Chapter 18 Problem Set Solutions

S.E. Van Bramer 2/22/96

1. Benzoic Acid (C6H5COOH) is a solid. 15.000 grams is dissolved in 200.00 mL of distilled water.

a) Benzioic acid is a weak acid that will dissociate to in water to form benzoate ions and hydronium ions.

b) C_6H_5COOH + H_2O <--> $C_6H_5COO^{1-}$ + H_3O^{1+}

c) benzoic acid is the proton donor (It is an acid)

d) water is the proton acceptor (It is the only avaialble base)

e) After the reaction has reached equlibrium:

$M := \frac{mole}{liter}$ $K_a := 6.46 \cdot 10^{-5}$ $K_w := 1.0 \cdot 10^{-14}$

$Mass_{benzoic} := 15.000 \cdot gm$ $V_{benzoic} := 200 \cdot mL$

$MW_{benzoic} := ((7 \cdot 12.001) + (2 \cdot 15.9994) + (6 \cdot 1.00794)) \cdot \frac{gm}{mole}$

$MW_{benzoic} = 122.05344 \cdot gm$

$mole_{benzoic} := \frac{Mass_{benzoic}}{MW_{benzoic}}$

$mole_{benzoic} = 0.1229 \cdot mole$

$C_{benzoic} := \frac{mole_{benzoic}}{V_{benzoic}}$

$C_{benzoic} = 0.61448 \cdot M$

C_6H_5COOH + H_2O <--> $C_6H_5COO^{1-}$ + H_3O^{1+}

Start	$C_{benzoic} = 0.61448 \cdot M$	0	0
Change	$-X$	X	X
Equlibrium	$C_{benzoic} - X$	X	X

Start with the Equlibrium Expression

$$K_a = \frac{X \cdot X}{C_{benzoic} - X}$$

Substitute in known values

$$6.46 \cdot 10^{-5} = \frac{X \cdot X}{0.614 - X}$$

Solve

Using the Quadratic $$X = \begin{pmatrix} 6.2657507532092816567 \cdot 10^{-3} \\ -6.3303507532092816567 \cdot 10^{-3} \end{pmatrix}$$

Assuming X is small in the denominator $$X = 6.2979679262441468867 \cdot 10^{-3}$$

These two answers are essentially identical.

Select the appropriate root:

$$X := 6.2657507532092816567 \cdot 10^{-3} \cdot M$$

Concentrations of species present

Benzoic Acid	$C_{benzoic} := C_{benzoic} - X$	$C_{benzoic} = 0.60822 \cdot M$
Benzoate	$C_{benzoate} := X$	$C_{benzoate} = 0.00627 \cdot M$
Hydronium Ion	$C_{H3O} := X$	$C_{H3O} = 0.00627 \cdot M$
	$pH := -\log\left(X \cdot M^{-1}\right)$	$pH = 2.20303$
Hydroxide Ion	$C_{OH} := \frac{1 \cdot 10^{-14}}{X}$	$C_{OH} = 0 \cdot m^6 \cdot M$
	$pOH := 14 - pH$	$pOH = 11.79697$

2. Sodium benzoate (NaC_6H_5COO) is a solid. Used as a preservative in most pop (soda back east). 10.000 grams is dissolved in 100.00 mL of distilled water?

a) Sodium benzoate is a salt that will dissocaite completely in water. The benzoate ion will then act as a weak base and undergo hydrolysis with water to form benzioic acid and hydroxide ions.

b) NaC_6H_5COO ----> $C_6H_5COO^{1-}$ + Na^{1+}

$C_6H_5COO^{1-}$ + H_2O <--> C_6H_5COOH + OH^{1-}

c) water is the proton donor (It acts as an acid)

d) benzoate ion is the proton acceptor (It is the only avaialble base)

e) After the reaction has reached equlibrium:

$$Mass_{Na\_benzoate} := 10.00 \cdot gm \qquad V_{Na\_benzoate} := 100 \cdot mL$$

$$MW_{Na\_benzoate} := (22.989768 + (7 \cdot 12.001) + (2 \cdot 15.9994) + (5 \cdot 1.00794)) \cdot \frac{gm}{mole}$$

