Preliminary remark when approaching acid-base chemistry problems in CH-100:

At the level of units, please be reminded that 1 M = 1 mol/L and that we accept that exact expression of the equilibrium constant should be written using **activities**, as opposed to **concentrations**. We make the approximation that the numerical values of concentrations expressed in mol/L are equal to the activities in a dilute system. Thus, each concentration should be divided by c_0 = 1 mol/L to obtain a dimensionless activity value for each reagent, which can then be used to calculate the equilibrium constant. Since this does not change the numerical result of acid–base calculations, we will ignore this formal aspect in the exercise solutions.

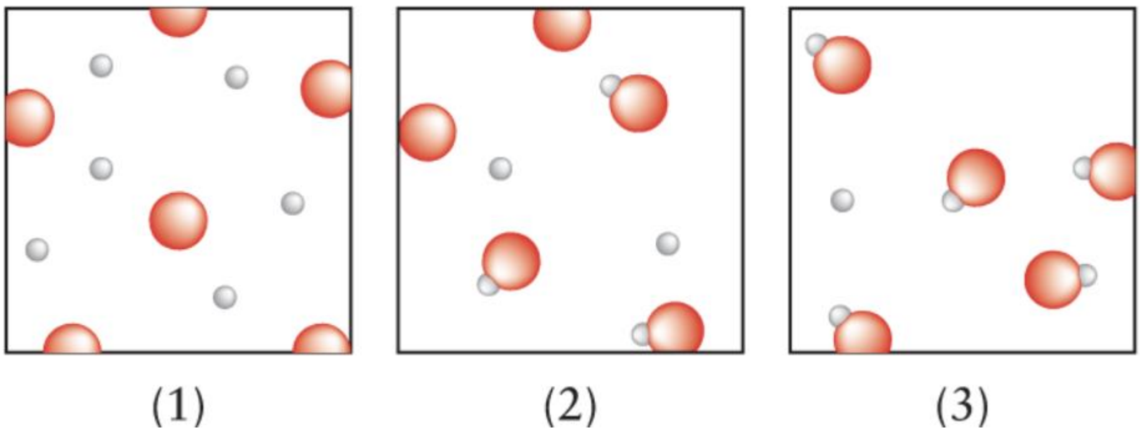
Exercise 1. Which of the following can be classified as reactions of Brønsted-Lowry acid and bases? For those that can be classified so, identify which reactant is the acid and which one is the base by Brønsted-Lowry definition. *Hint: It may help to write the net ionic equations following dissolution in water.*

a) NH_4I (aq) + H_2O (l) ⇌ NH_3 + H_3O^+ + I^-

b) CH_3COOH (aq) + NH_3 (aq) ⇌ CH_3CONH_2 (aq) + H_2O (l)

c) HSO_3^- (aq) + $CH_3NH_3^+$ (aq) ⇌ H_2SO_3 (aq) + CH_3NH_2 (aq)

Exercise 2. The images shown represent the solutes in the solutions of three acids (water molecules are not shown, hydrogen atoms and hydronium ions are represented by small gray spheres and conjugate bases are represented by large red spheres).



a) Which acid is strong acid?
b) Which acid has the strongest conjugate base?
c) Which acid has the highest pK_a

Exercise 3. In the table below you will find several examples of weak acids and bases with their K constants under aqueous conditions at 25˚C. For each example, there are fields corresponding to the acid or base form as well as it's conjugate base or acid, respectively.

Substance	Type	K_a	K_b	pK_a	pK_b
$HA_{(1)}$	Weak acid	3.2×10^{-6}			
$HA_{(2)}$	Weak acid			4.75	
$B_{(1)}$	Weak base		1.8×10^{-5}		
$B_{(2)}$	Weak base				5.10

a) For each substance, determine any missing K_a/K_b or pK_a/pK_b values.

b) Which acid is stronger among $HA_{(1)}$ and $HA_{(2)}$. Explain your rationale.

c) Which base is stronger among $B_{(1)}$ and $B_{(2)}$. Explain your rationale.

Exercise 4. Determine how the pH of pure water at 25 °C changes when sodium hydroxide (NaOH), a strong base, is dissolved to produce a final concentration:

a) $2 \cdot 10^{-2}$ mol/L
b) $2 \cdot 10^{-8}$ mol/L

Kw of water at 25˚C is $1 \cdot 10^{-14}$.

