Lesson 3: Hydrogen Ions and pH

Ion Product Constant for Water

Write the self-ionization equation for water. Compare the numbers of hydronium and hydroxide ions formed.

The **ion product constant for water (Kw)** is the value of the equilibrium constant expression for the self-ionization of water.

Writing *Kw*

$[H_2O]$ does not appear in the denominator. Why?

.....

The Ion Product of Water

$$K_w = [H^+][OH^-]$$

K_w is the ion product constant for water. $[H^+]$ represents the concentration of the hydrogen ion. $[OH^-]$ represents the concentration of the hydroxide ion.

In dilute aqueous solutions, the product of the concentrations of the hydrogen ion and the hydroxide ion equals K_w.

Experiments show that in pure water at 298 K, $[H^+]$ and $[OH^-]$ are both equal to 1.0×10^{-7} M. Calculate Kw.

Kw and Le Châtelier's Principle

Does Kw change when the concentration of hydrogen ions increases? Why?

Explain this change in terms of Le Châtelier's principle.

Calculate $[H^+]$ and $[OH^-]$ Using Kw

At 298 K, the H^+ ion concentration in a cup of coffee is 1.0×10^{-5} M. What is the OH^- ion concentration in the coffee? Is the coffee acidic, basic, or neutral?

The concentration of either the H+ ion or the OH- ion is given for four aqueous solutions at 298 K. For each solution, calculate [H+] or [OH-]. State whether the solution is acidic, basic, or neutral.

a. $[H^+] = 1.0 \times 10^{-13}$ M

b. $[OH^-] = 1.0 \times 10^{-7}$ M

c. $[OH^-] = 1.0 \times 10^{-3}$ M

d. $[H^+] = 4.0 \times 10^{-5}$ M

What is pH?

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

The **pH** of a solution is the negative logarithm of the hydrogen ion concentration.

A solution with a pH of 0.0 is strongly .....; a solution with a pH of 14.0 is strongly .....

A change of one pH unit represents a tenfold change in ion concentration. Determine whether seawater (pH=8) or detergent (pH=10) has a higher concentration of H^+ ions. How many times higher?

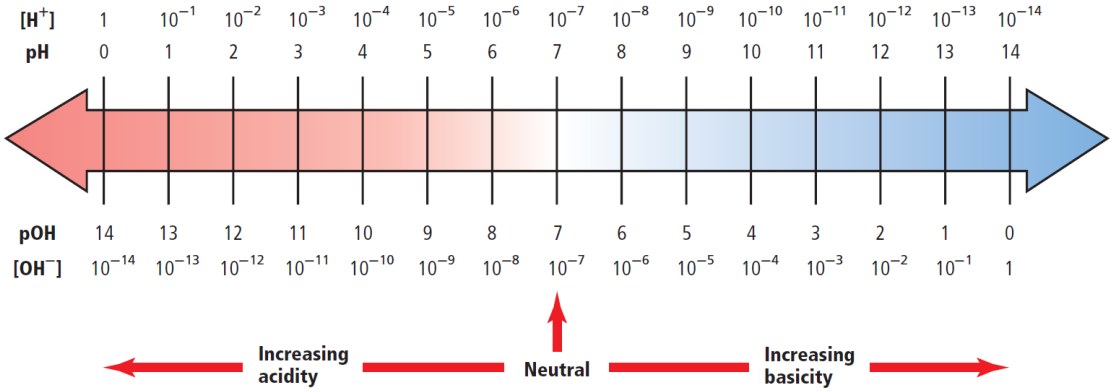
.....

What is pOH?

$$pOH = -\log [OH^-]$$

The **pOH** of a solution is the negative logarithm of the hydroxide ion concentration.

$$pH + pOH = 14.00$$



What is the pH of a neutral solution at 298 K?

Calculate the pH of solutions having the following ion concentrations at 298 K.

a. $[H^+] = 1.0 \times 10^{-2}$ M

b. $[H^+] = 3.0 \times 10^{-6}$ M

c. $[H^+] = 0.0055$ M

d. $[H^+] = 0.000084$ M

Challenge Calculate the pH of a solution having $[OH^-] = 8.2 \times 10^{-6}$ M.

A typical cleaner has a hydroxide ion concentration of 4.0×10^{-3} M. calculate the pOH and pH of a cleaner at 298 K.

