ACID-BASE EQILIBRIUM SYSTEMS

For all the acid base equilibrium systems we can write down

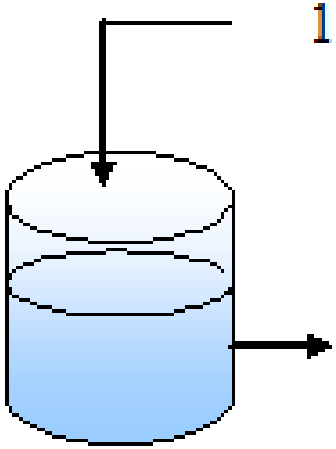
- Mass balance equation
- Charge balance equation

Mass Balance Equation

Mass Balance Equation

The quantity of all species in a solution containing a particular atom (or group atoms) must equal the amount of that atom (or group atoms) delivered to the solution.

Ex.



1 mole of H_3PO_4

1 L DI water

$$[H_3PO_4] = \frac{n}{V} = \frac{1 \text{mole}}{1L} = 1\ M$$

So the equilibrium involves the following reactions:

$$H_2O \longleftrightarrow H^+ + OH^-$$

$$H_3PO_{4\,(aq)} \longleftrightarrow H^+ + H_2PO_4^-{}_{(aq)}$$

$$H_2PO_4^-{}_{(aq)} \longleftrightarrow H^+ + HPO_4^{2-}{}_{(aq)}$$

$$HPO_4^{2-}{}_{(aq)} \longleftrightarrow H^+ + PO_4^{3-}{}_{(aq)}$$

$$\underline{n_{H3PO4\ (initial)}} = n_{H3PO4\ (final)} + n_{H2PO4} + n_{HPO4} + n_{PO4}$$

1 mole

$$\underline{[H_3PO_4]_{(initial)}} = [H_3PO_4]_{(final)} + [H_2PO_4^-] + [HPO_4^{2-}] + [PO_4^{3-}]$$

1 M

Call $[H_3PO_4]_{(initial)} = TOTPO_4$

$TOTPO_4$ **=** sum of the concentrations of all the species in solution that contain the chemical group PO_4.

$$TOTPO_4 = [H_3PO_4] + [H_2PO_4^-] + [HPO_4^{2-}] + [PO_4^{3-}]$$

Mass Balance Equation

Mass Balance Equation

The quantity of all species in a solution containing a particular atom (or group atoms) must equal the amount of that atom (or group atoms) delivered to the solution.

$$TOTPO_4=[H_3PO_4] + [H_2PO_4^-] + [HPO_4^{2-}] + [PO_4^{3-}]$$

Charge Balance Equation

Charge balance equation of any aqueous solution is:

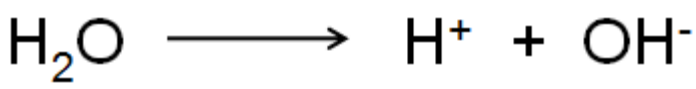
$$n_1[C_1] + n_2[C_2] + \ldots\ldots\ldots = m_1[A_1] + m_2[A_2] + \ldots\ldots\ldots$$

- C's are the concentrations of all the (+)'ly charged ions.
- n is the magnitude of the (+) charge.
- A's are the concentrations of all the (-)'ly charged ions.
- m is the magnitude of the (-) charge.

Ex.

Write down the charge balance of the previous system.

Hint: Consider all the equilibrium species. Do not forget the dissociation of water.



$$1[H^+] = 1[H_2PO_4^-] + 2[HPO_4^{2-}] + 3[PO_4^{3-}] + 1[OH^-]$$

Ex.

1 mol of Na_2SO_4 is added into 1 L DI water. Write down the mass balance and charge balance equations.

$$Na_2SO_{4(s)} \longrightarrow 2Na^+_{(aq)} + SO_4^{2-}{}_{(aq)}$$

initial	1 mol	-	-
after dissoc.	-	2 mol	1 mol

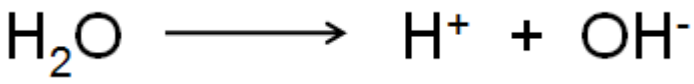
We start with 1 M Na_2SO_4 ⟶ 2 M Na^+ and 1 M SO_4^{2-}

$$[Na^+] = 2\,[SO_4^{2-}]$$

Mass balance between Na^+ and SO_4^{2-}

Charge Balance Equation

To write down the charge balance equation we have to consider the dissociation of water also.



$$[H^+] + [Na^+] = 2\,[SO_4^{2-}] + [OH^-]$$

Ex.

