Section 8.4: Calculations Involving Acidic Solutions

Tutorial 1 Practice, page 513

1. **Given:** [HCl (aq)] = 0.0700 mol/L
   Required: $[OH^-(aq)]$
   Analysis: $[H^+(aq)]$ = 0.0700 mol/L because HCl is a strong acid

$$[OH^-(aq)] = \frac{1.0\times10^{-14}}{[H^+]}$$

Solution: $$[OH^-(aq)] = \frac{1.00\times10^{-14}}{7.00\times10^{-2}}$$

$$[OH^-(aq)] = 1.43 \times 10^{-13}\ \text{mol/L}$$

2. **Given:** [HBr (aq)] = 0.0380 mol/L; pH = 2.78
   Required: pH, pOH
   Analysis: $[H^+(aq)]$ = 0.0350 mol/L because HBr is a strong acid
   $pH = -\log[H^+(aq)]$
   $pOH = 14.00 - pH$
   Solution: $pH = -\log[H^+(aq)]$
   $= -\log(3.5\times 10^{-2}) = 1.46$
   $pH = 1.46$
   $pOH = 14.00 - 1.46$
   $= 12.54$

Tutorial 2 Practice, page 516

1. **Given:** $[HC_3H_5O_2\ (aq)]$ = 0.050 mol/L; pH = 2.78
   Required: percentage ionization
   Analysis: $[H^+(aq)] = 10^{-pH}$

$$\frac{\text{percentage ionization}}{100} = \frac{[H^+(aq)]}{[HC_3H_5O_2(aq)]}$$

Solution: $[H^+(aq)] = 10^{-2.78}$
$[H^+(aq)]$ = 0.00166 mol/L

$$\frac{\text{percentage ionization}}{100} = \frac{0.00166}{0.050}$$

percentage ionization = 3.3 %

2. **Given:** [HF (aq)] = 0.100 mol/L; percentage ionization = 7.8 %
   Required: K_a
   Analysis: $HF(aq) \rightleftharpoons H^+(aq) + F^-(aq)$

$$K_a = \frac{[H^+(aq)][F^-(aq)]}{[HF(aq)]}$$

Solution: decrease in HF concentration = (7.8 %)(0.100 mol/L)
= 0.0078 mol/L

	$HF(aq)$ $\rightleftharpoons$	$H^+(aq)$ +	$F^-(aq)$
I	0.100	0	0
C	− 0.0078	+ 0.0078	+ 0.0078
E	0.0922	0.0078	0.0078

$$K_a = \frac{(0.0078)(0.0078)}{(0.0922)}$$

$K_a = 6.6 \times 10^{-4}$

Tutorial 3 Practice, page 520

1. Given: [HCN (aq)] = 6.18×10^{-3} mol/L; $K_a = 6.2 \times 10^{-10}$

Required: pH

Analysis:

	$HCN(aq)$ $\rightleftharpoons$	$H^+(aq)$ +	$CN^-(aq)$
I	6.18×10^{-3}	0	0
C	$-x$	$+x$	$+x$
E	$6.18 \times 10^{-3} - x$	x	x

$$K_a = \frac{[H^+(aq)][CN^-(aq)]}{[HCN(aq)]}$$

Solution:
$$6.2 \times 10^{-10} = \frac{(x)(x)}{(6.18 \times 10^{-3} - x)}$$
$$6.2 \times 10^{-10} \approx \frac{(x)(x)}{(6.18 \times 10^{-3})}$$
$$x^2 \approx 3.83 \times 10^{-12}$$
$$x = [H^+(aq)]$$
$$\approx 1.96 \times 10^{-6} \text{ mol/L}$$

pH = $-\log(1.96 \times 10^{-6})$

pH = 5.71

2. Given: $[HNO_2(aq)] = 0.10$ mol/L; $K_a = 4.6 \times 10^{-4}$
Required: pH
Analysis:

	$HNO_2(aq)$ $\rightleftharpoons$	$H^+(aq)$ +	$NO_2^-(aq)$
I	0.10	0	0
C	$-x$	$+x$	$+x$
E	$0.10 - x$	x	x

