Key CONCEPTS

1 The table summarizes how parabolas in the form $y = a(x - h)^2 + k$ are obtained by transforming the function $y = x^2$.

Operation	Resulting Equation	Transformation
Multiply by a.	$y = ax^2$	Reflects in the x-axis, if $a < 0$.
		Stretches vertically (narrows), if $a > 1$ or $a < -1$.
		Shrinks vertically (widens), if $-1 < a < 1$.
Replace x by $(x - h)$.	$y = a(x - h)^2$	Shifts h units to the right, if $h > 0$.
		Shifts h units to the left, if $h < 0$.
Add k.	$y = a(x - h)^2 + k$	Shifts k units upward, if $k > 0$.
		Shifts k units downward, if $k < 0$.

2 Some geometric properties of the parabola $y = a(x - h)^2 + k$ are summarized in the following table.

	Sign of a	
Property	**positive**	**negative**
Vertex	(h, k)	(h, k)
Axis of Symmetry	$x = h$	$x = h$
Direction of Opening	up	down
Comparison with $y = ax^2$	congruent	congruent

Communicate Your Understanding

1. For each function, describe how you would find the coordinates of the vertex, the equation of the axis of symmetry, and the maximum or minimum value.

a) $y = (x + 5)^2 + 2$ **b)** $y = 3(x - 2)^2 - 4$ **c)** $y = -2(x + 4)^2 + 3$

2. Describe how you would determine the intercepts of the parabola $y = (x - 3)^2 - 4$.

3. Explain whether it is possible for a parabola to have

a) no y-intercept **b)** no x-intercepts

Practice

A

1. Sketch each parabola and state the direction of the opening, the coordinates of the vertex, the equation of the axis of symmetry, the domain and range, and the maximum or minimum value.

a) $y = (x + 5)^2$ **b)** $y = -(x + 1)^2$ **c)** $y = (x - 3)^2$
d) $y = (x + 2)^2 + 4$ **e)** $y = -(x - 2)^2 - 5$ **f)** $y = (x + 3)^2 - 5$
g) $y = (x + 6)^2 + 2$ **h)** $y = (x - 5)^2 - 4$ **i)** $y = -(x + 4)^2 + 3$

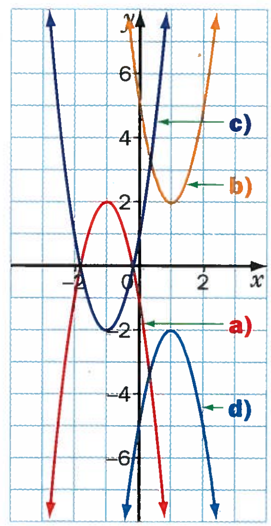
2. Without sketching each parabola, state the direction of the opening, the coordinates of the vertex, the equation of the axis of symmetry, the domain and range, and the maximum or minimum value.

a) $y = (x - 5)^2$
b) $y = -(x + 4)^2$
c) $y = (x - 2)^2 + 1$
d) $y = -(x + 1)^2 - 2$

3. For each parabola, state the direction of the opening, how the parabola is stretched or shrunk, the coordinates of the vertex, the equation of the axis of symmetry, and the maximum or minimum value.

a) $y = 2(x - 1)^2$
b) $y = -0.5(x + 7)^2$
c) $y = -2(x - 4)^2 + 7$
d) $y = 4(x + 3)^2 - 4$
e) $y = -3(x - 5)^2 + 6$
f) $y = -0.4(x - 8)^2 - 1$
g) $y = \frac{1}{3}(x + 6)^2 - 7$
h) $y = 0.5(x + 1)^2 - 5$
i) $y = 2.5(x + 1.5)^2 - 9$
j) $y = -1.2(x - 2.6)^2 + 3.3$

4. The four graphs represent the four equations $y = 3(x - 1)^2 + 2$, $y = 3(x + 1)^2 - 2$, $y = -3(x + 1)^2 + 2$, and $y = -3(x - 1)^2 - 2$. Match each graph with the correct equation.



