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{5x + 5\Delta x + 3 - 5x - 3}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{5\Delta x}{\Delta x}$$
$$= \lim_{\Delta x \to 0} 5 = 5$$

At $(-2, -7)$: $m = 5$

2. $f(x) = \sqrt{x + 3}$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{\sqrt{x + \Delta x + 3} - \sqrt{x + 3}}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{x + \Delta x + 3 - (x + 3)}{\Delta x\left(\sqrt{x + \Delta x + 3} + \sqrt{x + 3}\right)}$$
$$= \lim_{\Delta x \to 0} \frac{1}{\sqrt{x + \Delta x + 3} + \sqrt{x + 3}}$$
$$= \frac{1}{2\sqrt{x + 3}}$$

At $(1, 2)$: $m = \dfrac{1}{2\sqrt{1 + 3}} = \dfrac{1}{4}$

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

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{\left[3(x + \Delta x) - (x + \Delta x)^2\right] - \left(3x - x^2\right)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{3x + 3\Delta x - \left(x^2 + 2x(\Delta x) + (\Delta x)^2\right) - \left(3x - x^2\right)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{3x + 3\Delta x - x^2 - 2x(\Delta x) - (\Delta x)^2 - 3x + x^2}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{3x - 2x(\Delta x) - (\Delta x)^2}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{\Delta x(3 - 2x - \Delta x)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} (3 - 2x - \Delta) = 3 - 2x$$

At $(4, -4)$: $m = 3 - 2(4) = 3 - 8 = -5$

4. $f(x) = 12$

$f'(x) = 0$

5. $f(x) = 19x + 9$

$f'(x) = 19$

6. $f(x) = x^4 - 3x^3 - 5x^2 + 8$

$f'(x) = 4x^3 - 9x^2 - 10x$

7. $f(x) = 12x^{1/4}$

$f'(x) = 3x^{-3/4} = \dfrac{3}{x^{3/4}}$

8. $f(x) = 4x^{-2}$

$f'(x) = -8x^{-3} = -\dfrac{8}{x^3}$

9. $f(x) = 10x^{-1/5} + x^{-3}$

$f'(x) = -2x^{-6/5} - 3x^{-4} = -\dfrac{2}{x^{-6/5}} - \dfrac{3}{x^4}$

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10. $f(x) = \dfrac{2x+3}{3x+2}$

$$f'(x) = \frac{(3x+2)(2)-(2x+3)(3)}{(3x+2)^2}$$
$$= \frac{6x+4-6x-9}{(3x+2)^2}$$
$$= -\frac{5}{(3x+2)^2}$$

11. $f(x) = (x^2+1)(-2x+4)$

$$f'(x) = (x^2+1)(-2) + (-2x+4)(2x)$$
$$= -6x^2 + 8x - 2$$

12. $f(x) = (x^2+3x+4)(5x-2)$

$$f'(x) = (x^2+3x+4)(5) + (5x-2)(2x+3)$$
$$= 5x^2 + 15x + 20 + 10x^2 + 11x - 6$$
$$= 15x^2 + 26x + 14$$

13. $f(x) = \dfrac{4x}{x^2+3}$

$$f'(x) = \frac{(x^2+3)(4) - 4x(2x)}{(x^2+3)^2}$$
$$= \frac{4x^2+12-8x^2}{(x^2+3)^2}$$
$$= \frac{-4x^2+12}{(x^2+3)^2}$$
$$= \frac{-4(x^2-3)}{(x^2+3)^2}$$

14. $f(x) = x^2 - 3x + 1; [0, 3]$

Average rate of change:

$$\frac{\Delta y}{\Delta x} = \frac{f(3)-f(0)}{3-0} = \frac{1-1}{3} = 0$$

$$f'(x) = 2x - 3$$

Instantaneous rates of change: $f'(0) = -3,\ f'(3) = 3$

15. $f(x) = 2x^3 + x^3 - x + 4; [-1, 1]$

Average rate of change:

$$\frac{\Delta y}{\Delta x} = \frac{f(1)-f(-1)}{1-(-1)} = \frac{6-4}{2} = 1$$

$$f'(x) = 6x^2 + 2x - 1$$

Instantaneous rates of change: $f'(-1) = 3,\ f'(1) = 7$

16. $f(x) = \dfrac{1}{3x}; [-5, -2]$

Average rate of change:

$$\frac{\Delta y}{\Delta x} = \frac{f(-2)-f(5)}{-2-(-5)} = \frac{-\frac{1}{6}-\left(-\frac{1}{15}\right)}{3} = \frac{-\frac{3}{30}}{3} = -\frac{1}{30}$$

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

Instantaneous rates of change:

$$f'(-2) = -\frac{1}{12},\ f'(-5) = -\frac{1}{75}$$

17. $f(x) = \sqrt[3]{x}; [8, 27]$

Average rate of change:

$$\frac{\Delta y}{\Delta x} = \frac{f(27)-f(8)}{27-8} = \frac{3-2}{19} = \frac{1}{19}$$

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

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

Instantaneous rates of change: $f'(8) = \dfrac{1}{12}$,

$$f'(27) = \frac{1}{27}$$

18. $P = -0.0125x^2 + 16x - 600$

(a) $\dfrac{dP}{dx} = -0.025x + 16$

When $x = 175$, $\dfrac{dP}{dx} = \$11.625$.

(b) $P(176) - P(175) = 1828.8 - 1817.1875$
$= \$11.6125$

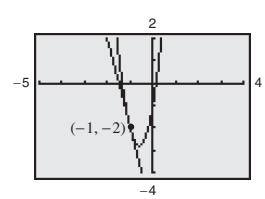
(c) The results are approximately equal.

19. $f(x) = 5x^2 + 6x - 1$

$$f'(x) = 10x + 6$$

At $(-1, -2)$, $m = -4$.

$$y + 2 = -4(x+1)$$
$$y = -4x - 6$$



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20. $f(x) = \dfrac{8}{\sqrt{x^3}} = 8x^{-3/2}$

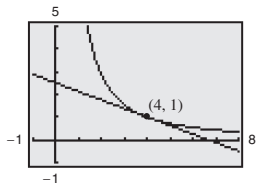
$f'(x) = -12x^{-5/2} = -\dfrac{12}{x^{5/2}} = -\dfrac{12}{x^2\sqrt{x}}$

$m = f'(4) = -\dfrac{12}{(4)^2\sqrt{4}} = -\dfrac{3}{8}$

$y - 1 = -\dfrac{3}{8}(x - 4)$

$y - 1 = -\dfrac{3}{8}x + \dfrac{3}{2}$

$y = -\dfrac{3}{8}x + \dfrac{5}{2}$



21. $f(x) = (x^2 + 1)(4x - 3)$

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

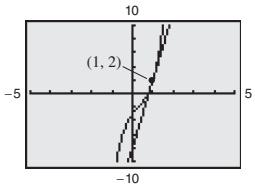
$= 4x^2 + 4 + 8x^2 - 6x$

$= 12x^2 - 6x + 4$

$m = f'(1) = 12(1)^2 - 6(1) + 4 = 10$

$y - 2 = 10(x - 1)$

$y = 10x - 8$



22. $f(x) = \dfrac{5x + 4}{2 - 3x}$

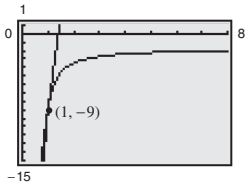
$f'(x) = \dfrac{(2 - 3x)(5) - (5x + 4)(-3)}{(2 - 3x)^2} = \dfrac{10 - 15x + 15x + 12}{(2 - 3x)^2} = \dfrac{22}{(2 - 3x)^2}$

$m = f'(1) = \dfrac{22}{(2 - 3(1))^2} = 22$

$y - (-9) = 22(x - 1)$

$y + 9 = 22x - 22$

$y = 22x - 31$



23. $S = -0.01722t^3 + 0.7333t^2 - 7.657t + 45.47,\ 7 \le t \le 13$

(a) $\dfrac{dS}{dt} = S'(t) = -0.051666t^2 + 1.4666t - 7.657$

(b) 2008: $S'(8) \approx \$0.77/\text{yr}$

2011: $S'(11) \approx \$2.22/\text{yr}$

2012: $S'(12) \approx \$2.50/\text{yr}$

Section 2.5 The Chain Rule

Skills Warm Up

1. $\sqrt[5]{(1 - 5x)^2} = (1 - 5x)^{2/5}$

2. $\sqrt[4]{(2x - 1)^3} = (2x - 1)^{3/4}$

3. $\dfrac{1}{\sqrt{4x^2 + 1}} = (4x^2 + 1)^{-1/2}$

4. $\dfrac{1}{\sqrt[6]{2x^3 + 9}} = (2x^3 + 9)^{-1/6}$

5. $\dfrac{\sqrt{x}}{\sqrt[3]{1 - 2x}} = x^{1/2}(1 - 2x)^{-1/3}$

6. $\dfrac{\sqrt{(3 - 7x)^3}}{2x} = \dfrac{(3 - 7x)^{3/2}}{2x} = (2x)^{-1}(3 - 7x)^{3/2}$

7. $3x^3 - 6x^2 + 5x - 10 = 3x^2(x - 2) + 5(x - 2)$

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

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Skills Warm Up —*continued*—

8. $5x\sqrt{x} - x - 5\sqrt{x} + 1 = x\left(5\sqrt{x} - 1\right) - 1\left(5\sqrt{x} - 1\right)$
$= (x - 1)\left(5\sqrt{x} - 1\right)$

9. $4\left(x^2 + 1\right)^2 - x\left(x^2 + 1\right)^3 = \left(x^2 + 1\right)^2\left[4 - x\left(x^2 + 1\right)\right]$
$= \left(x^2 + 1\right)^2\left(4 - x^3 - x\right)$

10. $-x^5 + 6x^3 + 7x^2 - 42 = -x^3\left(x^2 - 6\right) + 7\left(x^2 - 6\right)$
$= \left(-x^3 + 7\right)\left(x^2 - 6\right)$
$= -\left(x^3 - 7\right)\left(x^2 - 6\right)$

	$y = f(g(x))$	$u = g(x)$	$y = f(u)$
1.	$y = (6x - 5)^4$	$u = 6x - 5$	$y = u^4$
2.	$y = \left(x^2 - 2x + 3\right)^3$	$u = x^2 - 2x + 3$	$y = u^3$
3.	$y = \sqrt{5x - 2}$	$u = 5x - 2$	$y = \sqrt{u}$
4.	$y = \sqrt[3]{9 - x^2}$	$u = 9 - x^2$	$y = \sqrt[3]{u}$
5.	$y = (3x + 1)^{-1}$	$u = 3x + 1$	$y = u^{-1}$
6.	$y = \left(x^2 - 3\right)^{-1/2}$	$u = x^2 - 3$	$y = u^{-1/2}$

7. $y = (4x + 7)^2$
$y' = 2(4x + 7)^1(4)$
$y' = 8(4x + 7)$
$= 32x + 56$

8. $y = \left(3x^2 - 2\right)^3$
$y' = 3\left(3x^2 - 2\right)^2(6x)$
$y' = 18x\left(3x^2 - 2\right)^2$

9. $y = \sqrt{3 - x^2} = \left(3 - x^2\right)^{1/2}$
$y' = \frac{1}{2}\left(3 - x^2\right)^{-1/2}(-2x)$
$y' = -x\left(3 - x^2\right)^{-1/2} = -\frac{x}{\left(3 - x^2\right)^{1/2}}$
$y' = -\frac{x}{\sqrt{3 - x^2}}$

10. $y = 4\sqrt[4]{6x + 5} = 4(6x + 5)^{1/4}$
$y' = 4\left(\frac{1}{4}\right)(6x + 5)^{-5/4}(6)$
$y' = 6(6x + 5)^{-5/4} = \frac{6}{(6x + 5)^{5/4}}$

11. $y = \left(5x^4 - 2x\right)^{2/3}$
$y' = \left(\frac{2}{3}\right)\left(5x^4 - 2x\right)^{-1/3}\left(20x^3 - 2\right)$
$y' = \left(\frac{2}{3}\right)\left(5x^4 - 2x\right)^{-1/3}(2)\left(10x^3 - 1\right)$
$y' = \left(\frac{4}{3}\right)\left(5x^4 - 2x\right)^{-1/3}\left(10x^3 - 1\right)$
$y' = \frac{4\left(10x^3 - 1\right)}{3\left(5x^4 - 2x\right)^{1/3}} = \frac{40x^3 - 4}{3\sqrt[3]{5x^4 - 2x}}$

12. $y = \left(x^3 + 2x^2\right)^{-1}$
$y' = (-1)\left(x^3 + 2x^2\right)^{-2}\left(3x^2 + 4x\right)$
$y' = -\frac{3x^2 + 4x}{\left(x^3 + 2x^2\right)^2}$

13. $f(x) = \frac{2}{1 - x^3} = 2\left(1 - x^3\right)^{-1}$; (c) General Power Rule

14. $f(x) = \frac{7}{(1 - x)^3} = 7(1 - x)^{-3}$; (c) General Power Rule

15. $f(x) = \sqrt[3]{8^2}$; (b) Constant Rule

16. $f(x) = \sqrt[3]{x^2} = x^{2/3}$; (a) Simple Power Rule

17. $f(x) = \frac{x^2 + 9}{x^3 + 4x^2 - 6}$; (d) Quotient Rule

18. $f(x) = \frac{x^{1/2}}{x^3 + 2x - 5}$; (d) Quotient Rule

19. $y' = 3(2x - 7)^2(2) = 6(2x - 7)^2$

20. $y = (3 - 5x)^4$
$y' = 4(3 - 5x)^3(-5) = -20(3 - 5x)^3$

21. $h'(x) = 2\left(6x - x^3\right)\left(6 - 3x^2\right) = 6x\left(6 - x^2\right)\left(2 - x^2\right)$

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22. $f(x) = (2x^3 - 6x)^{4/3}$

$f'(x) = \left(\frac{4}{3}\right)(2x^3 - 6x)^{1/3}(6x^2 - 6)$

$f'(x) = \left(\frac{4}{3}\right)(2x^3 - 6x)^{1/3}(6)(x^2 - 1)$

$f'(x) = 8(2x^3 - 6x)^{1/3}(x^2 - 1)$

23. $f(t) = \sqrt{t + 1} = (t + 1)^{1/2}$

$f'(t) = \frac{1}{2}(t + 1)^{-1/2}(1) = \frac{1}{2\sqrt{t + 1}}$

24. $g(x) = \sqrt{5 - 3x} = (5 - 3x)^{1/2}$

$g'(x) = \frac{1}{2}(5 - 3x)^{-1/2}(-3) = -\frac{3}{2\sqrt{5 - 3x}}$

25. $s(t) = \sqrt{2t^2 + 5t + 2} = (2t^2 + 5t + 2)^{1/2}$

$s'(t) = \frac{1}{2}(2t^2 + 5t + 2)^{-1/2}(4t + 5) = \frac{4t + 5}{2\sqrt{2t^2 + 5t + 2}}$

26. $y = 9\sqrt[3]{4x^2 + 3} = 9(4x^2 + 3)^{1/3}$

$y' = 9\left(\frac{1}{3}\right)(4x^2 + 3)^{-2/3}(8x)$

$y' = 24x(4x^2 + 3)^{-2/3}$

$y' = \frac{24x}{(4x^2 + 3)^{2/3}}$

27. $f(x) = 2(2 - 9x)^{-3}$

$f'(x) = 2(-3)(2 - 9x)^{-4}(-9) = \frac{54}{(2 - 9x)^4}$

28. $g(x) = \frac{3}{(7x^2 + 6x)^5} = 3(7x^2 + 6x)^{-5}$

$g'(x) = 3(-5)(7x^2 + 6x)^{-6}(14x + 6)$

$g'(x) = -15(7x^2 + 6x)^{-6}(14x + 6)$

$g'(x) = -\frac{15(14x + 6)}{(7x^2 + 6x)^6}$

29. $f(x) = \frac{1}{\sqrt{(x^2 + 11)^7}} = (x^2 + 11)^{-7/2}$

$f'(x) = \left(-\frac{7}{2}\right)(x^2 + 11)^{-9/2}(2x)$

$f'(x) = -7x(x^2 + 11)^{-9/2}$

$f'(x) = -\frac{7x}{(x^2 + 11)^{9/2}} = -\frac{7x}{\sqrt{(x^2 + 11)^9}}$

30. $y = (4 - x^3)^{-4/3}$

$y' = \left(-\frac{4}{3}\right)(4 - x^3)^{-7/3}(-3x^2) = \frac{4x^2}{3(4 - x^2)^{7/3}}$

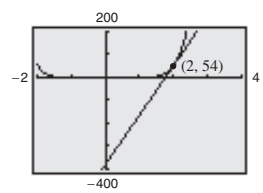
31. $f'(x) = 2(3)(x^2 - 1)^2(2x) = 12x(x^2 - 1)^2$

$f'(2) = 24(3^2) = 216$

$f(2) = 54$

$y - 54 = 216(x - 2)$

$y = 216x - 378$



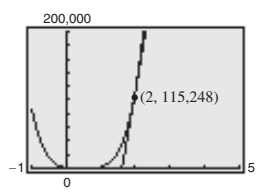
32. $f'(x) = 12(9x - 4)^3(9) = 108(9x - 4)^3$

$f'(2) = 12(14)^3(9) = 296{,}352$

$f(2) = 3(14)^4 = 115{,}248$

$y - 115{,}248 = 296{,}352(x - 2)$

$y = 296{,}352x - 477{,}456$



33. $f(x) = \sqrt{4x^2 - 7} = (4x^2 - 7)^{1/2}$

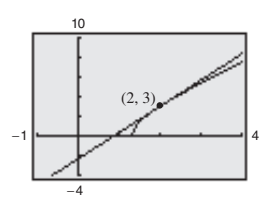
$f'(x) = \frac{1}{2}(4x^2 - 7)^{-1/2}(8x) = \frac{4x}{\sqrt{4x^2 - 7}}$

$f'(2) = \frac{8}{3}$

$f(2) = 3$

$y - 3 = \frac{8}{3}(x - 2)$

$y = \frac{8}{3}x - \frac{7}{3}$



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34. $f(x) = x\sqrt{x^2+5} = x(x^2+5)^{1/2}$

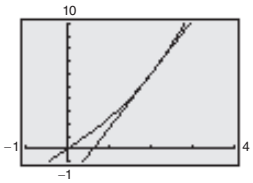
$$f'(x) = x\left[\frac{1}{2}(x^2+5)^{-1/2}(2x)\right] + (x^2+5)^{1/2}(1)$$
$$= x^2(x^2+5)^{-1/2} + (x^2+5)^{1/2}$$
$$= (x^2+5)^{-1/2}\left[x^2 + (x^2+5)\right]$$
$$= \frac{2x^2+5}{\sqrt{x^2+5}}$$

$f'(2) = \frac{13}{3}$

$f(2) = 6$

$y - 6 = \frac{13}{3}(x-2)$

$y = \frac{13}{3}x - \frac{8}{3}$



35. $f(x) = \sqrt{x^2-2x+1} = (x^2-2x+1)^{1/2}$

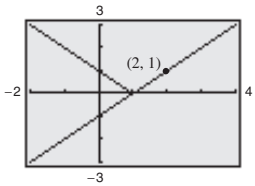
$$f'(x) = \frac{1}{2}(x^2-2x+1)^{-1/2}(2x-2)$$
$$= \frac{x-1}{\sqrt{x^2-2x+1}}$$
$$= \frac{x-1}{|x-1|}$$

$f'(2) = 1$

$f(2) = 1$

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

$y = x - 1$



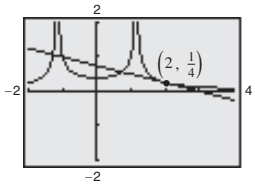
36. $f'(x) = -\frac{2}{3}(4-3x^2)^{-5/3}(-6x) = \frac{4x}{(4-3x^2)^{5/3}}$

$f'(2) = \frac{4(2)}{(-8)^{5/3}} = \frac{8}{-32} = -\frac{1}{4}$

$f(2) = (-8)^{-2/3} = \frac{1}{4}$

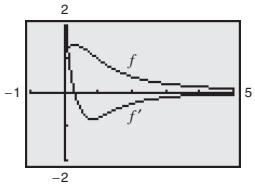
$y - \frac{1}{4} = -\frac{1}{4}(x-2)$

$y = -\frac{1}{4}x + \frac{3}{4}$



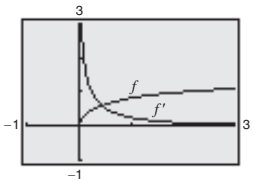
37. $f'(x) = \frac{1-3x^2-4x^{3/2}}{2\sqrt{x}(x^2+1)^2}$

f has a horizontal tangent when $f' = 0$.