Calculate the pH and pOH of aqueous solutions with the following concentrations at 298 K.

a. $[OH^-] = 1.0 \times 10^{-6}$ M

b. $[OH^-] = 6.5 \times 10^{-4}$ M

c. $[H^+] = 3.6 \times 10^{-9}$ M

d. $[H^+] = 2.5 \times 10^{-2}$ M

e. $[OH^-] = 0.000033$ M

f. $[H^+] = 0.0095$ M

Challenge Calculate pH and pOH for an aqueous solution containing 1.0×10^{-3} mol of HCl dissolved in 5.0 L of solution.

Calculating ion concentrations from pH

$$[H^+] = \text{antilog}(-pH)$$

$$[OH^-] =$$

Calculate $[H^+]$ and $[OH^-]$ in each of the following solutions.

a. Milk, pH = 6.50.

c. Milk of magnesia, pH = 10.50

b. Lemon juice, pH = 2.37

d. Household ammonia, pH = 11.90

e.Blood, pH = 7.40

Challenge Calculate the $[H^+]$ and $[OH^-]$ in a sample of seawater with a pOH = 5.60.

Molarity and the pH of strong acids and bases

Strong acids and bases are essentially 100% in the form of ions in solution.

If a flask contains 0.1M HCl. What is the $[H^+]$ in the flask? .....

If a flask contains 0.1M NaOH. What is the $[OH^-]$ in the flask? .....

Explain why you cannot obtain the $[H^+]$ directly from the molarity of a weak acid solution.

.....

Strong polyprotic acid and Multiple OH^-

The concentration of hydroxide ions in a 7.5×10^{-4} M solution of $Ca(OH)_2$ is .....

Calculating Ka from pH

Write the Ka expression for $HF(aq) \rightleftharpoons H^+(aq) + F^-(aq)$

Calculate Ka for HF if the pH of 0.100M solution is 3.20.

$[H^+] = [F^-] =$ .....

$[HF] = 0.100M -$ ..... = ...

The pH of a 0.100M solution of formic acid (HCOOH) is 2.38. What is Ka for HCOOH?

1.8×10^{-4}

Calculate the Ka for a 0.220M solution of H_3AsO_4, pH = 1.50

5.4×10^{-3}

Calculate the Ka for a 0.0400M solution of $HClO_2$, pH = 1.80

1.1×10^{-2}

Calculate the Ka of the following acids using the given information.

a. **0.00330M solution of benzoic acid (C_6H_5COOH), pOH = 10.70**

8.9×10^{-5}

b. **0.100M solution of cyanic acid (HCNO), pOH = 11.00**

1.0×10^{-5}

c. **0.150M solution of butanoic acid (C_3H_7COOH), pOH = 11.18**

1.5×10^{-5}

Challenge Calculate the Ka of a 0.0091M solution of an unknown acid (HX) having a pOH of 11.32. Use Table 4 to identify the acid.

6.3×10^{-4}(HF)

Measuring pH

Figure 16 The approximate pH of a solution can be obtained by wetting a piece of pH paper with the solution and comparing the color of the wet paper with a set of standard colors as shown in **a.** The portable pH meter in **b,** which is being used to measure the pH of rain water, provides a more accurate measurement in the form of a digital display of the pH.

What is the K_a value of 0.0091 M solution of hydrofluoric acid HF with a pH =2.68?	ما قيمة K_a لمحلول حمض الهيدروفلوريك HF تركيزه 0.0091 M و pH=2.68؟

$$HF(aq) \rightleftharpoons H^+(aq) + F^-(aq)$$

a. $K_a = 6.3 \times 10^{-4}$

b. $K_a = 7.6 \times 10^{-5}$

c. $K_a = 9.9 \times 10^{-5}$

d. $K_a = 4.8 \times 10^{-4}$

If $[OH^-] = 2.5 \times 10^{-7}$ *M* in a solution.

What is the pH of the solution?

إذا كان $[OH^-] = 2.5 \times 10^{-7}$ *M* في محلول ما.

فما قيمة pH للمحلول؟

- 4.7
- 6.6
- 7.4
- 3.5

The pH of a 0.200 M solution of hydrofluoric acid HF is 2.15. What is the Ka value of HF acid?

الرقم الهيدروجيني pH لمحلول 0.200 M من حمض الهيدروفلوريك HF هو 2.15 . ما قيمة Ka لحمض HF؟

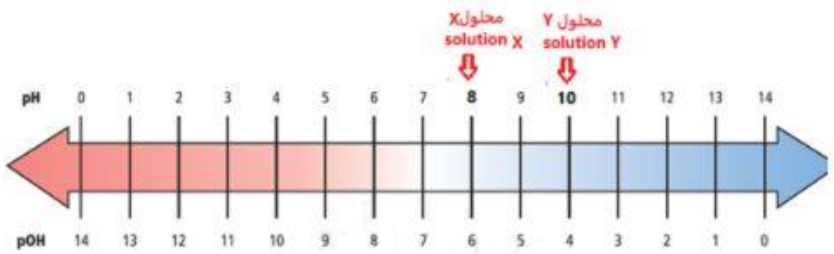
- 4.7×10^{-11}
- 3.2×10^{-9}
- 1.8×10^{-5}
- 2.6×10^{-4}

What is the pH value of 6.50×10^{-2} *M* calcium hydroxide $Ca(OH)_2$ solution?

