Solar Education for NY
SchoolPower ...Naturally

The Chemistry of Refining Crude Oil
SPN LESSON #12

LEARNING OUTCOME: Students come to view energy from several viewpoints. They work with the processes of

- Phase changes and the many energy transformations and transfers involved in that physical change;
- chemical change and the energy it releases.

LESSON OVERVIEW: The fractional distillation of crude oil is featured. This major fossil fuel of the modern age is viewed as an example of stored chemical energy. Alcohol and water are separated and recaptured by taking advantage of the differences in the two substances' boiling points. The many components of crude oil are explored and students are introduced to organic chemical formulas, characteristics of changes in phases, and laboratory distillation procedures.

GRADE-LEVEL APPROPRIATENESS: This Level II Physical Setting, technology education lesson is intended for students in grades 5–8.

***MATERIALS* (per group)**

Safety goggles (per person)
Lab apron (per person)
Bunsen burner
Ring stand with utility clamp
Metal pan
3 medium test tubes
Test tube rack
Boiling chip
2-hole stopper
10 cm glass tubing with 90^{o} bend
Thermometer
15 mL of isopropyl alcohol–water mixture

Stirring rod
Graduated cylinder
Grease pencil or marker
4 paper strips, 10 cm x 1 cm
60 cm rubber tubing

SAFETY

Students should be made familiar with proper laboratory safety procedures including the location of fire extinguishers, fire blankets, and safety showers (where available). Instruct students regarding the proper and safe use of Bunsen burners and matches, and stress the importance of keeping the volatile components of the fractional distillation away from the flame during the collection of distillates. All students should wear safety goggles. Hair should be tied back and lab aprons worn.

TEACHING THE LESSON

This activity should not be undertaken until after students have completed instruction in basic laboratory procedures and safety. You may want students to assemble their laboratory equipment on the day or during the period before undertaking the distillation. Give students a chance to review the procedures during classroom instruction, and again overnight as homework, so they are thoroughly familiar with the general nature of the task. If feasible, have students work in groups of three to carry out lab procedures and collect data. Questions from the Develop Your Understanding section can be completed for homework and discussed in class the following day to clarify responses. This lesson might require three to four class periods to complete.

ACCEPTABLE RESPONSES FOR DEVELOP YOUR UNDERSTANDING SECTION

Introduction:

1. Numbers will vary somewhat but should follow this pattern.

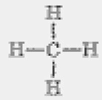
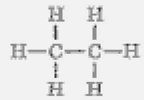
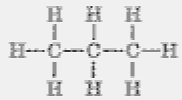
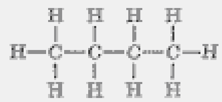
Energy Source	CO-CO_2	NO-NO_2	SO-SO_2	Other
Wood	high	low	low	heat
Coal	high	medium	high	heat
Oil	high	low-medium	low	heat
Uranium	none	none	none	heat

2. The potential of oil spills during extraction from the ground and during transport

Lab Section:

4. Data will vary but should indicate a nearly level trend during changes and a rising rapidly trend in between.
8. Test tube #1 should have the strongest odor, test tube #3 the weakest.
9. Test tube #1 ignites easily (the alcohol), #2 grudgingly (mixture), and #3 not at all (water).
10. Boiling temperature: the alcohol boils (evaporates) at around 82^{o}C.
11. CH_4 (methane), C_2H_6 (ethane), C_3H_8 (propane), C_4H_{10} (butane)

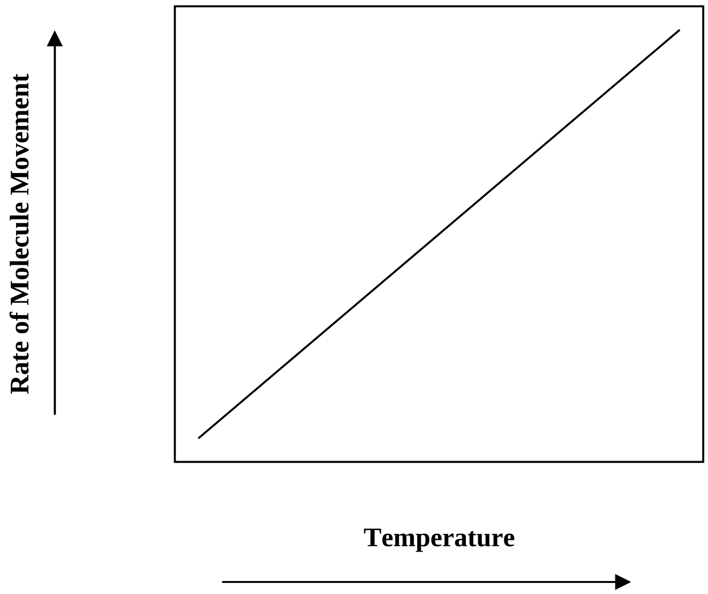
12.