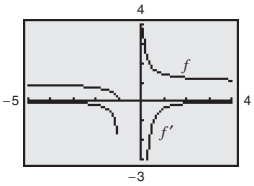
38. $f'(x) = \frac{\sqrt{2}}{2\sqrt{x}(x+1)^{3/2}}$

f' is never 0.



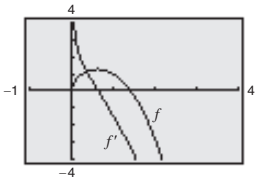
39. $f'(x) = -\frac{\sqrt{(x+1)/x}}{2x(x+1)}$

f' is never 0.



40. $f'(x) = \frac{2-5x^2}{2\sqrt{x}}$

f has a horizontal tangent when $f' = 0$.



41. $y = (4-x^2)^{-1}$

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

General Power Rule

42. $s(t) = \frac{1}{t^2+3t-1} = (t^2+3t-1)^{-1}$

$$s'(t) = -1(t^2+3t-1)^{-2}(2t+3)$$
$$= -\frac{2t+3}{(t^2+3t-1)^2}$$

General Power Rule

43. $y = -\frac{5t}{(t+8)^2}$

$$y' = \frac{(t+8)^2(5) - (5t)(2)(t+8)(1)}{\left((t+8)^2\right)^2}$$
$$y' = \frac{5(t+8)\left[(t+8)-2t\right]}{(t^2+8)^4}$$
$$y' = \frac{5(t+8)(-t+8)}{(t+8)^4} = \frac{5(t-8)}{(t+8)^3}$$

Quotient Rule and Chain Rule

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44. $f(x) = 3x(x^3 - 4)^{-2}$

$$f'(x) = 3x\left[(-2)(x^3 - 4)^{-3}(3x^2)\right] + (x^3 - 4)^{-2}(3)$$
$$= -18x^3(x^3 - 4)^{-3} + 3(x^3 - 4)^{-2}$$
$$= -3(x^3 - 4)^{-3}\left[6x^3 - (x^3 - 4)\right]$$
$$= \frac{-3(5x^3 + 4)}{(x^3 - 4)^3}$$

Product Rule and Chain Rule

45. $f(x) = (2x - 1)(9 - 3x^2)$

$$f'(x) = (2x - 1)(-6x) + (9 - 3x^2)(2)$$
$$= -12x^2 + 6x + 18 - 6x^2$$
$$= 18 + 6x - 18x^2$$
$$= -6(3x^2 - 2x - 3)$$

Product Rule and Simple Power Rule

46. $y = (7x + 4)(x^3 - 2x^2)$

$$y' = (7x + 4)(3x^2 - 4x) + (x^3 - 2x^2)(7)$$
$$= 21x^3 - 16x^2 - 16x + 7x^3 - 14x^2$$
$$= 28x^3 - 30x^2 - 16x$$

Product Rule and Simple Power Rule

47. $y = \dfrac{1}{\sqrt{x + 2}} = (x + 2)^{-1/2}$

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

General Power Rule

48. $g(x) = \dfrac{3}{\sqrt[3]{x^3 - 1}} = 3(x^3 - 1)^{-1/3}$

$$g'(x) = 3\left(-\frac{1}{3}\right)(x^3 - 1)^{-4/3}(3x^2) = -\frac{3x^2}{(x^3 - 1)^{4/3}}$$

General Power Rule

49. $f(x) = x(3x - 9)^3$

$$f'(x) = x(3)(3x - 9)^2(3) + (3x - 9)^3(1)$$
$$= (3x - 9)^2\left[9x + (3x - 9)\right]$$
$$= 9(x - 3)^2(12x - 9)$$
$$= 27(x - 3)^2(4x - 3)$$

Product and General Power Rule

50. $f(x) = x^3(x - 4)^2$

$$= x^3(x^2 - 8x + 16)$$
$$= x^5 - 8x^4 + 16x^3$$
$$f'(x) = 5x^4 - 32x^3 + 48x^2$$
$$= x^2(5x^2 - 32x + 48)$$
$$= x^2(5x - 12)(x - 4)$$

Simple Power Rule

51. $y = x\sqrt{2x + 3} = x(2x + 3)^{1/2}$

$$y' = x\left[\frac{1}{2}(2x + 3)^{-1/2}(2)\right] + (2x + 3)^{1/2}$$
$$= (2x + 3)^{-1/2}\left[x + (2x + 3)\right]$$
$$= \frac{3(x + 1)}{\sqrt{2x + 3}}$$

Product and General Power Rule

52. $y = 2t\sqrt{t + 6} = 2t(t + 6)^{1/2}$

$$y' = 2t\left[\frac{1}{2}(t + 6)^{-1/2}(1)\right] + (t + 6)^{1/2}(2)$$
$$= t(t + 6)^{-1/2} + 2(t + 6)^{1/2}$$
$$= (t + 6)^{-1/2}\left[t + 2(t + 6)\right]$$
$$= (t + 6)^{-1/2}(3t + 12)$$
$$= \frac{3t + 12}{\sqrt{t + 6}} = \frac{3(t + 4)}{\sqrt{t + 6}}$$

Product and General Power Rule

53. $y = t^2\sqrt{t - 2} = t^2(t - 2)^{1/2}$

$$y' = t^2\left[\frac{1}{2}(t - 2)^{-1/2}(1)\right] + 2t(t - 2)^{1/2}$$
$$= \frac{1}{2}(t - 2)^{-1/2}\left[t^2 + 4t(t - 2)\right]$$
$$= \frac{t^2 + 4t(t - 2)}{2\sqrt{t - 2}}$$
$$= \frac{t(5t - 8)}{2\sqrt{t - 2}}$$

Product and General Power Rule

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54. $y = \sqrt{x}(x-2)^2 = x^{1/2}(x-2)^2$

$$y' = x^{1/2}\left[2(x-2)^1(1)\right] + (x-2)^2\left(\frac{1}{2}x^{-1/2}\right)$$

$$= 2\sqrt{x}(x-2) + \frac{(x-2)^2}{2\sqrt{x}}$$

$$= \frac{4x(x-2) + (x-2)^2}{2\sqrt{x}}$$

$$= \frac{(x-2)[4x + (x-2)]}{2\sqrt{x}}$$

$$= \frac{(x-2)(5x-2)}{2\sqrt{x}}$$

Product and General Power Rule

55. $y = \left(\dfrac{6-5x}{x^2-1}\right)^2$

$$y' = 2\left(\frac{6-5x}{x^2-1}\right)\left[\frac{(x^2-1)(-5) - (6-5x)(2x)}{(x^2-1)^2}\right]$$

$$= \frac{2(6-5x)(5x^2-12x+5)}{(x^2-1)^3}$$

Quotient and General Power Rule

56. $y = \left(\dfrac{4x^2-5}{2-x}\right)^3$

$$y' = 3\left(\frac{4x^2-5}{2-x}\right)^2\left[\frac{(2-x)(8x) - (4x^2-5)(-1)}{(2-x)^2}\right]$$

$$= 3\left(\frac{4x^2-5}{2-x}\right)^2\left[\frac{16x - 8x^2 + 4x^2 - 5}{(2-x)^2}\right]$$

$$= 3\left(\frac{4x^2-5}{2-x}\right)^2\left[\frac{-4x^2 + 16x - 5}{(2-x)^2}\right]$$

$$= \frac{3(4x^2-5)^2(-4x^2+16x-5)}{(2-x)^3}$$

Quotient and General Power Rule

57. $y = (x^3 - 2x^2 - x + 1)^2$

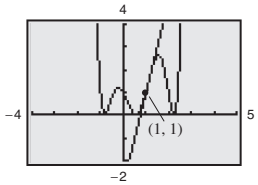
$$y' = 2(x^3 - 2x^2 - x + 1)(3x^2 - 4x - 1)$$

$$m = y'(1) = 2\left((1)^3 - 2(1)^2 - (1) + 1\right)\left(3(1)^2 - 4(1) - 1\right)$$

$$= 2(-1)(-2) = 4$$

$$y - 1 = 4(x-1)$$

$$y = 4x - 3$$



58. $f(x) = (3x^3 + 4x)^{1/5}$

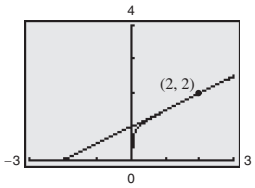
$$f'(x) = \frac{1}{5}(3x^3 + 4x)^{-4/5}(9x^2 + 4)$$

$$= \frac{9x^2 + 4}{5(3x^3 + 4x)^{4/5}}$$

$$m = f'(2) = \frac{1}{2}$$

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

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



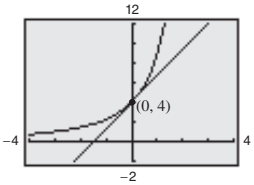
59. $f(t) = \dfrac{36}{(3-t)^2} = 36(3-t)^{-2}$

$$f'(t) = -72(3-t)^{-3}(-1) = \frac{72}{(3-t)^3}$$

$$f'(0) = \frac{72}{27} = \frac{8}{3}$$

$$y - 4 = \frac{8}{3}(t - 0)$$

$$y = \frac{8}{3}t + 4$$



60. $s(x) = \dfrac{1}{\sqrt{x^2 - 3x + 4}} = (x^2 - 3x + 4)^{-1/2}$

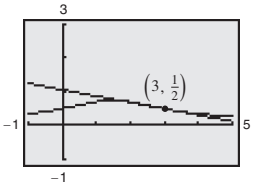
$$s'(x) = -\frac{1}{2}(x^2 - 3x + 4)^{-3/2}(2x - 3)$$

$$= \frac{3 - 2x}{2(x^2 - 3x + 4)^{3/2}}$$

$$s'(3) = \frac{3-6}{2(4)^{3/2}} = -\frac{3}{16}$$

$$y - \frac{1}{2} = -\frac{3}{16}(x - 3)$$

$$y = -\frac{3}{16}x + \frac{17}{16}$$



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61. $f(t) = (t^2 - 9)\sqrt{t + 2} = (t^2 - 9)(t + 2)^{1/2}$

$$f'(t) = (t^2 - 9)\left[\frac{1}{2}(t + 2)^{-1/2}\right] + (t + 2)^{1/2}(2t)$$

$$= \frac{1}{2}(t^2 - 9)(t + 2)^{-1/2} + 2t(t + 2)^{1/2}$$

$$= (t + 2)^{-1/2}\left[\frac{1}{2}(t^2 - 9) + 2t(t + 2)\right]$$

$$= (t + 2)^{-1/2}\left[\frac{1}{2}t^2 - \frac{9}{2} + 2t^2 + 4t\right]$$

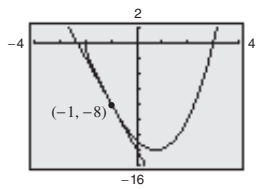
$$= (t + 2)^{-1/2}\left(\frac{5}{2}t^2 + 4t - \frac{9}{2}\right)$$

$$= \frac{\frac{5}{2}t^2 + 4t - \frac{9}{2}}{\sqrt{t + 2}}$$

$$f'(-1) = -6$$

$$y - (-8) = -6[t - (-1)]$$

$$y = -6t - 14$$



62. $y = -\dfrac{2x}{\sqrt{1 - x}} = -\dfrac{2x}{(1 - x)^{1/2}}$

$$y' = -\left[\frac{(1 - x)^{1/2}(2) - \left(\frac{1}{2}\right)(1 - x)^{-1/2}(-1)(2x)}{\left((1 - x)^{1/2}\right)^2}\right]$$

$$= -\left[\frac{2(1 - x)^{1/2} + x(1 - x)^{-1/2}}{1 - x}\right]$$

$$= -\left[\frac{(1 - x)^{-1/2}(2(1 - x) + x)}{1 - x}\right]$$

$$= -\left[\frac{(1 - x)^{-1/2}(2 - 2x + x)}{1 - x}\right]$$

$$= -\left[\frac{(1 - x)^{-1/2}(2 - x)}{1 - x}\right]$$

$$= -\left[\frac{(2 - x)}{(1 - x)^{3/2}}\right]$$

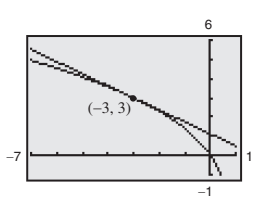
$$= \frac{x - 2}{(1 - x)^{3/2}}$$

$$y'(-3) = \frac{(-3) - 2}{(1 - (-3))^{3/2}} = \frac{-5}{4^{3/2}} = -\frac{5}{8}$$

$$y - 3 = -\frac{5}{8}(x - (-3))$$

$$y - 3 = -\frac{5}{8}x - \frac{15}{8}$$

$$y = -\frac{5}{8}x + \frac{9}{8}$$



63. $f(x) = \dfrac{x + 1}{\sqrt{2x - 3}} = \dfrac{x + 1}{(2x - 3)^{1/2}}$

$$f'(x) = \frac{(2x - 3)^{1/2}(1) - (x + 1)\left(\frac{1}{2}\right)(2x - 3)^{-1/2}(2)}{(2x - 3)}$$

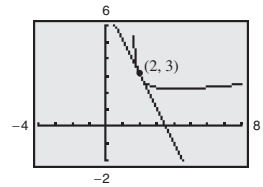
$$= \frac{(2x - 3) - (x + 1)}{(2x - 3)^{3/2}}$$

$$= \frac{x - 4}{(2x - 3)^{3/2}}$$

$$f'(2) = \frac{1 - 3}{1} = -2$$

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

$$y = -2x + 7$$



64. $y = \dfrac{x}{\sqrt{25 + x^2}} = x(25 + x^2)^{-1/2}$

$$y' = x\left[-\tfrac{1}{2}(25 + x^2)^{-3/2}(2x)\right] + (25 + x^2)^{-1/2}(1)$$

$$= -x^2(25 + x^2)^{-3/2} + (25 + x^2)^{-1/2}$$

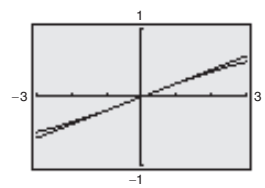
$$= (25 + x^2)^{-3/2}\left[-x^2 + (25 + x^2)\right]$$

$$= \frac{25}{(25 + x^2)^{3/2}}$$

$$y'(0) = \frac{1}{5}$$

$$y - 0 = \frac{1}{5}(x - 0)$$

$$y = \frac{1}{5}x$$



65. $f(x) = \sqrt[3]{x^2 + 4} = (x^2 + 4)^{1/3}$

$$f'(x) = \frac{1}{3}(x^2 + 4)^{-2/3}(2x)$$

$$f'(x) = \frac{2x}{3(x^2 + 4)^{2/3}}$$

Set $f'(x) = \dfrac{2x}{3(x^2 + 4)^{2/3}} = 0.$

$$2x = 0$$

$$x = 0 \rightarrow y = f(0) = \sqrt[3]{4}$$

Horizontal tangent at: $(0, \sqrt[3]{4})$

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66. $f(x) = \sqrt{5x^2 + x - 3} = \left(5x^2 + x - 3\right)^{1/2}$

$f'(x) = \frac{1}{2}\left(5x^2 + x - 3\right)^{-1/2}(10x + 1)$

$f'(x) = \dfrac{10x + 1}{2\left(5x^2 + x - 3\right)^{1/2}}$

Set $f'(x) = \dfrac{10x + 1}{2\left(5x^2 + x - 3\right)^{1/2}} = 0.$

$10x + 1 = 0$

$x = -\frac{1}{10} \rightarrow y = f\left(-\frac{1}{10}\right) = \sqrt{-\frac{61}{20}}$

Because $\sqrt{-\frac{61}{20}}$ is not a real number, there is no point of horizontal tangency.

67. $f(x) = \dfrac{x}{\sqrt{2x - 1}} = \dfrac{x}{(2x - 1)^{1/2}}$

$f'(x) = \dfrac{(2x - 1)^{1/2}(1) - x\left(\frac{1}{2}(2x - 1)^{-1/2}(2)\right)}{\left[(2x + 1)^{1/2}\right]^2}$

$f'(x) = \dfrac{(2x - 1)^{1/2} - x(2x - 1)^{-1/2}}{(2x + 1)}$

$f'(x) = \dfrac{(2x - 1)^{-1/2}\left[(2x - 1) - x\right]}{(2x - 1)}$

$f'(x) = \dfrac{x - 1}{(2x - 1)^{3/2}}$

Set $f'(x) = \dfrac{x - 1}{(2x - 1)^{3/2}} = 0.$

$x - 1 = 0$

$x = 1 \rightarrow y = f(1) = \frac{1}{\sqrt{1}} = 1$

Horizontal tangent at: $(1, 1)$

68. $f(x) = \dfrac{5x}{\sqrt{3x - 2}} = \dfrac{5x}{(3x - 2)^{1/2}}$

$f'(x) = \dfrac{(3x - 2)^{1/2}(5) - 5x\left(\frac{1}{2}(3x - 2)^{-1/2}(3)\right)}{\left[(3x - 2)^{1/2}\right]^2}$

$f'(x) = \dfrac{5(3x - 2)^{1/2} - \frac{15}{2}x(3x - 2)^{-1/2}}{(2x + 1)}$

$f'(x) = \dfrac{\frac{5}{2}(3x - 2)^{-1/2}\left[2(3 - x2) - 3x\right]}{(2x - 1)}$

$f'(x) = \dfrac{5(3x - 4)}{2(3x - 2)^{3/2}}$

Set $f'(x) = \dfrac{5(3x - 4)}{2(3x - 2)^{3/2}} = 0.$

$5(3x - 4) = 0$

$3x - 4 = 0$

$x = \frac{4}{3} \rightarrow y = f\left(\frac{4}{3}\right) = \frac{20}{3\sqrt{2}}$

Horizontal tangent at: $\left(\frac{4}{3}, \frac{10}{3\sqrt{2}}\right)$

69. $A' = 1000(60)\left(1 + \frac{r}{12}\right)^{59}\left(\frac{1}{12}\right) = 5000\left(1 + \frac{r}{12}\right)^{59}$

(a) $A'(0.08) = 50\left(1 + \frac{0.08}{12}\right)^{59}$

$\approx$ \$74.00 per percentage point

(b) $A'(0.10) = 50\left(1 + \frac{0.10}{12}\right)^{59}$

$\approx$ \$81.59 per percentage point

(c) $A'(0.12) = 50\left(1 + \frac{0.12}{12}\right)^{59}$

$\approx$ \$89.94 per percentage point

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70. $N = 400\left[1 - 3\left(t^2 + 2\right)^{-2}\right]$

$$\frac{dN}{dt} = N'(t) = 400\left[(-3)(-2)\left(t^2 + 2\right)^{-3}(2t)\right]$$

$$= \frac{4800t}{\left(t^2 + 2\right)^3}$$

(a) $N'(0) = 0$ bacteria/day

(b) $N'(1) \approx 177.8$ bacteria/day

(c) $N'(2) \approx 44.4$ bacteria/day

(d) $N'(3) \approx 10.8$ bacteria/day

(e) $N'(4) \approx 3.3$ bacteria/day

(f) The rate of change of the population is decreasing as time passes.

