

FIRE BEHAVIOR FOR ENTRY LEVEL FIREFIGHTERS



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Fire Behavior for Entry Level Firefighters

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Glossary

Detailed Licensing

Licensing

A detailed breakdown of this resource's licensing can be found in **Back Matter/Detailed Licensing**.

About This Resource

About This Resource

Fire Behavior for Entry Level Firefighters provides a practical introduction to the basic scientific concepts that influence fire behavior. Unlike many existing textbooks which are written for experienced firefighters, the material is written to be appropriate for entry level fire protection students and focuses on key principles, essential concepts, and current research which influence firefighting tactics and safety. The author, Robert Smith, is an instructor in the Fire Protection Technician program at Western Technical College.

This Open Educational Resource was developed with support from an [Open Western OER Fellowship](#) grant provided by Western Technical College and the Wisconsin Technical College System. Peer review and feedback was provided by Michelle Blum.

Questions or communication regarding this resource may be directed to library@westerntc.edu.

Audio Files

Computer-generated audio files have been created for each chapter of this text. These files are available to download from the folder linked below.

[Fire Behavior for Entry Level Firefighters Audio Files \(link to OneDrive folder\)](#)

1: INTRODUCTION

Learning Objectives

- Differentiate between modern fire behavior and legacy fuels.

Knowledge and understanding of the scientific principles that influence how a fire behaves is a critical aspect of performing safely and effectively as a firefighter. This is especially true in the modern fire environment. Due to numerous factors, the modern fire environment is significantly more volatile, meaning fires can grow in a matter of seconds, and the environment can quickly deteriorate beyond what firefighter clothing can protect against.

1.1: Fire Behavior and Fire Dynamics Defined

1.2: Changes in the Fire Environment

1.3: Why Study Fire Behavior and Fire Dynamics?

1.4: Review

1.1: Fire Behavior and Fire Dynamics Defined

Fire Behavior

Fire behavior for this course refers to the way that a fire interacts with the fuel and oxygen available and the environment in which the fire is in. Understanding fire behavior is what guides tactics and strategies on the fire ground, as well as helps to keep firefighters safe.

Fire Dynamics

The key element to understanding fire behavior on any fireground is by having a comprehensive knowledge of fire dynamics.

Fire dynamics is defined by the National Fire Protection Association as “The detailed study of how chemistry, fire science, and the engineering disciplines of fluid mechanics and heat transfer interact to influence fire behavior.”¹

A large part of understanding fire dynamics is through knowledge of the scientific principles that influence all aspects of fire. This knowledge begins with understanding the scientific terminology associated with burning.

This course will spend a significant amount of time covering terminology and then connecting these terms and principles to fire behavior. Success in this course will depend largely on knowledge and understanding of the terminology and the scientific principles associated with those terms.

References

¹ National Fire Protection Association. (2024). *NFPA 921: Guide for fire and explosion investigations*. <https://link.nfpa.org/free-access/publications/921/2024>

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1.2: Changes in the Fire Environment

Changes in the Fire Environment

Over the past several decades, homes have undergone a dramatic change in the way they are built, the materials they are built with, and how they are furnished. These changes have made the fire environment that firefighters work in significantly more dangerous and require that firefighters have a much better understanding of fire behavior than previous generations needed to operate safely and successfully in the fire environment.

Modern Furnishings

The most significant change in the fire environment that today's firefighters face is the introduction of polymers such as foams and plastics. Polymers are synthetic materials primarily made from natural gas and petroleum. What makes these materials so different is that they are capable of burning faster and hotter than the natural materials, such as wood and cotton, that many products inside the home used to be made of (legacy fuels). Take a look at the home furnishings comparison video to see how the modern furnishings compare to these legacy furnishings.

Home Furnishings Comparison

Consider how modern furnishings made of synthetic materials compare to legacy furnishings such as wood and cotton impact the fire environment.

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

[View this Vimeo Video online](#)



Video: [2020 FSRI Home Furnishings Comparison \(Natural vs. Synthetic\)](#) by [Fire Safety Research Institutes](#), 2020. Used according to FSRI [Terms of Use](#).

Larger Spaces

Another change that has had an impact on the fire environment is the size of homes and the spaces within homes. Homes today have increased dramatically in size. In fact, according to research from the UL Fire Safety Research Institute, homes in 1973 averaged just 1600 square feet while in 2008 they averaged 2500 square feet.¹ In addition to larger home sizes, new building materials such as engineered supports have allowed significantly more open floor plans. With less compartmentalization, these open floor plans allow fire, smoke and heat to move more freely throughout the structure, resulting in fire consuming more fuel, and involving the structure itself in a shorter timeline.

Lighter Weight Building Materials

As mentioned above, many components in modern structures utilize engineered materials. For example, rather than using traditional boards such as a 2x10 to support a floor, modern homes utilize engineered I-beams made from small-dimension wood and oriented strand board as seen below. While these products have equal or even greater load-bearing strength, they have significantly faster failure rates when exposed to fire. In fact, according to the National Institute of Technology research, houses built with legacy materials collapse after 35-48 minutes exposed to fire, while homes built with lightweight materials risk collapse in just 3-5 minutes.



Figure 1.2.1: Floor trusses.

Copyright: "Floor Trusses" by [ArmchairBuilder.com](https://www.armchairbuilder.com), licensed under [CC BY 2.0](https://creativecommons.org/licenses/by/2.0/).



Figure 1.2.2: Lightweight engineered floor truss

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Smaller Lots

Building lots have also decreased in size in the past 50 years. In 1976, the average lot size was over 10,000 square feet.² However, in 2024, the average lot was just 8500 square feet and 40% of homes were built on lots less than 7000 square feet.³ Larger homes and smaller lots mean that the risk of fire moving from a single structure to multiple structures is more likely, and firefighters have less room to operate around homes.

Void Spaces

Modern engineering has also allowed more complex designs. Today's homes emphasize visual appeal and often have complex roof designs to add character and uniqueness to homes. These designs result in uninhabitable spaces throughout the structure. These spaces can allow fire to spread into other parts of the structure, and create challenges for firefighters to access and extinguish fire in these spaces.



Figure 1.2.3: Modern home with complex roof design.
Copyright: "Fancy new house in Northwest Austin" by rutlo, licensed under [CC BY 2.0](#).

New Technology

The final factor that has changed the modern fire environment is the technology that is being incorporated into structures. Solar systems are becoming increasingly common on homes. In 2025, about 7% of homes had solar systems, nearly twice that in 2020, and by 2030, solar systems are expected to be present on more than 15% of homes.⁴

Solar systems present several hazards to firefighters. First, the panels block access to roof spaces, increasing time to access fires in attic spaces, and reducing access points. Additionally, solar panels do not stop generating electricity. While these systems do have switches to disconnect the panels from the home, they will remain energized up to that switch, posing a potential electrocution hazard to firefighters. Finally, these systems typically have large battery systems in basements or mechanical rooms, presenting an electrical hazard as well as chemical hazards and possible metal fires. These batteries also pose a re-ignition hazard as well. In addition to solar panels, wind turbines are also increasing in popularity and present similar challenges to firefighters.



Figure 1.2.4: Photovoltaic panels on modern home.
Copyright: "180511-F-BO262-1009" by Roland Balik, U.S. Air Force. Public domain.

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1.3: Why Study Fire Behavior and Fire Dynamics?

Understanding fire behavior and fire dynamics is essential for firefighters to operate safely and effectively, especially in today's more hazardous fire environment. Fire behavior refers to how a fire interacts with fuel, oxygen, and its surroundings, guiding tactical decisions on the fireground. A key component of this is fire dynamics, which involves the scientific study of how chemistry, heat transfer, and fluid movement influence fire development. Building this understanding requires familiarity with key terminology and principles that explain how fires ignite, grow, and spread.

The modern fire environment has become significantly more dangerous due to changes in building construction and household contents. Synthetic materials like plastics now dominate furnishings, burning faster and hotter than traditional materials such as wood and cotton. Additionally, homes are larger, more open, and built with lightweight engineered materials that can fail more quickly under fire conditions. Features like void spaces and newer technologies (e.g., solar panels and batteries) further complicate the fire environment. These changes mean fires can intensify rapidly, making it critical for firefighters to have a strong scientific understanding of fire dynamics to recognize hazards and respond effectively.

1.4: Review

1. Define Fire Behavior
2. Define Fire Dynamics
3. What factors have changed the way fires behave in the modern fire environment?

2: BASIC CONCEPTS OF FIRE BEHAVIOR

Learning Objectives

- Describe fuel, heat, and oxygen, chemical reaction (components of the fire tetrahedron).
- Explain fire as an oxidation reaction.
- Define the characteristics of solids, liquids, and gases.
- Define fire as a reaction (oxidation and exothermic reactions).
- Explain how heat is transferred through conduction, convection, and radiation.
- Reflect on how the scientific terminology connects to various fires.
- Define flammable and combustible materials using scientific properties.
- Define the five classes of fire based on pictures, videos, or demonstrations.

In order to gain an understanding of concepts related to fire behavior, it is necessary to have an understanding of the basic scientific terminology and scientific principles. This unit will cover the terms and concepts that will be needed to understand the phenomena that are discussed in the remaining units. Some of this terminology is likely a review from your previous educational experiences, and some may be new to you. It is important that you have a solid understanding of each of the terms in this unit. You should be able to describe or define each of these terms in order to prepare for the remainder of this course.

2.1: Scientific Concepts and Terminology

2.2: Fire Terminology

2.3: Fire Triangle

2.4: Classes of Fire

2.5: Summary

2.6: Review

2.1: Scientific Concepts and Terminology

Matter

Matter is any substance that has mass and takes up space.¹

While there are numerous **states of matter** in the physical sciences, for the purposes of this course, we will focus on three: solid, liquid, and gas.

- **Gas** – Matter that has no definitive size or shape
- **Liquid** – Matter that has a definite volume but no definite shape
- **Solid** – Matter that has a definite shape and volume

These definitions are simple enough, and it is easy to understand the difference between air, water and a block of wood. However, when examining fire dynamics, the state of matter significantly influences the process of burning depending on a fuel's state of matter. The process of burning in each of these states will be discussed in subsequent units.

Heat

Heat is a form of energy characterized by vibration of molecules and capable of initiating and supporting chemical changes and changes of state.²

Heat is a key aspect of modern fire behavior. A large amount of time will be spent on heat release rate in Unit 6. Heat and temperature are often thought of as the same thing, however it is important to understand that temperature is a measurement of heat.

Temperature

Temperature is a measurement of the amount or degree of heat (vibration of molecules) in an object or substance.³

There are three typical temperature scales that are utilized in this course and in the scientific information that you will see as you continue to learn fire behavior throughout your career in the fire service. You will primarily see Fahrenheit and Celsius used in fire behavior research; Kelvin is also cited occasionally. Each of these scales are defined by their association with both the freezing point and the boiling point of water.

- **Fahrenheit** – A temperature scale that has freezing set at 32 degrees and the boiling point set at 212 degrees.
- **Celsius** – A temperature scale that has freezing set at 0 degrees and the boiling point set at 100 degrees.
- **Kelvin** – A temperature scale that starts at absolute zero.

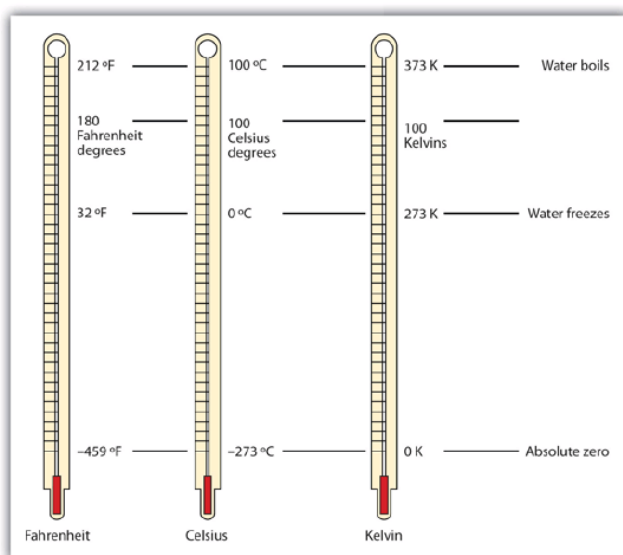


Figure 2.1.1: Fahrenheit, Celsius, and Kelvin Temperatures

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Heat Capacity

Heat capacity describes the amount of energy required to increase (or decrease) the temperature of a certain mass of material by a certain amount.⁴ Heat capacity is an important aspect in creating fuel, igniting fuel and cooling fires. For instance, wood will begin to produce flammable vapors at around 400°F, which means the surface of a chunk of firewood needs to be heated to that temperature in order to burn. This means that to start a campfire, enough of the wood needs to be heated to produce vapors, but also enough excess energy needs to be available (heat feedback loop) to heat more wood to continue the sustained reaction. Heat capacity also works in the opposite direction, where water absorbs a certain amount of heat when applied to a fire. Water's high heat capacity is what makes it a preferred extinguishing agent.

Expansion of Matter

Substances tend to expand when they are heated. In fact, this property was utilized to create analog thermometers. Because the molecules within the object have more motion as they heat up, it makes sense that most substances will expand when heated.⁵

This property has some significant implications for firefighters. For instance, steel beams can expand, causing them to buckle or push over supporting walls. Water expands 1700 times as it turns to steam, which can force superheated steam and gases into the normally cooler lower layers that firefighters operate in.



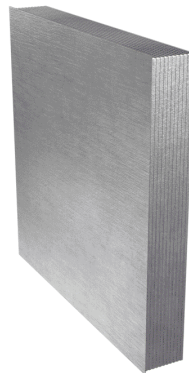
Figure 2.1.2: Building with fire damage.

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Heat Transfer

Heat, or the vibration of molecules, is transferred from high heat to low heat. Firefighters must understand this phenomenon, as they typically are the coolest part of a room that is on fire, which means heat from nearly everything in the room will be transferring to them. Heat is transferred in three different ways: conduction, convection, and radiation.

Conduction is "heat transfer to another body or within a body by direct contact."⁶

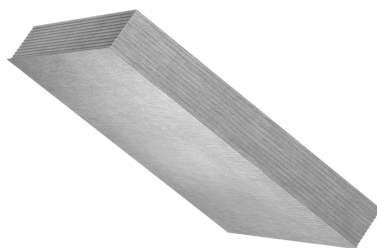


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Figure 2.1.3: Conduction Animation.

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Convection is "heat transfer by circulation within a medium such as gas or a liquid."⁷

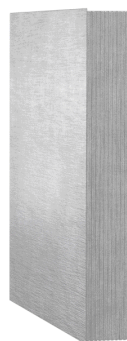


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Figure 2.1.4: Convection Animation.

