Introduction to Biochemistry and Molecular Biology

DOPAMINE
SCIENTIFIC TEAM

Lecture 2

Introduction into Biochemistry

"لا تُعادُوا مَا تَجهَلون فَإنّ
أكثَرَ الْعِلمِ لا تَعرِفون"

علي بن أبي طالب

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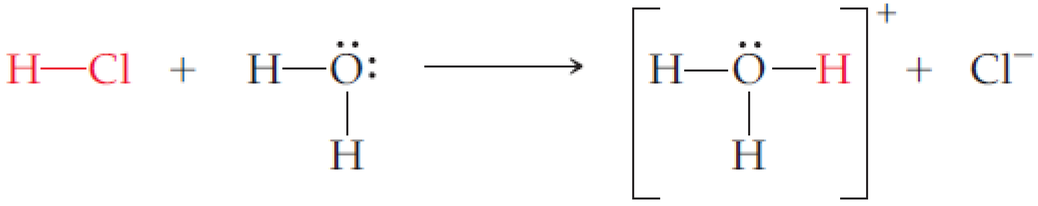
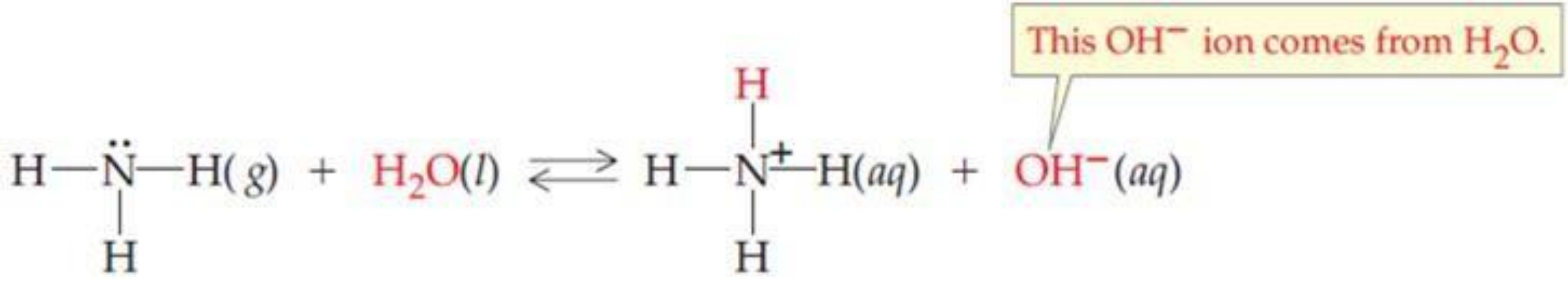
Types of acids and bases

- Arrhenius acids and bases
- Acid: a substance that produces H+ when dissolved in water
    - H+ Reacts with water-producing hydronium ion (H_3O^+).



$$\mathrm{H{-}Cl} + \mathrm{H{-}}\underset{\substack{|\\ \mathrm{H}}}{\ddot{\mathrm{O}}}{:} \longrightarrow \left[\mathrm{H{-}}\underset{\substack{|\\ \mathrm{H}}}{\ddot{\mathrm{O}}}\mathrm{{-}H}\right]^+ + \mathrm{Cl^-}$$

- Base: a substance that produces OH^- when dissolved in water.



$$\mathrm{H{-}}\underset{\substack{|\\ \mathrm{H}}}{\ddot{\mathrm{N}}}\mathrm{{-}H}(g) + \mathrm{H_2O}(l) \rightleftharpoons \mathrm{H{-}}\overset{\substack{\mathrm{H}\\ |}}{\underset{\substack{|\\ \mathrm{H}}}{\mathrm{N}^+}}\mathrm{{-}H}(aq) + \mathrm{OH^-}(aq)$$

This OH^- ion comes from H_2O.