71. $V = \dfrac{k}{\sqrt{t+1}}$

When $t = 0$, $V = 10{,}000$.

$$10{,}000 = \frac{k}{\sqrt{0+1}} \Rightarrow k = 10{,}000$$

$$V = \frac{10{,}000}{\sqrt{t+1}}$$

$$V = 10{,}000(t+1)^{-1/2}$$

$$\frac{dV}{dt} = -5000(t+1)^{-3/2}(1) = -\frac{5000}{(t+1)^{3/2}}$$

When $t = 1$,

$$\frac{dV}{dt} = -\frac{5000}{(2)^{3/2}} = -\frac{2500}{\sqrt{2}} \approx -\$1767.77 \text{ per year.}$$

When $t = 3$, $\dfrac{dV}{dt} = -\dfrac{5000}{(4)^{3/2}} = -\$625.00$ per year.

72. (a) From the graph, the tangent line at $t = 4$ is steeper than the tangent line at $t = 1$. So, the rate of change after 4 hours is greater.

(b) The cost function is a composite function of x units, which is a function of the number of hours, which is not a linear function.

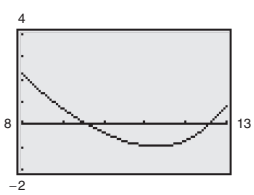
73. (a) $r = \left(0.3017t^4 - 9.657t^3 + 97.35t^2 - 266.8t - 242\right)^{1/2}$

$$\frac{dr}{dt} = r'(t) = \frac{1}{2}\left(0.3017t^4 - 9.657t^3 + 97.35t^2 - 266.8t - 242\right)^{-1/2} \cdot \left(1.2068t^3 - 28.971t^2 + 194.7t - 266.8\right)$$

$$= \frac{1.2068t^3 - 28.971t^2 + 194.7t - 266.8}{2\sqrt{0.3017t^4 - 9.657t^3 + 97.35t^2 - 266.8t - 242}}$$

Chain Rule

(b)



(c) The rate of change appears to be the greatest when $t = 8$ or 2008.

The rate of change appears to be the least when $t \approx 9.60$, or 2009, and when $t \approx 12.57$, or 2012.

Section 2.6 Higher-Order Derivatives

Skills Warm Up

1. $-16t^2 + 292 = 0$

$$-16t^2 = -292$$

$$t^2 = \frac{73}{4}$$

$$t = \pm\frac{\sqrt{73}}{2}$$

2. $-16t^2 + 88t = 0$

$$-8t(2t - 11) = 0$$

$$-8t = 0 \rightarrow t = 0$$

$$2t - 11 = 0 \rightarrow t = \tfrac{11}{2}$$

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Skills Warm Up —*continued*—

3. $-16t^2 + 128t + 320 = 0$

$-16(t^2 - 8t - 20) = 0$

$-16(t - 10)(t + 2) = 0$

$t - 10 = 0 \rightarrow t = 10$

$t + 2 = 0 \rightarrow t = -2$

4. $-16t^2 + 9t + 1440 = 0$

$$t = \frac{-9 \pm \sqrt{9^2 - 4(-16)(1440)}}{2(-16)}$$

$$= \frac{-9 \pm \sqrt{92241}}{-32}$$

$$= \frac{9 \pm 3\sqrt{10249}}{32}$$

$t \approx -9.21$ and $t \approx 9.77$

5. $y = x^2(2x + 7)$

$$\frac{dy}{dx} = x^2(2) + 2x(2x + 7)$$

$$= 2x^2 + 4x^2 + 14x$$

$$= 6x^2 + 14x$$

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

$$\frac{dy}{dx} = (x^2 + 3x)(4x) + (2x + 3)(2x^2 - 5)$$

$$= 4x^3 + 12x^2 + 4x^3 - 10x + 6x^2 - 15$$

$$= 8x^3 + 18x^2 - 10x - 15$$

7. $y = \dfrac{x^2}{2x + 7}$

$$\frac{dy}{dx} = \frac{(2x + 7)(2x) - (x^2)(2)}{(2x + 7)^2}$$

$$= \frac{4x^2 + 14x - 2x^2}{(2x + 7)^2}$$

$$= \frac{2x^2 + 14x}{(2x + 7)^2}$$

$$= \frac{2x(x + 7)}{(2x + 7)^2}$$

8. $y = \dfrac{x^2 + 3x}{2x^2 - 5}$

$$\frac{dy}{dx} = \frac{(2x^2 - 5)(2x + 3) - (x^2 + 3x)(4x)}{(2x^2 - 5)^2}$$

$$= \frac{4x^3 + 6x^2 - 10x - 15 - 4x^3 - 12x^2}{(2x^2 - 5)^2}$$

$$= \frac{-6x^2 - 10x - 15}{(2x^2 - 5)^2}$$

9. $f(x) = x^2 - 4$

Domain: $(-\infty, \infty)$

Range: $[-4, \infty)$

10. $f(x) = \sqrt{x - 7}$

Domain: $[7, \infty)$

Range: $[0, \infty)$

1. $f(x) = 9 - 2x$

$f'(x) = -2$

$f''(x) = 0$

2. $f(x) = 4x + 15$

$f'(x) = 4$

$f''(x) = 0$

3. $f(x) = x^2 + 7x - 4$

$f'(x) = 2x + 7$

$f''(x) = 2$

4. $f(x) = 3x^2 + 4x$

$f'(x) = 6x + 4$

$f''(x) = 6$

5. $g(t) = \frac{1}{3}t^3 - 4t^2 + 2t$

$g'(t) = t^2 - 8t + 2$

$g''(t) = 2t - 8$

6. $f(x) = -\frac{5}{4}x^4 + 3x^2 - 6x$

$f'(x) = -5x^3 + 6x - 6$

$f''(x) = -15x^2 + 6$

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7. $f(t) = \dfrac{2}{t^3} = 2t^{-3}$

$f'(t) = -6t^{-4}$

$f''(t) = 24t^{-5} = \dfrac{24}{t^5}$

8. $g(t) = \dfrac{5}{6t^4} = \dfrac{5}{6}t^{-4}$

$g'(t) = -\dfrac{10}{3}t^{-5}$

$g''(t) = \dfrac{50}{3}t^{-6} = \dfrac{50}{3t^6}$

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

$f'(x) = 9(2 - x^2)^2(-2x) = -18x(2 - x^2)^2$

$f''(x) = (-18x)2(2 - x^2)(-2x) + (2 - x^2)^2(-18)$

$= 18(2 - x^2)[4x^2 - (2 - x^2)]$

$= 18(2 - x^2)(5x^2 - 2)$

10. $y = 4(x^2 + 5x)^3$

$y' = 4(3)(x^2 + 5x)^2(2x + 5)$

$= (24x + 60)(x^4 + 10x^3 + 25x^2)$

$= 24x^5 + 300x^4 + 1200x^3 + 1500x^2$

$y'' = 120x^4 + 1200x^3 + 3600x^2 + 3000x$

11. $f(x) = \dfrac{x + 1}{x - 1}$

$f'(x) = \dfrac{(x - 1)(1) - (x + 1)(1)}{(x - 1)^2}$

$= -\dfrac{2}{(x - 1)^2} = -2(x - 1)^{-2}$

$f''(x) = 4(x - 1)^{-3}(1) = \dfrac{4}{(x - 1)^3}$

12. $g(x) = \dfrac{1 - 4x}{x - 3}$

$g'(x) = \dfrac{(x - 3)(-4) - (1 - 4x)(1)}{(x - 3)^2}$

$= \dfrac{-4x + 12 - 1 + 4x}{(x - 3)^2}$

$= \dfrac{11}{(x - 3)^2} = 11(x - 3)^{-2}$

$g''(x) = -22(x - 3)^{-3}(1) = -\dfrac{22}{(x - 3)^3}$

13. $f(x) = x^5 - 3x^4$

$f'(x) = 5x^4 - 12x^3$

$f''(x) = 20x^3 - 36x^2$

$f'''(x) = 60x^2 - 72x$

14. $f(x) = x^4 - 2x^3$

$f'(x) = 4x^3 - 6x^2$

$f''(x) = 12x^2 - 12x$

$f'''(x) = 24x - 12 = 12(2x - 1)$

15. $f(x) = 5x(x + 4)^3$

$= 5x(x^3 + 12x^2 + 48x + 64)$

$= 5x^4 + 60x^3 + 240x^2 + 320x$

$f'(x) = 20x^3 + 180x^2 + 480x + 320$

$f''(x) = 60x^2 + 360x + 480$

$f'''(x) = 120x + 360$

16. $f(x) = (x^3 - 6)^4$

$f'(x) = 4(x^3 - 6)^3(3x^2)$

$= 12x^{11} - 216x^8 + 1296x^5 - 2592x^2$

$f''(x) = 132x^{10} - 1728x^7 + 6480x^4 - 5184x$

$f'''(x) = 1320x^9 - 12{,}096x^6 + 25{,}920x^3 - 5184$

17. $f(x) = \dfrac{3}{8x^4} = \dfrac{3}{8}x^{-4}$

$f'(x) = -\dfrac{3}{2}x^{-5}$

$f''(x) = \dfrac{15}{2}x^{-6}$

$f'''(x) = -45x^{-7} = -\dfrac{45}{x^7}$

18. $f(x) = -\dfrac{2}{25x^5}$

$f(x) = -\dfrac{2}{25}x^{-5}$

$f'(x) = \dfrac{2}{5}x^{-6}$

$f''(x) = -\dfrac{12}{5}x^{-7}$

$f'''(x) = \dfrac{84}{5}x^{-8} = \dfrac{84}{5x^8}$

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19. $g(t) = 5t^4 + 10t^2 + 3$

$g'(t) = 20t^3 + 20t$

$g''(t) = 60t^2 + 20$

$g''(2) = 60(4) + 20 = 260$

20. $f(x) = 9 - x^2$

$f'(x) = -2x$

$f''(x) = -2$

$f''(-\sqrt{5}) = -2$

21. $f(x) = \sqrt{4 - x} = (4 - x)^{1/2}$

$f'(x) = -\frac{1}{2}(4 - x)^{-1/2}$

$f''(x) = -\frac{1}{4}(4 - x)^{-3/2}$

$f'''(x) = -\frac{3}{8}(4 - x)^{-5/2} = \frac{-3}{8(4 - x)^{5/2}}$

$f'''(-5) = \frac{-3}{8(9)^{5/2}} = -\frac{1}{648}$

22. $f(t) = \sqrt{2t + 3} = (2t + 3)^{1/2}$

$f'(t) = \frac{1}{2}(2t + 3)^{-1/2}(2) = (2t + 3)^{-1/2}$

$f''(t) = -\frac{1}{2}(2t + 3)^{-3/2}(2) = -(2t + 3)^{-3/2}$

$f'''(t) = \frac{3}{2}(2t + 3)^{-5/2}(2) = \frac{3}{(2t + 3)^{5/2}}$

$f'''\left(\frac{1}{2}\right) = \frac{3}{32}$

23. $f(x) = (x^3 - 2x)^3 = x^9 - 6x^7 + 12x^5 - 8x^3$

$f'(x) = 9x^8 - 42x^6 + 60x^4 - 24x^2$

$f''(x) = 72x^7 - 252x^5 + 240x^3 - 48x$

$f''(1) = 12$

24. $g(x) = (x^2 + 3x)^4 = x^8 + 12x^7 + 54x^6 + 108x^5 + 81x^4$

$g'(x) = 8x^7 + 84x^6 + 324x^5 + 540x^4 + 324x^3$

$g''(x) = 56x^6 + 504x^5 + 1620x^4 + 2160x^3 + 972x^2$

$g''(-1) = -16$

25. $f'(x) = 2x^2$

$f''(x) = 4x$

26. $f''(x) = 20x^3 - 36x^2$

$f'''(x) = 60x^2 - 72x = 12x(5x - 6)$

27. $f'''(x) = 4x^{-4}$

$f^{(4)}(x) = -16x^{-5}$

$f^{(5)}(x) = 80x^{-6} = \frac{80}{x^6}$

28. $f''(x) = 4\sqrt{x - 2} = 4(x - 2)^{1/2}$

$f'''(x) = 4\left(\frac{1}{2}\right)(x - 2)^{-1/2}(1) = 2(x - 2)^{-1/2}$

$f^{(4)}(x) = 2\left(-\frac{1}{2}\right)(x - 2)^{-3/2}(1) = -(x - 2)^{-3/2}$

$f^{(5)}(x) = \frac{3}{2}(x - 2)^{-5/2}(1) = \frac{3}{2(x - 2)^{5/2}}$

29. $f^{(5)}(x) = 2(x^2 + 1)(2x)$

$= 4x^3 + 4x$

$f^{(6)}(x) = 12x^2 + 4$

30. $f'''(x) = 4x + 7$

$f^{(4)}(x) = 4$

$f^{(5)}(x) = 0$

31. $f'(x) = 3x^2 - 18x + 27$

$f''(x) = 6x - 18$

$f''(x) = 0 \Rightarrow 6x = 18$

$x = 3$

32. $f(x) = (x + 2)(x - 2)(x + 3)(x - 3)$

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

$= x^4 - 13x^2 + 36$

$f'(x) = 4x^3 - 26x$

$f''(x) = 12x^2 - 26$

$f''(x) = 0 \Rightarrow 12x^2 = 26$

$x = \pm\sqrt{\frac{13}{6}} = \pm\frac{\sqrt{78}}{6}$

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33. $f(x) = x\sqrt{x^2 - 1} = x(x^2 - 1)^{1/2}$

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

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

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

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

$$f''(x) = 0 \Rightarrow 2x^3 - 3x = x(2x^2 - 3) = 0$$

$$x = \pm\sqrt{\frac{3}{2}} = \pm\frac{\sqrt{6}}{2}$$

$x = 0$ is not in the domain of f.

34. $f'(x) = \dfrac{(x^2 + 3)(1) - (x)(2x)}{(x^2 + 3)^2} = \dfrac{3 - x^2}{(x^2 + 3)^2} = (3 - x^2)(x^2 + 3)^{-2}$

$$f''(x) = (3 - x^2)\left[-2(x^2 + 3)^{-3}(2x)\right] + (x^2 + 3)^{-2}(-2x)$$

$$= -2x(x^2 + 3)^{-3}\left[2(3 - x^2) + (x^2 + 3)\right]$$

$$= \frac{-2x(9 - x^2)}{(x^2 + 3)^3}$$

$$= \frac{2x(x^2 - 9)}{(x^2 + 3)^3}$$

$$f''(x) = 0 \Rightarrow 2x(x^2 - 9) = 0$$

$$x = 0, \pm 3$$

35. (a) $s(t) = -16t^2 + 144t$

$v(t) = s'(t) = -32t + 144$

$a(t) = v'(t) = s''(t) = -32$

(b) $s(3) = 288$ ft

$v(3) = 48$ ft/sec

$a(3) = -32$ ft/sec^2

(c) $v(t) = 0$

$-32t + 144 = 0$

$-32t = -144$

$t = 4.5$ sec

$s(4.5) = 324$ ft

(d) $s(t) = 0$

$-16t^2 + 144t = 0$

$-16t(t - 9) = 0$

$t = 0$ sec $\quad t = 9$ sec

$v(9) = -32(9) + 144 = -144$ ft/sec

This is the same speed as the initial velocity.

36. (a) $s(t) = -16t^2 + 1250$

$v(t) = s'(t) = -32t$

$a(t) = v'(t) = -32$

(b) $s(t) = 0$ when $16t^2 = 1250$, or

$t = \sqrt{78.125} \approx 8.8$ sec.

(c) $v(8.8) \approx -282.8$ ft/sec

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37. $\dfrac{d^2s}{dt^2} = \dfrac{(t+10)(90) - (90t)(1)}{(t+10)^2} = \dfrac{900}{(t+10)^2}$

t	0	10	20	30	40	50	60
$\dfrac{ds}{dt}$	0	45	60	67.5	72	75	77.14
$\dfrac{d^2s}{dt^2}$	9	2.25	1	0.56	0.36	0.25	0.18

As time increases, the acceleration decreases. After 1 minute, the automobile is traveling at about 77.14 feet per second.

38. $s(t) = -8.25t^2 + 66t$

$v(t) = s'(t) = -16.50t + 66$

$a(t) = s''(t) = -16.50$

t	0	1	2	3	4	5
$s(t)$	0	57.75	99	123.75	132	123.75
$v(t)$	66	49.50	33	16.50	0	−16.50
$a(t)$	−16.50	−16.50	−16.50	−16.50	−16.50	−16.50

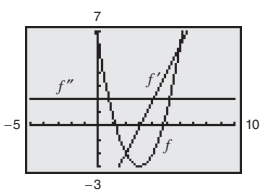
It takes 4 seconds for the car to stop, at which time it has traveled 132 feet.

39. $f(x) = x^2 - 6x + 6$

$f'(x) = 2x - 6$

$f''(x) = 2$

(a)

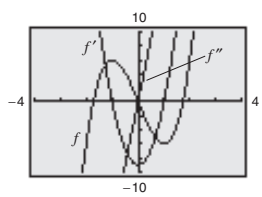


(b) The degree decreased by 1 for each successive derivative.

(c) $f(x) = 3x^2 - 9x$

$f'(x) = 6x - 9$

$f''(x) = 6$



(d) The degree decreases by 1 for each successive derivative.

40. Graph A is the position function. Graph B is the velocity function. Graph C is the acceleration function. Explanations will vary. Sample explanation:
The position function appears to be a third-degree function, while the velocity is a second-degree function, and the acceleration is a linear function.