$$K_a = \frac{[H^+(aq)][NO_2^-(aq)]}{[HNO_2(aq)]}$$

Solution:
$$4.6 \times 10^{-4} = \frac{(x)(x)}{(0.10 - x)}$$
$$4.6 \times 10^{4} \approx \frac{(x)(x)}{0.10}$$
$$x^2 \approx 4.6 \times 10^{-5}$$
$$x = [H^+(aq)]$$
$$\approx 6.78 \times 10^{-3} \text{ mol/L}$$

$\text{pH} = -\log(6.78 \times 10^{-3})$
$\text{pH} = 2.17$

Tutorial 4 Practice, page 521

1. Given: $[HC_2H_6NO_2(aq)] = 0.050$ mol/L; pH = 3.08
Required: K_a
Analysis:
$HC_2H_6NO_2(aq) \rightleftharpoons H^+(aq) + C_2H_6NO_2^-(aq)$

$$K_a = \frac{[H^+(aq)][C_2H_6NO_2^-(aq)]}{[HC_2H_6NO_2(aq)]}$$

Solution: $[H^+(aq)] = 10^{-pH}$
$[H^+(aq)] = 10^{-pH} = 10^{-3.08}$
$[H^+(aq)] = 8.32 \times 10^{-4}$ mol/L

$$K_a = \frac{(8.32 \times 10^{-4})(8.32 \times 10^{-4})}{(0.050)}$$

$K_a = 1.4 \times 10^{-5}$

2. Given: $[HC_7H_5O_2(aq)]$ = 0.25 mol/L; pH = 2.40

Required: K_a

Analysis:

$$HC_7H_5O_2(aq) \rightleftharpoons H^+(aq) + C_7H_5O_2^-(aq)$$

$$K_a = \frac{[H^+(aq)][C_7H_5O_2^-(aq)]}{[HC_7H_5O_2(aq)]}$$

Solution: $[H^+(aq)] = 10^{-pH}$

$[H^+(aq)] = 10^{-pH} = 10^{-2.40}$

$[H^+(aq)] = 3.98 \times 10^{-3}$ mol/L

$$K_a = \frac{(3.98 \times 10^{-3})(3.98 \times 10^{-3})}{(0.25)}$$

$K_a = 6.3 \times 10^{-5}$

Tutorial 5 Practice, page 524

1. Given: $[H_3PO_4(aq)]$ = 1.00 mol/L; $K_{a1} = 7.1 \times 10^{-3}$; $K_{a2} = 6.3 \times 10^{-8}$; $K_{a3} = 4.2 \times 10^{-13}$

Required: pH

Analysis: K_{a2} and K_{a3} are so much smaller than K_{a1} that they do not affect pH.

	$H_3PO_4(aq)$	$\rightleftharpoons$	$H^+(aq)$	+	$H_2PO_4^-(aq)$
I	1.00		0		0
C	$-x$		$+x$		$+x$
E	$1.00 - x$		x		x

$$K_a = \frac{[H^+(aq)][H_2PO_4^-(aq)]}{[H_3PO_4(aq)]}$$

Solution: $7.1 \times 10^{-3} = \dfrac{(x)(x)}{(1.00 - x)}$

$$7.1 \times 10^{-3} \approx \frac{(x)(x)}{(1.0)}$$

$x^2 \approx 7.1 \times 10^{-3}$

$x = [H^+(aq)]$

≈ 0.0843 mol/L

pH = −log(0.0843)

pH = 1.07

2. Given: $[NaHSO_4(aq)] = 0.100$ mol/L; K_{a2} for $H_2SO_4 = 1.0 \times 10^{-2}$

Required: pH

Analysis: $NaHSO_4(aq) \rightleftharpoons Na^+(aq) + HSO_4^-(aq)$

$HSO_4^-(aq) \rightleftharpoons H^+(aq) + SO_4^{2-}(aq)$

	$HSO_4^-(aq)$ $\rightleftharpoons$	$H^+(aq)$ +	$SO_4^{2-}(aq)$
I	0.100	0	0
C	$-x$	$+x$	$+x$
E	$0.100 - x$	x	x