Types of acids and bases

- The Brønsted-Lowry acid: any substance (proton donor) able to give a hydrogen ion (H^+-a proton) to another molecule.
  - Monoprotic acid: HCl, HNO_3, CH_3COOH 1 mole from Monoprotic will produce 1 mole of proton
  - Diprotic acid: H_2SO_4 1 mole from diprotic will produce 2 moles of protons
  - Triprotic acid: H_3PO_3 1 mole from triprotic will produce 3 moles of protons

- Brønsted-Lowry base: any substance that accepts a proton (H^+) from an acid.
  - $NaOH$, NH_3, KOH

The base doesn't have to produce a hydroxyl ion; it can accept a proton. For example, NH3 (it can accept a proton and that's why it's considered a base).

Water = amphoteric

It has two behaviors

- Substances that can act as an acid in one reaction and as a base in another are called **amphoteric substances.** It depends on the substance that it will react with.
  - **Example: water**
- With ammonia (NH_3), water acts as an acid because it donates a proton (hydrogen ion) to ammonia.

$$\underset{\text{Base}}{NH_3} + \underset{\text{Act as acid}}{H_2O} \leftrightarrow NH_4^{+} + OH^{-}$$

- With hydrochloric acid, water acts as a base.

$$\underset{\text{Acid}}{HCl} + \underset{\text{Act as base}}{H_2O} \rightarrow H_3O^+ + Cl^-$$

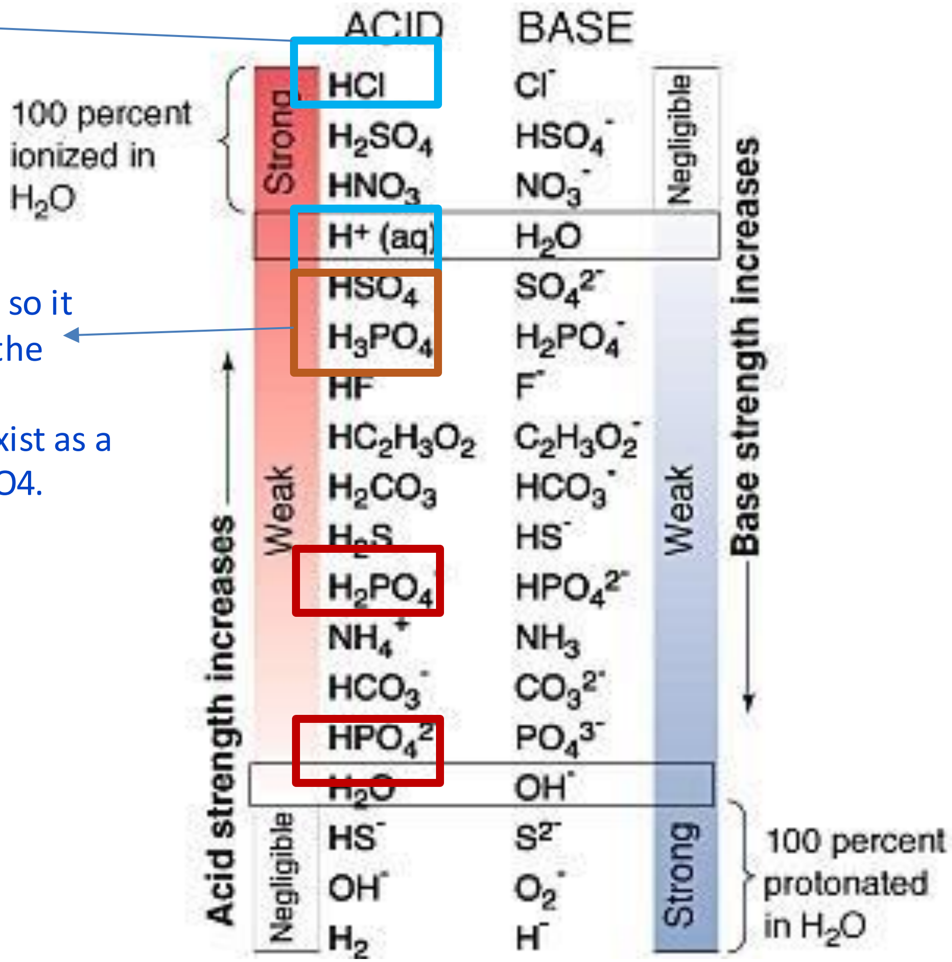
Ampho = 'both' or 'dual'

Acid/base strength

Strong acids are more dissociated into the products than reactants.