5. Sketch each parabola.

a) $y = (2 + x)^2$
b) $y = 3 + (x - 1)^2$
c) $y - 4 = -2(3 + x)^2$
$y = 2(3 + x^2) + 4$
d) $y + \frac{6}{5} = 3(x - 5)^2 + \frac{1}{5}$

6. Sketch each parabola and estimate any intercepts.

a) $y = (x - 2)^2$
b) $y = (x + 2)^2 - 9$
c) $y = (x - 3)^2 - 1$
d) $y = -(x + 2)^2 + 1$

7. Determine any x- and y-intercepts by graphing using a graphing calculator or graphing software. Round to the nearest tenth, if necessary.

a) $y = (x + 1)^2 - 3$
b) $y = 2(x - 1)^2 - 4$
c) $y = -4(x - 1)^2 + 1$
d) $y = -5(x + 3)^2 - 2$
e) $y = 0.25(x + 4)^2$
f) $y = -0.5(x + 3)^2 + 2$

Section 4.1 pp. 197–199

Practice **1. a)** function **b)** function **c)** not a function **d)** function **e)** function **f)** not a function **2. a)** 3 **b)** 23 **c)** –5 **d)** –13 **e)** –21 **f)** 395 **g)** –3 **h)** –7 **i)** 3995 **3. a)** 6 **b)** 2 **c)** –2 **d)** 14 **e)** 8 **f)** –12 **g)** 7 **h)** 8.2 **i)** 0 **4. a)** 9 **b)** 5 **c)** 9 **d)** 105 **e)** 105 **f)** 5.25 **g)** 5.01 **5. a)** 3 **b)** 1 **c)** 19 **d)** 163 **e)** 243 **f)** 1.5 **g)** 1.5 **6. b)** yes **7. a)** function **b)** not a function **c)** function **d)** not a function **8. a)** domain: {3, 4, 5, 6}, range: {–2, 0, 1, 3} **b)** domain: {–3, –1, 1, 3, 5}, range: {2, 3, 4} **c)** domain: {–2, –1, 0, 1}, range: {3, 4} **d)** domain: {–1}, range: {1, 2, 3, 4} **9. a)** domain: {–2, –1, 0, 1, 2}, range: {1, 2, 5}; function **b)** domain: {0, 1, 2, 3}, range: {–2, –1, 0, 1}; not a function **10. a)** domain: {–2, 0, 2, 4, 6}, range: {0, 2, 4, 6, 8} **b)** domain: set of real numbers, range: set of real numbers **c)** domain: set of real numbers, range: $y \le 2$ **d)** domain: {1}, range: set of real numbers **11.** {2, 3, 6}

Applications and Problem Solving **12. a)** 2; 2.5 **b)** speed: independent, Mach number: dependent. The Mach number depends on the speed. **13. b)** 17.6 million **c)** 2039 **14. b)** No, the domain and range are both the set of real numbers. **c)** x does not have a minimum or maximum value. The domain is the set of real numbers. y has a minimum value of 0, but no maximum value. The range is the set of real numbers greater than 0. **15. a)** range: set of real numbers **b)** range: $y \ge -2$ **16. a)** ±2 **b)** ±4 **c)** 0 **d)** $\pm\sqrt{11}$ **17. a)** no **b)** Yes, there is only one name for every set of fingerprints. **18.** No, there are likely several people with the same first name. **19.** Since the x-coordinates of the points on a vertical line are all equal, if a vertical line passes through more than one point of the graph of a relation, then the relation contains two different points with the same x-coordinate, and so is not a function. **20. a)** $y = 8a + 3$ **b)** $y = -1 - 3n$ **c)** $y = m^2 - 2m + 2$ **d)** $y = 8k^2 + 8k - 1$ **e)** $y = 9t^2 + 6t - 4$ **f)** $y = 12w^2 - 32w + 25$ **21.** It is a vertical line. **22. a)** A closed dot is used to show the location of an ordered pair on a graph; an open dot is used to show that an ordered pair is omitted from the graph. **b)** It looks like steps. **c)** domain: $0 \le t \le 4$, range: {120, 200, 280, 360} **d)** (0.5, 120), (1, 120) **e)** (1, 120), (2, 200) **f)** No, the graph is a function.