CH_4	
C_2H_6	
C_3H_8	
C_4H_{10}	

Develop Your Understanding Section:

1. Graph line should rise steadily to ~82^o where it levels until most of the alcohol has evaporated. Graph line then rises again until water starts to boil; at that point it once again levels off at 100^o.
2. Because the fluid was heating
3. The alcohol was evaporating rapidly, changing phase.
4. The alcohol had evaporated.
5. Heat energy was gained, causing a change in phase.
6. Energy was lost to the environment as the gas condensed.
7. Heat was transferred to the test tube mostly by convection (upward movement of less-dense air molecules) and radiation (electromagnetic waves created within heated atoms). Conduction (the exchange of kinetic energy from atom to atom) carried the heat through the glass test tube into the fluid.
8. The movement of heated atoms and molecules

9.



10. The chemical bonding energy in the molecules of alcohol
11. No
12. The combustion of the gas in the Bunsen burner: $C_3H_8 + 5\ O_2 \longrightarrow 3\ CO_2 + 4\ H_2O$
13. Carbon dioxide and water
14. Yes, carbon dioxide can cause suffocation and it is a greenhouse gas.
15. No, energy cannot be created or destroyed.
16. Yes, stored chemical bonding energy changed into both heat and light.
17. Nonrenewable
18. Sunlight
19. Photosynthesis in green plants

ADDITIONAL SUPPORT FOR TEACHERS

SOURCE FOR THIS ADAPTED ACTIVITY

This lesson was adapted from the *ISIS: Fossil Fuels* module developed at Florida State University and published by Ginn and Company, 1980.

BACKGROUND INFORMATION

The processing of crude oil typically begins with the removal of salts and water. The remainder is then heated to approximately 650°F; this heat vaporizes the lighter fuel elements such as propane and gasoline as part of the fractional distillation process. Generally, the less carbon contained in the molecular formula of a petroleum component, the lower the boiling point and melting point, as the chart below shows. Teachers may want to have their students graph these relationships, as a prelude to discussing them.

Number of carbon atoms	**Name of alkane**	**Molecular formula**	**Melting point (º C)**	**Boiling point (º C)**
1	Methane			
2	Ethane			
3	Propane			
4	Butane			
5	Pentane			
6				
7				
8				
9				
10				

Number of carbon atoms	Name of alkane	Molecular formula	Melting point (°C)	Boiling point (°C)
1	methane	CH_4	–182	–161
2	ethane	C_2H_6	–172	–88
3	propane	C_3H_8	–187.7	–42.1
4	butane	C_4H_{10}	–138.4	–0.5
5	pentane	C_5H_{12}	–129.7	36.1
6	hexane	C_6H_{14}	–95	69
7	heptane	C_7H_{16}	–90.6	98.4
8	octane	C_8H_{18}	–56.8	125.7
9	nonane	C_9H_{20}	–51	150.8
10	decane	$C_{10}H_{22}$	–29.7	174.1

REFERENCES FOR BACKGROUND INFORMATION

The Florida Board of Regents: *ISIS: Fossil Fuels*, Ginn and Company, 1980.

LINKS TO MST LEARNING STANDARDS AND CORE CURRICULA

Standard 1—Analysis, Inquiry, and Design: Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

Mathematical Analysis Key Idea 1: Abstraction and symbolic representation are used to communicate mathematically.

M1.1a: Identify independent and dependent variables.

M1.1b: Identify relationships among variables including: direct, indirect, cyclic, constant; identify non-related material.

Scientific Inquiry Key Idea 1: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process.

Scientific Inquiry Key Idea 2: Beyond the use of reasoning and consensus, scientific inquiry involves the testing of proposed explanations involving the use of conventional techniques and procedures and usually requiring considerable ingenuity.

S2.1: Use conventional techniques and those of their own design to make further observations and refine their explanations, guided by a need for more information.

S2.1a: Demonstrate appropriate safety techniques.

S2.1b: Conduct an experiment designed by others.

S2.1d: Use appropriate tools and conventional techniques to solve problems about the natural world, including:

- measuring
- observing
- describing

Standard 6—Interconnectedness: Common Themes: Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.

Key Idea 2: Models are simplified representations of objects, structures, or systems used in analysis, explanation, interpretation, or design.

2.1: Select an appropriate model to begin the search for answers or solutions to a question or problem.

