Introduction

• Technically, fire is a chemical reaction that requires fuel, oxygen, and heat to occur

• In this chapter, we will cover the physical science that affects the ignition and development of a fire

• You can use this chapter to interpret what you see on the fire ground and to develop methods to prevent, extinguish, and investigate fires

• We will also cover the phases of fire to assist you in selecting the proper tactics to attack and extinguish fires

• All of this knowledge should help you recognize hazards to yourself and others while at work on a fire ground
Physical Science

• FIRE is a rapid chemical reaction that give off energy and products of combustion that are very different in composition from the fuel and oxygen that combined to produce them

• To understand this reaction, we need to look at some basic concepts of physical science

• Physical science is the study of the physical world around us and includes the sciences of chemistry and physics and the laws related to matter and energy
Introduction

- Firefighters will have to deal rapidly, with a variety of conditions
- This chapter deals primarily with the types of fire a structural firefighter encounters
- Fire has been both a help and a hindrance to mankind throughout history
- It has heated our homes, cooked our food, and helped us to become technologically advanced
- In its hostile mode, it has endangered us for as long as we have used it
Measurement Systems

• Any scientific discussion present information using numbers.
• We regularly use numerical systems to describe our hose lines 1 ¾-inch {45 mm} or the capacity of pump on an engine 1,500 gpm {5,678 lpm} or the length of a ladder 24 feet {7.3 m}
• For these numbers to make sense, they must be base on a unit of measurement describing what is being measured such as distance, mass, or time
• In the U.S., we use the English or Customary system
• Other nations and the scientific community use the metric system called the International System of Units or SI
# Measurement Systems

The Base Units of Measurement are as follows

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Customary System</th>
<th>SI System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Foot {ft}</td>
<td>Meter {m}</td>
</tr>
<tr>
<td>Mass</td>
<td></td>
<td>Kilogram {kg}</td>
</tr>
<tr>
<td>Time</td>
<td>Second {s}</td>
<td>Second {s}</td>
</tr>
<tr>
<td>Temperature</td>
<td>Fahrenheit {°F}</td>
<td>Celsius {°C}</td>
</tr>
<tr>
<td>Electric Current</td>
<td>Ampere {A}</td>
<td>Ampere {A}</td>
</tr>
<tr>
<td>Amount of a substance</td>
<td></td>
<td>Mole {mol}</td>
</tr>
<tr>
<td>Luminous Intensity</td>
<td></td>
<td>Candela {cd}</td>
</tr>
</tbody>
</table>
Measurement Systems

• One reason why the scientific community uses the SI is that it is a very logical and simple system based on powers of 10.

• This allows for the conversion of units without the fractions needed with the Customary System.

• Examples
  – In the customary system, the unit of length is the foot. The inch is now $1/12^{th}$ of a foot, the yard is 36 inches, the mile is 5,280 feet or 1,760 yards.
  – In the SI the unit of length is the meter, with decimeters, centimeters and below being smaller, and kilometers, mega meters, etc. being longer units, all powers of 10.
## Measurement Systems

### Names & Symbols for SI Prefixes

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Symbol</th>
<th>Multiply by</th>
<th>Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tera</td>
<td>T</td>
<td>$10^{12}$th power,</td>
<td>1 Trillion</td>
</tr>
<tr>
<td>Giga</td>
<td>G</td>
<td>$10^{9}$th power,</td>
<td>1 Billion</td>
</tr>
<tr>
<td>Mega</td>
<td>M</td>
<td>$10^{6}$th power,</td>
<td>1 Million</td>
</tr>
<tr>
<td>Kilo</td>
<td>k</td>
<td>$10^{3}$rd power,</td>
<td>1 Thousand</td>
</tr>
<tr>
<td>Deci</td>
<td>d</td>
<td>$10^{–1}$st power,</td>
<td>one tenth</td>
</tr>
<tr>
<td>Centi</td>
<td>c</td>
<td>$10^{–2}$nd power,</td>
<td>one hundredth</td>
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<tr>
<td>Milli</td>
<td>m</td>
<td>$10^{–3}$rd power,</td>
<td>one thousandth</td>
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<tr>
<td>Micro</td>
<td>μ</td>
<td>$10^{–6}$th power,</td>
<td>one millionth</td>
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<tr>
<td>Nano</td>
<td>n</td>
<td>$10^{–9}$th power,</td>
<td>one billionth</td>
</tr>
<tr>
<td>Pico</td>
<td>p</td>
<td>$10^{–12}$th power,</td>
<td>one trillionth</td>
</tr>
</tbody>
</table>
Energy and Work