Investigation pp. 200–203

1 Translations on a Coordinate Grid **1. a)** D′(2, 4), E′(–2, 4), F′(–2, –2) **b)** P′(–1, 4), Q′(–5, 6), R′(–7, –3) **c)** U′(–3, –4), V′(–1, 3), W′(0, 0) **d)** F′(4, –1), G′(–2, 6), H′(1, –2) **e)** A′(1, –3), B′(7, –4), C′(5, –7) **f)** J′(–1, –2), K′(–4, –1), L′(–6, –6) **2.** R(1, –4), S(–2, 3), T(–4, –5) **3. a)** A′(7, 3), B′(3, 8), C′(1, 4) **b)** A″(6, –2), B″(2, 3), C″(0, –1) **c)** 3 units to the right, 2 units downward

2 Reflections on a Coordinate Grid **1. a)** A′(2, –4), B′(1, –1), C′(6, –2) **b)** D′(0, –3), E′(5, –4), F′(2, 0) **c)** P′(1, –2), Q′(–3, 2), R′(3, 1) **2. a)** A′(–1, 3), B′(–2, 1), C′(–6, 3) **b)** D′(–1, 2), E′(0, –2), F′(–3, 1) **c)** P′(2, 1), Q′(3, –3), R′(–1, –2) **3. a)** (2, –3), (–2, 3) **b)** (–1, 2), (1, –2) **c)** (–3, –2), (3, 2) **d)** (4, 0), (–4, 0) **4.** A′(–1, 1), B′(–5, 2), C′(–3, 6) **5.** R′(2, –5), S′(–2, –4), T′(–1, 2) **6. a)** y-axis **b)** x-axis

3 Dilatations on a Coordinate Grid **1. a)** 2 **b)** $\frac{1}{3}$ **2. a)** A′(6, 4), B′(2, 8) **b)** C′(3, 2), D′(–1, 1) **c)** E′(–3, –3), F′(3, 6) **d)** G′(3, 1), H′(–2, 0) **3.** R′(6, 9), S′(–3, 12), T′(–9, –6) **4.** D′(3, 2), E′(–1, 3), F′(–2, –2), G′(2, –3) **5. b)** 8 **c)** P′(–6, 6), Q′(–6, –6), R′(6, –6) **d)** 72 **e)** P″(–1, 1), Q″(–1, –1), R″(1, –1) **f)** 2 **g)** 9:1; $\frac{1}{4}$:1 **h)** The first term is the square of the scale factor.

Section 4.2 pp. 213–216

Practice **1. a)** up; (0, 5); $x = 0$; domain: set of real numbers, range: $y \ge 5$; minimum: 5 **b)** up; (0, –2); $x = 0$; domain: set of real numbers, range: $y \ge -2$; minimum: –2 **c)** down; (0, –1); $x = 0$; domain: set of real numbers, range: $y \le -1$; maximum: –1 **d)** down; (0, 4); $x = 0$; domain: set of real numbers, range: $y \le 4$; maximum: 4 **e)** up; (0, 0); $x = 0$; domain: set of real numbers, range: $y \ge 0$; minimum: 0 **f)** down; (0, 0); $x = 0$; domain: set of real numbers, range: $y \le 0$; maximum: 0 **g)** up; (0, –1); $x = 0$; domain: set of real numbers, range: $y \ge -1$; minimum: –1 **h)** down; (0, 0); $x = 0$; domain: set of real numbers, range: $y \le 0$; maximum: 0 **i)** down; (0, –3); $x = 0$; domain: set of real numbers, range: $y \le -3$; maximum: –3 **j)** up; (0, 1); $x = 0$; domain: set of real numbers, range: $y \ge 1$; minimum: 1 **k)** down; (0, 7); $x = 0$; domain: set of real numbers, range: $y \le 7$; maximum: 7 **l)** down; (0, –6); $x = 0$; domain: set of real numbers, range: $y \le -6$; maximum: –6 **2. a)** The graph of $y = x^2 - 4$ is a translation of the graph of $y = x^2$ 4 units downward **b)** The graph of $y = -x^2 + 5$ is a translation of the graph of $y = -x^2$ 5 units upward. **c)** The graph of $y = 3x^2$ is a vertical stretch of the graph of $y = x^2$ by a factor of 3. **d)** The graph of $y = -\frac{1}{3}x^2$ is a vertical shrink of the graph of $y = -x^2$ by a factor of $\frac{1}{3}$ **e)** The graph of $y = 2x^2 - 2$ is a translation of the graph of $y = 2x^2 + 7$ 9 units downward. **f)** The graph of