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Radiation is heat transfer by way of electromagnetic waves.⁸



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Figure 2.1.5: Radiation Animation.

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As mentioned earlier, heat transfer can have significant impacts on firefighters. The animation below illustrates the three ways these heat transfer impacts firefighters.

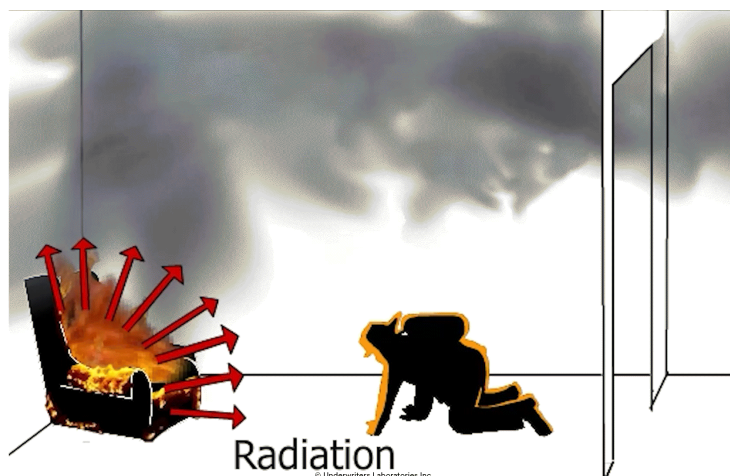


Figure 2.1.6: Heat Transfer to Firefighter.

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Energy

Energy can be defined as the ability to do work.⁹ Energy comes in many forms such as mechanical, thermal, chemical, and electrical. Most energy can be divided into two categories: potential and kinetic. Kinetic energy is the energy of moving matter, while potential energy refers to objects with stored energy. A swinging axe would be described as kinetic mechanical energy, however if a firefighter held the axe in the air waiting to swing it down, this would represent potential mechanical energy. Another example would be a can of gasoline, which would be chemical and thermal potential energy when stored and kinetic chemical and thermal energy once ignited.

Work is done whenever a force is used to move matter.¹⁰ When work is done, energy is transferred from one object to another. For example, when a firefighter uses energy to swing an axe, he transfers energy to the axe. The moving axe, in turn, transfers energy to door.

Like work, energy is measured in the joule (J), or newton-meter (N·m)

Measurements

- BTUs
- Calories
- Newtons

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2.2: Fire Terminology

Fire

NFPA defines fire as a rapid oxidation process, which is an exothermic chemical reaction, resulting in the evolution of light and heat in varying intensities.¹

Oxidation Reaction

- **Exothermic** reaction – Chemical reaction that releases energy because it takes less energy to break bonds in the reactants than is released when new bonds form in the product.² Fire is an exothermic reaction that releases energy in the form of heat and light, as well as biproducts in the form of smoke.
- **Endothermic** reaction – A chemical reaction that needs a constant input of energy to continue because it takes more energy to break bonds in the reactants than is released when new bonds form in the products.

Flame

A body or stream of gaseous material involved in the combustion process and emitting radiant energy at specific wavelength bands determined by the combustion chemistry of the fuel. In most cases, some portions of the emitted radiant energy is visible to the human eye.³

Premixed flame – A flame for which the fuel and oxidizer are mixed prior to combustion, as in a laboratory Bunsen burner or a gas cooking range.

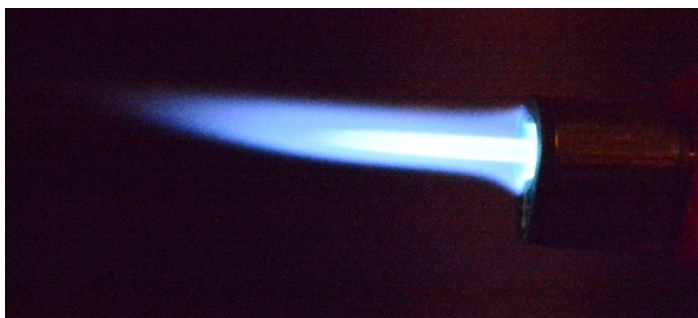


Figure 2.2.1: A Premixed Flame.

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Diffusion flame – A flame in which fuel and air mix or diffuse together at the region of combustion. Diffusion flames can be further categorized by the nature of how the fuel and air enter the combustion zone.



Figure 2.2.2: A Diffusion Flame.
Copyright: "flame" by Liz West, licensed [CC BY 2.0](#).

Laminar flame – A laminar flame has a well-defined luminous body as a result of consistent introduction of fuel and oxygen into the combustion zone. A great example of this flame is a candle.



Figure 2.2.3: A Laminar Flame.
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Turbulent flame – A turbulent flame is characterized by a luminous body that fluctuates greatly as a result of varying involvement of fuel and air. A campfire is a great example of a turbulent flame.



Figure 2.2.4: A Turbulent Flame.
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Fire Plume

The **fire plume** is the column of hot gases, flames, and smoke, rising above a fire—also called convection column, thermal updraft or thermal column (NFPA 921). While the flame is the visible luminous part of the combustion byproducts, the fire plume represents all visible and invisible combustion byproducts. The fire plume is what typically causes the spread of fire throughout a structure or to new fuels. Keep in mind that the fire plume will typically rise above the fire following the path of least resistance. In a room, the plume will rise until it is blocked by the ceiling, then will move outward.

Flame Plume

The **flame plume** is the visible or luminous portion of the fire plume.

Heat of Combustion

The heat of combustion is the amount of heat released during the combustion of a specified amount of fuel.⁴ Heat of combustion refers to the total amount of heat that will be released if a fuel is completely combusted or burned. Heat of combustion is just one of many factors that influence overall fire behavior. While heat of combustion represents the total amount of heat in a certain amount and type of fuel, it is important to understand that the actual amount of heat that is produced can vary. Different fuels release heat at different rates when burned, and the fuel can be consumed at varying rates during the combustion process.

Heat Release Rate

Heat release rate is the rate at which fire releases energy - this is also known as power. HRR is measured in units of Watts (W), which is an International System unit equal to one Joule per second. Depending on the size of the fire, HRR is also measured in Kilowatts (equal to 1,000 Watts) or Megawatts (equal 1,000,000 Watts).⁵

Mass Burning Rate

Mass Burning Rate or Mass Burning Flux refers to the rate at which a fuel is consumed when burned. The mass burning is a key aspect that differentiates legacy fuels like wood and cotton from modern fuels such as foams and plastics. Modern fuels are able to be consumed at a much faster rate.

Heat of Combustion, Heat Release Rate, and Mass Burning Rate are all important aspects that influence overall fire behavior. Simply put, heat of combustion is the total amount of energy available in a fuel, heat release rate is the speed at which that heat is released, and mass burning rate refers to the speed at which fuel is consumed. Each of these concepts are separate yet related.

For example, a faster mass burning rate will result in a higher heat release rate.

Smoke

The airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion, together with the quantity of air that is entrained or otherwise mixed into the mass.⁶ Only about 10% of smoke in a typical fire is visible. Smoke is a key aspect of fire behavior. Smoke should always be considered to be unburned fuel.

Smoke is Fuel Demonstration

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

[View this YouTube Video online](#)



Video: "Candle Smoke Flashback Demonstration (candle magic trick)" by Firesciencetools.com. YouTube Standard License.

Smoke (unburned fuel) can spread fire throughout a structure.

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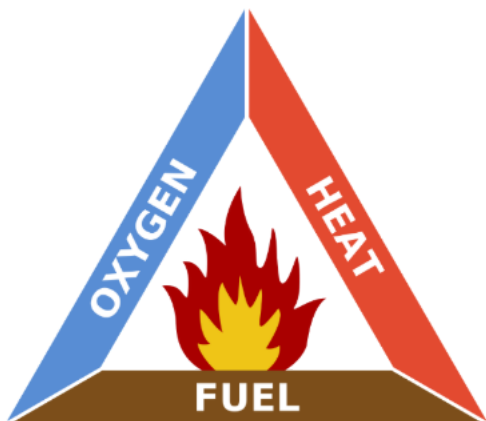
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6. National Fire Protection Association. (2024). *NFPA 921: Guide for fire and explosion investigations*. <https://link.nfpa.org/free-access/publications/921/2024>

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2.3: Fire Triangle

Fire Triangle

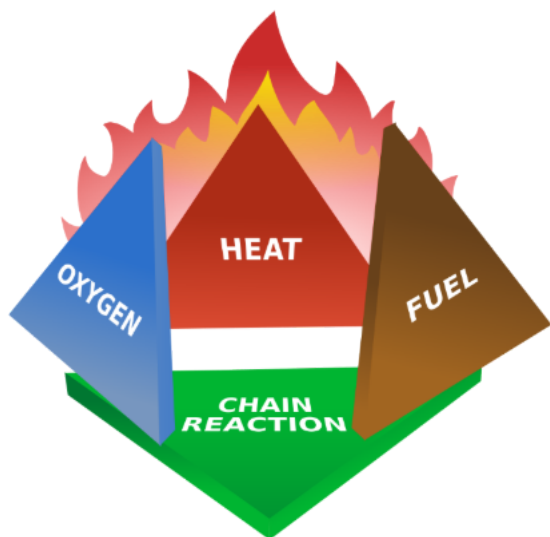
The Fire Triangle is a simple conceptual representation of fire from a chemical reaction standpoint.¹



The fire triangle is represented by three elements that are each needed in order for a combustion reaction to occur.

1. **Fuel** is the first part of the fire triangle that fire needs in order to burn. The fuel is the part of the reaction that contains the energy.
2. **Oxygen** is the second part of the fire triangle that fire needs. Fire is an oxidation reaction, therefore oxygen is needed in sufficient quantities in or for the fuel to be oxidized during the reaction. Large quantities of oxygen within the reaction zone can significantly increase the burning rate, and the intensity of a fire.
3. **Heat** is the final part of the fire triangle. Heat is what initiates the oxidation reaction. The oxidation reaction also generates heat which then causes more reactions. Once enough fuel is oxidized, the reaction becomes self-sustaining.

Fire Tetrahedron



The fire tetrahedron is a graphical representation of fire that includes a fourth side. As mentioned above, the oxidation reaction generates the heat needed to continue to feed the reaction. Removal of any of the three sides of the fire triangle from the reaction will result in the extinguishment of the fire. However, there are also chemicals

that can stop the chemical reaction without the removal of any of the 3 sides of the fire triangle. This approach to extinguishment is represented by the fire tetrahedron which consists of:

1. Fuel
 2. Oxygen
 3. Heat
 4. Uninhibited Chemical Chain Reaction
-

References

1. "Fire triangle" (n.d.) In *Wikipedia*. Retrieved August 18, 2026 from https://en.wikipedia.org/wiki/Fire_triangle. Licensed CC BY-NC-SA 4.0.

Images: "Fire Triangle" and "Fire Tetrahedron" by Gustavb on [Wikimedia Commons](#). Licensed CC BY-SA 3.0.

2.4: Classes of Fire

Fires are classified by the fuels that are being oxidized in the reaction.¹ As a firefighter it is critical to have an understanding of each of these classes, as they also correspond to ideal extinguishing methods that can be utilized as well as hazards that may be encountered.

- **Class A** – Fire involving fuels comprised of ordinary combustible materials. These fuels include wood, paper, textiles and most plastics. Class A fuels are the most common fuels. Class A fuel fires are typically extinguished by cooling, or removing the heat from the reaction.



Figure 2.4.1: Class A Fire.

Copyright: "Dumpster fire in front of the Waldo building" by bousinka, licensed CC BY-SA 2.0.

- **Class B** – Fire involving flammable and combustible fluids (liquid and gaseous state) such as gasoline, diesel, propane or alcohols. Class B fires are typically extinguished by separating the oxygen from the fuel, utilizing foam.



Figure 2.4.2: Class B Fire.

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- **Class C** – Fire involving energized electrical components. This includes appliances, wiring, electrical storage systems or solar panels. Class C fires, once deenergized, are classified based on their primary fuel. Class C fires need to be extinguished using materials or techniques that do not conduct electricity, or should be deenergized before extinguishment.

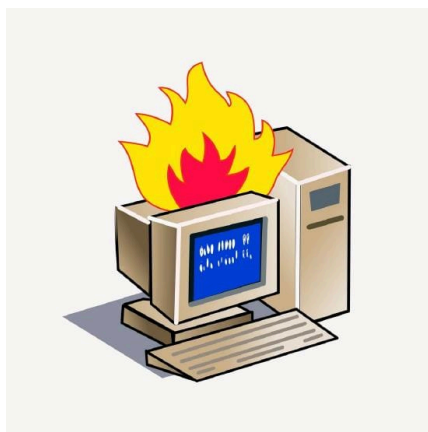


Figure 2.4.3: Class C Fire.

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- **Class D** – Fire involving combustible metals. Magnesium, titanium and lithium are a few examples of these metals. Class D fires are very difficult to extinguish, often the fire is separated from oxygen or the chemical chain reaction is inhibited.



Figure 2.4.4: Class D Fire.

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- **Class K** – Fire involving cooking oils, greases or fats. Class K fires are extinguished by separation of oxygen from the fuel and cooling of the fuel. Water should never be used on Class K fires.



Figure 2.4.5: Class K Fire

Copyright: "A volunteer attempts to extinguish a grease fire..." by A1C Brittain Crolley. Public Domain.

Table 1. Classes of Fire

Fire Class	Fuel Type	Common Examples	Typical Extinguishment Method	Notes
Class A	Ordinary combustible materials	Wood, paper, textiles, most plastics	Cool the material, usually by removing the heat from the reaction	Class A is the most common type of fire.
Class B	Flammable and combustible fluids (liquid and gaseous states)	Gasoline, diesel, propane, alcohols	Separate the oxygen from the fuel using foam	
Class C	Energized electrical components	Appliances, wiring, electrical storage systems, solar panels	Use non-conductive extinguishing materials or techniques, or deenergize before extinguishment	Once deenergized, classify the fire based on the material burning, such as Class A or B.
Class D	Combustible metals	Magnesium, titanium, lithium	Separate the fire from oxygen or inhibit the chemical chain reaction	Class D fires are very difficult to extinguish
Class K	Cooking oils, greases, or fats	Cooking oils, grease, fat	Separate oxygen from the fuel and cool the fuel	Never use water on Class K fires.