• Energy is simply defined as the capacity to perform work

• Work occurs when a force is applied to an object over a distance
  – Work is the transformation of energy from one form to another

• The SI unit for work is the joule

• The customary system unit for work is the foot-pound
Energy and Work

- **Chemical** - Energy released as a result of a chemical reaction such as combustion
- **Mechanical** - Energy an object in motion possesses such as a rock rolling down a hill
- **Electrical** - Energy developed when electrons flow through a conductor
- **Heat** – Energy transferred between two bodies of differing temperature such as the sun and the earth
- **Light** – Visible radiation produced at the atomic level such as a flame produced during the combustion reaction
- **Nuclear** – Energy released when atoms are split {fission} or joined together {fusion}; nuclear power plants generate power as a result of the fission of uranium-235
Energy and Work

• Energy exists in two states: kinetic and potential
  – **Kinetic Energy:** Energy possessed by a moving object
  – **Potential Energy:** Energy possessed by an object that can be released in the future
    • A rock on the edge of a cliff possesses potential mechanical energy. When it falls, the potential energy is converted to kinetic energy
    • In a fire, fuel has potential chemical energy, as the fuel burns, the chemical energy is converted to kinetic energy in the form of heat and light
Power

• An amount of energy delivered over a given period of time

• Throughout history, people have used fire to generate power in many ways.

• A fuel’s potential energy is released during combustion and converted to kinetic energy to run a generator or turn a shaft that powers a machine. The derived units for power are horsepower \( \{\text{hp}\} \) in the customary system and watts \( \{\text{W}\} \) in SI.

• In the study of fire behavior, researchers frequently address power when they consider the rate at which various fuels or fuel packages release heat \( \{\text{HRR Heat release rate}\} \) as they burn.
Heat and Temperature

• Heat is the energy transferred from one body to another when the temperatures of the bodies are different.

• Heat is the most common form of energy encountered on earth.

• Temperature is an indicator of heat and is the measure of the warmth or coldness of an object based on some standard.
  
  – In most cases, this standard is based on the freezing and boiling point of water.
    
    • 0° C to 32° C       SI base
    • 32° F to 212° F   Customary System
Heat and Temperature

- The SI unit for all forms of energy including heat is the joule.
- Heat was described in terms of calories or British thermal units for many years:
  - A Calorie is the amount of heat required to raise the temperature of 1 gram of water 1 degree Celsius.
  - The Btu is the amount of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit.
- These are not approved SI units but are still frequently used.
- The relationship between the calorie and the joule is called the mechanical equivalent of heat, where 1 calorie = 4.187 joules and 1 Btu equals 1,055 joules.
Transmission of Heat

• This is a basic concept in the study of fire
• The transfer of heat from the initial fuel package to other fuels in and beyond the area of fire origin controls the growth of any fire
• This helps us estimate the size of a fire before attacking it and to evaluate the effectiveness of an attack
• The definition of heat makes it clear that for heat to be transferred from one body to another, the two bodies must be at different temperatures.
• Heat moves from warmer objects to those that are cooler
Transmission of Heat

• The rate at which heat is transferred is related to the temperature differential of the bodies, the greater the difference, the faster the transfer rate

• This is measured as energy flow over time
  – Is SI it is measured in kilowatts \( \text{kW} \)
  – In the customary system it is Btu’s

• Heat can be transferred from one body to another by three mechanisms:
  – Conduction
  – Convection
  – Radiation
Conduction

- Conduction is a point-to-point transmission of energy which happens when something {a metal rod} is heated at one end with a flame and the heat travels throughout the object.
- This is due to the increased activity of atoms within the object.
- The atoms in the heated in begin moving faster and bumping into their neighbors which causes an increase in the collisions between atoms, with each collision transferring energy to the atom being hit.
- Heat cannot be conducted through a vacuum because there is no medium for point-to-point contact.
Conduction

