SCH4U-C

8

Acids, Esters, Amides, and Polymers

Introduction

Organic chemistry has enhanced our way of life by introducing a host of new materials. This branch of chemistry has given us plastics, medications, clothing, food, and many other consumer materials. Unfortunately, since plastics are synthetic, they are new to nature, and nature has no way of decomposing them. Consequently, synthetic garbage accumulates in our ecosystems when plastic is (unintentionally or intentionally) dumped.

Perhaps one of the most offensive examples of this is a huge floating mat of plastic in the Pacific Ocean, often referred to as the Great Pacific Garbage Patch. The vortex of ocean currents northeast of Hawaii cause plastic waste from around the world to accumulate in a large mass in the vortex's relatively calm centre. This mass of plastic has increased tenfold in size since the end of the Second World War and is now over half the size of Ontario!

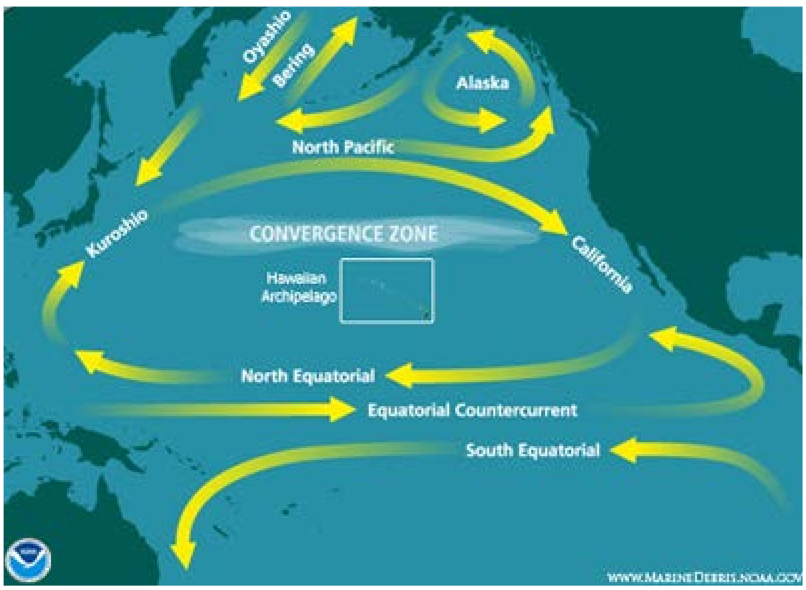


Figure 8.1: A map of the convergence zone containing the Great Pacific Garbage Patch

Source: http://marinedebris.noaa.gov/marinedebris101/images/STCZ.jpg

In this lesson, you will learn about some of the organic chemicals used to make these synthetic materials, including their properties and the reactions they undergo. The lesson concludes with a look at what you can do about the problem of accumulating synthetic waste.

Planning Your Study

You may find this time grid helpful in planning when and how you will work through this lesson.

Suggested Timing for This Lesson (Hours)	
Carboxylic Acids	1
Esters and Amides	1
Polymers	1½
Key Questions	1

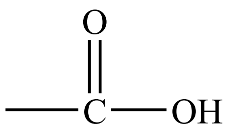
What You Will Learn

After completing this lesson, you will be able to

- name and draw the structural formulas of acids, esters, and amides
- predict the physical and chemical properties of these compounds
- predict the reactions that these compounds undergo
- distinguish between the terms polymer, monomer, and repeating unit
- distinguish between two of the most common types of polymerization reactions
- assess the impact of synthetic materials like plastics on the environment

Carboxylic Acids

Carboxylic acids, also called organic acids, are a group of organic compounds that contain the carboxyl group as its functional group. This is symbolized as either

 or —COOH.

Carboxyl groups are always found on an end of a molecule, rather than within the chain. The most familiar carboxylic acid is ethanoic acid, commonly known as acetic acid. Vinegar is a 5% solution of this compound. In general, carboxylic acids are weak acids that have a distinctive sour taste. Some organic acids are found in foods, such as the citric acid in citric fruits and the oxalic acid in rhubarb. When milk spoils, bacteria cause lactic acid to form. The acid causes milk to curdle, as it spoils. The same result can be obtained by pouring a little vinegar into milk—try it! Lactic acid also forms in your muscles, as a result of exercise. The buildup of lactic acid in your muscles is partly responsible for some of the fatigue you feel, as you exercise.

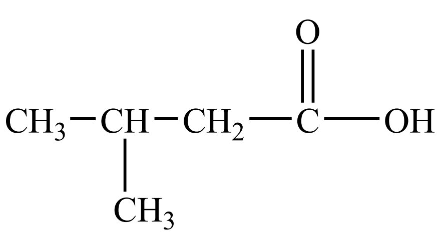
Naming Carboxylic Acids

Naming carboxylic acids follows many of the rules you've learned so far.

The steps are identical to those of alkenes, alcohols, aldehydes, and ketones, seen earlier. The only change to be made for acids is that the suffix used will be "-oic acid." Where an aldehyde, for example, would be named "pentanal," the corresponding acid would be named "pentanoic acid." Aldehydes and acids have one similarity in that the functional group is found on the end of the carbon chain.

Example

Name this compound:



Solution

The compound is 3-methylbutanoic acid. Recall that the number one carbon will be the carbon on the functional group. Numbering is determined by the location of the functional group.

Acids with Multiple Carboxyl Groups

Some organic acids can have multiple carboxyl groups in their structure. The prefixes “di-” and “tri-” are used to indicate the number of carboxyl groups in the structure. The presence of more than three carboxyl groups in organic acids is rare. As you determine the length of the longest carbon chain, don’t forget to include the carbons of the carboxyl groups. For example, the acid in Figure 8.2 is called hexandioic acid because

- it has six carbon atoms in its longest chain (“hex-”)
- it has only single bonds in its longest chain (“-an-”)
- it has two carboxyl groups (“-dioic” acid)

This example can also be used to illustrate another way of drawing organic structures, called a skeletal formula. A skeletal formula is particularly convenient for large molecules. Each corner of the zigzag pattern represents one link (of CH_2) in the carbon chain. Since carbon–carbon single bonds are free to rotate, it makes no difference whether the double-bonded oxygen in the carboxyl group (O=C—OH) is pointing up or down.

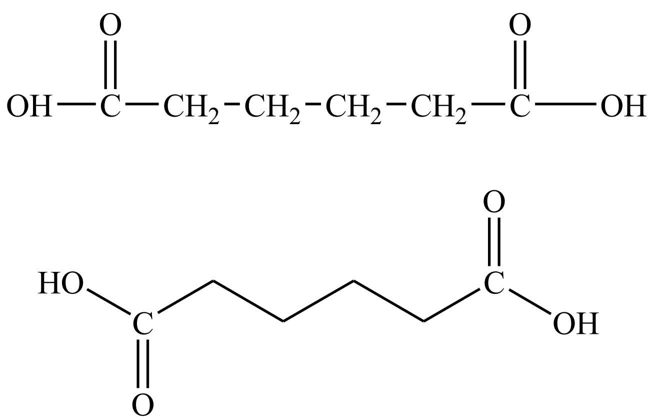


Figure 8.2: Two ways to show the structure of hexandioic acid are the structural formula (top) and the skeletal formula (bottom). Hexandioic acid is also seen written as hexanedioic acid. The common name is adipic acid.