- Acids differ in their ability to release protons. Strength depends on the ability to dissociate into ions. The easier the acid releases protons, the stronger the acid.
  - Strong acids dissociate 100%.
- Bases differ in their ability to accept protons.
  - Strong bases have a strong affinity for protons.
- For multi-protic acids (H_2SO_4, H_3PO_4), each proton is donated at different strengths. The release of the first proton is easier than the release of the second proton.

It is a weak acid, so it exists mainly in the form of H3PO4. Some of it will exist as a proton and H2PO4.



ACID	BASE
HCl	Cl^-
H_2SO_4	HSO_4^-
HNO_3	NO_3^-
$H^+ (aq)$	H_2O
HSO_4	SO_4^{2-}
H_3PO_4	$H_2PO_4^-$
HF	F^-
$HC_2H_3O_2$	$C_2H_3O_2^-$
H_2CO_3	HCO_3^-
H_2S	HS^-
H_2PO_4	HPO_4^{2-}
NH_4^+	NH_3
HCO_3^-	CO_3^{2-}
HPO_4^{2}	PO_4^{3-}
H_2O	OH^-
HS^-	S^{2-}
OH^-	O_2^-
H_2	H^-

H2SO4 is stronger than HSO4- because it dissociate protons stronger than HSO4-

Rule

- The stronger the acid, the weaker the conjugate base.
- Strong vs. weak acids
  - Strong acids and bases are one-way reactions

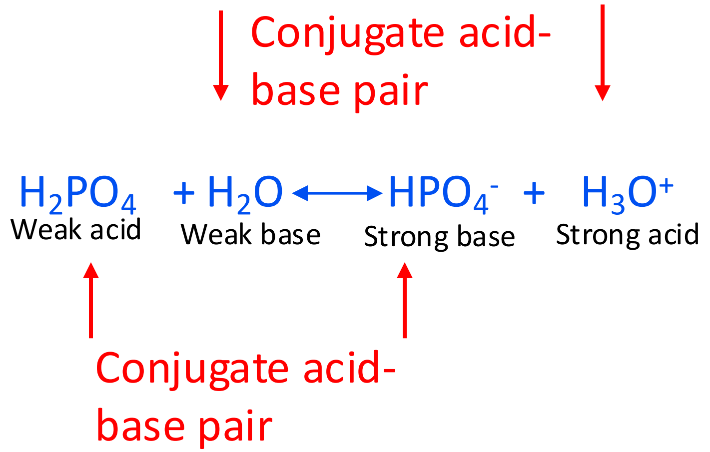
$$HCl \rightarrow H^+ + Cl^-$$

$$NaOH \rightarrow Na^+ + OH^-$$

  - Weak acids and bases do not ionize completely

$$HC_2H_3O_2 \leftrightarrow H^+ + C_2H_3O_2^-$$

$$NH_3 + H_2O \leftrightarrow NH_4^+ + OH^-$$



Conjugate acid-base pair

$$H_2PO_4 + H_2O \longleftrightarrow HPO_4^- + H_3O^+$$

Weak acid

Weak base

Strong base

Strong acid

Conjugate acid-base pair

H3PO4 releases a proton producing H2PO4 and a proton. H2PO4 -> conjugate base of H3PO4.

If H2PO4 acts as an acid, it will produce HPO4 as a conjugate base.

If HPO4 acts as an acid, it will produce PO4 as a conjugate base.

Equilibrium constant and Acid dissociation constant

- Acid/base solutions are at constant equilibrium.
- We can write equilibrium constant (K_{eq}) for such reactions

$HA \quad <--> \quad H^+ + A^-$

K_{eq} in all reactions is the ratio of the concentration of products to the concentration of reactants.

Note: $H_3O^+ = H^+$

$$K_a = \frac{[H_3O^+] \cdot [A^-]}{[HA]}$$

In every reaction the quantity of reactants and products is constant because every acid has a constant Ka.

