

# Properties of Acids and Bases

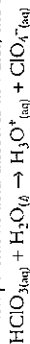
**Note to teacher:** You will notice that there are two different formats for the Sample Problems in the student textbook. Where appropriate, the Sample Problem contains the full set of steps: Problem, What Is Required, What Is Given, Plan Your Strategy, Act on Your Strategy, and Check Your Solution.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

Student Textbook page 557

### 1. Problem

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



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

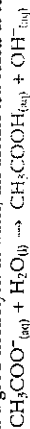
The conjugate acid-base pairs are  $\text{HClO}_4/\text{ClO}_4^-$  and  $\text{H}_2\text{O}/\text{H}_3\text{O}^+$ .

#### 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:



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:



#### Check Your Solution

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

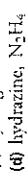
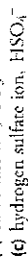
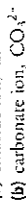
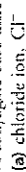
### 3. Problem

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



#### Solution

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



#### Check Your Solution

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

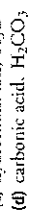
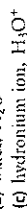
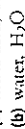
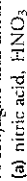
### 4. Problem

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



#### Solution

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



#### Check Your Solution

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

## Solutions for Practice Problems

Student Textbook pages 557-558

### 5. Problem

Write equations to show how the hydrogen sulfide ion,  $\text{HS}^-$ , 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  $\text{HS}^-$  and  $\text{H}_2\text{O}$ .  $\text{HS}^-$  can be both an acid and a base.

### Plan Your Strategy

$\text{HS}^-$  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  $\text{HS}^-$  ion, plus one proton, making it  $\text{H}_2\text{S}$ .

**Step 2** Write the formula for the conjugate base. This will be the same formula as the acid  $\text{H}_2\text{O}$ , minus one proton, making it the negative  $\text{OH}^-$  ion.

**Step 3** Identify the states of the reactants and products. Water is liquid and the  $\text{HS}^-$  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.

$\text{HS}^-$  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  $\text{HS}^-$  ion, minus one proton, making it  $\text{S}^{2-}$ .

**Step 2** Write the formula for the conjugate acid. This will be the same formula as the base  $\text{H}_2\text{O}$ , plus one proton, making it the positive  $\text{H}_3\text{O}^+$  ion.

**Repeat Steps 3 and 4 above.**

### Act on Your Strategy

As a base:  $\text{HS}^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{S}(\text{aq}) + \text{OH}^-(\text{aq})$

As an acid:  $\text{HS}^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{S}^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$

### 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)  $\text{H}_3\text{PO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{PO}_4^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$

(b)  $\text{O}^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2\text{OH}^-(\text{aq})$

### 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)  $\text{H}_2\text{O}(\text{l}) + \text{H}_3\text{PO}_4(\text{aq}) \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{H}_2\text{PO}_4^-(\text{aq})$   
conjugate acid      conjugate base  
base      acid

The conjugate acid-base pairs are  $\text{HS}^-/\text{H}_2\text{S}$  and  $\text{H}_2\text{O}/\text{OH}^-$ .

(b)  $\text{O}^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons 2\text{OH}^-(\text{aq})$   
conjugate acid      conjugate base  
acid      base

The conjugate acid-base pairs are  $\text{O}^{2-}/\text{OH}^-$  and  $\text{H}_2\text{O}/\text{OH}^-$ .

### 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)  $\text{H}_2\text{O}(\text{l})$  is acting as a proton receiver or a base and in 6(b)  $\text{H}_2\text{O}(\text{l})$  is acting as a proton donor or an acid. Therefore,  $\text{H}_2\text{O}(\text{l})$  is amphoteric.

### 8. Problem

Identify the acid-base pair in each reaction.

(a)  $\text{NH}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq})$

(b)  $\text{CH}_3\text{COOH}(\text{l}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{CH}_3\text{COO}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$

### 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  $\text{H}_2\text{O}(\text{l})/\text{OH}^-(\text{aq})$  and  $\text{NH}_3(\text{aq})/\text{NH}_4^+(\text{aq})$

(b)  $\text{CH}_3\text{COOH}/\text{CH}_3\text{COO}^-$ ;  $\text{H}_2\text{O}/\text{H}_3\text{O}^+$

### 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)  $\text{H}_2\text{O}(\text{l})$  is acting as a proton donor and is an acid and in 8(b)  $\text{H}_2\text{O}(\text{l})$  is acting as a proton receiver and is a base.

## Solutions for Practice Problems

Student Textbook page 564

### 10. Problem

Predict the direction for the following equations. State whether reactants or products are favoured, and give reasons to support your decision.

