بسم الله الرحمن الرحيم

BioChemistry

﴿ وَلَقَدْ خَلَقْنَا الْإِنسَانَ وَنَعْلَمُ مَا تُوَسْوِسُ بِهِ نَفْسُهُ وَنَحْنُ أَقْرَبُ إِلَيْهِ مِنْ حَبْلِ الْوَرِيدِ ﴾

MID | Lecture 2

Acids and Bases

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Color coding used in the modified:

- *Black: the original slides*
- *Navy Blue: the doctor’s explanation/words*
- *Gray: additional information and explanation*
- *Red: important information*

Acids and bases

Types of acids and bases depends

- Acid: a substance that produces H^+ when dissolved in water
  - H^+ reacts with water-producing hydronium ion (H_3O^+).
  - (Cl^-) is a conjugate base. It acts as a base

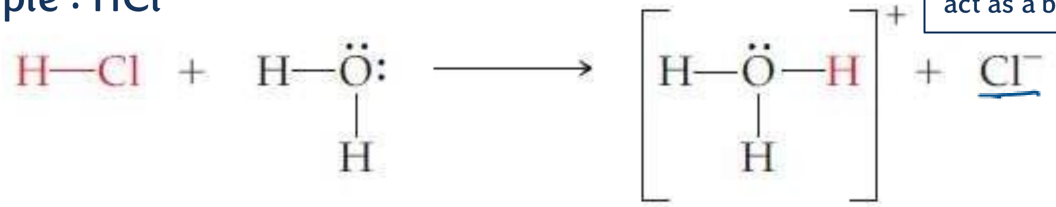
Acids can be divided into three types depending on How many protons they can produce :

- Monoprotic acid: HCl, HNO_3, CH_3COOH
- Diprotic acid: H_2SO_4
- Triprotic acid: H_3PO_3

For monoprotic acids : They produce one proton (one mol of the acid can produce one mol of protons)

According to the base definition Cl- can bind to a proton so it can act as a base

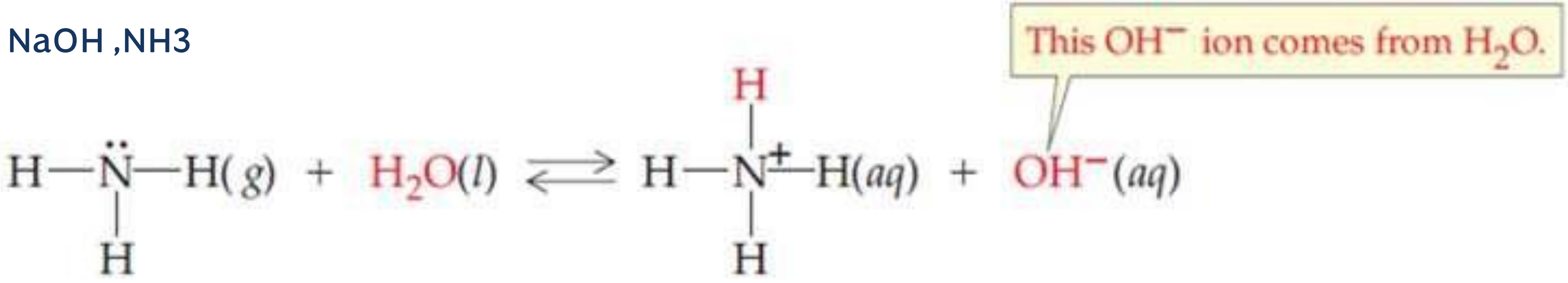
Example : HCl



- Base: a substance that produces OH^- when dissolved in water or accepts a proton (H^+) from an acid.
  - Na^+ or NH_4^+ is a conjugate acid.

$$NaOH \longrightarrow Na^+ + {}^-OH$$

Examples : NaOH ,NH3



Water = amphoteric

It has two natures

- Substances that can act as an acid in one reaction and as a base in another are called **amphoteric substances.**
  - **Example: water**

Depending on the substance that reacts with

- With ammonia (NH_3), water acts as an acid because it donates a proton (hydrogen ion) to ammonia.