- The value of the K_a indicates the direction of the reaction.
  - When K_a is greater than 1 the product side is favored. Strong acid
  - When K_a is less than 1 the reactants are favored. Weak acid

What is pKa?

$$pK_a = -\log K_a$$

It is used to measure the strength of acid by using a simple number.

When the Ka increase the pka decrease

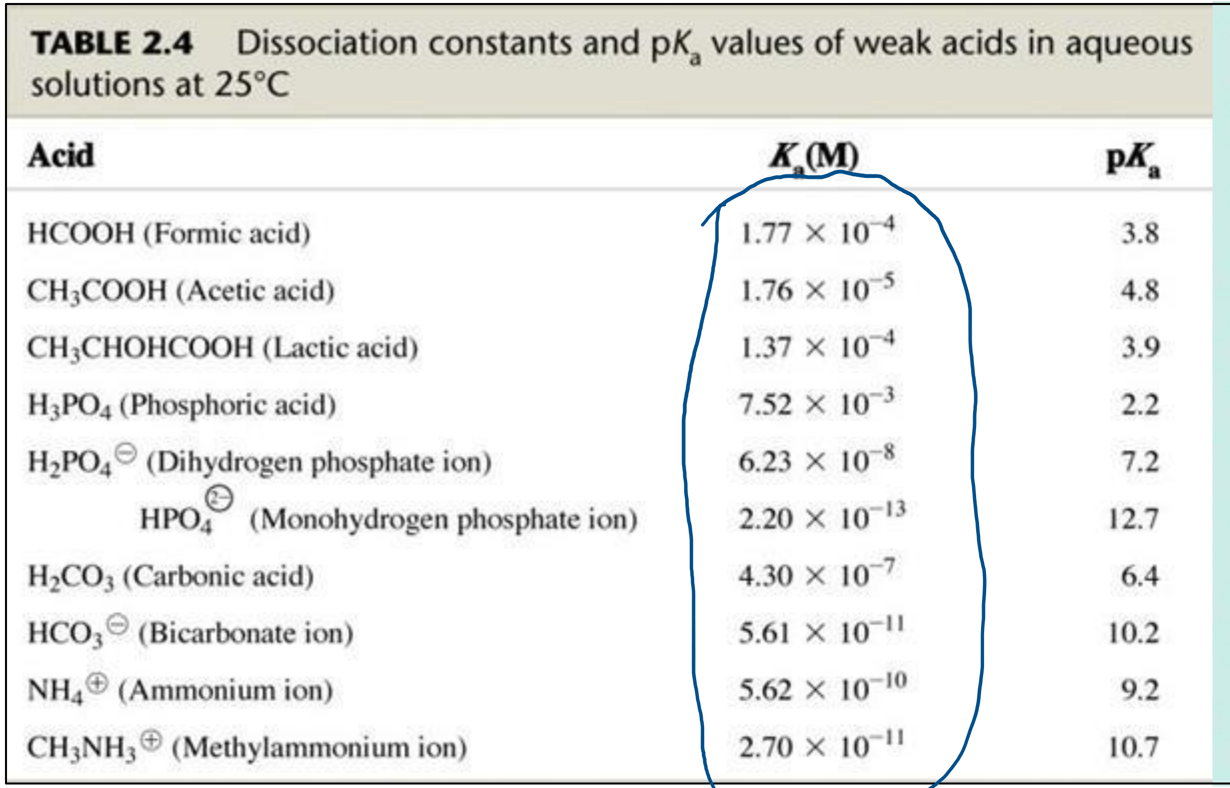


TABLE 2.4 Dissociation constants and pK_a values of weak acids in aqueous solutions at 25°C

