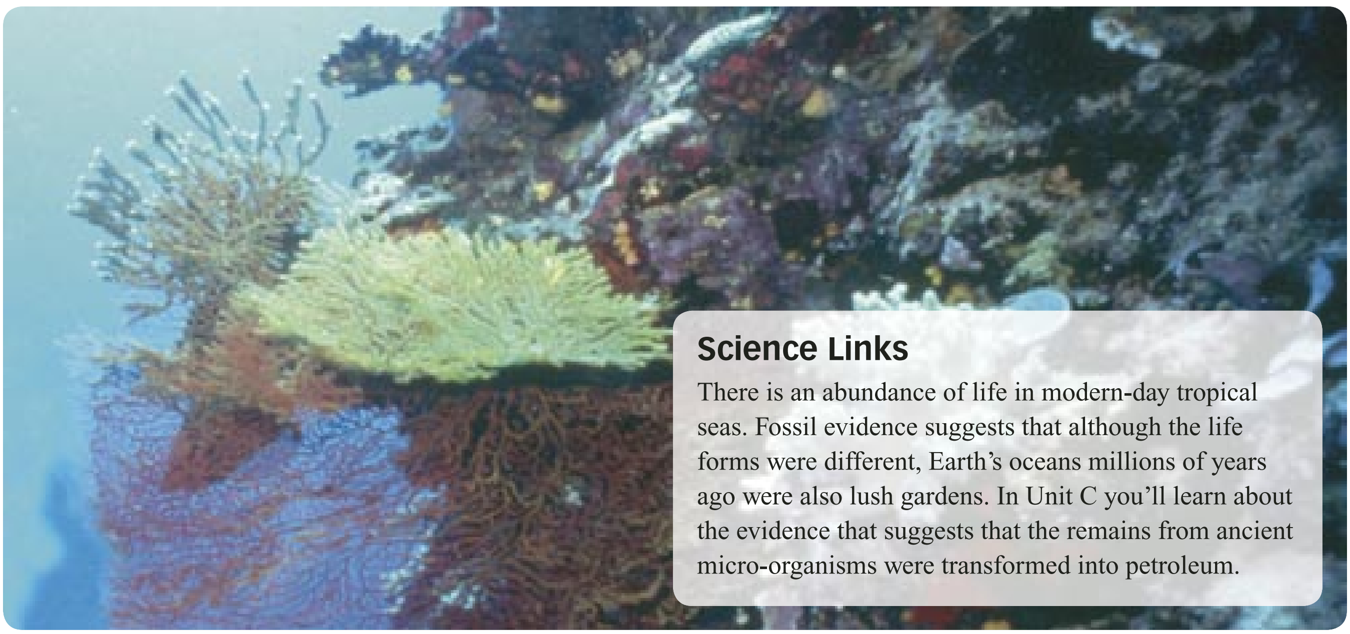
3.3 Petroleum Is the Source

Figure A3.13: Each of these products has one thing in common—petroleum.

Scientists suspect that atoms in plastics were once part of microscopic plants and animals that lived in oceans millions of years ago. If this theory is correct, that means many of the atoms in any plastic item were once in the cells of ancient micro-organisms that lived in shallow tropical seas. What is the connection between marine life from millions of years ago and plastics? The answer is **petroleum**.

petroleum: liquid hydrocarbons formed over millions of years from the remains of ancient microscopic marine organisms



Science Links

There is an abundance of life in modern-day tropical seas. Fossil evidence suggests that although the life forms were different, Earth's oceans millions of years ago were also lush gardens. In Unit C you'll learn about the evidence that suggests that the remains from ancient micro-organisms were transformed into petroleum.

Petroleum contains a large variety of hydrocarbons of different sizes. It might be easier to think of petroleum as a soup of hydrocarbon molecules.

After locating the resource, the petroleum is pumped out of the ground and is separated into different components. Each component is a mixture of smaller molecules, called a **fraction**. The process of separating and processing petroleum into different fractions is called **refining**.

How is a refinery able to separate groups of molecules from the large and diverse mixture of hydrocarbons that is petroleum? How does this process work? To answer these questions, you need to look at the physical properties of the substances you are trying to separate.

Figure A3.14: An oil refinery separates petroleum into its component molecules.

fraction: a group of compounds found in petroleum with similar properties and uses

refining: an industrial process that separates, purifies, and alters raw materials

Try This Activity

Separating Components of a Mixture

Science Skills

✓ Initiating and Planning

Purpose

You will design a procedure for separating the components of a mixture.

Materials

- 50 mL of salt
- 50 mL of wood chips
- 50 mL of sand
- 50 mL iron filings
- glass beaker (or jar)

CAUTION!