Properties of Carboxylic Acids

Most of the properties of carboxylic acids can be attributed to the carboxyl group. Because the hydrogen-to-oxygen bond in these compounds is highly polar, hydrogen bonding occurs between the molecules. As a result, organic acids have higher melting and boiling points than the comparable alkane. The polarity of the carboxyl group gives water two very polar sites on the acid molecule to attract to. As long as the structure is not too big for water to tow, the organic acid will be soluble in a polar solvent such as water.

However, as you saw with other polar organic compounds, the solubility of carboxylic acids decreases as the size of the alkyl chain increases. As the alkyl chain (the tail) of the structure gets larger and larger, water molecules at room temperature will not possess enough kinetic energy to “tow” the large molecule around, even though the water can attach very well to it. Think of a small car with a trailer hitch. That small car could readily attach to a large tractor trailer, but wouldn't be able to tow that trailer around. For example, ethanoic acid (commonly known as acetic acid) is very soluble in water, while hexanoic acid is essentially insoluble (Figure 8.3).

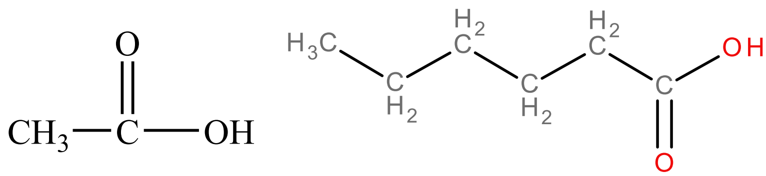


Figure 8.3: Compounds with small alkyl groups like ethanoic acid (left) are more soluble in water than molecules with large carbon chains or carbon tails, like hexanoic acid (right).

The carboxyl groups are polar, while the alkyl groups are essentially non-polar.

Reactions of Carboxylic Acids

Carboxylic acids are commonly involved in two types of reactions: neutralization and esterification.

Neutralization

One of the most common reactions that carboxylic acids undergo is acid–base neutralization. As you learned in earlier courses, an acid reacts with a base to form water and an ionic salt. The salt produced in these reactions is made up of positive and negative ions, which remain after neutralization. The general form of the chemical equation for these reactions is:

acid + base → water + salt

For example, consider this reaction in which acetic acid is neutralized by sodium hydroxide:

$CH_3COOH_{(aq)} + NaOH_{(s)} \rightarrow H_2O_{(l)} + NaCH_3COO_{(aq)}$

Note that the hydrogen atom found on the carboxyl group of the acid combines with the hydroxide ion from the sodium hydroxide to form water. The ionic salt, sodium ethanoate (or sodium acetate), is made of the ions left over as a result of neutralization.

Esterification

Acids also react with alcohols to form another group of organic compounds called esters. These reactions are called esterification. The general form of an esterification reaction is:

acid + alcohol → ester + water

For example, consider this reaction in which ethanoic acid is esterified by methanol:

$CH_3OH_{(aq)}$ + $CH_3COOH_{(aq)}$ → $CH_3COOCH_{3(aq)}$ + $H_2O_{(l)}$

Methanol ethanoic acid methyl ethanoate

At first glance, this reaction appears similar to neutralization. However, they differ because of the following three factors:

- Alcohols are not basic.
- The ester is a molecular compound, and not an ionic one.
- These reactions require heat and a catalyst in order to proceed. (In the earlier example, sulfuric acid was the catalyst, and its formula was placed above the arrow in the equation.)

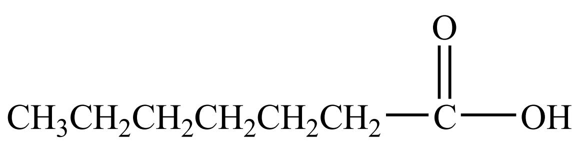
You'll learn more about esters in the next section.

Support Questions

Be sure to try the Support Questions on your own before looking at the suggested answers provided.

39. Name these acid compounds:

a)



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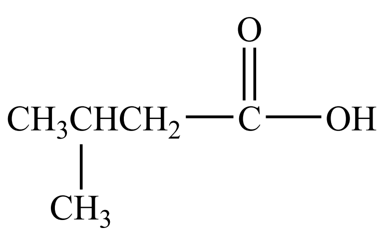

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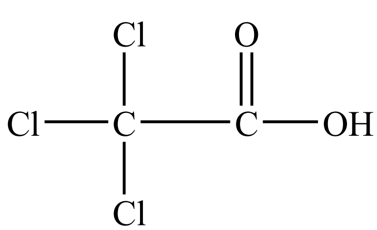

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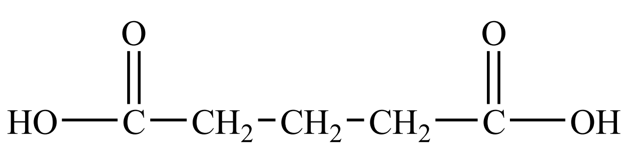


Suggested answer

40. Consider the following four organic acids:

$HCOOH$ CH_3COOH CH_3CH_2COOH $CH_3CH_2CH_2COOH$

a) Why does the solubility of these compounds in water decrease as the length of the carbon chain increases?

b) Why do the melting points of these compounds increase as the length of the carbon chain increases? (**Hint:** because each one has the identical carboxyl group, each has the same dipole-dipole forces of attraction as well as H-bonding forces caused by the OH group on the carboxyl group. What force changes with carbon chain length?)

Suggested answer

41. Use skeletal formulas to show the chemical equation for the neutralization of benzoic acid (a benzene ring with a carboxyl group attached to one of the carbons) with sodium hydroxide. Look back at the neutralization example involving acetic acid. Try to name the salt formed when benzoic acid is used.

Suggested answer

Esters and Amides

Esters and amides are two main classes of organic compounds that can be made from organic acids. Like acids, ester and amide compounds are polar molecules. Therefore their melting and boiling points are higher than those of the alkane of comparable length. Their polarity also makes these compounds soluble in water. However, as the size of the alkyl chains increases, their polarity decreases, making them less soluble.

Esters

Esters have the general chemical formula $R{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}OR'$. Note that they are similar to acids, except for the fact that the hydrogen of the carboxyl group is replaced with an alkyl group, R′.

Many esters are produced by flowering plants because esters cause the necessary distinctive, and often pleasant, odours that attract pollinators, such as bees. For example, octyl ethanoate smells like oranges, while methyl salicylate smells like wintergreen-flavoured mints (Figure 8.4).