References

¹ National Fire Protection Association. (2026). *NFPA 10: Standard for portable fire extinguishers*. <https://link.nfpa.org/free-access/publications/10/2026>

2.5: Summary

Understanding fire behavior begins with a solid foundation in basic scientific concepts and terminology. Matter is anything that has mass and occupies space, and it exists primarily in three states relevant to fire science: solids, liquids, and gases. Heat is a form of energy created by the vibration of molecules and is essential for initiating and sustaining combustion, while temperature is simply a measure of that heat. Firefighters must understand how heat behaves because heated materials expand, stored energy is released, and heat moves naturally from hotter areas to cooler areas. Heat transfer occurs through conduction (direct contact), convection (movement through gases or liquids), and radiation (electromagnetic waves), all of which significantly affect firefighter safety and fire spread.

Energy is the ability to do work and is transferred whenever a force causes movement. Fire itself is an exothermic oxidation reaction that releases energy in the form of heat and light. The visible glowing portion of combustion is called the flame, while the fire plume includes all of the hot gases, smoke, and combustion products rising from the fire. Important fire behavior concepts include heat of combustion, which is the total amount of energy available in a fuel; heat release rate, which describes how quickly that energy is released; and mass burning rate, which measures how quickly fuel is consumed. Together, these factors determine the intensity and growth of a fire.

The Fire Triangle illustrates the three elements required for combustion: fuel, oxygen, and heat. The Fire Tetrahedron expands on this concept by adding the uninhibited chemical chain reaction, recognizing that some extinguishing agents stop the combustion process by interrupting the reaction itself. Smoke consists of gases, liquids, and solid particles produced during combustion and is a major hazard in fire incidents. Fires are also classified according to the fuel involved. Class A fires involve ordinary combustibles like wood and paper, Class B fires involve flammable liquids and gases, Class C fires involve energized electrical equipment, Class D fires involve combustible metals, and Class K fires involve cooking oils and fats. Understanding these fundamental concepts provides the scientific foundation needed to analyze fire behavior, predict fire growth, and apply appropriate firefighting and fire suppression strategies.

2.6: Review

1. What is the difference between heat and temperature, and why is this distinction important in understanding fire behavior?
2. Describe the three methods of heat transfer and provide a fire service example of each.
 - Conduction
 - Convection
 - Radiation
3. How do heat of combustion, heat release rate (HRR), and mass burning rate differ from one another, and how do they influence fire behavior?
4. What are the four components of the Fire Tetrahedron, and how does it differ from the Fire Triangle?
5. Define a fire plume and explain its role in the spread of fire within a structure.
6. Match each class of fire (A, B, C, D, and K) with the type of fuel involved and an appropriate extinguishment method.

Fire Classes Table

Fire Class	Fuel Type	Typical Extinguishment Method
Class A		
Class B		
Class C		
Class D		
Class K		

3: GASEOUS FUEL COMBUSTION

Learning Objectives

- Describe how heat sources initiate fire.
- Explain how temperature and pressure change the state of matter.
- Demonstrate how temperature and pressure change the state of matter.
- Demonstrate ignition temperature.

This unit is the first of three units that will examine fires based on the state of matter the fuel is in. Each of these units will include concepts that are unique to the fuels' state as well as concepts that will carry over into the following units. This unit examines fires based on fuels in a gaseous state of matter.

3.1: Gaseous Fuels and Flammability

3.2: Ignition and Propagation

3.3: Pressure and Gas Laws

3.4: Summary

3.5: Review

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3.1: Gaseous Fuels and Flammability

Nearly all fuels need to be converted to the gaseous state, a “state of matter that has neither a fixed volume nor a fixed shape” in order to burn.¹ This conversion will be discussed in the following chapters. Because gaseous fuels are already in a gaseous state, these fuels often require the least amount of energy to ignite, and can result in explosive reactions due to the speed at which the reaction occurs.

Flammability Limits

The upper and lower concentration limit at a specified temperature and pressure of a flammable gas or vapor of an ignitable liquid in air, expressed as a percentage of fuel by volume that can be ignited.² The upper and lower flammability limits can also be referred to as the explosive limits.

The **upper flammability limit (UFL)** or the upper explosive limit (UEL) refers to the highest concentration of fuel, or the highest ratio of fuel in air that will support combustion. Concentrations above this limit are considered too **rich** to burn and will not ignite even if exposed to an ignition source such as an open flame.

The **lower flammability limit (LFL)** or lower explosive limit (LEL) refers to the lowest concentration of fuel, or the lowest ratio of fuel in air that will support combustion. Concentrations below this limit are considered too **lean** to burn and do not have enough fuel to ignite or support combustion.

Combustion will only occur within the flammable range as depicted in the illustration below.

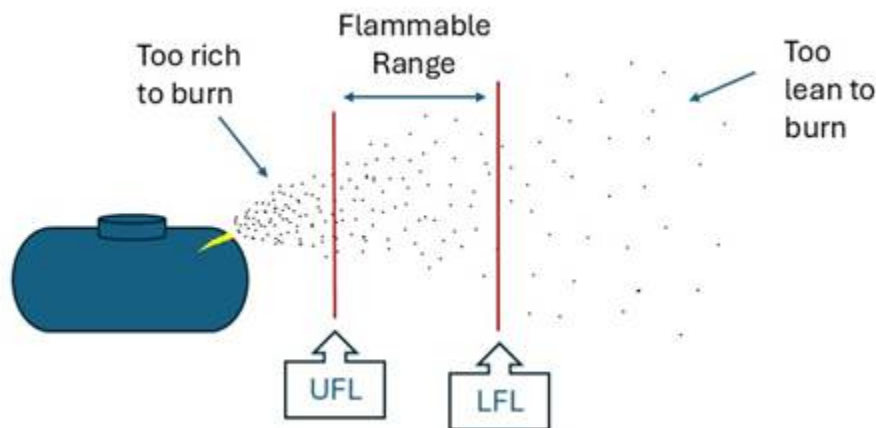


Figure 3.1.1: Flammable range.

Stoichiometric Reactions

A balanced chemical equation not only describes some of the chemical properties of substances—by showing us what substances react with what other substances to make what products—but also shows numerical relationships between the reactants and the products. The study of these numerical relationships is called stoichiometry.³

In a balanced or stoichiometric reaction, all of the products that are involved in the reaction are converted into the new product. For example, you can think of the reaction as a recipe for grilled cheese. The recipe would be 2 slices of bread, 1 slice of cheese, and 1 tablespoon of butter. If you had each of these ingredients in the exact quantities and combined them they would equal 1 grilled cheese sandwich. However, if you had a loaf of bread with 20 slices of bread, a package of cheese with 24 slices, and 8 tablespoons of butter, you could combine them to make 8 grilled cheese sandwiches, however you would have 12 slices of bread and 16 slices of cheese left over. This is not a stoichiometric reaction and much more representative of a fire. Fires rarely occur as

stoichiometric reactions, however, we can characterize some fires as more stoichiometric than others, meaning they utilize more of the fuel in a complete combustion reaction. For example, if we compare the campfire to that of the blowtorch, we can see that the campfire is far less stoichiometric, resulting in smoke and soot being left over or not being utilized completely in the reaction.

Vapor Density

Also termed specific gravity of a gas, **vapor density** is the ratio of the average molecular weight of a gas or vapor to the average molecular weight of air.⁴

Air is considered to have a molecular weight of 1. Therefore, gases with a vapor density of less than 1 will rise in air, and gases with a vapor density of less than one will sink in air. Knowing the vapor density of a gas can be helpful in understanding where vapors will accumulate. For example, propane, which has a vapor density of 1.5 will accumulate in the lower floors of a structure such as the basement, or in low levels of terrain.

References

- ¹. Adapted from Brainard, J. (2014). 4.2 Behavior of gases. In *CK-12 Physical Science For Middle School*. <https://www.ck12.org/book/ck-12-physical-science-for-middle-school/r2/section/4.2/>. Licensed CC BY-NC.
- ². National Fire Protection Association. (2024). *NFPA 921: Guide for fire and explosion investigations*. <https://link.nfpa.org/free-access/publications/921/2024>
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- ⁴. National Fire Protection Association. (2024). *NFPA 921: Guide for fire and explosion investigations*. <https://link.nfpa.org/free-access/publications/921/2024>

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3.2: Ignition and Propagation

Ignition

Ignition refers to the process of initiating self-sustained combustion.¹

The **minimum ignition energy** is lowest capacitive spark energy capable of igniting the most ignition sensitive concentration of a flammable vapor-air mixture or a combustible dust-air mixture as determined by standard test procedure. Minimum ignition energy can be understood better comparing the vapors from both gasoline and diesel fuel at room temperature. Gasoline can be ignited by a static spark of just a few millijoules. However, a match at 11-1400°F, which produces around 1100 Joules can be dropped in a pool of diesel without lighting the vapors.

Autoignition is the initiation of combustion by heat but without a spark or flame. This is also known as **thermal ignition**.

Piloted ignition refers to the initiation of combustion through direct contact with flame.

Propagation

Flame propagation refers to the movement of the flame front through an ignitable mixture. You can see an example of a flame propagation through ignitable vapors in the picture below. Flame propagation is a chain reaction of vapors igniting, creating heat and flame, and subsequently igniting the vapors nearby. This sequence of reactions can happen at an incredibly fast rate depending on the type and concentration of vapors.



Figure 3.2.1: Flame propagation
Copyright: Cropped from "Fireball closeup" by ToastyKen, CC BY 2.0.

Detonation is the propagation of a combustion zone at a velocity greater than the speed of sound in the unreacted medium.

Deflagration is the propagation of a combustion zone at a velocity that is less than the speed of sound in the unreacted medium.

References

¹ National Fire Protection Association. (2024). *NFPA 921: Guide for fire and explosion investigations*. <https://link.nfpa.org/free-access/publications/921/2024>

3.3: Pressure and Gas Laws

Pressure

Pressure refers to the amount of force pushing against a given area.¹ For this course, **vapor pressure** refers to the pressure exerted on a container from a substance that has been converted to its gaseous phase. An example of this is in a phenomenon called BLEVE, or Boiling Liquid Expanding Vapor Explosion. This occurs when a pressurized storage tank such as a propane tank is subjected to fire. The heat causes the liquified propane to vaporize, increasing the pressure inside the tank and weakening the integrity of the tank itself causing the tank to explode. You can check out this event in the video below.

Boiling Liquid Expanding Vapor Explosion

This wordless video depicts the BLEVE phenomenon.

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

[View this Interactive Content online](#)



Video: "FEMA - BLEVE Boiling Liquid Expanding Vapor Explosion Demonstration Training Video" by The Federal Emergency Management Agency (FEMA), U.S. Department of Homeland Security. Public Domain. Retrieved from the [Internet Archive](#).

Gas Laws

Boyle's Law

Boyle's Law states if the temperature of a gas is held constant, increasing the volume of the gas decreases its pressure.

Boyle's Law

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[View this YouTube Video online](#)



Video: "The Sci Guys: Science at Home - SE2 - EP9: Boyle's Law of Ideal Gases" by The Sci Guys. YouTube Standard License.

Charles's Law

Charles's Law states if the pressure of a gas is held constant, increasing its temperature increases its volume.

Charles Law

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Video: "The Sci Guys: Science at Home - SE2 - EP10: Charles's Law of Ideal Gases" by The Sci Guys. YouTube Standard License.

Combined Gas Law

The **combined gas law** is a combination of Boyle's law, Charles's law, and Gay-Lussac's law. The combined gas law states that when the amount of gas remains the same, pressure, volume and temperature can all change.

Combined Gas Law

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Video: "The Sci Guys: Science at Home - SE3 - EP6: Egg in a Bottle - Combined Gas Law" by The Sci Guys. YouTube Standard License.

References

- ¹. Adapted from Brainard, J. (2014). 4.2 Behavior of Gases. In *CK-12 Physical Science For Middle School*. <https://www.ck12.org/book/ck-12-physical-science-for-middle-school/r2/section/4.2/>. Licensed CC BY-NC.

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3.4: Summary

This unit introduces the fire behavior characteristics of gaseous fuels, which are often the easiest fuels to ignite because they are already in the gaseous state required for combustion. A key concept is the flammable range, which exists between the Lower Explosive Limit (LEL/LFL) and the Upper Explosive Limit (UEL/UFL). Fuel-air mixtures that are too lean or too rich will not burn, even if an ignition source is present. The unit also discusses stoichiometric reactions, which occur when fuel and oxygen are present in ideal proportions for complete combustion. While most fires are not perfectly stoichiometric, understanding this concept helps explain why some fires burn more efficiently and produce fewer combustion byproducts such as smoke and soot.

The unit also examines factors that influence how gases behave and ignite. Vapor density describes whether a gas will rise or sink relative to air, an important consideration when assessing hazards and predicting gas movement. Ignition is the process that initiates self-sustained combustion and can occur through piloted ignition, where an external flame or spark is present, or through autoignition (thermal ignition), where sufficient heat alone causes ignition. The amount of energy required to ignite a fuel-air mixture is known as the minimum ignition energy. Once ignition occurs, the flame can move through the mixture in a process known as flame propagation, which may occur as a deflagration (subsonic flame spread) or a detonation (supersonic flame spread).

The unit concludes with an introduction to pressure, vapor pressure, and the gas laws that govern the behavior of gases. Pressure is the force exerted over a given area, while vapor pressure refers to the pressure created when a substance enters its gaseous phase. Boyle's Law explains the relationship between pressure and volume, while Charles's Law describes the relationship between temperature and volume. These concepts are combined in the Combined Gas Law, which demonstrates how pressure, volume, and temperature interact with one another. Understanding these principles is essential for firefighters because changing gas conditions can significantly affect fire development, explosion potential, and the behavior of pressurized containers exposed to heat.

3.5: Review

1. Carbon Monoxide (CO) has a vapor density of .97. If you were to respond to a home for a suspected Carbon Monoxide (CO) leak, where would you hold your detector to have the best chance of detecting CO.
 - At the floor level
 - At the ceiling level
 - Halfway between the ceiling and the floor
 - None of the above
2. Why do gaseous fuels often ignite more easily and burn more rapidly than solid or liquid fuels?
3. What is the difference between the Lower Explosive Limit (LEL) and the Upper Explosive Limit (UEL), and why are they important for firefighter safety?
4. What is a stoichiometric reaction, and how does a perfectly balanced reaction differ from most real-world fires?
5. How does vapor density affect the movement of gases in air, and why is this important during emergency incidents involving flammable gases?
6. Compare and contrast piloted ignition and autoignition (thermal ignition). Provide an example of each.
7. Using Boyle's Law, Charles's Law, and the Combined Gas Law, explain how changes in pressure, volume, and temperature can affect the behavior of gases in a pressurized container exposed to fire.

