Chapter 14

Properties of Acids and Bases

Note to teacher: You will notice that there are two different formats for the Sample Problems in the student textbook. Where appropriate, the Sample Problem contains the full set of steps: Problem, What Is Required, What Is Given, Plan Your Strategy, Act on Your Strategy, and Check Your Solution. Where a shorter solution is appropriate, the Sample Problem contains only two steps: Problem and Solution. Where relevant, a Check Your Solution step is also included in the shorter Sample Problems.

Solutions for Practice Problems

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1. Problem

When perchloric acid dissolves in water, the following reaction occurs:

$HClO_{3(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + ClO_4^-{}_{(aq)}$

Identify the conjugate acid-base pairs.

What is Required?

You must identify the conjugate acid-base pairs.

What is Given?

The chemical equation is given.

Plan Your Strategy

Identify the proton donor on the left side of the equation as the acid and the proton receiver on the left side as the base. Identify the conjugate acid and base on the right side of the equation by the difference of a single proton from the acid and base on the left side

Act on Your Strategy

The conjugate acid-base pairs are $HClO_{3(aq)}/ClO_4^-{}_{(aq)}$ and $H_2O_{(l)}/H_3O^+_{(aq)}$

Check Your Answer

The acid-base pairs differ by one proton as expected.

2. Problem

Sodium acetate is a good electrolyte. In water, the acetate ion reacts as follows:

$$CH_3COO^-_{(aq)} + H_2O_{(l)} \rightarrow CH_3COOH_{(aq)} + OH^-_{(aq)}$$

Identify the conjugate acid-base pairs.

What Is Required?

You have to identify the conjugate acid-base pairs in the sodium acetate reaction.

What Is Given?

The balanced chemical equation is given.

Plan Your Strategy

Step 1 Identify the proton donor on the left side of the equation. This is the acid. The other reactant is the proton receiver, which is the base.

Step 2 Identify the proton receiver as a product on the right side of the equation. It has the same basic formula as the base, plus one extra proton. This is the conjugate acid of the base reactant.

Step 3 The other product is, by default, the conjugate base of the acid reactant. It has one less proton than the acid reactant.

Act on Your Strategy

Conjugate Acid-Base Pairs:

$CH_3COOH_{(aq)} / CH_3COO^-_{(aq)}$

$H_3O^+_{(aq)} / H_2O_{(l)}$

Check Your Solution

The formulas of the conjugate acid-base pairs differ by only one proton, as expected.

3. Problem

Name and write the formula of the conjugate base of each molecule or ion.

(a) HCl

(b) HCO_3^-

(c) H_2SO_4

(d) $N_2H_5^+$

Solution

A conjugate base differs from the molecule or ion by having one less proton.

(a) chloride ion, Cl^-

(b) carbonate ion, CO_3^{2-}

(c) hydrogen sulfate ion, HSO_4^-

(d) hydrazine, N_2H_4

Check Your Solution

In each case, the conjugate base has one less proton than its acid.

4. Problem

Name and write the formula of the conjugate acid of each molecule or ion.

(a) NO_3^-

(b) OH^-

(c) H_2O

(d) HCO_3^-

Solution

A conjugate acid differs from the molecule or ion by having one more proton.

(a) nitric acid, HNO_3

(b) water, H_2O

(c) hydronium ion, H_3O^+

(d) carbonic acid, H_2CO_3

Check Your Solution

In each case, the conjugate acid has one more proton than its base.

Solutions for Practice Problems

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5. Problem

Write equations to show how the hydrogen sulfide ion, HS^-, can be classified as amphoteric. First show the ion acting as an acid, then show the ion acting as a base.

What Is Required?
You have to write balanced equations for the reaction of the hydrogen sulfide ion with water.

What Is Given?
The reactants are HS^- and H_2O. HS^- can be both an acid and a base.

Plan Your Strategy
HS^- as a base: The water is, by default, the acid.
Step 1 Write the formula for the conjugate acid. This will be the same formula as the base HS ion, plus one proton, making it H_2S.
Step 2 Write the formula for the conjugate base. This will be the same formula as the acid H_2O, minus one proton, making it the negative OH^- ion.
Step 3 Identify the states of the reactants and products. Water is liquid and the HS ion is aqueous. The products will be aqueous too.
Step 4 Put the equation together and check that the number of atoms on the left equal the atoms on the right.
HS^- as an acid: The water is, by default, the base.
Step 1 Write the formula for the conjugate base. This will be the same formula as the acid HS ion, minus one proton, making it S^{2-}.
Step 2 Write the formula for the conjugate acid. This will be the same formula as the base H_2O, plus one proton, making it the positive H_3O^+ ion.
Repeat Steps 3 and 4 above.