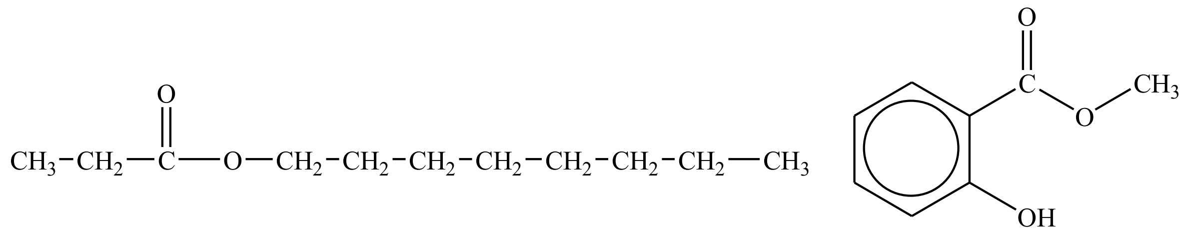
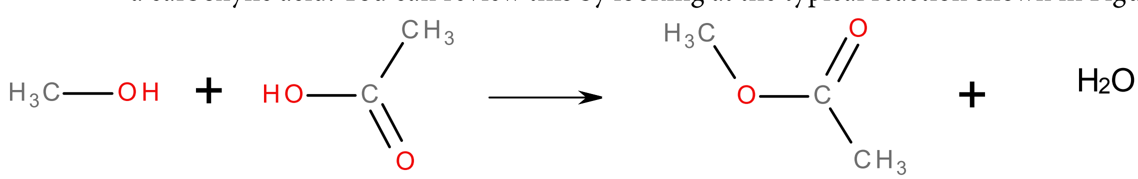


Figure 8.4: Esters are often large molecules with distinctive aromas. Octyl ethanoate (left) and methyl salicylate (right) are two common esters.

Figure 8.5: Food products containing esters

Source: http://commons.wikimedia.org/wiki/File:Quail_08_bg_041506.jpg

As you learned in the previous section, esters are produced from the reaction of an alcohol with a carboxylic acid. You can review this by looking at the typical reaction shown in Figure 8.6.



Methanol Ethanoic acid Methyl ethanoate

Figure 8.6: The synthesis of a typical ester, methyl ethanoate

Note that the net result of this reaction is that the methyl group of the alcohol replaces the hydrogen atom of the acid. If you examine the structure of the ester, you will see the methyl group of the alcohol on the left side. The remaining part of the structure is the acid molecule with the one H removed from the OH group. The hydroxyl group of the alcohol and the hydrogen of the acid combine to form water. Sulfuric acid (H_2SO_4) is necessary to initiate the reaction. Without it, the reaction would not occur. Above the arrow of the equation, we would write H_2SO_4.

Naming Esters

As the previous example illustrates, there are two parts to the name of an ester—one from the alcohol, and the other from the acid. The "methyl" in methyl ethanoate comes from methanol, and the "ethanoate" comes from ethanoic acid (Figure 8.7).

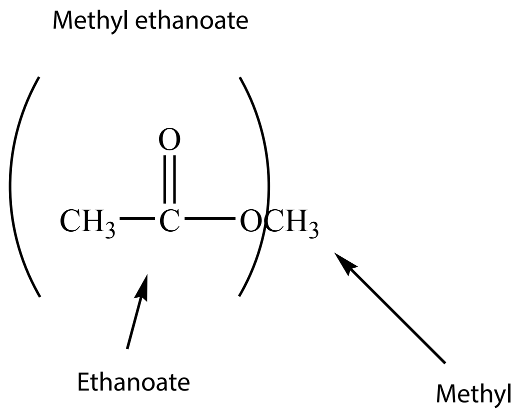


Figure 8.7: There are two parts to the name of an ester.

There are three steps for naming esters:

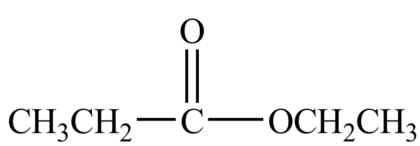
Step 1: Write the name of the alkyl group attached to the oxygen atom.

Step 2: Identify the parent acid of the acid portion. Change the ending of the acid name to "-oate."

Step 3: As with acids, the carboxyl carbon is defined as the first carbon of the "-oate" chain. Any side chains in this portion of the ester are numbered in relation to this carbon atom.

Example

Name this compound:



Solution

The answer is ethyl propanoate.

Amides

Amides are similar in structure to carboxylic acids, except that the hydroxyl portion of the carboxyl group is replaced with an amino group. The general structural formula of an amide is as follows:

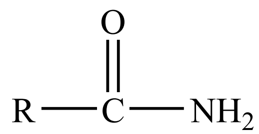


Figure 8.8: The general structural formula of an amide

Amides, which you'll learn about in the next section, are primary building blocks for proteins and synthetic polymers.

Naming Amides

There are three steps for naming amides:

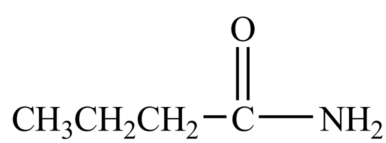
Step 1: Identify the parent acid of the amide. This would be the acid molecule you would have if the amino group on this structure were replaced with the OH group found on the corresponding acid.

Step 2: Change the "-oic acid" ending of the acid name to "-amide"

Step 3: As with esters, the carboxyl carbon is defined as the first carbon of the "-amide" chain.

Example

Name this compound:



Solution

Temporarily cross out the amino group on the structure and replace it with an OH group, making this an acid. What name would it have? Change the "-oic acid" suffix to "-amide." The compound is butanamide.

Synthesis of Amides

An acid reacts with ammonia to form an amide. For example, look at the following reaction:

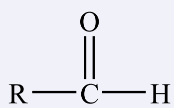
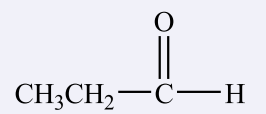
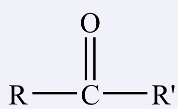
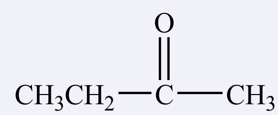
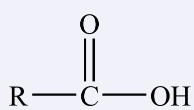
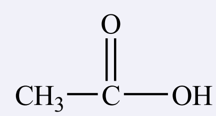
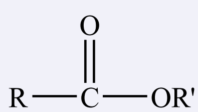
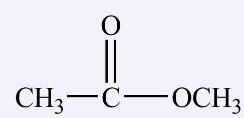
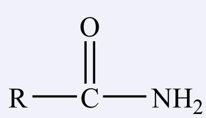
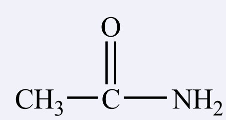
Propanoic acid Ammonia Propanamide Water

Figure 8.9: Propanoic acid reacts with ammonia to form propanamide and water.

Note the similarity between this reaction and the synthesis of an ester. Amides can also be formed through the reaction of acids with organic amines. Naming these amides is beyond the scope of this course.

This concludes a discussion of the organic compounds and their functional groups that are covered in this course. All of them are summarized in the following table. In your notes, review the reactions of each type. Write down how they might be synthesized from other molecules. What similarities and differences do you notice in the various classes of molecules? Write down any properties of each class that were given in the text.