Iron filings can be very messy. If you get these filings on your fingers, they can be quickly transferred to your clothing where they may leave permanent stains, especially if they get wet.

Procedure

step 1: Combine the salt, wood chips, sand, and iron filings in the plastic bucket. Stir the components to make the mixture as uniform as possible.

step 2: Use your knowledge of the properties for each substance to design a procedure that will allow you to separate the mixture into its individual components.

Analysis

1. For each component of the mixture, describe the properties you would use to separate that component from the mixture.
2. Is the order in which you separate the fractions from the mixture important? Give a reason for your answer.
3. Imagine you are on a deserted island in the middle of the ocean and there is no source of fresh water on the island. The only water available to you is the salt water from the ocean. Devise a procedure you could use to separate the salt from the water to obtain fresh water.

Separating Petroleum into Its Fractions

The properties of each substance—salt, sand, iron filings, and woodchips—were used to determine the methods for separation. For example, a magnet was used to separate the iron filings because only the filings were attracted to the magnet. In the case of petroleum, the property used to separate the components of the mixture is the unique boiling point for each group of hydrocarbons. You can explore this process by using a computer applet in the next activity.

Figure A3.15: Magnets are so effective at attracting iron filings that the filings can be difficult to remove from the surfaces of the magnets.

Utilizing Technology

From Petroleum to Gasoline

Science Skills
✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

You will use the "Fractional Distillation" applet on the Science 20 Textbook CD to explore the process of separating petroleum into its components.

Background

Before starting this activity, read through the procedure and the analysis to get a sense of what information you will need to record and what questions you will need to answer. This applet uses the term *crude oil* interchangeably with *petroleum*. Throughout this textbook, you can consider these two terms to mean the same thing.

Procedure

step 1: Obtain the handout "Atmospheric Distillation Tower" from the Science 20 Textbook CD. Add labels to this graphic as you complete the applet.

step 2: Work through the applet by completing all the activities on each page.

step 3: Return to the various pages of the applet as you answer the analysis questions.

Analysis

1. Add the missing labels to the "Atmospheric Distillation Tower" handout.

2. Define *isomers*. Provide an example that illustrates its meaning.

3. Cracking is a process used in the refining of petroleum.

- **a.** Define *cracking*. Provide a balanced chemical equation to illustrate its meaning.
- **b.** Suggest a reason why the word *cracking* was applied to this chemical process.

4. Alkylation is a process used to make 2,2,4-trimethylpentane, a key component in gasoline.

- **a.** Identify the other name for 2,2,4-trimethylpentane.
- **b.** Describe *alkylation*. Use the balanced chemical equation for the production of 2,2,4-trimethylpentane to illustrate your answer.
- **c.** Earlier, you learned that an alkyl group is an alkane with one hydrogen atom removed that acts as a branch in a larger molecule. Use this information to suggest why the process of making 2,2,4-trimethylpentane is called alkylation.