2.2: Use models to study processes that cannot be studied directly (e.g., when the real process is too slow, too fast, or too dangerous for direct observation).

2.3: Demonstrate the effectiveness of different models to represent the same thing and the same model to represent different things.

Key Idea 6: Plants and animals depend on each other and their physical environment.

6.1: Describe the flow of energy and matter through food chains and food webs.

6.1a: Energy flows through ecosystems in one direction, usually from the Sun, through producers to consumers and then to decomposers. This process may be visualized with food chains or energy pyramids.

6.2: Provide evidence that green plants make food and explain the significance of this process to other organisms.

6.2a: Photosynthesis is carried on by green plants and other organisms containing chlorophyll. In this process, the Sun's energy is converted into and stored as chemical energy in the form of a sugar. The quantity of sugar molecules increases in green plants during photosynthesis in the presence of sunlight.

7.1: Describe how living things, including humans, depend upon the living and nonliving environment for their survival.

7.1e: The environment may contain dangerous levels of substances (pollutants) that are harmful to organisms. Therefore, the good health of environments and individuals requires the monitoring of soil, air, and water, and taking steps to keep them safe.

7.2: Describe the effects of environmental changes on humans and other populations.

7.2c: Overpopulation by any species impacts the environment due to the increased use of resources. Human activities can bring about environmental degradation through resource acquisition, urban growth, land-use decisions, waste disposal, etc.

7.2d: Since the Industrial Revolution, human activities have resulted in major pollution of air, water, and soil. Pollution has cumulative ecological effects such as acid rain, global warming, or ozone depletion. The survival of living things on our planet depends on the conservation and protection of Earth's resources.

Key Idea 3: Matter is made up of particles whose properties determine the observable characteristics of matter and its reactivity.

3.1: Observe and describe properties of materials, such as density, conductivity, and solubility.

3.1a: Substances have characteristic properties. Some of these properties include color, odor, phase at room temperature, density, solubility, heat and electrical conductivity, hardness, and boiling and freezing points.

3.1c: The motion of particles helps to explain the phases (states) of matter as well as changes from one phase to another. The phase in which matter exists depends on the attractive forces among its particles.

3.1d: Gases have neither a determined shape nor a definite volume. Gases assume the shape and volume of a closed container.

3.1e: A liquid has definite volume, but takes the shape of a container.

3.1f: A solid has definite shape and volume. Particles resist a change in position.

3.1g: Characteristic properties can be used to identify different materials, and separate a mixture of substances into its components. For example, iron can be removed from a mixture by means of a magnet. An insoluble substance can be separated from a soluble substance by such processes as filtration, settling, and evaporation.

3.2: Distinguish between chemical and physical changes.

3.2a: During a physical change a substance keeps its chemical composition and properties. Examples of physical changes include freezing, melting, condensation, boiling, evaporation, tearing, and crushing.

3.2b: Mixtures are physical combinations of materials and can be separated by physical means.

3.2c: During a chemical change, substances react in characteristic ways to form new substances with different physical and chemical properties. Examples of chemical changes include burning of wood, cooking of an egg, rusting of iron, and souring of milk.

3.2d: Substances are often placed in categories if they react in similar ways. Examples include metals, nonmetals, and noble gases.

3.2e: The Law of Conservation of Mass states that during an ordinary chemical reaction matter cannot be created or destroyed. In chemical reactions, the total mass of the reactants equals the total mass of the products

3.3: Develop mental models to explain common chemical reactions and changes in phases of matter.

3.3a: All matter is made up of atoms. Atoms are far too small to see with a light microscope.

3.3b: Atoms and molecules are perpetually in motion. The greater the temperature, the greater the motion.

3.3c: Atoms may join together in well-defined molecules or may be arranged in regular geometric patterns.

3.3d: Interactions among atoms and/or molecules result in chemical reactions.

Key Idea 4: Energy exists in many forms, and when these forms change energy is conserved.

Introduction: Temperature is a direct measurement of the average kinetic energy of the particles in a sample of material. It should be noted that temperature is not a measurement of heat.

4.1: Describe the sources and identify the transformations of energy observed in everyday life.

4.1a: The Sun is a major source of energy for Earth. Other sources of energy include nuclear and geothermal energy.

4.1b: Fossil fuels contain stored solar energy and are considered nonrenewable resources. They are a major source of energy in the United Phases. Solar energy, wind, moving water, and biomass are some examples of renewable energy resources.

4.1c: Most activities in everyday life involve one form of energy being transformed into another. For example, the chemical energy in gasoline is transformed into mechanical energy in an automobile engine. Energy, in the form of heat, is almost always one of the products of energy transformations.