ما قيمة pH لمحلول هيدروكسيد الكالسيوم $Ca(OH)_2$ تركيزه 6.50×10^{-2} *M* ؟

9.8	○
7.5	○
4.3	○
13.1	○

Which is the correct arrangement according to the pOH values of the solutions (X), (Y), and (Z) which have the following characteristic?	ما الترتيب التصاعدي الصحيح حسب قيمة pOH للمحاليل (X) و (Y) و (Z) ذات الخصائص التالية ؟
(X): $pH = 10.5$ (Y): $[H^+] = 10^{-12}$ (Z): $[OH^-] = 10^{-9}$	
A. (lowest) $(Y) \rightarrow (X) \rightarrow (Z)$ (highest)	A. (الأقل) $(Y) \leftarrow (X) \leftarrow (Z)$ (الأكبر)
B. (lowest) $(X) \rightarrow (Y) \rightarrow (Z)$ (highest)	B. (الأقل) $(X) \leftarrow (Y) \leftarrow (Z)$ (الأكبر)
C. (lowest) $(Z) \rightarrow (X) \rightarrow (Y)$ (highest)	C. (الأقل) $(Z) \leftarrow (X) \leftarrow (Y)$ (الأكبر)
D. (lowest) $(X) \rightarrow (Z) \rightarrow (Y)$ (highest)	D. (الأقل) $(X) \leftarrow (Z) \leftarrow (Y)$ (الأكبر)

How many times increases the concentration of hydrogen ions $[H^+]$ in the solution X than in the solution Y according to the figure below?	كم مرّة يزيد تركيز أيون الهيدروجين $[H^+]$ في المحلول X عن المحلول Y حسب الرسم أدناه؟
	
A. 2 times	A. 2 (مرّتان)
B. 10 times	B. 10 مرّات
C. 100 times	C. 100 مرّة
D. 1000 times	D. 1000 مرّة

Which is the correct arrangement according to the pH values of the solutions (X), (Y), and (Z) which have the following characteristic?	ما الترتيب التصاعدي الصحيح حسب قيمة pH لكل من المحاليل (X) و (Y) و (Z) ذات الخصائص التالية؟

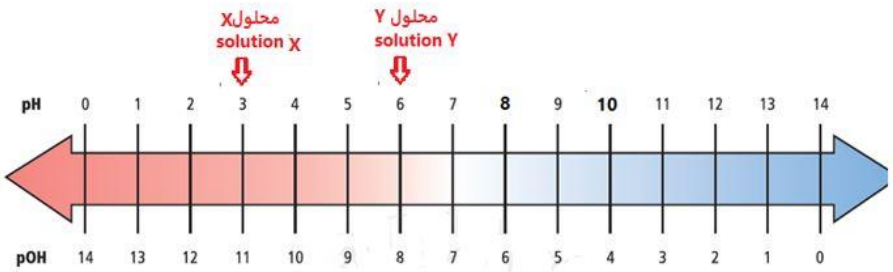
(X): $\mathbf{pOH = 9.5}$

(Y): $\mathbf{[H^+] = 10^{-9}}$

(Z): $\mathbf{[OH^-] = 10^{-6}}$

A. (lowest) $(Y) \rightarrow (X) \rightarrow (Z)$ (highest)	**A.** (الأقل) $(Z) \leftarrow (X) \leftarrow (Y)$ (الأكبر)
B. (lowest $(X) \rightarrow (Y) \rightarrow (Z)$ (highest)	**B.** (الأقل) $(Z) \leftarrow (Y) \leftarrow (X)$ (الأكبر)
C. (lowest) $(Z) \rightarrow (X) \rightarrow (Y)$ (highest)	**C.** (الأقل) $(Y) \leftarrow (X) \leftarrow (Z)$ (الأكبر)
D. (lowest) $(X) \rightarrow (Z) \rightarrow (Y)$ (highest)	**D.** (الأقل) $(Y) \leftarrow (Z) \leftarrow (X)$ (الأكبر)

How many times increases the concentration of hydrogen ions $[H^+]$ in the solution X than in the solution Y according to the figure below?	كم مرّة يزيد تركيز أيون الهيدروجين $[H^+]$ في المحلول X عن المحلول Y حسب الرسم أدناه؟



A. 2 times	**A. 2 (مرّتان)**
B. 10 times	**B. 10 مرّات**
C. 100 times	**C. 100 مرّة**
D. 1000 times	**D. 1000 مرّة**

Which of the following aqueous solutions is acidic?