• In general, heat transfer early in the development of all fires is almost entirely due to conduction.
• Later, as the fire grows, hot gases begin to flow over objects some distance away from the point of ignition and conduction again becomes a factor.
• The heat from the gases in direct contact with structural components or other fuel packages is transferred to the object by conduction.
• Insulation is closely related to conduction, it does its job by slowing the conduction of heat between two bodies.
• The best insulators used in building construction are those made of fine particles or fibers with void spaces between them filled with a gas such as air.
Convection

• As fires grow, the air around them is heated by conduction and then the hot air and products of combustion begin to rise

• If you hold your hand over a flame, you are able to feel the heat even though your hand is not in direct contact with the flame, the heat is being transferred to your hand by convection

• Convection is the transfer of heat energy by the movement of heated liquids or gases

• When heat is transferred by convection, there is movement or circulation of a fluid from one place to another, always from the warmer area to the cooler area
Radiation

- If you hand your hand a few inches out to the side of a candle, you would also feel heat.
- This is due to Radiation, which is the transmission of energy as an electromagnetic wave without an intervening medium.
- As an electromagnetic wave, the energy travels in a straight line at the speed of light.
- All warm objects radiate heat, with the best example being heat from the sun.
- Radiation is the cause of most exposure fires.
- Heat energy being transmitted by radiation travels through vacuums and substantial air spaces that would normally disrupt conduction and convection.
- Materials that reflect radiated energy will disrupt travel.
Matter

• Physical materials you see are called matter, which is the “stuff” that makes up our universe
• Matter is anything that occupies space and has mass
• Matter can be described by its physical appearance or more technically by its physical properties such as mass, size, or volume
• In addition to properties that can be measured, matter also possesses properties that can be observed such as its physical state {solid, liquid, or gas}, color, or smell
Matter

• Water is a good example of physical states:
  • At sea level, atmospheric pressure is defined as 760 mm of mercury measured on a barometer. At these constants, water can exist in three states of matter:
    – Below 32° F it exists as a solid called ice
    – From 32° F to 212° F it exists in a liquid form called water
    – Above 212° F it exists as a gas call steam
  • Pressure can also help determine which state that matter will exist in. Examples {liquefied O², LP gas}
Matter

- Matter is also described using terms derived from its physical properties of mass and volume
  - Density is a measure of how tightly the molecules of a solid substance are packed together
    - This is determined by dividing the mass of a substance by its volume
- Liquids are described with the term specific gravity
  - This is the ratio of the mass of a given volume of a liquid compared with the mass of an equal volume of water
    - Water has a specific gravity of 1
    - Liquids with a specific gravity less than 1 will float
    - Liquids with a specific gravity more than 1 will sink
Matter

• The description for gases is vapor density

• This is defined as the density of gas or vapor in relation to air

  – Air has a vapor density of 1

  – Gases with a vapor density less than 1 will rise

  – Gases with a vapor density more than 1 will fall
Conservation of Mass and Energy

• As fire consumes fuel, its mass is reduced.
• What happens to this material? Where does it go?
• The Law of Conservation of Mass-Energy is the answer {Law of Conservation of Mass}
• This Law Says:
  – Mass and energy may be converted from one to another, but there is never any net loss of total mass-energy.
• Mass and energy are neither created nor destroyed
• This law is fundamental to the science of fire
Conservation of Mass and Energy

• The reduction in the mass of a fuel results in the release of energy in the form of light and heat

• This enables calculation of the heat release rate of materials by using instruments that determine mass loss and temperature gain when a fuel is burned

• For us, we should use this information during size-up
  – The more fuel available to burn, the more potential there is for greater amounts of energy being released as heat during a fire
  – The more heat released, the more extinguishing agent we need to put the fire out
Chemical Reactions

• Whenever matter is transformed from one state to another, or a new substance is produced, the transformation is called a chemical reaction.

• The simplest of these is when a matter changes state {ice to water} which is called a physical change.