$$K_a = \frac{[H^+(aq)][SO_4^{2-}(aq)]}{[HSO_4^{2-}(aq)]}$$

Solution: $1.0 \times 10^{-2} = \dfrac{(x)(x)}{(0.100 - x)}$

$$1.0 \times 10^{-2} \approx \frac{(x)(x)}{(0.1)}$$

$$x^2 \approx 1.0 \times 10^{-3}$$

$$x = [H^+(aq)]$$

$$\approx 0.0316 \text{ mol/L}$$

pH = −log(0.0316)

pH = 1.50

Section 8.4 Questions, page 525

1. (a) Given: [HCN (aq)] = 0.0100 mol/L; $K_a = 6.2 \times 10^{-10}$

Required: pH

Analysis:

	$HCN(aq)$ $\rightleftharpoons$	$H^+(aq)$ +	$CN^-(aq)$
I	0.0100	0	0
C	$-x$	$+x$	$+x$
E	$0.0100 - x$	x	x

$$K_a = \frac{[H^+(aq)][CN^-(aq)]}{[HCN(aq)]}$$

Solution: $6.2 \times 10^{-10} = \dfrac{(x)(x)}{(0.0100 - x)}$

$$6.2 \times 10^{-10} \approx \frac{(x)(x)}{(0.0100)}$$

$$x^2 \approx 6.2 \times 10^{-12}$$

$$x = [H^+(aq)]$$

$$\approx 2.49 \times 10^{-6} \text{ mol/L}$$

pH = $-\log(2.49 \times 10^{-6})$

pH = 5.60

(b) Given: $[HF(aq)] = 0.25$ mol/L; $K_a = 6.6 \times 10^{-4}$

Required: pH

Analysis:

	$\mathbf{HF(aq)} \rightleftharpoons$	$\mathbf{H^+(aq)}$ +	$\mathbf{F^-(aq)}$
I	0.25	0	0
C	$-x$	$+x$	$+x$
E	$0.25 - x$	x	x

$$K_a = \frac{[H^+(aq)][F^-(aq)]}{[HF(aq)]}$$

Solution:
$$6.6 \times 10^{-4} = \frac{(x)(x)}{(0.25 - x)}$$
$$6.6 \times 10^{-4} \approx \frac{(x)(x)}{(0.25)}$$
$$x^2 \approx 1.65 \times 10^{-4}$$
$$x = [H^+(aq)]$$
$$\approx 1.28 \times 10^{-2}\text{ mol/L}$$

$\text{pH} = -\log(1.28 \times 10^{-2})$

$\text{pH} = 1.89$

(c) Given: $[HC_3H_5O_3(aq)] = 0.0010$ mol/L; $K_a = 1.4 \times 10^{-4}$

Required: pH

Analysis:

	$\mathbf{HC_3H_5O_3(aq)} \rightleftharpoons$	$\mathbf{H^+(aq)}$ +	$\mathbf{C_3H_5O_3^-(aq)}$
I	0.0010	0	0
C	$-x$	$+x$	$+x$
E	$0.0010 - x$	x	x

$$K_a = \frac{[H^+(aq)][C_3H_5O_3^-(aq)]}{[HC_3H_5O_3(aq)]}$$

Solution:
$$1.4 \times 10^{-4} = \frac{(x)(x)}{(0.0010 - x)}$$
$$1.4 \times 10^{-4} \approx \frac{(x)(x)}{(0.0010)}$$
$$x^2 \approx 1.4 \times 10^{-7}$$
$$x = [H^+(aq)]$$
$$\approx 3.74 \times\times 10^{-4}\text{ mol/L}$$

