SECTION A PETROLEUM—WHAT IS IT?

Introduction

The word "petroleum" is probably quite familiar to you. But do you know what petroleum is or what it is made of? Can you explain what properties make it useful for both burning and building? In this section you will explore the characteristics of some key compounds found in petroleum. Specifically, you will focus on their structure, bonding, and properties.

A.1 WHAT *IS* PETROLEUM?

The word "petroleum" comes from the Latin words petra ("rock") and oleum ("oil").

Petroleum is a vitally important world resource. As pumped from underground, petroleum is known as crude oil, or "black gold." This liquid varies from colorless to greenish-brown to black, and may be as thin as water or as thick as soft tar. Crude oil cannot be used in its natural state. Instead, it is shipped by pipeline, ocean tanker, train, or barge to oil refineries, where it is separated into simpler mixtures. Some of these mixtures are ready for use, whereas others require further refinement. Refined petroleum is chiefly a mixture of various hydrocarbons—molecular compounds that contain atoms of the elements hydrogen and carbon only. Can you see how this class of compounds got its name?

Nearly 50% of the total energy needs of the United States are met by burning petroleum. Thus most petroleum is consumed as a fuel. Converted to gasoline, petroleum powers millions of automobiles in the United States, each traveling an average of 11 000 miles annually. Other petroleum-based fuels provide heat to homes and businesses, deliver energy to generate electricity, and propel diesel engines and jet aircraft.

But petroleum's importance goes beyond its use as just a fuel. Its other major use is as a raw material from which a stunning array of familiar and useful products are manufactured—from CDs, sports equipment, clothing, automobile parts, and carpeting to prescription drugs and artificial limbs. Based on your experiences with petroleum fuels and products, what percent of petroleum would you estimate is used for burning? For building? Can you identify other uses of petroleum? The answers in the next paragraph may surprise you.

What did you predict for the percent of petroleum used for burning? Fifty percent? Sixty percent? Astonishingly, 84% of petroleum is burned outright as fuel. Only about 7% is used for producing substances such as medications and plastics. The remaining 9% is used as lubricants, road-paving materials, and an assortment of miscellaneous products. For every gallon of petroleum that is used to produce useful products, more than five gallons are burned to release energy.

What happens to molecules in petroleum when they are burned or used in manufacturing? As in all chemical reactions, the atoms become rearranged to form new molecules. When hydrocarbons burn, they react with oxygen gas in the air to form carbon dioxide (CO_2) gas and water vapor.

These gases disperse in the air. The hydrocarbon fuel is used up; it will take millions of years for natural processes to replace it. Thus petroleum is a nonrenewable resource—much like the minerals you studied in Unit 2.

Like other resources, petroleum is not uniformly distributed around the world. Approximately 57% of the world's known crude oil reserves are located in just five Middle Eastern nations: Iran, Iraq, Kuwait, Saudi Arabia, and the United Arab Emirates. By contrast, the petroleum reserves of North America amount to only about 7% of the world's known supply. The distribution of crude oil reserves does not necessarily correspond to population or use of petroleum. For example, Asia, the Far East, and Oceania account for 60% of the world's population, but this region has only about 4% of the world's petroleum reserves. Figure 1 shows these global distributions.

You have just learned what petroleum is, what it is used for, and where it is found. Petroleum is actually a complex mixture of hydrocarbons that must be refined or separated into simpler mixtures in order to be useful. In the following activity, you will find out about this basic separation process as you investigate a simple mixture of two liquids.