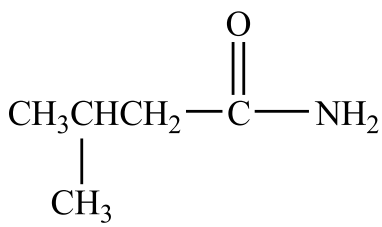
Table 8.1: Organic functional groups

General structure	Functional group name	Example	Structural formula of example
R–X, where X is a halogen	Organic halide	Chloromethane	CH_3Cl
$R–NH_2$	Amine	Ethanamine	$CH_3CH_2NH_2$
R–OH	Alcohol	Ethanol	CH_3CH_2OH
R–OR'	Ether	Methoxyethane	$CH_3OCH_2CH_3$
	Aldehyde	Propanal	
	Ketone	Butanone	
	Acid	Ethanoic acid	
	Ester	Methyl ethanoate	
	Amide	Ethanamide	

Support Questions

42. Name the following compounds. Identify the family for each compound.

a)



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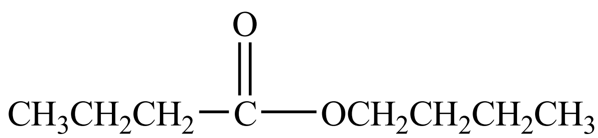

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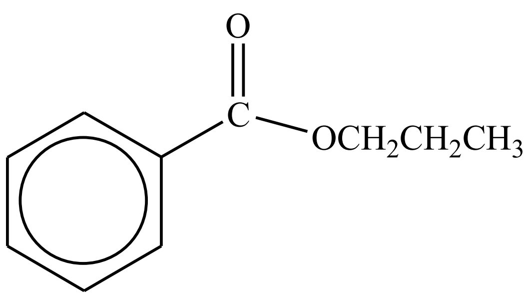


Suggested answer

43. Draw the structural formula for these compounds:

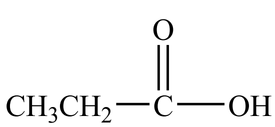
a) methyl propanoate

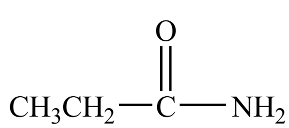
b) ethyl ethanoate

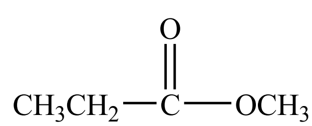
c) methanamide

Suggested answer

44. Which of these three compounds—propanoic acid (left), propanamide (middle), and methyl propanoate (right)—are capable of hydrogen bonding? Why?



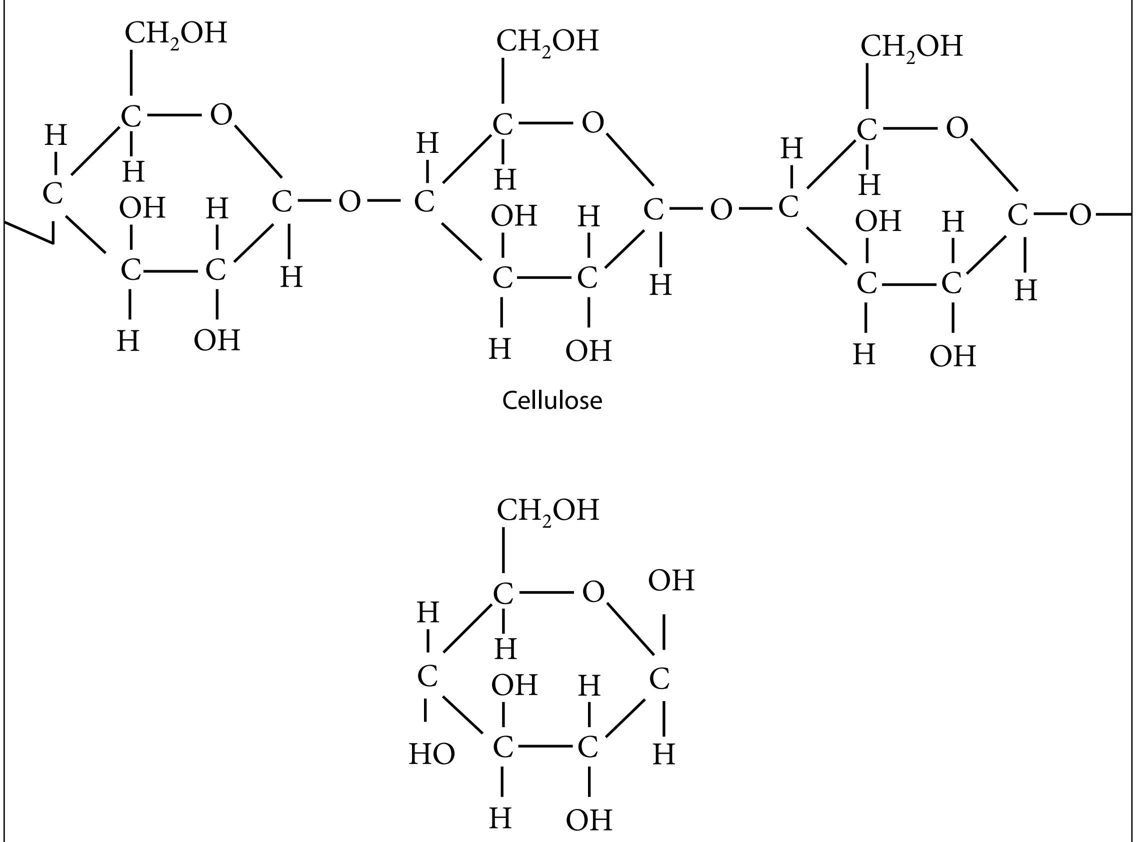




Suggested answer

Polymers

In earlier lessons, you learned that carbon is capable of forming long molecules. This is possible because of the strength and stability of the C—C bond. As a result, there are numerous examples in nature of organic molecules that are hundreds of atoms long. One common example is cellulose, which is the main structural material in plant tissue. For example, blades of grass are mostly cellulose. Each cellulose molecule consists of thousands of carbon, hydrogen, and oxygen atoms (Figure 8.10). A more detailed look at its structure reveals that cellulose is made up of a countless number of glucose molecules strung together like pearls on a necklace. Glucose is the simplest form of sugar.



Cellulose

Glucose

Figure 8.10: Cellulose is a polymer of glucose.

Large molecules made up of smaller repeating units are called polymers. There are many natural polymers, in addition to cellulose. Proteins, for example, are polymers with amino acids as their repeating unit (Figure 8.11). There are 20 naturally-occurring amino acids that differ only by their R group. Amino acids are carboxylic acids with an amino group, $—NH_2$, and an R group attached to the second carbon.