41. (a) $y(t) = -21.944t^3 + 701.75t^2 - 6969.4t + 27{,}164$

(b) $y'(t) = -65.832t^2 + 1403.5t - 6969.4$

$y''(t) = -131.664t + 1403.5$

(c) Over the interval $8 \le t \le 13$, $y'(t) > 0$; therefore, y is increasing over $8 \le t \le 13$, or from 2008 to 20013.

(d)
$$\begin{aligned} y''(t) &= 0 \\ -131.664t + 1403.5 &= 0 \\ -131.664t &= -1403.5 \\ t &\approx 10.66 \text{ or } 2010 \end{aligned}$$

42. Let $y = xf(x)$.

Then,
$$\begin{aligned} y' &= xf'(x) + f(x) \\ y'' &= xf''(x) + f'(x) + f'(x) \\ &= xf''(x) + 2f'(x) \\ y''' &= xf'''(x) + f''(x) + 2f''(x) \\ &= xf'''(x) + 3f''(x). \end{aligned}$$

In general $y^{(n)} = \left[xf(x)\right]^{(n)} = xf^{(n)}(x) + nf^{(n-1)}(x)$.

43. True. If $y = (x+1)(x+2)(x+3)(x+4)$, then y is a fourth-degree polynomial function and its fifth derivative $\dfrac{d^5y}{dx^5}$ equals o.

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44. True. The second derivative represents the rate of change of the first derivative, the same way that the first derivative represents the rate of change of the function.

45. Answers will vary.

Section 2.7 Implicit Differentiation

Skills Warm Up

1.
$$\begin{aligned} x - \frac{y}{x} &= 2 \\ x^2 - y &= 2x \\ -y &= 2x - x^2 \\ y &= x^2 - 2x \end{aligned}$$

2.
$$\begin{aligned} \frac{4}{x-3} &= \frac{1}{y} \\ 4y &= x - 3 \\ y &= \frac{x-3}{4} \end{aligned}$$

3.
$$\begin{aligned} xy - x + 6y &= 6 \\ xy + 6y &= 6 + x \\ y(x+6) &= 6 + x \\ y &= \frac{6+x}{x+6} \\ y &= 1,\ x \neq -6 \end{aligned}$$

4.
$$\begin{aligned} 7 + 4y &= 3x^2 + x^2y \\ 4y - x^2y &= 3x^2 - 7 \\ y(4 - x^2) &= 3x^2 - 7 \\ y &= \frac{3x^2 - 7}{4 - x^2},\ x \neq \pm 2 \end{aligned}$$

5.
$$\begin{aligned} x^2 + y^2 &= 5 \\ y^2 &= 5 - x^2 \\ y &= \pm\sqrt{5 - x^2} \end{aligned}$$

6.
$$\begin{aligned} x &= \pm\sqrt{6 - y^2} \\ x^2 &= 6 - y^2 \\ x^2 - 6 &= -y^2 \\ 6 - x^2 &= y^2 \\ \pm\sqrt{6 - x^2} &= y \end{aligned}$$

7. $\dfrac{3x^2 - 4}{3y^2}$, $(2, 1)$

$$\frac{3(2^2) - 4}{3(1^2)} = \frac{3(4) - 4}{3} = \frac{8}{3}$$

8. $\dfrac{x^2 - 2}{1 - y}$, $(0, -3)$

$$\frac{0^2 - 2}{1 - (-3)} = \frac{-2}{4} = -\frac{1}{2}$$

9. $\dfrac{7x}{4y^2 + 13y + 3}$, $\left(-\dfrac{1}{7}, -2\right)$

$$\frac{7\left(-\frac{1}{7}\right)}{4(-2)^2 + 13(-2) + 3} = \frac{-1}{16 - 26 + 3} = \frac{-1}{-7} = \frac{1}{7}$$

1.
$$\begin{aligned} x^3y &= 6 \\ x^3\frac{dy}{dx} + 3x^2y &= 0 \\ x^3\frac{dy}{dx} &= -3x^2y \\ \frac{dy}{dx} &= -\frac{3x^2}{x^3}y = -\frac{3}{x}y \end{aligned}$$

2.
$$\begin{aligned} 3x^2 - y &= 8x \\ 6x - \frac{dy}{dx} &= 8 \\ -\frac{dy}{dx} &= 8 - 6x \\ \frac{dy}{dx} &= 6x - 8 \end{aligned}$$

3.
$$\begin{aligned} y^2 &= 1 - x^2 \\ 2y\frac{dy}{dx} &= -2x \\ \frac{dy}{dx} &= -\frac{x}{y} \end{aligned}$$

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4.
$$y^3 = 5x^3 + 8x$$
$$3y^2\frac{dy}{dx} = 15x^2 + 8$$
$$\frac{dy}{dx} = \frac{15x^2 + 8}{3y^2}$$

5.
$$y^4 - y^2 + 7y - 6x = 9$$
$$4y^3\frac{dy}{dx} - 2y\frac{dy}{dx} + 7\frac{dy}{dx} - 6 = 0$$
$$\left(4y^3 - 2y + 7\right)\frac{dy}{dx} = 6$$
$$\frac{dy}{dx} = \frac{6}{4y^3 - 2y + 7}$$

6.
$$4y^3 + 5y^2 - y - 3x^3 = 8x$$
$$12y^2\frac{dy}{dx} + 10y\frac{dy}{dx} - \frac{dy}{dx} - 9x^2 = 8$$
$$\left(12y^2 + 10y - 1\right)\frac{dy}{dx} = 8 + 9x^2$$
$$\frac{dy}{dx} = \frac{8 + 9x^2}{12y^2 + 10y - 1}$$

7.
$$xy^2 + 4xy = 10$$
$$y^2 + 2xy\frac{dy}{dx} + 4y + 4x\frac{dy}{dx} = 0$$
$$(2xy + 4x)\frac{dy}{dx} = -y^2 - 4y$$
$$\frac{dy}{dx} = -\frac{y^2 + 4y}{2xy + 4x}$$

8.
$$2xy^3 - x^2y = 2$$
$$2y^3 + 6xy^2\frac{dy}{dx} - 2xy - x^2\frac{dy}{dx} = 0$$
$$\left(6xy^2 - x^2\right)\frac{dy}{dx} = 2xy - 2y^3$$
$$\frac{dy}{dx} = \frac{2xy - 2y^3}{6xy^2 - x^2}$$

9.
$$\frac{2x + y}{x - 5y} = 1$$
$$2x + y = x - 5y$$
$$6y = -x$$
$$y = -\frac{1}{6}x$$
$$\frac{dy}{dx} = -\frac{1}{6}$$

10.
$$\frac{xy - y^2}{y - x} = 1$$
$$xy - y^2 = y - x$$
$$y(x - y) = -(x - y)$$
$$y = -1$$
$$\frac{dy}{dx} = 0$$

11.
$$\frac{2y}{y^2 + 3} = 4x$$
$$2y = 4x\left(y^2 + 3\right)$$
$$2y = 4xy^2 + 12x$$
$$2\frac{dy}{dx} = 8xy\frac{dy}{dx} + 4y^2 + 12$$
$$2\frac{dy}{dx} - 8xy\frac{dy}{dx} = 4y^2 + 12$$
$$\frac{dy}{dx} = \frac{4y^2 + 12}{2 - 8xy}$$

12.
$$\frac{4y^2}{y^2 - 9} = x^2$$
$$\frac{\left(y^2 - 9\right)\left(8y\frac{dy}{dx}\right) - 4y^2\left(2y\frac{dy}{dx}\right)}{\left(y^2 - 9\right)^2} = 2x$$
$$\frac{8y\frac{dy}{dx}\left(y^2 - 9 - y^2\right)}{\left(y^2 - 9\right)^2} = 2x$$
$$\frac{-72y\frac{dy}{dx}}{\left(y^2 - 9\right)^2} = 2x$$
$$\frac{dy}{dx} = \frac{2x\left(y^2 - 9\right)^2}{-72y}$$
$$\frac{dy}{dx} = -\frac{x\left(y^2 - 9\right)^2}{36y}$$

13.
$$x^2 + y^2 = 16$$
$$2x + 2y\frac{dy}{dx} = 0$$
$$2y\frac{dy}{dx} = -2x$$
$$\frac{dy}{dx} = -\frac{x}{y}$$

At $(0, 4)$, $\frac{dy}{dx} = -\frac{0}{4} = 0$.

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14.
$$x^2 - y^2 = 25$$
$$2x - 2y\frac{dy}{dx} = 0$$
$$-2y\frac{dy}{dx} = -2x$$
$$\frac{dy}{dx} = \frac{x}{y}$$

At (5, 0), $\frac{dy}{dx}$ is undefined.

15.
$$y + xy = 4$$
$$\frac{dy}{dx} + x\frac{dy}{dx} + y = 0$$
$$\frac{dy}{dx}(1 + x) = -y$$
$$\frac{dy}{dx} = -\frac{y}{x+1}$$

At $(-5, -1)$, $\frac{dy}{dx} = -\frac{1}{4}$.

16.
$$xy - 3y^2 = 2$$
$$x\frac{dy}{dx} + y - 6y\frac{dy}{dx} = 0$$
$$\frac{dy}{dx}(x - 6y) = -y$$
$$\frac{dy}{dx} = -\frac{y}{x - 6y}$$

At $(7, 2)$, $\frac{dy}{dx} = -\frac{2}{7 - 6(2)} = \frac{2}{5}$.

17.
$$x^2 - xy + y^2 = 4$$
$$2x - \left(x\frac{dy}{dx} + y\right) + 2y\frac{dy}{dx} = 0$$
$$2x - x\frac{dy}{dx} - y + 2y\frac{dy}{dx} = 0$$
$$\frac{dy}{dx}(2y - x) = y - 2x$$
$$\frac{dy}{dx} = \frac{y - 3x^2}{2y - x}$$

At $(-2, -1)$, $\frac{dy}{dx} = \frac{(-1) - 3(-2)^2}{2(-1) - (-2)} = \frac{-7}{0}$; $\frac{dy}{dx}$ is undefined.

18.
$$x^2y + y^3x = -6$$
$$x^2\frac{dy}{dx} + 2xy + y^3 + 3y^2\frac{dy}{dx}x = 0$$
$$\frac{dy}{dx}\left(x^2 + 2xy\right) = -2xy - y^2$$
$$\frac{dy}{dx} = \frac{-\left(2xy + y^3\right)}{x^2 + 3xy^2}$$
$$\frac{dy}{dx} = \frac{y\left(2x + y^2\right)}{x\left(x + 3y^2\right)}$$

At $(2, -1)$, $\frac{dy}{dx} = -\frac{(-1)\left(2(2) + (-1)^2\right)}{(2)\left((2) + 3(-1)^2\right)} = -\frac{-5}{10} = \frac{1}{2}$.

19.
$$xy - x = y$$
$$x\frac{dy}{dx} + y - 1 = \frac{dy}{dx}$$
$$x\frac{dy}{dx} - \frac{dy}{dx} = 1 - y$$
$$\frac{dy}{dx}(x - 1) = 1 - y$$
$$\frac{dy}{dx} = \frac{1 - y}{x - 1} = -\frac{y - 1}{x - 1}$$

At $\left(\frac{3}{2}, 3\right)$, $\frac{dy}{dx} = -\frac{3 - 1}{\frac{3}{2} - 1} = -\frac{2}{\frac{1}{2}} = -4$.

20.
$$x^3 + y^3 = 6xy$$
$$3x^2 + 3y^2\frac{dy}{dx} = 6\left(x\frac{dy}{dx} + y\right)$$
$$3x^2 + 3y^2\frac{dy}{dx} = 6x\frac{dy}{dx} + 6y$$
$$\left(3y^2 - 6x\right)\frac{dy}{dx} = 6y - 3x^2$$
$$\frac{dy}{dx} = \frac{6y - 3x^2}{3y^2 - 6x}$$
$$\frac{dy}{dx} = \frac{3\left(2y - x^2\right)}{3\left(y^2 - 2x\right)}$$
$$\frac{dy}{dx} = \frac{2y - x^2}{y^2 - 2x}$$

At $\left(\frac{4}{3}, \frac{8}{3}\right)$, $\frac{dy}{dx} = \frac{4}{5}$.

21.
$$x^{1/2} + y^{1/2} = 9$$
$$\frac{1}{2}x^{-1/2} + \frac{1}{2}y^{-1/2}\frac{dy}{dx} = 0$$
$$x^{-1/2} + y^{-1/2}\frac{dy}{dx} = 0$$
$$\frac{dy}{dx} = \frac{-x^{-1/2}}{y^{-1/2}} = -\sqrt{\frac{y}{x}}$$

At (16, 25), $\frac{dy}{dx} = -\frac{5}{4}$.

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22.
$$x^{2/3} + y^{2/3} = 5$$
$$\frac{2}{3}x^{-1/3} + \frac{2}{3}y^{-1/3}\frac{dy}{dx} = 0$$
$$\frac{dy}{dx} = \frac{-x^{-1/3}}{y^{-1/3}} = -\frac{y^{1/3}}{x^{1/3}} = -\sqrt[3]{\frac{y}{x}}$$

At $(8, 1)$, $\frac{dy}{dx} = -\frac{1}{2}$.

23.
$$\sqrt{xy} = x - 2y$$
$$\sqrt{x}\sqrt{y} = x - 2y$$
$$\sqrt{x}\left(\frac{1}{2}y^{-1/2}\frac{dy}{dx}\right) + \sqrt{y}\left(\frac{1}{2}x^{-1/2}\right) = 1 - 2\frac{dy}{dx}$$
$$\frac{\sqrt{x}}{2\sqrt{y}}\frac{dy}{dx} + 2\frac{dy}{dx} = 1 - \frac{\sqrt{y}}{2\sqrt{x}}$$
$$\frac{dy}{dx} = \frac{1 - \frac{\sqrt{y}}{2\sqrt{x}}}{\frac{\sqrt{x}}{2\sqrt{y}} + 2} \cdot \frac{2\sqrt{x}\sqrt{y}}{2\sqrt{x}\sqrt{y}}$$
$$= \frac{2\sqrt{xy} - y}{x + 4\sqrt{xy}}$$
$$= \frac{2(x - 2y) - y}{x + 4(x - 2y)}$$
$$= \frac{2x - 5y}{5x - 8y}$$

At $(4, 1)$, $\frac{dy}{dx} = \frac{1}{4}$.

24.
$$(x + y)^3 = x^3 + y^3$$
$$3(x + y)^2\left(1 + \frac{dy}{dx}\right) = 3x^2 + 3y^2\frac{dy}{dx}$$
$$3(x + y)^2 + 3(x + y)^2\frac{dy}{dx} = 3x^2 + 3y^2\frac{dy}{dx}$$
$$(x + y)^2\frac{dy}{dx} - y^2\frac{dy}{dx} = x^2 - (x + y)^2$$
$$\frac{dy}{dx}\left[(x + y)^2 - y^2\right] = x^2 - \left(x^2 + 2xy + y^2\right)$$
$$\frac{dy}{dx} = \frac{-\left(2xy + y^2\right)}{x^2 + 2xy} = -\frac{y(2x + y)}{x(x + 2y)}$$

At $(-1, 1)$, $\frac{dy}{dx} = -1$.

25.
$$y^2\left(x^2 + y^2\right) = 2x^2$$
$$y^2\left(2x + 2y\frac{dy}{dx}\right) + \left(x^2 + y^2\right)\left(2y\frac{dy}{dx}\right) = 4x$$
$$2xy^2 + 2y^3\frac{dy}{dx} + 2x^2y\frac{dy}{dx} + 2y^3\frac{dy}{dx} = 4x$$
$$\frac{dy}{dx}\left(4y^3 + 2x^2y\right) = 4x - 2xy^2$$
$$\frac{dy}{dx} = \frac{2x\left(2 - y^2\right)}{2y\left(2y^2 + x^2\right)}$$
$$\frac{dy}{dx} = \frac{x\left(2 - y^2\right)}{y\left(2y^2 + x^2\right)}$$

At $(1, 1)$, $\frac{dy}{dx} = \frac{1}{3}$.

26.
$$\left(x^2 + y^2\right)^2 = 8x^2y$$
$$2\left(x^2 + y^2\right)\left(2x + 2y\frac{dy}{dx}\right) = 8x^2\frac{dy}{dx} + y(16x)$$
$$4x^3 + 4x^2y\frac{dy}{dx} + 4xy^2 + 4y^3\frac{dy}{dx} = 8x^2\frac{dy}{dx} + 16xy$$
$$\frac{dy}{dx}\left(4x^2y + 4y^3 - 8x^2\right) = 16xy - 4x^3 - 4xy^2$$
$$\frac{dy}{dx} = \frac{4\left(4xy - x^3 - xy^2\right)}{4\left(x^2y + y^3 - 2x^2\right)}$$
$$\frac{dy}{dx} = \frac{x\left(4y - x^2 - y^2\right)}{x^2y + y^3 - 2x^2}$$

At $(2, 2)$, $\frac{dy}{dx} = 0$.

27.
$$3x^2 - 2y + 5 = 0$$
$$6x - 2\frac{dy}{dx} = 0$$
$$\frac{dy}{dx} = 3x$$

At $(1, 4)$, $\frac{dy}{dx} = 3$.

28.
$$4x^2 + 2y - 1 = 0$$
$$8x + 2\frac{dy}{dx} = 0$$
$$\frac{dy}{dx} = -\frac{8x}{2} = -4x$$
$$\frac{dy}{dx}(-1) = -4(-1) = 4$$

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29. $x^2 + y^2 = 4$

$$2x + 2y\frac{dy}{dx} = 0$$

$$\frac{dy}{dx} = -\frac{x}{y}$$

At $\left(\sqrt{3}, 1\right)$, $\dfrac{dy}{dx} = -\dfrac{\sqrt{3}}{1} = -\sqrt{3}$.

30. $4x^2 + 9y^2 = 36$

$$8x + 18\frac{dy}{dx} = 0$$

$$\frac{dy}{dx} = -\frac{4x}{9y}$$

At $\left(\sqrt{5}, \dfrac{4}{3}\right)$, $\dfrac{dy}{dx} = -\dfrac{4\sqrt{5}}{9(4/3)} = -\dfrac{\sqrt{5}}{3}$.

31. $x^2 - y^3 = 0$

$$2x - 3y^2\frac{dy}{dx} = 0$$

$$\frac{dy}{dx} = \frac{2x}{3y^2}$$

At $(-1, 1)$, $\dfrac{dy}{dx} = -\dfrac{2}{3}$.

32. $(4 - x)y^2 = x^3$

$$y^2 = \frac{x^3}{4 - x}$$

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

$$2y\frac{dy}{dx} = \frac{12x^2 - 3x^3 + x^3}{(4 - x)^2}$$

$$2y\frac{dy}{dx} = \frac{12x^2 - 2x^3}{(4 - x)^2}$$

$$\frac{dy}{dx} = -\frac{2x^2(x - 6)}{2y(4 - x)^2}$$

$$\frac{dy}{dx} = -\frac{x^2(x - 6)}{y(4 - x)^2}$$

At $(2, 7)$, $\dfrac{dy}{dx} = 2$.