Act on Your Strategy
As a base: $HS^-_{(aq)} + H_2O_{(l)} \rightarrow H_2S_{(aq)} + OH^-_{(aq)}$
As an acid: $HS^-_{(aq)} + H_2O_{(l)} \rightarrow S^{2-}_{(aq)} + H_3O^+_{(aq)}$

Check Your Solution
The formulas of the conjugate acid-base pairs differ by only one proton, as expected. The number of H, S, and O atoms on the left equal their numbers on the right.

6. Problem
Identify the conjugate acid-base pairs in each reaction.
(a) $H_3PO_{4(aq)} + H_2O_{(l)} \rightleftharpoons H_2PO_4^-{}_{(aq)} + H_3O^+_{(aq)}$
(b) $O^{2-}_{(aq)} + H_2O_{(l)} \rightarrow 2OH^-_{(aq)}$

Solution
On the left side of the equation, the acid is the molecule or ion that donates a proton. The base is the molecule or ion that accepts the proton. On the right side of the equation, you can identify the conjugate acid and base by the difference of a single proton from the base and acid on the left side.
(a) base conjugate acid
$H_2O_{(l)} + H_3PO_{4(l)} \rightleftharpoons H_3O^+_{(aq)} + H_2PO_4^-{}_{(aq)}$
acid conjugate base
The conjugate acid-base pairs are HS^-/H_2S and H_2O/OH^-.

(b) base conjugate acid
$O^{2-}_{(aq)} + H_2O_{(l)} \rightleftharpoons 2OH^-_{(aq)}$
acid conjugate base
The conjugate acid-base pairs are O^{2-}/OH^- and H_2O/OH^-.

Check Your Solution
The conjugate acid-base pairs differ by one proton. The acid has one more proton than its conjugate base.

7. Problem
For each reaction in question 6, identify the amphoteric chemical species, and identify as either an acid or a base.

Solution
An amphoteric species is a substance that can act as an acid in one reaction and as a base in a different reaction.
In 6(a) $H_2O_{(l)}$ is acting as a proton receiver or a base and in 6(b) $H_2O_{(l)}$ is acting as a proton donor or an acid. Therefore, $H_2O_{(l)}$ is amphoteric.

8. Problem
Identify the acid-base pair in each reaction.
(a) $NH_{3(aq)} + H_2O_{(l)} \rightarrow NH_4^+{}_{(aq)} + OH^-_{(aq)}$
(b) $CH_3COOH_{(aq)} + H_2O_{(l)} \rightarrow CH_3COO^-_{(aq)} + H_3O^+_{(aq)}$

Solution
The species on the left side of the equation that donates a proton is the acid and the receiver of this proton is a base. The conjugate acid and base on the right will differ by one proton from the acid and base on the left side.
(a) The acid-base pairs are $H_2O_{(l)}/OH^-_{(aq)}$ and $NH_4^+{}_{(aq)}/NH_{3(aq)}$
(b) CH_3COOH/CH_3COO^-; H_2O/H_3O^+

Check Your Solution
The acid-base pairs differ by one proton.

9. Problem
For each reaction in question 8, identify the amphoteric chemical species, and identify its role as either an acid or a base.

Solution
An amphoteric species is a substance that can act as an acid in one reaction and as a base in a different reaction.
In 8(a) $H_2O_{(l)}$ is acting as a proton donor and is an acid and in 8(b) $H_2O_{(l)}$ is acting as a proton receiver and is a base.