4: LIQUID FUEL COMBUSTION

Learning Objectives

- Define ignition temperature, flashpoint, and flame point.
- Define specific heat and latent heat of vaporization.
- Explain how temperature and pressure change the state of matter.
- Demonstrate how temperature and pressure change the state of matter.
- Demonstrate ignition temperature.
- Define flammable and combustible materials using scientific properties.

This unit examines fires based on fuels in a liquid state of matter. Liquid fuels require a phase change from liquid to gas in order to undergo the combustion reaction. The temperature, or amount of heat needed to transition these fuels through the phase change varies greatly.

[4.1: Liquid Fuels](#)

[4.2: Summary](#)

[4.3: Review](#)

4.1: Liquid Fuels

Specific Gravity

Specific gravity refers to the ratio of the mass of a given volume of a substance to the mass of an equal volume of water.¹ Similar to air when discussing vapor density, water is given a value of 1, therefore, liquids that have a specific gravity of less than one will float on water and liquids that have specific gravity of greater than 1 will sink. This is often observed when you see petroleum products like gas or oil in water, often seen in a rainbow like formation floating on top. This also is visible in some salad dressing like Italian dressing where the primary components of vinegar and oil will separate into layers when stored.



Figure 4.1.1: Oil spill.

Copyright: "A vivid iridescent oil spill on rough asphalt surface" by Jared Brotman, CC0.

Boiling Point

Boiling is a type of vaporization (change of state from liquid to gas) that occurs when the average kinetic energy of the molecules in the liquid becomes large enough for molecules in the liquid separate from each other and convert into the gaseous form. The buoyant force or kinetic energy of the gas bubbles will cause them to rise up and out of the liquid. Boiling happens when these buoyant gasses overcome atmospheric pressure. Boiling will take place at different temperatures with different atmospheric pressures.

As the liquid heats up, the energy of the bubbles increases until a certain point where the bubbles overcome atmospheric pressure. This is known as the **boiling point**.² Water has a boiling point of 212 °F (100°C) however, liquid fuels can have varied boiling points. Many flammable liquids can be above their boiling points at normal environmental temperatures.

Liquid Fuel Fires

Ignitable liquids, or liquids that can support combustion, will not do so in the liquid state. These liquids must first be converted to vapor. This conversion requires energy, which can come from ambient temperature, an ignition source, or from the heat generated from the fire itself, known as a heat feedback loop. Gasoline, which can release vapors at temperatures as low as 0°F needs only the temperature of the environment to have sufficient energy to convert to a gas. However, diesel fuel, which does not begin to release sufficient amounts of vapor until around 140° is hard to ignite even with a lit match.

Flash Point

The lowest temperature of a liquid, as determined by specific laboratory tests at which the liquid gives off vapors at a sufficient rate to support a momentary flame across the surface is called the **flash point**.³ The flash point is exactly that, a flash of flame.

The Flash Point is the primary physical characteristic utilized by NFPA 30 to classify ignitable liquids. These liquids are primarily broken into two categories, Flammable and Combustible. However, these liquids are further broken down by NFPA 30 into three classes based on flash point and boiling point, with class I considered flammable, and class II & III considered to be combustible liquids.

- A **flammable liquid** has a flash point that is below 100° F and a maximum vapor pressure of 40 PSI.
- A **combustible liquid** has a flash point at or above 100°F.

Class	Flash Point	Boiling Point
I A	Below 73° F	Below 100° F
I B	Below 73° F	Above 100° F
I C	At or above 73° F and below 100° F	
II	At or above 100° F and below 140° F	
III A	At or above 140° F and below 200° F	
III B	At or above 200° F	

Fire Point

The **fire point** of a liquid is the temperature at which a liquid gives off sufficient vapors to **sustain** combustion. The fire point of a liquid is typically about 10° to 50° F above the flash point. It is important to keep in mind that a fuel needs not only the energy to heat the fuel to its boiling point, but then will take an additional amount of energy to convert the fuel into a gas. The energy required to make this final conversion to a gas is referred to as the latent heat of vaporization.

Latent Heat

Latent heat of vaporization describes the amount of heat required to convert one gram of a substance from a liquid form to a gaseous form.⁴ Keep in mind that this conversion takes place without an increase in temperature.

The Latent Heat of Vaporization of Water is 970 BTU or 570 Calories.

A BTU (British Thermal Unit) is a measurement of the amount of energy required to raise a pound of water 1°F. (approximately 1055 Joules)

If we put a pint of water or 2 cups, (which is approximately a pound of water) on the stove to boil, and assume it comes out of the tap at 65°F, it would require 147 BTU's to heat the water to it's boiling point and then another 970 BTU's to convert it to steam.

Fuels have varying boiling points and latent heat of vaporization factors; however, they all require energy to become gases.

Ignition

Autoignition temperature refers to the lowest temperature at which a combustible material ignites in air without a spark or flame.⁵ As with Latent Heat of vaporization, different fuels have varied auto ignition temperatures which can vary widely. Below is a list of common liquid fuels and their autoignition temperatures.

- Gasoline - 477°F
- Diesel fuel - 422°F
- Kerosene - 428°F

- Ethanol - 685°F

Spontaneous ignition refers to the initiation of combustion of a material by an internal chemical or biological reaction that has produced sufficient heat to ignite the material. If you had a shop class in school, you may have had a specific container for oily rags. This is because these rags can undergo a biological reaction, creating enough heat to ignite spontaneously. Another example of spontaneous ignition is a hay fire, which are caused by the same process. These organic compounds essentially decompose and generate enough heat to ignite the surrounding material. This process can take a few hours or several months to generate the heat needed to ignite.

Aerosols

Aerosols are fine particles that are suspended in the air. These particles can be either liquid or solid particles. Aerosols present a more significant hazard because the extremely fine particles essentially absorb energy more quickly and vaporize and ignite more easily. Aerosol particles will propagate rapidly once just a few particles ignite. This same concept is responsible for dust explosions, which will be examined in Unit 5 – Solid Fuel Combustion.

Wicking

Also referred to as capillary action, **wicking** refers to the movement of a liquid within another material caused by the liquid's cohesion and adhesion properties. Wicking can be observed in a towel soaking up water. Wicking can increase the surface of a fuel and reduce the mass of the fuel, which can allow it to vaporize and ignite at lower temperatures. This is why the wax on a candle burns around the wick, but does not burn on the surface of the liquid below the wick.



Figure 4.1.2: Candle flame.

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Tank Fires

Tank fires, or fires in liquid fuel storage tanks like the one pictured below, can present unique challenges to firefighters and must be monitored closely as firefighters work to extinguish the fire to prevent extremely dangerous situations.



Figure 4.1.3: Oil tank fire.

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When water and foam are used to fight tank fires, the water, having a specific gravity greater than the fuel, will sink below the fuel. As the temperature of the fuel increases, it can heat the water to its boiling point. As the water vapor forms bubbles and rises to the surface, it creates thin layers that ignite as the bubbles break the surface. This is known as **frothing**. As the fuel continues to heat up, the amount of water vaporizing will increase and can result in burning fuel spilling over the top of the tank, **sloppover**, or an almost explosive reaction known as **boilover**, where the sudden expansion can push very large amounts of burning fuel out of the tank.

Boilover

The wordless video depicts boilover.

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

[View this YouTube Video online](#)



Video: "BoilOver From API 2001" by Bakr Mammar. [Standard YouTube License](#).

Miscibility

Miscibility and solubility are very similar concepts, but we will focus on miscibility for this course.

Miscibility can be defined as the ability of a substance (liquid) to form a homogeneous solution in another substance, or completely dissolve into each other. For example, ethanol, which is found in many gasolines, is miscible in water.

The miscibility of alcohol-based fuels presents challenges to firefighters trying to utilize water-based foam to separate the fuel from the oxygen. The alcohol combines with the water in the foam and essentially pulls the water out of the foam.

Miscibility

Watch the video to learn more about the combination of alcohol and water-based foam.

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

[View this YouTube Video online](#)



Video: "Ethanol's Affect On Fire Foam" by James Cottrell. Standard YouTube License.

Surface Tension

Surface tension is an effect caused by an imbalance of forces on the atoms at the surface of a liquid.⁶ Surface tension can be observed when you spill water on your shirt and the water droplet remains on the surface rather than soak into the clothing. You may also have done the experiment where you float a paperclip on the surface of the water.



Figure 4.1.1: Paperclip floating on water due to surface tension.
Copyright: "Paperclip-floating-on-water" by Wbreslyn, licensed CC0.)

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1. National Fire Protection Association. (2024). *NFPA 921: Guide for fire and explosion investigations*. <https://link.nfpa.org/free-access/publications/921/2024>
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5. National Fire Protection Association. (2024). *NFPA 921: Guide for fire and explosion investigations*. <https://link.nfpa.org/free-access/publications/921/2024>

⁶. Ball, D. W. (2011). 10.3 Properties of Liquids. In *Beginning Chemistry*. <https://2012books.lardbucket.org/boo...f-liquids.html>. Licensed CC BY-NC-SA 3.0.

4.2: Summary

This unit examines the fire behavior characteristics of liquid fuels and the processes required for them to burn. Unlike gases, liquids cannot burn in their liquid form and must first be converted into vapor. Several properties influence this process, including specific gravity, which compares a liquid's density to water and determines whether it will float or sink. Another important concept is the boiling point, the temperature at which a liquid changes to a gas. Different fuels have different boiling points, which affects how easily they produce ignitable vapors. Because vapor production is critical to combustion, flammable liquids such as gasoline ignite much more readily than combustible liquids such as diesel fuel.

The unit also explores several temperature-based properties that influence ignition and fire development. The flash point is the lowest temperature at which a liquid produces enough vapor to momentarily ignite, while the fire point is the temperature at which sufficient vapor is produced to sustain combustion. Fuels must absorb energy not only to reach their boiling point but also to undergo the change from liquid to gas. This additional energy requirement is known as the latent heat of vaporization. Other important concepts include autoignition temperature, where a fuel ignites without an external flame or spark, and spontaneous ignition, which occurs when internal chemical or biological processes generate enough heat to initiate combustion. Understanding these properties helps firefighters assess ignition hazards and predict how liquid fuels may behave under fire conditions.

The unit concludes with several special considerations related to liquid fuel fires. Aerosols present increased hazards because their fine particles can vaporize and ignite rapidly, leading to fast fire spread or explosions. Wicking increases a fuel's exposed surface area and promotes vaporization, explaining how candles burn efficiently. Large-scale tank fires pose unique risks, including frothing, slopover, and boilover, which can occur when water trapped beneath burning fuel is heated and rapidly converted to steam. The concepts of miscibility and surface tension also influence firefighting tactics. Fuels such as alcohols that are miscible with water can degrade traditional foam blankets, while surface tension affects how liquids spread, penetrate materials, and interact with suppression agents. Together, these concepts provide firefighters with a foundation for understanding the ignition, combustion, and extinguishment of liquid fuel fires.

4.3: Review

1. Why must liquid fuels be converted into vapor before they can burn, and how do boiling point and vapor production influence this process?
2. What is the difference between specific gravity and vapor density, and how can specific gravity affect firefighting operations involving fuel spills on water?
3. Compare and contrast flash point, fire point, and autoignition temperature. Why are these temperatures important when assessing fire hazards?
4. What is latent heat of vaporization, and why does it take significantly more energy to convert a liquid into a gas than it does to heat the liquid to its boiling point?
5. Describe how aerosols and wicking can increase the likelihood of ignition and fire spread. Provide an example of each.
6. What are frothing, slopover, and boilover, and why do these phenomena make liquid fuel tank fires especially dangerous for firefighters?

5: SOLID FUEL COMBUSTION

Learning Objectives

- Demonstrate flaming combustion.
- Demonstrate smoldering combustion.
- Discuss stages of fire development (ignition, growth, fully developed, decay).
- Identify stages of fire development through pictures, videos, and time-temperature graphs.
- Review key fire-related terms such as pyrolysis, combustion, and flameover.

This unit examines fires based on fuels in a solid state of matter. As with liquid fuels, solid fuel combustion requires a phase change. In some cases, this is from solid to liquid, then to gas, or in many cases, solids are converted directly to gases. Both processes require enough energy in the form of heat to initiate these phase changes.

[5.1: Solid Fuels](#)

[5.2: Phases of Fire](#)

[5.3: Variables That Influence Combustion](#)

[5.4: Examples](#)

[5.5: Summary](#)

[5.6: Review](#)

5.1: Solid Fuels

As stated in Unit 2, a **solid** is a state of matter that has a fixed volume and fixed shape.¹

In order for a solid fuel to be utilized in the combustion reaction, the fuel must be converted to a gas. In an example such as wax from a candle, this is done through simple phase changes. The wax is converted to a liquid due to the radiative heat transfer, then once wicked up into the reaction zone, a second phase change converts the liquid to a gas. However, with most fuels such as wood and many plastics, the solid does not go through a phase change, rather, it is chemically broken down in a process called pyrolysis.

Pyrolysis is a process in which a material is decomposed or broken down into simpler molecular compounds by the effects of heat alone. Pyrolysis often precedes combustion.

Char is a carbonaceous material that has been burned or pyrolyzed and has a blackened appearance.²



Figure 5.1.1: Charred wood.

Copyright: "charred wood" by [siaronj](#), licensed [CC BY 2.0](#).

Melting is the phase change that occurs when a substance converts from a solid to a liquid. Because a liquid has more energy than a solid, that means that energy must be provided to a substance to get it to change its phase. In the melting process, molecules in their solid state absorb energy. That energy loosens the tight bonds between the molecules, allowing them to move about more freely. Heat is required to convert a solid to a liquid. That heat must come from somewhere. When melting occurs, the surrounding environment cools down after it provides that heat.

Dehydration is the process of water being removed. This can happen in the early stages of pyrolysis during the combustion process.

Smoldering combustion is self-sustained glowing combustion without flame, usually with incandescence and smoke.



Figure 5.1.1: Smoldering combustion.
Copyright: "Smoldering Fire" by pfly, licensed CC BY-SA 2.0.

References

- ¹. Brainard, J. (2014). 4.1 Solids, liquids, gases, and plasmas. In *CK-12 Physical Science For Middle School*. <https://www.ck12.org/book/ck-12-physical-science-for-middle-school/r2/section/4.1/>. Licensed CC BY-NC.
- ². National Fire Protection Association. (2024). *NFPA 921: Guide for fire and explosion investigations*. <https://link.nfpa.org/free-access/publications/921/2024>

5.2: Phases of Fire

Fire Development Phases

Incipient Phase

The early stage of fire development, where the fire's progression is limited to a fuel source and the thermal hazard is localized to the area of the burning material.¹

Growth Phase

The stage of fire development where the heat release rate from an incipient fire has increased to the point where heat transferred from the fire and the combustion products are pyrolyzing adjacent fuel sources and the fire begins to spread across the ceiling of the fire compartment (rollover).

