



# Teacher's Resource Guide



the chemistry of **fire**



## Introduction

Discovery Education and the Society of Fire Protection Engineers (SFPE) are proud to present “The Chemistry of Fire,” a multimedia resource kit that introduces your students to the chemistry of fire and fire prevention. This resource kit will help you and your students become more aware of what it takes to prevent and battle fires, and to relate this to the chemistry you are already teaching them.

This teacher’s guide offers your students an opportunity to see real-world applications of their classroom material. There are five engaging lesson plans related to the chemistry of fire. Some of these lessons have the students complete activities related to fire while other lessons have the teacher completing demonstrations for the class. You can efficiently implement the lessons as part of your existing chemistry curriculum. The lessons in this resource kit do not have to be performed over seven consecutive periods, but should be placed in context within the curriculum. Each standards-based lesson includes lab preparation instructions, a list of materials, student directions, a vocabulary list, debriefing questions, and extension activities.

Throughout the guide you’ll also find brief biographical sketches of fire protection engineers and links to the Discovery and SFPE Web sites for additional information.

Finally, to complement the lessons, there is a three-part DVD presenting 1) Fire Safety in Buildings 2) Demonstrations from the resources kit, and 3) Careers in Fire Protection Engineering. Look inside the back cover for specific suggestions on how to most effectively integrate the lessons and DVD.

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As you go through these lessons with your classes, please follow correct safety procedures as you would with any chemistry demonstration or lab. A few reminders: always wear goggles and aprons, try demonstrations and labs before doing them with the class, have proper fire safety equipment nearby, and dispose of waste in a manner that is consistent with MSDS sheets.

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#### Special thanks to:

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# Lesson 1

## Chemistry of Fire

Length – One 45-minute period

### Overview

- What is fire?
- Fuel compositions
- Test for water vapor in smoke
- Test for carbon dioxide in smoke
- Products of combustion  
(overview of the products of combustion)

### Student Learning Objectives

Students will understand the following:

- 1) The products of complete combustion reactions are carbon dioxide and water.
- 2) Incomplete combustion reactions can produce carbon monoxide and partially combusted fuels in addition to water and carbon dioxide.

### Standards Alignment

See page 16

### Suggested Materials

Candle, matches or lighter, beaker, glass jar with metal lid, water, ice, calcium hydroxide, 2 cans of soda (one cold and one at room temperature)

*2-part experiment*

- Part I: Investigation
- Part II: Questions/Applications/Simulations/Debriefing/Testing

### Teacher Preparation

- 1) Place a can of soda in the refrigerator overnight or long enough for it to get cold.
- 2) Make a saturated solution of  $\text{Ca}(\text{OH})_2$  – enough to fill a glass jar  $\frac{1}{4}$  of the way. Make sure there is no solid  $\text{Ca}(\text{OH})_2$  in the solution. This can be made by adding about 10g (one teaspoon) of calcium hydroxide to a half liter of water and stirring vigorously. This makes a saturated solution that should be allowed to stand until all of the excess lime sinks to the bottom. Carefully pour off the clear liquid through filter paper into a storage bottle. Keep tightly closed.
- 3) Prepare a candle that is short enough to stand inside the glass jar with the lid closed – melt a little wax and then place the end of the candle in that wax. Hold the candle until the candle wax has had a chance to set so that the candle will not fall over.

This lesson will start with a general discussion of what fire is. Fire is an exothermic chemical reaction that involves fuel and oxygen. Other oxidation reactions can be discussed, such as the rusting of iron or the yellowing of paper. While these reactions also liberate energy, they do so at a much slower rate than fire.

Typical fuel compositions can be discussed. Ask students to name some fuels that they may be familiar with – a few examples are in the table below. Most fuels found in homes, schools, and businesses are of the form  $\text{C}_x\text{H}_y$  or  $\text{C}_x\text{H}_y\text{O}_z$ , including cellulosic-wood-based materials and plastics, although some fuels do contain other elements, such as nitrogen or chlorine. For this exercise, we'll stick with fuels of the form  $\text{C}_x\text{H}_y$  or  $\text{C}_x\text{H}_y\text{O}_z$ , because most things that are found in homes fall into this category.



Many oxidation/reduction reactions can be broken into subcategories (combustion, single replacement, and synthesis). Depending on the level of your students, you may simply want to refer to these reactions as combustion and not get into the details of oxidation/reduction reactions.

Chemical Name	Chemical Formula	Use
Methane	$\text{CH}_4$	Bunsen burners
Propane	$\text{C}_3\text{H}_8$	Gas grills
Butane	$\text{C}_4\text{H}_{10}$	Lighters
Octane	$\text{C}_8\text{H}_{18}$	Major gasoline component
Ethanol	$\text{C}_2\text{H}_5\text{OH}$ (or $\text{C}_2\text{H}_6\text{O}$ )	Alcohol in beer and wine
Isopropyl alcohol	$\text{C}_3\text{H}_7\text{OH}$ (or $\text{C}_3\text{H}_8\text{O}$ )	Rubbing alcohol

continued >>>

Ask the students what products will be produced when a fuel is lit on fire. Write the student answers on the board and then conduct the following demonstrations to prove what the products of the reaction are. Tell student volunteers to wear safety goggles when performing these experiments.

### **Teacher Demonstration – Water Vapor Test**

Tell the students you have two cans of soda and that it is their job to note any observations. Take out a can of cold soda and a can of room temperature soda. Ask the students what is happening to the cold can of soda and the room temperature can of soda. Discuss the condensation formed on the sides of the can. What would happen if the can were set on the table on a dry day? Little or no condensation would form. Ask students why these two cases are different.

The answer is that there are different concentrations of water vapor in the air on humid days and dry days. The dew point of the air is related to the concentration of the water vapor in the air. The dew point is a measure of the temperature at which the air becomes saturated with water vapor and cannot hold any more. At the dew point, water vapor will begin to condense (or precipitate) out of the air. On the humid day, the can will be at a temperature below the dew point, so water vapor will condense on the can. The water that condenses on the can was originally “in solution” with the air. On the dry day, the can might not be below the dew point.

Fill a beaker about half full with water and add some ice. Light a candle and place the water-filled beaker above the flame. Water vapor created in the candle flame should condense on the beaker or flask.

### **Student Activities – Carbon Dioxide Test**

To begin the next exercise, ask students to write and balance the following equation:



ANSWER:



$\text{CaCO}_3$  is less soluble in water than  $\text{Ca(OH)}_2$ , so it will precipitate out of solution. The  $\text{CaCO}_3$  is white in color, so the solution will appear cloudy when the  $\text{CaCO}_3$  precipitates out of solution.