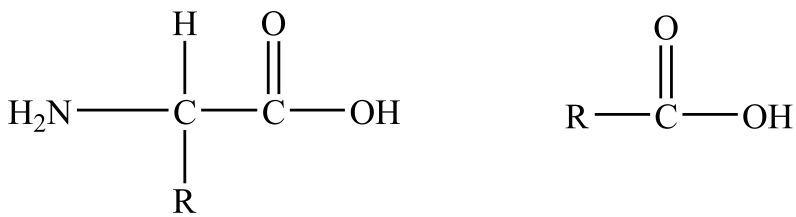


Figure 8.11: General formulas of amino acids (left) and carboxylic acids (right). Amino acids are carboxylic acids with an amino group on the second carbon.

An excellent example of a biological polymer is deoxyribonucleic acid or DNA. DNA is found in the nucleus of every cell of your body. The structural backbone of DNA is four different repeating units called organic bases. All of your genetic information is coded within the sequence of these four units. The sequence of organic base units is much like the sequence of letters that are used to create words and sentences in English.

Polymerization Reactions

Chemists have also learned how to construct synthetic polymers in the laboratory. The raw chemicals used to make these polymers are called monomers. For example, ethene (or ethylene) is the monomer used to synthesize polyethylene, a polymer used in a variety of applications ranging from clear plastic wraps to margarine tubs. The process of making a polymer from its monomers is called polymerization. There are two principal types of polymerization: addition polymerization and condensation polymerization.

Addition Polymerization

Addition polymerization, the first main type of polymerization, involves monomer units linking together without eliminating any atoms. Alkenes typically undergo addition polymerization reactions. Figure 8.12 shows the polymerization of ethene (or ethylene). During the reaction, one of the bonds of the double bond in each molecule is broken. This occurs either through another chemical reaction or because of a flash of light. The flash actually breaks one carbon–carbon bond in each ethene, which leaves both carbon atoms with a single electron. Rather than re-bonding to form the C=C, these carbon atoms use their single electrons to form single covalent bonds with adjacent molecules. The net result is a long carbon-to-carbon chain made up of repeating CH_2 units.

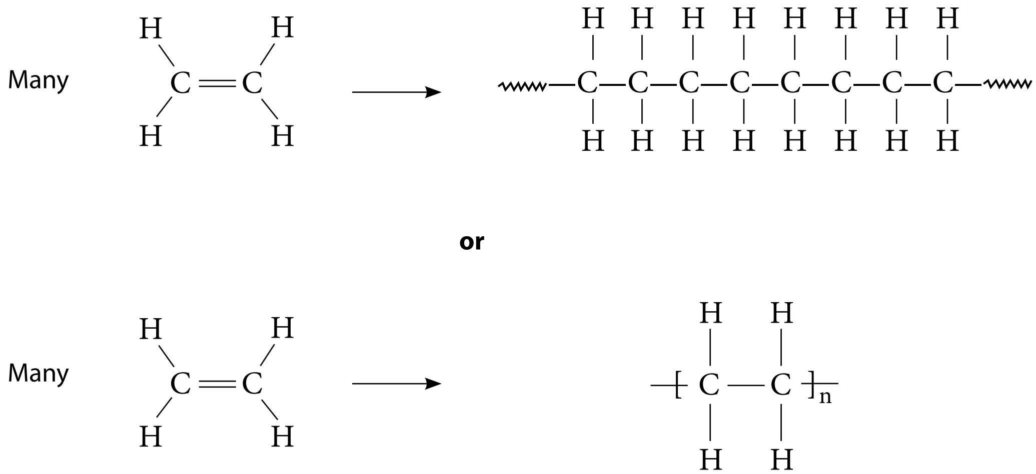


Figure 8.12: Polymerization of ethene (or ethylene) to form polyethylene. The bracketed portion in the lower structure is the repeating unit of the polymer, C_2H_4. The zigzag lines (top right) and the letter "n" (bottom right) both symbolize "many."

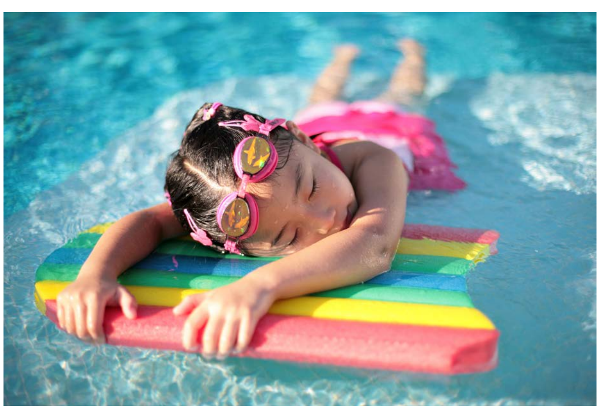


Figure 8.13: Polyethylene products include foam pool toys.

Source: http://commons.wikimedia.org/wiki/File:Girl_with_styrofoam_swimming_board.jpg

An economically useful polymerization reaction is the production of polyvinyl chloride. The monomer for this compound is called chloroethene (Figure 8.14).

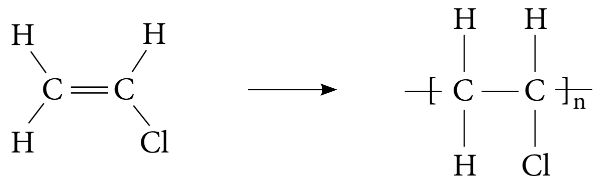


Figure 8.14: Polymerization of polyvinyl chloride (or PVC)

Note that chloroethene is similar to ethane, except for the fact that one of its hydrogen atoms is replaced by a chlorine atom. There are hundreds of different addition polymers, each with at least one application. Table 8.2 summarizes some of the more common addition polymers and their applications.

Table 8.2: Common addition polymers

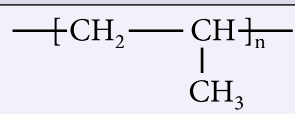
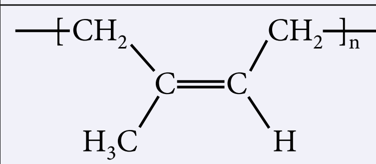
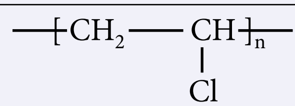
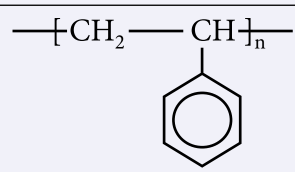
Polymer	Repeating unit	Application
Polypropylene		Plastic containers, outdoor carpeting
Polyisoprene		Rubber products, such as balls and waterproof boots
PVC (polyvinyl chloride)		Plastic water pipes, flooring
Polystyrene		Insulation, hard plastic cases for DVDs

Figure 8.15: Polypropylene and PVC products include bags, drink containers, stacking chairs, and PVC tubing and pipes.

