Unit 3

FIRE BEHAVIOR

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OBJECTIVES

After completing this lesson, students should be able to:

- Describe the chemistry and physics of fire.
- Identify the sources of heat.
- Describe the characteristics of fire.
- Describe the effects of oxygen on fire.
- Define combustion.
- Describe vapor pressure and vapor density.
- Describe the meaning of flammable and explosive limits.
- Describe the three types of heat transfers.
- Describe the significance of the thermal conductivity of materials.
- Describe fuel types and their effect on combustion.
- Describe the basis for the theory of fire extinguishment.
- Identify the classes of fire and methods of extinguishment.
- Describe the effect of thermal balance.

INTRODUCTION

Key Points

- Fire has played a major role in the development of society.
- Fire has been a friend as well as an enemy.
- Burning is also known as combustion, which is a simple chemical reaction.
- The American Heritage Dictionary defines burning as a rapid, persistent chemical change that releases heat and light and is accompanied by flame, especially the exothermic oxidation of a combustible substance.
- It is important to understand the behavior of fire and what causes it to begin, grow, and spread.

FIRE TRIANGLE, TETRAHEDRON, AND PYRAMID

Key Points

- The combustion process is depicted as a triangle with each side representing elements of combustion.
- Heat, fuel, and oxygen are essential elements of combustion.
- Through research it was found that a fourth element existed. This was the actual chemical reaction that permitted flame propagation.
- The essential elements of combustion are now shown using a fire tetrahedron.

MEASUREMENTS

Key Points

- Measurement is an important part of firefighting.
- Firefighters need to be familiar with terms used for heat, electricity, volume, length, energy output, concentrations, and weight.
- Understanding the measurements, and the limits for each of these elements, as they relate to safety of the fireground is very important.

CHEMISTRY AND PHYSICS OF FIRE

Key Points

Instructor's note: As this section may be difficult for students to understand, examples of certain concepts are provided in italicized text to help the student understand the material.

- The universe is made up of a substance referred to as matter.
- Not all matter can be picked up by the use of human senses.
- Matter is never destroyed, although it may change in its form.

  Example: Iron will rust and deteriorate into dust after years.
- All living things are made up of millions of cells.
- Cells are made up of compounds, which are made up of molecules, a chemical combination of the atoms from two or more elements.
- Substances that are, or were, once living are referred to as organic.
- Organic substances generally contain carbon, hydrogen, and oxygen in their composition.
- A nonliving substance can be considered organic if it is made up of chemicals that were at some point alive.

  Example: Some plastics, such as those used in the PVC pipe found in many plumbing systems, are made up of oils known as hydrocarbons. These oils are the remains of prehistoric living organisms.
- Organic compounds are made up of many different forms of substances, which are made of various chemicals that exist in the universe.
- Chemicals are made up of combination of molecules, which are joined together and separated by bonding actions that use a form of electricity as energy.

  Example: Water is made up of hydrogen and oxygen molecules. Water is composed of two hydrogen molecules and one oxygen molecule (H_2O).
- The combination and separation of these molecules and atoms provide the basis for what causes oxidation and combustion.
- Atoms are made up of smaller particles known as electrons, protons, and neutrons.
- The nucleus (center) of the atom is made up of neutrons and protons. Electrons orbit (rotate) around the nucleus.
- Atoms that lack electrons will be quick to link up and form molecules. If the atom has a good balance it will remain stable.

- There are some substances that are nonliving that are referred to as inorganic substances.
- Minerals are examples of inorganic substances.
- For the most part, only organic materials will burn. However, there are some exceptions.
- The term bond is the atomic glue that holds molecules together. It is in this bond that fire or combustion has its origins.
- When molecules join, heat is absorbed. This is known as an endothermic reaction.
- When bonds break, heat is released. This is known as an exothermic reaction. If the release of the heat is rapid and continuous, fire and heat are generated.
- The ability to recognize a chemical compound will help the firefighter identify which extinguishment agent to use.
- Most chemicals that are stable will maintain their form unless something presents itself to change.
- An oxidizer acts as a catalyst in the breakdown of such otherwise stable molecules.
- An oxidizer possesses a chemical property that can pull apart a molecule and break apart the bond that existed.
- If this oxidation process continues through a self-sustained chemical reaction, combustion occurs.
- The unique characteristic of these elements is that they all have the same chemical properties in their attraction and combination with other chemicals.
- If the reaction is slow, a gradual deterioration of the material will occur over time.