Calcium hydroxide [ $\text{Ca(OH)}_2$ ] can be used to test for carbon dioxide, since calcium carbonate will form and precipitate out of solution in the presence of carbon dioxide. To test for carbon dioxide in the products of combustion from

a candle, place a candle in a jar that is about  $\frac{1}{4}$  full of a saturated calcium hydroxide solution (the candle should be shorter than the jar). Ignite the candle and close the jar.

Allow the candle to go out from depleting the oxygen from the air in the jar. Once the candle is extinguished, quickly and carefully remove the candle and re-close the jar. Agitate the beaker, and calcium carbonate should form.

With these two experiments, the presence of water and carbon dioxide in candle smoke has been shown. However, fires generally do not burn perfectly, and compounds other than water vapor and carbon dioxide can generally be found in combustion products. These compounds include carbon monoxide and hydrocarbons that are formed by incomplete combustion. If there is not sufficient oxygen available (such as a big fire in a small room), then significant quantities of carbon monoxide can be created. It is these products, particularly carbon monoxide, that injure or kill people in fires.

The amount of carbon monoxide that is formed is a function of the amount of air that is present in the area of the fire. If there is sufficient air available, a negligible amount of carbon monoxide will be formed. However, in situations where there is little air available, such as when a fire fills a room, significant quantities of carbon monoxide can be formed. This carbon monoxide can be carried with the smoke to areas that are remote from the fire. This is the reason that people are taught to stay low in smoke. Because the smoke is less dense than normal air, it will tend to rise, and the freshest air will be near the floor.

### **Extensions**

More and more people are placing carbon monoxide detectors in their homes.

Students may research the following:

- 1) Why are people placing carbon monoxide detectors in their homes?
- 2) Should carbon monoxide detectors be placed near the ceiling or near the floor? Why?
- 3) In which rooms should homeowners usually place the detectors?
- 4) How do the detectors work to determine that carbon monoxide is present in the home?
- 5) What does carbon monoxide do to the human body?

## Evaluation

**Oral or Written:** Students will explain what fire is and what occurs when a fire is burning by demonstrating clear understanding of the two objectives and relevant vocabulary.

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## Vocabulary

(some definitions taken from dictionary.com)

**Combustion** – A process in which a substance reacts with oxygen to yield heat and light

**Concentration** – The amount of a specified substance in a unit amount of another substance

**Condensation** – The act or process of reducing a gas or vapor to a liquid or solid form

**Dew Point** – A measure of the temperature at which the air becomes saturated with water vapor and cannot hold any more

**Exothermic** – Releases heat

**Endothermic** – Absorbs heat

**Femto** –  $10^{-15}$

**Fuel** – Something consumed to produce energy

**Organic chemistry** – The chemistry of compounds containing carbon

**Solution** – The process by which a gas, liquid, or solid is dispersed homogeneously in a gas, liquid, or solid without chemical change

**Precipitate** – To cause (a substance) to be separated from a solution



## CAREER CONNECTION

**Stacy N. Welch, PE**  
Senior Fire Protection Engineer  
Marriott International

*When I was accepted into the College of Engineering at the University of Maryland, I went to an open house where each area of engineering was introduced. I was drawn to the human component of Fire Protection Engineering. I was excited about the possibility of saving a life or preventing a disaster through something I designed or was involved in. I graduated with a Bachelor of Science degree in Fire Protection Engineering and have been in the fire protection field for ten years.*

*Today, I work in the hospitality industry. I review construction plans, communicate with architects and contractors, and survey buildings to ensure that our hotels will be safe and that the fire protection systems are designed and installed in accordance with codes and our own standards. I take pride in having the opportunity to increase awareness in regard to fire protection and life safety. Because of my involvement, buildings are safer – it doesn't get better than that.*

*Fire Protection Engineering is a great field. It involves all kinds of science – from how fires burn to how water moves to how steel responds to heat to how smoke travels. Fire protection engineers are in demand, so you get a choice of jobs. In addition, you learn that fire protection is all around you – from the exits in public buildings, to the fire sprinklers in your school, to the smoke detectors in your home.*

# Lesson 2

## Combustion Reactions

(laboratory demonstration)

Length – One to two 45-minute periods



View a demonstration of this experiment on the DVD.

### Overview

- Balance equations for the burning of different fuels
- Discuss the fire tetrahedron

### Student Learning Objectives

Students will understand the following:

- 1) How to write and balance combustion reactions.
- 2) Fuel, oxygen, heat and a chemical chain reaction are all necessary for fire to occur.

### Standards Alignment

See page 16

### Suggested Materials

Propane supply, plastic hose, dish washing soap, beaker, water, matches, safety goggles

#### 2-part experiment

- Part I: Investigation
- Part II: Questions/Applications/Simulations/Debriefing/Testing

In lesson 1, students proved that water and carbon dioxide are products of combustion reactions. The purpose of this lesson is to write combustion reactions and balance the reactions for typical fuels. Before starting to write and balance combustion reactions, complete the following demonstration with your students.

### Teacher Preparation

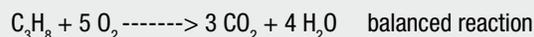
- 1) Please try the demonstration on your own before doing it in class. The amount of propane gas released should be small the first time so you are not startled by the combustion reaction.

#### Teacher Demonstration – Combustion Reaction

Fill a beaker full of water and add some dish soap. Hook a plastic hose up to the propane supply. Place the end of the hose into the beaker of soapy water. Slowly turn on the propane gas. Turn off the gas supply and take the hose from

the beaker. Away from the beaker, strike a match and then carefully place it into the beaker – the bubbles that were produced with propane will combust dramatically. This can be repeated numerous times with the same water/soap mixture. Now have a discussion with your students, asking the following questions:

- 1) What did they observe? Could regular dish soap bubbles be lit on fire? What type of reaction did they observe?
- 2) Write a chemical equation for what just occurred. How did they know what the products were? Remind them of the demonstrations from the previous lesson.
- 3) Is the reaction balanced?



A prototypical fuel can be provided, such as  $\text{C}_{20}\text{H}_{42}$  (an approximation for candle wax). Students should be asked to balance an equation for the burning of this wax.



Here are some other reactions the students can complete and balance. Share the following hint with your students – balance oxygen last in combustion reactions. Ask students if they can remember the names and uses of some of these fuels from the previous lesson.