Acid	K_a(M)	pK_a
HCOOH (Formic acid)	1.77×10^{-4}	3.8
CH_3COOH (Acetic acid)	1.76×10^{-5}	4.8
$CH_3CHOHCOOH$ (Lactic acid)	1.37×10^{-4}	3.9
H_3PO_4 (Phosphoric acid)	7.52×10^{-3}	2.2
$H_2PO_4^{\ominus}$ (Dihydrogen phosphate ion)	6.23×10^{-8}	7.2
$HPO_4^{2\ominus}$ (Monohydrogen phosphate ion)	2.20×10^{-13}	12.7
H_2CO_3 (Carbonic acid)	4.30×10^{-7}	6.4
$HCO_3^{\ominus}$ (Bicarbonate ion)	5.61×10^{-11}	10.2
$NH_4^{\oplus}$ (Ammonium ion)	5.62×10^{-10}	9.2
$CH_3NH_3^{\oplus}$ (Methylammonium ion)	2.70×10^{-11}	10.7

Less than1—> weak acid

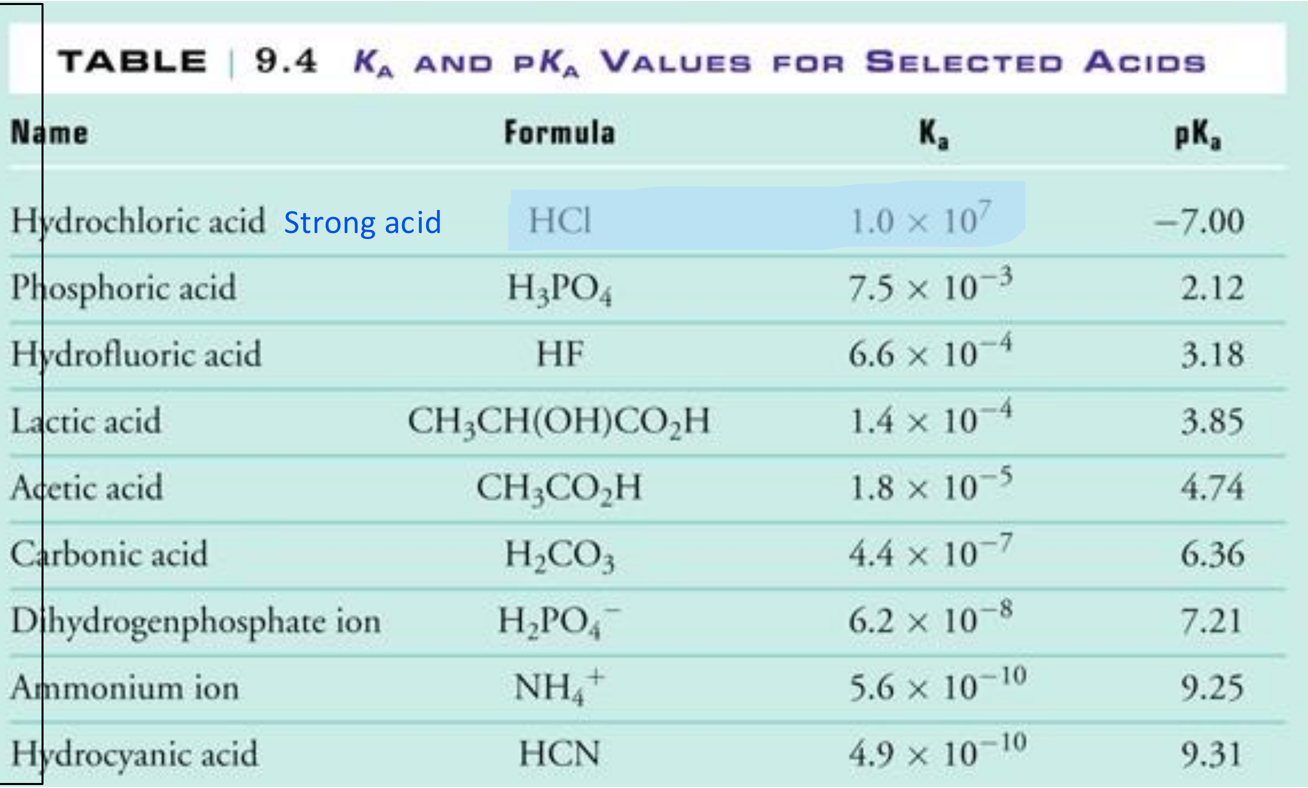


TABLE | 9.4 K_A AND pK_A VALUES FOR SELECTED ACIDS

Name	Formula	K_a	pK_a
Hydrochloric acid Strong acid	HCl	1.0×10^{7}	−7.00
Phosphoric acid	H_3PO_4	7.5×10^{-3}	2.12
Hydrofluoric acid	HF	6.6×10^{-4}	3.18
Lactic acid	$CH_3CH(OH)CO_2H$	1.4×10^{-4}	3.85
Acetic acid	CH_3CO_2H	1.8×10^{-5}	4.74
Carbonic acid	H_2CO_3	4.4×10^{-7}	6.36
Dihydrogenphosphate ion	$H_2PO_4^-$	6.2×10^{-8}	7.21
Ammonium ion	NH_4^+	5.6×10^{-10}	9.25
Hydrocyanic acid	HCN	4.9×10^{-10}	9.31

The higher the Ka or the lower the pKa —> the more acidic

Molarity of solutions

- Solutions can be expressed in terms of its concentration or molarity.
- Moles of a solution are the amount in grams in relation to its molecular weight (MW or a.m.u.).

moles = grams / MW

- A molar solution is where the number of grams equal to its molecular weight (moles) in 1 liter of solution.

M = moles / volume (L)

When we have
10ml we write it
0.01 liters

- Since (mol = grams / MW), you can calculate the grams of a chemical you need to dissolve in a known volume (L) of water to obtain a certain concentration (M) using the following formula:

grams = M x volume (L) x MW

- Acids and bases can also be expressed in terms of their normality (N) or equivalence (Eq).