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

- With hydrochloric acid, water acts as a base.

$$HCl + H_2O \rightarrow H_3O^+ + Cl^-$$

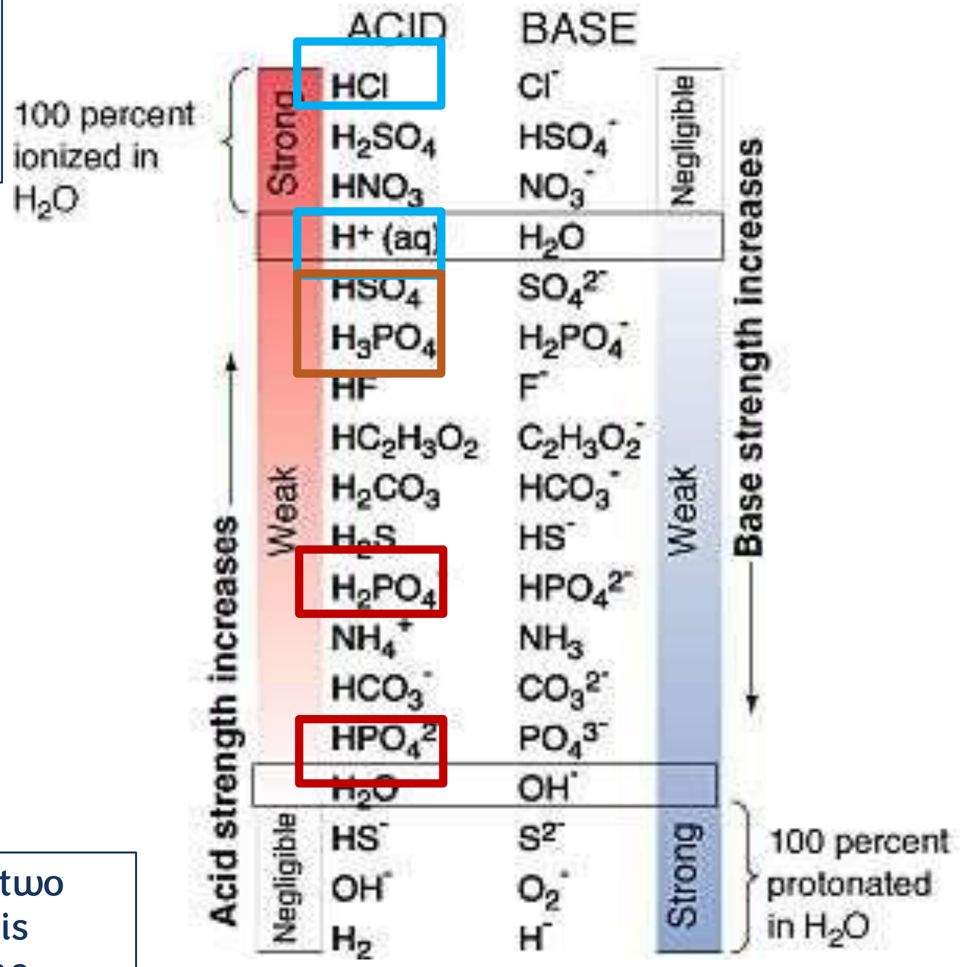
Ampho = 'both' or 'dual'

Acid/base strength

We can't say that H3PO4 is stronger than HCL because it releases 3 protons , It only depends on how easy an acid releases this proton

HCl is a strong acid because it prefers to be in the ionic form (dissociated , product form) rather than the acidic form (protonated form)

On the other hand H3PO4 (a weak acid) prefers to be in the acidic form so acids have different strength depending on how easily they release a proton



- Acids differ in their ability to release protons.
  - 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.