Fully Developed Phase

The stage of fire development where heat release rate has reached its peak within a compartment.

Decay Phase

The stage of fire development within a structure characterized by either a decrease in the fuel load or available oxygen to support combustion, resulting in lower temperatures and lower pressure in the fire area.

All Four Stages

Fire Development: Four Stages

You can see examples of these phases in the video below..

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

[View this YouTube Video online](#)



Video: "[Fire Development: Four Stages](#)" by UL Xplorlabs. [YouTube Standard License](#).

References

- ¹. National Fire Protection Association. (2020). *NFPA 1410: Standard on training for emergency scene operations*. <https://link.nfpa.org/free-access/publications/1410/2020>

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5.3: Variables That Influence Combustion

Flame Spread

Flame spread refers to the movement of the oxidation reaction across the fuel. The speed at which flame spread occurs is determined by several factors, including orientation and fuel characteristics. Flame spread can occur rather slowly, such as across a log in a campfire, or with explosive speed such as when a flame propagates through a cloud of flammable gas.

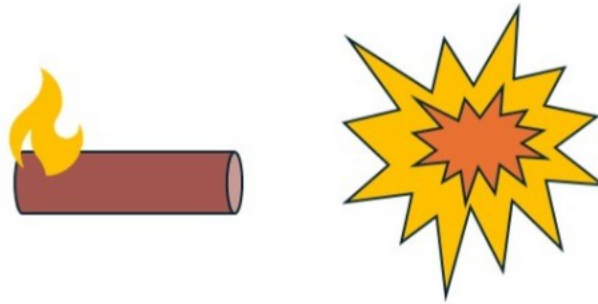


Figure 5.3.1: Flame spread.

Surface-to-Mass Ratio

Surface-to-mass ratio impacts combustion in two ways.

First, it increases the amount of surface that can be heated, and therefore can contribute fuel to the combustion reaction.

In the example below, the 1" x 2" green block has 10 square inches of surface area. The blue blocks together have the same mass as the green block; however, the blue blocks have 12 square inches of surface area.

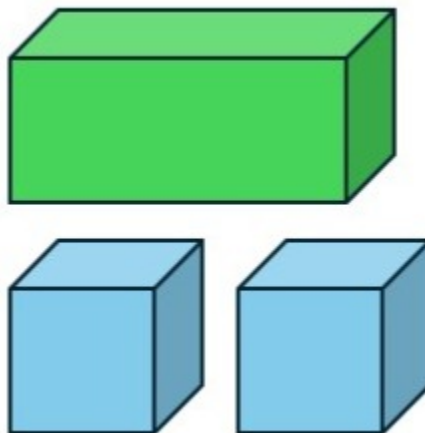


Figure 5.3.2: Surface-to-mass ratio: surface area.

The second way that the surface-to-mass ratio impacts combustion is by overall mass.

Remember, heat moves from hot to cold, so as the surface of the fuel is heated, the heat moves through the fuel, essentially cooling the surface. As the surface area increases relative to mass, the size of the fuel being heated decreases, reducing the ability to absorb heat from the surface and therefore allowing the fuel to ignite sooner.

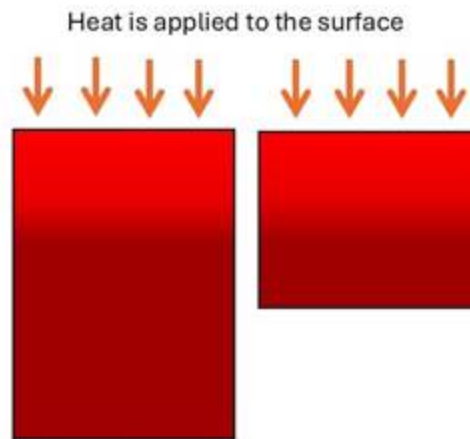


Figure 5.3.3: Surface-to-mass ratio: overall mass.

Orientation and Geometry

The fuel's orientation and geometry influence the combustion process. For example, a match being held with the flame up will consume the fuel slower, because the heat is primarily moving in the opposite direction of the fuel. However, if you hold the match upside down, the fire plume is able to heat much more fuel as it moves upward, therefore, growing in size and consuming the fuel at a faster rate.

A Christmas tree, due to its many small branches and needles all evenly spaced, has a geometric arrangement that favors fire growth.

Thermal Inertia

Thermal inertia refers to the speed at which heat travels through a material. This speed is described as either thermally thick or thermally thin.

Materials that are considered **thermally thick** do not transfer heat readily through their mass. Thermally thick materials when heated on one side, will be slow to have heat reach the other side. Wooden blocks or boards would be a good example of something that is thermally thick.

Materials that are considered **thermally thin** transfer heat quickly through their mass. A metal pan is a good example of a thermally thin material. Heat is transferred from one side to the other very quickly. Thermally thin fuels will ignite faster than thermally thick fuels.

Area

Much like the surface-to-mass ratio, the area that is being heated impacts the amount of fuel that can contribute to the fire. A fire can double in size every 30 seconds, so the amount of area of fuel involved is a key aspect of fire growth.

Density

The density of fuel impacts how easily a fuel can be pyrolyzed. Denser fuels require more heat for longer periods of time to turn the solids into combustible gases.

Other Factors

In addition to the above, factors such as moisture content in the fuel and the amount of heat being transferred to the fuel can

influence the rate of combustion and fire growth.

5.4: Examples

Dust Fires

Dust fires are a uniquely hazardous situation caused by fuel that takes advantage of many of the combustion influences above. Very fine particles can combust with very little energy, and are able to propagate, just like gaseous combustion. This propagation and expansion caused by the near instant involvement of a cloud of dust can create an explosive reaction. The fine particles of dust can result in explosions even with typically non-combustible materials such as iron dust created in manufacturing processes. Dust explosions are a serious concern in places such as machine shops, woodshops, and granaries.

Metal Fires

Metal fires involve combustible metals such as magnesium, titanium or aluminum. Fires involving combustible metals can be exceptionally difficult for firefighters. Combustible metals burn at very high temperatures and can react violently with water or other extinguishing agents and require specific techniques and materials to extinguish. These metals are common in manufacturing and machining, but can also be found in fireworks, vehicles, fertilizers and even packaging and construction materials. Many of these metals become a bigger hazard when found in dust or ribbon form. A great example of this is steel wool. Steel, which is not considered combustible, will burn easily as steel wool. In fact, there are numerous incidents where dust from steel manufacturing became ignited and resulted in deadly explosions.

Burning Steel Wool

Example of a metal fire.

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

[View this YouTube Video online](#)



Video: "The Sci Guys: Science at Home - Burning Steel Wool" by The Sci Guys. YouTube Standard License.

5.5: Summary

This unit focuses on solid fuel combustion and the processes that allow solid materials to become part of a fire. Unlike gases and some liquids, most solid fuels must be chemically broken down before they can burn. This process, known as pyrolysis, uses heat to decompose solid materials into combustible gases that can support combustion. Common examples include wood and many plastics. The unit also introduces concepts such as melting, dehydration, char formation, and smoldering combustion, all of which can occur during the early stages of fire development. Understanding these processes helps explain how solid fuels ignite, sustain combustion, and contribute to fire growth.

The unit also examines the stages of fire development, including the incipient, growth, fully developed, and decay phases. As a fire progresses, heat release increases and additional fuels become involved through pyrolysis and flame spread. Several fuel characteristics influence the rate of combustion and fire growth. These include surface-to-mass ratio, orientation and geometry, thermal inertia, fuel area, and density. Fuels with a high surface-to-mass ratio, such as wood shavings or finely divided materials, ignite more quickly because more surface area is exposed to heat. Similarly, fuel arrangement and orientation can increase heat transfer and accelerate fire spread. Materials that are thermally thin allow heat to penetrate quickly and generally ignite faster than thermally thick materials.

The unit concludes by exploring special hazards associated with solid fuels. Dust fires and dust explosions occur when fine combustible particles become suspended in air, creating fuel-air mixtures that can ignite and propagate rapidly. These incidents can occur with materials that may not normally be considered highly combustible, such as metal dust. The unit also discusses metal fires, which involve combustible metals such as magnesium, titanium, and aluminum. These fires burn at extremely high temperatures and often react dangerously with water and common extinguishing agents, requiring specialized firefighting techniques. Understanding how fuel characteristics, fire development, and special fuel hazards influence combustion provides firefighters with the knowledge needed to predict fire behavior and apply safe and effective suppression strategies.

5.6: Review

1. What is pyrolysis, and why is it necessary for most solid fuels such as wood and plastics to burn?
2. Describe the four phases of fire development (incipient, growth, fully developed, and decay) and explain what characterizes each phase.
3. How does the surface-to-mass ratio of a fuel influence ignition and fire growth? Provide an example of a fuel with a high surface-to-mass ratio.
4. What is the difference between thermally thick and thermally thin materials, and how does thermal inertia affect a fuel's ignition characteristics?
5. How do fuel orientation and geometry influence flame spread and overall fire behavior? Give an example of how changing a fuel's orientation can affect its burning rate.
6. Why are dust explosions and combustible metal fires considered especially hazardous, and what factors make these incidents difficult for firefighters to manage safely?

6: FIRES WITHIN STRUCTURES

Learning Objectives

- Connect fuel configuration with scientific measured results (such as time temperature charts).
- Discuss factors that influence fire progression.
- Demonstrate how fuel load and configuration impact fire behavior.
- Identify the conditions leading up to flashover and backdraft phenomena.
- Discuss factors that influence fire progression.
- Review key fire-related terms such as pyrolysis, combustion, and flameover.
- Apply key fire-related terms such as pyrolysis, combustion, and flameover.
- Explain the role of thermal layering and buoyancy in fire dynamics.
- Explain the concept of flowpath in structural fires.
- Predict flowpath based on fire environment.
- Describe the value and limitations of smoke reading (velocity, color, amount, etc.).

Fires within enclosures such as a room or structure present some unique challenges to firefighters. Within an enclosure a fire's behavior is impacted by pressures, both atmospheric and fire-related, as well as oxygen availability. Moreover, as firefighters enter or open the structure or room, they can significantly impact the behavior of the fire, both negatively and positively.

6.1: Fire Growth

6.2: Flowpath

6.3: Summary

6.4: Review

6.1: Fire Growth

Phases of Fire Review

Before examining aspects of enclosure fires, it is important to have a good understanding of the four phases of fire growth.

Take a moment to review the growth phases of fire:

1. Incipient Phase
2. Growth Phase
3. Fully Developed Phase
4. Decay Phase

Heat Release Rate

The **heat release rate** is the rate at which heat and energy is generated by burning.¹ One of the biggest influences on modern fire behavior is the heat release rates of modern fuels. Heat release rate has a direct impact on fire growth and spread within a structure as well as oxygen availability.

Heat release rates are displayed visually on graphs called **heat release rate curves** that plot the amount of heat being released and the fire timeline. They can be displayed for a single item, such as a chair, or for an entire room or fuel package.

Heat Release Rate and Temperature

Video: [Heat Release Rate and Temperature](#) by [Fire Safety Research Institutes](#), 2025. Used with permission; see [Terms of Use](#).

Heat Release

See an example of fire growth of an office chair and the corresponding heat release rate graph.

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

[View this YouTube Video online](#)



Video "Heat Release Rate" by [NYUFireResearch](#). [YouTube Standard License](#).

The fire growth curve can visually depict a fire's behavior within an enclosure. Each growth curve will show each phase of the fire from ignition to decay. However, because the ignition phase timeline varies greatly even with identical fuel packages, growth curves generally begin as the ignition phase begins to transition to the growth phase.

Traditional Fire Growth

Fires involving legacy fuels in traditional structures are typically what is considered a fuel-controlled fire. This means that the fire has the oxygen needed to consume the entire fuel load and the fuel availability controls the transition of the fire through each phase. These fires have a steady upward heat release rate through the growth phase, then level off during the fully developed

phase until the fuel is consumed and the fire begins to decay. This pattern often results in a somewhat square fire growth curve.

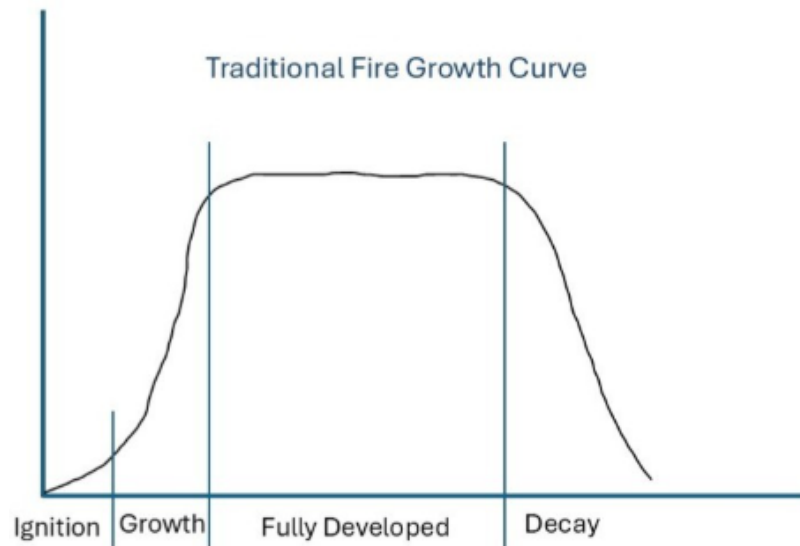


Figure 6.1.1: Traditional fire growth curve.

Modern Fire Growth

Fires involving modern fuels which have much faster heat release rates, in modern structures that allow less oxygen entrainment within the structure, result in a fire that is oxygen controlled. Because of the higher heat release rates, the fuels consume oxygen much faster than traditional fuels. This results in an environment that lacks enough oxygen to support combustion.

Modern growth curves often enter an oxygen-limited phase as they reach the fully developed phase, resulting in a period of decay. If nothing changes in this environment, the fire will eventually extinguish itself due to lack of oxygen. However, often what happens is that oxygen is reintroduced. This reintroduction can be caused by a failure of a window by heat, or by someone opening a door or window. Many firefighters have been hurt or even killed by reintroducing oxygen to the fire while entering the structure to fight the fire. Even though a fire is in the oxygen-limited status, the residual heat still pyrolyzes fuel, so there is an increase in gaseous fuel waiting for that reintroduction of oxygen. Because of this, often, the fire transitions to flashover (described below) shortly after oxygen is introduced.

