

# Buffers Practice Problems

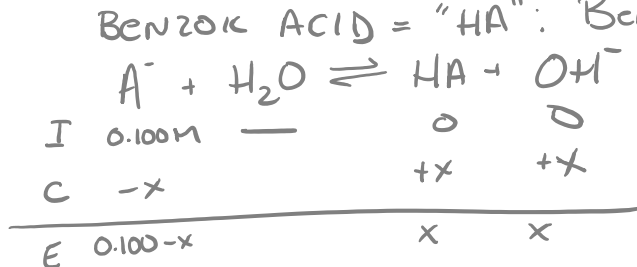
November 7, 2016 7:51 PM

1. A buffer is prepared by mixing 500 mL of 0.100 M sodium benzoate ( $K_a$ , benzoic acid =  $6.3 \times 10^{-5}$ ) and 25 mL of 0.800 M HCl.

a. Is the initial 0.0100 M benzoate solution a buffer (before adding HCl)?

Hm. Is it? Buffers need "similar" amounts of conj. acid & base. How much of each will there be just from dissociation?

Benzoic Acid = "HA": Benzoate = " $A^-$ "



$$K_b = \frac{K_w}{K_a} = \frac{1.5873 \times 10^{-10}}{6.3 \times 10^{-5}} = 1.6 \times 10^{-10}$$

\* why start with  $K_b$  (not  $K_a$ )?  
We only have  $A^-$  in solution  $\rightarrow$  math in the  $K_a$  ICE table will get weird ( $H_2O \approx 0$  initially can no longer be true)

$$K_b = \frac{[OH^-][HA]}{[A^-]} = 1.6 \times 10^{-10}$$

$$= \frac{x \cdot x}{0.100 - x} \approx \frac{x^2}{0.100} = 1.6 \times 10^{-10}$$

$$x = 3.984 \times 10^{-6} = 4.0 \times 10^{-6}$$

\*  $1.6 \times 10^{-10} \ll 0.100$  so "small-x" assumption can be used \*

So  $[HA] = 0.0000040 \text{ M}$   
 $[A^-] = 0.0999960 \text{ M} \approx 0.100 \text{ M}$

$[A^-]:[HA]$  ratio  $\approx 25000$   
 to be a good buffer we need  $[HA]:[A^-]$  to be within 10x (i.e. between 0.1 & 10).

\* NO! the solution of a weak acid with a small  $K_a$  is NOT a buffer. \*

b. What is the pH after the addition of the HCl?

• What will be in solution?

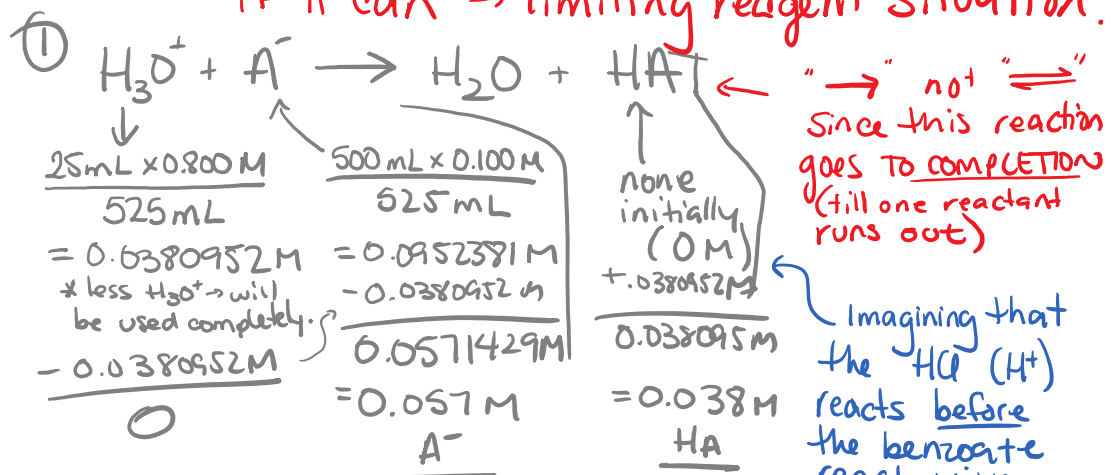
$\rightarrow$  Benzoic acid (HA)  $\leftarrow$  tiny amount

$\rightarrow$  benzoate ( $A^-$ )  $\leftarrow$  lots

$\rightarrow H^+$   $\leftarrow$  less than HA, but still significant

$\rightarrow Cl^-$   $\leftarrow$  (directions?)

- What can these do? (Reactions!)
  - $\text{Cl}^-$  → Not a lot. A "very weak" conj. base of strong acid. Won't react with acids, bases or  $\text{H}_2\text{O}$ . "SPECTATOR ION"
  - benzoic acid → an exceedingly tiny amount. We can safely ignore it for now.
  - benzoate → lots. A weak base.
  - $\text{H}^+$  (or  $\text{H}_3\text{O}^+$ ) from  $\text{HCl}$  → some. Strong acid!
- Strong acid (or strong base) will neutralize if it can → limiting reagent situation.



② Now: find pH...