4.1d: Different forms of energy include heat, light, electrical, mechanical, sound, nuclear, and chemical. Energy is transformed in many ways.

4.1e: Energy can be considered to be either kinetic energy, which is the energy of motion, or potential energy, which depends on relative position.

4.2: Observe and describe heating and cooling events.

4.2a: Heat moves in predictable ways, flowing from warmer objects to cooler ones, until both reach the same temperature.

4.2b: Heat can be transferred through matter by the collisions of atoms and/or molecules (conduction) or through space (radiation). In a liquid or gas, currents will facilitate the transfer of heat (convection).

4.2c: During a phase change, heat energy is absorbed or released. Energy is absorbed when a solid changes to a liquid and when a liquid changes to a gas. Energy is released when a gas changes to a liquid and when a liquid changes to a solid.

4.3: Observe and describe energy changes as related to chemical reactions.

4.3a: In chemical reactions, energy is transferred into or out of a system. Light, electricity, or mechanical motion may be involved in such transfers in addition to heat.

4.5: Describe situations that support the principle of conservation of energy.

4.5a: Energy cannot be created or destroyed, but only changed from one form into another.

4.5b: Energy can change from one form to another, although in the process some energy is always converted to heat. Some systems transform energy with less loss of heat than others.

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www.nyserda.org

Should you have questions about this activity or suggestions for improvement, please contact Bill Peruzzi at billperuz@aol.com

(STUDENT HANDOUT SECTION FOLLOWS)

Name ____________________________________

Date ____________________________________

The Chemistry of Refining Crude Oil

Introduction

Energy resources are becoming increasingly important to humankind as population growth places increasingly greater demands on Earth's natural resources. Our increased population size also has spurred the growth of both technological development and industrial production, and this growth has in turn created an increased demand for energy supplies. The development of modern societies has spurred a shift in the use of energy resources from wood to coal to oil and, to a certain extent, uranium. The use of each of these energy sources produces environmental costs; these costs are incurred during harvesting, transporting, and the actual process of releasing the energy contained within each of these materials.

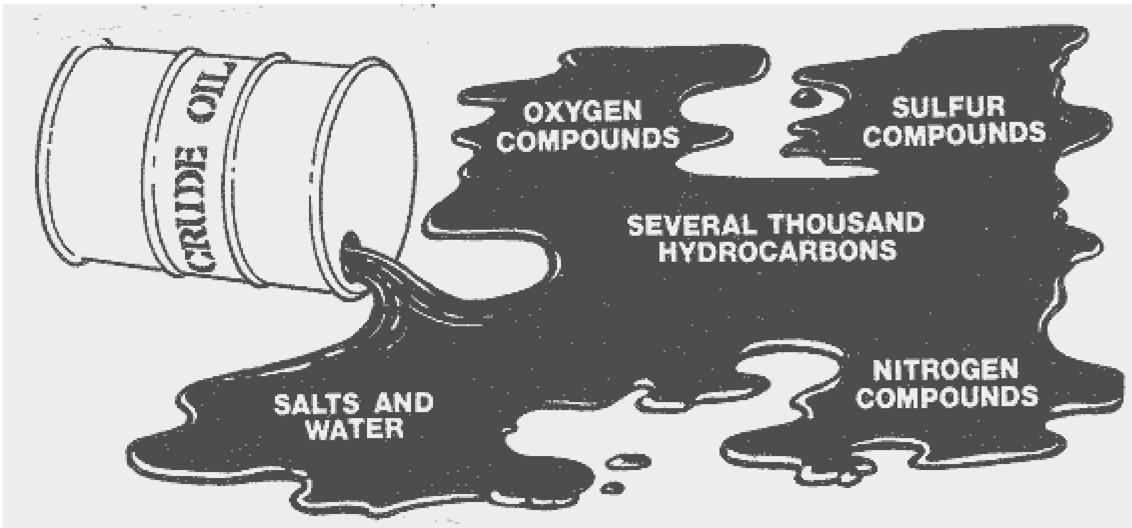
1. How does each of these energy sources compare to solar energy in terms of air pollution produced and kilowatt-hours of energy released? [Use your school's DAS system to obtain this information.] Fill in the chart below.

Energy Source	CO-CO_2	NO-NO_2	SO-SO_2	Other
Wood				
Coal				
Oil				
Uranium				

Petroleum, one of the world's most important resources, has had a huge effect on the world economy. From this resource, a wide variety of energy-rich products are produced—most importantly, oil and gasoline. Most people are aware that crude oil is pumped from underground sources, mostly from reservoirs in the OPEC member countries, and then it is shipped to oil refineries for processing. But what processing occurs at the oil refinery and how does it produce so many petroleum products? You will explore these questions by modeling the process of fractional distillation and investigating the properties of the crude oil that makes the processing possible.

