ACTIVITY 9

Introduction to Acid – Base Reactions

WHY?

Chemical reactivity can be understood by identifying the reactants as acids or bases. Blood acidity is important for health, acid-base reactions are used in industry to produce many materials, and acid rain is a complex environmental issue. You need to recognize acids and bases and evaluate their effects in order to use these reactions for benefit and to avoid harm.

LEARNING OBJECTIVE

- Identify the characteristics of acids and bases

SUCCESS CRITERIA

- Quickly recognize acids and bases
- Write acid-base reactions correctly

PREREQUISITES

- **Activity 3:** *Molecular Representations*
- **Activity 5:** *Balanced Chemical Reaction Equations*
- **Activity 8:** *Some Types of Chemical Reactions: An Introduction*

INFORMATION

An *acid* is a chemical species that donates a proton to another species.

A *base* is a chemical species that accepts a proton from another species.

TASK

Label each of the reactants in the model on the following page (Figure 9.1) *acid* or *base*, using the definitions of an acid and a base given previously.

Model: Acids and Bases

Figure 9.1

1. $HCl(aq) + NH_3(aq) \longrightarrow NH_4^+(aq) + Cl^-(aq)$
   acid *base*
2. $H_2O(l) + NH_3(aq) \longrightarrow NH_4^+(aq) + OH^-(aq)$
   acid *base*
3. $HCl(aq) + H_2O(l) \longrightarrow H_3O^+(aq) + Cl^-(aq)$
   acid *base*
4. $H_3PO_4(aq) + H_2O(l) \longrightarrow H_2PO_4^-(aq) + H_3O^+(aq)$
   acid *base*
5. $H_2PO_4^-(aq) + H_2O(l) \longrightarrow HPO_4^{2-}(aq) + H_3O^+(aq)$
   acid *base*

s = solid, aq = aqueous, l = liquid

Key Questions

1. For the reactions in the model, how did you determine whether a reactant was an acid or a base?

   According to Brønsted-Lowry theory, an acid is a proton donor and a base is a proton acceptor. The reactant that donated a proton is an acid and the reactant that accepted the proton is a base.

2. Does any substance in the model act both a proton donor (acid) and as a proton acceptor (base)? Explain how this can or cannot occur. A substance that can act either as an acid or a base is called amphoteric; an amphoteric substance that can either donate or accept a proton is also called amphiprotic.

   In the model, water acts as both a proton donor and as a proton acceptor and therefore is an amphoteric substance. When water reacts with ammonia, water is a proton donor and acts as an acid while ammonia acts as a base. When water reacts with hydrochloric acid, the water accepts a proton and acts as a base while hydrochloric acid acts as an acid. The dihydrogen phosphate ion ($H_2PO_4^-$) is also amphoteric. In general, any substance that acts both as an acid and a base is called amphoteric.

3. Would you call sodium hydroxide, NaOH, an acid or a base? Why? Sodium hydroxide ionizes in water to give $Na^+(aq)$ and $OH^-(aq)$.

   Sodium hydroxide produces hydroxide ions in water, which is the Arrhenius definition of a base. Since hydroxide ions readily accepts protons, hydroxide satisfies the Brønsted-Lowry definition of a base as a proton acceptor.

4. What is an example of an acid or a base that you have encountered outside the chemistry laboratory?

   Cleansers (with ammonia) and drain cleaners are bases. Vinegar and lemon juice are acids.

EXERCISES

1. In the context of reversing the reactions in the model, label the acids on the right-hand side of the reaction equations in the model.

   Reactions 1 and 2: NH_4^+ *Reactions 3-5: H_3O^+*

2. In the context of reversing the reactions in the model, label the bases on the right-hand side of the reaction equations in the model.

   Reactions 1 and 3: Cl^- *Reaction 2: OH^-*

   Reaction 4: $H_2PO_4^-$ *Reaction 5: HPO_4^{2-}*

3. Write the acid-base reaction for NH_3 reacting with HNO_2 and identify the acid and the base on the reactant side and on the product side.

   $$\underset{\text{base}}{NH_3(aq)} + \underset{\text{acid}}{HNO_2(aq)} \longrightarrow \underset{\text{acid}}{NH_4^+(aq)} + \underset{\text{base}}{NO_2^-(aq)}$$

4. Complete the following table for the reaction equations in the model. Label each reactant and product as *acid* or *base*. Reaction 1 is done for you.

   The shaded cells in the table contain answers.

Reaction	Reactant	Corresponding Product
1	HCl (acid)	Cl^- (base)
1	NH_3 (base)	NH_4^+ (acid)
2	*H_2O (acid)*	*OH^- (base)*
2	*NH_3 (base)*	*NH_4^+ (acid)*
3	*HCl (acid)*	*Cl^- (base)*
3	*H_2O (base)*	*H_3O^+ (acid)*
4	*H_3PO_4 (acid)*	*$H_2PO_4^-$ (base)*
4	*H_2O (base)*	*H_3O^+ (acid)*
5	*$H_2PO_4^-$ (acid)*	*HPO_4^{2-} (base)*
5	*H_2O (base)*	*H_3O^+ (acid)*

5. Examine your entries in the table in Exercise 4 and identify how the acids and the bases in each row differ.

   Each reactant and its corresponding product differ by one proton. If the reactant is an acid, its corresponding product is a base, and vice versa. The acid has the proton, the base does not.

INFORMATION

Notice in the model that, following the loss of a proton, an acid on the left-hand side of a reaction equation produces a corresponding base on the right-hand side. These acid-base pairs are called *conjugate acid-base pairs*. A *conjugate acid-base pair* is any two substances that can be converted from one to the other simply by transferring a proton between them.

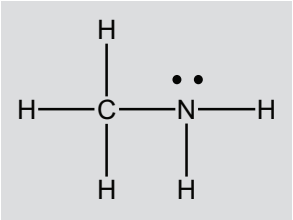
EXERCISES

6. Complete the following table of conjugate acid-base pairs.

The shaded cells in the table contain answers.

Acid	Base
HCN	CN^-
HNO_3	*NO_3^-*
H_2CO_3 (a diprotic acid)	*HCO_3^-*
HCO_3^-	CO_3^{2-}
NH_3	NH_2^-
$HClO_4$	*ClO_4^-*
$CH_3NH_3^+$	CH_3NH_2
$(CH_3)_2NH_2^+$	*$(CH_3)_2NH$*

7. Draw the structural formula of CH_3NH_2, and add 2 dots to the nitrogen atom to represent the pair of nonbonding electrons. Use your drawing to explain why the hydrogen ion attaches to nitrogen and not to carbon.



The nonbonding pair of electrons on the nitrogen is used to form the bond between the nitrogen and the hydrogen ion. There are no electrons available on the carbon.

8. For the following reaction identify the reactant that is an acid, the reactant that is a base, and the two conjugate acid-base pairs present.

$$H_2SO_4 + HPO_4^{2-} \longrightarrow HSO_4^- + H_2PO_4^-$$

acid *base*

H_2SO_4 (acid) / HSO_4^- (conjugate base)
HPO_4^{2-} (base) / $H_2PO_4^-$ (conjugate acid)