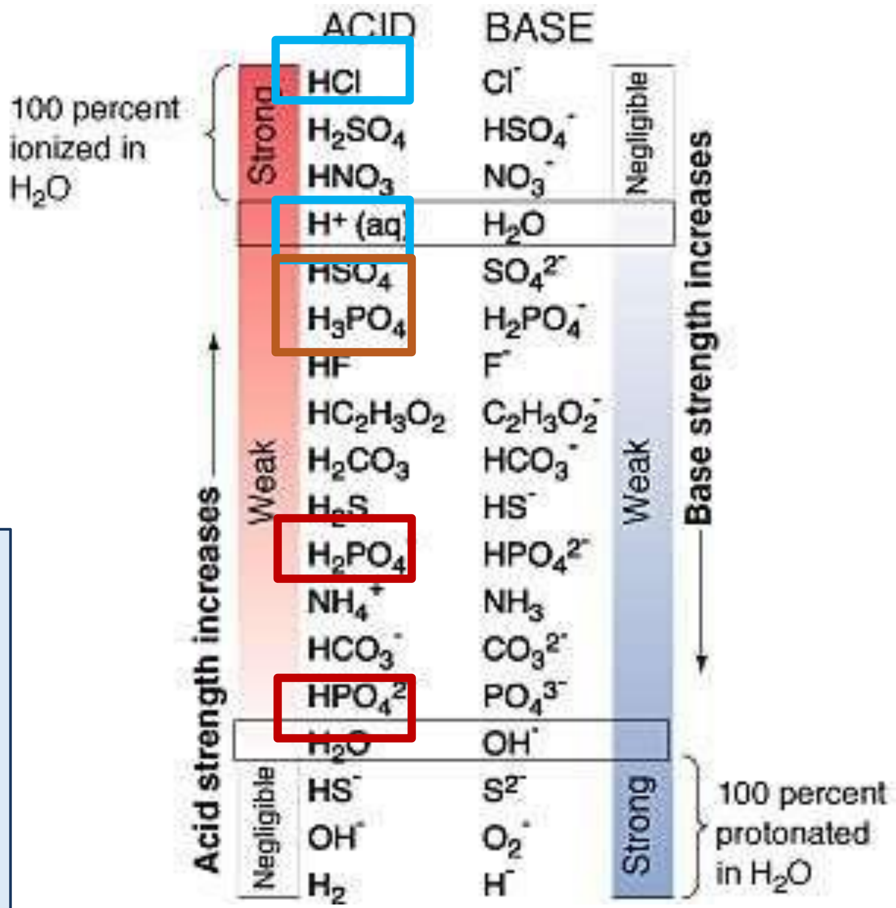
H2SO4 (sulfuric acid) is a strong diprotic acid. It can donate two protons (H^+), but the two dissociation steps are not equally strong (not in the same strength) . The first proton is released almost completely, while the second proton is released less easily because the second dissociation is weaker. However , it still releases both protons relatively easily.

Now let's talk about H_3PO_4

H_3PO_4 (phosphoric acid) is a **weak acid**. It releases its **first proton (H^+)** relatively easily, forming **$H_2PO_4^-$ (dihydrogen phosphate)**.
$H_2PO_4^-$ can also act as an acid by releasing a **second proton**, forming **HPO_4^{2-} (monohydrogen phosphate)**. However, it is a **weaker acid than H_3PO_4**, so the second proton is released **less easily** than the first.
HPO_4^{2-} can also act as an acid by releasing a **third proton**, forming **PO_4^{3-} (phosphate)**. However, it is an even **weaker acid than $H_2PO_4^-$**, making the third proton much more difficult to release than the second.

Therefore, each successive proton is released less easily than the previous one, meaning that the acidity decreases with each dissociation step.
So the strength of an acid depends on how easily it can donate a proton.