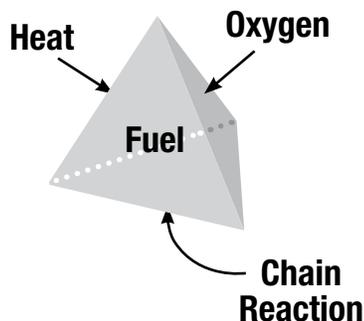
- a)  $\text{CH}_4 + \text{O}_2 \longrightarrow$
- b)  $\text{C}_3\text{H}_8 + \text{O}_2 \longrightarrow$
- c)  $\text{C}_2\text{H}_5\text{OH} + \text{O}_2 \longrightarrow$
- d)  $\text{C}_4\text{H}_{10} + \text{O}_2 \longrightarrow$
- e)  $\text{C}_8\text{H}_{18} + \text{O}_2 \longrightarrow$

ANSWERS:

- a)  $\text{CH}_4 + 2 \text{O}_2 \longrightarrow \text{CO}_2 + 2 \text{H}_2\text{O}$
- b)  $\text{C}_3\text{H}_8 + 5 \text{O}_2 \longrightarrow 3 \text{CO}_2 + 4 \text{H}_2\text{O}$
- c)  $\text{C}_2\text{H}_5\text{OH} + 3 \text{O}_2 \longrightarrow 2 \text{CO}_2 + 3 \text{H}_2\text{O}$
- d)  $2 \text{C}_4\text{H}_{10} + 13 \text{O}_2 \longrightarrow 8 \text{CO}_2 + 10 \text{H}_2\text{O}$
- e)  $2 \text{C}_8\text{H}_{18} + 25 \text{O}_2 \longrightarrow 16 \text{CO}_2 + 18 \text{H}_2\text{O}$

Referring back to the demonstration, ask the students why the bubbles did not start on fire immediately. This would be a great opportunity to start a discussion on the “fire tetrahedron.” The “fire tetrahedron” is used to represent the things that must be present for fire to occur. Each side of the tetrahedron is labeled with one of these essentials needed for fire to occur: fuel, oxygen, heat, and the chemical chain reaction. Remove any one of these and fire will not be possible (or will go out).

Fire protection engineers use strategies that involve removing one or more sides of the fire tetrahedron to protect people and property from fire.



### Application

In pairs, pass out a fire scenario; have the students discuss the following items and then share their scenarios and ideas with the class:

- 1) Based on the fire tetrahedron, will the fire occur?
- 2) If the fire will not occur, what is missing from the fire tetrahedron that prevents the fire from occurring?

**Case Study Fire #1** – It is a nice cool sunny day, and Abby decides to get her bike in the garage, when she notices the gasoline can next to her bike. Abby opens the airtight container and then leaves on her bike. Will a fire start?

**Case Study Fire #2** – Working in his oxygen-free fume hood, Clark has obtained some alcohol and matches to conduct an experiment. He must return to the stockroom to obtain a few more items. Will a fire start while Clark is away?

**Case Study Fire #3** – The lights have gone out in Vineeta's house and it is very dark. Vineeta has gone to get a candle and some matches. She strikes the match near the wick of the candle. Will the candle light?

**Case Study Fire #4** – Cole is camping for the weekend and has brought along his propane gas stove. He did not notice that the tank was empty when he left home. Cole turns on the gas supply and strikes a match. Will the propane gas stove ignite?

**Case Study Fire #5** – Yena and Sarah are going to bake a birthday cake for Yena's mother. As they put the cake in the gas oven, they notice that the oven is not warm. Looking under the gas oven, they notice that the pilot light is out. Yena makes sure the gas is on and strikes a match near the pilot light. Will the pilot light catch on fire?

**Case Study Fire #6** – Juan put an inverted glass jar on top of a candle that was burning. The jar will not allow any air in or out of the candle container. Will the candle continue to burn?

Teacher Answers:

**Case Study #1** – No, there is no heat to start the fire.

**Case Study #2** – No, neither heat nor oxygen is present.

**Case Study #3** – Yes

**Case Study #4** – No, there is no fuel.

**Case Study #5** – Yes

**Case Study #6** – No, the jar will run out of oxygen.

### Extensions

- 1) Students may research the properties of the fuels discussed in lessons 1 and 2. Are some of these fuels more dangerous than others? What is the cost of these fuels? At what temperature would these fuels catch on fire?
- 2) Students may research the following terms: flash point and autoignition temperature. Students can look at MSDS sheets for the fuels discussed in lessons 1 and 2.
- 3) Students may research the history of the fire tetrahedron.

### Evaluation

**Oral or Written:** Students will use the fire tetrahedron to come up with fire scenarios in which fire may or may not occur and tell why it may or may not occur, by demonstrating clear understanding of the two objectives and relevant vocabulary.



Burning propane-filled bubbles



## CAREER CONNECTION



**Rima Adawi**  
*Project Coordinator  
Region South Fire and Rescue Service  
Sweden*

*For a long time, I wanted to become a physician, but just before my last year of high school, I changed my mind. I sat down with a catalogue of all the education programs in Sweden, and when I came to the Fire Protection Engineering program I suddenly stopped. I read about the program and found it very interesting. I decided to apply.*

*I work at a Fire and Rescue Service, where I am positioned at the fire prevention unit. My current work is mainly related to a project called "Dwelling Fires." The purpose of the project is to reduce both the frequency and consequences of dwelling fires. In addition, I work following up various activities of the prevention unit at the Fire and Rescue Service, which means that I try to measure whether we are doing what we should be doing and what effect the activities have.*

*What has surprised me the most is how many different opportunities you have as an FPE. Being an FPE is much more than just working with fire protection. For example, many of my former classmates work for insurance companies, as safety managers for different industries, or as emergency and crisis managers for municipalities. Furthermore, as an FPE you have the opportunity to work in many different countries.*



Propane supply immersed in bubble liquid

## Lesson 3

### How Does Fire Burn?

(classroom exercises and laboratory experiments)

Length – Two 45-minute periods



View a demonstration  
of this experiment  
on the DVD.

#### Overview

- Ignition
- Premixed and diffusion flames
- Solid, liquid, and gaseous fuels
- Structure of a diffusion flame

#### Student Learning Objectives

Students will understand the following:

- 1) The difference between a diffusion flame and a premixed flame.
- 2) How to use a Bunsen burner and what the correct flame looks like.
- 3) How a candle burns.