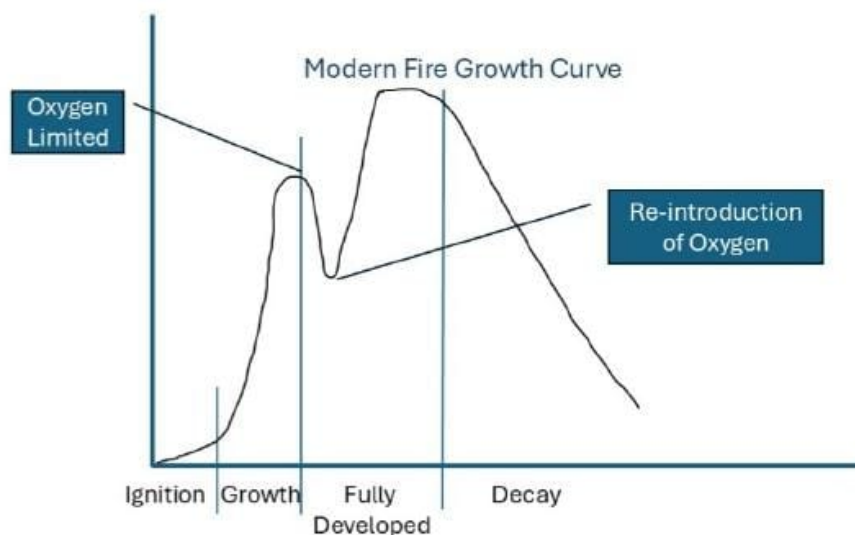


Figure 6.1.2: Modern fire growth curve.

Flameover

Also called rollover, **flameover** is the condition where unburned fuel from the originating fire has accumulated in the upper layer to a sufficient concentration that it ignites and burns. This can occur without ignition of or prior to the ignition of other fuels separate from the origin.²

Flameover

Example of flameover.

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[View this YouTube Video online](#)



Video: "[Fire fighting rollover demo](#)" by DangerDad828. [YouTube Standard License](#).

Flashover

Flashover is a transition phase in the development of a compartment fire in which surfaces exposed to thermal radiation reach ignition temperature more or less simultaneously, and fire spreads rapidly throughout the space, resulting in full room involvement or total involvement of the compartment or enclosed space.³

Flashover

Example of flashover.

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[View this YouTube Video online](#)



Video: "[Flashover Demonstration](#)" by OakRidgeRD. [YouTube Standard License](#).

Not every compartment fire will transition to flashover. Fuel type and availability, as well as oxygen availability, are key to the room transitioning. While a single upholstered chair contains enough energy (heat of combustion) to transition a typical residential room into flashover, there needs to be enough fuel that can be pyrolyzed in order to bring the compartment into flashover.

Flashover is considered unsurvivable for firefighters or occupants so it is important that firefighters are able to recognize when flashover may occur and either cool the space, or exit the area.

There are several indicators that can be observed by firefighters that indicate a compartment is beginning to transition to flashover. These indicators are typically categorized as technical and non-technical.

The **technical indicators of flashover** are temperature and heat flux. While these indicators are important, they do not mean much to firefighters inside a burning structure.

The **non-technical indicators of flashover** are observations that have been reported as the environment nears or transitions to flashover. Below are some of these indicators:

1. Lowering neutral plane – In some instances, as the upper layer becomes hotter and more gasses accumulate the neutral plane will lower as pressures increase in the space. This will be dependent on ventilation profile of the space.
2. Visible pyrolysis – often the fuels in the entire room will begin to pyrolyze due to the radiant and conductive heat transfer from the superheated gasses in the upper layer. This pyrolysis can be seen just before flashover in the above video.
3. Breaking windows – Often as a room transitions to flashover, the rapid increase in temperature will result in windows breaking. This action is an indicator that flashover has occurred rather than a sign that it will happen.

Backdraft

A deflagration resulting from the sudden introduction of air into a confined space containing oxygen-deficient product of incomplete combustion.⁵ A backdraft is relatively uncommon, but a very dangerous situation.

Backdraft

You can see an example of backdraft in the video below.

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

[View this YouTube Video online](#)



Video: "Daniel's Block Fire-BACKDRAFT" by [Elia Clemente](#). [YouTube Standard License](#).

Fuel Controlled Fire

A **fuel controlled fire** is one in which the heat release rate and growth are controlled by the characteristics of the fuel, such as quantity and geometry, and in which adequate air for combustion is available.

Fuel Load

Fuel load refers to the total quantity of combustible contents of a building, space, or fire area, including interior finish and trim, expressed in heat units or the equivalent weight in wood. While fuel load is the total quantity of fuel available, the type and arrangement of that fuel will determine the size and heat release rate of a fire.

Plume Formation

A fire plume is made up of the byproducts of combustion such water, carbon dioxide, carbon monoxide, hydrogen cyanide, along with other gases and particles. Because these products are heated, thermal buoyancy causes these gases and particles to rise vertically within the space. The fire plume will continue to rise until it reaches a barrier such as a ceiling, which will result in a ceiling jet, or until the gases cool to the point that the atmospheric gases cause enough drag to stop the gases from rising.

The **ceiling jet** is a relatively thin layer of flowing hot gasses that develops under a horizontal surface as a result of plume impingement and the flowing gas being forced to move horizontally. The ceiling jet cause convective heat transfer within the room and into other rooms. Additionally, as the ceiling jet continues to contribute to the heat in the upper layers, radiative heat transfer will heat fuel below the upper layer.

The thermal plume will always follow the path of least resistance. In an enclosure, as the thermal plume continues to flow upward

and then outward forming the ceiling jet, heated gases and particles will flow horizontally until they meet a wall. When this happens, the gases will begin to fill the space, forming an upper layer of combustion products. This layer will continue to fill the space, causing the upper layer to continually grow toward the lower part of the space. This will continue until the fire begins to decay, or the upper layer is able to find another path out of the space such as a doorway or window.

Open Floor Plan Fire

You can see these concepts illustrated in the video below.

Video: [Open Floor Plan Fire: Impact of Temperature and Pressure on Fire Behavior](#) by Fire Safety Research Institutes, 2025. Used according to FSRI [Terms of Use](#).

Ventilation Controlled Fire

Also known as oxygen controlled or oxygen limited fire, a **ventilation controlled fire** refers to a fire in which the heat release rate and growth are controlled by the availability of oxygen within the space.

Full Room Involvement

Full room involvement refers to a fire that has spread to all or most of the fuel in the room. Full room involvement may or may not include flashover. A similar term, fully involved structure, has the same meaning but refers to the fuel in the entire structure being involved.

References

1. National Fire Protection Association. (2024). *NFPA 921: Guide for fire and explosion investigations*. <https://link.nfpa.org/free-access/publications/921/2024>
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4. National Fire Protection Association. (2024). *NFPA 921: Guide for fire and explosion investigations*. <https://link.nfpa.org/free-access/publications/921/2024>

6.2: Flowpath

Flowpath refers to the movement of hot, high-pressure gases out of the structure and the movement of colder, low-pressure gases into the structure of a compartment.



Figure 6.2.1: Gasoline Can.

Copyright: "Gasoline-can" by Morewrite? licensed CC BY-SA 4.0.

Flowpath can be compared to the openings of a gas can, or a soda can. If only one opening is used, and the vessel is tipped slightly, the liquid will flow out the bottom of the opening, and fresh air will flow in through the top of the opening. If the can is tipped further, the liquid will flow out of the entire opening until the pressure inside falls below the outside pressure; then air will be sucked in. This results in the “glug-glug” motion you may be familiar with. However, if the vent is opened, or we poke a hole in the can, the “glug-glug” stops because air can flow in one opening, and out the other. This situation also allows the most liquid to flow out of the container.

This is the same thing that happens inside a room. The pressure of the heated gasses is similar to tipping the can. Openings in the room or structure function similarly to the opening in the cans.

Heat Release

Here is a great video provided by the Fire Safety Research Institute.

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

[View this Vimeo Video online](#)



Video: [Fire Flow Path](#) by [UL Research Institutes' Fire Safety Research Institute](#), 2025. Copyright: All rights reserved, used with permission from Underwriters Laboratory; see [Terms of Use](#).

Neutral Plane

The **neutral plane** refers to the horizontal plane that separates the high-pressure gases from the low-pressure gases. In the gas can analogy, this would be where the liquid and air pass by each other when the can is tipped. The neutral plane is often visible on bi-directional openings and can give firefighters valuable size-up information.

Uni-Directional Opening

A uni-directional opening refers to an opening where gasses in the entire opening are moving in one direction. Uni-directional openings can either be inlets or outlets. Typically, if a uni-directional opening exists, there is another uni-directional opening or bi-directional opening on the structure somewhere. It is important to identify the location of these other openings prior to entering the structure.

Bi-Directional Opening

A bi-directional opening has both an outlet and an inlet on the same opening. Bi-directional openings can be identified by the existence of the neutral plane.

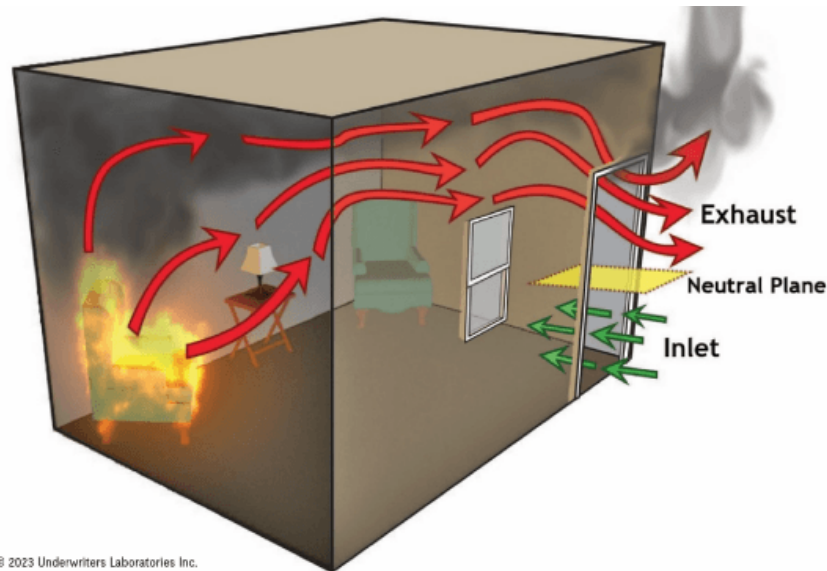


Figure 6.2.1: Flowpath.

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6.3: Summary

This unit examines how fires behave inside enclosed spaces such as rooms and buildings and explains why these fires present significant dangers to firefighters. Unlike open-air fires, enclosure fires are heavily influenced by heat release rates, oxygen availability, pressure differences, and ventilation. Modern furnishings made of synthetic materials produce much higher heat release rates than traditional fuels, causing fires to grow much more rapidly. As a result, many modern structure fires become ventilation-controlled (oxygen-limited) rather than fuel-controlled, meaning fire growth is limited by available oxygen rather than available fuel. Even when visible flames diminish due to oxygen depletion, hot gases continue to pyrolyze fuel, creating a potentially explosive environment if oxygen is suddenly reintroduced through an opened door, window, or ventilation opening.

The unit also explores key fire behavior phenomena including flameover (rollover), flashover, and backdraft. Flashover is one of the most dangerous events in firefighting, occurring when nearly all combustible surfaces in a compartment ignite almost simultaneously due to intense heat. Firefighters must recognize warning signs such as a lowering neutral plane, visible pyrolysis of room contents, and rapidly increasing temperatures. A backdraft occurs when oxygen is suddenly introduced into an oxygen-deficient space containing heated combustion products, causing a violent deflagration. Understanding these events is critical for firefighter safety and tactical decision-making.

In addition, the unit explains how fire plumes, ceiling jets, and upper-layer development contribute to fire spread within a structure. Hot gases rise in a thermal plume, spread across the ceiling as a ceiling jet, and eventually form a growing upper layer of heat and smoke. These processes increase radiant and convective heat transfer throughout the enclosure, potentially leading to flashover. The concepts of flow path, neutral plane, and uni-directional and bi-directional openings are also introduced, demonstrating how air and combustion products move through a structure. Because firefighters can significantly alter these flow paths when opening doors or windows, understanding enclosure fire dynamics is essential for controlling fire growth, improving occupant survivability, and operating safely on the fireground.

6.4: Review

1. What is the difference between a fuel-controlled fire and a ventilation-controlled (oxygen-limited) fire, and why are modern structure fires often ventilation-controlled?
2. Define flashover and identify at least three warning signs that firefighters may observe as a compartment approaches flashover conditions.
3. What is a backdraft, and what conditions must exist for a backdraft to occur?
4. Describe how a fire plume, ceiling jet, and upper layer develop within a compartment fire and how they contribute to fire spread.
5. What is a flow path, and how can opening a door or window change fire behavior inside a structure?
6. A firefighter arrives at a structure fire and observes smoke pushing from a doorway with a lowering neutral plane and visible pyrolysis of furniture throughout the room. What fire behavior event is likely developing, and what actions should the firefighter consider to improve safety?

7: EXTINGUISHMENT

Learning Objectives

- Identify suppression agents and their uses (foam, CO₂, dry chemicals, etc.)
- Define how suppression agents interact with the fire triangle/tetrahedron.
- Connect appropriate suppression agents to each class of fire.
- Compare advantages and limitations of different suppression methods on various classes of fire.
- Connect the scientific properties of water to its ability to extinguish fire.
- Discuss limitations of using water as an extinguishing agent.
- Explain how various extinguishing agents perform on a fire.
- Explain why various methods of extinguishment are preferred over others.
- Describe advancements such as clean agents and ultra-high pressure as extinguishing methods.

Extinguishment of fire can be understood utilizing the fire triangle and fire tetrahedron. Removing any side will stop the sustained reaction from continuing. In some instances, reintroducing the removed element will allow the reaction to restart again, so it is important to monitor an extinguished fire to ensure that the reaction does not restart.

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7.1: Removing Elements

Removal of Heat

Removal of heat, or cooling of the fire is effective by stopping the heat feedback loop, causing the fuel to stop being vaporized, or pyrolyzed. As a result, removal of heat is effective on solid and liquid fueled fires. Removal of heat is the most common method of extinguishment utilized by structural firefighters.



Figure 7.1.1: Cooling of the fire.

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Removal of Fuel

Removal of fuel separates the fuel from the oxygen and heat needed to complete the oxidation reaction. This can be by creating a barrier between the fuel and the oxygen, or simply shutting off the fuel supply such as turning off a burner on the stove. Another example can be seen below where wildland firefighters construct a fire line, or an area without fuel that prevents the fire from being able to continue burning.



Figure 7.1.2: Wildland firefighters constructing a fire line.