  Example: Metal tools that are not put away will begin to rust over time. This rust is the oxidation process in which bonds are pulled away.
- The oxidation process is much more evident during combustion.

SOURCES OF HEAT

Key Points

- Heat is the energy source that powers the universe.
- Heat can neither be created nor destroyed.
- Heat is the physical manifestation of energy as it changes from one form to another.
- The phenomenon of heat comes from four basic sources.

- The four sources of heat are chemical, electrical, mechanical, and nuclear.

Chemical

- The most common source of heat that firefighters deal with on a regular basis is the chemical reaction that releases heat as a by-product.
- Anything that burns does so through a chemical reaction in which heat is released as the bonds of the molecules break down.
- Pyrolysis is the decomposition or transformation of a compound caused by heat.

Mechanical

- Friction causes heat that can reach levels hot enough to ignite any surrounding combustible material.

  Example: Two sticks rubbing together can ignite due to friction.
- The buildup of heat from friction is often the cause of fire in machinery.
- When extinguishing the fire, ensuring that the source of heat has been stopped becomes significant.
- A fire may be extinguished even if the heat source is still pumping in heat; however, the likelihood of keeping the fire extinguished is reduced.

Electrical

- Electricity is the most recognized source of heat.
- An electrical current can generate heat.
- Electricity is simply the flow of electrons from an area where there are too many electrons to an area where there are not enough electrons.
- The place where electrons are in large quantities is referred to as being negatively charged.
- The place where electrons are lacking is referred to as being positively charged.
- Electrons travel through a conductor to reach their destination.
- An electrical conductor permits the flow of electrons from one place to another.
- When the electrical flow occurs, one electron jumps onto an atom, which releases another to move on to the next atom.
- Depending on the density of the conductor and the insulation surrounding it, the heat generated by the transfer varies greatly.

- Electrical energy is a heat source.
- It is important for firefighters to recognize forms of electrical energy.

Nuclear

- Nuclear energy generates heat the same way as do other forms of energy.
- Radioactive materials are very unstable and are constantly breaking down as they seek to form more stable molecules.
- There is little that firefighters can do to safely fight a fire that has been caused by a nuclear heat source.
- Regardless of the type, the heat source is generally the initiator of the fire that ignites surrounding combustibles.
- Once the heat source is removed, the extinguishment of the fire is simply a matter of removing the oxygen or fuel to break up the flame's chain reaction.

COMBUSTION

Key Points

- Combustion is often confused with the term fire.
- Fire is defined as a chemical reaction that is a self-sustaining process that emits light and heat as a by-product of that reaction.
- In combustion, the released heat energy is reinvested in the process, causing the continued reaction to occur repeatedly.
- If not controlled, and there is access to fuel, oxygen, and heat, the growth will accelerate.

OXYGEN AND ITS EFFECT ON COMBUSTION

Key Points

- The earth's atmosphere contains about 21 percent oxygen.
- Oxygen acts as a catalyst to the combustion process.
- Oxidation is the technical term used to describe the chemical reaction.
- The presence of oxygen can affect a material's combustibility.
- Higher concentrations of oxygen can cause some materials to ignite spontaneously or permit

materials to burn that would not normally burn at regular oxygen level concentrations.

VAPOR PRESSURE AND VAPOR DENSITY

Key Points

- Pressure is defined as the application of continuous force by one body on another body that it is touching.
- Vapor pressure is the measurable amount of pressure being exerted by a liquid substance as it converts to a gas and exerts pressure against a confined container.
- Molecules in a closed container are constantly circulating and colliding.
- Some molecules escape into the air and fill the area with molecules in a gaseous state. This process is known as diffusion.
- If the weight of the gas is lighter than the surrounding atmosphere, molecules will continue to escape. This process is called evaporation.
- Equilibrium is reached when there are as many molecules being freed from the liquid as there are being reabsorbed.
- Air pressure changes at different altitudes.
- At sea level, air pressure is 14.7 pounds per square inch (psi).
- Vapor density describes the weight of a gas as compared to normal air and is identified as a number.
- Gases that weigh less than the same volume of air will be lighter and tend to rise.

  Example: Methane has a vapor density lower than that of air and will rise.
- Gases with a weight greater than the same volume of air will be heavier and tend to drop to low lying areas.