$y = -0.25x^2$ is a reflection of the graph of $y = 0.25x^2$ in the x-axis. **3. a)** $y = -2x^2 + 3$ **b)** $y = 2x^2 - 3$ **c)** $y = 2x^2 + 3$ **d)** $y = -2x^2 - 3$ **4. a)** down; (0, 0); domain: set of real numbers, range: $y \le 0$; maximum: 0 **b)** up; (0, −11.4); domain: set of real numbers, range: $y \ge -11.4$; minimum: −11.4 **c)** down; (0, 4.7); domain: set of real numbers, range: $y \le 4.7$; maximum: 4.7 **d)** up; (0, −3); domain: set of real numbers, range: $y \ge -3$; minimum: −3 **e)** down; (0, −8.3); domain: set of real numbers, range: $y \le -8.3$; maximum: −8.3 **f)** up; (0, 9.9); domain: set of real numbers, range: $y \ge 9.9$; minimum: 9.9 **g)** up; (0, 3.5); domain: set of real numbers, range: $y \ge 3.5$; minimum: 3.5 **h)** down; (0, −0.5); domain: set of real numbers, range: $y \le -0.5$; maximum: −0.5 **5. a)** It becomes the point (2, 13). **b)** It becomes the point (2, −1). **c)** It becomes the point (2, −2). **d)** It becomes the point (2, −2). **6. a)** (0, −9), x-intercepts: ±3, y-intercept: −9 **b)** (0, 1), x-intercepts: none, y-intercept: 1 **c)** (0, 4), x-intercepts: ±2, y-intercept: 4 **d)** (0, −8), x-intercepts: ±2, y-intercept: −8 **e)** (0, 16), x-intercepts: none, y-intercept: 16 **f)** (0, 18), x-intercepts: ±3, y-intercept: 18 **g)** (0, −3), x-intercepts: none, y-intercept: −3 **h)** (0, 5), x-intercepts: ±1, y-intercept: 5 **7. a)** ±1.4 **b)** ±1.7 **c)** no x-intercepts **d)** ±2.2 **e)** ±1.4 **f)** ±2.4
Applications and Problem Solving **8.** −7.5; The graph is symmetric about the y-axis. **9. a)** $A = \frac{1}{2}h^2$ **c)** 0, 0 **d)** domain: $h \ge 0$, range: $A \ge 0$ **10. a)** $y = 5x^2$ **b)** $y = -6x^2$ **c)** $y = -8x^2 - 7$ **d)** $y = 0.2x^2 + 3$
11. $k = -15$ **12. b)** 2 m **c)** 150 m **d)** 17 m
13. a) (−3, 7), (2, 2) **b)** Answers may vary.
14. a) $y = x^2 + 2$ **b)** $y = -x^2 - 1$ **c)** $y = 2x^2 - 3$ **d)** $y = -\frac{1}{2}x^2 + 4$ **15. a)** $n = 2p^2 - 4$ **b)** $n = -2p^2 + 4$ **c)** They are reflections of each other in the n-axis.
16. a) $A = \pi r^2$ **c)** No, the domain of the function is $r \ge 0$. **d)** domain: $r \ge 0$, range: $A \ge 0$
17. a) $A = 400 - s^2$ **b)** 16 **d)** domain: $0 \le s \le 16$, range: $144 \le A \le 400$ **Technology Extension** Answers may vary.

