

## 5.3: Condensation Reactions

### Learning Objectives

- Construct products of condensation reactions.

In a **condensation reaction**, two (or more) molecules combine to form a single molecule. A small molecule, often water, is usually removed during a condensation reaction. Amino acids are important biological molecules that have an amine functional group on one end of the molecule and a carboxylic acid functional group on the other end. When two amino acids combine in a condensation reaction, a covalent bond forms between the carboxyl carbon of one amino acid and the amine nitrogen of the second amino acid. A molecule of water is then removed as a second product.

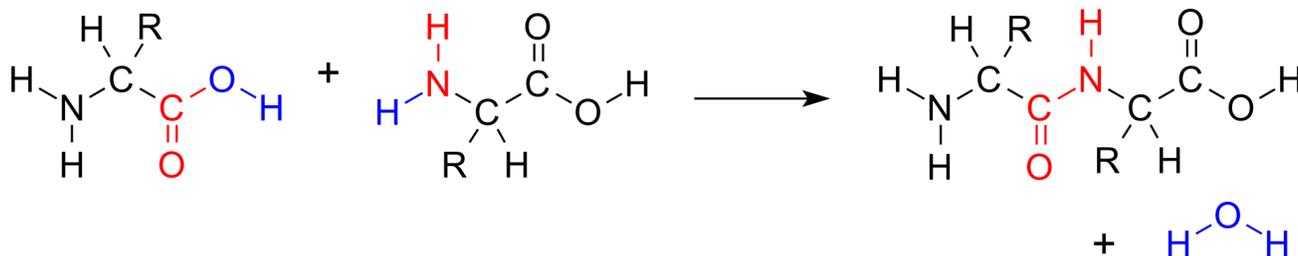


Figure 5.3.1: Amino acids join together to form a molecule called a dipeptide. The  $-\text{OH}$  from the carboxyl group of one amino acid combines with a hydrogen atom from the amine group of the other amino acid to produce water (blue).

This reaction forms a molecule called a dipeptide and the carbon-nitrogen covalent bond is called a peptide bond or amide bond. When repeated numerous times, a long molecule called a protein is eventually produced.

### Esterification

An **esterification reaction** is a condensation reaction in which reactants (typically an alcohol and carboxylic acid) combine to produce an ester.

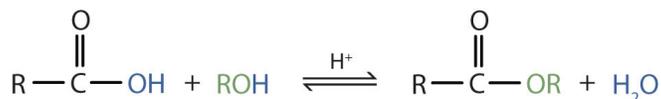


Figure 5.3.2: Reaction scheme for a condensation reaction.

Esterification is a subcategory of condensation reactions because a water molecule is produced in the reaction. The reaction is catalyzed by a strong acid, usually sulfuric acid. When the carboxylic acid butanoic acid is heated with an excess of methanol and a few drops of sulfuric acid, the ester methyl butanoate is produced. Methyl butanoate has the scent of pineapples.

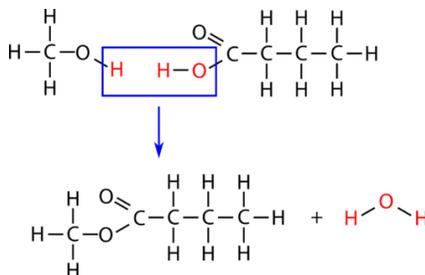


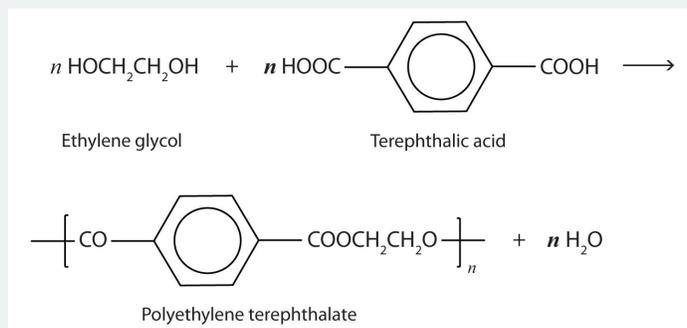
Figure 5.3.3: Esterification reaction between methanol and butanoic acid to produce methyl butanoate.

### A Closer Look: Condensation Polymers

A commercially important esterification reaction is condensation polymerization, in which a reaction occurs between a dicarboxylic acid and a dihydric alcohol (diol), with the elimination of water. Such a reaction yields an ester that contains a

free (unreacted) carboxyl group at one end and a free alcohol group at the other end. Further condensation reactions then occur, producing polyester polymers.

The most important polyester, polyethylene terephthalate (PET), is made from terephthalic acid and ethylene glycol monomers:



Polyester molecules make excellent fibers and are used in many fabrics. A knitted polyester tube, which is biologically inert, can be used in surgery to repair or replace diseased sections of blood vessels. PET is used to make bottles for soda pop and other beverages. It is also formed into films called Mylar. When magnetically coated, Mylar tape is used in audio- and videocassettes. Synthetic arteries can be made from PET, polytetrafluoroethylene, and other polymers.

## Amidation

An **amidation reaction** is a condensation reaction in which reactants (typically an amine and carboxylic acid) combine to produce an amide. The addition of ammonia ( $\text{NH}_3$ ) to a carboxylic acid forms an amide, but the reaction is very slow in the laboratory at room temperature. Water molecules are split out, and a bond is formed between the nitrogen atom and the carbonyl carbon atom.

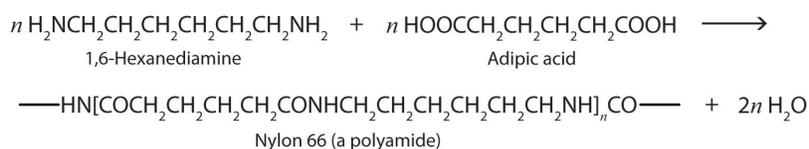


Figure 5.3.4: Amidation reaction between ammonia and acetic acid to produce acetamide.

In living cells, amide formation is catalyzed by enzymes. Proteins are polyamides; they are formed by joining amino acids into long chains. In proteins, the amide functional group is called a *peptide bond*.

## Polyamides

Just as the reaction of a diol and a diacid forms a polyester, the reaction of a diacid and a diamine yields a polyamide. The two difunctional monomers often employed are adipic acid and 1,6-hexanediamine. The monomers condense by splitting out water to form a new product, which is still difunctional and thus can react further to yield a polyamide polymer.



Some polyamides are known as *nylons*. Nylons are among the most widely used synthetic fibers—for example, they are used in ropes, sails, carpets, clothing, tires, brushes, and parachutes. They also can be molded into blocks for use in electrical equipment, gears, bearings, and valves.

### ✓ Example 5.3.1

- From what carboxylic acid and what alcohol can isopropyl nonanoate be made?
- From what carboxylic acid and what amine can N-propylhexanamide be made?

### Solution

- nonanoic acid and isopropyl alcohol
- hexanoic acid and propylamine

### ? Exercise 5.3.1

- From what carboxylic acid and what alcohol can cyclobutyl butyrate be made?
- From what carboxylic acid and what amine can butanamide be made?

### Summary

- A condensation reaction is a reaction in which two molecules combine to form a single molecule.
- An esterification is a condensation reaction in which an ester is formed from an alcohol and a carboxylic acid.
- An amidation is a condensation reaction in which an amid is formed from an amine and a carboxylic acid.

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