#### Standards Alignment

See page 16

#### Suggested Materials

##### Student Activity – each group needs:

Bunsen burner, match, glass rod, striker, paper clip

##### Teacher Demonstration

Candle, Bunsen burner, filter paper, glass bulb dropper, wire mesh, Petri dish, acetone (fingernail polish remover), striker

##### Optional mini demonstration materials

Straw, food coloring, beaker, celery, graduated cylinder, water

##### 2-part experiment

- Part I: Investigation
- Part II: Questions/Applications/Simulations/Debriefing/Testing

#### Teacher Preparation

- 1) Please try all activities and demonstrations on your own before doing them in the classroom.
- 2) When the students place the match into the paper clip, make sure it is straight and placed in the center of the Bunsen burner barrel or the match will light immediately.
- 3) If you are going to do the celery demonstration, you will need to place the celery in colored water overnight before showing it to the students in class.

#### Teacher Demonstration – Ignition

At the beginning of this lesson, students should be asked why a gas stove requires a pilot light or electric spark igniter to light when the gas is turned on. Although the gas and air may be mixed in sufficient proportion to react (burn), the burner will only ignite when a spark or flame is present. Once the stove is ignited, the spark or pilot light is not needed anymore.

The answer is that the fire, like all reactions, requires activation energy to start. Because fire is an exothermic reaction, the activation energy is provided from the fire itself once ignited.

Next, note that the striker could not ignite a candle. In fact, if a lit match is quickly touched against the wick, the candle will not ignite. Ask the students why this is. The answer is that the wax fuel is not in a form that would support combustion. The fuel must first be melted and vaporized before it will ignite. If the match is held near the wick long enough, a flame will appear.

Following this discussion, show students how to start the flow of gas to a Bunsen burner and strike a striker above it. Note that the flame appears almost instantaneously. The striker simply provides the activation energy to the gas/air mixture.

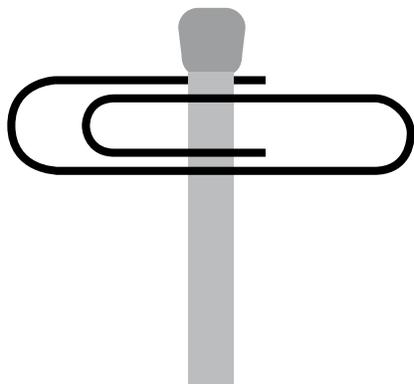
#### Student Activities – Shapes of Diffusion Flames

With a partner, allow the students to learn how a Bunsen burner works and how fire burns.

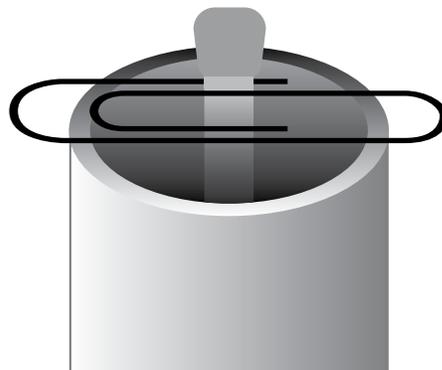
- 1) Close the air supply of the Bunsen burner so that no air is entering into the Bunsen burner. Turn on the gas supply and ignite the Bunsen burner. Hold a clean glass rod in the tip of the flame of the Bunsen burner. What do you observe about the glass rod? What color is the flame?
- 2) Turn off the gas supply and open the air supply so that air is entering the Bunsen burner. Turn on the gas supply and once again ignite the Bunsen burner. Clean off the glass rod. Hold the clean glass rod in the tip of the flame of the Bunsen burner. What do you observe about the glass rod? What color is the flame? What is the difference between the two flames? Which flame is better when using a Bunsen burner?
- 3) Turn off the gas\*. Close the air supply to the Bunsen burner again. Take an UNLIT match and a paper clip. Slide the match into the paper clip so just the head of the match is on one side and the rest of the match is on the other side of the paper clip. Place the paper clip with match inside the Bunsen burner barrel – make sure the match is as low as it will go and that it is exactly in the middle of the Bunsen burner barrel. See picture on the next page. Turn on the gas and ignite the

⋮ Bunsen burner with the striker. What do you observe?  
 ⋮ Wait 10 – 20 seconds, and turn off the gas. Did the  
 ⋮ match light? Why not?

✱ The flame is a diffusion flame (see illustrations below). The purpose of this activity is to show the inner part of the flame is cool and does not have enough energy to light the match.



Setup of match and paper clip



Proper placement of the paper clip and match in the Bunsen burner

✱ Usually, a premixed flame is desired when using a Bunsen burner in chemistry class. This activity uses a diffusion flame. Because most accidental fires involve diffusion flames, fire protection engineers study diffusion flames.



Match inserted in Bunsen burner

### Answers to Questions from Student Activities

- 1) Black soot should form on the glass rod. The flame will burn with a yellow color.
- 2) No soot should form on the glass rod – soot is not produced in the flame. The flame will burn with a blue color. The difference is in how the fuel and air are mixed prior to burning. The first flame had the fuel and air mix in the flame. In the second flame, oxygen was mixed with the fuel prior to burning, before the fuel-air mixture reached the flame. When the air supply is closed, the fuel and air do not mix until they reach the flame. Inside the flame, only fuel exists, and outside the flame only air exists. This type of flame is called a “diffusion flame.”

The yellow color is caused by the formation of soot, which is black and glows yellow at the flame temperature. The soot itself is burned before it exits the flame. If the air supply is opened, the fuel and air mix before they reach the flame. This is called a “premixed flame.” The blue color is caused by chemiluminescence, which is caused by the vibration of the fuel molecules before they are burned.

- 3) If the students were careful, the match should not have lit. This shows that the inside of the flame is cooler. If the students put the match in the correct place, the match may not light at all, while some matches may light after a few seconds due to air moving in the classroom.

### **Teacher Demonstration – Shapes of Diffusion Flames**

Another way to show a premixed flame is to once again light a match and blow out an ignited candle (note that the candle must have been burning for a few minutes before it is blown out for this to work). Place the lit match near the candle in the “smoke.” A flame can be observed to travel down the path of the “smoke” and relight the candle. This occurs because the “smoke,” which is really wax vapors, is premixed with air, and the flame can travel down the path of the wax vapor-air mixture back to the candle.