Petroleum chemists have identified this fossil fuel as a complex **mixture** of many different compounds that developed underground under low-oxygen conditions from marine-deposited organic compounds. The diagram below shows the complexity of crude oil.

General Components of Petroleum (Crude Oil)



The “several thousand hydrocarbons” in the middle of the diagram are obviously the main components of petroleum. They are a series of carbon-based chemical compounds that are also composed of the elements hydrogen and oxygen. The remaining components, other than salts and water, may be thought of as impurities that typically remain in the final petroleum products and cause air pollution when burned.

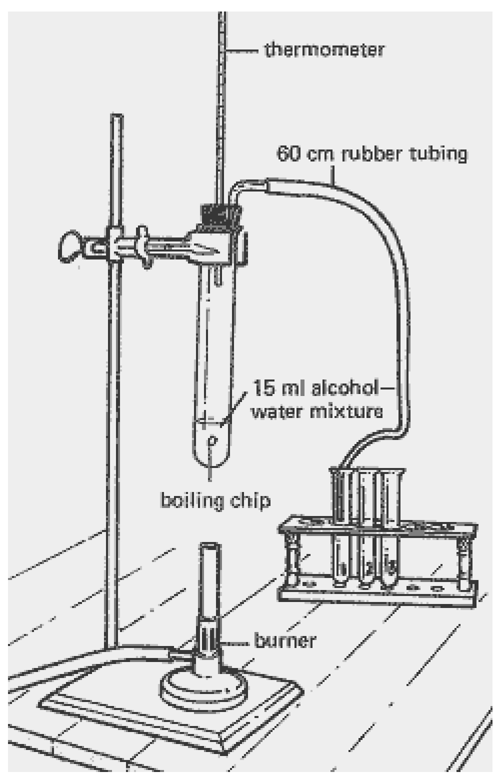
2. What other environmental problem does the diagram above illustrate?

____

____

Materials (per group)

Safety goggles (per person)
Lab apron (per person)
Bunsen burner
Ring stand with utility clamp
Metal pan
3 medium test tubes
Test tube rack
Boiling chip
2-hole stopper
10 cm glass tubing with 90^o bend
Thermometer
15 mL of isopropyl alcohol–water mixture



Stirring rod
Graduated cylinder
Grease pencil/marker
4 paper strips, 10 cm x 1 cm
60 cm rubber tubing

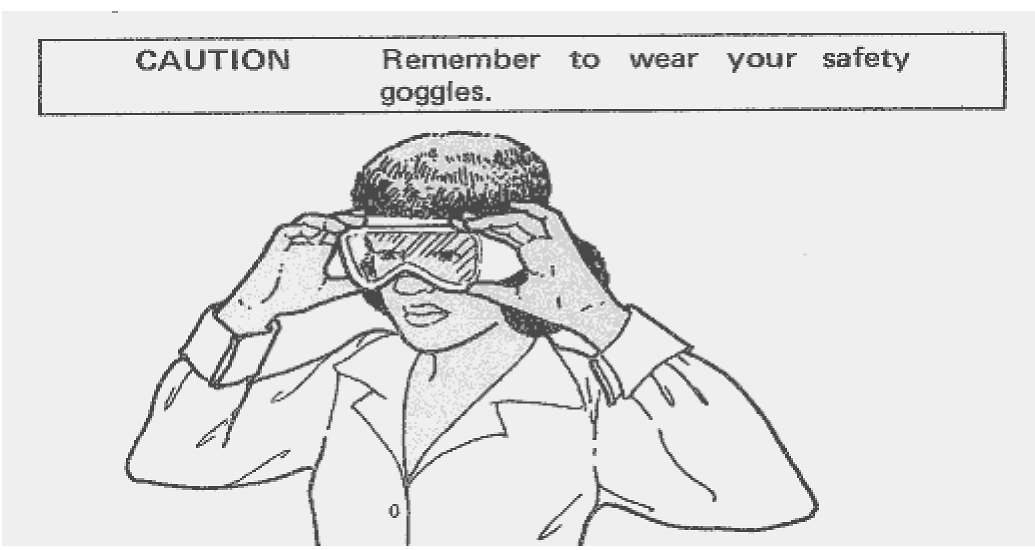
Procedure

1. Gather your laboratory materials and set up the apparatus as shown in the diagram above. Remove the test tube stopper. Place the 15 mL of alcohol-water mixture and the boiling chip in the test tube. Replace the stopper.
2. Use the grease pencil to label the three test tubes in the test tube rack: 1, 2, and 3. Place them in that order in the rack, as shown above.
3. Being careful to keep the test tube rack and rubber tubing away from the burner, place the open end of the rubber tubing into test tube #1.
4. Record the temperature of the mixture at this time in the chart below. Continue to record the temperature of the mixture every minute throughout the experiment.

