Simple Step-by-Step Guides to Solving Chemistry Problems

Strong Acids & Bases

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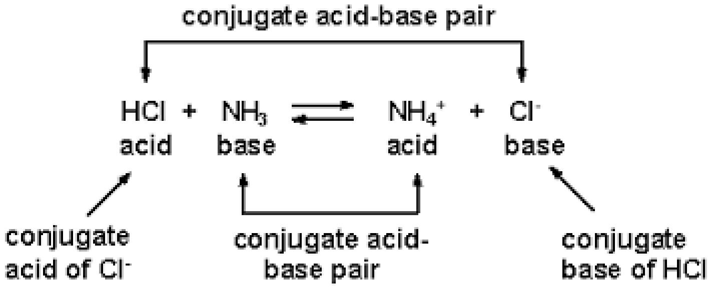
Strong Acids & Bases

- **Calculate pH of strong acids from hydrogen ion concentrations**
- **Calculate pH of strong bases from hydroxide ion concentrations**
- **Calculate Hydrogen and Hydroxide ion concentrations from pH**

Acids and bases can be defined in many ways. The simplest definition, developed by Svante Arrhenius in the 1880s, simply states that acids produce hydrogen ions (H+) in water, whilst bases produce hydroxide ions (OH-) – **Arrhenius Water theory**. To allow insoluble substances to be classified as acids and bases, the **Bronsted Lowry theory** (1923) defines an acid as a proton donor and a base as a proton acceptor. The chemical species formed by the acceptance of a proton (H+) is known as a **conjugate acid**. On the other hand, a **conjungate base** is the chemical species left over after the acid has donated a proton.



The number of substances classified as acids and bases was further expanded by the **Lewis theory** in the 1930s. This theory defines acids as electron pair acceptors and bases as electron pair donors. It is worth noting that all substances classified as acids and bases under the Arrhenius theory are also acids and bases in both the Lowry Bronsted and Lewis theories.

pH – power of Hydrogen

Acidity and basicity are measured by the pH (**p**otential of **H**ydrogen) scale. The pH scale ranges from 0 to 14. Acids have a pH of less than 7 whilst bases have a pH value of greater than 7. Water at pH is neutral, being neither acidic or basic. More precisely, pH is the negative logarithm of the hydrogen ion concentration:

$$\mathbf{pH = -\log [H^+]}$$

$$\mathbf{[H^+] = 10^{-pH}}$$

Square brackets denote concentration to a chemist. The fact that the pH scale is logarithmic means that for each change in pH unit the concentration of H^+ ions changes 10-fold. For instance, an acid with a pH of 1 has a hydrogen ion concentration of 0.1M, whilst a solution of pH 2 has a hydrogen ion concentration of 0.01M.

pOH is the logarithmic expression of hydroxide ion concentration.

$$\mathbf{pOH^- = -log\ [OH^-]}$$
$$\mathbf{[OH^-] = 10^{-pOH}}$$

For a given solution at 25oC,

$$\mathbf{pH + pOH = 14}$$
$$\mathbf{[H^+]\ [OH^-] = 1 \times 10^{-14}}$$

Strong Acids and Bases

Strong acids, HyA and strong bases, B(OH)n totally dissociate (ionise) in water:

Strong acid: $H_yA + yH_2O \rightarrow A^-_{(aq)} + yH_3O^+_{(aq)}$

Strong base: $B(OH)_n + H_2O \rightarrow B^{n+}_{(aq)} + nOH^-_{(aq)}$

This allows the concentration of H^+ and OH^- to be determined from the concentrations of the strong acid and strong base. ie

Strong acid: $[H^+] = y \times [H_yX]$

$pH = -\log \{y \times [H_yX]\}$

Strong base: $[OH^-] = n \times [B(OH)_n]$

$pOH = -\log \{ n \times [B(OH)_n] \}$

$pH = 14 - pOH$

Calculate pH of strong acids from hydrogen ion concentrations

Essential equation: $pH^- = -\log [H^+]$

Step 1: write a balanced equation for the complete dissociation of the acid, i.e.

$$H_yA \rightarrow A^-_{(aq)} + yH^+_{(aq)}$$

Step 2: determine the concentration of H+ ion ie, $[H^+] = y \times [H_yA]$

Step 3: calculate pH using pH = $-\log_{10}\{y \times [H^+]\}$

Example: Calculate the pH of a 0.01 M solution of nitric acid, HNO_3.

Step 1: $HNO_{3(aq)} \longrightarrow H^+_{(aq)} + NO_3^-{}_{(aq)}$

Step 2: $[H^+] = 1 \times 0.01 = 0.01M$

Step 3: pH = -log [0.01] = 2

Casio calculator 'button sequence':

+/-	log	0	.	0	1	=

Answer: **2**

Calculate pH of strong bases from hydroxide ion concentrations

Essential equations:

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

$$pOH = 14 - pH$$

Step 1: write a balanced equation showing the complete dissociation of the base, ie

$$B(OH)_{n\,(aq)} + H_2O_{(l)} \rightarrow B^+_{(aq)} + nOH^-_{(aq)}$$

Step 2: determine the concentration of OH- ion ie, n x concentration of base.