Exercise

- How many grams do you need to make 5M NaCl solution in 100 ml (MW 58.4)?

--> 100ml = 0.1L (NOTICE: it HAS to be in Liters)

- grams = 58.4 x 5 M x 0.1 liter = 29.29 g

(This means that we will dissolve 29.3g of NaCl in 100ml, to get a 5M solution)

Equivalents

- When it comes to acids, bases and ions, it is useful to think of them as equivalents. (Because we eliminate anything related to the number of charges, volume, molarity; we standardize it)
- An equivalent is the amount of moles of hydrogen ions that an acid can donate .
  - or a base can accept.
- A 1 g-Eq of any ion is defined as the molar mass of the ion divided by the ionic charge.

Examples

- For acids:
- 1 mole HCl = 1 mole [H^+] = 1 equivalent
- 1 mole H_2SO_4 = 2 moles [H^+] = 2 equivalents
  - 1 eq of H_2SO_4 = ½ mol (because 1 mole gives two moles of H^+ ions)

- For ions:
- One equivalent of Na^+ = 23.1 g
- One equivalent of Cl^- = 35.5 g
- One equivalent of Mg^{2+} = (24.3)/2 = 12.15 g

Remember: One equivalent of any acid neutralizes one equivalent of any base.

(In neutralization; the only thing you must take into consideration is ***equivalence***, NOT volume or molarity)
One eq of X should be equal to one eq of Y, regardless of charges).

Molarity and equivalents

Equivalents = n x M x volume (L)

-> **M:** molarity of acid/base.
-> **V:** volume of acid/base.
-> **Little n:** number of protons it can release/accept, number of charges, or number of hydroxyl ions it can release.

One equivalent of any acid neutralizes one equivalent of base.

Based on the equation above, since *x* eq of an acid is neutralized by the same *x* eq of a base, then (n x M x vol) of an acid is neutralized by (n x M x vol) of a base.