Sources: http://commons.wikimedia.org/wiki/File:Plastiktueten.jpg; http://commons.wikimedia.org/wiki/File:Korean_beverage-Nurungji_cha-01.jpg; http://commons.wikimedia.org/wiki/File:Red_Polypropylene_Chair_with_Stainless_Steel_Structure.JPG; http://commons.wikimedia.org/wiki/File:Plastic_tubing.jpg

Condensation Polymerization

The second main type of polymerization is condensation polymerization. During condensation polymerization, a water molecule is released as monomers polymerize. For example, amino acids are the monomers of proteins.

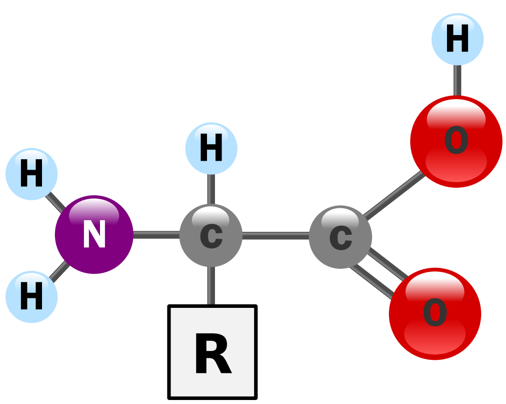
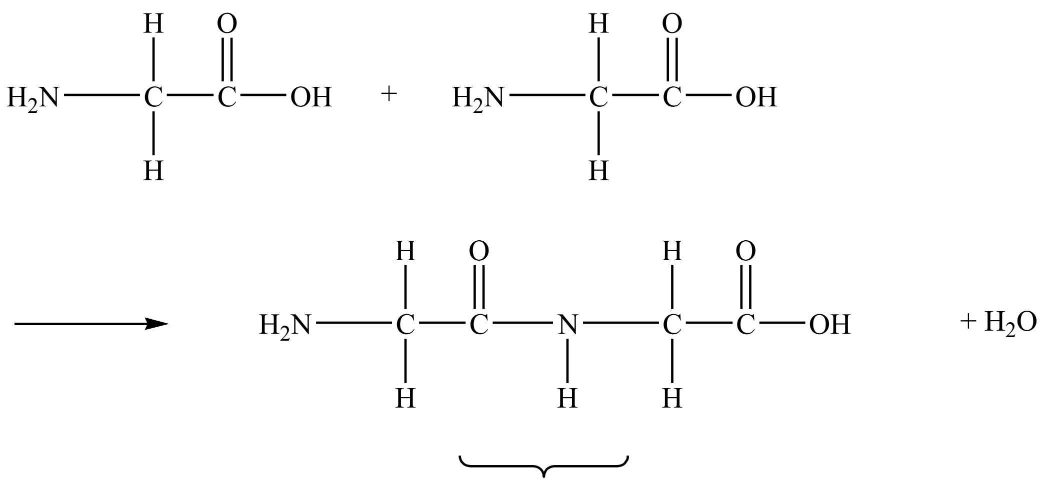


Figure 8.16: A generic amino acid

Source: http://en.wikipedia.org/wiki/File:AminoAcidball.svg

Glycine is the smallest of all of the amino acids. Figure 8.17 shows two glycine molecules joining to form a larger molecule. A single protein is made up of thousands of these units joined together.



An amide bond, also known as a peptide bond

Figure 8.17: Condensation reaction linking two glycine molecules

The bond that links the two glycine molecules together is called an amide bond. In proteins, this bond is also called a peptide bond.

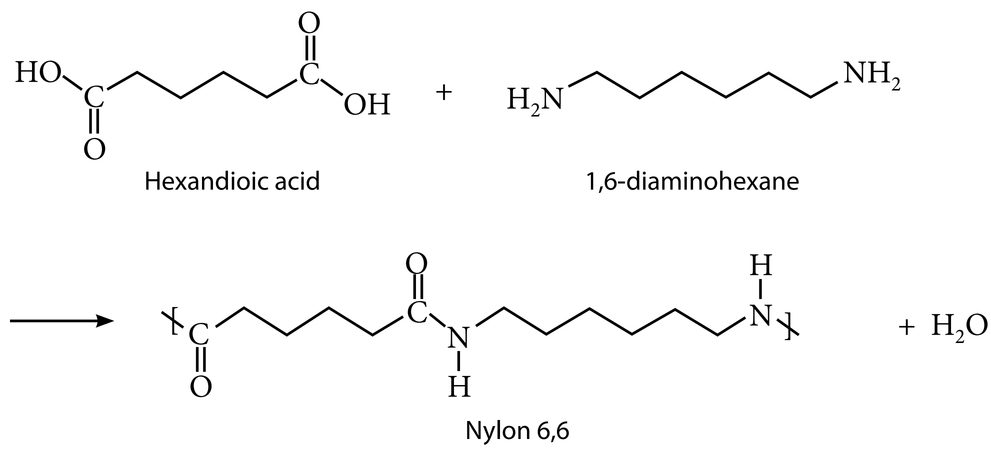
Another example of a condensation polymer is nylon. There are many different types of nylons, each with at least one application.

Running shoes Strap Toothbrushes

Figure 8.18 Nylon products

Sources: http://commons.wikimedia.org/wiki/File:US_Navy_110420-N-RM525-580_Samaritan%27s_Feet,_a_non-governmental_organization,_donated_shoes_which_were_distributed_to_students_at_the_Alpha_Boys_Sc.jpg; http://commons.wikimedia.org/wiki/File:Hose_strap_folded.jpg; http://commons.wikimedia.org/wiki/File:Toothbrush_x3_20050716_002.jpg

Nylons differ because of the different monomers used to synthesize them. For example, nylon 6,6 is a particular nylon that is produced from the condensation polymerization of the two monomers shown in Figure 8.19. It gets the "6,6" portion of its name from the fact that both the acid and the amine used to make it have six carbon atoms per molecule. Note that the bond linking the two monomers is also an amide bond.



Equation for synthesis of nylon 6,6 drawn with skeletal formulas

$$\left[\overset{\overset{\displaystyle O}{\|}}{C} - CH_2 - CH_2 - CH_2 - CH_2 - \underbrace{\overset{\overset{\displaystyle O}{\|}}{C} - NH}_{\text{Amide bond}} - CH_2 - CH_2 - CH_2 - CH_2 - CH_2 - CH_2 - NH \right]_n$$

Structural formula of a repeating unit of nylon 6,6

Figure 8.19: Synthesis (upper diagram) and repeating unit (lower diagram) of nylon 6,6

Polyethylene terephthalate, or PET for short, is used to make plastic bottles. PET can be used as an example to show how to determine the monomers used to make a condensation polymer. As shown in Figure 8.20, PET consists of two groups: terephthalate and ethylene.