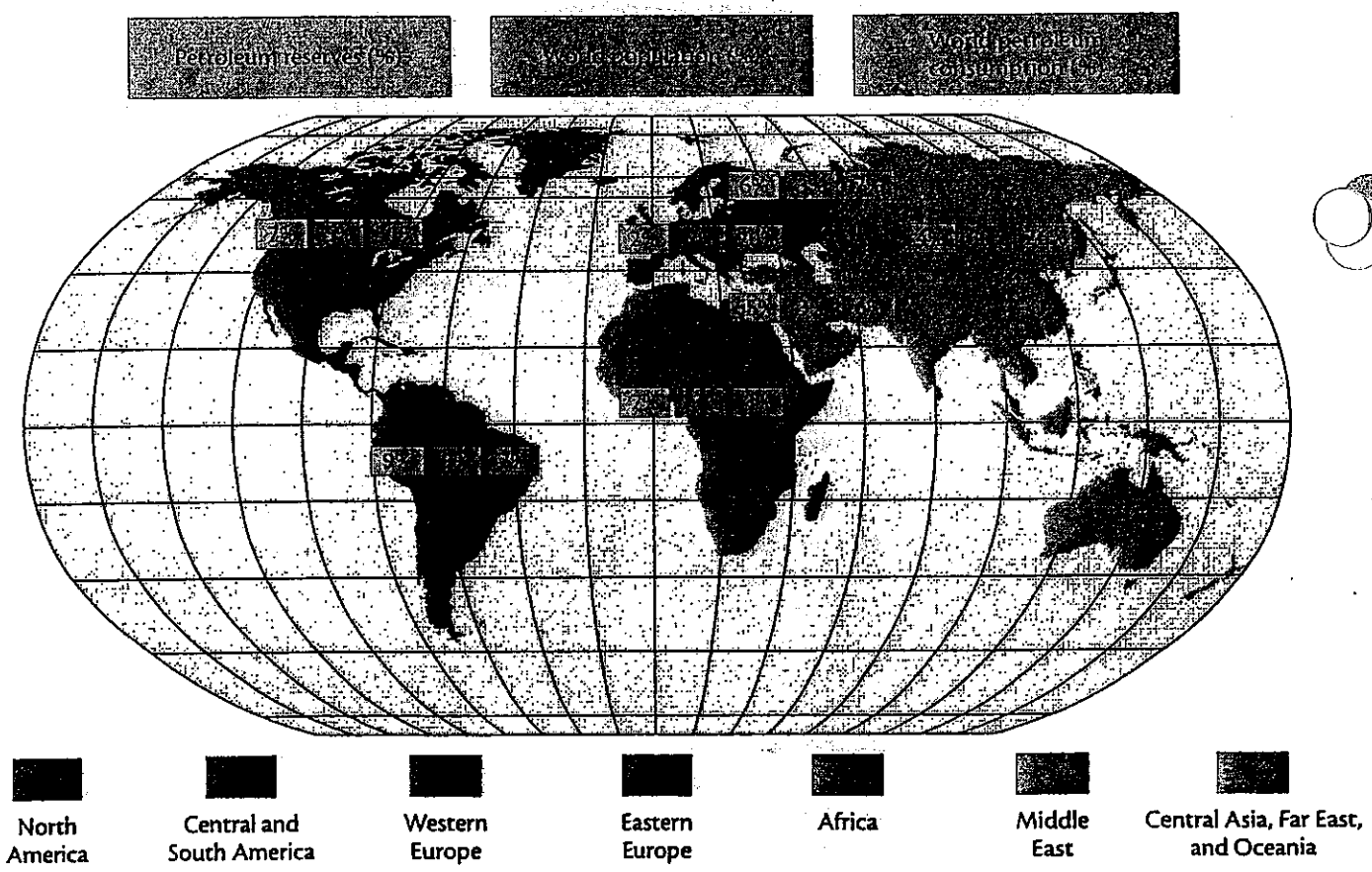

Figure 1 *Distribution of world's petroleum reserves, population, and consumption of petroleum.*

the graph line should appear flat (horizontal). How well do these plateaus match the temperatures at which the first drops of each distillate were collected?

3. Using data in Figure 2 on page 178, identify each distillate sample.
4. Compile your data with the data of those students who distilled the same mixture.
   a. Find the mean and the mode for each distillate temperature.
   b. All laboratory teams did not obtain the same distillation temperatures. Why?
5. In which distillate was iodine more soluble? Explain.
6. What laboratory tests could you perform to decide whether the liquid left behind in the flask is a mixture or a pure substance?
7. Of the substances listed in Figure 2, which two would be most difficult to separate by distillation? Why?
8. a. What would a graph of time vs. temperature look like for the distillation of a mixture of all four substances listed in Figure 2?
   b. Sketch the graph and describe its features.

The statistical mode is the most frequently reported value in a set of data.

A.3 PETROLEUM REFINING

Unlike the simple laboratory mixture you investigated in the preceding activity, crude oil is a mixture of many compounds. Separating such a complex mixture requires the application of distillation techniques to large-scale oil refining. The refining process does not separate each compound contained in crude oil. Rather, it produces several distinctive mixtures called **fractions**. This process is known as **fractional distillation**. Compounds in each fraction have a particular range of boiling points and specific uses. Figure 4 illustrates the fractional distillation (fractionation) of crude oil.

