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Chemistry
Teach Yourself Series
Topic 1: pH (Unit 2)

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Contents

Acids and bases

As it appears in Unit 2

Substances can be classified as **acids**, **bases** or neither (**neutral**). They can be classified by testing their properties or studying their chemical formula.

Properties

Properties of acids	**Properties of bases**
Turn blue litmus red Sour taste Can react with metals to produce hydrogen (not all) Can neutralize bases	Turn red litmus blue Soapy feel Can neutralize acids

Examples

Acids	**Neutral**	**Basic (or alkaline)**
HCl H_2SO_4 HNO_3 CH_3COOH	Hexane C_6H_{14} Ethanol C_2H_5OH	NaOH LiOH $Ca(OH)_2$ NH_3

The examples above show the definition of an acid or base is not as simple as the presence or absence of hydrogen atoms or OH groups.

Characteristic reactions of acids

Many of the reactions of acids follow general rules;

1. acid + metal → salt + hydrogen gas
   $2HCl(aq) + Zn(s) \rightarrow ZnCl_2(aq) + H_2(g)$

2. acid + carbonate → salt + carbon dioxide + water
   $2HCl(aq) + CaCO_3(s) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$

3. acid + base → salt + water
   $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$

Review Questions

1. Write a balanced equation for each of the following reactions.

a. nitric acid + magnesium

_____

b. sulfuric acid + magnesium carbonate

_____

c. nitric acid + lithium hydroxide

_____

2. Classify the following as acids or bases or neutral.

HF ___ $Mg(OH)_2$ ____ HBr ____ C_2H_6 _____ KOH _____

Ionic equations

Ionic equations can be used to provide **more detail** about the reactions occurring. **Spectator ions** are **omitted**.

Examples: Write ionic equations for the following reactions:

1. zinc metal in nitric acid.
   zinc nitrate and hydrogen gas are formed *work out the products*
   $Zn(s) + 2H^+(aq) + 2NO_3^-(aq) \rightarrow Zn^{2+}(aq) + 2NO_3^-(aq) + H_2(g)$ *include all ions*
   $Zn(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$ *delete spectator ions*

2. hydrochloric acid and lithium hydroxide solutions
   lithium chloride and water
   $H^+(aq) + Cl^-(aq) + Li^+(aq) + OH^-(aq) \rightarrow Li^+(aq) + Cl^-(aq) + H_2O(l)$
   $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

3. calcium carbonate added to nitric acid
   calcium nitrate and carbon dioxide and water
   $CaCO_3(s) + 2H^+(aq) + 2NO_3^-(aq) \rightarrow Ca^{2+}(aq) + 2NO_3^-(aq) + CO_2(g) + H_2O(l)$
   $CaCO_3(s) + 2H^+(aq) \rightarrow Ca^{2+}(aq) + CO_2(g) + H_2O(l)$

Review Question

3. Write ionic equations for each of the following;

a. hydrochloric acid and iron

_____

b. sulfuric acid and potassium hydroxide

_____

c. hydrochloric acid and sodium carbonate solid

_____

Acid definition:

A substance that can donate a proton (H^+)

Examples

$HCl(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$

(H^+)

$HNO_3(aq) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$

HCl acts as an acid because it donates an H^+ to water. Water is now H_3O^+, known as a hydronium ion. A chloride ion is also formed.

Hexane is not acidic as it does not donate any of its hydrogen atoms.

Base definition:

A substance that can accept a proton (H^+)

Examples

$NH_3(aq) + H_2O(l) \rightleftarrows NH_4^+(aq) + OH^-(aq)$

(H^+)

$HCO_3^-(aq) + H_2O(l) \rightleftarrows H_2CO_3(aq) + OH^-(aq)$

Ammonia, NH_3, acts as a base when it accepts a proton to form NH_4^+.

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Solutions to Review Questions

1.

a. $2HNO_3(aq) + Mg(s) \rightarrow Mg(NO_3)_2(aq) + H_2(g)$

b. $H_2SO_4(aq) + MgCO_3(s) \rightarrow MgSO_4(aq) + CO_2(g) + H_2O(l)$

c. $HNO_3(aq) + LiOH(aq) \rightarrow LiNO_3(aq) + H_2O(l)$

2. Classify the following as acids or bases or neutral.
HF acid $Mg(OH)_2$ base HBr acid C_2H_6 neutral KOH base

3. **a**. $2H^+(aq) + Fe(s) \rightarrow Fe^{2+}(aq) + H_2(g)$

b. $2H^+(aq) + 2OH^-(aq) \rightarrow 2H_2O(l)$

c. $Na_2CO_3(s) + 2H^+(aq) \rightarrow 2Na^+(aq) + CO_2(g) + H_2O(l)$

4.

a. HBr(aq): acid $H_2O(l)$: base

b. $CH_3COO^-(aq)$: base $H_2O(l)$: acid

5.

a. $HPO_4^{2-}(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + PO_4^{3-}(aq)$

b. $HSO_4^-(aq) + H_2O(l) \rightleftarrows H_2SO_4(aq) + OH^-(aq)$

6.

a. HI / I^- **b**. $H_2PO_4^-$ / HPO_4^{2-} **c**. NH_4^+ / NH_3

7.

a. HS^- / H_2S **b**. $H_2PO_4^-$ / H_3PO_4 **c**. NH_3 / NH_4^+

8. $HI(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + I^-(aq)$

9. Step 1: $H_3PO_4(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + H_2PO_4^-(aq)$

Step 2: $H_2PO_4^-(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + HPO_4^{2-}(aq)$

Step 3: $HPO_4^{2-}(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + PO_4^{3-}(aq)$

Overall: $H_3PO_4(aq) + 3H_2O(l) \rightleftarrows 3H_3O^+(aq) + PO_4^{3-}(aq)$

10. $NH_3(aq) + H_2O(l) \rightleftarrows NH_4^+(aq) + OH^-(aq)$ *water acting as an acid*

$NH_4^+(aq) + H_2O(l) \rightleftarrows NH_3(aq) + H_3O^+(aq)$ *water acting as a base*

11. $CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(l)$

12.

a. $pH = -\log_{10}(1.0) = 0$

b. $pH = -\log_{10}(0.10) = 1$

c. $pH = -\log_{10}(0.00001) = 5$

13.

concentration M	**pH**
1.0	0
0.10	1
0.001	3
0.10	1
0.0001	4
0.000001	6

14.

a. $[H_3O^+] = 10^{-1} = 0.1$ M

b. $[H_3O^+] = 10^{-5} = 0.00001$ M

15.

a. $[H_3O^+][OH^-] = 10^{-14}$

$[OH^-] = 0.001 = 10^{-3}$

$\Rightarrow [H_3O^+] \times 10^{-3} = 10^{-14}$

$\Rightarrow [H_3O^+] = \frac{10^{-14}}{10^{-3}} = 10^{-11}$ $\Rightarrow pH = -\log(10^{-11}) = 11$

b. $[H_3O^+][OH^-] = 10^{-14}$

$[OH^-] = 0.01 \times 2 = 0.02$

$\Rightarrow [H_3O^+] \times 0.02 = 10^{-14}$

$\Rightarrow [H_3O^+] = \frac{10^{-14}}{0.02} = 5x10^{-13}$ $\Rightarrow pH = -\log(5 \times 10^{-13}) = 12.3$

16. **a**. Dilution factor of 100 => pH rises by 2 to 4.

b. Dilution factor of 10 => pH drops by 1 to 11.