What is the conjugate base for the following:
Acetic acid (CH_3COOH) : Acetate (CH_3COO^-)
Lactic acid ($C_3H_6O_3$) : Lactate ($C_3H_5O_3^-$)
Phosphoric acid (H_3PO_4) : Dihydrogen phosphate ($H_2PO_4^-$)
Dihydrogen phosphate ($H_2PO_4^-$) : Monohydrogen phosphate (HPO_4^{2-})
monohydrogen phosphate (HPO_4^{2-}) : Phosphate (PO_4^{3-})
Note:
The conjugate base of an acid is formed after the acid loses one proton (H^+).
Naming:
Most conjugate bases end with the suffix "-ate"



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
    - $HC_2H_3O_2 \leftrightarrow H^+ + C_2H_3O_2^-$
    - $NH_3 + H_2O \leftrightarrow NH_4^+ + OH^-$

And vice versa ,the weaker the acid the stronger the conjugate base ☺

Cl^- is a very weak base. It has very little tendency to bind a proton (H^+), so it prefers to remain in its ionic form (Cl^-). Similarly, acetic acid (CH_3COOH) is a weak acid. It has only a limited tendency to donate a proton, so most of it remains in its protonated (acid) form rather than dissociating into H^+ and CH_3COO^-.

Equilibrium constant and acid dissociation constant

Any acid or base whether strong or weak exist in equilibrium

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

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

Equilibrium constant

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

Concentration of the products

Concentration of the reactant

Note: $H_3O^+ = H^+$

- The value of the K_a indicates the direction of the reaction.
  - When K_a is greater than 1, the product side is favored.

    The acid or base is strong (more products than reactant)

  - When K_a is less than 1, the reactants are favored.

    The acid or base is weak

What is pKa?

$$pK_a = -\log K_a$$

The Ka of acetic acid is 1.76×10^{-5}. This small value means that only a small fraction of acetic acid molecules dissociate into H^+ and CH_3COO^-, while most molecules remain as undissociated acetic acid (CH_3COOH). Therefore, acetic acid is a weak acid.

The Ka of HCl is approximately 10^7. This very large Ka means that HCl dissociates almost completely. At equilibrium, there are about 10^7 times more products (H^+ and Cl^-) than undissociated HCl, making it a strong acid

Example: lactic acid is stronger than acetic acid 3.9 is lower than 4.8 so it's stronger

General rule:

- **The larger the Ka, the stronger the acid.**
- **The lower the pKa, the stronger the acid**

Phosphoric acid is a **triprotic acid**, so it has **three pKa values**, one for each proton released. **$pK_{a1} \approx 2.2$** → the **first proton** is released relatively easily.
$pK_{a2} \approx 7.2$ → the **second proton** is released less easily.
$pK_{a3} \approx 12.7$ → the **third proton** is released with great difficulty.

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

TABLE 9.4 K_A AND pK_A VALUES FOR SELECTED ACIDS

Name	Formula	K_a	pK_a
Hydrochloric 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

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)

Molarity is the expression of concentration of solutions

- 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

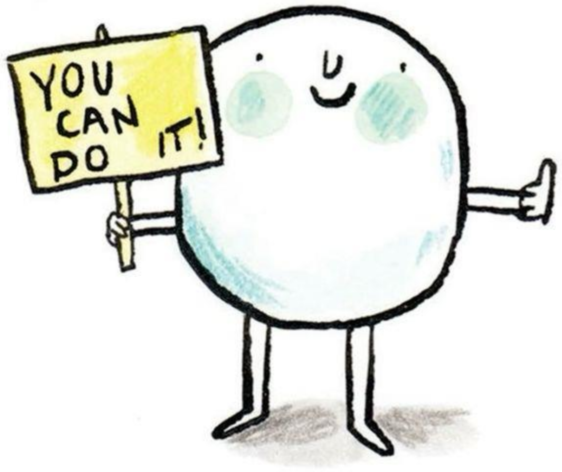
- Acids and bases can also be expressed in terms of their normality (N) or equivalence (Eq).

Exercise

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

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

Don't forget to convert the volume into liters ☺



Equivalents

- When it comes to acids, bases, and ions, it is useful to think of them as equivalents.
- An equivalent is the number of moles of hydrogen ions that an acid can donate.
  - or a base can accept.
- For ions, one **equivalent (Eq) is** equal to the number of ions that carry 1 mol of charge.

اللهم إني وكلتك أمري فكن لي خير وكيل
، ودبر لي أمري فإني لا أُحسن التدبير.