33. Implicitly: $1 - 2y\dfrac{dy}{dx} = 0$

$$\frac{dy}{dx} = \frac{1}{2y}$$

Explicitly: $y = \pm\sqrt{x - 1}$

$$= \pm(x - 1)^{1/2}$$

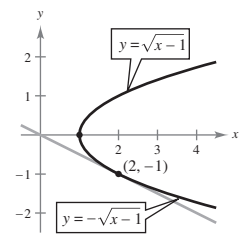
$$\frac{dy}{dx} = \pm\frac{1}{2}(x - 1)^{-1/2}(1)$$

$$= \pm\frac{1}{2\sqrt{x - 1}}$$

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

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

At $(2, -1)$, $\dfrac{dy}{dx} = -\dfrac{1}{2}$.



34. Implicitly: $8y\dfrac{dy}{dx} - 2x = 0$

$$\frac{dy}{dx} = \frac{x}{4y}$$

Explicitly: $y = \pm\dfrac{1}{2}\sqrt{x^2 + 7}$

$$= \pm\frac{1}{2}\left(x^2 + 7\right)^{1/2}$$

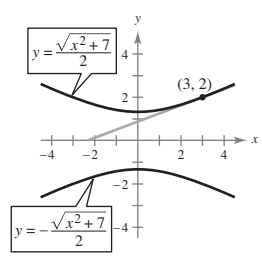
$$\frac{dy}{dx} = \pm\frac{1}{4}\left(x^2 + 7\right)^{-1/2}(2x)$$

$$= \pm\frac{x}{2\sqrt{x^2 + 7}}$$

$$= \frac{x}{4\left(\pm\frac{1}{2}\sqrt{x^2 + 7}\right)}$$

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

At $(3, 2)$, $\dfrac{dy}{dx} = \dfrac{3}{8}$.



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35. $x^2 + y^2 = 100$

$$2x + 2y\frac{dy}{dx} = 0$$

$$\frac{dy}{dx} = -\frac{x}{y}$$

At (8, 6):

$$m = -\frac{4}{3}$$

$$y - 6 = -\frac{4}{3}(x - 8)$$

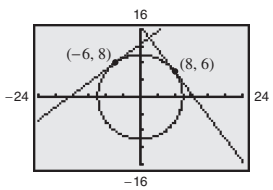
$$y = -\frac{4}{3}x + \frac{50}{3}$$

At $(-6, 8)$:

$$m = \frac{3}{4}$$

$$y - 8 = \frac{3}{4}(x + 6)$$

$$y = \frac{3}{4}x + \frac{25}{2}$$



36. $x^2 + y^2 = 9$

$$2x + 2y\frac{dy}{dx} = 0$$

$$\frac{dy}{dx} = -\frac{x}{y}$$

At (0, 3):

$$m = 0$$

$$y - 3 = 0(x - 0)$$

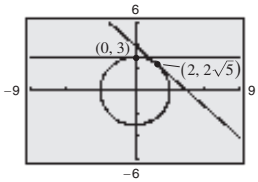
$$y = 3$$

At $\left(2, \sqrt{5}\right)$:

$$m = -\frac{2}{\sqrt{5}} = -\frac{2\sqrt{5}}{5}$$

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

$$y = -\frac{2\sqrt{5}}{5}x + \frac{9\sqrt{5}}{5}$$



37. $y^2 = 5x^3$

$$2y\frac{dy}{dx} = 15x^2$$

$$\frac{dy}{dx} = \frac{15x^2}{2y}$$

At $\left(1, \sqrt{5}\right)$:

$$m = \frac{15}{2\sqrt{5}} = \frac{3\sqrt{5}}{2}$$

$$y - \sqrt{5} = \frac{3\sqrt{5}}{2}(x - 1)$$

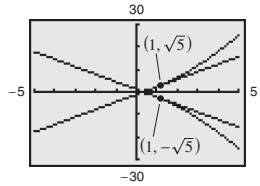
$$y = \frac{3\sqrt{5}}{2}x - \frac{\sqrt{5}}{2}$$

At $\left(1, -\sqrt{5}\right)$:

$$m = \frac{-15}{2\sqrt{5}} = -\frac{3\sqrt{5}}{2}$$

$$y + \sqrt{5} = -\frac{3\sqrt{5}}{2}(x - 1)$$

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



38. $4xy + x^2 = 5$

$$4x\frac{dy}{dx} + 4y + 2x = 0$$

$$\frac{dy}{dx} = -\frac{4y + 2x}{4x} = -\frac{2y + x}{2x}$$

At (1, 1):

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

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

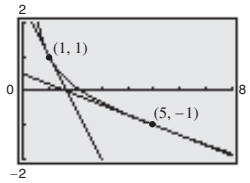
$$y = -\frac{3}{2}x + \frac{5}{2}$$

At $(5, -1)$:

$$m = -\frac{3}{10}$$

$$y + 1 = -\frac{3}{10}(x - 5)$$

$$y = -\frac{3}{10}x + \frac{1}{2}$$



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39. $x^3 + y^3 = 8$

$$3x^2 + 3y^2\frac{dy}{dx} = 0$$

$$3y^2\frac{dy}{dx} = -3x^2$$

$$\frac{dy}{dx} = -\frac{x^2}{y^2}$$

At $(0, 2)$:

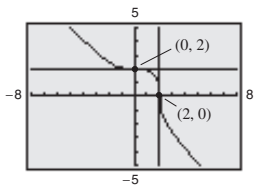
$$m = \frac{dy}{dx} = 0$$

$$y - 2 = 0(x - 0)$$

$$y = 2$$

At $(2, 0)$:

$m = \dfrac{dy}{dx}$ is undefined.



The tangent line is $x = 2$.

40. $x^2y - 8 = -4y$

$$x^2y + 4y = 8$$

$$y(x^2 + 4) = 8$$

$$y = \frac{8}{x^2 + 4} = 8(x^2 + 4)^{-1}$$

$$\frac{dy}{dx} = 8(-1)(x^2 + 4)^{-2}(2x)$$

$$\frac{dy}{dx} = -\frac{16x}{(x^2 + 4)^2}$$

At $(-2, 1)$:

$$m = \frac{dy}{dx} = -\frac{16(-2)}{\left((-2)^2 + 4\right)^2} = \frac{32}{64} = \frac{1}{2}$$

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

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

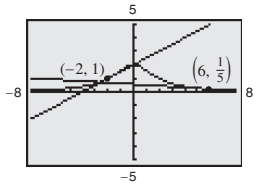
At $\left(6, \frac{1}{5}\right)$:

$$m = \frac{dy}{dx} = -\frac{16(6)}{\left[(6)^2 + 4\right]^2} = -\frac{96}{1600} = -\frac{3}{50}$$

$$y - \frac{1}{5} = -\frac{3}{50}(x - 6)$$

$$y - \frac{1}{5} = -\frac{3}{50}x + \frac{9}{25}$$

$$y = -\frac{3}{50}x + \frac{14}{25}$$

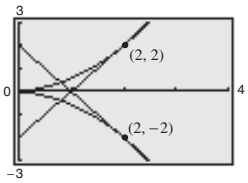


41. $y^2 = \dfrac{x^3}{4 - x}$

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

$$2y\frac{dy}{dx} = \frac{2x^2(6 - x)}{(4 - x)^2}$$

$$\frac{dy}{dx} = \frac{x^2(6 - x)}{y(4 - x)^2}$$



At $(2, 2)$:

$$m = 2$$

$$y - 2 = 2(x - 2)$$

$$y = 2x - 2$$

At $(2, -2)$:

$$m = -2$$

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

$$y = -2x + 2$$

42. $x + y^3 = 6xy^3 - 1$

$$y^3 - 6xy^3 = -1 - x$$

$$y^3(1 - 6x) = -(1 + x)$$

$$y^3 = \frac{x + 1}{6x - 1}$$

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

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

$$\frac{dy}{dx} = -\frac{7}{3y^2(6x - 1)^2}$$

At $(-1, 0)$:

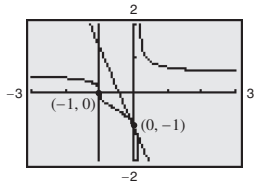
$m = \dfrac{dy}{dx}$ is undefined. The tangent line is $x = -1$.

At $(0, -1)$:

$$m = \frac{dy}{dx} = -\frac{7}{3}$$

$$y - (-1) = -\frac{7}{3}(x - 0)$$

$$y = -\frac{7}{3}x - 1$$



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43. $p = \dfrac{2}{0.00001x^3 + 0.1x}, \; x \geq 0$

$$0.00001x^3 + 0.1x = \frac{2}{p}$$
$$0.00003x^2\frac{dx}{dp} + 0.1\frac{dx}{dp} = -\frac{2}{p^2}$$
$$\left(0.00003x^2 + 0.1\right)\frac{dx}{dp} = -\frac{2}{p^2}$$
$$\frac{dx}{dp} = -\frac{2}{p^2\left(0.00003x^2 + 0.1\right)}$$

44. $p = \dfrac{4}{0.000001x^2 + 0.05x + 1}, \; x \geq 0$

$$0.000001x^2 + 0.05x + 1 = \frac{4}{p}$$
$$0.000002x\frac{dx}{dp} + 0.05\frac{dx}{dp} = -\frac{4}{p^2}$$
$$(0.000002x + 0.05)\frac{dx}{dp} = -\frac{4}{p^2}$$
$$\frac{dx}{dp} = -\frac{4}{p^2(0.000002x + 0.05)}$$

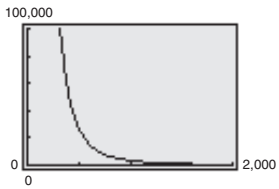
45.
$$p = \sqrt{\frac{200 - x}{2x}}, \; 0 < x \leq 200$$
$$2xp^2 = 200 - x$$
$$2x(2p) + p^2\left(2\frac{dx}{dp}\right) = -\frac{dx}{dp}$$
$$\left(2p^2 + 1\right)\frac{dx}{dp} = -4xp$$
$$\frac{dx}{dp} = -\frac{4xp}{2p^2 + 1}$$

46.
$$p = \sqrt{\frac{500 - x}{2x}}, \; 0 < x \leq 500$$
$$2xp^2 = 500 - x$$
$$2x(2p) + p^2\left(2\frac{dx}{dp}\right) = -\frac{dx}{dp}$$
$$\frac{dx}{dp}\left(2p^2 + 1\right) = -4xp$$
$$\frac{dx}{dp} = -\frac{4xp}{2p^2 + 1}$$

47. (a)
$$100x^{0.75}y^{0.25} = 135{,}540$$
$$100x^{0.75}\left(0.25y^{-0.75}\frac{dy}{dx}\right) + y^{0.25}\left(75x^{-0.25}\right) = 0$$
$$\frac{25x^{0.75}}{y^{0.75}} \cdot \frac{dy}{dx} = -\frac{75y^{0.25}}{x^{0.25}}$$
$$\frac{dy}{dx} = -\frac{3y}{x}$$

When $x = 1500$ and $y = 1000$, $\dfrac{dy}{dx} = -2$.

(b)

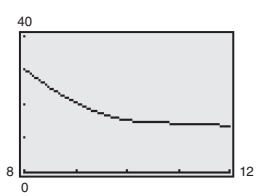


If more labor is used, then less capital is available. If more capital is used, then less labor is available.

48. (a) As price increases, the demand decreases.

(b) For $x > 0$, the rate of change of demand, x, with respect to the price, p, is always decreasing; that is, for $x > 0$, $\dfrac{dx}{dp}$ is never increasing.

49. (a)
$$y^2 - 35{,}892.5 = -27.0021t^3 + 888.789t^2 - 9753.25t$$
$$y^2 = -27.0021t^3 + 888.789t^2 - 9753.25t + 35{,}892.5$$
$$y = \pm\sqrt{-27.0021t^3 + 888.789t^2 - 9753.25t + 35{,}892.5}$$



The numbers of cases of Chickenpox decreases from 2008 to 2012.

(b) It appears that the number of reported cases was decreasing at the greatest rate during 2008, $t = 8$.

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(c) $y^2 - 35{,}892.5 = -27.0021t^3 + 888.789t^2 - 9753.25t$

$$2y\frac{dy}{dt} = -81.0063t^2 + 1777.578t - 9753.25t$$

$$y' = \frac{dy}{dt} = \frac{-81.0063t^2 + 1777.578t - 9753.25}{2y}$$

t	8	9	10	11	12
y	30.40	20.51	15.39	14.51	13.40
y'	−11.79	−7.71	−2.54	−0.06	−3.26

The table of values for y' agrees with the answer in part (b) when the greatest value of y' is -11.79 thousand cases per year.

Section 2.8 Related Rates

Skills Warm Up

1. $A = \pi r^2$

2. $V = \frac{4}{3}\pi r^3$

3. $SA = 6s^2$

4. $V = s^3$

5. $V = \frac{1}{3}\pi r^2 h$

6. $A = \frac{1}{2}bh$

7.
$$x^2 + y^2 = 9$$
$$\frac{d}{dx}\left[x^2 + y^2\right] = \frac{d}{dx}[9]$$
$$2x + 2y\frac{dy}{dx} = 0$$
$$2y\frac{dy}{dx} = -2x$$
$$\frac{dy}{dx} = \frac{-2x}{2y}$$
$$= \frac{-x}{y}$$

8.
$$3xy - x^2 = 6$$
$$\frac{d}{dx}\left[3xy - x^2\right] = \frac{d}{dx}[6]$$
$$3y + 3x\frac{dy}{dx} - 2x = 0$$
$$3x\frac{dy}{dx} = 2x - 3y$$
$$\frac{dy}{dx} = \frac{2x - 3y}{3x}$$

9.
$$x^2 + 2y + xy = 12$$
$$\frac{d}{dx}\left[x^2 + 2y + xy\right] = \frac{d}{dx}(12)$$
$$2x + 2\frac{dy}{dx} + y + x\frac{dy}{dx} = 0$$
$$2\frac{dy}{dx} + x\frac{dy}{dx} = -y - 2x$$
$$\frac{dy}{dx}(2 + x) = -y - 2x$$
$$\frac{dy}{dx} = \frac{-y - 2x}{2 + x}$$

10.
$$x + xy^2 - y^2 = xy$$
$$\frac{d}{dx}\left[x + xy^2 - y^2\right] = \frac{d}{dx}[xy]$$
$$1 + y^2 + 2xy\frac{dy}{dx} - 2y\frac{dy}{dx} = y + x\frac{dy}{dx}$$
$$2xy\frac{dy}{dx} - 2y\frac{dy}{dx} - x\frac{dy}{dx} = y - y^2 - 1$$
$$\frac{dy}{dx}(2xy - 2y - x) = y - y^2 - 1$$
$$\frac{dy}{dx} = \frac{y - y^2 - 1}{2xy - 2y - x}$$

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1. $y = \sqrt{x},\ \dfrac{dy}{dt} = \dfrac{1}{2}x^{-1/2}\dfrac{dx}{dt} = \dfrac{1}{2\sqrt{x}}\dfrac{dx}{dt},\ \dfrac{dx}{dt} = 2\sqrt{x}\dfrac{dy}{dt}$

(a) When $x = 4$ and $\dfrac{dx}{dt} = 3,\ \dfrac{dy}{dt} = \left(\dfrac{1}{2\sqrt{4}}\right)(3) = \dfrac{3}{4}.$

(b) When $x = 25$ and $\dfrac{dy}{dt} = 2,\ \dfrac{dx}{dt} = 2\sqrt{25}(2) = 20.$

2. $y = 3x^2 - 5x,\ \dfrac{dy}{dt} = 6x\dfrac{dx}{dt} - 5\dfrac{dx}{dt},\ \dfrac{dy}{dt} = (6x - 5)\dfrac{dx}{dt},\ \dfrac{\frac{dy}{dt}}{6x - 5} = \dfrac{dx}{dt}$

(a) When $x = 3$ and $\dfrac{dx}{dt} = 2,\ \dfrac{dy}{dt} = \big(6(3) - 5(2)\big) = 26.$

(b) When $x = 2$ and $\dfrac{dy}{dt} = 4,\ \dfrac{4}{6(2) - 5} = \dfrac{4}{7} = \dfrac{dx}{dt}.$

3. $xy = 4,\ x\dfrac{dy}{dt} + y\dfrac{dx}{dt} = 0,\ \dfrac{dy}{dt} = \left(-\dfrac{y}{x}\right)\dfrac{dx}{dt},\ \dfrac{dx}{dt} = \left(-\dfrac{x}{y}\right)\dfrac{dy}{dt}$

(a) When $x = 8,\ y = \dfrac{1}{2}$, and $\dfrac{dx}{dt} = 10,\ \dfrac{dy}{dt} = -\dfrac{1/2}{8}(10) = -\dfrac{5}{8}.$

(b) When $x = 1,\ y = 4$, and $\dfrac{dy}{dt} = -6,\ \dfrac{dx}{dt} = -\dfrac{1}{4}(-6) = \dfrac{3}{2}.$

4. $x^2 + y^2 = 25,\ 2x\dfrac{dx}{dt} + 2y\dfrac{dy}{dt} = 0,\ \dfrac{dy}{dt} = -\dfrac{x}{y}\dfrac{dx}{dt},\ \dfrac{dx}{dt} = -\dfrac{y}{x}\dfrac{dy}{dt}$

(a) When $x = 3,\ y = 4$, and $\dfrac{dx}{dt} = 8,\ \dfrac{dy}{dt} = -\dfrac{3}{4}(8) = -6.$

(b) When $x = 4,\ y = 3$, and $\dfrac{dy}{dt} = -2,\ \dfrac{dx}{dt} = -\dfrac{3}{4}(-2) = \dfrac{3}{2}.$

5. $A = \pi r^2,\ \dfrac{dr}{dt} = 3,\ \dfrac{dA}{dt} = 2\pi r\dfrac{dr}{dt} = 6\pi r$

(a) When $r = 6,\ \dfrac{dA}{dt} = 2\pi(6)(3) = 36\pi$ in.^{2}/min.

(b) When $r = 24,\ \dfrac{dA}{dt} = 2\pi(24)(3) = 144\pi$ in.^{2}/min.

6. $V = \dfrac{4}{3}\pi r^3,\ \dfrac{dr}{dt} = 3,\ \dfrac{dV}{dt} = 4\pi r^2\dfrac{dr}{dt} = 12\pi r^2$

(a) When $r = 9,\ \dfrac{dV}{dt} = 12\pi(9)^2 = 972\pi$ in.^{3}/min.

(b) When $r = 16,\ \dfrac{dV}{dt} = 12\pi(16)^2 = 3072\pi$ in.^{3}/min.

7. $A = \pi r^2,\ \dfrac{dA}{dt} = 2\pi r\dfrac{dr}{dt}$

If $\dfrac{dr}{dt}$ is constant, then $\dfrac{dA}{dt}$ is not constant; $\dfrac{dA}{dt}$ is proportional to r.

8. $V = \dfrac{4}{3}\pi r^3,\ \dfrac{dV}{dt} = 4\pi r^2\dfrac{dr}{dt}$

If $\dfrac{dr}{dt}$ is constant, $\dfrac{dV}{dt}$ is *not* constant since it is proportional to the square of r.