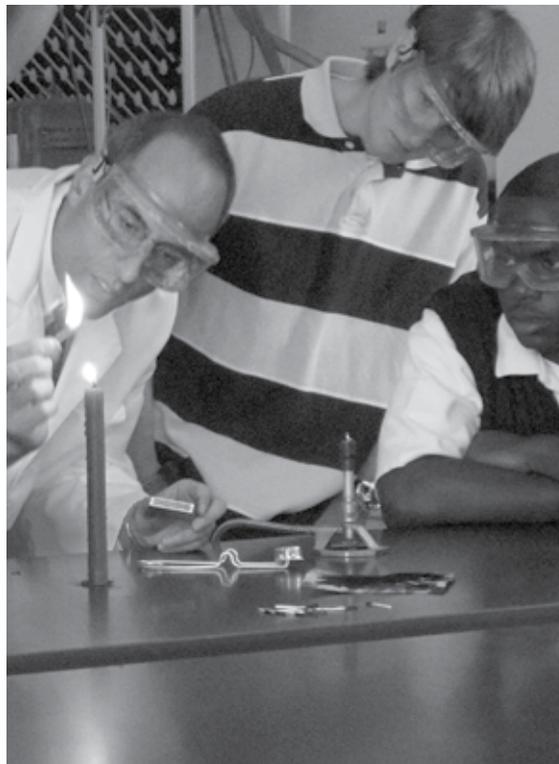
Next, lower a piece of filter paper so that it is in the flame. Holding the filter paper steady, allow it to begin to char, but remove it before it ignites. The char should have formed a ring pattern, which shows that the outside of the flame is the hottest part.

With the candle ignited, slowly lower the wire mesh until it bisects the flame vertically. The wire mesh absorbs heat from the flame so that the activation energy is lost from the flame zone above the wire mesh. Note that the color of the “smoke” changes as the wire mesh begins to bisect the flame. Ask students to explain the differences in the color of the “smoke.” The smoke is initially black, which is soot that is created in the candle. Usually, this soot is burned before it exits the flame, but the screen interrupts the burning as it approaches the tip of the flame. As the screen is lowered more, the color of the “smoke” changes to white, which is wax vapor.

With the screen bisecting the flame, one can look down into the flame and see its structure. The flame can be seen to be hollow, with wax vapors inside it and a very thin flame sheet, which is where the reaction occurs. With the wire mesh held carefully in place, it is sometimes possible to reignite the unburned wax above the wire mesh.

The soot in the flame can be observed by dimming the lights in the room and placing the candle between a light source, such as a flashlight or projector, and a screen or piece of white paper (make sure that the candle is not close enough to the screen or paper to ignite it). Adjust the light source so that it is possible to see the shadow of the flame. The shadow shows that some of the light is blocked by the flame itself. This is because while the soot in the flame glows, it still is able to block light.

Last, expel the air from a glass dropper bulb (squeeze the bulb). Place the tip of the dropper inside the flame and allow the dropper bulb to fill with the matter that is inside the flame. Ask the students for their observations



The “smoke” from a freshly extinguished candle can easily be ignited.

about the substance that is in the dropper and what it might be. It can be observed that the vapors that fill the dropper are white, and that these vapors are wax in its gaseous form. The vapors can be expelled onto a lit match, and they will reignite.

Ask the students to look at the candle flame and observe the wick. While the wick is blackened, it does not burn; also, the wick does not extend outside of the flame. Ask students why this might be. The answer is that the wick is never heated above the boiling temperature of the wax. Through capillary action, the wick draws liquid wax from the wax cup that forms at the top of a lit candle. The flame then heats the liquid wax on the wick and vaporizes it. The vaporized fuel travels to the flame zone where it is burned. The heat of the flame itself burns the wick at the point where the wick touches the flame.

To help with capillary action here are few mini demonstrations you could do for your students

- 1) Take out a graduated cylinder and add some water – the water forming a meniscus is a result of capillary action. The smaller the diameter of the graduated cylinder the more pronounced the capillary action will be.
- 2) Take a piece of freshly cut celery and place it in a container of colored water. Allow to sit overnight. The next day, cut the celery in half and you will see that the food coloring traveled up the celery stalk. You could also do this with white carnations, but this may take longer than one night.

### **Teacher Demonstration – States of Matter for Combustion**

It can also be demonstrated that the liquid fuel does not heat the wick above the liquid's boiling point by trimming a piece of filter paper so that it completely fits inside a Petri dish, pouring a few milliliters of acetone inside the Petri dish, and igniting the acetone. While the fuel burns, the paper does not. In fact, if the paper is sufficiently flat, the acetone will completely burn without igniting the paper. This is because the temperature of the wick or filter paper is below the boiling temperature of the wax or the acetone, which is below the temperature at which the wick or filter paper will ignite.

The DVD states that fuels must be in a gaseous state for combustion to occur. This is true for the vast majority of fires. However, there are cases where combustion can occur in the solid or liquid phase. Examples include mists, dusts, burning metals, and smoldering combustion.

### **Extensions**

- 1) Students may research the four or five leading causes of fire in the home. These can then later be used in lesson 5.

### **Evaluation**

**Oral or Written:** Students will explain the processes that occur in a candle as solid wax is burned.

### **Vocabulary**

**Activation energy** – The energy necessary to start a reaction

**Boiling point** – The temperature at which a substance boils

**Capillary action** – The movement of a liquid along the surface of a solid caused by the attraction of molecules of the liquid to the molecules of the solid

**Chemiluminescence** – The emission of light by an atom or molecule that is in an excited state

**Ignition** – The process of initiating combustion or starting a fire

**Temperature** – A measure of the average kinetic energy of the molecules that comprise the object



## **CAREER CONNECTION**

### **Bernie Till** *Defense Programs Fire Protection Engineering Lead/Principal Fire Protection Engineer*

*I'm always proud of being a fire protection engineer. It is a job where you won't always know how many lives you saved or how much destruction you prevented, but you always know you are making a difference. You can know that people are safe from fire because of what you do – even if sometimes they never even know you did it. Some opportunities that I found particularly rewarding were testifying to legislators regarding fire sprinkler effectiveness and providing fire sprinklers in Habitat for Humanity houses. I've been a fire protection engineer for 13 years and a volunteer firefighter for 20 years.*

*The fire protection profession is so broad. You can do almost anything in which you have a personal interest, including computers, design, consulting, litigation, or forensic fire protection. And careers are not just limited to big cities in the U.S. The opportunities are worldwide.*

*If I was looking for a candidate for a fire protection job, I would want someone who is technically competent, yet able to understand the needs of and communicate with those seeking technical assistance. Key to me is someone who is honest and demonstrates integrity by doing the right things for the right reasons. Fire protection engineering is one of those jobs where cutting a corner can result in disastrous consequences.*

# Lesson 4

## Spread of Fires

(laboratory experiments)

Length – Two 45-minute periods



View a demonstration of this experiment on the DVD.

### Overview

- Discussion of modes of heat transfer
- Conduction experiment
- Convection experiment

### Student Learning Objectives

Students will understand the following:

- 1) There are three ways heat can be transferred – conduction, convection, and radiation.
- 2) Different materials conduct heat at different rates due to their specific heats, densities, and thermal conductivities.