$\text{pH} = -\log(3.74 \times 10^{-4})$

$\text{pH} = 3.43$

(d) Given: $[HCO_2H(aq)] = 0.150$ mol/L; $K_a = 1.8 \times 10^{-4}$

Required: pH

Analysis:

	$HCO_2H(aq)$ $\rightleftharpoons$	$H^+(aq)$ +	$HCO_2^-(aq)$
I	0.150	0	0
C	$-x$	$+x$	$+x$
E	$0.150 - x$	x	x

$$K_a = \frac{[H^+(aq)][HCO_2^-(aq)]}{[HCO_2H(aq)]}$$

Solution:

$$1.8 \times 10^{-4} = \frac{(x)(x)}{(0.150 - x)}$$

$$1.8 \times 10^{-4} \approx \frac{(x)(x)}{(0.15)}$$

$$x^2 \approx 2.7 \times 10^{-5}$$

$$x = [H^+(aq)]$$

$$\approx 5.20 \times 10^{-3} \text{ mol/L}$$

$\text{pH} = -\log(5.20 \times 10^{-3})$

$\text{pH} = 2.28$

2. (a) Given: $[HC_3H_5O_2\ (aq)] = 0.50$ mol/L; pH = 2.6

Required: percentage ionization

Analysis: $[H^+(aq)] = 10^{-\text{pH}}$

$$\frac{\text{percentage ionization}}{100} = \frac{[H^+(aq]}{[HC_3H_5O_2\ (aq)]}$$

Solution: $[H^+(aq)] = 10^{-2.6}$

$[H^+(aq)] = 0.00251$ mol/L

$$\frac{\text{percentage ionization}}{100} = \frac{0.00251}{0.50}$$

percentage ionization = 0.50 %

(b) Given: [peracetic acid (aq)] = 0.15 mol/L; pH = 4.5

Required: percentage ionization

Analysis: $[H^+(aq)] = 10^{-\text{pH}}$

$$\frac{\text{percentage ionization}}{100} = \frac{[H^+(aq]}{[HC_3H_5O_2\ (aq)]}$$

Solution: $[H^+(aq)] = 10^{-4.5}$

$[H^+(aq)] = 0.0000316$ mol/L

$$\frac{\text{percentage ionization}}{100} = \frac{0.00000316}{0.15}$$

percentage ionization = 0.021 %

(c) Given: [sorbic acid (aq)] = 0.01 mol/L; pH = 3.4

Required: percentage ionization

Analysis: $[H^+(aq)] = 10^{-pH}$

$$\frac{\text{percentage ionization}}{100} = \frac{[H^+(aq]}{[HC_3H_5O_2\ (aq)]}$$