Modelling Math p. 216

b) 1st quadrant; d and t must be non-negative. **c)** 5.4 s **d)** 13.5 s

Section 4.3 pp. 222–227

Practice **1. a)** up; (−5, 0); $x = -5$; domain: set of real numbers, range: $y \ge 0$; minimum: 0 **b)** down; (−1, 0); $x = -1$; domain: set of real numbers, range: $y \le 0$; maximum: 0 **c)** up; (3, 0); $x = 3$; domain: set of real numbers, range: $y \ge 0$; minimum: 0 **d)** up; (−2, 4); $x = -2$; domain: set of real numbers, range: $y \ge 4$; minimum: 4 **e)** down; (2, −5); $x = 2$; domain: set of real numbers, range: $y \le -5$; maximum: −5 **f)** up; (−3, −5); $x = -3$; domain: set of real numbers, range: $y \ge -5$; minimum: −5 **g)** up; (−6, 2); $x = -6$; domain: set of real numbers, range: $y \ge 2$; minimum: 2 **h)** up; (5, −4); $x = 5$; domain: set of real numbers, range: $y \ge -4$; minimum: −4 **i)** down; (−4, 3); $x = -4$; domain: set of real numbers, range: $y \le 3$; maximum: 3 **2. a)** up; (5, 0); $x = 5$; domain: set of real numbers, range: $y \ge 0$; minimum: 0 **b)** down; (−4, 0); $x = -4$; domain: set of real numbers, range: $y \le 0$; maximum: 0 **c)** up; (2, 1); $x = 2$; domain: set of real numbers, range: $y \ge 1$; minimum: 1 **d)** down; (−1, −2); $x = -1$; domain: set of real numbers, range: $y \le -2$; maximum: −2 **3. a)** up; vertically stretched by a factor of 2; (1, 0); $x = 1$; minimum: 0 **b)** down; vertically shrunk by a factor of 0.5; (−7, 0); $x = -7$; maximum: 0 **c)** down; vertically stretched by a factor of 2; (4, 7); $x = 4$; maximum: 7 **d)** up; vertically stretched by a factor of 4; (−3, −4); $x = -3$; minimum: −4 **e)** down; vertically stretched by a factor of 3; (5, 6); $x = 5$; maximum: 6 **f)** down; vertically shrunk by a factor of 0.4; (8, −1); $x = 8$; maximum: −1 **g)** up; vertically shrunk by a factor of $\frac{1}{3}$; (−6, −7); $x = -6$; minimum: −7 **h)** up; vertically shrunk by a factor of 0.5; (−1, −5); $x = -1$; minimum: −5 **i)** up; vertically stretched by a factor of 2.5; (−1.5, −9); $x = -1.5$; minimum: −9 **j)** down; vertically stretched by a factor of 1.2; (2.6, 3.3); $x = 2.6$; maximum: 3.3
4. a) $y = -3(x + 1)^2 + 2$ **b)** $y = 3(x - 1)^2 + 2$ **c)** $y = 3(x + 1)^2 - 2$ **d)** $y = -3(x - 1)^2 - 2$
6. a) x-intercept: 2; y-intercept: 4 **b)** x-intercepts: −5, 1; y-intercept: −5 **c)** x-intercepts: 2, 4; y-intercept: 8 **d)** x-intercepts: −3, −1; y-intercept: −3
7. a) x-intercepts: −2.7, 0.7; y-intercept: −2 **b)** x-intercepts: −0.4, 2.4; y-intercept: −2 **c)** x-intercepts: $\frac{1}{2}, \frac{3}{2}$; y-intercept: −3 **d)** x-intercepts: none; y-intercept: −47 **e)** x-intercept: −4; y-intercept: 4 **f)** x-intercepts: −5, −1; y-intercept: −2.5
Applications and Problem Solving **8. a)** 83 m **b)** 6.0 s
9. a) $y = (x - 7)^2$ **b)** $y = -(x + 5)^2$ **c)** $y = 2(x - 3)^2 - 5$ **d)** $y = -3(x - 6)^2 + 7$ **e)** $y = -0.5(x + 1)^2 - 1$ **f)** $y = 1.5(x + 8)^2 + 9$ **10. a)** $y = (x - 1)^2 + 5$ **b)** $y = -(x + 3)^2$ **c)** $y = 3(x - 4)^2 - 2$ **d)** $y = -2(x - 2)^2 - 3$ **e)** $y = 0.4(x + 3)^2 - 3$ **f)** $y = 5(x - 4.5)^2$ **g)** $y = -4(x - 3)^2$ **h)** $y = 2(x + 5)^2 - 6$ **11.** −11
12. $x = -1$; The axis of symmetry is halfway between the x-intercepts. It is the vertical line passing through