Exercise 5. In the table below you will find several examples of Broensted acids and bases:

	Conj. Pair 1	Conj. Pair 2	Conj. Pair 3	Conj. Pair 4
Acidic form	HCO_3^-	NH_4^+		
Basic form			HSO_3^-	HS^-
K_a at 25˚C	$4,7 \cdot 10^{-11}$		$1,6 \cdot 10^{-2}$	
pK_a at 25˚C		9.25		7.00

a) Please complete the missing fields in the table.
b) For each conjugate pair, determine if the predominant form (= present at higher concentration) will be acidic or basic at:

pH=3
pH=7
pH=11

Exercise 6. 0.02 M benzoic acid (C_6H_5COOH) was dissolved in water and the resulting solution has a pH of 2.96. Calculate the pKa of this acid.

Exercise 7.

a) Ammonia (NH_3) was dissolved in 1L of water to the final concentration of 0.1 mol/L. Considering that the pKa (NH_4^+) = 9.25, calculate the resulting pH of the solution.

b) If 1L of pure water was added to this solution while maintain the same temperature, what would be the effect on pH.

Exercise 8. Consider 100 mL of an aqueous solution containing $CH_3COO^-Na^+$ at the concentration of 0.2 mol/L. Assume that the salt has completely dissolved into ions in water.

a) What is the pH of the resulting solution?

b) Determine the pH of the solution after the addition of 0.1 g of sodium hydroxide (NaOH). Assume negligible effect on the total volume of the solution.

c) What will be the change in pH following the addition of 1 L of pure water (H_2O) to the solution resulting from b).

pKa (CH_3COOH) = 4.75
MW (NaOH = 40 g/mol.

Exercise 9. You are working with a buffer solution based on the acid-base conjugate pair (HA, A^-) with **pKa = 4.76**. You apply some amount of strong base to adjust the pH of solution, and you experimentally measure that it is now at **pH = 6.0**. Determine the ratio between the base and acid forms of this buffer (assume T=25˚C and standard aqueous conditions).

Quick Answers:

1. a) and c) are acid-base reactions by Bronsted-Lowry definition; b) is not

In a)

- NH_4^+ → Brønsted–Lowry acid
- H_2O → Brønsted–Lowry base

In c)

- $CH_3NH_3^+$ → Brønsted–Lowry acid
- HSO_3^- → Brønsted–Lowry base

2. a) Solution 1; b) Solution 3; c) Solution 3;

3.
a)

Substance	Type	K_a	K_b	pK_a	pK_b
$HA_{(1)}$	Weak acid	3.2×10^{-6}	3.13×10^{-9}	**5.495**	**8.505**
$HA_{(2)}$	Weak acid	1.78×10^{-5}	5.62×10^{-10}	**4.75**	**9.25**
$B_{(1)}$	Weak base	5.57×10^{-10}	1.8×10^{-5}	**9.255**	**4.745**
$B_{(2)}$	Weak base	1.26×10^{-9}	7.94×10^{-6}	**8.90**	**5.10**

b) $HA_{(2)}$ is stronger than $HA_{(1)}$.
c) $B_{(1)}$ is stronger than $B_{(2)}$.

4. a) 12.3; b) 7.043

5.
a)

	Conj. Pair 1	Conj. Pair 2	Conj. Pair 3	Conj. Pair 4
Acidic form	HCO_3^-	NH_4^+	H_2SO_3	H_2S
Basic form	CO_3^{2-}	NH_3	HSO_3^-	HS^-
K_a at 25°C	$4.7 \cdot 10^{-11}$	$5.6 \cdot 10^{-10}$	$1.6 \cdot 10^{-2}$	$1.0 \cdot 10^{-7}$
pK_a at 25°C	10.33	9.25	1.80	7.00

b)

	Conj. Pair 1	Conj. Pair 2	Conj. Pair 3	Conj. Pair 4
pH = 3	HCO_3^-	NH_4^+	HSO_3^-	H_2S
pH = 7	HCO_3^-	NH_4^+	HSO_3^-	H_2S and HS^-
pH = 11	CO_3^{2-}	NH_3	HSO_3^-	HS^-

6. $pK_a = 4.19$

7. a) 11.12; b) 10.97

8. a) 9.03; b) 12.4; c) 11.36

9. 17.38