### Standards Alignment

See page 16

### Suggested Materials

Glass rod, metal rods – various metals, beakers, water (ice and hot), thermometer, graduated cylinder, Bunsen burner or hot plate, shortening (such as Crisco, preferably in bar form), ice cubes (approximately the same size), ring stand, fan

#### 2-part experiment

- Part I: Investigation
- Part II: Questions/Applications/Simulations/Debriefing/Testing

### Teacher Preparation

- 1) Cut up shortening into small cubes. You might want to place them in the refrigerator to firm them up even more.
- 2) You may want to label the metal rods with random letters so you know what metals each pair of students is using.

Fires grow and spread through the transfer of heat from areas or items that are burning to areas or items that are not burning. Since it involves the ignition of items or portions of items that are not burning, the science behind fire spread is very similar to the science behind ignition. Recall that ignition was discussed in lesson 2.

There are three ways in which heat can be transferred: conduction, convection, and radiation. Before discussing heat transfer, it is useful to review temperature. The temperature of an object is a measure of the average kinetic energy of the molecules that comprise the object. All molecules move, and the higher the temperature, the more rapidly the molecules move. At absolute zero (0 K or  $-273^{\circ}\text{C}$ ), movement of molecules would stop.

### Conduction

In solids, conduction heat transfer involves the transfer of energy through the solid from molecules with greater energy to those with less energy. This transfer could occur through molecular collisions or by vibration or transport by free electrons in solids.

Energy always flows from hotter objects to cooler objects, just as gravity always pulls in the downward direction.

### Convection

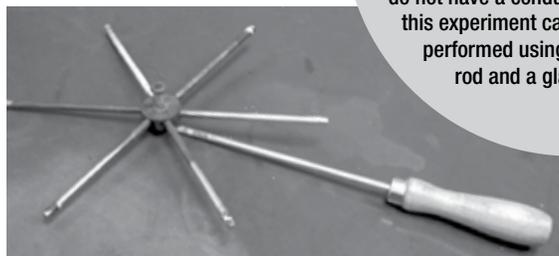
Convection heat transfer involves the transfer of energy associated with the interaction of molecules at the interface (solid-liquid, solid-gas, or liquid-gas) between two materials.

An example to help students distinguish between conduction and convection is cooking a turkey in a fryer. When the inside of the bird is cooked, that is conduction. When the outside skin of the bird is browned and cooked, that is convection.

### Radiation

Radiation heat transfer is entirely different from conduction or convection: it involves the transfer of energy via electromagnetic waves. The transfer of heat from the sun to the earth occurs via radiation. Indeed, there is very little matter between the earth and the sun that would allow for the transfer of energy at a molecular level. All materials give off thermal radiation at an intensity that is proportional to the temperature (in Kelvin) raised to the fourth power.

### Student Activity – Conduction Experiment



 A conductometer can be purchased at your chemical supply company. The spokes are made of different metals. The manufacturer suggests using beeswax, but household crayons can also be used. If you do not have a conductometer, this experiment can be performed using a metal rod and a glass rod.

Set up a ring stand to hold the glass rod horizontally. Cut small pieces of shortening or beeswax, and carefully place them on both ends of a glass rod and a metal rod. Balance the metal rod on the ring stand and heat the middle of the rod with the Bunsen burner. Repeat with the glass rod. Observe which cube melts off of the rods first. Explain the observation.

Heat is conducted along the rods to the shortening or beeswax. As the rods heat up, the shortening or beeswax will begin to melt. The shortening or beeswax will fall off of the metal rod with the highest conductivity first. The metal with the highest conductivity is the better conductor. This would be a great opportunity to discuss the conductivity of various objects.

### Convection Experiment

**Equipment needed:** ice cubes (approximately the same size), fan

Turn on the fan and place one ice cube so that the fan blows directly onto it. Place the other ice cube in another location in the same room where the fan does not blow on it. Observe the melting of the ice cubes.

The ice cube that has the fan blowing on it will melt first. Although the temperature surrounding both ice cubes is approximately the same, the ice cube that has the fan blowing on it will melt first because heat from the air is transferred to it more quickly. Heat from the blowing air is transferred to the ice cube more quickly because of the increased motion of the air, which is at a temperature above the freezing point of water.

### Extensions

- 1) More homes are now installing convection ovens. Students may research why so many people are purchasing ovens that have the convection feature.
- 2) When cooking in the home, many pots and pans are made out of metal. Students may research why most pots and pans are made out of metals and what metals they are made of.
- 3) In this lesson, conductors were the major focus. Something else that is just as important are insulators. Students may research the following things about insulators:
  - a) What are insulators?
  - b) What makes a good insulator? Why?
  - c) How do insulators relate to the discussion of good conductors?

### Evaluation

**Oral or Written:** Students will explain how the various modes of heat transfer can affect the spread of fire by demonstrating clear understanding of the two objectives and relevant vocabulary.

### Vocabulary

**Absolute zero** – (0 K or  $-273\text{ }^{\circ}\text{C}$ ) – movement of molecules would stop

**Conduction** – Involves the transfer of energy through a material from molecules with greater energy to those with less energy

**Convection** – Involves the transfer of energy associated with the interaction of molecules at the interface between two materials of dissimilar state of matter

**Kinetic energy** – Energy of motion

**Radiation** – Involves the transfer of energy via electromagnetic waves



## CAREER CONNECTION

### Ana Ortiz, Fire Protection Engineer, NASA Johnson Space Center

*I knew I wanted to be an engineer when I was in high school and throughout junior college, but I did not know what kind. I started off as an architecture major, but it wasn't too interesting. I then switched to civil engineering, which was not exciting either. I told myself that there had to be an engineering field that I would have a passion for. For about two to three months, I researched online and at libraries.*

*One day I approached a firefighter who was working on a fire truck. I asked if he knew any fire protection engineers. A few minutes later, he introduced me to a gentleman who explained about all the different areas and responsibilities of fire protection engineering. I was hooked.*

*As a fire protection engineer, I routinely inspect buildings for life safety and fire protection issues, conduct plan reviews for fire alarm and sprinkler systems; oversee fixed fire suppression systems; coordinate with occupational health, environmental, and other safety professionals and organizations; and I am available 24/7 for any mishaps. Fire protection engineering deals with a little bit of everything, from chemicals to industrial places to fire studies to the life safety of people and property.*

# Lesson 5

## Prevention and Protection

(classroom discussion with demonstrations)

Length – One 45-minute period



View a demonstration  
of this experiment  
on the DVD.

### Overview

- How fires are extinguished
- Ignition sources and fire-safe cigarettes
- Smoke alarms
- Fire prevention in the home

### Student Learning Objectives

Students will understand the following:

- 1) How water extinguishes fires.
- 2) How the two most common types of smoke alarms (ionization and photoelectric) work.