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

23.1 g of Na^+ equals 1 mole of positive charge, same applies to Cl^- but since Mg^{2+} has two positive charges per mole, only half of its molar mass provides us with 1 mole of positive charge.

While for an Aluminum ion that has 3 positive charges, we divide its molecular mass by 3 to have 1 mole of positive charge

The typical concentration of Mg^{2+} in blood is 3 mEq/L. How many milligrams of Mg^2+ are in 250 mL of blood?

Exercise

Try this yourself!

- Calculate milligrams of Ca^{2+} in blood if total concentration of Ca^{2+} is 5 mEq/L.

- 1 Eq of Ca^{2+} = 40.1 g/2 =20.1 g

- Grams of Ca^{2+} in blood =
- = (5 mEq/L) x (1 Eq/1000 mEq) x (20.1 g/ 1 Eq)
- = 0.1 g/L
- =100 mg/L

Electrolytes

- Electrolytes are **electrically-charged minerals** when dissolved in water, such as <u>sodium, potassium, chloride, calcium, magnesium, phosphate, and bicarbonate.</u>

- They are vital for various body functions such as nerve and muscle function, fluid balance, acid-base balance, and blood pressure.

- Heavy and continuous diarrhea from conditions such as cholera can result in dehydration and very low sodium levels in the body [hyponatremia).

- Heavy sweating during strenuous exercise can also lead to dehydration and loss of electrolytes.

If the concentration of these ions becomes abnormal, organs and cells can't function normally
Low sodium can cause hallucinations

During WC hydration breaks, players drink juices that has electrolytes to replenish the loss of minerals

Molarity and equivalents

An equivalent treats all substances the same, regardless of whether they are acids, bases, ions, strong, weak, concentrated, or dilute

Equivalents = n x M x volume (L)

n = the number of H^+, OH^-, electrons, or charges, depending on the reaction
M = molarity

One equivalent of any acid neutralizes one equivalent of base.

If we neutralize an acid with a base each of one equivalent, that doesn't mean that they have same volume or concentration. For example: 1 mole of H_2SO_4 cannot neutralize 1 mole of sodium hydroxide because it provides twice as many H^+ ions as one mole of NaOH can neutralize

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.

Titration

- Titration means that we <u>add an acid to a base slowly</u>.
- 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 (not mere M, vol, or n).

Problem 1

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 0.12 x 22.4 =1 x M2 x 12

M2 = (0.12 x 22.4) / 12

M2 = 0.224 M

What are the equivalents for each one of them?

Sine we are titrating, equivalents of both the acid and the base should be equal

Problem 2

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?

- 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.

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

What are the equivalents for each one of them?

Antacids

Basic salts or weak bases that neutralize acid in the stomach (Titration)

$$CaCO_3 + 2\ HCl \rightarrow CaCl_2 + H_2O + CO_2$$
$$NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2$$
$$Al(OH)_3 + 3\ HCl \rightarrow AlCl_3 + 3\ H_2O$$
$$Mg(OH)_2 + 2\ HCl \rightarrow MgCl_2 + 2\ H_2O$$

- Alkaline compounds (neutralize HCl)
- They reduce stomach acidity and provide relief from **heartburn** and **indigestion** (dyspepsia).
- They reduce the digestion of proteins by pepsin (pH 1-2 vs. 3.5-5).
- Examples: **Magnesium Hydroxide, Aluminum Hydroxide, Calcium Carbonate, Sodium Bicarbonate**

Ionization of water

- 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:

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

It exist in equilibrium just like any other solution, so it has an equilibrium constant

Equilibrium constant

Pure water doesn't mainly exist in ionic form (exist as H_2O)

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

Constant

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

Constant
(check next slide)

The equilibrium constant equals the concentration of products divided by the concentration of reactants

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

In this equation, we have two constants and multiplying them gives us a constant as well, the value is in the next slide

Kw

- 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 1×10^{-14} for:

$$K_{eq} = \frac{[H^{\oplus}][OH^{\ominus}]}{H_2O} \longrightarrow \underline{K_{eq}(55.5\ M)} = [H^{\oplus}][OH^{\ominus}]$$