the midpoint of the line segment joining the x-intercepts. **13.** $x = -3$ **14. a)** 38.5 m **b)** 1 m **c)** 5 s **d)** 25 m **15. a)** 10 m **b)** 20 m **c)** 40 m **d)** 7.5 m **e)** No, the ball would be at a height of 5.1 m, which is too high to jump. **f)** $h = -0.025d^2$ **16. a)** 6 m **b)** 20 m **c)** 2 m; 2 m **d)** 38 m **e)** 2.76 m **17. a)** The graphs in each pair are identical. **b)** $(x - h)^2 = (h - x)^2$ **18. b)** (−2, −3), (1, 6) **c)** Answers may vary. **19. a)** $m = n$ **b)** $m > n$ **c)** $m < n$ **20.** $k = 4$ **21. a)** $y = (x + 4)^2 - 5$ **b)** $y = -(x - 3)^2 + 2$ **c)** $y = -(x - 1)^2 + 6$ **d)** $y = 3(x + 2)^2 + 3$ **e)** $y = -2(x + 5)^2 - 3$ **f)** $y = \frac{1}{2}(x - 6)^2 + 4$ **22. a)** $y = 2(x - 1)^2 + 2$ **b)** $y = -(x + 2)^2 + 3$ **c)** $y = \frac{1}{2}(x - 2)^2 - 4$ **d)** $y = -\frac{1}{4}(x + 4)^2 - 1$ **23. a)** $a = 2, k = 4$ **b)** $a = -1, k = -4$ **c)** $a = -2, k = 5$ **24. a)** vertex on y-axis **b)** vertex on x-axis **c)** vertex at (0, 0) **25. a)** $A = (x - 2)^2 + 3$ **c)** $x = 2$ **d)** 0 **26. a)** $y = -3(x - 2)^2 - 1$ **b)** $y = 3(x + 2)^2 + 1$ **c)** $y = -3(x + 2)^2 - 1$ **27. a)** (±30, 0.36) **b)** $y = 0.0004x^2$ **c)** $y = 0.0004(x + 30)^2 - 0.36$ **d)** $y = 0.0004(x - 30)^2 - 0.36$ **e)** 0.16 cm **Technology Extension** Answers may vary.

Section 4.4 pp. 234–239

Practice **1. a)** 49 **b)** 36 **c)** 1 **d)** 81 **e)** 25 **f)** 100 **2. a)** $y = (x + 3)^2 - 6$; (−3, −6), $x = -3$; Points may vary. (0, 3), (1, 10) **b)** $y = (x - 2)^2 - 5$; (2, −5), $x = 2$; Points may vary. (0, −1), (1, −4) **c)** $y = (x + 5)^2 + 5$; (−5, 5), $x = -5$; Points may vary. (0, 30), (1, 41) **d)** $y = (x - 1)^2 + 2$; (1, 2), $x = 1$; Points may vary. (0, 3), (2, 3) **e)** $y = (x + 6)^2 - 8$; (−6, −8), $x = -6$; Points may vary. (0, 28), (1, 41) **f)** $y = (x - 4)^2 - 4$; (4, −4), $x = 4$; Points may vary. (0, 12), (1, 5) **3. a)** $y = x^2 - 4$ **b)** $y = -x^2 + 4x$ **c)** $y = x^2 - 4x$ **d)** $y = x^2 + 4x$ **e)** $y = -x^2 + 4$ **f)** $y = -x^2 - 4x$ **4. a)** (1, −9); $x = 1$; x-intercepts: −2, 4; y-intercept: −8; $y \geq -9$ **b)** (3, 1); $x = 3$; x-intercepts: none; y-intercept: 10; $y \geq 1$ **c)** (−2, −4); $x = -2$; x-intercepts: −4, 0; y-intercept: 0; $y \geq -4$ **d)** (6, 4); $x = 6$; x-intercepts: none; y-intercept: 40; $y \geq 4$ **5. a)** $y = -(x - 4)^2 + 5$; (4, 5); $x = 4$. Points may vary: (0, −11), (1, −4) **b)** $y = -(x + 4)^2 + 9$; (−4, 9); $x = -4$. Points may vary. (0, −7), (1, −16) **c)** $y = -(x + 2)^2 - 3$; (−2, −3); $x = -2$. Points may vary. (0, −7), (1, −12) **d)** $y = -(x + 1)^2 + 1$; (−1, 1); $x = -1$; Points may vary. (0, 0), (1, −3) **6. a)** (−1, 4); $x = -1$; x-intercepts: −3, 1; y-intercept: 3; $y \leq 4$ **b)** (−2, −8); $x = -2$; x-intercepts: none; y-intercept: −12; $y \leq -8$ **c)** (4, 4); $x = 4$; x-intercepts: 2, 6; y-intercept: −12; $y \leq 4$ **d)** (5, 0); $x = 5$; x-intercept: 5; y-intercept: −25; $y \leq 0$ **7. a)** minimum: −7 **b)** maximum: 5 **c)** maximum: 16 **d)** minimum: 0 **e)** minimum: −30 **f)** maximum: 13 **g)** minimum: −28 **h)** maximum: −3 **8. a)** $y = 3(x + 1)^2 - 11$; (−1, −11); $x = -1$; $y \geq -11$ **b)** $y = -2(x + 3)^2 + 18$; (−3, 18); $x = -3$; $y \leq 18$ **c)** $y = 2(x - 1)^2 + 3$; (1, 3); $x = 1$; $y \geq 3$ **d)** $y = -4(x - 1)^2 - 3$; (1, −3); $x = 1$; $y \leq -3$ **e)** $y = 4(x - 2)^2 - 16$; (2, −16); $x = 2$; $y \geq -16$ **f)** $y = -3(x - 2)^2 - 2$; (2, −2); $x = 2$; $y \leq -2$ **9. a)** minimum: 1 at $x = -1$ **b)** maximum: 6 at $x = 5$ **c)** maximum: 7 at $x = -3$ **d)** maximum: −1 at $x = 3$ **e)** minimum: −2 at $x = 2$ **f)** minimum: 2 at $x = 1$ **g)** maximum: 8 at $x = 2$ **h)** maximum: 0 at $x = 1$