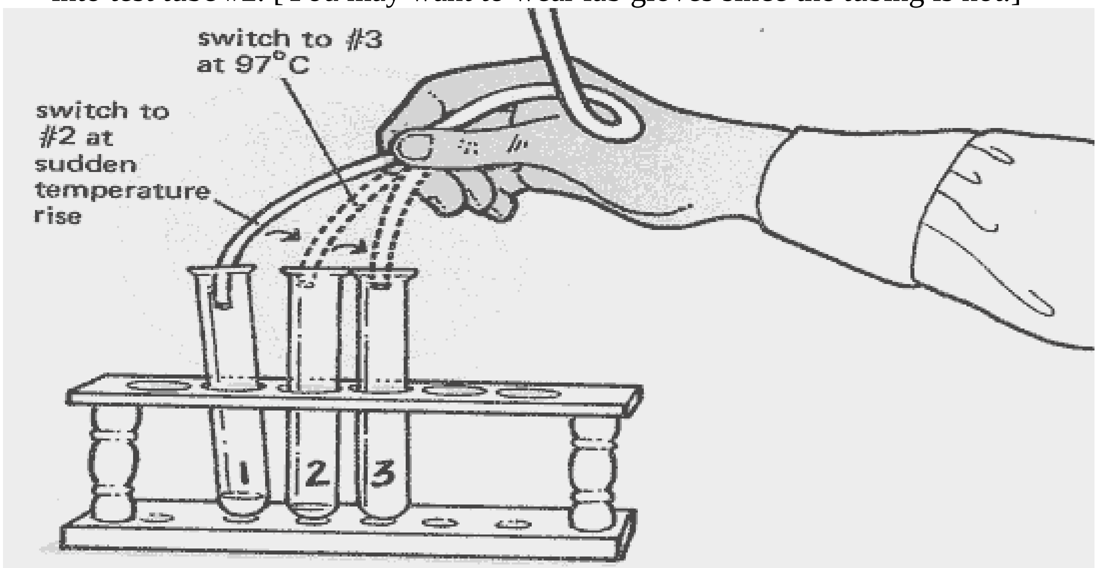
Time	0	1	2	3	4	5	6	7	8	9	10
Temp.											

Time	11	12	13	14	15	16	17	18	19	20
Temp.										

Time	21	22	23	24	25	26	27	28	29	30
Temp.										



5. Light the burner; adjust to low flame height. Gently heat the mixture in the test tube until the fluid begins to gently boil. Mark this temperature on your temperature data chart above with the letter *B*.
6. When the temperature within the mixture starts to increase rapidly, switch the tubing into test tube #2. [You may want to wear lab gloves since the tubing is hot.]



7. Continue heating the mixture. When the temperature reaches 97°C, transfer the collection tube to test tube #3. Continue heating the mixture until only a few milliliters of fluid remain. Turn off the Bunsen burner.

You have completed the fractional distillation of the isopropyl alcohol–water mixture, a much simpler mixture than that found in crude oil. You have three fractions, or parts, of the original mixture. Let's see how the fractions are different from each other and from the original mixture.

8. Using the wafting technique pictured below, carefully smell each fraction to determine the difference in odor of each fluid.

Describe the differences in the fluid odors in the three test tubes.

____

____

9. Test each fraction to see how easily it burns by following these instructions. Dip a 10 cm x 1 cm paper strip halfway into the fluid in each of the three test tubes. Place each strip on the metal pan. With a match, carefully try to ignite the wet end of each strip. Describe how easily each strip ignited.