5. The performance rating of gasoline is improved by adding hydrocarbons that have undergone a reforming reaction.

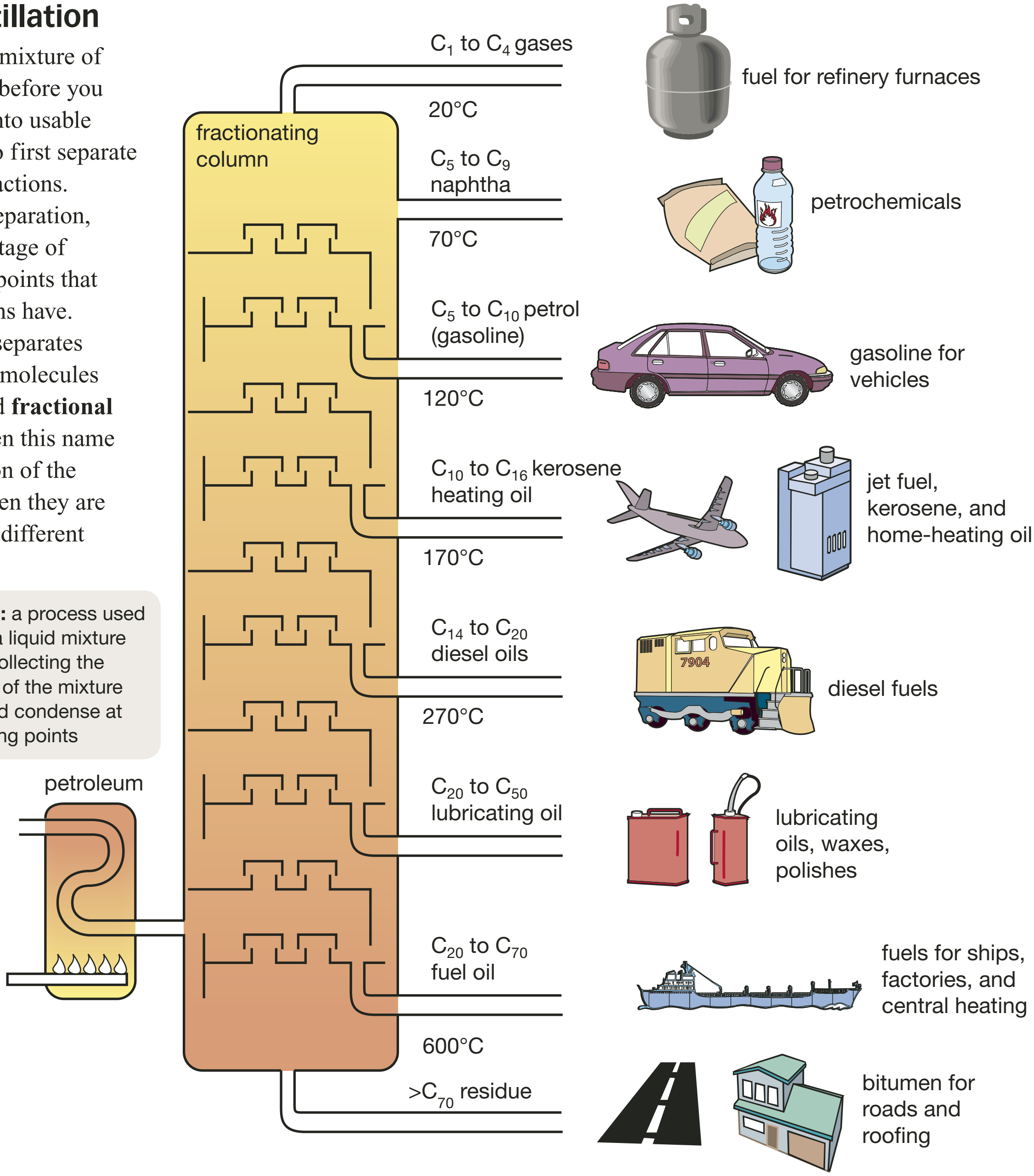
- **a.** Define *reforming*, and use a balanced chemical equation to illustrate your answer.
- **b.** Suggest a reason why the term *reforming* was applied to this process.

Fractional Distillation

Since petroleum is a mixture of many hydrocarbons, before you can turn petroleum into usable products, you need to first separate it into its different fractions. To accomplish this separation, refineries take advantage of the different boiling points that different hydrocarbons have.

The process that separates the different sizes of molecules in petroleum is called **fractional distillation**. It is given this name because the separation of the molecules occurs when they are gases and can rise to different levels in the tower.

fractional distillation: a process used for the separation of a liquid mixture by vaporizing it and collecting the different components of the mixture as they cool down and condense at their appropriate boiling points



In Lesson 3.2 you discovered that the boiling point of a hydrocarbon increases as the number of carbons within the hydrocarbon increases. Here is a quick summary of how the petroleum industry uses fractional distillation:

step 1: The petroleum is vaporized in a hot furnace.

step 2: The petroleum vapour is placed into a tall column.

step 3: The hot vapours rise inside the column. As the vapour moves away from the heat source, it cools.

step 4: As the vapour cools, it not only drops in temperature, but the molecules condense to form liquids at different places in the tower. By condensing at different locations in the tower, the fractions can be collected separately.

step 5: Fractions with high boiling points—the largest molecules in the mixture—will condense first at the bottom of the column. Fractions with lower boiling points—the smallest molecules in the mixture—condense higher in the column. Those fractions that are gaseous at normal temperatures are collected at the top of the column as gases.