  Example: Propane has a vapor density greater than air and will sink.
- Vapor pressure is the force exerted on the sides of a closed container.

BLEVE

- A boiling liquid expanding vapor explosion (BLEVE) occurs when a vessel holding liquid ruptures. This occurs as a result of pressure being exerted on its sides when the liquid it holds boils and the resulting pressure exceeds the container's ability to hold it.
- Even a vessel containing a non-flammable liquid can rupture violently, sending fragments flying everywhere.

- A flammable liquid can create a great fireball causing increased fire extension.
- If the liquid is a hazardous material, additional hazards must be dealt with.

IGNITION

Key Points

- When a substance begins to heat up, it liberates gases that can burn.
- When all the necessary ingredients of a self-sustaining chemical reaction are present, ignition occurs.
- Ignition is the point where the need for outside heat application ceases and the ability for the material to sustain combustion comes from the heat generation of the material itself.

BOILING POINT

Key Points

- All materials obey the laws of nature and exist in one of three forms or states: solid, liquid, or gas.
- Pressure and temperature affect the state of matter. 70° F and 14.7 psi for pressure have been established as normal.
- When a substance is described as being in a normal state, it is understood that it is at that temperature and pressure.
- A change in temperature or pressure may cause a change in the form of the substance.
- Gases compressed to liquids under great pressure generate heat, and liquids that boil absorb heat.

FLAMMABLE AND EXPLOSIVE LIMITS

Key Points

- A combustible material must meet certain requirements before it can oxidize.
- Depending on the makeup of the compound, different concentrations of oxygen may be required. This concentration is described in terms of percentages.
- Combustion can only take place when a substance is a gas. Levels of the gases are described in terms of percentages.
- Gases can only ignite when certain concentrations of that substance are present in air.

- If not enough combustible gas is present, the mixture is deemed too lean to burn. If there is too much gas, it is too rich to burn.
- When the concentration of a gas falls into the range where it can ignite, it is said to be within its flammable or explosive limit.
- Flammable limits can change depending on the temperature.
- Limits can contract or expand depending on the surrounding condition.
- Specialized instruments have been developed to display the measurements of flammable and explosive limits.

THE BURNING PROCESS-CHARACTERISTICS OF FIRE BEHAVIOR

Key Points

- The process of burning occurs in clearly defined stages.
- It is important for the firefighter to understand and recognize the various stages of the burning process and adjust firefighting tactics accordingly.

Growth Stage

- The speed of the growth and size of the fire is dependent on several factors:
  - Oxygen supply: The amount of oxygen that is available.
  - Fuel: The size of the fire will depend on the amount of fuel available.
  - Container size: The size of the structure will affect how fast it grows.
  - Insulation: Greater insulation keeps the heat trapped.

Fully Developed Stage

- At this stage, all contents within the perimeter of the fire's boundaries are burning.
- In a structure, the amount of air that gets introduced to the fire area determines the speed and extent of a fully developed stage fire.
- In an outside fire, the amount of fuel available will determine the size of the fire.

Decay Stage

- At the point when all fuel has been consumed, the fire will begin to diminish in size.

- When the fuel is totally used, the fire will begin to extinguish itself.
- As the decay stage progresses, even a fire that was air-controlled will become fuel-dependent as the amount of fire decreases.
- These factors will dictate the tactics that will be used when fighting a fire.

MODES OF HEAT TRANSFER

Key Points

- Heat is a by-product of combustion that is of significant importance to the firefighter.
- The substance being heated, the distance covered by the material being heated, and the ability of the substance to retain heat will be factors in the spread of fire.
- Heat transfers its energy from one substance to another through conduction, convection, and radiation.

Conduction

- When a hot object transfers its heat, it is doing so through conduction.
- The heat transfer can be to another object or to another part of the object.
- When an object is heated, molecules and atoms are excited and a chain reaction occurs that spreads the heat.
- Heat is conducted through different materials at different rates.
- Density, time, and application of heat will affect the rate of conduction.

Convection

- Air that is hotter than its surroundings rises.
- Air that is cooler than its surroundings sinks.
- As air is heated, molecules become excited and demand more space to accommodate the vibrations, pushing onto one another as they seek the space.