Copyright: "Wildland firefighters for the Gila District" by BLMArizona. [Public Domain](#).

Removal of Oxygen

Removal of the oxygen from the reaction also works by separating the fuel and the oxygen. In some cases, this is done concurrently with removal of fuel, for example when applying a foam blanket, or smothering a fire with sand. Oxygen can also be removed from the fire by introducing a heavier gas such as argon or carbon dioxide to displace the oxygen from the fire environment.

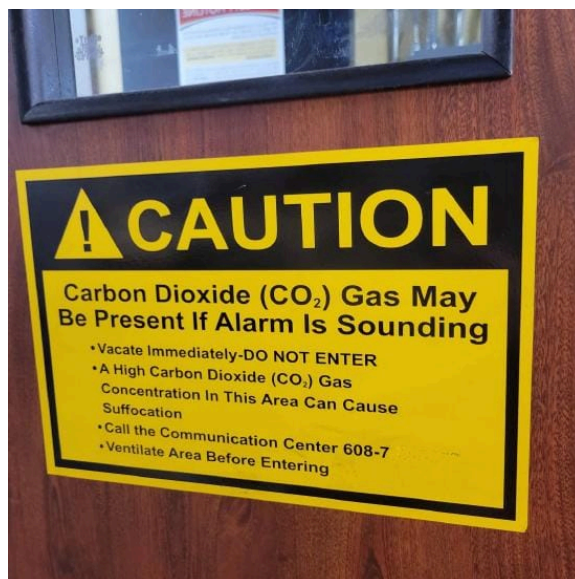


Figure 7.1.3: Carbon dioxide presence.

Inhibiting the Chemical Chain Reaction

The final method of extinguishment is by attacking the chemical chain reaction itself, rather than removing a component of the reaction.

Chain reactions usually consist of many repeating elementary steps, each of which has a chain carrier. Once started, chain reactions continue until the reactants are exhausted. Fire and explosions are some of the phenomena associated with chain reactions. The chain carriers are some intermediates that appear in the repeating elementary steps. These are usually free radicals.¹

Agents extinguish fire through inhibition stop or slow the free radicals' activity so they cannot continue to repeat the chain reaction or work as an intermediary between the reacting elements.

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7.2: Suppression Agents

Water

Water extinguishes fire primarily by cooling, although it can also smother or separate fuel and oxygen.^{1,2,3} Water is the most commonly used extinguishing agent used by firefighters. Water is an excellent agent for Class A fires which is the primary fuel in structural and wildland firefighting.

Water is a superior cooling agent due to two properties:

1. **Specific Heat** – Specific heat refers to the amount of energy needed to raise a substance to its vaporization point.
2. **Latent Heat of Vaporization** – Latent Heat of Vaporization is similar to Specific heat and refers to the energy that is required to convert a substance from a liquid to a gas.

Both these concepts were discussed in Unit 4 – Liquid Fuel Fires. In Unit 4, it was discussed in relation to the amount of heat needed to vaporize fuel. In the case of water as an extinguishing agent, these concepts work in the opposite direction and refer to the ability of water to absorb heat produced by combustion. As stated in Unit 4, If we put a pint of water or 2 cups, (approximately a pound of water) on the stove to boil, and assume it comes out of the tap at 65°F, it would require 147 BTU's to reach its boiling point, and then another 970 BTU's to convert it to steam.

When we look at this as an extinguishing agent, a gallon of water (16 cups) would absorb 1176 BTUs as it heated to its vaporization point, and then another 7760 BTUs as the water is converted to steam. Wood on average has a **heat of combustion** of 6000 to 9000 BTU's. This means it takes about a gallon of water to absorb the heat created by a pound of wood, assuming we can convert the entire gallon to steam.

Advantages of water:

1. Availability – Water is a readily available resource in most parts of the United States.
2. Cost – Water is an inexpensive extinguishing agent compared to other agents, and in some areas, water can be obtained by firefighters with no cost at all.
3. Effectiveness – Water is a very effective extinguishing agent because it can both smother or separate fuel and oxygen in addition to being an exceptional method of cooling.

Disadvantages of water:

1. Weight – Water weighs approximately 8.34 pounds (lbs.) per gallon. Considering a typical firefighting handline can flow anywhere from 150 to 400 gallons per minute. That weight can put an enormous load on a structure that may already be compromised due to fire.
2. Runoff – Water runoff can cause numerous problems on a fire scene. First, if contaminated with hazardous materials, water can create a substantial environmental impact and require additional cleanup efforts beyond fire suppression. Additionally, runoff within a structure can lead to extensive water damage to areas that may otherwise be unaffected by the fire itself. Finally, water can cause safety hazards and access issues on the fire scene.
3. Reactivity – Water reacts with certain materials such as combustible metals and liquids which makes water hazardous to use as an extinguishing agent in certain situations.
4. Conductivity – Water, or more specifically the minerals and other impurities in water, conduct electricity, which can present a hazard to firefighters when used on class C fires.
5. Volume Expansion – Water absorbs a large amount of heat when being converted to steam, however as it is turned to steam, water expands 1700 times. To put this in perspective, a gallon of water takes up .13368056 cubic feet of space (approximately 1/8 of a cubic foot). Once converted to steam, that steam occupies 227 cubic feet of space. A 10 x 10 room has 800 cubic feet, so the steam will fill up about a 4th of the room. This steam can push smoke and fire out of the room or down to the floor where firefighters are. This impact needs to be considered when firefighters apply water to fires.

Carbon Dioxide

Carbon Dioxide is a gas with a vapor density of 1.53 which means that its weight will push oxygen out of the area where it is utilized, extinguishing fires by removing oxygen from the combustion reaction.^{4,5} CO₂ also has some cooling properties as well.

Advantages of Carbon Dioxide:

1. Non-reactive – CO₂ exists in the atmosphere already, so it does not react with chemicals or the surroundings.
2. Clean – CO₂ does not cause additional damage.

Disadvantages of Carbon Dioxide:

1. Limited effectiveness in wind or open spaces
2. Gas under high pressure, so tanks are bulky and heavy.
3. Expensive in relation to water.

Foam

Firefighting **foam** comes in two different categories. Class A foam, utilized in wildland and structural firefighting and Class B foam which is used to extinguish flammable liquid fires.^{6,7}

Class A Foam

Class A foam extinguishes fire primarily by cooling.

Advantages of Class A foam:

1. One key aspect of Class A foam is its surfactant properties. A surfactant reduces the surface tension of water, allowing it to soak into fuels such as leaf litter, piles of trash, or upholstered furniture.
2. Class A foam can also be designed to stick or hold in place. This is used to keep water on exposures of fire such as the siding on neighboring buildings.

Disadvantages of Class A foam:

1. Adding Class A foam to firefighting water takes additional labor and logistics, and increases the cost associated with extinguishment.
2. Mixing Class A foam effectively typically requires specific equipment such as foam eductors or proportioners.

Class B Foam

Class B foam extinguishes by separating fuel vapors from the oxygen in the air. The water in foam also provides some cooling to both the fuel and exposures, reducing the possibility of reignition. There are many types of Class B foams, but the most common is Aqueous Film Forming Foam (AFFF)



Figure 7.2.1: Firefighter foam.

Copyright: "Firefighter training in Djibouti, August 2011" by US Army Africa, licensed CC BY 2.0.

Advantages of Class B foam:

1. Provides superior firefighting capabilities for liquid fuel fires.

Disadvantages of Class B foam:

1. Class B foam is expensive and can require additional labor and logistics, especially in large-scale operations such as aircraft or fuel storage fires.
2. Applying Class B foam takes specialized training and equipment such as eductors, proportioners and aerating nozzles.
3. May need to be reapplied several times to maintain an adequate foam blanket.
4. May be difficult to apply or maintain in certain weather conditions such as high winds.
5. Class B foam blankets can be broken down by polar solvents such as alcohol based fuels like ethanol. There are alcohol resistant Class B foams that must be used in these situations but these foams are more expensive.
6. Many Class B foams contain PFOA/PFOS chemicals which are carcinogenic and environmental hazards. Foams that do not contain these chemicals are starting to be available.

Wet Chemical

Wet chemical is used specifically for fires involving cooking oils.⁸ Wet chemical forms a barrier or crust over cooking oil through a reaction called saponification. This extinguishes by separating the fuel and oxygen, but also provides some cooling. Wet chemical is found in commercial kitchen hood systems, as well as in Class K extinguishers that protect those kitchens.



Figure 7.2.2: Extinguisher in a commercial kitchen.

Copyright: "Housing Improvement Project Goal 2: Canyon Mess Hall commercial kitchen (before)" by YellowstoneNPS. Public Domain.)

Dry Chemical

Advantages of dry chemical:⁹

1. Relatively inexpensive when compared to many other agents.
2. Most dry chemicals are easy to obtain and quickly refilled/recharged.
3. Dry chemical agents do not conduct electricity so they are safe for Class C fires.

Disadvantages of dry chemical:

1. Dry chemicals are very fine powders that are easily spread throughout the area when used and are difficult to clean up.
2. Dry chemical agents can cake, so extinguishers or systems require regular maintenance.



Figure 7.2.3: ABC Fire Extinguisher.

Copyright: "ABC fire extinguisher" by ProjectManhattan. Public Domain.

Dry Powder

Dry Powder is utilized on Class D fires.¹⁰ Dry powders can be in extinguishers, systems, or simply in a container ready to be scooped onto metal fires. Dry powders are designed specifically for a metal type or group of metal types and are placed specifically for the anticipated hazard.

Halogenated Agents

Halogenated Agents extinguish fire by inhibiting the chemical chain reaction of a fire.¹¹ However, these agents present a large environmental hazard due to their atmospheric ozone-depleting properties. At one time, Halon was very common in both installed systems and extinguishers, but due to their environmental impact, most of these have been replaced by other agents. While halons still exist, they are no longer being manufactured. They are primarily used in aerospace to protect extremely high-value equipment such as aircraft. The Department of Defense maintains a large stockpile of Halon for this purpose.

Clean Agents

Clean agents came about as a replacement for halogenated agents.¹² These agents leave no residue when used, and are environmentally friendly. Many manufacturers have patented their own types of clean agents made of various chemicals. These products work in various ways. Some are made of inert chemicals such as nitrogen or argon and simply displace oxygen to extinguish fires. Other chemicals inhibit the chemical chain reaction. These agents are used both in portable extinguishers as well as installed systems. Clean agents are expensive, so they are typically utilized to protect high-value or sensitive areas such as electronics, chemicals, or museum spaces.

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class-d-fire-extinguisher

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7.3: Summary

This unit examines the principles of fire extinguishment and the various suppression agents used by firefighters. Fire extinguishment is based on the Fire Triangle and Fire Tetrahedron, which illustrate that removing any component necessary for combustion will stop the fire. Fire can be extinguished by removing heat, removing fuel, removing oxygen, or inhibiting the chemical chain reaction. Cooling with water is the most common method used in structural firefighting because it interrupts the heat feedback loop and prevents fuels from continuing to vaporize or pyrolyze. Other methods include removing fuel by shutting off a fuel source or creating a fire break, smothering the fire to remove oxygen, or using specialized agents that interrupt the chemical reactions sustaining combustion.

The unit also explores the properties, advantages, and limitations of common suppression agents. Water is the most widely used extinguishing agent because of its availability, low cost, and exceptional cooling capacity. Its effectiveness comes from its high specific heat and latent heat of vaporization, which allow it to absorb large amounts of energy from a fire. However, water also has limitations, including its weight, potential to cause water damage, electrical conductivity, reactivity with certain fuels, and significant expansion when converted to steam. Carbon dioxide (CO₂) extinguishes fires by displacing oxygen and leaves no residue, making it useful for protecting sensitive equipment. Foam agents are divided into Class A and Class B foams. Class A foam improves water penetration into ordinary combustibles, while Class B foam creates a barrier that separates flammable liquid vapors from oxygen, making it highly effective on liquid fuel fires.

The unit concludes with a discussion of specialized extinguishing agents. Wet chemical agents are designed specifically for cooking oil and grease fires, where they extinguish fire through a process called saponification that creates a protective barrier over the fuel. Dry chemical agents are commonly used in portable extinguishers and are effective on a variety of fire classes, including energized electrical fires. Dry powder agents are designed specifically for combustible metal fires and must be matched to the type of metal involved. The unit also discusses halogenated agents, which suppress fire by interrupting the chemical chain reaction but are largely being phased out because of environmental concerns. Their replacement, clean agents, provide effective fire suppression with minimal residue and environmental impact, making them ideal for protecting high-value assets such as electronics, museums, and sensitive industrial equipment. Understanding how different extinguishing agents work allows firefighters to select the most effective and safest suppression strategy for a given fire.

7.4: Review

1. What are the four methods of fire extinguishment represented by the Fire Triangle and Fire Tetrahedron, and how does each method stop combustion?
2. Why is water considered the most common extinguishing agent in structural firefighting, and how do specific heat and latent heat of vaporization contribute to its effectiveness?
3. What are some of the advantages and disadvantages of using water as a suppression agent, particularly in structural fires?
4. Compare and contrast the primary extinguishing mechanisms of carbon dioxide (CO₂), Class A foam, and Class B foam.
5. Why are wet chemical agents used for Class K fires, and what is the role of saponification in extinguishing cooking oil and grease fires?
6. What types of fires are dry chemical, dry powder, and clean agents designed to extinguish, and what factors influence when each agent should be used?

8: COURSE SUMMARY AND LIVE FIRE LAB

Learning Objectives

- Demonstrate how fuel load and configuration impact fire behavior.
- Demonstrate the concept of flowpath.

8.1: Course Summary

8.2: Course Review

8.3: Lab Preparation

8.4: Reflection

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8.1: Course Summary

This course covered the foundations of fire behavior and fire dynamics, which are essential for firefighter safety and effective decision-making on the fireground. A fire's behavior is influenced by the interaction of fuel, oxygen, heat, and the surrounding environment. Fire dynamics studies how chemistry, heat transfer, fluid movement, and combustion processes influence fire growth and spread.

Modern Fire Environment

The modern fire environment is far more hazardous than in previous decades. Homes are larger, more open, and frequently built with lightweight engineered materials that can fail within minutes of fire exposure. Modern furnishings contain synthetic polymers such as plastics and foams that burn hotter and faster than traditional wood and cotton furnishings. Smaller lot sizes increase exposure risks between structures, while complex roof designs create hidden void spaces that allow undetected fire spread. New technologies such as solar panels, battery energy storage systems, and wind turbines introduce electrical hazards, chemical hazards, and re-ignition concerns.