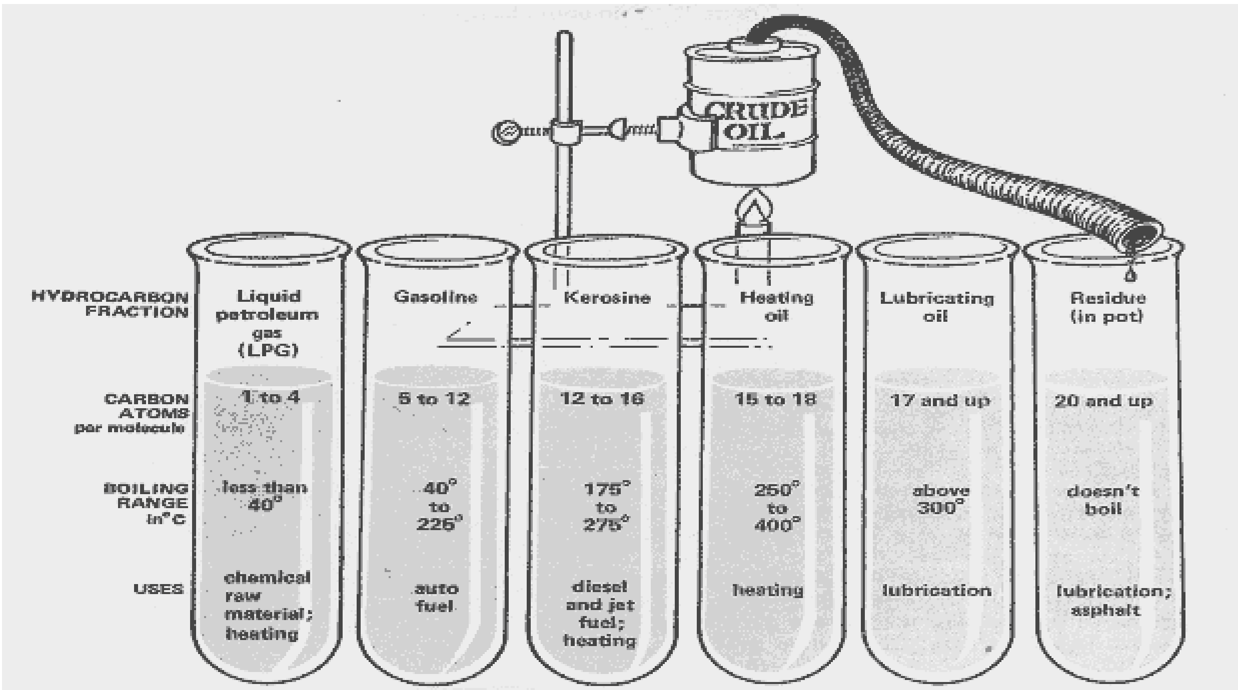
____

____

10. What property allowed you to separate the two substances? ______________________

Each of the fractions you collected has properties separate from the other fractions. Test tube #1 contains almost pure isopropyl alcohol. Test tube #2 contains a mix of water and alcohol similar to the original mixture. Test tube #3 contains almost pure water. If you repeated the fractional distillation process again with each of these fluids, the alcohol and water could be separated even more completely. This repetition of distillation is essentially how the distillation of crude oil into its many parts is accomplished in modern oil refineries.

11. The diagram below illustrates some of the major component parts in the crude oil mixture that are separated from one another through the process of fractional distillation that you undertook in this lab exercise.



Write a possible chemical formula for one of the hydrocarbon components of LPG (liquid petroleum gas).