Step 3: calculate pOH using pOH = $-\log_{10}\{n \times [OH^-]\}$

Step 4: pH = 14 - pOH

Example: Calculate the pH of a 0.3 M solution of $Ca(OH)_2$

Step 1: $Ca(OH)_{2\,(aq)} + H_2O \rightarrow Ca^{2+}_{(aq)} + 2OH^-_{(aq)}$

Step 2: $[OH^-] = 2 \times 0.3 = 0.6M$

Step 3: pOH = -log [0.6] = 0.22

Casio calculator 'button sequence':

| +/- | log | 0 | . | 0 | 6 | = |

Step 4: pH = 14 -0.22 = 13.78

Answer: **13.78**

Calculate Hydrogen Ion Concentration and from pH

Essential equation:

$$[H^+] = 10^{-pH}$$

Example: Calculate the hydrogen ion concentration of a solution with a pH of 4.2

$[H+] = 10^{-pH}$

$= 10^{-4.2}$

$= 6.3 \times 10^{-5}$ M

Casio calculator 'button sequence':

| SHIFT | Log | +/- | 4 | . | 2 | = |

Answer: **6.3×10^{-5} M**

Calculate hydroxide ion concentration from pH

Essential equations:

$$pOH = 14 - pH$$

$$[OH^-] = 10^{-pOH}$$

Step 1: Convert pH to pOH using pOH = 14 – pH

Step 2: Calculate hydroxide ion concentration using $[OH^-] = 10^{-pH}$

Example: Calculate the hydrogen ion concentration of a solution with a pH of 6.7

Step 1: pOH = 14 – pH
= 14 – 6.7
= 7.3

Step 2: $[OH-] = 10^{-pOH}$
$= 10^{-7.3}$
$= 5.01 \times 10^{-8}$

Casio calculator 'button sequence'

SHIFT | Log | +/- | 7 | . | 3 | =

Answer: **5.01×10^{-8}**

Practice Problems

1. Determine the pH of the following solutions:
   a. 0.02 M HCl
   b. 0.25 M H_2SO_4
   c. 0.010 M NaOH
   d. 0.0035 M HCl
   e. 1.0 M HNO_3
   f. 1.0 M KOH
   g. 2.3×10^{-5} M HCl
   h. 0.003 M H_3PO_4
   i. 1.67×10^{-4} M $Ca(OH)_2$

2. What is the [H+] and [OH-] concentrations of the solutions with the following pH values ?
   a. 1
   b. 7
   c. 9
   d. 3.4
   e. 7.8
   f. 11.3

3. Complete the following table

$[H_3O^+]$	$[OH^-]$	pH	pOH	Acidic/Basic?
1.0×10^{-9} M				
	4.1×10^{-2} M			

		3.75		
			5.45	

4. An unknown substance is dissolved in water to a concentration of 8.90×10^{-3} M. If this solution has a pH of 2.97, decide whether the substance is an acid or a base, and whether it is weak or strong.

5. An unknown substance is dissolved in water to a concentration of 4.5×10^{-4} M. If this solution has a pH of 10.9, decide whether the substance is an acid or a base, and whether it is weak or strong.

6. Consider the mixing of the two solutions below:

   - 35.91 mL of 0.4891 M NaOH
   - 28.75 mL of 0.4114 M HCl

   Identify which reagent is in excess, and use this to calculate the final pH of the mixture after the two solutions have been fully reacted.

7. 2.63 g NaOH are dissolved in 156 cm^3 of solution. Determine the NaOH concentration and pH of the resulting solution.

8. What is the pH of a solution made by dissolving 1.21g calcium oxide to a total volume of 2.00 L?

9. At 298 K, 25.0 cm^3 of a solution of a strong acid contained 1.50×10^{-3} M of hydrogen ions.
   i) Calculate the hydrogen ion concentration in this solution and hence its pH.
   ii) Calculate the pH of the solution formed after the addition of 50.0 cm^3 of 0.150 M NaOH to the original 25.0 cm^3 of acid.

10. A 25.0 cm^3 sample of 0.25 M nitric acid solution is titrated with 0.10 M sodium hydroxide. Calculate the pH of the solution After the addition of 62.5 cm^3 sodium hydroxide.

Answers are given on the following page.