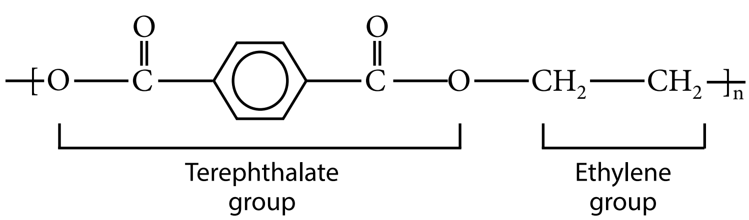
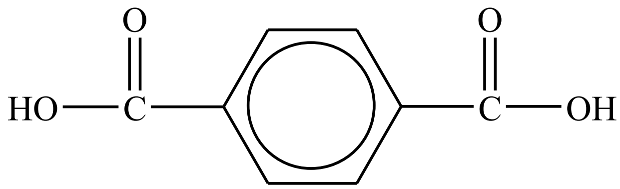


Figure 8.20: Repeating units of polyethylene terephthalate or PET

Note that the terephthalate group nearly has a carboxyl group at both ends (carboxyl groups are formed if hydrogen is added at both ends), as shown below in the formula for terephthalic acid. This suggests that the monomer must have been a dicarboxylic acid. Simply adding hydrogen to each oxygen atom ending on the terephthalate group gives you the acid monomer. The hydrogen atoms are lost during polymerization.



Terephthalic acid (Benzene-1,4-dicarboxylic acid)

Figure 8.21: Terephthalic acid is one of the monomers used to make polyethylene terephthalate, the plastic from which beverage bottles are made.

In order to produce a water molecule, the ethylene group must have had hydroxyl groups at each end. Therefore, the monomer is 1,2-ethandiol (Figure 8.22).

$$HO-CH_2-CH_2-OH$$

1,2-ethandiol

Figure 8.22: The monomer 1,2-ethandiol is also used to make polyethylene terephthalate, the plastic from which beverage bottles are made.

Polymers and the Environment

Nature is quite adept at recycling matter. This is necessary because the amount of matter on earth is limited. Other than the occasional meteor that lands on earth, the atoms that make up the matter you see around you have been here since the earth first formed. For example, the atoms in the cellulose molecules in the paper you are holding have been used over and over again since the beginning of time. Since cellulose is a natural material, nature has a way of breaking down this paper and recycling its atoms. In the future, these atoms may resurface in a plant or an animal. For many synthetic polymers however, this is not the case. Because their molecules are foreign to nature, there are few natural processes that can decompose them. So, the atoms in these polymers remained locked within the polymer for hundreds of years. It’s no wonder that many of our cities are quickly running out of landfill sites for their garbage. This also explains why the Great Pacific Garbage Patch, which you read about in this lesson’s introduction, continues to grow.

There are, of course, several ways to avoid adding to the plastic problem we face. Perhaps the most obvious one is to recycle. Many consumer products like plastic water bottles already have recycling codes stamped on them. The number inside the recycling code's symbol indicates what type of plastic the product contains. For example, the number 1 corresponds to PET. Placing number codes on plastic products facilitates the sorting of these materials, once they arrive at a recycling depot. Figure 8.23 shows the recycling symbol for PET.

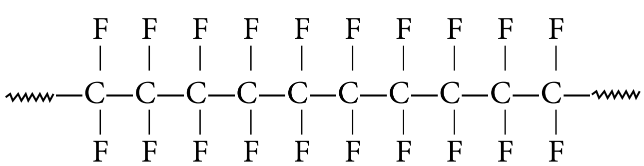
Figure 8.23: The recycling code for PET is 1. Each number represents the code for a specific type of plastic. In this case, the number 1 inside the recycling symbol means that the plastic is PET.

Recycling, however, cannot be the only solution. Because the recycling process is energy-intensive, it indirectly pollutes the environment. Exhaust emissions from the trucks involved in the curbside pickup of recyclable materials contribute to greenhouse gases in the air, and to smog. Energy is also required to run the machinery of a recycling plant. In Ontario, a significant amount of this energy is generated using non-renewable resources, such as fossil fuels and uranium. The combustion of fossil fuels also emits greenhouse gases and smog. So, the most direct way of minimizing plastic waste is to avoid using plastic, in the first place. One example of this is the gradual trend towards using reusable bags and beverage bottles, instead of disposable plastic bags and bottles.

Support Questions

45. Draw the structural diagram of two repeating units of a polymer formed from the monomer, 2-chloropropene. (**Hint:** The polymer is formed from the unsaturated alkene. The polymer is saturated.) Suggested answer

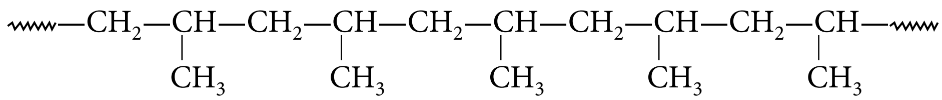
46. This image shows a portion of an addition polymer.



a) Identify the repeating unit. (**Hint:** the repeating unit originated from the alkene monomer that must have had at least two carbons in it.)

b) Name and draw the structural formula of the monomer. Suggested answer

47. Consider the following polymer:



a) Identify the repeating unit. (**Hint:** On the diagram, take a pen or pencil and place brackets around the repeating structure.)

b) Name the type of polymerization that produces this polymer.

c) Name and draw the structural formula of the monomer used to make this polymer. (**Hint:** take the repeating unit identified earlier, draw it, replace the double bond that disappeared in the polymerization reaction and add missing hydrogens from the structure.)

Suggested answer

48. a) Using structural formulas, write a chemical equation for the reaction of one molecule each of propandioic acid and 1,2-diaminoethane. What type of product is formed when an organic acid and an amine react?

b) Predict what would happen if another 1,2-diaminoethane molecule were present.

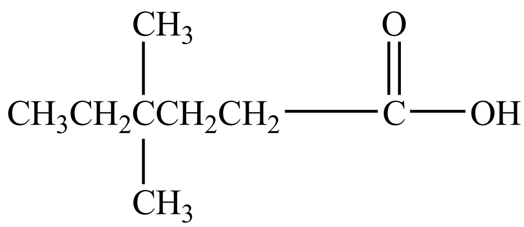
Suggested answer

Key Questions

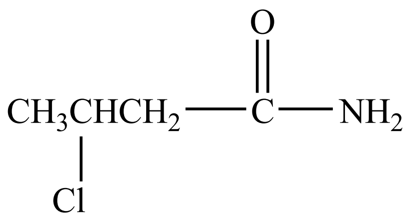
Now work on your Key Questions in the online submission tool. You may continue to work at this task over several sessions, but be sure to save your work each time. When you have answered all the unit's Key Questions, submit your work to the ILC.

29. Name the following compounds. **(6 marks total)**

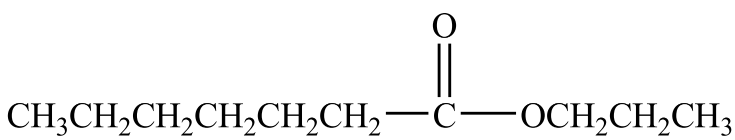
a)



b)

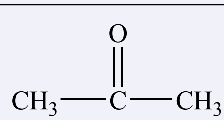


c)



30. Write a chemical equation for the synthesis of ethyl 2-methylpropanoate. Use structural formulas for each organic compound in your equation. Name each reactant. **(6 marks)**

31. **a)** Complete the table below by identifying the types of intermolecular forces in each of the following three-carbon compounds. **Note:** It is possible for there to be more than one type of intermolecular force present in a given compound. **(3 marks)**

Compound	Boiling point (°C)	Types of Intermolecular Forces
$CH_3CH_2CH_3$	–59	
	56	
$CH_3CH_2CH_2OH$	87	

b) Account for the boiling points by referring to the intermolecular forces. **(2 marks)**

32. Many offices and schools have already banned the sale of bottled water within their premises. As an expert in environmental chemistry, you have been hired by the Ministry of the Environment to do research and provide advice on the following issue:

Issue: What impact would a total ban on water sold in plastic bottles have on Ontario consumers and on Ontario's environment?