Applications and Problem Solving **10.** 5, −5 **11.** 17, 17 **12. a)** minimum: −14 at $x = -2$ **b)** minimum: −9 at $x = -10$ **c)** maximum: 5 at $x = -5$ **d)** minimum: −5 at $x = 2$ **e)** maximum: 5 at $x = 4$ **f)** maximum: 20 at $x = 100$ **g)** minimum: 1.5 at $x = -1$ **h)** maximum: −0.5 at $x = 3$ **13. a)** (−2, −1) **b)** (1, −9) **c)** $\left(\frac{3}{4}, -\frac{25}{8}\right)$ **d)** (−1, 12) **14. a)** 20 m **b)** 100 m **c)** 200 m **15. a)** 4.25 m **b)** 5 m **c)** 2 m **16. a)** 46 m **b)** 480 m **c)** 17 m **17. a)** 84 m **b)** 75 m **c)** 71 m **18. a)** 100 m by 100 m **b)** 10 000 m² **19.** 15 m **20.** $30 **21.** 12.5 cm² **22. a)** 123.6 m **b)** 7 s **23. a)** The x-coordinates are both 0; the y-coordinates are opposites. **b)** opposite **24. a)** The graph is a straight line. **b)** The graph is a parabola with the y-axis as its axis of symmetry. **25. a)** $k = 9$ **b)** $k < 9$ **c)** $k > 9$ **26. a)** $k = -8$ **b)** $k > -8$ **c)** $k < -8$ **Technology Extension** Answers may vary.

Career Connection p. 239

1. a) $R = (2000 - 100x)(8 + x)$ **b)** (6, 19 600) **c)** $14 **d)** 1400 **2. a)** People will stop buying because of high price. **b)** People will stop buying because of poor quality.

Modelling Math p. 240

a) Earth: 22 m; Mars: 52 m; Pluto: 402 m
b) Earth: 2 s; Mars: 5 s; Pluto: 40 s

Section 4.5 p. 241

1. a) $y = x(x - 4) - 1$ **b)** $y = x(x - 8) + 6$ **c)** $y = 3x(x - 4) + 4$ **d)** $y = 2x(x - 2) + 3$ **e)** $y = x(x + 2) - 5$ **f)** $y = x(x + 6) + 7$ **g)** $y = 2x(x + 6) - 2$ **h)** $y = -x(x - 4) - 2$ **i)** $y = -4x(x - 2) + 1$ **j)** $y = -2x(x + 2) - 3$ **2.** Substituting $x = 0$ and $x = s$ into the equation shows that $(0, t)$ and (s, t) are two points on the parabola. Thus, the x-coordinate of the vertex is $\frac{s}{2}$.

Substituting $x = \frac{s}{2}$ into the equation and