First, the crude oil is heated to about 400 °C in a furnace. It is then pumped into the base of a distilling column (fractionating tower), which is usually more than 30 m (100 ft) tall. Many of the component substances of the heated crude oil vaporize. The temperature of the column is highest at the bottom and decreases toward the top. Trays are arranged at appropriate heights inside the column to collect the various fractions.

During distillation, the vaporized molecules move upward in the distilling column. The smaller, lighter molecules have low boiling points and either condense high in the column or are drawn off the top of the tower as gases. Fractions with higher boiling points contain larger molecules, which are more difficult to separate from one another and thus require more thermal energy to vaporize. These molecules condense in trays lower in the column. Substances with the highest boiling points never vaporize. These thick, or viscous, liquids—called bottoms—drain from the column's base. Each arrow in Figure 4 indicates the name of a particular fraction and its boiling-point range.

As you learn more about the characteristics of the fractions obtained from petroleum, think about how their products find uses in both traditional and electric vehicles.

Although the names given to various fractions and their boiling ranges may vary somewhat, crude oil refining always has the same general features.

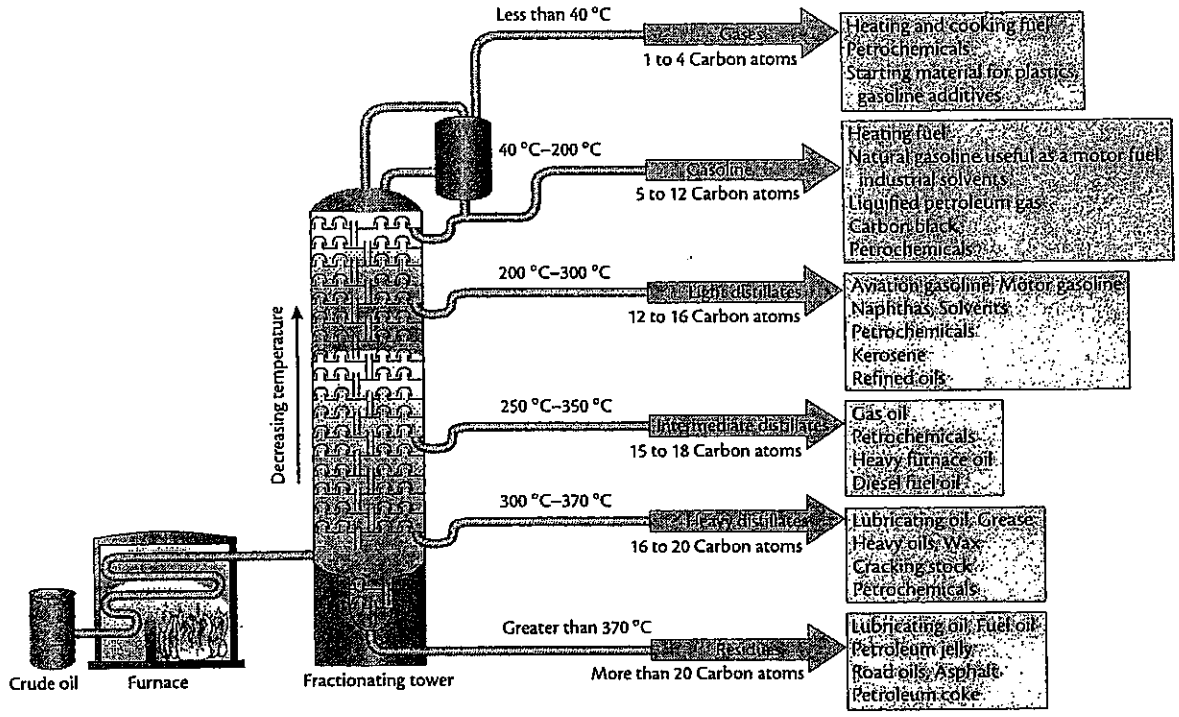

Figure 4 *A fractioning tower.*

A.4 A LOOK AT PETROLEUM'S MOLECULES

Petroleum's gaseous fraction contains compounds with low boiling points (less than 40 °C). These small hydrocarbon molecules, which contain from one to four carbon atoms, have low boiling points because they are only slightly attracted to each other or to other molecules in petroleum. Forces of attraction between molecules are called **intermolecular forces.** As a result of weak intermolecular forces, these small hydrocarbon molecules readily separate from each other and rise through the distillation column as gases.