(Concentrations at 298 K)

أي المحاليل المائية التالية حمضي ؟

(التراكيز عند 298 K)

D المحلول Solution D	C المحلول Solution C	B المحلول Solution B	A المحلول Solution A
$[H^+] = 4.0 \times 10^{-4}$	$[OH^-] = 1.0 \times 10^{-7}$	$[OH^-] = 1.0 \times 10^{-3}$	$[H^+] = 1.0 \times 10^{-13}$

Solution A	المحلول A
Solution B	المحلول B
Solution D	المحلول D
Solution C	المحلول C

What is the correct ascending order according to the **pH** value for each of the following solutions?

ما الترتيب التصاعدي الصحيح حسب قيمة **pH** لكل من المحاليل التالية ؟

الأمونيا المنزلية Household ammonia	عصير الليمون Lemon juice	حليب المغنيسيا Milk of magnesia	الحليب Milk
pOH= 2.10	**pH= 2.37**	$[OH^-]= 3.2\times 10^{-4}$	$[H^+]= 3.2\times 10^{-7}$

- Milk of magnesia → milk → lemon juice → household ammonia — حليب المغنيسيا ← الحليب ← عصير الليمون ← الأمونيا المنزلية
- Milk → household ammonia → lemon juice → milk of magnesia — الحليب ← الأمونيا المنزلية ← عصير الليمون ← حليب المغنيسيا
- Household ammonia → lemon juice → milk → milk of magnesia — الأمونيا المنزلية ← عصير الليمون ← الحليب ← حليب المغنيسيا
- Lemon juice → milk → milk of magnesia → household ammonia — عصير الليمون ← الحليب ← حليب المغنيسيا ← الأمونيا المنزلية

What is the value of K_a of 0.0400 M solution of acid $HClO_2$ with pH=1.80?

ما قيمة K_a لمحلول حمض $HClO_2$ تركيزه 0.0400 M و pH=1.80؟

- 4.9×10^{-9}
- 5.8×10^{-3}
- 1.0×10^{-2}
- 2.6×10^{-4}

What is the value of K_a of 0.0044 M solution of acid C_6H_5COOH with pH=3.30?

ما قيمة K_a لمحلول حمض C_6H_5COOH تركيزه 0.0044 M و pH=3.30؟

- 3.8×10^{-2} ○
- 2.6×10^{-4} ○
- 6.5×10^{-5} ○
- 4.9×10^{-9} ○

What is the correct ascending order according to the $[OH^-]$ value for each of the following solutions?

ما الترتيب التصاعدي الصحيح حسب قيمة $[OH^-]$ لكل من المحاليل التالية ؟

المحلول A Solution A	المحلول B Solution B	المحلول C Solution C	المحلول D Solution D
pOH= 5.60	pH= 7.40	$[OH^-]= 4.0\times 10^{-3}$M	$[H^+]= 2.5\times 10^{-2}$M

Solution **D** → solution **B** → solution **A** → solution **C** — المحلول ***D*** ← المحلول ***B*** ← المحلول ***A*** ← المحلول ***C***

Solution **B** → solution **C** → solution **D** → solution **A** — المحلول ***B*** ← المحلول ***C*** ← المحلول ***D*** ← المحلول ***A***

Solution **C** → solution **A** → solution **B** → solution **D** — المحلول ***C*** ← المحلول ***A*** ← المحلول ***B*** ← المحلول ***D***

Solution **A** → solution **B** → solution **C** → solution **D** — المحلول ***A*** ← المحلول ***B*** ← المحلول ***C*** ← المحلول ***D***

Which of the following solutions is basic?

(Concentrations at 298 K)

أي المحاليل التالية قاعدي؟

(التراكيز عند 298 K)

فنجان قهوة Coffee cup	ماء نقي Pure water	ماء البحر Seawater	عصير الليمون Lemon juice
$[H^+]= 1.0\times 10^{-5}$	$[OH^-]= 1.0\times 10^{-7}$	$[OH^-]= 1.0\times 10^{-6}$	$[H^+]= 6.0\times 10^{-3}$

Pure water — ماء نقي

Lemon juice — عصير الليمون

Seawater — ماء البحر

Coffee cup — فنجان قهوة