• More complex reactions, known as chemical changes, occur when substances are transformed into new substances with different physical and chemical properties such as hydrogen and oxygen combining to form water.
  – This changes chemical and physical properties of both
Chemical Reactions

- Chemical and physical changes almost always involve an exchange of energy.
- Reactions that give off energy as they occur are called **exothermic**.
- Reactions that absorb energy as they occur are called **endothermic**.
- One of the most common chemical reactions is **oxidation** which is the chemical bond between oxygen and another element.
- Oxygen is common and reacts with almost every other element found on the planet.
Oxidation

- Oxidation is an exothermic reaction that can be rapid or slow.
- Most common example is rusting iron where the combination of oxygen and iron produces a flaky red compound called iron oxide or rust.
- Look at figure 2.9 for examples of the varying speeds of different types of oxidation.
Combustion

• The terms fire and combustion are often used interchangeably although in all reality, fire is a form of combustion
  – Combustion is a self-sustaining chemical reaction yielding energy or products that cause further reactions of the same kind
  – Fire is a rapid, self-sustaining oxidization process accompanied by the evolution of heat and light of varying intensities

• Again, these reactions can range from very slow, to very fast and they can release a large amount of energy over a very short time
Fire Tetrahedron

• For combustion to occur, four components are necessary:
  – Oxygen {oxidizing agent}
  – Fuel
  – Heat
  – Self-sustained chemical reaction

• These four components make up the fire tetrahedron
  {figure 2.10} and all four must be in place for combustion to occur

• Remove any one of the four and combustion will not occur

• To extinguish a fire, you must remove one of these components from the reaction process
Oxygen / Oxidizing Agents

- These are materials that yield oxygen or other oxidizing gases during the course of a chemical reaction.
- Oxidizers themselves are not combustible, but they support combustion when combined with a fuel.
- Oxygen is the most common oxidizer, but many other things also fall into this category.
  - See Table 2.3 on page 41 for an example oxidizer chart of some of the more common agents.
Oxygen / Oxidizing Agents

- Oxygen is considered the primary oxidizing agent and is present at approximately 21% at all times in the air around us.
- Combustion can be supported at oxygen concentrations as low as 14% @ 70° F.
- As temperatures increase, lower concentrations of O² are needed to support flaming combustion.
- Some research indicates in these conditions, you can have combustion with O² saturations of less than 2%.
Oxygen / Oxidizing Agents

– When $O^2$ levels are $> 21\%$, the atmosphere is said to be *oxygen enriched*

– At these levels materials exhibit very different burning characteristics

– Materials burn more rapidly and may ignite much easier than normal

– Some petroleum based materials may auto-ignite

– Materials that do not normally burn, may ignite and burn readily, with one prime example being Nomex®
  
  • At approximately 31% $O^2$, Nomex® ignites and burns vigorously

– Fires in these atmospheres are much more difficult to extinguish and present safety hazards
Fuel

- This is the substance being oxidized or burned in the combustion process
- It is also called the reducing agent
- Most common fuels contain carbon with combinations of hydrogen and oxygen
  - This can be further broken down into hydrocarbon-based fuels and cellulose-based materials
- The combustion process involves two key fuel-related factors:
  - The physical state of the fuel
  - The distribution of the fuel
Fuel

• A fuel may be found in any of the three states of matter:
  – Solid, liquid, or gas

• To burn, fuels must normally be in the gaseous state
  – For solids and liquids, energy must be expended to cause these state changes

• Solid fuels become fuel gases by *Pyrolysis*
  – *Pyrolysis* is the chemical decomposition of a substance through the action of heat
Fuel

- Solid fuels have a definite shape and size
- This property significantly affects their ease of ignition
- The primary consideration is the surface-to-mass ratio
  - This is the surface area of the fuel in proportion to the mass
    - Wood is a good example: A log from a tree has a high mass, but the surface area is low. When cut into boards, the surface area is increased, thus increasing the surface-to-mass ratio. The sawdust that is produced has an even higher surface-to-mass ratio and if you sand the boards, the dust created has an even higher ratio and is the most flammable of any of these forms of wood from this tree
- See figure 2.11 in your book for an example
Fuel

- The position of the solid fuel also affects the burn speed
  - If the fuel is vertical, the fire spread will be more rapid than if it is horizontal
    - A piece of plywood lying across saw horses would burn more slowly than a piece that was standing vertically