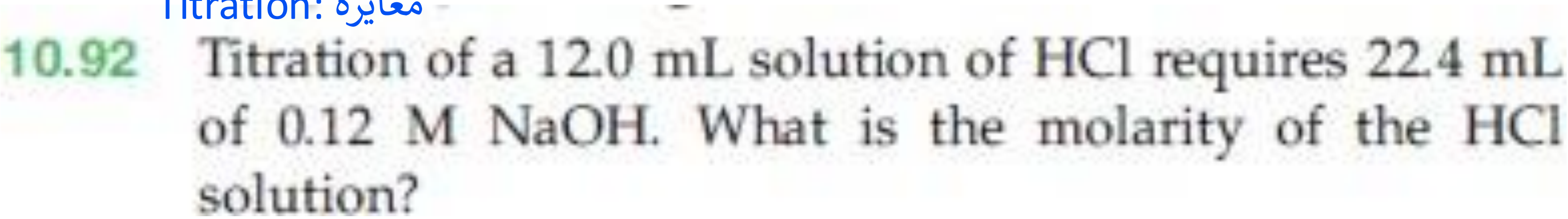
--> When 1 eq of base neutralizes 1 eq of acid:

1 Acid eq = 1 Base eq

$$M \times V \times n = M \times V \times n$$

Problem 1

Titration: معايرة



10.92 Titration of a 12.0 mL solution of HCl requires 22.4 mL of 0.12 M NaOH. What is the molarity of the HCl solution?

- Note that each one produces 1 mole of the ions (H^+ or OH^-), so 1M of HCl is equal to 1M of NaOH.

Eq of base = Eq of acid

n x M1 x Vol1 = n x M2 x Vol2

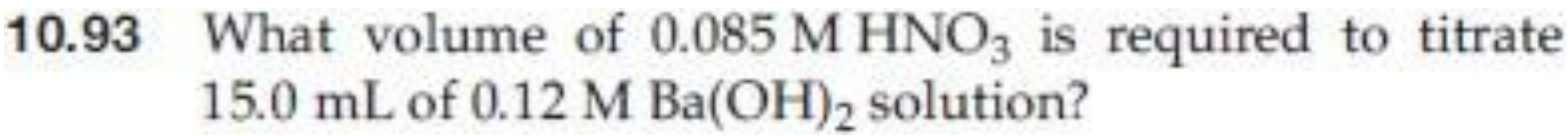
1 x M1 x 12= 1 x 0.12 x 22.4

M1 = (0.12 x 22.4) / 12

M1 = 0.224 M

Problem 2

Little n for HNO_3 = 1 (produces 1mol of proton)



10.93 What volume of 0.085 M HNO_3 is required to titrate 15.0 mL of 0.12 M $Ba(OH)_2$ solution?

Little n for $Ba(OH)_2$ = **2** (produces 2mol of hydroxyl ions)

- Note that 1 mole of HNO_3 produces 1 mole of H^+, but 1 mole of $Ba(OH)_2$ produces 2 moles of OH^-. In other words, the n is different.
- Also, remember that **Equivalents = n x M x volume (L), where n is the number of charges or the number of H + (or OH-) the acid or base can produce or accept.**
- Titration means that we an acid to a base slowly. At one point during titration, the acid and the base neutralize or cancel each other. In other words, "to titrate" means "to neutralize". At the point of neutralization, the concentration of H+ is equal to the concentration of OH-. The best way to calculate how much acid is needed to neutralize a base (or the opposite) is to calculate the equivalents.

Eq of acid = Eq of base

N x M1 x Vol1 = n x M2 x Vol2

1 x 0.085 x Vol = 2 x 0.12 x 15

Vol = (2 x 0.12 x 15) / 1 x 0.085 Vol = 42.35 mL

Ionization of water

(exists at a certain equilibrium)

- Water dissociates into hydronium (H_3O^+) and hydroxyl (OH^-) ions.
- For simplicity, we refer to the hydronium ion as a hydrogen ion (H^+) and write the reaction equilibrium as:

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

Equilibrium constant

- The equilibrium constant Keq of the dissociation of water is:

$$K_{eq} = \frac{[H^{\oplus}]\,[OH^{\ominus}]}{H_2O}$$

- The equilibrium constant for water ionization under standard conditions is 1.8 x 10^{-16} M.

  Water mainly exists as H_2O, not as its ions.