Matter

Fire behavior is closely tied to the properties of matter, heat, and energy. Matter exists as solids, liquids, and gases, and most fuels must be converted into a gaseous state before they can burn. Heat is energy associated with molecular motion and is transferred by conduction, convection, and radiation. Heat capacity determines how much energy a substance absorbs before changing temperature. Expansion caused by heating can create structural hazards and dramatic effects such as water expanding approximately 1,700 times when converted to steam.

Fire

Fire is an exothermic oxidation reaction that releases heat, light, smoke, and combustion byproducts. Key concepts include heat of combustion (total energy available), heat release rate (speed of energy release), and mass burning rate (speed of fuel consumption). Modern fuels often have high heat release rates and high mass burning rates, contributing to rapid fire growth. Smoke consists largely of unburned fuel and plays a major role in fire spread.

Fire Triangle and Tetrahedron

The fire triangle includes fuel, heat, and oxygen. The fire tetrahedron adds the uninhibited chemical chain reaction. Fires are classified according to fuel type: Class A (ordinary combustibles), Class B (flammable liquids and gases), Class C (energized electrical equipment), Class D (combustible metals), and Class K (cooking oils and fats). Understanding fire classes helps firefighters select appropriate extinguishing methods.

Gaseous Fuels

Gaseous fuels ignite easily because they are already in the state needed for combustion. Important concepts include flammability limits, vapor density, ignition energy, autoignition, piloted ignition, flame propagation, deflagration, and detonation. Vapor density helps predict where gases will accumulate, while flammability limits identify concentrations that are too rich or too lean to burn.

Liquid Fuels

Liquid fuels burn only after converting to vapors. Important concepts include flash point, fire point, boiling point, latent heat of vaporization, vapor pressure, and specific gravity. Gasoline ignites readily because it produces vapors at low temperatures, while diesel requires much more heating. Tank fires may experience frothing, slopover, or boilover, creating significant hazards.

Solid Fuels

Solid fuels generally burn through pyrolysis, where heat chemically decomposes materials into combustible gases. Factors affecting combustion include surface-to-mass ratio, orientation, geometry, thermal inertia, density, moisture content, and area exposed to heat. Dust fires and combustible metal fires present unique and severe hazards due to rapid ignition and extreme temperatures.

Phases of Fire Development

Fire development progresses through four phases: incipient, growth, fully developed, and decay. Traditional fires were often fuel-controlled, while modern fires are frequently ventilation-controlled because synthetic fuels consume oxygen quickly. Oxygen-limited fires can become extremely dangerous when oxygen is suddenly reintroduced.

Enclosure Fires

Important fire phenomena include rollover (flameover), flashover, and backdraft. Flashover occurs when nearly all combustible surfaces in a compartment reach ignition temperature simultaneously, resulting in rapid room involvement. Backdraft occurs when oxygen is suddenly introduced into an oxygen-deficient fire environment containing unburned combustion products.

Within structures, fire plumes, ceiling jets, upper smoke layers, flow paths, neutral planes, and ventilation profiles strongly influence fire spread. Understanding uni-directional and bi-directional openings helps firefighters predict smoke and fire movement and safely control ventilation.

Extinguishment

Fire extinguishment is achieved by removing one side of the fire tetrahedron: fuel, heat, oxygen, or by inhibiting the chemical chain reaction. Water remains the most common extinguishing agent because of its tremendous cooling ability. Other agents include carbon dioxide, Class A and B foams, wet chemicals, dry chemicals, dry powders, halogenated agents, and clean agents. Each agent has specific advantages, limitations, and appropriate fuel applications.

8.2: Course Review

Course Review Questions

1. Why do firefighters today require a stronger understanding of fire dynamics than previous generations?
2. How do open floor plans influence fire movement within a structure?
3. What is the primary difference between modern polymer-based furnishings and legacy furnishings?
4. Why do lightweight engineered structural components present a greater collapse hazard during fires?
5. What hazards do solar energy systems create for firefighters during suppression operations?
6. How does heat capacity influence both fire growth and fire suppression?
7. Why is water considered an effective cooling agent for structural firefighting?
8. Describe one firefighter hazard caused by the expansion of matter when heated.
9. Compare conduction, convection, and radiation as methods of heat transfer.
10. How does heat release rate differ from heat of combustion?
11. Why should smoke always be considered a fuel source?
12. What additional concept does the fire tetrahedron include that the fire triangle does not?
13. Why are Class C fires classified differently once the electrical source is removed?
14. What do the Upper Flammability Limit (UFL) and Lower Flammability Limit (LFL) tell firefighters about a fuel-air mixture?
15. How does vapor density help predict the movement of leaking gases?
16. Differentiate between autoignition and piloted ignition.
17. What is the significance of a fuel's flash point? How does this compare to fire point?
18. How does latent heat of vaporization affect both fire growth and extinguishment?
19. Why can wicking allow a fuel to ignite more readily?
20. Explain why dust explosions can occur with materials that are not normally considered highly combustible.
21. How does surface-to-mass ratio affect the ignition and burning rate of solid fuels?
22. What is the difference between a fuel-controlled fire and a ventilation-controlled fire?
23. List three non-technical indicators that may signal flashover conditions are developing.
24. How do flow paths influence firefighter safety during interior operations?
25. What are the four methods of extinguishment represented by the fire tetrahedron concept?

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8.3: Lab Preparation

Live Fire Lab

The Max Fire Box serves as the final lab for this course. This is an opportunity to visually witness many of the concepts discussed in previous units.

These concepts include:

- Fire growth stages
- Heat release rate
- Flowpath – Unidirectional and bi-directional
- Neutral plane
- Rollover
- Flashover
- Backdraft
- Pyrolysis
- Heat transfer
- Char
- Melting
- Heat release rate
- Flammability limits
- Ceiling jet
- Fire Plume
- Upper layer development
- Ventilation

Be sure to review each of these concepts prior to the lab.

Max Fire Box Lab Preview

You can see some of what the Max Fire Box lab will include by watching this video.

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

[View this YouTube Video online](#)



Video: "One-Story and Two-Story Fire Behavior Training With the Max Fire Box Phase II" by Max Fire Training. YouTube Standard License.

Thermal Imaging Cameras

During the live fire lab, we will be utilizing numerous thermal imaging cameras (TICs) to enhance learning. TICs display heat rather than light allowing us to see aspects of fire behavior that would otherwise be invisible to the naked eye. TICs have limitations and there can be a big difference between different cameras depending on their design. TICs have become increasingly valuable to understanding fire conditions and are now a standard tool utilized during initial sizeup as well as important to rescue and overhaul operations.



Figure 8.3.1: Thermal imaging camera.

Thermal Imaging Introduction

Take some time to view the below video to learn more about how thermal imaging cameras operate.

This interactive element is not available in this format. Visit the link or scan the QR code to access it online.

[View this YouTube Video online](#)



Video: "AttackPRO - Thermal Imaging 101" by Seek Thermal. YouTube Standard License.

8.4: Reflection

In at least five fully developed paragraphs, Discuss what you witnessed during the Max Fire Box lab and how it impacted your learning and understanding of fire dynamics as it relates to what you studied in this course. Be sure to utilize the correct terminology as presented in this course.

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GLOSSARY

A

Aerosol | Fine particles that are suspended in air.

Autoignition | Initiation of combustion by heat but without a spark or flame.

B

Backdraft | A deflagration resulting from the sudden introduction of air into a confined space containing oxygen-deficient product of incomplete combustion.

Bi-Directional opening | An opening within a flowpath that has both an outlet and an inlet on the same opening

Boiling Point | Temperature at which a liquid boils and turns to vapor.

Boyles Law | [Gas law stating that, if the temperature of a gas is held constant, increasing the volume of the gas decreases its pressure.](#)

British Thermal Unit | The amount of energy required to raise the temperature of one pound of water by one degree Fahrenheit.

C

Calorie | The energy required to raise the temperature of 1 gram of water by 1 °C.

Ceiling Jet | A relatively thin layer of flowing hot gasses that develops under a horizontal surface as a result of plume impingement and the flowing gas being forced to move horizontally.

Char | Carbonaceous material that has been burned or pyrolyzed and has a blackened appearance.

Charles Law | [Gas law stating that, if the pressure of a gas is held constant, increasing its temperature increases its volume.](#)

Combined Gas Law | Gas law states that when the amount of gas remains the same, pressure, volume and temperature can all change.

Combustible Liquid | Any liquid that has a flash point at or above 100°F.

Conduction | Heat transfer to another body or within a body by direct contact.

Convection | Heat transfer by circulation within a medium such as gas or a liquid.

D

Decay Phase | The stage of fire development within a structure characterized by either a decrease in the fuel load or available oxygen to support combustion, resulting in lower temperatures and lower pressure in the fire area

Deflagration | Propagation of a combustion zone at a velocity that is less than the speed of sound in the unreacted medium.

Dehydration | The process of water being removed.

Detonation | Propagation of a combustion zone at a velocity greater than the speed of sound in the unreacted medium.

Diffusion Flame | A flame in which fuel and air mix or diffuse together at the region of combustion.

E

endothermic reaction | [Chemical reaction that needs a constant input of energy to continue because it takes more energy to break bonds in the reactants than is released when new bonds form in the products.](#)

Energy | The ability to do work

Exothermic Reaction | [Chemical reaction that releases energy because it takes less energy to break bonds in the reactants than is released when new bonds form in the product.](#)

F

Fire | A rapid oxidation process, which is an exothermic chemical reaction, resulting in the evolution of light and heat in varying intensities

Fire Behavior | The way a fire interacts with available fuel, oxygen, and its surrounding environment

Fire Dynamics | Detailed study of how chemistry, fire science, and the engineering disciplines of fluid mechanics and heat transfer interact to influence fire behavior

Fire Plume | The column of hot gases, flames, and smoke, rising above a fire.

Fire Point | The temperature at which a liquid gives off sufficient vapors to sustain combustion.

Flame | A body or stream of gaseous material involved in the combustion process and emitting radiant energy at specific wavelength bands determined by the combustion chemistry of the fuel.

Flame Propagation | The movement of the flame front through an ignitable mixture

Flame Spread | Flame spread refers to the movement of the oxidation reaction across the fuel.

Flameover | The condition where unburned fuel from the originating fire has accumulated in the upper layer to a sufficient concentration that it ignites and burns.

Flammability Limit | The upper and lower concentration limit at a specified temperature and pressure of a flammable gas or vapor of an ignitable liquid in air, expressed as a percentage of fuel by volume that can be ignited.

Flammable Liquid | A liquid that has a flash point that is below 100° F and a maximum vapor pressure of 40 PSI.

Flash Point | The lowest temperature of a liquid, as determined by specific laboratory tests at which the liquid gives off vapors at a sufficient rate to support a momentary flame across the surface.

Flashover | A transition phase in the development of a compartment fire in which surfaces exposed to thermal radiation reach ignition temperature more or less simultaneously, and fire spreads rapidly throughout the space, resulting in full room involvement or total involvement of the compartment or enclosed space.

Flowpath | The movement of hot, high-pressure gases out of the structure and the movement of colder, low-pressure gases into the structure of a compartment.

Fuel Load | The total quantity of combustible contents of a building, space, or fire area, including interior finish and trim, expressed in heat units or the equivalent weight in wood.

Fully Developed Phase | The stage of fire development where heat release rate has reached its peak within a compartment.

G

Gases | [Matter that has no definitive size or shape](#)

Growth Phase | The stage of fire development where the heat release rate from an incipient fire has increased to the point where heat transferred from the fire and the combustion products are pyrolyzing adjacent fuel sources and the fire begins to spread across the ceiling of the fire compartment

H

Heat | A form of energy characterized by vibration of molecules and capable of initiating and supporting chemical changes and changes of state.

Heat Capacity | [The amount of energy required to increase \(or decrease\) the temperature of a certain mass of material by a certain amount.](#)

Heat of Combustion | The amount of heat released during the combustion of a specified amount of fuel.

Heat release rate | [The rate at which fire releases energy.](#)

I

Ignition | The process of initiating self-sustained combustion.

Incipient Phase | The early stage of fire development, where the fire's progression is limited to a fuel source and the thermal hazard is localized to the area of the burning material.

L

Laminar Flame | A flame that has a well-defined luminous body as a result of consistent introduction of fuel and oxygen into the combustion zone

Latent Heat of Vaporization | [The amount of heat required to convert one gram of a substance from a liquid form to a gaseous form](#)

Liquid | [Matter that has a definite volume but no definite shape](#)

M

Mass Burning Rate | The rate at which a fuel is consumed when burned.

Matter | Any substance that has mass and takes up space

Melting | Melting is the phase change that occurs when a substance converts from a solid to a liquid.

Minimum Ignition Energy | The lowest capacitive spark energy capable of igniting the most ignition sensitive concentration of a flammable vapor-air mixture or a combustible dust-air mixture as determined by standard test procedure.

Miscibility | The ability of a substance (liquid) to form a homogeneous solution in another substance.

N

Neutral Plane | The horizontal plane that separates the high-pressure gases from the low-pressure gases.

Newton | Energy required to accelerate a mass of one kilogram at one meter per second.

P

Piloted Ignition | Initiation of combustion through direct contact with flame.

Pressure | [Amount of force pushing against a given area.](#)

Pyrolysis | A process in which a material is decomposed or broken down, into simpler molecular compounds by the effects of heat alone.

R

Radiative | Heat transfer by way of electromagnetic waves.

S

Smoke | The airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion, together with the quantity of air that is entrained or otherwise mixed into the mass.

Smoldering Combustion | Self-sustained glowing combustion without flame, usually with incandescence and smoke.

Solid | [Matter that has a definite shape and volume](#)

Specific Gravity | The ratio of the mass of a given volume of a substance to the mass of an equal volume of water.

Spontaneous Ignition | Initiation of combustion of a material by an internal chemical or biological reaction that has produced sufficient heat to ignite the material.

Stoichiometric | The precise quantity of a reactant required to react completely with the other reactants according to the balanced chemical equation.

Surface tension | [The cohesive force that holds particles together at the surface of a liquid](#)

T

Temperature | A measurement of the amount or degree of heat (vibration of molecules) in an object or substance.

Thermal Inertia | Speed at which heat travels through a material.

Turbulent Flame | A flame characterized by a luminous body that fluctuates greatly as a result of varying involvement of fuel and air.

U

Uni-directional opening | An opening within a flowpath where gasses in the entire opening are moving in one direction.

V

Vapor Density | The ratio of the average molecular weight of a gas or vapor to the average molecular weight of air.

Vapor Pressure | The pressure exerted on a container from a substance that has been converted to its gaseous phase.

W

Wicking | The movement of a liquid within another material caused by the liquid's cohesion and adhesion properties.

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