Radiation

- When combustion occurs, light is produced. Light travels by way of lightwaves.
- These lightwaves range from ultraviolet to infrared.
- Electromagnetic forces in lightwaves travel across vacuums and deposit themselves on remote objects.

Example: The sun heats the earth through radiation.

- Radiation is a major contributor to flashover, in which the heat buildup at the upper levels in a compartment radiates heat down into a room.
- Objects in the room at lower levels approach and reach their respective ignition temperature through this process.
- The heat leg of the fire tetrahedron has to be kept from developing in order to prevent the fire from extending.

THERMAL CONDUCTIVITY OF MATERIALS

Key Points

- All matter will conduct heat.
- The ability to conduct thermal energy depends on its density.
- The less dense an object is, the more difficult it is for heat to be transferred through it.

PHYSICAL STATE OF FUELS AND EFFECT ON COMBUSTION

Key Points

- Matter can be found in one of three states: solid, liquid, or gas.
- Most fuels must be in their gaseous states to take part in combustion.
- The physical state of matter can affect combustion.

Solid

- Molecules in a solid material are packed closely together. This criterion gives the material its density and its physical state.
- When heat is applied, the molecules become agitated and begin to collide with each other. This causes molecules to break apart and free up components of the material.
- Heat that is produced causes additional molecules to break away from the solid physical state, becomes a gas, and combusts.
- When the amount of heat applied exceeds the ability of the mass to dissipate it, chemical breakdowns occur, resulting in the self-sustaining burning reaction that continues until it is either interrupted or runs out of fuel.

Liquid

- In a liquid, the ability to burn is dependent on the substance's ability to place its molecules into suspension.
- A liquid cannot burn unless it is in suspension, which is referred to as atomization.
- Similar to a solid, a liquid will act as a heat sink and dissipate the introduced heat into the cooler areas of the liquid.
- When the entire pool of liquid is heated or the ability to dissipate is overcome by the application of heat, a rise in the temperature of the liquid will occur, resulting in boiling or flash point ignition.
- In most cases, there is a physical state transformation from solid to liquid to gas before combustion can take place.

Gas

- A gas, unlike the other two states, is primed for combustion. It is in a ready-made state that will permit a chemical reaction.
- Awareness of these properties and their place in the combustion process is another weapon in the arsenal of fighting fire.

THERMAL BALANCE AND IMBALANCE

Key Points

- When combustion occurs, heat is liberated as part of the oxidation process.
- It is the physical characteristics of thermal balance and imbalance that causes smoke to column and mushroom.
- Heated air and smoke rise. The hotter the air, the faster and more violent the ascent.
- When a thermal balance is reached, the ascent stops and establishes equilibrium with the atmosphere. This causes a mushroom effect of the smoke, similar to the scene inside a structure, when smoke reaches a ceiling and spreads out vertically.

THEORY OF FIRE EXTINGUISHMENT

Key Points

- The way to stop a fire is to remove one of its essential ingredients.
- If any of the ingredients are removed, the fire will collapse.

- Temperature diminution, fuel elimination, oxygen elimination, or chemical flame repression will extinguish fire.

CLASSES OF FIRE

Key Points

- Fires have been classified into different types based on the substance burning:
  - Class A: Fires made up of ordinary combustibles.
  - Class B: Fires fueled by liquids, gases, or grease-type fuels.
  - Class C: Fires fueled by electricity.
  - Class D: Fires fueled by metals.

    Examples: thorium, titanium, plutonium, lithium, magnesium, and sodium.
- Since each type of fuel has different burning characteristics, the method of extinguishing them differs.
- Class A--Extinguished by cooling the fire.
- Class B--Extinguished by using some type of smothering agent to prevent oxygen from getting to the fuel.
- Class C--Extinguished by removing the fuel, then by treating as Type A or B.
- Class D--Each metal's characteristics must be evaluated.
- Extinguishment agents are labeled by several codes. Letter, shape, and color are attached to fire extinguishers for better recognition, identification, and utilization.

WRAP-UP

Key Points

- The combustion process results from the actual chemical reaction of heat, fuel, and oxygen.
- For the most part, only organic materials will burn. However, there are some exceptions.
- Heat sources are chemical, mechanical, or nuclear.
- The burning process goes through three stages: growth, fully developed stage, and the decay stage.
- Heat is transferred through conduction, convection, and radiation.

- Fires are classified into different types and are extinguished differently.