- With Liquid Fuels gases are produced by the vaporization process
  - This is the transformation of a liquid to its vapor or gaseous state
    - This occurs as molecules escape from the liquid’s surface into the surrounding atmosphere
Fuel

• For the molecules to break loose, there must be some energy input
• This energy is normally heat
• Vaporization of liquid fuels generally requires less energy input than does pyrolysis for solid fuels
  – Primarily this is due to the different densities of the substances in solid and liquid states and the fact that molecules of liquid substances have more energy than those of solids
  – Surface to mass ratio is also a factor with liquids as it is with solids
Fuel

• A liquid fuel assumes the shape of its container
  – When it is spilled, it assumes the shape of the ground, flows, and accumulates in low areas
    • When contained, the specific volume of a liquid has a relatively low surface-to-mass ratio
    • When released, this ratio increase significantly as does the amount of the fuel vaporized from the surface

• Gaseous fuels can be the most dangerous because they are already in the natural state required for ignition.
  – No pyrolysis or vaporization is needed to prepare them to burn
Fuel

• For combustion to occur after a fuel has been converted into a gaseous state, it must be mixed with air, or an oxidizer, in the proper ratio

• The range of concentrations of the fuel vapor and air is called the flammable {explosive} range
  – This is reported using the percent by volume of gas or vapor in air for the lower flammable limit {LFL} and upper flammable limit {UFL}
  – The lower flammable limit is the minimum concentration of fuel vapor an air that supports combustion
  – Concentrations that are below the LFL are too lean to burn
Fuel

- The upper flammable limit is the concentration above which combustion cannot take place
  - Concentrations that are above the UFL are too rich to burn
- Table 2.4 on page 44 will give you an idea of some of the flammable ranges for selected materials
- These are reported at ambient temperatures and atmospheric pressures
  - Variations in these can cause the range to vary considerably
  - Generally, increases in temperature or pressure broaden the range and decreases narrow it
Heat

- This is the energy component of the fire tetrahedron
  - When it comes in contact with a fuel, the energy supports the combustion reaction in the following ways
    - Causes the pyrolysis or vaporization of solid and liquid fuels and the production of ignitable vapors or gases
    - Provide the energy necessary for ignition
    - Causes the continuous production and ignition of fuel vapors or gases so that the combustion reaction can continue
  - For our discussion of fire and its behavior, chemical, electrical, and mechanical energy are the most common sources of heat that result in ignition of fuel
Chemical Heat

• This is the most common source of heat in combustion reactions
  – When any combustible is in contact with oxygen, oxidation occurs which almost always results in the production of heat
    • The heat from a burning match is an example of chemical heat energy
  – Self-heating {spontaneous} is a form of chemical heat energy that occurs when a material increase in temperature without the addition of external heat
  – This energy is normally produced slowly by oxidation and is lost to the surroundings almost as fast as it is generated
Chemical Heat

• For self-heating to cause ignition, the material must be heated to its ignition temperature

• For this to happen, the following must occur
  – The rate of heat production must be great enough to raise the temperature of the material to its ignition temperature
  – The available air supply \{ventilation\} in and around the material being heated must be adequate to support combustion
  – The insulation properties of the material immediately surround the fuel must be such that the heat being generated does not dissipate
Chemical Heat

• An example of spontaneous ignition could be a number of oil-soaked rags that are rolled into a ball and thrown into a corner
  – The heat generated by the oxidation of the oil and cloth may not be allowed to dissipate from the pile, causing the temperature of the cloth to rise and eventually cause ignition

• As more heat is generated, the rate of oxidation and heat production increase, doubling with each 18° F increase in the temperature of the reacting materials
  – Table 2.5 lists some materials subject to self-heating
Electrical Heat

• Can generate temperatures high enough to ignite any combustible materials near the heated area and can occur in several ways, such as:
  – Current flow through resistance
  – Over current or overload
  – Arcing
  – Sparking
  – Static
  – Lightning
Mechanical Heat

• Is generated by friction and compression
  – Friction heat is created by the movement of two surfaces against each other which results in heat and / or sparks being generated
  – Compression heat is generated when a gas is compressed
  – Diesel engines use this principle to ignite fuel vapors without a spark plug
  – This is also the reason our SCBA cylinders fell warm to the touch after they have been filled
Nuclear Heat

• Generated when atoms are split \{fission\} or combined \{fusion\}
  – In a controlled setting fission heats water to drive steam turbines and produce electricity
  – Fusion reactions cannot be contained at this time and have no commercial use
  – The sun’s heat is a product of a fusion reaction and thus is a form of nuclear energy
Self-Sustained Chemical Reaction

• Combustion requires a fuel \{in the gaseous or vapor state\}, an oxidizer, and heat to come together in a very specific way.