9. $V = \dfrac{4}{3}\pi r^3,\ \dfrac{dV}{dt} = 10,\ \dfrac{dV}{dt} = 4\pi r^2\dfrac{dr}{dt},$

$\dfrac{dr}{dt} = \left(\dfrac{1}{4\pi r^2}\right)\dfrac{dV}{dt}$

(a) When $r = 1,\ \dfrac{dr}{dt} = \dfrac{1}{4\pi(1)^2}(10) = \dfrac{5}{2\pi}$ ft/min.

(b) When $r = 2,\ \dfrac{dr}{dt} = \dfrac{1}{4\pi(2)^2}(10) = \dfrac{5}{8\pi}$ ft/min.

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10. $V = \frac{1}{3}\pi r^2 h = \frac{1}{3}\pi r^2(3r) = \pi r^3$

$\frac{dV}{dt} = 3\pi r^2 \frac{dr}{dt} = 6\pi r^2$

(a) When $r = 6$, $\frac{dV}{dt} = 6\pi(6)^2 = 216\pi$ in.^{3}/min.

(b) When $r = 24$, $\frac{dV}{dt} = 6\pi(24)^2 = 3456\pi$ in.^{3}/min.

11. (a) $\frac{dC}{dt} = 0.75\frac{dx}{dt} = 0.75(150)$

$= 112.5$ dollars per week

(b) $\frac{dR}{dt} = 250\frac{dx}{dt} - \frac{1}{5}x\frac{dx}{dt}$

$= 250(150) - \frac{1}{5}(1000)(150)$

$= 7500$ dollars per week

(c) $P = R - C$

$\frac{dP}{dt} = \frac{dR}{dt} - \frac{dC}{dt} = 7500 - 112.5$

$= 7387.5$ dollars per week

12. (a) $\frac{dC}{dt} = 1.05\frac{dx}{dt} = 1.05(250) = 262.5$ dollars/week

(b) $\frac{dR}{dt} = \left(500 - \frac{2x}{25}\right)\frac{dx}{dt} = \left(500 - \frac{2(5000)}{25}\right)(250)$

$= 25{,}000$ dollars/week

(c) $P = R - C$

$\frac{dP}{dt} = \frac{dR}{dt} - \frac{dC}{dt} = 25{,}000 - 262.5$

$= 24{,}737.5$ dollars/week

13. $R = 1200x - x^2$, $\frac{dR}{dt} = 1200\frac{dx}{dt} - 2x\frac{dx}{dt}$,

$\frac{dR}{dt} = (1200 - 2x)\frac{dx}{dt}$

(a) When $\frac{dx}{dt} = 23$ units/day and $x = 300$ units,

$\frac{dR}{dt} = [1200 - 2(300)](23) = \$13{,}800$ per day.

(b) When $\frac{dx}{dt} = 23$ units/day and $x = 450$ units,

$\frac{dR}{dt} = [1200 - 2(450)](23) = \$6900$ per day.

14. $R = 510x - 0.3x^2$, $\frac{dR}{dt} = 510\frac{dx}{dt} - 0.6x\frac{dx}{dt}$,

$\frac{dR}{dt} = (510 - 0.6x)\frac{dx}{dt}$

(a) When $\frac{dx}{dt} = 9$ units/day and $x = 400$ units,

$\frac{dR}{dt} = [510 - 0.6(400)](9) = \$2430$ per day.

(b) When $\frac{dx}{dt} = 9$ units/day and $x = 600$ units,

$\frac{dR}{dt} = [510 - 0.6(600)](9) = \$1350$ per day.

15. $V = x^3$, $\frac{dx}{dt} = 6$, $\frac{dV}{dt} = 3x^2\frac{dx}{dt}$

(a) When $x = 2$, $\frac{dV}{dt} = 3(2)^2(6) = 72$ cm^3/sec.

(b) When $x = 10$, $\frac{dV}{dt} = 3(10)^2(6) = 1800$ cm^3/sec.

16. $A = 6x^2$, $\frac{dx}{dt} = 6$, $\frac{dA}{dt} = 12x\frac{dx}{dt}$

(a) When $x = 2$, $\frac{dA}{dt} = 12(2)(6) = 144$ cm^2/sec.

(b) When $x = 10$, $\frac{dA}{dt} = 12(10)(6) = 720$ cm^2/sec.

17. Let x be the distance from the boat to the dock and y be the length of the rope.

$12^2 + x^2 = y^2$

$\frac{dy}{dt} = -4$

$2x\frac{dx}{dt} = 2y\frac{dy}{dt}$

$\frac{dx}{dt} = \frac{y}{x}\frac{dy}{dt}$

When $y = 13$, $x = 5$ and

$\frac{dx}{dt} = \frac{13}{5}(-4) = -10.4$ ft/sec.

As $x \to 0$, $\frac{dx}{dt}$ increases.

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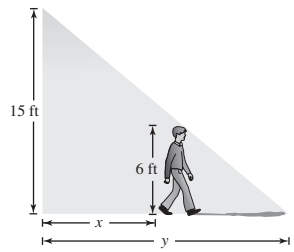
18.



(a) $\dfrac{15}{6} = \dfrac{y}{y - x} \Rightarrow 15y - 15x = 6y$

$$9y = 15x$$

$$y = \frac{5}{3}x$$

Find $\dfrac{dy}{dt}$ if $\dfrac{dx}{dt} = 5$ ft/sec when $x = 10$ ft.

$$\frac{dy}{dt} = \frac{5}{3}\frac{dx}{dt}$$

$$\frac{dy}{dt} = \frac{5}{3}(5) = \frac{25}{3} \text{ ft/sec}$$

(b) Find $\dfrac{d}{dt}(y - x)$ if $\dfrac{dx}{dt} = 5$ ft/sec and

$\dfrac{dy}{dt} = \dfrac{25}{3}$ ft/sec when $x = 10$ ft.

$$\frac{d}{dt}(y - x) = \frac{dy}{dt} - \frac{dx}{dt}$$

$$= \frac{25}{3} - 5 = \frac{10}{3} \text{ ft/sec}$$

19. $x^2 + 6^2 = s^2$

$$2x\frac{dx}{dt} = 2s\frac{ds}{dt}$$

$$\frac{dx}{dt} = \frac{s}{x}\frac{ds}{dt}$$

When $s = 10$, $x = 8$ and $\dfrac{ds}{dt} = 240$:

$$\frac{dx}{dt} = \frac{10}{8}(-240) = 300 \text{ mi/hr.}$$

20. $s^2 = 90^2 + x^2$, $x = 26$, $\dfrac{dx}{dt} = -30$

$$2s\frac{ds}{dt} = 2x\frac{dx}{dt}$$

$$\frac{ds}{dt} = \frac{x}{s}\frac{dx}{dt}$$

When $x = 26$,

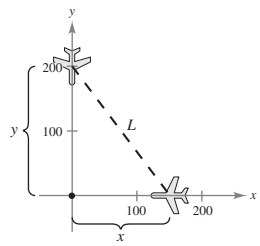
$$\frac{ds}{dt} = \frac{26}{\sqrt{90^2 + 26^2}}(-30) \approx -8.33 \text{ ft/sec.}$$

21. (a) $L^2 = x^2 + y^2$, $\dfrac{dx}{dt} = -450$, $\dfrac{dy}{dt} = -600$, and

$$\frac{dL}{dt} = \frac{x(dx/dt) + y(dy/dt)}{L}$$

When $x = 150$ and $y = 200$, $L = 250$ and

$$\frac{dL}{dt} = \frac{150(-450) + 200(-600)}{250} = -750 \text{ mph.}$$



(b) $t = \dfrac{250}{750} = \dfrac{1}{3}$ hr $= 20$ min

22. $S = 2250 + 50x + 0.35x^2$

$$\frac{dS}{dt} = 50\frac{dx}{dt} + 0.70x\frac{dx}{dt}$$

$$\frac{dS}{dt} = 50(125) + 0.70(1500)(125)$$

$$= \$137{,}500 \text{ per week}$$

23. $V = \pi r^2 h$, $h = 0.08$, $V = 0.08\pi r^2$, $\dfrac{dV}{dt} = 0.16\pi r\dfrac{dr}{dt}$

When $r = 150$ and $\dfrac{dr}{dt} = \dfrac{1}{2}$,

$$\frac{dV}{dt} = 0.16\pi(150)\left(\frac{1}{2}\right) = 12\pi = 37.70 \text{ ft}^3/\text{min.}$$

24. $P = R - C$

$$= xp - C$$

$$= x(50 - 0.01x) - (4000 + 40x - 0.02x^2)$$

$$= 50x - 0.01x^2 - 4000 - 40x + 0.02x^2$$

$$= 0.01x^2 + 10x - 4000$$

$$\frac{dP}{dt} = 0.02x\frac{dx}{dt} + 10\frac{dx}{dt}$$

When $x = 800$ and $\dfrac{dx}{dt} = 25$,

$$\frac{dP}{dt} = 0.02(800)(25) + (10)(25) = \$650/\text{week.}$$

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25. $P = R - C = xp - C = x(6000 - 25x) - (2400x + 5200)$

$$= -25x^2 + 3600x - 5200$$

$$\frac{dP}{dt} = -50x\frac{dx}{dt} + 3600\frac{dx}{dt}$$

$$\frac{dx}{dt} = \frac{1}{3600 - 50x}\frac{dP}{dt}$$

When $x = 44$ and $\frac{dP}{dt} = 5600$, $\frac{dx}{dt} = \frac{1}{3600 - 50(44)}(5600) = 4$ units per week.

26. (a) For supply, if $\frac{dx}{dt}$ is negative, then $\frac{dp}{dt}$ is negative. For demand, if $\frac{dx}{dt}$ is negative, then $\frac{dp}{dt}$ is positive.

(b) For supply, if $\frac{dp}{dt}$ is positive, then $\frac{dx}{dt}$ is positive. For demand, if $\frac{dp}{dt}$ is positive, then $\frac{dx}{dt}$ is negative.

Review Exercises for Chapter 2

1. Slope $\approx \frac{-4}{2} = -2$

2. Slope $\approx \frac{4}{2} = 2$

3. Slope ≈ 0

4. Slope $\approx \frac{-2}{4} = -\frac{1}{2}$

5. Answers will vary. Sample answer:
$t = 8$; slope $\approx$ \$225 million/yr; Revenue was increasing by about \$225 million per year in 2008.
$t = 10$; slope $\approx$ \$350 million/yr; Revenue was increasing by about \$350 million per year in 2010.

6. Answers will vary. Sample answer:
$t = 10$; slope ≈ -20 thousand/year; The number of farms was decreasing by about 20 thousand per year in 2010.
$t = 12$; slope ≈ -10 thousand/year; The number of farms was decreasing by about 10 thousand per year in 2012.

7. Answers will vary. Sample answer:
$t = 1$: $m \approx 65$ hundred thousand visitors/month; The number of visitors to the national park is increasing at about 65,000,000/per month in January.
$t = 8$: $m \approx 0$ visitors/month; The number of visitors to the national park is neither increasing nor decreasing in August.
$t = 12$: $m \approx -1000$ hundred thousand/month; The number of visitors to the national park is decreasing at about 1,000,000,000 visitors per month in December.

8. (a) At t_1, the slope of $g(t)$ is greater than the slope of $f(t)$, so the rafter whose progress is given by $g(t)$ is traveling faster.

(b) At t_2, the slope of $f(t)$ is greater than the slope of $g(t)$, so the rafter whose progress is given by $f(t)$ is traveling faster.

(c) At t_3, the slope of $f(t)$ is greater than the slope of $g(t)$, so the rafter whose progress is given by $f(t)$ is traveling faster.

(d) The rafter whose progress is given by $f(t)$ finishes first. The value of t where $f(t) = 9$ is smaller than the value of t where $g(t) = 9$.

9. $f(x) = -3x - 5; (-2, 1)$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{-3(x + \Delta x) - 5 - (-3x - 5)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{-3\Delta x}{\Delta x} = -3$$

$f'(-2) = -3$

10. $f(x) = 7x + 3; (-1, -4)$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{7(x + \Delta x) + 3 - (7x + 3)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{7\Delta x}{\Delta x} = 7$$

$f'(-1) = 7$

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11. $f(x) = x^2 + 9; (3, 18)$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{(x + \Delta x)^2 + 9 - (x^2 + 9)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{x^2 + 2x\Delta x + (\Delta x)^2 + 9 - x^2 - 9}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{2x\Delta x + (\Delta x)^2}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{\Delta x(2x + \Delta x)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} (2x + \Delta x) = 2x$$
$$f'(3) = 2(3) = 6$$

12. $f(x) = x^2 - 7x; (1, -6)$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{(x + \Delta x)^2 - 7(x + \Delta x) - (x^2 - 7x)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{x^2 + 2x\Delta x + (\Delta x)^2 - 7x - 7\Delta x - x^2 + 7x}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{2x\Delta x + (\Delta x)^2 - 7\Delta x}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{\Delta x(2x + \Delta x - 7)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} (2x + \Delta x - 7) = 2x - 7$$
$$f'(1) = 2(1) - 7 = -5$$

13. $f(x) = \sqrt{x + 9}; (-5, 2)$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{\sqrt{x + \Delta x + 9} - \sqrt{x + 9}}{\Delta x} \cdot \frac{\sqrt{x + \Delta x + 9} + \sqrt{x + 9}}{\sqrt{x + \Delta x + 9} + \sqrt{x + 9}}$$
$$= \lim_{\Delta x \to 0} \frac{(x + \Delta x + 9) - (x + 9)}{\Delta x\left[\sqrt{x + \Delta x + 9} + \sqrt{x + 9}\right]}$$
$$= \lim_{\Delta x \to 0} \frac{1}{\sqrt{x + \Delta x + 9} + \sqrt{x + 9}} = \frac{1}{2\sqrt{x + 9}}$$
$$f'(-5) = \frac{1}{4}$$

14. $f(x) = \sqrt{x - 1}; (10, 3)$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{\sqrt{x + \Delta x - 1} - \sqrt{x - 1}}{\Delta x} \cdot \frac{\sqrt{x + \Delta x - 1} + \sqrt{x - 1}}{\sqrt{x + \Delta x - 1} + \sqrt{x - 1}}$$
$$= \lim_{\Delta x \to 0} \frac{(x + \Delta x - 1) - (x - 1)}{\Delta x\left[\sqrt{x + \Delta x - 1} + \sqrt{x - 1}\right]}$$
$$= \lim_{\Delta x \to 0} \frac{1}{\sqrt{x + \Delta x - 1} + \sqrt{x - 1}} = \frac{1}{2\sqrt{x - 1}}$$
$$f'(10) = \frac{1}{6}$$

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15. $f(x) = \dfrac{1}{x-5}$; $(6, 1)$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\dfrac{1}{x+\Delta x-5} - \dfrac{1}{x-5}}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{(x-5) - (x+\Delta x-5)}{\Delta x(x+\Delta x-5)(x-5)}$$

$$= \lim_{\Delta x \to 0} \frac{-1}{(x+\Delta x-5)(x-5)} = -\frac{1}{(x-5)^2}$$

$$f'(6) = -1$$

16. $f(x) = \dfrac{1}{x+6}$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\dfrac{1}{x+\Delta x+6} - \dfrac{1}{x+6}}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{(x+6) - (x+\Delta x+6)}{\Delta x\left[(x+\Delta x+6)(x+6)\right]}$$

$$= \lim_{\Delta x \to 0} \frac{-1}{(x+\Delta x+6)(x+6)}$$

$$= -\frac{1}{(x+6)^2}$$

$$f'(-3) = -\frac{1}{(-2+6)^2} = -\frac{1}{16}$$

19. $f(x) = -\dfrac{1}{2}x^2 + 2x$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\left[-\frac{1}{2}(x+\Delta x)^2 + 2(x+\Delta x)\right] - \left(-\frac{1}{2}x^2 + 2x\right)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{-\frac{1}{2}x^2 - x(\Delta x) - \frac{1}{2}(\Delta x)^2 + 2x + 2\Delta x + \frac{1}{2}x^2 - 2x}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\Delta x\left(-x - \frac{1}{2}\Delta x + 2\right)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \left(-x - \tfrac{1}{2}\Delta x + 2\right) = -x + 2$$

17. $f(x) = 9x + 1$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\left[9(x+\Delta x) + 1\right] - (9x+1)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{9x + 9\Delta x + 1 - 9x - 1}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{9\Delta x}{\Delta x}$$

$$= \lim_{\Delta x \to 0} 9 = 9$$

18. $f(x) = 1 - 4x$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\left[1 - 4(x+\Delta x)\right] - (1-4x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{1 - 4x - 4\Delta x - 1 + 4x}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{-4\Delta x}{\Delta x}$$

$$= \lim_{\Delta x \to 0} -4 = -4$$

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20. $f(x) = 3x^2 - \frac{1}{4}x$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\left[3(x + \Delta x)^2 - \frac{1}{4}(x + \Delta x)\right] - \left(3x^2 - \frac{1}{4}x\right)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{3x^2 + 6x(\Delta x) + 3(\Delta x)^2 - \frac{1}{4}x - \frac{1}{4}\Delta x - 3x^2 + \frac{1}{4}x}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{6x(\Delta x) + 3(\Delta x)^2 - \frac{1}{4}\Delta x}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\Delta x\left(6x + 3(\Delta x) - \frac{1}{4}\right)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \left(6x + 3(\Delta x) - \frac{1}{4}\right) = 6x - \frac{1}{4}$$

21. $f(x) = \sqrt{x - 5}$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\sqrt{x + \Delta x - 5} - \sqrt{x - 5}}{\Delta x} \cdot \frac{\sqrt{x + \Delta x - 5} + \sqrt{x - 5}}{\sqrt{x + \Delta x - 5} + \sqrt{x - 5}}$$

$$= \lim_{\Delta x \to 0} \frac{(x + \Delta x - 5) - (x - 5)}{\Delta x\left(\sqrt{x + \Delta x - 5} + \sqrt{x - 5}\right)}$$

$$= \lim_{\Delta x \to 0} \frac{1}{\sqrt{x + \Delta x - 5} + \sqrt{x - 5}} = \frac{1}{2\sqrt{x - 5}}$$

22. $f(x) = \sqrt{x} + 3$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\left[\sqrt{x + \Delta x} + 3\right] - \left(\sqrt{x} + 3\right)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\sqrt{x + \Delta x} - \sqrt{x}}{\Delta x} \cdot \frac{\sqrt{x + \Delta x} + \sqrt{x}}{\sqrt{x + \Delta x} + \sqrt{x}}$$

$$= \lim_{\Delta x \to 0} \frac{(x + \Delta x) - x}{\Delta x\left(\sqrt{x + \Delta x} + \sqrt{x}\right)}$$

$$= \lim_{\Delta x \to 0} \frac{1}{\sqrt{x + \Delta x} + \sqrt{x}} = \frac{1}{2\sqrt{x}}$$

23. $f(x) = \frac{5}{x}$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\frac{5}{x + \Delta x} - \frac{5}{x}}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\frac{5x - 5(x + \Delta x)}{x(x + \Delta x)}}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{-5\Delta x}{\Delta x\left[x(x + \Delta x)\right]}$$

$$= \lim_{\Delta x \to 0} -\frac{5}{x(x + \Delta x)} = -\frac{5}{x^2}$$

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24. $f(x) = \dfrac{1}{x+4}$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x+\Delta x) - f(x)}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\dfrac{1}{x+\Delta x+4} - \dfrac{1}{x+4}}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{\dfrac{(x+4)-(x+\Delta x+4)}{(x+4)(x+\Delta x+4)}}{\Delta x}$$

$$= \lim_{\Delta x \to 0} \frac{-\Delta x}{\Delta x\left[(x+4)(x+\Delta x+4)\right]}$$

$$= \lim_{\Delta x \to 0} -\frac{1}{(x+4)(x+\Delta x+4)} = -\frac{1}{(x+4)^2}$$

25. y is not differentiable at $x = -1$. At $(-1, 0)$, the graph has a vertical tangent line.