Water has a concentration that is 55.5 molar and it's constant

- This constant, Kw, is called the ***ion product of water*** or Kw

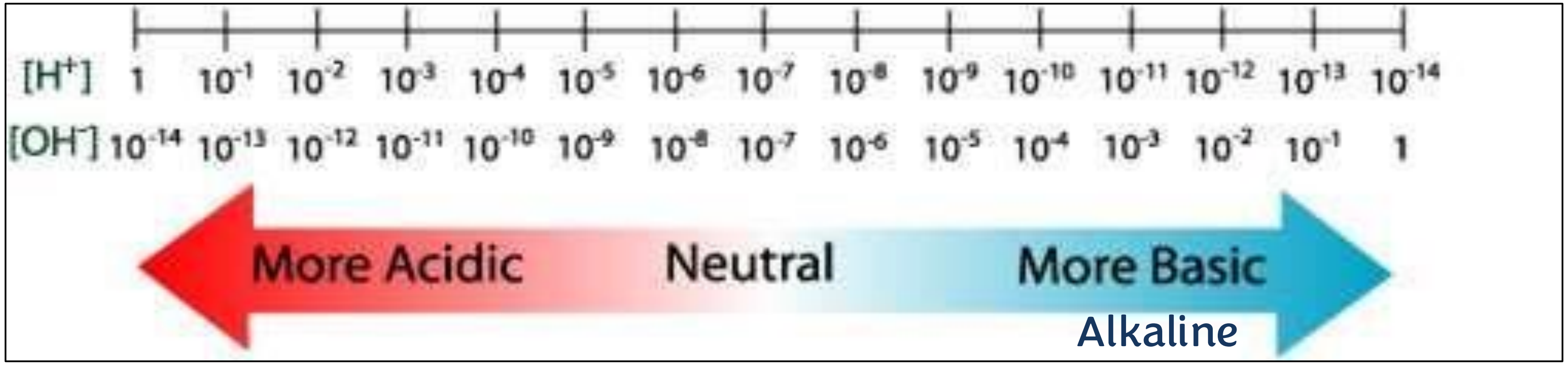
$$K_w = [H^{\oplus}][OH^{\ominus}] = 1.0 \times 10^{-14}\ M^2$$

This is the value we get by multiplying the concentration of water by the equilibrium constant