• Combustion, once it occurs, can only continue when enough heat energy is produced to cause the continued development of fuel vapors or gases.
  – Scientists call this type of reaction a chain reaction which is a series of reactions that occur in sequence with the result of each individual reaction being added to the rest.
Self-Sustained Chemical Reaction

• Example of a self-sustained chemical reaction:

• A Forest Fire:
  – The heat from one tree may initiate the reaction \{burning\} of a second tree, which, in turn ignites a third, and so on. The fire will then go on at a steady rate. But if one burning tree ignites, say, two others, and each of these two ignite two more, for a total of four, and so on, the rate of burning speeds rapidly. Such uncontrolled, runaway chain reactions are at the heart of nuclear bombs.
Fire Development

• When all four components of the fire tetrahedron come together, ignition occurs
  – For the fire to grow, heat must be transmitted beyond the first material, to additional fuel packages
• Early in the development of fire, heat rises and forms a plume of hot gas
  – If the fire is outside or in a large building, the plume rises unobstructed, and air is drawn into it as it rises
  – The air being pulled in is cooler than the fire gases, which cools the gases above the fire
  – The spread of fire in open areas is primarily due to heat energy that is transmitted from the plume to nearby fuels
Fire Development

- Development of fires in a compartment is more complex than those in the open
  - A compartment, in this context, is an enclosed room or space within a building
  - The term compartment fire is defined as a fire that occurs within such a space

- Growth and development of a compartment fire is usually controlled by the availability of fuel and oxygen

- If fuel is limited, the fire is fuel controlled, when oxygen is limited, the fire is ventilation controlled
Fire Development

• Researchers have attempted to describe compartment fires in terms of stages or phases that occur as the fire develops. These are:
  – Ignition
  – Growth
  – Flashover
  – Fully Developed
  – Decay

• Figure 2.17 shows this in time and temperature
  – The ignition and development of a compartment fire is complex and influenced by variables and therefore not all fires will go through each of the stages described
Ignition

• The period when the four elements of the fire tetrahedron come together and combustion begins

• The physical act of ignition can be piloted {caused by a spark or flame} or non-piloted {caused when a material reaches its ignition temperature as the result of self-heating} such as spontaneous ignition

• At this time, the fire is small and generally confined to the material first ignited

• All fire occur as a result of some type of ignition
Growth

- As a fire plume develops after ignition, it begins to draw air from the surrounding space.
- The plume in a compartment is rapidly affected by the ceiling and walls of the space:
  - The first impact is the amount of air that enters the plume, the air is cooler than the gases generated by the fire and has a cooling effect on the temperature within the plume.
  - The location of the fuel in relation to the walls determines the amount of air that is brought in and thus the amount of cooling that takes place.
  - Fuel in corners entrain even less air and have the highest plume temperatures, which significantly affects the temperatures in the developing hot gas layer above the fire.
Growth

- As the gases rise, they spread outward when they hit the ceiling and continue to spread to the walls on the other side of the compartment
- Once they have contacted all walls, they begin to deepen toward the floor
- Temperatures during this period depend on the amount of heat conducted into the ceiling and walls as the gases flow over them and on the location of the initial fuel package
- Gas temperatures decrease as the distance from the centerline of the plume increases \{2.18\}
- This stage will continue if fuel and oxygen are available, with temperature increases as it grows
Flashover

- This is the transition between the growth and fully developed fire stages and is not a specific event such as ignition.
- Condition in the compartment change very rapidly as the fire changes from one dominated by the burning of the materials first ignited to one that involves all of the exposed combustible surfaces in the compartment.
- The hot gasses at the ceiling cause radiant heating of combustible material remote from the fire origin.
Flashover