26. y is not differentiable at $x = 0$. At $(0, 3)$, the graph has a node.

27. y is not differentiable at $x = 0$. The function is discontinuous at $x = 0$.

28. y is not differentiable at $x = -1$. At $(-1, 0)$, the graph has a cusp.

29. $y = -6$

$y' = 0$

30. $f(x) = 5$

$f'(x) = 0$

31. $f(x) = x^7$

$f'(x) = 7x^6$

32. $h(x) = \dfrac{1}{x^{-4}}$

$h(x) = x^{-4}$

$h'(x) = -4x^{-5}$

$h'(x) = \dfrac{-4}{x^5}$

33. $f(x) = 4x^2$

$f'(x) = 8x$

34. $g(t) = 8t^6$

$g'(t) = 48t^5$

35. $f(x) = \dfrac{5x^3}{4}$

$f'(x) = \dfrac{15x^2}{4}$

36. $y = 3x^{2/3}$

$y' = 2x^{-1/3}$

$y' = \dfrac{2}{x^{1/3}}$

37. $g(x) = 2x^4 + 3x^2$

$g'(x) = 8x^3 + 6x$

38. $f(x) = 6x^2 - 4x$

$f'(x) = 12x - 4$

39. $y = x^2 + 6x - 7$

$y' = 2x + 6$

40. $y = 2x^4 - 3x^3 + x$

$y' = 8x^3 - 9x^2 + 1$

41. $f(x) = 2x^{-1/2}$; $(4, 1)$

$f'(x) = -x^{-3/2}$

$f'(4) = -(4)^{-3/2} = -0.125$

42. $y = \dfrac{3}{2x} + 3$; $\left(\dfrac{1}{2}, 6\right)$

$y = \dfrac{3}{2}x^{-1} + 3$

$y' = -\dfrac{3}{2}x^{-2} = -\dfrac{3}{2x^2}$

$y'\left(\dfrac{1}{2}\right) = \dfrac{3}{2\left(\frac{1}{2}\right)^2} = 6$

43. $g(x) = x^3 - 4x^2 - 6x + 8$; $(-1, 9)$

$g'(x) = 3x^2 - 8x - 6$

$g'(-1) = 3(-1)^2 - 8(-1) - 6 = 5$

44. $y = 2x^4 - 5x^3 + 6x^2 - x$; $(1, 2)$

$y' = 8x^3 - 15x^2 + 12x - 1$

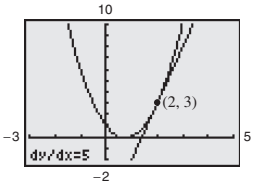
$y'(1) = 8(1)^3 - 15(1)^2 + 12(1) - 1 = 4$

45. $f'(x) = 4x - 3$

$f'(2) = 5$

$y - 3 = 5(x - 2)$

$y = 5x - 7$



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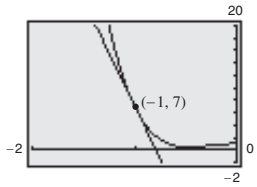
46. $y' = 44x^3 - 10x$

$y'(-1) = -34$

$y - 7 = -34(x + 1)$

$y = -34x - 27$



47. $f(x) = \sqrt{x} - \dfrac{1}{\sqrt{x}} = x^{1/2} - x^{-1/2}$

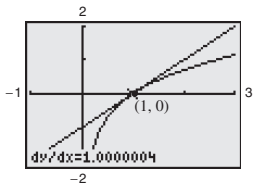
$f'(x) = \dfrac{1}{2}x^{-1/2} + \dfrac{1}{2}x^{-3/2}$

$= \dfrac{1}{2\sqrt{x}} + \dfrac{1}{2x^{3/2}}$

$f'(1) = 1$

$y - 0 = 1(x - 1)$

$y = x - 1$



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

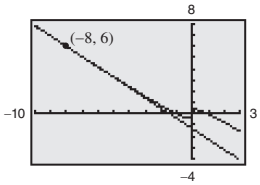
$f'(x) = \dfrac{1}{3}x^{-2/3} - 1 = \dfrac{1}{3\sqrt[3]{x^2}} - 1$

$f'(-8) = \dfrac{1}{3\sqrt[3]{(-8)^2}} - 1 = \dfrac{1}{12} - 1 = -\dfrac{11}{12}$

$y - 6 = -\dfrac{11}{12}(x + 8)$

$y - 6 = -\dfrac{11}{12}x - \dfrac{22}{3}$

$y = -\dfrac{11}{12}x - \dfrac{4}{3}$



49. $R = -0.5972t^3 + 51.187t^2 - 485.54t + 2199.0$

$\dfrac{dR}{dt} = R'(t) = -1.7916t^2 + 102.374t - 485.54$

(a) 2008: $R'(8) = m \approx 218.8$

2010: $R'(10) = m \approx 359.0$

(b) Results should be similar.

(c) The slope shows the rate at which sales were increasing or decreasing in that particular year, or value of t.

In 2008, the revenue was increasing about \$218.8 million per year, and in 2010, revenue was increasing about \$359.0 million per year.

50. $N = 0.2083t^4 - 7.954t^3 + 11.96t^2 - 706.5t + 3891$

$\dfrac{dN}{dt} = N'(t) = 0.8332t^3 - 23.862t^2 + 23.92t - 706.5$

(a) 2010: $N'(10) = m \approx -2020.33$

2012: $N'(12) = m \approx -2415.85$

(b) Results should be similar.

(c) The slope shows the rate at which the number of farms was increasing or decreasing in that particular year, or value of t.

In 2010, the number of farms was decreasing about 2020.33 thousand per year, and in 2012, the number of farms was decreasing about 2415.85 thousand per year.

51. $f(t) = 4t + 3; [-3, 1]$

Average rate of change:

$\dfrac{f(1) - f(-3)}{1 - (-3)} = \dfrac{7 - (-9)}{4} = 4$

Instantaneous rate of change:

$f'(t) = 4$

$f'(1) = 4$

$f'(-3) = 4$

52. $f(x) = x^2 + 3x - 4; [0, 1]$

Average rate of change: $\dfrac{f(1) - f(0)}{1 - 0} = \dfrac{0 - (-4)}{1} = 4$

Instantaneous rate of change:

$f'(x) = 2x + 3$

$f'(1) = 5$

$f'(0) = 3$

53. $f(x) = x^{2/3}; [1, 8]$

Average rate of change: $\dfrac{f(8) - f(1)}{8 - 1} = \dfrac{4 - 1}{7} = \dfrac{3}{7}$

Instantaneous rate of change:

$f'(x) = \dfrac{2}{3x^{1/3}}$

$f'(8) = \dfrac{1}{3}$

$f'(1) = \dfrac{2}{3}$

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54. $f(x) = x^3 - x^2 + 3; [-2, 2]$

Average rate of change: $\dfrac{f(2) - f(-2)}{2 - (-2)} = \dfrac{7 - (-9)}{4} = 4$

Instantaneous rate of change: $f'(x) = 3x^2 - 2x$

$f'(2) = 8$

$f'(-2) = 16$

55. $s(t) = -16t^2 - 30t + 600$

(a) Average velocity $= \dfrac{s(3) - s(1)}{3 - 1} = \dfrac{366 - 554}{2} = -94$ ft/sec

(b) $v(t) = s'(t) = -32t - 30$

$v(1) = -62$ ft/sec

$v(3) = -126$ ft/sec

(c) $s(t) = 0$

$-16t^2 - 30 + 600 = 0$

$16t^2 + 30t - 600 = 0$

$$t = \frac{-(30) \pm \sqrt{(30)^2 - 4(16)(-600)}}{2(16)} = \frac{-30 \pm \sqrt{39{,}300}}{32}$$

$t \approx 5.26$ sec

(d) $v(t) = s'(5.26) = -32(5.26) - 30 = -198.32$ ft/sec

56. (a) $s(t) = -16t^2 + 276$

$v(t) = s'(t) = -32t$

(b) Average velocity $= \dfrac{s(2) - 2(0)}{2 - 0}$

$= \dfrac{212 - 276}{2}$

$= -32$ ft/sec

(c) $v(t) = -32t$

$v(2) = -64$ ft /sec

$v(3) = -96$ ft /sec

(d) $s(t) = 0$

$-16t^2 + 276 = 0$

$16t^2 = 276$

$t^2 = \dfrac{276}{16}$

$t \approx 4.15$ sec

(e) $v(4.15) = -132.8$ ft/sec

57. $C = 2500 + 320x$

$\dfrac{dC}{dx} = 320$

58. $C = 24{,}000 + 450x - x^2, 0 \le x \le 225$

$\dfrac{dC}{dx} = 450 - 2x$

59. $C = 370 + 2.55\sqrt{x} = 370 + 2.25x^{1/2}$

$\dfrac{dC}{dx} = \dfrac{1}{2}(2.55)\left(x^{-1/2}\right) = \dfrac{1.275}{\sqrt{x}}$

60. $C = 475 + 5.25x^{2/3}$

$\dfrac{dC}{dx} = 5.25\left(\dfrac{2}{3}x^{-1/3}\right) = \dfrac{3.5}{\sqrt[3]{x}}$

61. $R = 150x - 0.6x^2$

$\dfrac{dR}{dx} = 150 - 1.2x$

62. $R = 150x - \dfrac{3}{4}x^2$

$\dfrac{dR}{dx} = 150 - \dfrac{3}{2}x$

63. $R = -4x^3 + 2x^2 + 100x$

$\dfrac{dR}{dx} = -12x^2 + 4x + 100$

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64. $R = 4x + 10x^{1/2}$

$\dfrac{dR}{dx} = 4 + \dfrac{5}{x^{1/2}}$

65. $P = -0.0002x^3 + 6x^2 - x - 2000$

$\dfrac{dP}{dx} = -0.0006x^2 + 12x - 1$

66. $P = -\dfrac{1}{15}x^3 + 4000x^2 - 120x - 144{,}000$

$\dfrac{dP}{dx} = -\dfrac{1}{5}x^2 + 8000x - 120$

67. $P = -0.05x^2 + 20x - 1000$

(a) Find $\dfrac{dP}{dx}$ when $x = 100$.

$\dfrac{dP}{dx} = -0.1x + 20 = P'(x)$

When $x = 100$, $\dfrac{dP}{dx} = P'(100) = \$10$.

(b) Find $\dfrac{\Delta P}{\Delta x}$ for $100 \le x \le 101$.

$\dfrac{P(101) - P(100)}{101 - 100} = 509.95 - 500 = \$9.95$

(c) Parts (a) and (b) differ by only \$0.05.

68. $P = -0.021t^2 + 2.77t + 148.9$

(a) $P(0) = 148.9$

$P(4) = 159.644$

$P(8) = 169.716$

$P(12) = 179.116$

$P(16) = 187.844$

$P(20) = 195.9$

$P(23) = 201.501$

These values are the populations in millions for Brazil from 1990 to 2013.

(b) $\dfrac{dP}{dt} = -0.042t + 2.77 = P'(t)$

(c) $P'(0) = 2.77$

$P'(4) = 2.602$

$P'(8) = 2.434$

$P'(12) = 2.266$

$P'(16) = 2.098$

$P'(20) = 1.93$

$P'(23) = 1.804$

These are the rates at which the population of Brazil is changing in millions per year from 1990 to 2013.

69. $f(x) = x^3(5 - 3x^2) = 5x^3 - 3x^5$

$f'(x) = 15x^2 - 15x^4 = 15x^2(1 - x^2)$

Simple Power Rule

70. $f(x) = 4x^2(2x^2 - 5) = 8x^4 - 20x^2$

$f'(x) = 32x^3 - 40x = 8x(4x^2 - 5)$

Simple Power Rule

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

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

$= 12x^3 - 25x^2 + 12x + 4x^3 - 8x^2$

$= 16x^3 - 33x^2 + 12x$

Product Rule and Simple Power Rule

72. $s = \left(4 - \dfrac{1}{t^2}\right)(t^2 - 3t) = (4 - t^{-2})(t^2 - 3t)$

$s' = (4 - t^{-2})(2t - 3) + (t^2 - 3t)(2t^{-3})$

$= 8t - 12 - 2t^{-1} + 3t^{-2} + 2t^{-1} - 6t^{-2}$

$= 8t - 12 - 3t^{-2}$

Product Rule and Simple Power Rule

73. $g(x) = \dfrac{x}{x + 3}$

$g'(x) = \dfrac{(x + 3)(1) - x(1)}{(x + 3)^2}$

$g'(x) = \dfrac{3}{(x + 3)^2}$

Quotient Rule and Simple Power Rule

74. $f(x) = \dfrac{2 - 5x}{3x + 1}$

$f'(x) = \dfrac{(3x + 1)(-5) - (2 - 5x)(3)}{(3x + 1)^2}$

$f'(x) = \dfrac{-15x - 5 - 6 + 15x}{(3x + 1)^2}$

$f'(x) = -\dfrac{11}{(3x + 1)^2}$

Quotient Rule and Simple Power Rule

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75. $f(x) = \dfrac{6x - 5}{x^2 + 1}$

$$f'(x) = \frac{(x^2 + 1)(6) - (6x - 5)(2x)}{(x^2 + 1)^2}$$

$$= \frac{6 + 10x - 6x^2}{(x^2 + 1)^2}$$

$$= \frac{2(3 + 5x - 3x^2)}{(x^2 + 1)^2}$$

Quotient Rule and Simple Power Rule

76. $f(x) = \dfrac{x^2 + x - 1}{x^2 - 1}$

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

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

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

Quotient Rule and Simple Power Rule

77. $f(x) = (5x^2 + 2)^3$

$$f'(x) = 3(5x^2 + 2)^2(10x)$$

$$= 30x(5x^2 + 2)^2$$

General Power Rule

78. $f(x) = \sqrt[3]{x^2 - 1} = (x^2 - 1)^{1/3}$

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

General Power Rule

79. $h(x) = \dfrac{2}{\sqrt{x + 1}} = 2(x + 1)^{-1/2}$

$$h'(x) = 2\left(-\frac{1}{2}\right)(x + 1)^{-3/2}$$

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

General Power Rule

80. $g(x) = \dfrac{6}{(3x^2 - 5x)^4} = 6(3x^2 - 5x)^{-4}$

$$g'(x) = 6(-4)(3x^2 - 5x)^{-5}(6x - 5)$$

$$= -\frac{24(6x - 5)}{(3x^2 - 5x)^5}$$

General Power Rule

81. $g(x) = x\sqrt{x^2 + 1} = x(x^2 + 1)^{1/2}$

$$g'(x) = x\left[\frac{1}{2}(x^2 + 1)^{-1/2}(2x)\right] + (1)(x^2 + 1)^{1/2}$$

$$= (x^2 + 1)^{-1/2}\left[x^2 + (x^2 + 1)\right]$$

$$= \frac{2x^2 + 1}{\sqrt{x^2 + 1}}$$

Product and General Power Rule

82. $g(t) = \dfrac{t}{(1 - t)^3}$

$$g'(t) = \frac{(1 - t)^3(1) - t(3)(1 - t)^2(-1)}{(1 - t)^6}$$

$$= \frac{(1 - t)^3 + 3t(1 - t)^2}{(1 - t)^6}$$

$$= \frac{(1 - t) + 3t}{(1 - t)^4} = \frac{2t + 1}{(1 - t)^4}$$

Quotient Rule and General Power Rule

83. $f(x) = x(1 - 4x^2)^2$

$$f'(x) = x(2)(1 - 4x^2)(-8x) + (1 - 4x^2)^2$$

$$= -16x^2(1 - 4x^2) + (1 - 4x^2)^2$$

$$= (1 - 4x^2)\left[-16x^2 + (1 - 4x^2)\right]$$

$$= (1 - 4x^2)(1 - 20x^2)$$

Product and General Power Rule

84. $f(x) = \left(x^2 + \dfrac{1}{x}\right)^5 = (x^2 + x^{-1})^5$

$$f'(x) = 5(x^2 + x^{-1})^4(2x - x^{-2})$$

$$= 5\left(x^2 + \frac{1}{x}\right)^4\left(2x - \frac{1}{x^2}\right)$$

General Power Rule

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85. $h(x) = \left[x^2(2x+3)\right]^3 = x^6(2x+3)^3$

$$h'(x) = x^6\left[3(2x+3)^2(2)\right] + 6x^5(2x+3)^3$$
$$= 6x^5(2x+3)^2\left[x + (2x+3)\right]$$
$$= 18x^5(2x+3)^2(x+1)$$

Product and General Power Rule

86. $f(x) = \left[(x-2)(x+4)\right]^2$

$$f'(x) = 2\left[(x-2)(x+4)\right]\left[(x-2)+(x+4)\right]$$
$$= 2(x-2)(x+4)(2x+2)$$
$$= 4(x-2)(x+4)(x+1)$$

Product and General Power Rule

87. $f(x) = x^2(x-1)^5$

$$f'(x) = 5x^2(x-1)^4 + 2x(x-1)^5$$
$$= x(x-1)^4\left[5x + 2(x-1)\right]$$
$$= x(x-1)^4(7x-2)$$

Product and General Power Rule

88. $f(s) = s^3\left(s^2-1\right)^{5/2}$

$$f'(s) = s^3\left(\tfrac{5}{2}\right)\left(s^2-1\right)^{3/2}(2s) + 3s^2\left(s^2-1\right)^{5/2}$$
$$= s^2\left(s^2-1\right)^{3/2}\left[5s^2 + 3\left(s^2-1\right)\right]$$
$$= s^2\left(s^2-1\right)^{3/2}\left(8s^2-3\right)$$

Product and General Power Rule

89. $h(t) = \dfrac{\sqrt{3t+1}}{(1-3t)^2} = \dfrac{(3t+1)^{1/2}}{(1-3t)^2}$

$$h'(t) = \frac{(1-3t)^2(1/2)(3t+1)^{-1/2}(3) - (3t+1)^{1/2}(2)(1-3t)(-3)}{(1-3t)^4}$$
$$= \frac{(3t+1)^{-1/2}\left[(1-3t)(3/2) + (3t+1)6\right]}{(1-3t)^3}$$
$$= \frac{3(9t+5)}{2\sqrt{3t+1}(1-3t)^3}$$

Quotient and General Power Rule

90. $g(x) = \left(\dfrac{3x+1}{x^2+1}\right)^2 = \dfrac{(3x+1)^2}{\left(x^2+1\right)^2}$

$$g'(x) = \frac{\left(x^2+1\right)^2(2)(3x+1)(3) - (3x+1)^2 2\left(x^2+1\right)2x}{\left(x^2+1\right)^4}$$
$$= \frac{6\left(x^2+1\right)^2(3x+1) - 4x(3x+1)^2\left(x^2+1\right)}{\left(x^2+1\right)^4}$$
$$= \frac{2(3x+1)\left(x^2+1\right)\left[3\left(x^2+1\right) - 2x(3x+1)\right]}{\left(x^2+1\right)^4}$$
$$= \frac{2(3x+1)\left(x^2+1\right)\left(-3x^2-2x+3\right)}{\left(x^2+1\right)^4}$$
$$= \frac{2(3x+1)\left(-3x^2-2x+3\right)}{\left(x^2+1\right)^3}$$

Quotient and General Power Rule.