### Standards Alignment

See page 16

### Suggested Materials

Bunsen burner, ring stand, ring, wire gauze, tongs, bathroom paper cups, lighter, water, thermometer, large beaker to extinguish burning cup, shallow dish, vegetable oil

2-part experiment

- Part I: Investigation
- Part II: Questions/Applications/Simulations/Debriefing/Testing

### Teacher Preparation

- 1) Please try the demonstrations on your own before doing them in class.

### Teacher Demonstration – How Fires Are Extinguished

*Start off with a mini demonstration* – boiling water in a paper cup. Set up a ring stand, ring, wire gauze, and Bunsen burner. Obtain some small paper bathroom cups from your grocery store.

Have the students take a cup out of the box – with a lighter, show the students that the cup will burn. Take another cup from the box, fill it with water, and place it on the wire gauze on the ring stand. Start the Bunsen burner and place it under the paper cup – the cup will not burn. Have tongs nearby in

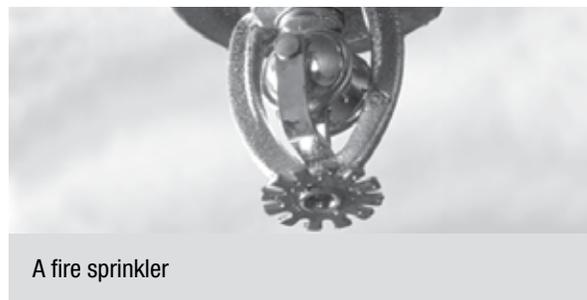
case you have to remove the cup with water – sometimes before the water boils the glue on the cup may start to give way, which will cause the water to stop boiling.

The water will start to heat up – you could monitor this with a thermometer. Ask the students why this cup didn't light on fire. You can lead this discussion back to boiling temperature, ignition temperature, and the "fire tetrahedron" discussed in lesson 2. This will lead to a discussion on how and why water is the most commonly used fire extinguishing agent.

Water is effective in extinguishing fires because it cools (removes heat), displaces oxygen by expanding to steam (removes oxygen), and dilutes the fuel source (removes fuel). Some of the chemical properties of water that make it an excellent extinguishing agent can be discussed.

According to the United States Fire Administration, each year in the United States more than 3,500 people die as a result of fire. Over 85% of these deaths occur in the home. One way to effectively extinguish fires and protect people from fire in the home is through the use of a home fire sprinkler system.

Home fire sprinklers are heat-activated devices designed to activate at a specific temperature. Each sprinkler is installed on or near the ceiling and is connected to a series of water-filled pipes. During a fire, heat from a fire is transferred to the sprinkler's sensing element. Once an automatic sprinkler reaches a predetermined temperature, the automatic sprinkler activates. As a result of this activation, water is released from the sprinkler in a distinctive pattern so that a typical residential fire is controlled and eventually suppressed.



A fire sprinkler

Cooking is the most common cause of fire in the home. There are cases when water does not effectively extinguish fire. For example, if a person attempts to use water to extinguish a grease pan fire, the water will boil and splatter the boiling grease. This process can be discussed along with the best means to extinguish a grease pan fire.

CO<sub>2</sub> is often used to extinguish fires in industrial applications in areas where water is not an effective extinguishing agent. It is used to extinguish flammable liquid fires, gas fires, and fires involving electrically energized equipment. Primarily, CO<sub>2</sub> extinguishes fires by displacing oxygen.



Carbon dioxide is used to extinguish a candle flame.

### Teacher Demonstration – CO<sub>2</sub>

Melt a little candle wax to secure a candle to the inside of a beaker. Be sure the beaker is taller than the candle (this works best if the candle is much shorter than the beaker.) Light the candle. In a separate beaker add some vinegar to some baking soda. This reaction will produce CO<sub>2</sub>, which is denser than air so it will settle to the bottom of the reaction beaker.

Carefully pour the CO<sub>2</sub> from the reaction beaker onto the burning candle – do not let any liquid leave the beaker. The “ghostly” CO<sub>2</sub> will extinguish the burning candle. There may be enough CO<sub>2</sub> to extinguish the candle one more time.



### Leading Causes of Fire in the Home

Cooking	– 32%
Heating Equipment	– 16%
Intentionally Set Fires	– 5%
Candles	– 4%
Smoking Materials	– 4%

(from National Fire Protection Association  
“Leading causes of structure fires in homes, 2000–2004 annual averages”)

### Ignition Sources and Fire-Safe Cigarettes

As discussed in lesson 3, normally an ignition source is needed to start a fire. Ask the students to list what they think are some of the most common sources of ignition for fires in the home. These ignition sources should include cooking, playing with matches, unattended candles, electrical equipment malfunctions, and smoking materials.

Although cooking is the leading cause of fires in the home, smoking materials are the leading cause of fire deaths in the home. As a transition, the students should be asked to do an Internet search on the topic of fire-safe cigarettes (see [www.firesafecigarettes.org](http://www.firesafecigarettes.org)). The students can be asked to describe the differences between regular cigarettes and fire-safe cigarettes and why fire-safe cigarettes reduce the risk of cigarette-ignited fires.

### Smoke Alarms

This discussion can start with a review of the information from lessons 1 and 2 about the deadly products of combustion. Next, the discussion will describe how properly installed smoke alarms in the home can provide an early warning of fire and how this early warning can prevent deaths and injuries from fire. According to the National Fire Protection Association, the fire death rate in homes with working smoke alarms is 51% less than the rate for homes without this protection.

There are two types of smoke alarms – ionization and photoelectric. Ionization smoke alarms have a small amount of radioactive material between two electrically charged plates. The radioactive material ionizes the air and causes a current to flow between the plates. When smoke enters the smoke alarm, it disrupts the flow of ions, thus reducing the flow of current and activating the alarm.

Photoelectric smoke alarms aim a light source into a sensing chamber at an angle away from the sensor. When smoke enters the smoke alarm, it reflects light onto the light sensor and activates the alarm.

Ionization alarms are usually more responsive to flaming fires and photoelectric alarms are generally more responsive to smoldering fires. Both types of alarms are effective in detecting fires.



A home smoke alarm

Based on what the students learned about smoke alarms and the information from previous sessions, the students should be able to answer the following discussion questions:

- Why is it important to install a smoke alarm on every level of the home?
- Why should smoke alarms be installed on or near the ceiling?
- Why is it important to keep smoke alarms clean?

### Preventing Fires in the Home

Students can refer back to their research on the leading causes of household fires from the list on page 14.