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

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

Because multiplying the ions by each other should always give us 1.0×10^{-14}

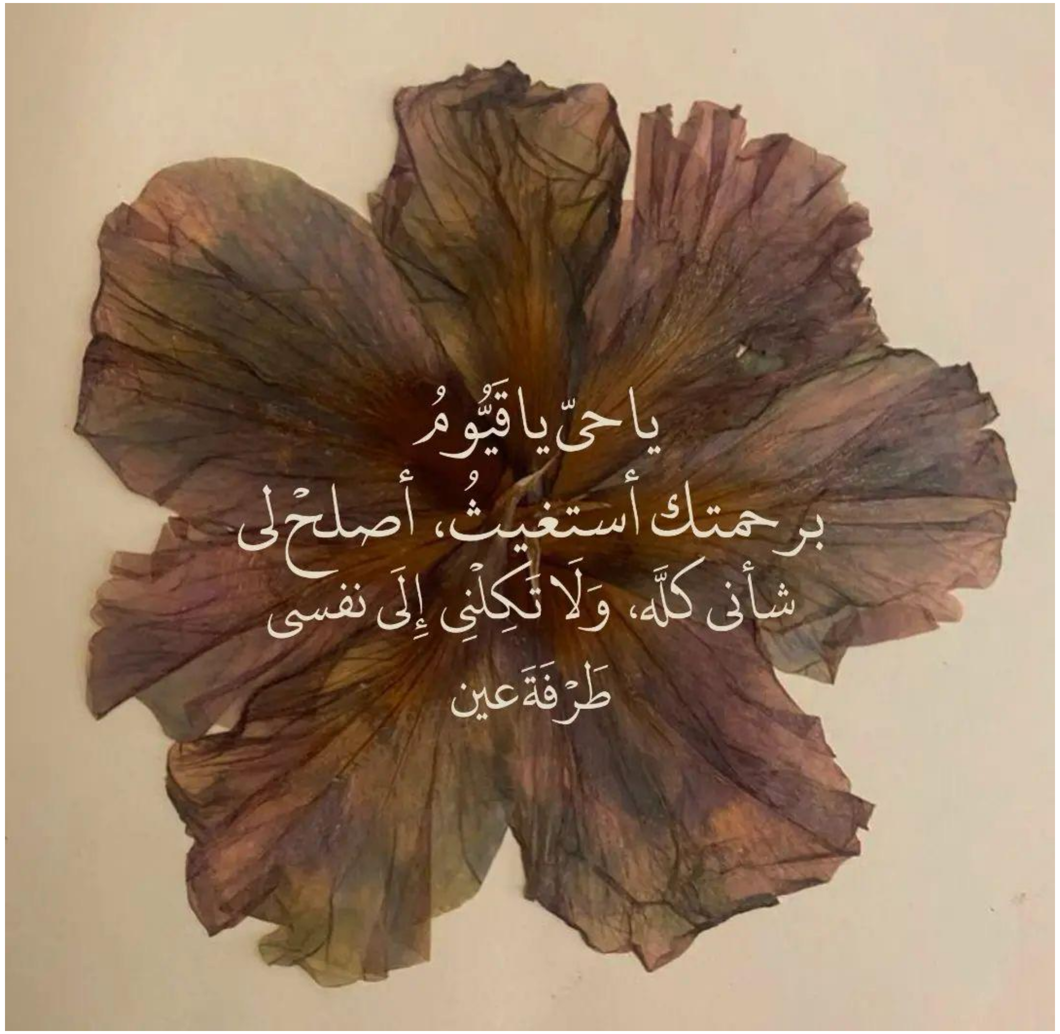


Now, let’s start doing this

[Quiz]

Additional Resources:

رسالة من الفريق العلمي:



تركب الطائرة مطمئنًا، مع أنك لا ترى المدرج من قمرة القيادة، ولا تعرف كيف تدار آلاف الأنظمة فيها ..ثم تخاف من غدٍ يعلم الله تفاصيله قبل أن يخلقه؟

وتغرس بذرًا صغيرًا في الأرض، ثم تنتظر منها شجرةً باسقة، لأنك تؤمن أن الله سينبتها .. أفلا تزرع في قلبك حسن الظن، وأنت تعلم أن الله ينبت الأمل بعد اليأس؟ 🌱

وترى الله يخرج من بين الصخور ماءً عذبًا، ومن بين الظلمات نورًا، ومن قلب الشدة فرجًا ..أفلا تحسن الظن بمن إذا أراد شيئًا أن يقول له كن فيكون؟ 🤍

وترى القمر يكتمل ثم ينقص، والشمس تغيب ثم تعود، والفصول تتعاقب دون أن يختل نظامها ..أفلا تتيقن أن لكل أمر في حياتك موعدًا قدّره الله بحكمة؟

وترى الورقة تسقط من الشجرة في اللحظة التي كتبها الله لها، فلا تتقدم ولا تتأخر ..أفلا تعلم أن ما كُتب لك لن يفوتك، وما فاتك لم يكن ليصيبك؟ 🍃

فإذا كان قلبك يطمئن لكل هذه السنن التي أجراها الله في هذا الكون، فاجعل أعظم طمأنينتك بمن أجرى تلك السنن؛ فإن رب الخير لا يأتي إلا بالخير، وكل تدبيره رحمة، وإن خفيت حكمته عن بصرك اليوم، وما من ابتلاء ساقه إليك إلا وفي طياته رحمة ولطف وأجر .فسلّم أمرك لله، ودع قلبك يستريح؛ لأن من أحسن تدبير الكون كله، لن يخطئ تدبير حياتك أبدًا .

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

Corrections from previous versions:

Versions	Slide # and Place of Error	Before Correction	After Correction
V0 → V1			
V1 → V2			