Add 1 mol of Na_2CO_3 into 1 L DI water. Write down the mass balance and charge balance equations for this solution.

Equilibrium reactions are

$$Na_2CO_{3(s)} \longrightarrow 2Na^+_{(aq)} + CO_3^{2-}{}_{(aq)}$$

$$H_2CO_{3(aq)} \rightleftharpoons H^+ + HCO_3^-{}_{(aq)}$$

$$HCO_3^-{}_{(aq)} \rightleftharpoons H^+ + CO_3^{2-}{}_{(aq)}$$

$$H_2O \rightleftharpoons H^+ + OH^-$$

Mass Balance Eq'n

$$[Na^+] = 2\,[CO_3^{2-}]_{(initial)}$$

$$[CO_3^{2-}]_{(initial)} = TOTCO_3$$

$$TOTCO_3 = [CO_3^{2-}]_{(final)} + [HCO_3^-] + [H_2CO_3]$$

MB: $$[Na^+] = 2\,\{\,[CO_3^{2-}] + [HCO_3^-] + [H_2CO_3]\,\}$$

Charge Balance Eq'n

CB: $$[H^+] + [Na^+] = 2\,[CO_3^{2-}] + [HCO_3^-] + [OH^-]$$

Equilibrium reactions are

$$Na_2CO_{3(s)} \longrightarrow 2Na^+_{(aq)} + CO_3^{2-}{}_{(aq)}$$

$$H_2CO_{3(aq)} \rightleftharpoons H^+ + HCO_3^-{}_{(aq)}$$

$$HCO_3^-{}_{(aq)} \rightleftharpoons H^+ + CO_3^{2-}{}_{(aq)}$$

$$H_2O \rightleftharpoons H^+ + OH^-$$

Ex.

Add 1 mol of Na_3PO_4 into 1 L DI water. Write down the mass balance and charge balance equations for this solution.

Equilibrium reactions are

$$Na_3PO_{4(s)} \longrightarrow 3Na^+_{(aq)} + PO_4^{3-}{}_{(aq)}$$

$$H_3PO_{4\,(aq)} \rightleftharpoons H^+ + H_2PO_4^-{}_{(aq)}$$

$$H_2PO_4^-{}_{(aq)} \rightleftharpoons H^+ + HPO_4^{2-}{}_{(aq)}$$

$$HPO_4^{2-}{}_{(aq)} \rightleftharpoons H^+ + PO_4^{3-}{}_{(aq)}$$

$$H_2O \rightleftharpoons H^+ + OH^-$$

Mass Balance Eq'n

$$[Na^+] = 3\ [PO_4^{3-}]_{(initial)}$$

$$[PO_4^{3-}]_{(initial)} = TOTPO_4$$

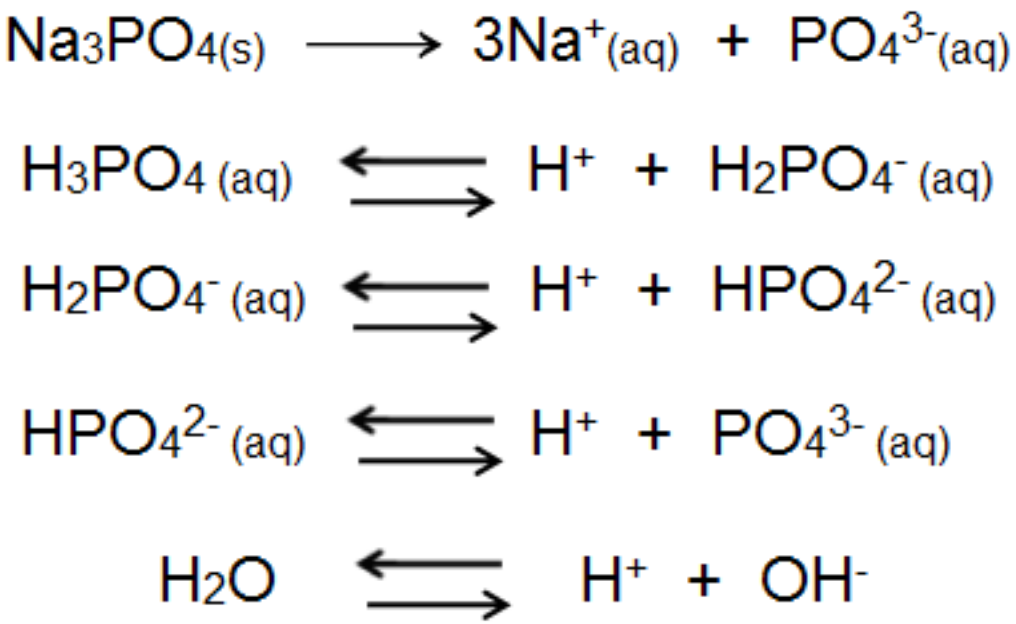
$$TOTPO_4 = [H_3PO_4] + [H_2PO_4^-] + [HPO_4^{2-}] + [PO_4^{3-}]$$