____

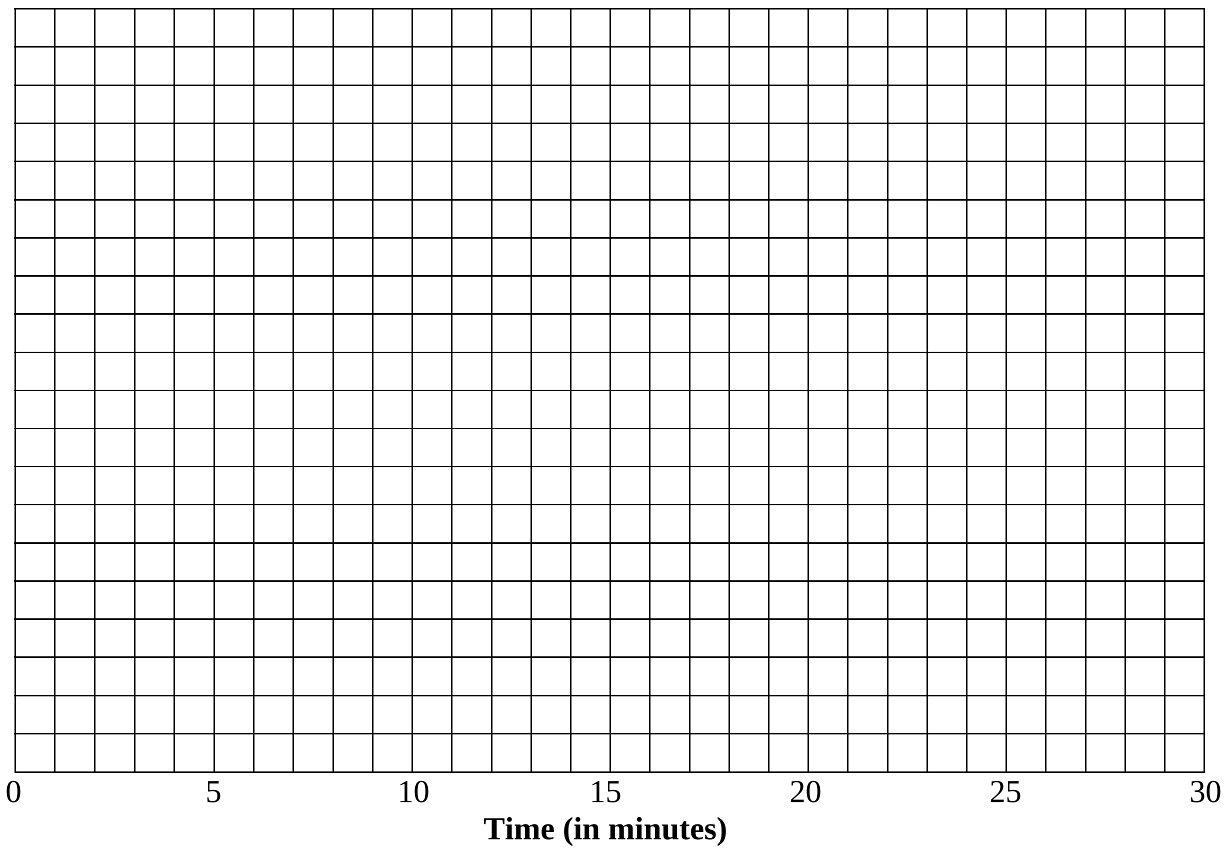
12. Diagram the atomic arrangement of this compound in the box to the right.

DEVELOP YOUR UNDERSTANDING

1. Graph the temperature changes over time that you recorded in the chart in step 4 of the procedure. Fill in an appropriate temperature scale for the vertical axis and give the graph a title.

Title: ____

____



2. Why did the temperature of the fluid mixture in the large test tube rise steadily for several minutes at the beginning of the experiment?

____

3. Why did the temperature then level off?

____

4. Why did the temperature level rise again?

____

5. In terms of energy, why did the fluid in the large test tube change to a gas? ___________

____

6. Why did drops of fluid form at the end of the rubber tubing? ______________________

____

7. Describe the energy transfer processes that transferred the heat from the Bunsen burner into the fluid in the large test tube. ____

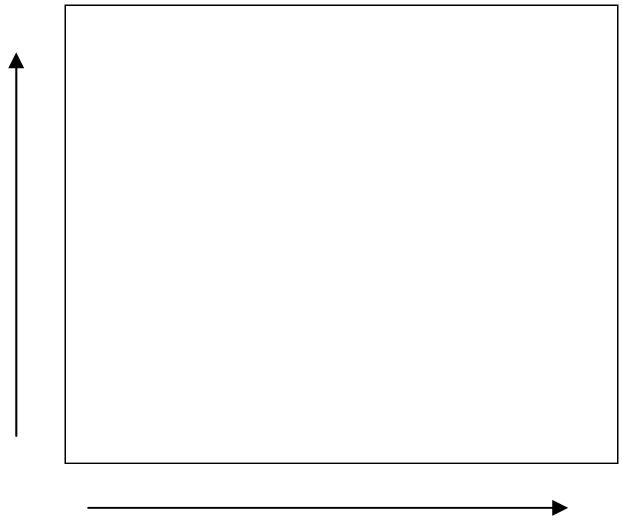
____

____

8. Give an example of kinetic energy present in this lab exercise. _____________________

____

9. Draw a line on the graph form on the next page which best represents the changes in the rate of movement of the molecules present in the mixture in the large test tube as the temperature increased during the lab exercise. Place the dependent and independent variables on the correct axes before you draw your line.



10. Give an example of potential energy present in this lab exercise. ______________________

____

11. Was there any evidence of chemical change occurring within the test tubes? ___________

12. What chemical change did occur within this exercise? ___________________________

____

13. What were the products of this chemical change? __________________________________

____

14. Are any of these products potentially harmful? ____ How? _________________________

____

15. Was any energy created in this lab activity? ______________________

16. Did any energy change from one form to another? _____ Describe any energy changes that occurred.

____

17. Are the fractions of petroleum renewable or nonrenewable resources? _______________

18. What was the original source of the energy located in petroleum? ____________________

19. What process originally trapped this energy on Earth? ______________________________