$$MW_{Na\_benzoate} = 144.03527 \cdot gm$$

$$mole_{Na\_benzoate} := \frac{Mass_{Na\_benzoate}}{MW_{Na\_benzoate}}$$

$$mole_{Na\_benzoate} = 0.06943 \cdot mole$$

$$C_{Na\_benzoate} := \frac{mole_{Na\_benzoate}}{V_{Na\_benzoate}}$$

$$C_{Na\_benzoate} = 0.69427 \cdot M$$

	C_6H_5COOH + H_2O	<--> $C_6H_5COO^{1-}$	+ H_3O^{1+}
Start	$C_{Na\_benzoate} = 0.69427 \cdot M$	0	0
Change	$-X$	X	X
Equlibrium	$C_{Na\_benzoate} - X$	X	X

Start with the Equlibrium Expression

$$K_b = \frac{X \cdot X}{C_{Na\_benzoate} - X} \qquad K_b := \frac{K_w}{K_a} \qquad K_b = 1.54799 \cdot 10^{-10}$$

Substitute in known values

$$1.548 \cdot 10^{-10} = \frac{X \cdot X}{0.694 - X}$$

Solve

Using the Quadratic

$$X = \begin{pmatrix} 1.0364824915313481043 \cdot 10^{-5} \\ -1.0364979715313481043 \cdot 10^{-5} \end{pmatrix}$$

Assuming X is small in the denominator

$$X = 1.036490231502448845 \cdot 10^{-5}$$

These two answers are essentially identical.

Select the appropriate root:

$$X := 1.036490231502448845 \cdot 10^{-5} \cdot M$$

Concentrations of species present

Benzoic Acid $\quad C_{benzoate} := C_{Na\_benzoate} - X \qquad C_{benzoate} = 0.69426 \cdot M$

Benzoate $\quad C_{benzoic} := X \qquad C_{benzoic} = 1.03649 \cdot 10^{-5} \cdot M$

Hydroxide Ion $\quad C_{OH} := X \qquad C_{OH} = 1.03649 \cdot 10^{-5} \cdot M$

$pOH := -\log\left(C_{OH} \cdot M^{-1}\right) \qquad pOH = 4.98443$

Hydronium Ion $\quad C_{H3O} := \dfrac{K_w \cdot M^2}{C_{OH}} \qquad C_{H3O} = 9.64794 \cdot 10^{-10} \cdot M$

$pH := -\log\left(C_{H3O} \cdot M^{-1}\right) \qquad pH = 9.01557$

3. Sodium Hydroxide (NaOH) is a solid. 5.000 grams is dissolved in 50.00 mL of distilled water?

a) Sodium hydroxide is a salt and a strong base. It will completely dissociate in water to form hydroxide ions and sodium ions

b) NaOH ----> OH^{1-} + Na^{1+}

c) NaOH is an Arrhenius base so it is not typically thought of in terms of proton donors and acceptors. One way to do this is that after the NaOH dissociates the hydroxide undergoes the following acid/base reaction.

OH^{1-} + H2O <--> H2O + OH^{1-}

Now the hydroxide can be considered the proton acceptor (base) and the water is considered the proton donor (acid)

e) After the reaction has reached equlibrium: (Note since NaOH is a strong base, it is not nessicary to work the equlibrium calcualtions. This reaction goes to completion.

$Mass_{NaOH} := 5.00 \cdot gm$ $\qquad V_{NaOH} := 50 \cdot mL$

$$MW_{NaOH} := (22.989768 + 15.9994 + 1.00794) \cdot \frac{gm}{mole}$$

$$MW_{NaOH} = 39.99711 \cdot gm$$

$$mole_{NaOH} := \frac{Mass_{NaOH}}{MW_{NaOH}}$$

$$mole_{NaOH} = 0.12501 \cdot mole$$

$$C_{NaOH} := \frac{mole_{NaOH}}{V_{NaOH}}$$

$$C_{NaOH} = 2.50018 \cdot M$$

Concentrations of species present

Hydroxide Ion $\qquad C_{OH} := C_{NaOH} \qquad C_{OH} = 2.50018 \cdot M$

$pOH := -\log\left(C_{OH} \cdot M^{-1}\right) \qquad pOH = -0.39797$

Hydronium Ion $\qquad C_{H3O} := \frac{K_w \cdot M^2}{C_{OH}} \qquad C_{H3O} = 3.99971 \cdot 10^{-15} \cdot M$