MB: $$[Na^+] = 3\{ [H_3PO_4] + [H_2PO_4^-] + [HPO_4^{2-}] + [PO_4^{3-}] \}$$

Charge Balance Eq'n

CB: $$[H^+] + [Na^+] = [H_2PO_4^-] + 2[HPO_4^{2-}] + 3[PO_4^{3-}] + [OH^-]$$

Equilibrium reactions are



Ex.

Add 1 mol of Na_2HPO_4 into 1 L DI water. Write down the mass balance and charge balance equations for this solution.

Equilibrium reactions are

$$Na_2HPO_{4(s)} \longrightarrow 2Na^+_{(aq)} + HPO_4^{2-}{}_{(aq)}$$

$$H_3PO_{4\,(aq)} \rightleftharpoons H^+ + H_2PO_4^-{}_{(aq)}$$

$$H_2PO_4^-{}_{(aq)} \rightleftharpoons H^+ + HPO_4^{2-}{}_{(aq)}$$

$$HPO_4^{2-}{}_{(aq)} \rightleftharpoons H^+ + PO_4^{3-}{}_{(aq)}$$

$$H_2O \rightleftharpoons H^+ + OH^-$$

Mass Balance Eq'n

$$[Na^+] = 2\ [HPO_4^{2-}]_{(initial)}$$

$$[HPO_4^{2-}]_{(initial)} = TOTPO_4$$

$$TOTPO_4 = [H_3PO_4] + [H_2PO_4^-] + [HPO_4^{2-}] + [PO_4^{3-}]$$

MB: $$[Na^+] = 2\{ [H_3PO_4] + [H_2PO_4^-] + [HPO_4^{2-}] + [PO_4^{3-}] \}$$

Charge Balance Eq'n

CB: $$[H^+] + [Na^+] = [H_2PO_4^-] + 2[HPO_4^{2-}] + 3[PO_4^{3-}] + [OH^-]$$

Ex.

Add 1 mol of NaH_2PO_4 into 1 L DI water. Write down the mass balance and charge balance equations for this solution.

Equilibrium reactions are

$$NaH_2PO_{4(s)} \longrightarrow Na^+_{(aq)} + H_2PO_4^-{}_{(aq)}$$

$$H_3PO_{4\,(aq)} \rightleftharpoons H^+ + H_2PO_4^-{}_{(aq)}$$

$$H_2PO_4^-{}_{(aq)} \rightleftharpoons H^+ + HPO_4^{2-}{}_{(aq)}$$

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Mass Balance Eq'n

$$[Na^+] = [H_2PO_4^-]_{(initial)}$$

$$[H_2PO_4^-]_{(initial)} = TOTPO_4$$

$$TOTPO_4 = [H_3PO_4] + [H_2PO_4^-] + [HPO_4^{2-}] + [PO_4^{3-}]$$

MB: $[Na^+] = [H_3PO_4] + [H_2PO_4^-] + [HPO_4^{2-}] + [PO_4^{3-}]$

Charge Balance Eq'n

CB: $[H^+] + [Na^+] = [H_2PO_4^-] + 2[HPO_4^{2-}] + 3[PO_4^{3-}] + [OH^-]$