(a)  $\text{NH}_4^+(\text{aq}) + \text{H}_2\text{PO}_4^-(\text{aq}) \rightarrow \text{NH}_3(\text{aq}) + \text{H}_3\text{PO}_4(\text{aq})$

(b)  $\text{H}_2\text{O}(\text{l}) + \text{HS}^-(\text{aq}) \rightarrow \text{OH}^-(\text{aq}) + \text{H}_2\text{S}(\text{aq})$

(c)  $\text{HF}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{F}^-(\text{aq}) + \text{HSO}_4^-(\text{aq})$

### 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)  $\text{H}_3\text{PO}_4(\text{aq})$  is a weaker base than  $\text{NH}_3(\text{aq})$  and  $\text{NH}_4^+(\text{aq})$  is a weaker acid than  $\text{H}_3\text{PO}_4(\text{aq})$ .

This reaction proceeds to the left or reactants are favoured.

(b)  $\text{HS}^-(\text{aq})$  is a weaker base than  $\text{OH}^-(\text{aq})$  and  $\text{H}_2\text{O}(\text{l})$  is a weaker acid than  $\text{H}_2\text{S}(\text{aq})$ .

The reaction will proceed to the left or reactants are favoured.

(c)  $\text{SO}_4^{2-}(\text{aq})$  is a weaker base than  $\text{F}^-(\text{aq})$  and  $\text{HF}(\text{aq})$  is a weaker acid than  $\text{HSO}_4^-(\text{aq})$ . 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.

- $\text{H}_2\text{PO}_4^- (\text{aq}) + \text{NH}_4^+ (\text{aq}) \rightarrow \text{H}_2\text{PO}_4^- (\text{aq}) + \text{NH}_3 (\text{aq})$
- $\text{H}_2\text{SO}_4 (\text{aq}) + \text{H}_2\text{O} (\text{l}) \rightarrow \text{HSO}_4^- (\text{aq}) + \text{H}_3\text{O}^+ (\text{aq})$
- $\text{H}_2\text{S} (\text{aq}) + \text{NH}_3 (\text{aq}) \rightarrow \text{HS}^- (\text{aq}) + \text{NH}_4^+ (\text{aq})$

### Solution

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

- $\text{H}_2\text{PO}_4^- (\text{aq})$  is a weaker base than  $\text{NH}_3 (\text{aq})$  and  $\text{NH}_4^+ (\text{aq})$  is a weaker acid than  $\text{H}_3\text{PO}_4 (\text{aq})$ .  
This reaction proceeds to the left or reactants are favoured.
- $\text{H}_2\text{SO}_4 (\text{aq})$  is a weaker acid than  $\text{H}_2\text{SO}_4 (\text{aq})$  and  $\text{HSO}_4^- (\text{aq})$  is a weaker base than  $\text{H}_2\text{O} (\text{l})$ . The reaction will proceed to the right or products are favoured.
- $\text{HS}^- (\text{aq})$  is a weaker base than  $\text{NH}_3 (\text{aq})$  and  $\text{NH}_4^+ (\text{aq})$  is as weaker acid than  $\text{H}_2\text{S} (\text{aq})$ . The reaction proceeds to the right or products are favoured.

## Solutions for Practice Problems

Student Textbook page 566

### 12. Problem

Determine  $[\text{H}_3\text{O}^+]$  and  $[\text{OH}^-]$  in each solution.

- 0.45 mol/L hydrochloric acid
- 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  $[\text{H}_3\text{O}^+]$  or  $[\text{OH}^-]$ . You can find the concentration of the other ion using  $K_w$ , as shown below:

$$K_w = 1.0 \times 10^{-14} = [\text{H}_3\text{O}^+][\text{OH}^-]$$

$$\text{(a) } [\text{HCl}] = 0.45 \text{ mol/L, so } [\text{H}_3\text{O}^+] = 0.45 \text{ mol/L}$$

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

$$= 2.2 \times 10^{-14} \text{ mol/L}$$

$$\text{(b) } [\text{NaOH}] = 1.1 \text{ mol/L}$$

$$\text{Therefore, } [\text{OH}^-] = 1.1 \text{ mol/L}$$

$$[\text{H}_3\text{O}^+] = \frac{1.0 \times 10^{-14} \text{ mol/L}}{1.1}$$

$$= 9.1 \times 10^{-15} \text{ mol/L}$$

### Check Your Solution

Solution (a) is a strong acid. Therefore,  $[\text{H}_3\text{O}^+]$  should be greater than  $1.0 \times 10^{-7}$ , and  $[\text{OH}^-]$  should be less than  $1.0 \times 10^{-7}$ . For a solution of a strong base, as in (b),  $[\text{OH}^-]$  should be greater than  $1.0 \times 10^{-7}$ , and  $[\text{H}_3\text{O}^+]$  should be less than  $1.0 \times 10^{-7}$ .

### 13. Problem

Determine  $[\text{H}_3\text{O}^+]$  and  $[\text{OH}^-]$  in each solution.

- 0.95 mol/L hydrobromic acid
- 0.012 mol/L calcium hydroxide