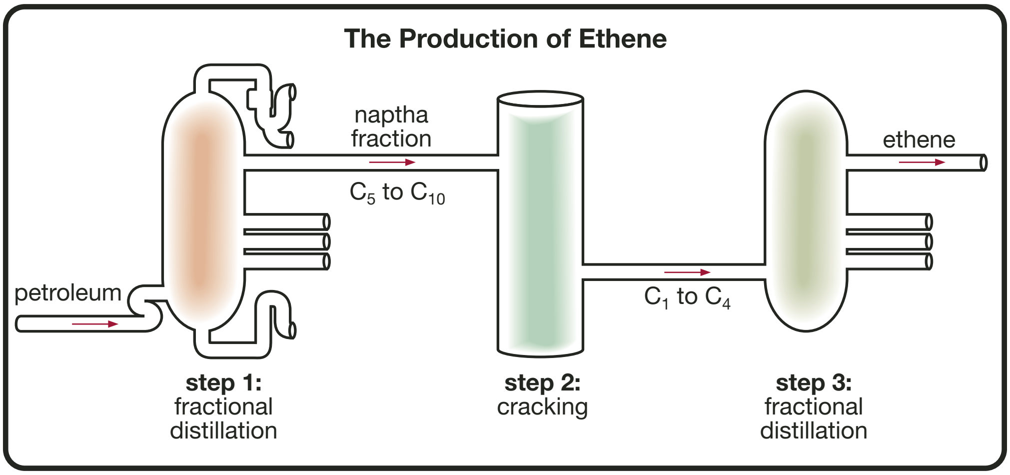
Processing Hydrocarbons

Smaller hydrocarbons are often more useful than larger hydrocarbons because they can easily be reacted to construct new molecules used to make products. Because smaller molecules are easier to manipulate in a chemical reaction, larger hydrocarbon molecules are often used as a source of smaller molecules. It is much easier to use smaller molecules as the building blocks to create larger molecules.

The breaking up of larger hydrocarbons to form smaller molecules is called **cracking**. A hydrocarbon can be cracked by catalytic cracking—a process that uses a catalyst and lower pressure and temperature—or by thermal cracking—a process that uses high pressure and temperature.

cracking: a reaction in which hydrocarbons are broken down into smaller molecules by means of heat (thermal cracking) or catalysts (catalytic cracking)

"The Production of Ethene" diagram shows how the naphtha fraction from a fractional distillation tower is passed to another pressurized tower where high-pressure steam is used to crack the molecules that form the naphtha mixture into smaller molecules.



The naphtha fraction shown between steps 1 and 2 contains a mixture of hydrocarbons containing between 5 and 10 carbon atoms. One molecule that could be in this naphtha fraction is $C_8H_{18}(g)$. The following equation shows how $C_8H_{18}(l)$ undergoes cracking in step 2 to produce ethene, $C_2H_4(g)$.

$$C_8H_{18}(l) \rightarrow 2\ C_2H_4(g) + C_3H_6(g) + CH_4(g)$$

The ethene is separated from the other products of the cracking reaction in step 3, where fractional distillation is used again. The ethene produced from cracking reactions is used to make polyethylene. This plastic is produced in larger quantities than any other plastic; approximately 50 million tonnes of polyethylene are produced worldwide every year.

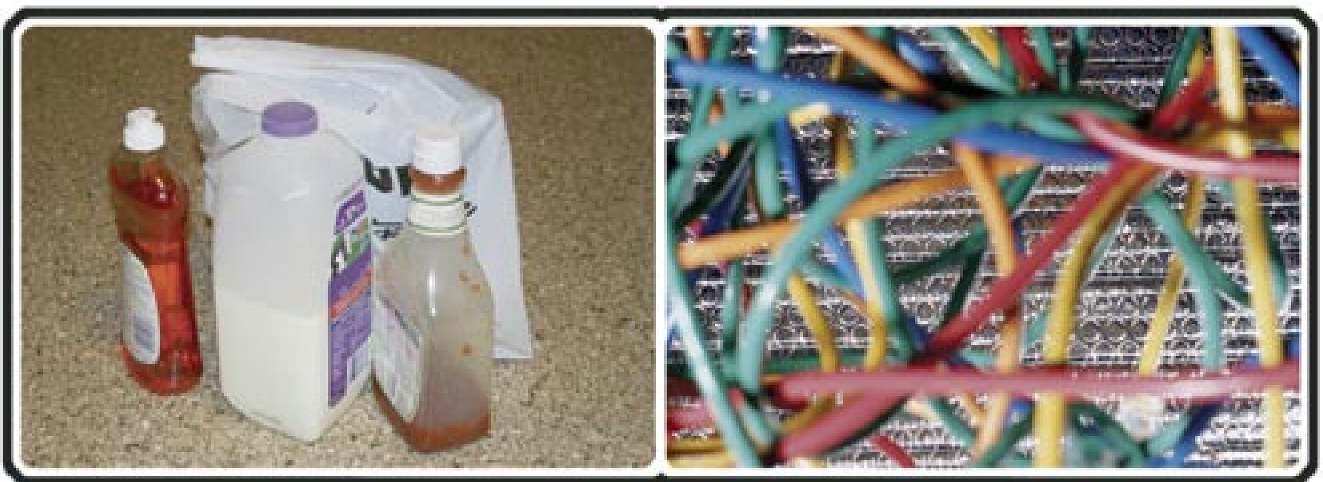


Figure A3.16: Polyethylene is used to make many products.