Solution: $[H^+(aq)] = 10^{-3.4}$

$[H^+(aq)] = 0.000398$ mol/L

$$\frac{\text{percentage ionization}}{100} = \frac{0.000398}{0.01}$$

percentage ionization = 4.0 %

3. (a) Given: $[H_2C_6H_6O_6\ (aq)] = 0.20$ mol/L; pH = 2.40

Required: K_a

Analysis: $HC_6H_7O_6(aq) \rightleftharpoons H^+(aq) + C_6H_7O_6^-(aq)$

$$K_a = \frac{[H^+(aq)][C_6H_7O_6^-(aq)]}{[HC_6H_7O_6(aq)]}$$

Solution: $[H^+(aq)] = 10^{-pH}$

$[H^+(aq)] = 10^{-pH} = 10^{-2.40}$

$[H^+(aq)] = 3.98 \times 10^{-3}$ mol/L

$$K_a = \frac{(3.98 \times 10^{-3})(3.98 \times 10^{-3})}{(0.20)}$$

$K_a = 7.9 \times 10^{-5}$

(b) Given: $[HNO_2\ (aq)] = 0.100$ mol/L; pH = 2.10

Required: K_a

Analysis: $HNO_2(aq) \rightleftharpoons H^+(aq) + NO_2^-(aq)$

$$K_a = \frac{[H^+(aq)][NO_2^-(aq)]}{[HNO_2(aq)]}$$

Solution: $[H^+(aq)] = 10^{-2.10}$

$[H^+(aq)] = 10^{-pH} = 10^{-2.40}$

$[H^+(aq)] = 7.94 \times 10^{-3}$ mol/L

$$K_a = \frac{(7.94 \times 10^{-3})(7.94 \times 10^{-3})}{(0.100)}$$

$K_a = 6.3 \times 10^{-4}$

4. Given: $[HC_2H_3O_2(aq)] = 1.00$ mol/L; $K_a = 1.8 \times 10^{-5}$
Required: percent ionization
Analysis:

	$HC_2H_3O_2(aq)$ $\rightleftharpoons$	$H^+(aq)$ +	$C_2H_3O_2^-(aq)$
I	1.00	0	0
C	$-x$	$+x$	$+x$
E	$1.00 - x$	x	x

$$K_a = \frac{[H^+(aq)][C_2H_3O_2^-(aq)]}{[HC_2H_3O_2(aq)]}$$

$$\frac{\text{percentage ionization}}{100} = \frac{[H^+(aq)]}{[HC_2H_3O_2(aq)]}$$

Solution: $1.8 \times 10^{-5} = \dfrac{(x)(x)}{(1.00 - x)}$

$$1.8 \times 10^{-5} \approx \frac{(x)(x)}{(1.00)}$$

$$x^2 \approx 1.8 \times 10^{-5}$$

$$x = [H^+(aq)]$$

$$\approx 4.24 \times 10^{-3} \text{ mol/L}$$

$$\frac{\text{percentage ionization}}{100} = \frac{0.000424}{1.00}$$

percentage ionization = 0.42 %

5. Given: $[HC_2H_3O_2(aq)] = 0.80$ mol/L; percent ionization = 1.3%
[HCl] = 1.0 mol/L; volume of HCl = 5 mL
Required: Volume of $HC_2H_3O_2(aq)$ as substitute for 5 mL HCl

Analysis: $\dfrac{\text{percentage ionization}}{100} = \dfrac{[H^+(aq)]}{[HC_2H_3O_2(aq)]}$

$$\frac{1.3}{100} = \frac{[H^+(aq)]}{0.8}$$

$$[H^+(aq)] = 0.0104 \text{ mol/L}$$

$$\frac{\text{Vol}_{HC_2H_3O_2(aq)}}{\text{Vol}_{HCl(aq)}} = \frac{[H^+{}_{HCl(aq)}]}{[H^+{}_{HC_2H_3O_2(aq)}]}$$

$$\frac{\text{Vol}_{HC_2H_3O_2(aq)}}{5 \text{ mL}} = \frac{1.0}{0.0104}$$

$$\text{Vol}_{HC_2H_3O_2(aq)} = 480 \text{ mL}$$

6. Given: $[HC_3H_5O_3(aq)]$ = 0.100 mol/L; percentage ionization = 3.7 %
Required: K_a
Analysis: $HC_3H_5O_3(aq) \rightleftharpoons H^+(aq) + C_3H_5O_3^-(aq)$

$$K_a = \frac{[H^+(aq)][C_3H_5O_3^-(aq)]}{[HC_3H_5O_3(aq)]}$$

Solution: decrease in $HC_3H_5O_3(aq)$ concentration = (3.7 %)(0.100 mol/L)
= 0.0037 mol/L

	$HC_3H_5O_3(aq)$ $\rightleftharpoons$	$H^+(aq)$ +	$C_3H_5O_3^-(aq)$
I	0.100	0	0
C	− 0.0037	+ 0.0037	+0.0037
E	0.0963	0.0037	0.0037

$$K_a = \frac{(0.0037)(0.0037)}{0.0963}$$

$K_a = 1.42 \times 10^{-4}$

7. Given: $[H_2C_6H_6O_6\ (aq)]$ = 0.091 mol/L; $K_{a1} = 6.7 \times 10^{-5}$; $K_{a2} = 2.5 \times 10^{-12}$
Required: pH
Analysis: K_{a2} is much smaller than K_{a1} so it does not affect pH.