$pH := -\log\left(C_{H3O} \cdot M^{-1}\right) \qquad pH = 14.39797$

4. The benzoic acid solution and the sodium benzoate solution are mixed together in a larg flask.

a) Benzioic acid is a weak acid and benzoate is the conjugate base so this system will form a buffer solution.

b) C_6H_5COOH + H_2O <--> $C_6H_5COO^{1-}$ + H_3O^{1+}

c) benzoic acid is the proton donor (It is an acid)

d) water is the proton acceptor (It is the only available base)

e) After the reaction has reached equilibrium:

First determine the concentration of the acid and the base after dilution:

$V_{total} := V_{benzoic} + V_{Na\_benzoate}$ $\qquad V_{total} = 300 \cdot mL$

$C_{acid} := \frac{mole_{benzoic}}{V_{total}}$ $\qquad C_{acid} = 0.40966 \cdot M$

$C_{base} := \frac{mole_{Na\_benzoate}}{V_{total}}$ $\qquad C_{base} = 0.23142 \cdot M$

Next look at the equilibrium

	C_6H_5COOH + H_2O	<-->	$C_6H_5COO^{1-}$	+ H_3O^{1+}
Start	$C_{acid} = 0.40966 \cdot M$		$C_{base} = 0.23142 \cdot M$	0
Change	$-X$		X	X
Equilibrium	$C_{acid} - X$		$C_{base} + X$	X

Start with the Equilibrium Expression

$$K_a = \frac{(C_{base} + X)\cdot X}{C_{acid} - X}$$

Substitute in known values

$$6.49\cdot 10^{-5} = \frac{(0.23142 + X)\cdot X}{0.40966 - X}$$

Solve

Using the Quadratic $X = \begin{pmatrix} 1.147969291519977\cdot 10^{-4} \\ -.2315996969291519977 \end{pmatrix}$

Assuming X is small compared to the concentration of the acid or the base $X = 1.1488606861982542563\cdot 10^{-4}$

These two answers are essentially identical.

Select the appropriate root:

$$X := 1.147969291519977\cdot 10^{-4}\cdot M$$

Concentrations of species present

Benzoic Acid	$C_{benzoic} := C_{acid} - X$	$C_{benzoic} = 0.40954 \cdot M$
Benzoate	$C_{benzoate} := C_{base} + X$	$C_{benzoate} = 0.23154 \cdot M$
Hydronium Ion	$C_{H3O} := X$	$C_{H3O} = 1.14797\cdot 10^{-4} \cdot M$
	$pH := -\log(X\cdot M^{-1})$	$pH = 3.94007$
Hydroxide Ion	$C_{OH} := \frac{1\cdot 10^{-14}\cdot M^2}{X}$	$C_{OH} = 8.71103\cdot 10^{-11} \cdot M$
	$pOH := 14 - pH$	$pOH = 10.05993$

5. 1.00 mL of the sodium hydroxide solution is added to the buffer.

Adding NaOH shifts the equilibrium from the above system. To solve for the new equilibrium conditions, two steps are required.

First since OH^- is a strong base, and benzoic acid is the strongest acid available,

$C_6H_5COOH + OH^- \leftrightarrow C_6H_5COO^{1-} + H_2O$

This reaction will go to completion so that for:

$C_{NaOH} = 2.50018 \cdot M$ $\qquad V_{NaOH} := 1 \cdot mL$

$mole_{NaOH} := C_{NaOH} \cdot V_{NaOH}$ $\qquad mole_{NaOH} = 0.0025 \cdot mole$

$V_{total} := V_{benzoic} + V_{Na\_benzoate} + V_{NaOH}$ $\qquad V_{total} = 0.301 \cdot liter$

The new initial, NON-EQULIBRIUM, conditions for benzoic acid and benzoate ion are:

Benzoic Acid

$mole_{acid} := mole_{benzoic}$

$mole_{acid} = 0.1229$

$mole_{benzoic} := mole_{acid} - mole_{NaOH}$

$$C_{benzoic} := \frac{\left(mole_{benzoic}\right)}{V_{total}}$$

$C_{benzoic} = 0.4 \cdot M$

Benzoate

$mole_{base} := mole_{Na\_benzoate}$

$mole_{base} = 0.06943$

$mole_{benzoate} := mole_{base} + mole_{NaOH}$

$$C_{benzoate} := \frac{\left(mole_{benzoate}\right)}{V_{total}}$$

$C_{benzoate} = 0.23896 \cdot M$

Based upon these initial concentrations, solve for the equilibrium values, assuming X reacts:

$$K_a = \frac{\left(C_{benzoate} + X\right) \cdot X}{C_{benzoic} - X}$$

Substitute in known values

$$6.49\cdot 10^{-5} = \frac{(0.23896 + X)\cdot X}{0.4 - X}$$

Solve

Using the Quadratic $X = \begin{pmatrix} 1.0855862725786263\cdot 10^{-4} \\ -.23913345862725786263 \end{pmatrix}$

Assuming X is small compared to the concentration of the acid or the base $X = 1.0863742885838634081\cdot 10^{-4}$

These two answers are essentially identical.

Select the appropriate root:

$$X := 1.0855862725786263\cdot 10^{-4}\cdot M$$

Concentrations of species present

Benzoic Acid	$C_{benzoic} := C_{benzoic} - X$	$C_{benzoic} = 0.39988\cdot M$
Benzoate	$C_{benzoate} := C_{benzoate} + X$	$C_{benzoate} = 0.23907\cdot M$
Hydronium Ion	$C_{H3O} := X$	$C_{H3O} = 1.08559\cdot 10^{-4}\cdot M$
	$pH := -\log\left(X\cdot M^{-1}\right)$	$pH = 3.96434$
Hydroxide Ion	$C_{OH} := \frac{1\cdot 10^{-14}\cdot M^2}{X}$	$C_{OH} = 9.21161\cdot 10^{-11}\cdot M$
	$pOH := 14 - pH$	$pOH = 10.03566$

6. 10.00 mL of the sodium hydroxide solution is added to the buffer.

Adding NaOH shifts the equilibrium from the above system. To solve for the new equilibrium conditions, two steps are required.

First since OH^- is a strong base, and benzoic acid is the strongest acid available,

$$C_6H_5COOH + OH^- \text{<-->} C_6H_5COO^{1-} + H_2O$$

This reaction will go to completion so that for:

$C_{NaOH} = 2.50018 \cdot M$ $V_{NaOH} := 10 \cdot mL$

$mole_{NaOH} := C_{NaOH} \cdot V_{NaOH}$ $mole_{NaOH} = 0.025 \cdot mole$

$V_{total} := V_{benzoic} + V_{Na\_benzoate} + V_{NaOH}$ $V_{total} = 0.31 \cdot liter$

The new initial, NON-EQULIBRIUM, conditions for benzoic acid and benzoate ion are:

Benzoic Acid

$mole_{acid} = 0.1229$

$mole_{benzoic} := mole_{acid} - mole_{NaOH}$

$$C_{benzoic} := \frac{(mole_{benzoic})}{V_{total}}$$

$C_{benzoic} = 0.3158 \cdot M$

Benzoate

$mole_{base} = 0.06943$

$mole_{benzoate} := mole_{base} + mole_{NaOH}$

$$C_{benzoate} := \frac{(mole_{benzoate})}{V_{total}}$$

$C_{benzoate} = 0.30461 \cdot M$

Based upon these initial concentrations, solve for the equilibrium values, assuming X reacts:

$$K_a = \frac{(C_{benzoate} + X) \cdot X}{C_{benzoic} - X}$$

Substitute in known values

$$6.49\cdot 10^{-5} = \frac{(0.30461 + X)\cdot X}{0.3158 - X}$$

Solve

Using the Quadratic $X = \begin{pmatrix} 6.72549552686874\cdot 10^{-5} \\ -.3047421549552686874 \end{pmatrix}$

Assuming X is small compared to the concentration of the acid or the base $X = 6.728413381044614425\cdot 10^{-5}$

These two answers are essentially identical.