Petroleum's liquid fractions—including gasoline, kerosene, and heavier oils—consist of molecules having from five to about twenty carbon atoms. Molecules with even more carbon atoms are found in the greasy solid fraction that does not vaporize. These thick, "sticky" compounds have the strongest intermolecular forces among all substances found in petroleum. It is not surprising that they are solids at room temperature.

Now complete the following activity to learn more about physical properties of hydrocarbons.

Just as "interstate highway" means a road that runs between states, intermolecular forces means forces between molecules.

HYDROCARBON BOILING POINTS — Building Skills 1

Chemists often gather and analyze data about the physical and chemical properties of substances. These data can be organized in many ways, but the most useful techniques uncover trends or patterns among the data.

The development of the Periodic Table is an example of this approach. To refresh your memory about the Periodic Table, refer back to Section 2A.1.

Figure 5 *The boiling points of selected hydrocarbons.*

Hydrocarbon Boiling Points	
Hydrocarbon	Boiling Point (°C)
Butane	−0.5
Decane	174.0
Ethane	−88.6
Heptane	98.4
Hexane	68.7
Methane	−161.7
Nonane	150.8
Octane	125.7
Pentane	36.1
Propane	−42.1

In a manner similar to the one you used earlier to predict a property of an unknown element, you can examine patterns among the boiling points of some hydrocarbons in order to make valuable predictions. Use the data found in Figure 5 to answer the following questions.

1. a. In what pattern or order are Figure 5 data organized?
   b. Is this a useful way to present the information? Explain.
2. You are searching for a trend or pattern among these boiling points.
   a. Propose a more useful way to arrange these data.
   b. Reorganize the data table based on your idea.

Use your reorganized data table to answer these questions.

3. Which substance(s) are gases (have already boiled) at room temperature (22 °C)?
4. Which substance(s) boil between 22 °C (room temperature) and 37 °C (body temperature)?
5. What can you infer about intermolecular forces among decane molecules compared to those in butane?

A.5 CHEMICAL BONDING

Chemical Bonding

Hydrocarbons and their derivatives are the focus of the branch of chemistry known as **organic chemistry.** These substances are called organic compounds because early chemists thought that living systems—plants or animals—were needed to produce them. However, chemists have known for more than 150 years how to make many organic compounds without any assistance from living systems. In fact, starting materials other than petroleum can be used to produce organic compounds. You will learn about some of these starting materials in Section C.

The carbon chain forms a framework to which a wide variety of other atoms can be attached.

In hydrocarbon molecules, carbon atoms are joined to form a backbone called a **carbon chain.** Hydrogen atoms are attached to the carbon backbone. Carbon's versatility in forming bonds helps to explain the abundance of different hydrocarbon compounds, as you will soon learn. Hydrocarbons

increases. For example, chemists have identified three pentane (C_5H_{12}) isomers. Their structural formulas are shown in Figure 10. Try building these and other models. Are other pentane isomers possible?

Alkane Isomers

Alkane	Structural Formula	Boiling Point (°C)
C_5H_{12} isomers	$CH_3-CH_2-CH_2-CH_2-CH_3$	36.1
	$CH_3-CH(CH_3)-CH_2-CH_3$	27.8
	$CH_3-C(CH_3)_2-CH_3$	9.5
Some C_8H_{18} isomers	$CH_3-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_3$	125.6
	$CH_3-CH_2-CH_2-CH_2-CH_2-CH(CH_3)-CH_3$	117.7
	$CH_3-CH(CH_3)-CH_2-C(CH_3)_2-CH_3$	99.2

Figure 10 *Some pentane and octane isomers.*

4. Now consider possible isomers of C_6H_{14}.
   a. Working with a partner, draw structural formulas for as many different C_6H_{14} isomers as possible. Compare your structures with those drawn by other groups.
   b. How many different C_6H_{14} isomers were found by your class?
5. Build models of one or more C_6H_{14} isomers, as assigned by your teacher.
   a. Compare the three-dimensional models built by your class with corresponding structures drawn on paper.
   b. Based on your examination of the three-dimensional models, how many different C_6H_{14} isomers are possible?

Because each isomer is a different substance, it has its own characteristic properties. In the next activity, you will examine boiling-point data for some alkane isomers.