	$H_2C_6H_6O_6\ (aq)$ $\rightleftharpoons$	$H^+(aq)$ +	$HC_6H_6O_6^-(aq)$
I	0.091	0	0
C	$-x$	$+x$	$+x$
E	$0.091 - x$	x	x

$$K_{a1} = \frac{[H^+(aq)][HC_6H_6O_6^-(aq)]}{[H_2C_6H_6O_6(aq)]}$$

Solution: $6.7 \times 10^{-5} = \dfrac{(x)(x)}{(0.091 - x)}$

$$(6.7 \times 10^{-5} \approx \frac{(x)(x)}{(0.091)}$$

$$x^2 \approx 6.10 \times 10^{-6}$$

$$x = [H^+(aq)] \approx 2.470 \times 10^{-3} \text{ mol/L}$$

pH = $-\log(2.470 \times 10^{-3})$
pH = 2.61

8. It would be better to use sodium bicarbonate because it is a weaker acid so it is only partially ionized. That means the reaction will be slower and less violent and that using too much base will not cause a problem.

9. (a) Given: $[HC_6H_5CO_2(aq)] = 8.3 \times 10^{-3}$ mol/L; pH = 3.14

Required: K_a

Analysis:

$HC_6H_5CO_2(aq) \rightleftharpoons H^+(aq) + C_6H_5CO_2^-(aq)$

$$K_a = \frac{[H^+(aq)][C_6H_5CO_2^-(aq)]}{[HC_6H_5CO_2(aq)]}$$

Solution: $[H^+(aq)] = 10^{-pH}$

$[H^+(aq)] = 10^{-3.14}$

$[H^+(aq)] = 7.24 \times 10^{-4}$ mol/L

$$K_a = \frac{(7.24 \times 10^{-4})(7.24 \times 10^{-4})}{(8.3 \times 10^{-3})}$$

$K_a = 6.3 \times 10^{-5}$

(b) Answers may vary. Sample answer: I predict that the pH of a non-carbonated fruit drink containing benzoic acid at a concentration of 8.3×10^{-3} mol/L would be less than 3.14. The benzoic acid at that concentration has a pH, of 3.14 and the fruit drink would also contain other acids, such as citric acid. In combination, these would probably result in a lower pH.

10. (a) Given: $[HC_2H_2O_2Cl(aq)] = 0.50$ mol/L; $K_a = 1.36 \times 10^{-3}$

Required: percent ionization

Analysis:

	$HC_2H_2O_2Cl(aq)$ $\rightleftharpoons$	$H^+(aq)$ +	$C_2H_2O_2Cl^-(aq)$
I	1.00	0	0
C	$-x$	$+x$	$+x$
E	$0.50 - x$	x	x

$$K_a = \frac{[H^+(aq)][C_2H_2O_2Cl^-(aq)]}{[HC_2H_2O_2Cl(aq)]}$$

$$\frac{\text{percentage ionization}}{100} = \frac{[H^+(aq)]}{[HC_2H_2O_2Cl(aq)]}$$

Solution: $1.36 \times 10^{-3} = \frac{(x)(x)}{(0.50 - x)}$

$1.36 \times 10^{-3} \approx \frac{(x)(x)}{(0.50)}$

$x^2 \approx 6.8 \times 10^{-4}$

$x = [H^+(aq)]$

$\approx 2.60 \times 10^{-2}$ mol/L

$$\frac{\text{percentage ionization}}{100} = \frac{0.026}{0.50}$$

percentage ionization = 5.1 %

(b) Answers will vary. Sample answer: Epinephrine, also known as adrenaline, is a hormone that is used to treat severe allergic reactions because it relaxes muscles in the airways. It can be a life-saving treatment but it can have side effects including vomiting, dizziness, and uncontrollable shaking.