5.4: Hydrolysis Reactions

Learning Objectives

- Distinguish between condensation and hydrolysis reactions.
- Identify the products of an acidic hydrolysis of an ester.
- Identify the products of a basic hydrolysis of an ester.
- Generate products of the hydrolysis of amides.

Condensation and hydrolysis reactions are chemical reactions involving organic compounds. These opposite reactions involve the building up or breaking down of organic molecules. As with other chemical reactions involving organic compounds, these processes result in a change in the class of organic compound represented.

Hydrolysis reactions are the reverse of condensation reactions. In a **hydrolysis reaction**, a larger molecule forms two (or more) smaller molecules and water is consumed as a reactant. Hydrolysis ("hydro" = water and "lysis" = break) involves adding water to one large molecule to break it into multiple smaller molecules.

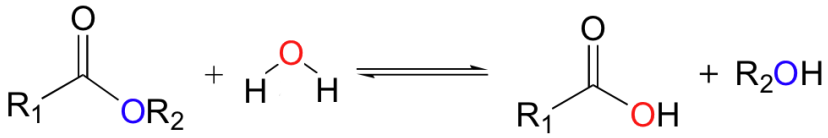


Figure 5.4.1: General reaction scheme of a hydrolysis reaction. FrozenMan, CC BY-SA 4.0, via Wikimedia Commons

Hydrolysis of Esters

The esterification reaction is reversible. The formation of the ester represents a condensation reaction, but the reverse reaction represents the hydrolysis of the ester. This hydrolysis can occur under acidic or basic conditions.

Acidic hydrolysis is simply the reverse of esterification. The ester is heated with a large excess of water containing a strong-acid catalyst. Like esterification, the reaction is reversible and does not go to completion.

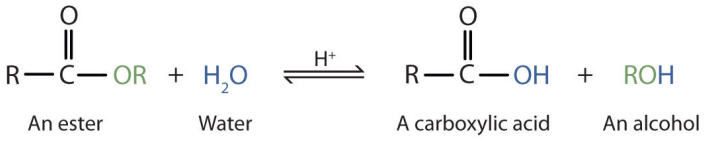


Figure 5.4.2: Reaction scheme for the acid-catalyzed hydrolysis of an ester.

As a specific example, butyl acetate and water react to form acetic acid and 1-butanol. The reaction is reversible and does not go to completion.

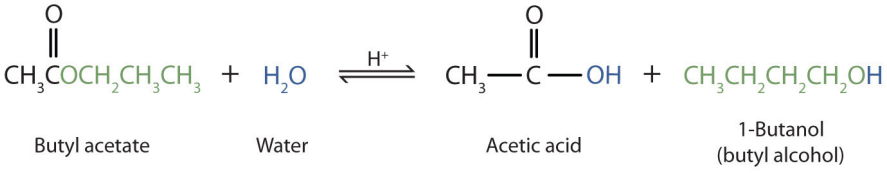


Figure 5.4.3: Acid-catalyzed hydrolysis of butyl acetate.

When an ester is heated in the presence of a strong base (such as sodium hydroxide [NaOH] or potassium hydroxide [KOH]), the ester breaks down. The products are an alcohol and the carboxylate salt.

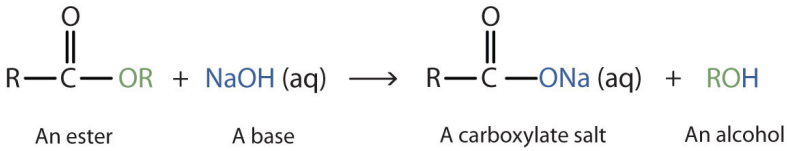


Figure 5.4.4: Reaction scheme for the base-catalyzed hydrolysis of an ester.

As a specific example, butyl acetate and water react to form acetic acid and 1-butanol. The reaction is reversible and does not go to completion.

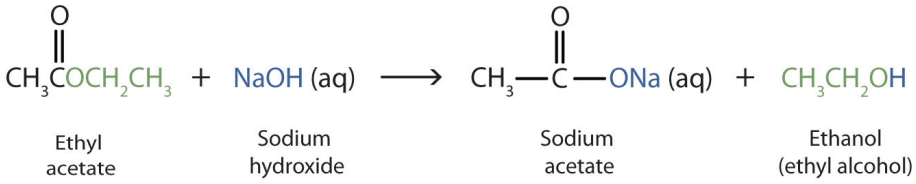


Figure 5.4.5: Base-catalyzed hydrolysis of ethyl acetate.