Select the appropriate root:

$$X := 6.728413381044614425\cdot 10^{-5}\cdot M$$

Concentrations of species present

Benzoic Acid	$C_{benzoic} := C_{benzoic} - X$	$C_{benzoic} = 0.31572 \cdot M$
Benzoate	$C_{benzoate} := C_{benzoate} + X$	$C_{benzoate} = 0.30468 \cdot M$
Hydronium Ion	$C_{H3O} := X$	$C_{H3O} = 6.72841 \cdot 10^{-5} \cdot M$
	$pH := -\log\left(X\cdot M^{-1}\right)$	$pH = 4.17209$
Hydroxide Ion	$C_{OH} := \frac{1\cdot 10^{-14}\cdot M^2}{X}$	$C_{OH} = 1.48623 \cdot 10^{-10} \cdot M$
	$pOH := 14 - pH$	$pOH = 9.82791$

7. 25.00 mL of the sodium hydroxide solution is added to the buffer.

Adding NaOH shifts the equilibrium from the above system. To solve for the new equilibrium conditions, two steps are required.

First since OH^- is a strong base, and benzoic acid is the strongest acid available,

$C_6H_5COOH + OH^- \leftrightarrow C_6H_5COO^{1-} + H_2O$

This reaction will go to completion so that for:

$C_{NaOH} = 2.50018 \cdot M$

$V_{NaOH} := 25 \cdot mL$

$mole_{NaOH} := C_{NaOH} \cdot V_{NaOH}$

$mole_{NaOH} = 0.0625 \cdot mole$

$V_{total} := V_{benzoic} + V_{Na\_benzoate} + V_{NaOH}$

$V_{total} = 0.325 \cdot liter$

The new initial, NON-EQULIBRIUM, conditions for benzoic acid and benzoate ion are:

Benzoic Acid

$mole_{acid} = 0.1229$

$mole_{benzoic} := mole_{acid} - mole_{NaOH}$

$$C_{benzoic} := \frac{(mole_{benzoic})}{V_{total}}$$

$C_{benzoic} = 0.1858 \cdot M$

Benzoate

$mole_{base} = 0.06943$

$mole_{benzoate} := mole_{base} + mole_{NaOH}$

$$C_{benzoate} := \frac{(mole_{benzoate})}{V_{total}}$$

$C_{benzoate} = 0.40594 \cdot M$

Based upon these initial concentrations, solve for the equilibrium values, assuming X reacts:

$$K_a = \frac{(C_{benzoate} + X) \cdot X}{C_{benzoic} - X}$$

Substitute in known values

$$6.49\cdot 10^{-5} = \frac{(0.40594 + X)\cdot X}{0.1858 - X} \qquad 6.49\cdot 10^{-5} = \frac{(0.40594)\cdot X}{0.1858}$$

Solve

Using the Quadratic

$$X = \begin{pmatrix} 2.969801110315791\cdot 10^{-5} \\ -.40603459801110315791 \end{pmatrix}$$

Assuming X is small compared to the concentration of the acid or the base

$$X = 2.9704931763314775583\cdot 10^{-5}$$

These two answers are essentially identical.

Select the appropriate root:

$$X := 2.969801110315791\cdot 10^{-5}\cdot M$$

Concentrations of species present

Benzoic Acid	$C_{benzoic} := C_{benzoic} - X$	$C_{benzoic} = 0.18579 \cdot M$
Benzoate	$C_{benzoate} := C_{benzoate} + X$	$C_{benzoate} = 0.40597 \cdot M$
Hydronium Ion	$C_{H3O} := X$	$C_{H3O} = 2.9698\cdot 10^{-5} \cdot M$
	$pH := -\log\left(X\cdot M^{-1}\right)$	$pH = 4.52727$
Hydroxide Ion	$C_{OH} := \frac{1\cdot 10^{-14}\cdot M^2}{X}$	$C_{OH} = 3.36723\cdot 10^{-10} \cdot M$
	$pOH := 14 - pH$	$pOH = 9.47273$