Most polyethylene is used to manufacture the thin plastic used in grocery bags, freezer bags, and cling wrap. It is also used to make plastic food containers and insulation for electrical cables and wire.

Practice

39. Outline the steps involved in the fractional distillation process.

40. Refer to the diagram and equation on page 141 that shows the production of ethene from the naphtha fraction. Assume that the compounds are unbranched hydrocarbons.

- **a.** Translate this chemical equation into a word equation that properly names each reactant and product.
- **b.** Identify each reactant and product as being an alkane, alkene, or alkyne.
- **c.** If this reaction generates 152.5 mol of ethene every second, how many moles of $C_8H_{18}(l)$ are required?

41. Ethene can also be produced by cracking ethane. In this reaction, another substance is produced in addition to ethene. Write a balanced chemical equation to describe this reaction.

Did You Know?

A ripe banana can speed up the ripening process of a bowl of unripe tomatoes. How does this happen? Does the banana signal the tomatoes that its time to ripen? As astonishing as this may sound, the banana does send a signal to the tomatoes, in the form of an invisible, odourless gas—ethene. This gas is naturally produced by fruit as it ripens, and its presence can trigger the ripening process in other fruit. Some plants are so sensitive to this effect that they can detect ethene at a concentration of only 1 ppm in air.

Try This Activity

Get Cracking

Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

Purpose

You will complete a pencil-and-paper exercise that has a surprising number of correct answers. You will take a saturated hydrocarbon chain with 15 carbon atoms and crack it to produce three smaller hydrocarbon molecules.

Procedure

Using a pencil, paper, and an eraser, try to write a balanced chemical equation to summarize a possible cracking reaction. Remember to add states of matter and to check that the equation is balanced. It may take a few attempts to make this work because even though a compound like CH_6 might help to balance your equation, you know that carbon has four bonds and each hydrogen has one. So, a compound like CH_6 is chemically impossible.

Analysis

1. Write the balanced chemical equation for your cracking reaction.
2. Draw the complete structural diagram of the original molecule with the 15 carbon atoms.
3. Draw the complete structural diagram of the three products of the cracking reaction. Add the names of each of the products of the cracking reaction.
4. Are any of your products unsaturated hydrocarbons? Explain why unsaturated compounds form during hydrocarbon cracking.
5. Describe how you could separate the resulting mixture of smaller hydrocarbons produced by the reaction.
6. Compare your results with those of your classmates. Why are there so many possible outcomes even though you all began with the same substance?

Cracking Is a Random Reaction

As was shown by the results of the "Get Cracking" activity, when you crack a single, large saturated hydrocarbon chain, a number of possible combinations of products can be produced. This is because the cracking action can occur at many places along the carbon chain.

Also, notice that you produce unsaturated hydrocarbons during this process. This is because the original molecule had only two carbon atoms at the end position, accommodating three hydrogen atoms each. If the result of cracking is three smaller molecules, that gives a total of six carbons in the end position. Now, there are not enough hydrogen atoms to have all of these new compounds become saturated. So, unsaturated hydrocarbons are produced since there is an insufficient number of hydrogen atoms to completely saturate the products of the reaction.

3.3 Summary

Petroleum is a complex mixture of many different hydrocarbons that can be separated using fractional distillation. This process uses the different boiling points of each group of hydrocarbons to separate the mixture into different fractions. Each fraction that results from this process contains compounds that have a surprisingly large number of applications. Sometimes hydrocarbons are broken into smaller hydrocarbon chains by the process called cracking.

3.3 Questions

Knowledge

1. Define each of the following terms.

- **a.** petroleum
- **b.** fraction
- **c.** refining
- **d.** separation
- **e.** fractional distillation
- **f.** cracking

2. Explain why it is often useful to subject larger hydrocarbons to cracking.

3. State two methods that industries use to break a large hydrocarbon to form smaller chains.

4. Draw the complete structural diagram of a saturated hydrocarbon chain that contains 12 carbons. Use your drawing to create a balanced chemical equation of a cracking reaction.

Applying Concepts

5. "All of our products come from Earth." Use ideas presented in this chapter to explain the accuracy of this statement.

6. Describe uses for the compounds found in the lower sections of a fractional distillation column.

7. Describe uses for the compounds found in the higher sections of a fractional distillation column.

8. You have a solution composed of two molecules with different boiling points. Describe a method in which you can separate the mixture into the two fractions.

9. Explain why it is important for industry to have effective and efficient ways of separating petroleum into different fractions.

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Legend: t = top, m = middle, b = bottom, l = left, r = right

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