Practice Problem Answers

1. Determine the pH of the following solutions:

a. 0.02 M HCl 1.7
b. 0.25 M H_2SO_4 0.30
c. 0.010 M NaOH 12
d. 0.0035 M HCl 2.46
e. 1.0 M HNO_3 0
f. 1.0 M KOH 14
g. 2.3×10^{-5} M HCl 4.6
h. 0.003 M H_3PO_4 2.046
i. 1.67×10^{-4} M $Ca(OH)_2$ 10.52

2. What is the [H+] and [OH-] concentrations of the solutions with the following pH values?

a. 1 $10^{-1} = 0.1$
b. 7 1×10^{-7}
c. 9 1×10^{-9}
d. 3.4 $10^{-3.4} = 3.98 \times 10^{-4}$
e. 7.8 $10^{-7.8} = 1.58 \times 10^{-8}$
f. 11.3 5.01×10^{-12}

3. Complete the following table

$[H_3O^+]$	$[OH^-]$	pH	pOH	Acidic/Basic?
1.0×10^{-9} M	1×10^{-5} M	9	5	Basic
2.4×10^{-13} M	4.1×10^{-2} M	12.6	1.4	Basic
1.78×10^{-4} M	5.6×10^{-11} M	3.75	10.25	Acidic
2.82×10^{-9} M	3.55×10^{-6} M	8.55	5.45	Basic

4. An unknown substance is dissolved in water to a concentration of 8.90×10^{-3} M. If this solution has a pH of 2.97, decide whether the substance is an acid or a base, and whether it is weak or strong.

Answer:
Since pH is less than 7, the unknown substance must be an acid
Strong acids totally dissociate: PH = -log $[8.9 \times 10^{-3}]$ = 2.05
Since actual acid has a Ph of 2.97, it must be weak.

5. An unknown substance is dissolved in water to a concentration of 4.5×10^{-4} M. If this solution has a pH of 10.65, decide whether the substance is an acid or a base, and whether it is weak or strong.

Answer:
Since pH is greater than 7, the unknown substance must be a base
Strong bases totally dissociate: pOH = -log $[4.5 \times 10^{-4}]$ = 3.35: pH = 14 – 3.35 = 10.65
Since actual acid has a pH of 2.97, it must be weak.

6. Consider the mixing of the two solutions below:

- 35.91 mL of 0.4891 M NaOH

- 28.75 mL of 0.4114 M HCl

Identify which reagent is in excess, and use this to calculate the final pH of the mixture after the two solutions have been fully reacted.

Answer:
Number of moles of NaOH = 35.91/1000 x 0.4891 = 0.0176
Number of moles of HCl = 28.75/1000 x 0.4114 = 0.0118
The base (NaOH) is in excess.
$[OH^-]$ concentration at the end of the reaction = 0.0176 – 0.0118 = 5.8 x10^{-3}
pOH = - log [OH-] = -log [5 x 10^{-3}] = 2.3
pH = 14 – pOH = 14 – 2.3 = 11.7

7. 2.63 g NaOH are dissolved in 156 cm^3 of solution. Determine the NaOH concentration and pH of the resulting solution.

Answer:
RFM [NaOH] = 40 g/mol
Number of moles in 2.63 g of NaOH = 2.63/40 = 0.0658
Therefore, 156 cm^3 contains 0.0658 moles
Concentration of NaOH solution = 1000/156 x 0.0658 = 0.4215
pOH = -log [0.4215] = 0.375
pH = 14 – 0.375 = 13.625

8. What is the pH of a solution made by dissolving 1.21g calcium oxide to a total volume of 2.00 L?

Answer:
RFM [CaO] = 56 g/mol
Number of moles in 1.21 g of CaO = 1.21/56 = 0.0216
Therefore, 2L contains 0.0216 moles
Concentration of CaO solution = 0.0216/2 = 0.0108
CaO dissolves in water to form $Ca(OH)_2$
pOH = -log [0.0108 x 2] = 1.67
pH = 14 – 1.67 = 12.44

9. At 298 K, 25.0 cm^3 of a solution of a strong acid contained 1.50 × 10^{-3} mol of hydrogen ions.
i) Calculate the hydrogen ion concentration in this solution and hence its pH.
ii) Calculate the pH of the solution formed after the addition of 50.0 cm^3 of 0.150 M NaOH to the original 25.0 cm^3 of acid.

Answer:
i) pH = -log [1.5 x 10^{-3}] = 2.82
ii) Number of moles in 50 cm^3 of 0.15M NaOH = 50/1000 x 0.15 = 7.5 x 10^{-3}
Number of moles OH^- remaining after addition to strong acid = 7.5 x 10^{-3} – 1.5 x 10^{-3} = 6 x 10^{-3}
pOH = -log [6 x 10^{-3}] = 2.22
pH = 14 – 2.22 = 11.78

10. A 25.0 cm^3 sample of 0.25 M nitric acid solution is titrated with 0.10 M sodium hydroxide. Calculate the pH of the solution After the addition of 62.5 cm^3 sodium hydroxide

Answer:

$NaOH + HNO_3 \rightarrow NaNO_3 + H_2O$
NaOH reacts with HNO_3 in 1:1 molar ratio:
Number of moles HNO_3 in 25.0cm^3 of 0.25M solution = 25/1000 x 0.25 = 0.00625
Number of moles NaOH in 62.5cm^3 of 0.1M solution = 62.5 /1000 x 0.1 = 0.00625
You have the same molar quantity of NaOH and HNO_3. When mixed you will have a solution of neutral $NaNO_3$ and no excess HNO3 or NaOH, strong acid and strong base.
The solution will be neutral - pH = 7.0