The strong base is not acting as a catalyst, but is consumed as a reactant in the reaction. This alkaline hydrolysis of an ester is referred to as **saponification** (Latin *sapon*, meaning "soap," and *facere*, meaning "to make"). The term saponification originally described the hydrolysis of long-chain esters called fatty acid esters to produce soap molecules, which are the salts of fatty acids. One such soap molecule is sodium stearate, formed from the hydrolysis of ethyl stearate.

$$\underset{\text{ethyl stearate}}{C_{17}H_{35}COOC_2H_5} + NaOH \rightarrow \underset{\text{sodium stearate (soap)}}{C_{17}H_{35}COO^-Na^+} + C_2H_5OH \tag{5.4.1}$$

Hydrolysis of Amides

Generally, amides resist hydrolysis in plain water, even after prolonged heating. In the presence of added acid or base, however, hydrolysis proceeds at a moderate rate. In living cells, amide hydrolysis is catalyzed by enzymes. Amide hydrolysis is illustrated in the following example:

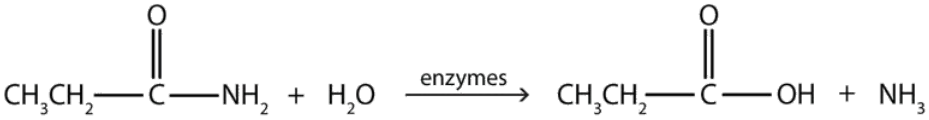


Figure 5.4.6: Reaction scheme for the hydrolysis of an amide.

> *Hydrolysis of an amide in acid solution actually gives a carboxylic acid and the salt of ammonia or an amine (the ammonia or amine initially formed is neutralized by the acid). Basic hydrolysis gives a salt of the carboxylic acid and ammonia or an amine.*

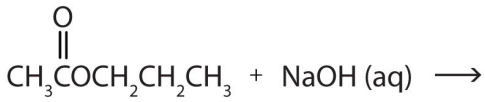
Career Focus: Athletic Trainer

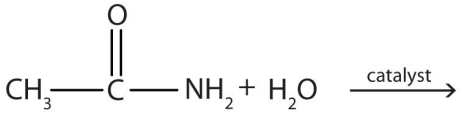
Athletic training is an allied health-care profession recognized by the American Medical Association. The athletic trainer's role is to recognize, evaluate, and provide immediate care for athletic injuries; prevent athletic injuries by taping, bandaging, and bracing vulnerable body parts; make referrals to medical doctors when necessary; and rehabilitate injured athletes. Athletic trainers work in high schools, colleges, and other organizations where athletics programs are found. Athletic trainers usually have a degree from an accredited athletic training program whose curriculum includes such basic science courses as biology, chemistry, and physics. These studies provide the necessary background for more applied courses, such as anatomy and physiology, exercise physiology, kinesiology, and nutrition. Knowledge of chemistry is necessary for understanding pharmacological and medical terminology. For example, athletic trainers must understand the action of numerous drugs, many of which are esters, amines, or amides like those mentioned in this chapter.

Athletic trainers may have administrative duties, such as the responsibility for ordering supplies. They also need to be able to evaluate nutritional supplements because providing the wrong one can get an athlete banned from competition and may bring sanctions against a school. In short, the athletic trainer is responsible for the overall health and well-being of the athletes in his or her charge.

Example 5.4.1

Complete each equation.

a. 

b. 

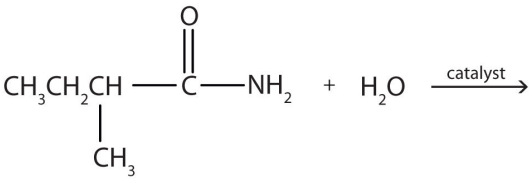
Solution

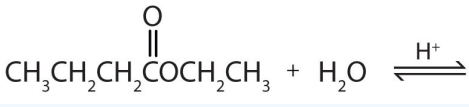
a. $CH_3COONa(aq) + CH_3CH_2CH_2OH$

b. $CH_3COOH + NH_3$

? Exercise 5.4.1

Complete each equation.

a. 

b. 

Summary

- A hydrolysis reaction is a reaction in which one molecule breaks apart to form multiple smaller molecules.
- Acidic hydrolysis of an ester gives a carboxylic acid and an alcohol.
- Basic hydrolysis (saponification) of an ester gives a carboxylate salt and an alcohol.
- The hydrolysis of an amide produces a carboxylic acid and ammonia or an amine.

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