Kw

(Molarity for H_2O in pure water is constant, and it equals 55.6M)

- Since there are 55.6 moles of water in 1 liter, the product of the hydrogen and hydroxide ion concentrations results in a value of 1 x 10^{-14} for:

$$K_{eq}\,(55.5\text{ M}) = [H^{\oplus}]\,[OH^{\ominus}]$$

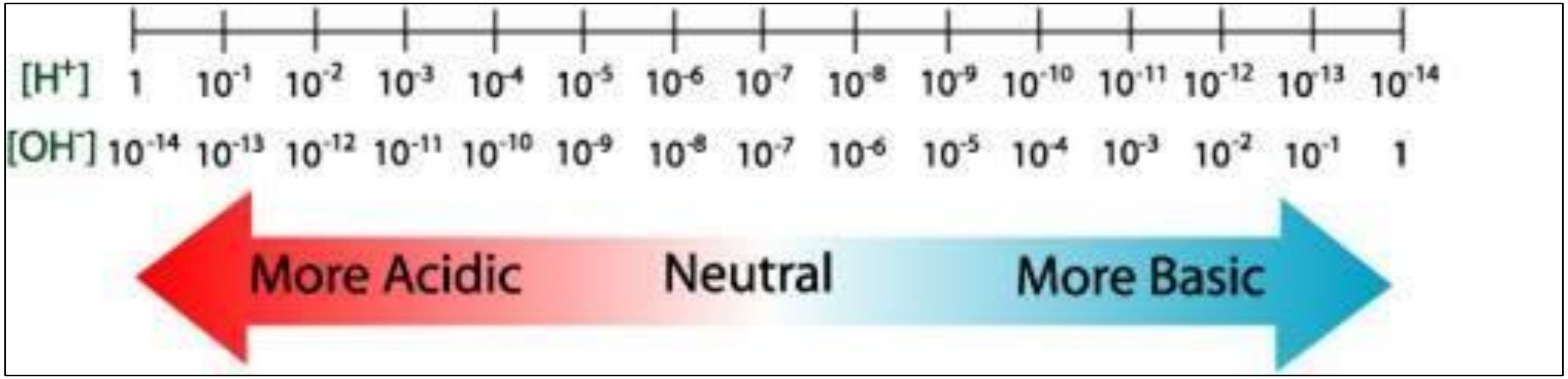
$$55.6\text{M} \times 1.8\text{M} \times 10^{-16} = 1\times10^{-14}\text{ M}^2$$

- This constant, Kw, is called the ion product for water

$$K_w = [H^{\oplus}]\,[OH^{\ominus}] = 1.0 \times 10^{-14}\text{ M}^2$$

$[H^+]$ and $[OH^-]$

- For pure water, there are equal concentrations of $[H^+]$ and $[OH^-]$, each with a value of 1×10^{-7} M.
- Since Kw is a fixed value, the concentrations of $[H^+]$ and $[OH^-]$ are inversely changing.
- If the concentration of H^+ is high (ACIDIC), then the concentration of OH^- must be low, and vice versa (BASIC) For example, if $[H^+] = 10^{-2}$ M, then $[OH^-] = 10^{-12}$ M



$[H^+]$	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-11}	10^{-12}	10^{-13}	10^{-14}
$[OH^-]$	10^{-14}	10^{-13}	10^{-12}	10^{-11}	10^{-10}	10^{-9}	10^{-8}	10^{-7}	10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	1

For any feedback, scan the code or click on it.

Corrections from previous versions:

Versions	Slide # and Place of Error	Before Correction	After Correction
V1 → V2			
V2 → V3			
V3 → V4			

Additional Resources:

1. Marks' Basic Medical Biochemistry page 126,127

رسالة من الفريق العلمي:

بارك الله في وقتنا ورزقنا العزيمة لتفريغ هذه المحاضرة
عسى أن نكون الوجهة الصحيحة ، فإن وَطِئنا على معلومة
خاطئة فهذا لأننا إنسان ، على أن تُصَوِبوا وَطأتنا وما كان
آدم إلا لآدم وحواء لحواء ، مع حرصنا على تفادي ذلك
راجين الله بأن نكون قد قُمنا بالتفريغ على أكمل وجه ،
بالتوفيق Dopamine، بالتوفيق دكاترة .