WAY 1: H-H equation

$$\text{pH} = \text{pK}_a + \log \frac{[\text{A}^-]}{[\text{HA}]}$$

$$\text{pH} = 4.20 + \log \frac{0.057\text{M}}{0.038\text{M}}$$

$$\text{pH} = 4.20 + 0.176$$

$$\boxed{\text{pH} = 4.38}$$

$$\begin{aligned} \text{pK}_a &= -\log K_a \\ &= -\log(6.3 \times 10^{-5}) \\ &= 4.20 \end{aligned}$$

WAY 2: ICE Table

$\text{HA} + \text{H}_2\text{O} \rightleftharpoons \text{A}^- + \text{H}_3\text{O}^+$			
I	0.038M	—	0.057M
C	-x		+x
E	0.038-x		0.057+x
	≈ 0.038		≈ 0.057

$$K_a = 6.3 \times 10^{-5} = \frac{[\text{A}^-][\text{H}_3\text{O}^+]}{[\text{HA}]}$$

$$1.3 \times 10^{-5} = 0.057x$$

\* This will work just as well with  $K_b$  and the base reaction! But it gives you  $[\text{OH}^-]$  instead of  $[\text{H}_3\text{O}^+]$  and I want pH and am lazy.

$\frac{0.038}{6.3 \times 10^{-5}} \approx 600$  \* Below the usual cutoff for "small-x" BUT having non-0 concentrations on both sides means the equilibrium will shift less (common-ion effect!) so we can

$$K_a = 6.3 \times 10^{-5} = \frac{[H_3O^+][A^-]}{[HA]}$$

$$6.3 \times 10^{-5} = \frac{0.057x}{0.038}$$

$$x = 4.2 \times 10^{-5} = [H_3O^+]$$

$$pH = -\log [H_3O^+]$$

$$= 4.38$$

the equilibrium will shift less (common-ion effect!) so we can cheat a little here. OR solve with quadratic  $\rightarrow$  it's always OK.

quick check:

$$\frac{4.2 \times 10^{-5}}{0.038} \times 100\% = 0.11\% \text{ (way less!)} \\ \text{assumption is fine :)}$$

$\swarrow$   $Na^+$  is also a spectator - ignoring it

- c. If I wanted to use that same 500 mL of 0.100 M benzoate and 0.8 M HCl to make a buffer with pH 4.00, how would I do that?

I will use H-H equation here (it's faster) BUT an ICE table will work just fine too (you'll know  $[H_3O^+]_E$  & solve for x).

so  $\rightarrow$  we want pH 4.00.

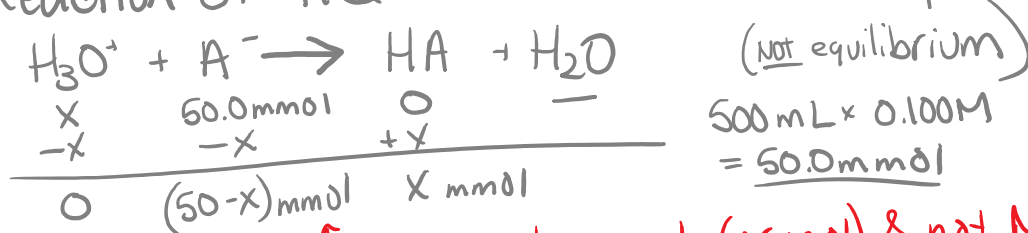
$\rightarrow$  we have 0.100 M " $A^-$ " (500 mL)

$\rightarrow$  we also have some 0.800 M HCl ( $\equiv H_3O^+$  &  $Cl^-$  each .800M)

benzoate = " $A^-$ "

Ignoring the reaction with  $H_2O$  initially means one less ICE table.

• Reaction of HCl & benzoate ( $Cl^-$  is spectator)



$\swarrow$  why mmol (or mol) & not M? we will add HCl but don't know how much! so final volume isn't known yet...

$$pH = pK_a + \log \frac{[A^-]}{[HA]}$$

$$4.00 = 4.20 + \log \frac{[A^-]}{[HA]}$$

$$-0.20 = \log \frac{[A^-]}{[HA]}$$

$$10^{-0.20} = \frac{[A^-]}{[HA]} = \frac{(50-x) \text{ mmol} \div V \text{ mL}}{(x) \text{ mmol} \div V \text{ mL}}$$

$\swarrow$  this is why H-H works in either mol or M

cancels :D phew

$$0.63 = \frac{50-x \text{ mmol}}{x \text{ mmol}}$$

$$0.63x = (50-x) \text{ mmol}$$

$$1.63x = 50 \text{ mmol}$$

This is the conjbase: conj acid ratio we need to achieve this pH (... at any concentration!)

$$X = 30.66 \text{ mmol}$$

$$X = 31 \text{ mmol}$$

How much 0.800 M  
HCl is this?

$$\frac{0.800 \text{ mol}}{\text{L}} = \frac{31 \text{ mmol}}{V \text{ mL}}$$

$$38.321 \text{ mL}$$

$$= \underline{38 \text{ mL}}$$

← this is how much  $\text{H}_3\text{O}^+$  (in mmol) we need to react with the weak base & make the buffer ratio we need to get the desired pH.

So: To make the pH 4.00 buffer, we should mix the 500 mL of 0.100 M sodium benzoate solution with 38 mL of 0.800 M HCl.