Solutions for Practice Problems

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10. Problem
Predict the direction for the following equations. State whether reactants or products are favoured, and give reasons to support your decision.
(a) $NH_4^+{}_{(aq)} + H_2PO_4^-{}_{(aq)} \rightarrow NH_{3(aq)} + H_3PO_{4(aq)}$
(b) $H_2O_{(l)} + HS^-_{(aq)} \rightarrow OH^-_{(aq)} + H_2S_{(aq)}$
(c) $HF_{(aq)} + SO_4^{2-}{}_{(aq)} \rightarrow F^-_{(aq)} + HSO_4^-{}_{(aq)}$

Solution
Using Figure 14.12, identify the weaker acid and the weaker base. The reaction will proceed towards the formation of these two species.
(a) $H_2PO_4^-{}_{(aq)}$ is a weaker base than $NH_{3(aq)}$ and $NH_4^+{}_{(aq)}$ is a weaker acid than $H_3PO_{4(aq)}$.
This reaction proceeds to the left or reactants are favoured..
(b) $HS^-_{(aq)}$ is a weaker base than $OH^-_{(aq)}$ and $H_2O_{(l)}$ is a weaker acid than $H_2S_{(aq)}$
The reaction will proceed to the left or reactants are favoured.
(c) $SO_4^{2-}{}_{(aq)}$ is a weaker base than $F^-_{(aq)}$ and $HF_{(aq)}$ is as weaker acid than $HSO_4^-{}_{(aq)}$.
The reaction proceeds to the left or reactants are favoured.

11. Problem

In which direction will the following reactions proceed? Explain why in each case.

(a) $H_2PO_4^-{}_{(aq)} + NH_4^+{}_{(aq)} \rightarrow H_3PO_{4(aq)} + NH_{3(aq)}$

(b) $H_2SO_{4(aq)} + H_2O_{(l)} \rightarrow HSO_4^-{}_{(aq)} + H_3O^+{}_{(aq)}$

(c) $H_2S_{(aq)} + NH_{3(aq)} \rightarrow HS^-{}_{(aq)} + NH_4^+{}_{(aq)}$

Solution

Using Figure 14.12, identify the weaker acid and the weaker base. The reaction will proceed towards the formation of these two species.

(a) $H_3PO_4{}_{(aq)}$ is a weaker base than $NH_{3(aq)}$ and $NH_4^+{}_{(aq)}$ is a weaker acid than $H_3PO_{4(aq)}$.
This reaction proceeds to the left or reactants are favoured..

(b) $H_3O^+{}_{(aq)}$ is a weaker acid than $H_2SO_{4(aq)}$ and $HSO_4^-{}_{(aq)}$ is a weaker base than $H_2O_{(l)}$. The reaction will proceed to the right or products are favoured.

(c) $HS^-{}_{(aq)}$ is a weaker base than $NH_{3(aq)}$ and $NH_4^+{}_{(aq)}$ is as weaker acid than $H_2S_{(aq)}$.
The reaction proceeds to the right or products are favoured.

Solutions for Practice Problems

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12. Problem

Determine $[H_3O^+]$ and $[OH^-]$ in each solution.

(a) 0.45 mol/L hydrochloric acid

(b) 1.1 mol/L sodium hydroxide

Solution

You know that hydrochloric acid is a strong acid and sodium hydroxide is a strong base. Since both dissociate completely in aqueous solutions, you can use their molar concentrations to determine $[H_3O^+]$ or $[OH^-]$. You can find the concentration of the other ion using K_w as shown below:

$K_w = 1.0 \times 10^{-14} = [H_3O^+][OH^-]$

(a) $[HCl] = 0.45$ mol/L, so $[H_3O^+] = 0.45$ mol/L

$$[OH^-] = \frac{1.0 \times 10^{-14}\ \text{mol/L}}{0.45}$$
$$= 2.2 \times 10^{-14}\ \text{mol/L}$$

(b) $[NaOH] = 1.1$ mol/L
Therefore, $[OH^-] = 1.1$ mol/L

$$[H_3O^+] = \frac{1.0 \times 10^{-14}\ \text{mol/L}}{1.1}$$
$$= 9.1 \times 10^{-15}\ \text{mol/L}$$

Check Your Solution

Solution (a) is a strong acid. Therefore, $[H_3O^+]$ should be greater than 1.0×10^{-7}, and $[OH^-]$ should be less than 1.0×10^{-7}. For a solution of a strong base, as in (b), $[OH^-]$ should be greater than 1.0×10^{-7}, and $[H_3O^+]$ should be less than 1.0×10^{-7}.

13. Problem

Determine $[H_3O^+]$ and $[OH^-]$ in each solution.

(a) 0.95 mol/L hydrobromic acid

(b) 0.012 mol/L calcium hydroxide