For each cause listed, the students should place the ignition scenarios in context with what they learned in lessons 1 through 4. Based on this discussion, the students can then discuss the best means to prevent these types of fires.

### Extensions

- 1) Students may research one of the following topics and then make a poster for the classroom. If time permits, have students share their posters with the class.
  - A) How do home fire sprinklers work?
  - B) Where should home smoke alarms be located?
  - C) Famous fires and how they started



Water is not effective at extinguishing grease fires.

### Evaluation

**Oral or Written:** Students will relate the fire tetrahedron to the best practices in putting out a fire by demonstrating clear understanding of the two objectives and relevant vocabulary.



## CAREER CONNECTION

**Erica Kuligowski**  
Fire Protection Engineer  
National Institute of Standards and Technology

*I became interested in fire protection engineering during a six-week Women In Engineering program the summer before my senior year of high school. I participated in two college-level courses that introduced me to the different opportunities in engineering. During the fire protection engineering seminar, we watched fire experiments and ran fire simulation computer models. I was so*

*surprised that people actually got paid to do something that was so fascinating. In the computer lab, I was able to simulate a house fire that began in the living room to learn where it would spread and what levels of smoke and toxic gases would develop. From then on, I realized that fire protection engineering was the career for me.*

*I now have bachelor's and master's degrees in fire protection engineering, and I am working on my PhD in sociology at the University of Colorado. I currently perform research on what people do during disasters and terrorist events.*

*Ensuring safer buildings and procedures during a fire is a necessary and rewarding job. Now that we are making buildings larger and taller, fire protection engineers are tasked with equipment designs and procedures that will bring people to safety in the event of a fire. Fire protection engineering is an ever-growing field that is continually using cutting-edge technology to ensure safer conditions for building occupants.*

# Standards Alignment for This Unit\*

- |   |                                      |
|---|--------------------------------------|
| 1) Chemical reactions occur all around us; for example, in health care, cooking, cosmetics, and automobiles.  | <i>Covered by lessons 1, 2, 3, 5</i> |
| 2) Chemical reactions may release or consume energy. Some reactions such as the burning of fossil fuels release large amounts of energy by losing heat and by emitting light.   | <i>Covered by lessons 1, 2, 3, 5</i> |
| 3) Chemical reactions can take place in time periods ranging from the few femtoseconds required for an atom to move a fraction of a chemical bond distance to geological time scales of billions of years.  | <i>Covered by lessons 1, 5</i>       |
| 4) A large number of important reactions involve the transfer of electrons (oxidation/reduction reactions) or hydrogen ions (acid/ base reactions) between reacting ions, molecules, or atoms.  | <i>Covered by lessons 1, 2, 3</i>    |
| 5) Carbon atoms can bond to one another in chains, rings, and branching networks to form a variety of structures, including synthetic polymers, oils, and the large molecules essential to life.  | <i>Covered by lessons 1, 2, 5</i>    |
| 6) In some materials, such as metals, electrons flow easily, whereas in insulating materials, such as glass, they can hardly flow at all.   | <i>Covered by lesson 4</i>           |
| 7) Everything tends to become less organized and less orderly over time. Thus, in all energy transfers, the overall effect is that energy is spread out uniformly. Examples are the transfer of energy from hotter to cooler objects by conduction, radiation, or convection, and the warming of the surroundings when we burn fuels. | <i>Covered by lessons 4, 5</i>       |
| 8) Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter.   | <i>Covered by lesson 4</i>           |

**\*SOURCES:**

*National Science Education Standards, National Research Council (1996).*

*Pathways to the Science Standards: guidelines for moving the vision into practice, middle school edition, National Science Teachers Association (1998).*

# Chemistry of Fire DVD Overview

## ***Fire Safety in Buildings*** TRT: 19:33

This video overviews the origins of fire safety from the burning of London to the terrorist attacks on September 11th. Understanding the chemistry of fire is the key to preventing fire disasters.

Suggested Integration:

- Use this as an introduction to the topic preceding the experiments. It will draw students into the importance of fire safety and the science behind it.
- If you choose to cover the five lessons throughout the year, consider sharing this segment before each lesson if a length of time has passed.



Look for this icon to view a demonstration of an experiment on the DVD.

## ***Demonstrations*** TRT: 11:39

This video features a fire protection engineer, Morgan Hurley, and high school students participating in chemistry experiments that he leads. It can be played in its entirety or in chapters for use with the individual lessons in this guide.

- This segment demonstrates many of the experiments presented in the five lessons.
- Use this segment to become familiar with the demonstrations before you try them on your own.
- Show the segment if the materials are not available at your school.

The following demonstrations have been included:

***Lesson 2*** – Combustion reactions

***Lesson 3*** – Ignition, shapes of diffusion flames, and states of matter for combustion

***Lesson 4*** – Conduction experiment

***Lesson 5*** – CO<sub>2</sub> demonstration, and how fires are extinguished

For your convenience, this segment is broken down into chapters on the DVD so you can find the demonstration of interest quickly.

## ***Careers in Fire Protection Engineering*** TRT: 3:17

This video highlights for students the exciting career of fire protection engineering. If world travel and saving the world from disaster sound like the stuff of action movies, explore the realities faced by three fire protection engineers who may inspire your young scientists.



SOCIETY OF  
FIRE PROTECTION  
ENGINEERS



### ***About The Society of Fire Protection Engineers***

Organized in 1950, the Society of Fire Protection Engineers is the professional society for engineers involved in the field of fire protection engineering. The purposes of SFPE are to advance the science and practice of fire protection engineering, maintain a high ethical standing among its members, and foster fire protection engineering education. SFPE's worldwide members include engineers in private practice, in industry, and in local, regional, and national government. Chapters are located in Canada, China, France, Italy, Japan, Korea, New Zealand, Saudi Arabia, Singapore, Spain, Sweden, and the United States.

For more information, visit [www.sfpe.org](http://www.sfpe.org)

### ***What is a fire protection engineer?***

According to the Society of Fire Protection Engineers, a fire protection engineer applies science and engineering principles to protect people, homes, workplaces, the economy and the environment from the devastating effects of fires. Fire protection engineers analyze how buildings are used, how fires start and grow, and how fires affect people and property. They use the latest technologies to design systems to control fires, alert people to danger, and provide means for escape. Fire protection engineers also work closely with other professionals, including engineers of other disciplines, architects, state and local building officials, and local fire departments to build fire safe communities. Fire protection engineers are in high demand. The number of available jobs far exceeds the supply.

For more information, visit:  
[www.careersinfireprotectionengineering.com](http://www.careersinfireprotectionengineering.com)

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