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91. $T = \dfrac{1300}{t^2 + 2t + 25} = 1300\left(t^2 + 2t + 25\right)^{-1}$

$T'(t) = -1300\left(t^2 + 2t + 25\right)^{-2}(2t + 2)$

$= -\dfrac{2600(t + 1)}{\left(t^2 + 2t + 25\right)^2}$

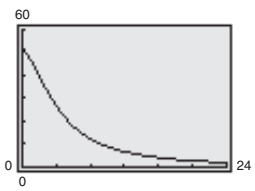
(a) $T'(1) = -\dfrac{325}{49} \approx -6.63°\text{F/hr}$

$T'(3) = -\dfrac{13}{2} \approx -6.5°\text{F/hr}$

$T'(5) = -\dfrac{13}{3} \approx -4.33°\text{F/hr}$

$T'(10) = -\dfrac{1144}{841} \approx -1.36°\text{F/hr}$

(b)



The rate of decrease is approaching zero.

92. When $L = 12$,

$V = \dfrac{L}{16}(D - 4)^2 = \dfrac{12}{16}(D - 4)^2 = \dfrac{3}{4}(D - 4)^2$

$\dfrac{dV}{dD} = \dfrac{3}{2}(D - 4).$

(a) When $D = 8$, $\dfrac{dV}{dD} = \left(\dfrac{3}{2}\right)(8 - 4) = 6$ board ft/in.

(b) When $D = 16$,

$\dfrac{dV}{dD} = \left(\dfrac{3}{2}\right)(16 - 4) = 18$ board ft/in.

(c) When $D = 24$,

$\dfrac{dV}{dD} = \left(\dfrac{3}{2}\right)(24 - 4) = 30$ board ft/in.

(d) When $D = 36$,

$\dfrac{dV}{dD} = \left(\dfrac{3}{2}\right)(36 - 4) = 48$ board ft/in.

93. $f(x) = 3x^2 + 7x + 1$

$f'(x) = 6x + 7$

$f''(x) = 6$

94. $f'(x) = 5x^4 - 6x^2 + 2x$

$f''(x) = 20x^3 - 12x + 2$

$f'''(x) = 60x^2 - 12 = 12\left(5x^2 - 1\right)$

95. $f'''(x) = -\dfrac{3}{x^4} = -3x^{-4}$

$f^{(4)}(x) = 12x^{-5}$

$f^{(5)}(x) = -60x^{-6}$

$f^{(6)}(x) = 360x^{-7} = \dfrac{360}{x^7}$

96. $f(x) = \sqrt{x} = x^{1/2}$

$f'(x) = \dfrac{1}{2}x^{-1/2}$

$f''(x) = -\dfrac{1}{4}x^{-3/2}$

$f'''(x) = \dfrac{3}{8}x^{-5/2}$

$f^{(4)}(x) = -\dfrac{15}{16}x^{-7/2} = -\dfrac{15}{16x^{7/2}}$

97. $f'(x) = 8x^{5/2}$

$f''(x) = 20x^{3/2}$

$f'''(x) = 30x^{1/2}$

$f^{(4)}(x) = 15x^{-1/2} = \dfrac{15}{x^{1/2}}$

98. $f''(x) = 9\sqrt[3]{x} = 9x^{1/3}$

$f'''(x) = 3x^{-2/3}$

$f^{(4)}(x) = -2x^{-5/3}$

$f^{(5)}(x) = \dfrac{10}{3}x^{-8/3} = \dfrac{10}{3x^{8/3}}$

99. $f(x) = x^2 + \dfrac{3}{x} = x^2 + 3x^{-1}$

$f'(x) = 2x - 3x^{-2}$

$f''(x) = 2 + 6x^{-3} = 2 + \dfrac{6}{x^3}$

100. $f'''(x) = 20x^4 - \dfrac{2}{x^3} = 20x^4 - 2x^{-3}$

$f^{(4)}(x) = 80x^3 + 6x^{-4}$

$f^{(5)}(x) = 240x^2 - 24x^{-5} = 240x^2 - \dfrac{24}{x^5}$

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101. (a) $s(t) = -16t^2 + 5t + 30$

$v(t) = s'(t) = -32t + 5$

$a(t) = v'(t) = s''(t) = -32$

(b) $s(t) = 0 = -16t^2 + 5t + 30$

Using the Quadratic Formula, $t \approx 1.534$ seconds.

(c) $v(t) = s'(t) = -32t + 5$

$v(1.534) \approx -44.09$ ft/sec

(d) $a(t) = v'(t) = -32$ ft/sec^2

102. $s(t) = \dfrac{1}{t^2 + 2t + 1} = (t + 1)^{-2}$

$v(t) = s'(t) = -2(t + 1)^{-3} = -\dfrac{2}{(t + 1)^3}$

$a(t) = v'(t) = 6(t + 1)^{-4} = \dfrac{6}{(t + 1)^4}$

103.
$$x^2 + 3xy + y^3 = 10$$
$$2x + 3x\frac{dy}{dx} + 3y + 3y^2\frac{dy}{dx} = 0$$
$$\frac{dy}{dx}(3x + 3y^2) = -2x - 3y$$
$$\frac{dy}{dx} = \frac{-2x - 3y}{3x + 3y^2} = -\frac{2x + 3y}{3(x + y^2)}$$

104.
$$x^2 + 9xy + y^2 = 0$$
$$2x + 9y + 9x\frac{dy}{dx} + 2y\frac{dy}{dx} = 0$$
$$(9x + 2y)\frac{dy}{dx} = -2x - 9y$$
$$\frac{dy}{dx} = \frac{-2x - 9y}{9x + 2y} = -\frac{2x + 9y}{9x + 2y}$$

105. $y^2 - x^2 + 8x - 9y - 1 = 0$
$$2y\frac{dy}{dx} - 2x + 8 - 9\frac{dy}{dx} = 0$$
$$(2y - 9)\frac{dy}{dx} = 2x - 8$$
$$\frac{dy}{dx} = \frac{2x - 8}{2y - 9}$$

106. $y^2 + x^2 - 6y - 2x - 5 = 0$
$$2y\frac{dy}{dx} + 2x - 6\frac{dy}{dx} - 2 = 0$$
$$\frac{dy}{dx}(2y - 6) = 2 - 2x$$
$$\frac{dy}{dx} = \frac{2 - 2x}{2y - 6} = \frac{1 - x}{y - 3}$$

107.
$$y^2 = x - y$$
$$2y\frac{dy}{dx} = 1 - \frac{dy}{dx}$$
$$2y\frac{dy}{dx} + \frac{dy}{dx} = 1$$
$$(2y + 1)\frac{dy}{dx} = 1$$
$$\frac{dy}{dx} = \frac{1}{2y + 1}$$

At $(2, 1)$, $\dfrac{dy}{dx} = \dfrac{1}{3}$.

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

108.
$$2x^{1/3} + 3y^{1/2} = 10$$
$$\frac{2}{3}x^{-2/3} + \frac{3}{2}y^{-1/2}\frac{dy}{dx} = 0$$
$$\frac{dy}{dx} = -\frac{4y^{1/2}}{9x^{2/3}}$$

At $(8, 4)$, $\dfrac{dy}{dx} = -\dfrac{2}{9}$.

$$y - 4 = -\frac{2}{9}(x - 8)$$
$$y = -\frac{2}{9}x + \frac{52}{9}$$

109.
$$y^2 - 2x = xy$$
$$2y\frac{dy}{dx} - 2 = x\frac{dy}{dx} + y$$
$$(2y - x)\frac{dy}{dx} = y + 2$$
$$\frac{dy}{dx} = \frac{y + 2}{2y - x}$$

At $(1, 2)$, $\dfrac{dy}{dx} = \dfrac{4}{3}$.

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

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110.
$$y^3 - 2x^2y + 3xy^2 = -1$$
$$3y^2\frac{dy}{dx} - 2x^2\frac{dy}{dx} - 4xy + 6xy\frac{dy}{dx} + 3y^2 = 0$$
$$\frac{dy}{dx}\left(3y^2 - 2x^2 + 6xy\right) = 4xy - 3y^2$$
$$\frac{dy}{dx} = \frac{4xy - 3y^2}{3y^2 - 2x^2 + 6xy}$$

At $(0, -1)$, $\frac{dy}{dx} = -1$.

$$y + 1 = -1(x - 0)$$
$$y = -x - 1$$

111. $A = \pi r^2$

$$\frac{dA}{dt} = 2\pi r\frac{dr}{dt}$$

(a) Find $\frac{dA}{dt}$ when $r = 3$ in. and $\frac{dr}{dt} = 2$ in./min.

$$\frac{dA}{dt} = 2\pi(3)(2) = 12\pi \text{ in.}^2/\text{min}$$
$$\approx 37.7 \text{ in.}^2/\text{min}$$

(b) Find $\frac{dA}{dt}$ when $r = 10$ in. and $\frac{dr}{dt} = 2$ in./min.

$$\frac{dA}{dt} = 2\pi(10)(2) = 40\pi \text{ in.}^2/\text{min}$$
$$\approx 125.7 \text{ in.}^2/\text{min}$$

112. $P = 375x - 1.5x^2$

$$\frac{dP}{dt} = 375\frac{dx}{dt} - 3.0x\frac{dx}{dt}$$
$$\frac{dP}{dt} = (375 - 3.0x)\frac{dx}{dt}$$

(a) $\frac{dP}{dt} = \left[375 - 3.0(50)\right](2) = \$450/\text{day}$

(b) $\frac{dP}{dt} = \left[375 - 3.0(100)\right](2) = \$150/\text{day}$

113. Let b be the horizontal distance of the water and h be the depth of the water at the deep end.

Then $b = 8h$ for $0 \le h \le 5$.

$$V = \frac{1}{2}bh(20) = 10bh = 10(8h)h = 80h^2$$
$$\frac{dV}{dt} = 160h\frac{dh}{dt}$$
$$\frac{dh}{dt} = \frac{1}{160h}\frac{dV}{dt} = \frac{1}{160h}(10) = \frac{1}{16h}$$

When $h = 4$, $\frac{dh}{dt} = \frac{1}{16(4)} = \frac{1}{64}$ ft/min.

114. $P = R - C$

$$= xp - C$$
$$= x(211 - 0.002x) - (30x + 1{,}500{,}000)$$
$$= 181x - 0.002x^2 - 1{,}500{,}000$$
$$\frac{dP}{dt} = 181\frac{dx}{dt} - 0.004x\frac{dx}{dt}$$
$$\frac{dP}{dt} = (181 - 0.004x)\frac{dx}{dt}$$
$$\frac{dP}{dt} = \left[181 - 0.004(1600)\right](15) = \$2619/\text{week}$$

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Chapter 2 Test Yourself

1. $f(x) = x^2 + 3;\ (3, 12)$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{(x + \Delta x)^2 + 3 - (x^2 + 3)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{x^2 + 2x\Delta x + (\Delta x)^2 + 3 - (x^2 + 3)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{2x\Delta x + (\Delta x)^2}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{\Delta x[2x + (\Delta x)]}{\Delta x}$$
$$= \lim_{\Delta x \to 0} 2x + \Delta x$$
$$= 2x$$

At $(3, 12)$: $m = 2(3) = 6$

2. $f(x) = \sqrt{x} - 2;\ (4, 0)$

$$f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{\sqrt{x + \Delta x} - 2 - (\sqrt{x} - 2)}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{\sqrt{x + \Delta x} - \sqrt{x}}{\Delta x}$$
$$= \lim_{\Delta x \to 0} \frac{1}{\sqrt{x + \Delta x} + \sqrt{x}}$$
$$= \frac{1}{2\sqrt{x}}$$

At $(4, 0)$: $m = \dfrac{1}{2\sqrt{4}} = \dfrac{1}{4}$

3. $f(t) = t^3 + 2t$

$f'(t) = 3t^2 + 2$

4. $f(x) = 4x^2 - 8x + 1$

$f'(x) = 8x - 8$

5. $f(x) = x^{3/2} + 6x^{1/2}$

$$f'(x) = \frac{3}{2}x^{1/2} + 3x^{-1/2} = \frac{3\sqrt{x}}{2} + \frac{3}{\sqrt{x}}$$

6. $f(x) = 5x^2 - \dfrac{3}{x^3} = 5x^2 - 3x^{-3}$

$$f'(x) = 10 + 9x^{-4} = 10x + \frac{9}{x^4}$$

7. $f(x) = (x + 3)(x^2 + 2x)$

$f(x) = x^3 + 5x^2 + 6x$

$f'(x) = 3x^2 + 10x + 6$

(Or use the Product Rule.)

8. $f(x) = \sqrt{x}(5 + x) = 5x^{1/2} + x^{3/2}$

$$f'(x) = \frac{5}{2}x^{-1/2} + \frac{3}{2}x^{1/2} = \frac{5}{2\sqrt{x}} + \frac{3\sqrt{x}}{2}$$

9. $f(x) = (3x^2 + 4)^2$

$$f'(x) = 2(3x^2 + 4)(6x)$$
$$= 36x^3 + 48x$$

10. $f(x) = \sqrt{1 - 2x} = (1 - 2x)^{1/2}$

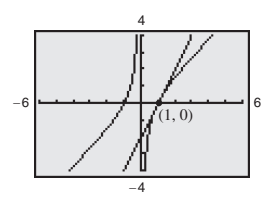
$$f'(x) = \frac{1}{2}(1 - 2x)^{-1/2}(-2)$$
$$= -\frac{1}{\sqrt{1 - 2x}}$$

11. $f(x) = \dfrac{(5x - 1)^3}{x}$

$$f'(x) = \frac{x(3)(5x - 1)^2(5) - (5x - 1)^3}{x^2}$$
$$= \frac{(5x - 1)^2[15x - (5x - 1)]}{x^2}$$
$$= \frac{(5x - 1)^2(10x + 1)}{x^2}$$

12. $f(x) = x - \dfrac{1}{x}$

$$f'(x) = 1 + \frac{1}{x^2}$$
$$f'(1) = 1 + \frac{1}{1^2} = 2$$
$$y - 0 = 2(x - 1)$$
$$y = 2x - 2$$



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13. $S = -2.1083t^3 + 70.811t^2 - 777.05t + 2893.6$

(a) $\dfrac{\Delta S}{\Delta t}$ for $10 \le t \le 12$

$$\frac{S(12) - S(10)}{12 - 10} = \frac{122.6416 - 95.9}{2}$$
$$= \$13.3708 \text{ billion/yr}$$

(b) $S'(t) = -6.3249t^2 + 141.622t - 777.05$

2010: $S'(10) = \$6.68$ billion/yr

2012: $S'(12) = \$11.6284$ billion/yr

(c) The annual sales of CVS Caremark from 2010 to 2012 increased by an average of about \$13.37 billion per year, and the instantaneous rates of change for 2010 and 2012 are \$6.68 billion per year and \$11.63 billion per year, respectively.

14. $P = 1700 - 0.016x$, $C = 715{,}000 + 240x$

Profit = Revenue − Cost

(a) Revenue: $R = xp$

$$R = x(1700 - 0.016x)$$
$$R = 1700x - 0.016x^2$$
$$P = R - C$$
$$P = \left(1700x - 0.016x^2\right) - (715{,}000 + 240x)$$
$$P = -0.016x^2 + 1460x - 715{,}000$$

(b) $\dfrac{dP}{dx} = -0.032x + 1460 = P'(x)$

$P'(700) = \$1437.60$

15. $f(x) = 2x^2 + 3x + 1$

$$f'(x) = 4x + 3$$
$$f''(x) = 4$$
$$f'''(x) = 0$$

16. $f(x) = \sqrt{3 - x} = (3 - x)^{1/2}$

$$f'(x) = \frac{1}{2}(3 - x)^{-1/2}(-1) = -\frac{1}{2}(3 - x)^{-1/2}$$
$$f''(x) = -\frac{1}{2}\left(-\frac{1}{2}\right)(3 - x)^{-3/2}(-1) = -\frac{1}{4}(3 - x)^{-3/2}$$
$$f'''(x) = -\frac{1}{4}\left(-\frac{3}{2}\right)(3 - x)^{-5/2}(-1)$$
$$= -\frac{3}{8}(3 - x)^{-5/2}$$
$$= -\frac{3}{8(3 - x)^{5/2}}$$

17. $f(x) = \dfrac{2x + 1}{2x - 1}$

$$f'(x) = \frac{(2x - 1)(2) - (2x + 1)(2)}{(2x - 1)^2}$$
$$= \frac{4}{(2x - 1)^2}$$
$$= -4(2x - 1)^{-2}$$
$$f''(x) = 8(2x - 1)^{-3}(2) = 16(2x - 1)^{-3}$$
$$f'''(x) = -48(2x - 1)^{-4}(2) = -\frac{96}{(2x - 1)^4}$$

18. $s(t) = -16t^2 + 30t + 75$

$$v(t) = s'(t) = -32t + 30$$
$$a(t) = v'(t) = s''(t) = -32$$

At $t = 2$: $s(2) = 71$ ft

$v(2) = -34$ ft/sec

$a(2) = -32$ ft/sec^2

19.
$$x + xy = 6$$
$$1 + x\frac{dy}{dx} + y = 0$$
$$x\frac{dy}{dx} = -y - 1$$
$$\frac{dy}{dx} = -\frac{y + 1}{x}$$

20. $y^2 + 2x - 2y + 1 = 0$

$$2y\frac{dy}{dx} + 2 - 2\frac{dy}{dx} = 0$$
$$\frac{dy}{dx}(2y - 2) = -2$$
$$\frac{dy}{dx} = -\frac{1}{y - 1}$$

21.
$$4x^2 - 3y^2 + x^3y = 5$$
$$8x - 6y\frac{dy}{dx} + x^3\frac{dy}{dx}3x^2y = 0$$
$$-6y\frac{dy}{dx} + x^3\frac{dy}{dx} = -8x - 3x^2y$$
$$\left(x^3 - 6y\right)\frac{dy}{dx} = -\left(8x + 3x^2y\right)$$
$$\frac{dy}{dx} = -\frac{8x + 3x^2y}{x^3 - 6y}$$
$$\frac{dy}{dx} = \frac{8x + 3x^2y}{6y - x^3} = \frac{x(8 + 3xy)}{6y - x^3}$$

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22. $V = \pi r^2 h = 20\pi r^3$

$$\frac{dV}{dt} = 60\pi r^2 \frac{dr}{dt}$$

(a) $\dfrac{dV}{dt} = 60\pi(0.5)^2(0.25) = 3.75\pi \text{ cm}^3/\text{min}$

(b) $\dfrac{dV}{dt} = 60\pi(1)^2(0.25) = 15\pi \text{ cm}^3/\text{min}$

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