Research:

Include the following factors in your research and decision making:

- The relative success of plastic recycling
- The time and energy required for recycling
- The safety of bottled water
- The cost of bottled water
- The amount of plastic water bottles in landfills
- The safety of municipal drinking water

Decision:

Make a recommendation on the issue. Provide supporting arguments for your decision. Provide references for your research.

Communicate and summarize your decision:

Write an answer of one to two paragraphs that clearly outlines your decision and provides factual evidence for why it was made. **(9 marks total)**

This is the last lesson in Unit 2. When you have completed all the Key Questions, submit your work to the ILC. A teacher will mark it and you will receive your results online.

Periodic Table

Atomic Number → 6
Symbol → C
Name → Carbon
Average Atomic Mass → 12.011
4 -4 2 ← Common Oxidation States

Period	Group 1 IA	Group 2 IIA	Group 3 IIIB	Group 4 IVB	Group 5 VB	Group 6 VIB	Group 7 VIIB	Group 8	Group 9 VIIIB	Group 10	Group 11 IB	Group 12 IIB	Group 13 IIIA	Group 14 IVA	Group 15 VA	Group 16 VIA	Group 17 VIIA	Group 18 VIIIA
1	1 H Hydrogen 1.00794 1 -1																	2 He Helium 4.002602
2	3 Li Lithium 6.941 1	4 Be Beryllium 9.012182 2											5 B Boron 10.811 3	6 C Carbon 12.011 4 -4 2	7 N Nitrogen 14.00674 3 -3 5	8 O Oxygen 15.9994 -2	9 F Fluorine 18.9984032 -1	10 Ne Neon 20.1797
3	11 Na Sodium 22.989768 1	12 Mg Magnesium 24.3050 2											13 Al Aluminum 26.981539 3	14 Si Silicon 28.0855 4	15 P Phosphorus 30.973762 5 -3 3	16 S Sulfur 32.066 6 -2 2	17 Cl Chlorine 35.4527 -1 1 3	18 Ar Argon 39.948
4	19 K Potassium 39.0983 1	20 Ca Calcium 40.078 2	21 Sc Scandium 44.955910 3	22 Ti Titanium 47.88 4 3	23 V Vanadium 50.9415 5 4 3	24 Cr Chromium 51.9961 3 2 6	25 Mn Manganese 54.93805 2 3 4	26 Fe Iron 55.847 2 3	27 Co Cobalt 58.93320 2 3	28 Ni Nickel 58.6934 2 3	29 Cu Copper 63.546 2 1	30 Zn Zinc 65.39 2	31 Ga Gallium 69.723 3	32 Ge Germanium 72.61 4	33 As Arsenic 74.92159 3 -3 5	34 Se Selenium 78.96 4 -2 6	35 Br Bromine 79.904 -1 1 5	36 Kr Krypton 83.80
5	37 Rb Rubidium 85.4678 1	38 Sr Strontium 87.62 2	39 Y Yttrium 88.90585 3	40 Zr Zirconium 91.224 4	41 Nb Niobium 92.90638 5 3	42 Mo Molybdenum 95.94 6 5 4	43 Tc Technetium (97.90772) 7	44 Ru Ruthenium 101.07 3 4 6	45 Rh Rhodium 102.90550 3 2 4	46 Pd Palladium 106.42 2 4	47 Ag Silver 107.8682 1	48 Cd Cadmium 112.411 2	49 In Indium 114.818 3	50 Sn Tin 118.710 4 2	51 Sb Antimony 121.757 3 -3 5	52 Te Tellurium 127.60 4 -2 6	53 I Iodine 126.90447 -1 1 5	54 Xe Xenon 131.29
6	55 Cs Cesium 132.90543 1	56 Ba Barium 137.327 2	57 La Lanthanum 138.9055 3	72 Hf Hafnium 178.49 4	73 Ta Tantalum 180.9479 5	74 W Tungsten 183.84 6 5 4	75 Re Rhenium 186.207 7 -1 6	76 Os Osmium 190.23 4 2 3	77 Ir Iridium 192.22 4 2 3	78 Pt Platinum 195.08 4 2	79 Au Gold 196.96654 3 1	80 Hg Mercury 200.59 2 1	81 Tl Thallium 204.3833 1 3	82 Pb Lead 207.2 2 4	83 Bi Bismuth 208.98037 3 5	84 Po Polonium (208.9824) 4 2	85 At Astatine (209.9871) -1 1 3	86 Rn Radon (222.01761)
7	87 Fr Francium (223.0197) 1	88 Ra Radium (226.0254) 2	89 Ac Actinium (227.0278) 3	104 Rf Rutherfordium (261.11)	105 Db Dubnium (262.114)	106 Sg Seaborgium (263.118)	107 Bh Bohrium (262.12)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 Ds Darmstadtium (269)	111 Rg Roentgenium (272)	112 Uub Ununbium (275)	113 Uut Ununtrium (278)	114 Uuq Ununquadium (282)	115 Uup Ununpentium	116 Uuh Ununhexium	117 Uus Ununseptium	118 Uuo Ununoctium

58 Ce Cerium 140.115 3 4	59 Pr Praseodymium 140.90765 3 4	60 Nd Neodymium 144.24 3	61 Pm Promethium (144.9127) 3	62 Sm Samarium 150.36 3 2	63 Eu Europium 151.965 3 2	64 Gd Gadolinium 157.25 3	65 Tb Terbium 158.92534 3 4	66 Dy Dysprosium 162.50 3	67 Ho Holmium 164.93032 3	68 Er Erbium 167.26 3	69 Tm Thulium 168.93421 3 2	70 Yb Ytterbium 173.04 3 2	71 Lu Lutetium 174.967 3
90 Th Thorium 232.0381 4	91 Pa Protactinium 231.03588 5 4	92 U Uranium 238.0289 6 5 4	93 Np Neptunium (237.0482) 5 4 3	94 Pu Plutonium (244.0642) 4 3 5	95 Am Americium (243.0614) 3 4 5	96 Cm Curium (247.0703) 3	97 Bk Berkelium (247.0703) 3 4	98 Cf Californium (251.0796) 3	99 Es Einsteinium (252.083)	100 Fm Fermium (257.0951)	101 Md Mendelevium (258.10)	102 No Nobelium (259.1009)	103 Lr Lawrencium (262.111)