- Radiant energy from the hot gas layer exceeds 20 kW/m² when flashover occurs.
- This causes pyrolysis in the combustible materials present.
- The gases are heated to their ignition temperature by the radiant energy from the gas layer.
- Flashover means the temperature in a compartment has resulted in the simultaneous ignition of all of the combustible contents in the space.
  - No exact temperature is available, but a range of 900° to 1,200° F {which correlates with the ignition temperature of carbon monoxide} is widely used.
Flashover

– Just prior to flashover, several things are happening:
  • The temperatures are rapidly increasing
  • Additional fuel packages are becoming involved
  • Fuel packages in the compartment are giving off combustible gases

– As flashover occurs the materials in the compartment and the gases ignite, resulting in full-room involvement with a heat release in the neighborhood of 10,000 kW or more

– Occupants that have not escaped before flashover occurs are not likely to survive

– Firefighter in a compartment at flashover are at extreme risk, even while wearing all proper PPE
Fully Developed

– All combustible materials in the compartment are involved in fire

– During this time the burning fuels in the compartment are releasing the maximum amount of heat possible for the available fuel packages and producing large volumes of fire gases

– Heat release and volume of fire gases depend on the number and size of ventilation openings, if not enough, fire often becomes ventilation controlled with large volumes of unburned gases produced

– Hot, unburned fire gases are likely to be flowing from the compartment of origin into adjacent spaces, igniting as they enter a space where air is available
Decay

- Available fuel has been consumed and the rate of heat release begins to decline
- The fire is becoming fuel controlled, diminishing the amount of fire and beginning to drop temperatures within the compartment
- The remaining mass of glowing embers can result in moderately high temperature in the compartment for some time
- This fire is now a backdraft potential
- We will talk about backdraft in a few minutes
Factors That Affect Fire Development

• From ignition to decay, several factors affect the fire behavior and development within the compartment:
  – Size, number, and arrangement of ventilation openings
  – Volume of the compartment
  – Thermal properties of the compartment enclosures
  – Ceiling height of the compartment
  – Size, composition, and location of the fuel package that is first ignited
  – Availability and locations of additional fuel packages \{target fuels\}
Factors That Affect Fire Development

- A fire must have air to support burning beyond the ignition stage.
- The size and number of ventilation openings determine how the fire develops within the space.
- The size, shape, and ceiling height determine if a significant hot gas layer will form.
- Location of the initial fuel package is also important in development of the hot gas layer.
- Fuel packages in the center of a room will entrain more air and are cooler than those against walls or in corners.
Factors That Affect Fire Development

- Because matter and energy are conserved, any loss in mass caused by fire is converted to energy
  - This energy is in the form of heat and light
- The amount of heat energy released over time in a fire is called the heat release rate \( \text{HRR} \) and is measure in Btu/s or kilowatts \( \text{kW} \)
  - This is directly related to the amount of fuel being consumed over time and the heat of combustion of the fuel being burned
- We should recognize potential fuel packages in buildings and use this to estimate the fire growth potential for the building
Factors That Affect Fire Development

• Materials with high heat release rates would be expected to burn rapidly once ignition occurs.

• Materials with lower heat release rates would be expected to take longer to develop.
  – In general, low density materials burn faster that higher density materials of similar makeup.

• Ignition of remote fuels are another problem.
  – The heat form the initial fire is transferred in the space by all three modes of heat transfer and begin igniting remote fuels, sometimes called target fuels.
  – When the temperature of the compartment reaches ignition temperature of fire gases, flashover occurs.
Special Considerations

• Several conditions or situations that occur during a fire’s growth and development should be discussed

• The next several slides provide an overview of these conditions and the potential safety concerns for each
Flameover / Rollover

• These terms describe a condition where flames move through or across the unburned gases during a fire’s progression
  – Flameover is different from flashover as it burns only fire gases and not the surfaces of other fuel packages

• This condition may occur during the growth stage in the hot gas layer

• Flames may be present in the layer as the gases reach their ignition temperature

• This adds to heat in the area, but is not flashover
  – This can also be seen as hot gases @ ignition temperature exit an area and mix with oxygen & ignite
Thermal Layering of Gases

• This is the tendency of gases to form into layers according to temperature
  – Other terms for this are heat stratification and thermal balance
• The hottest gases tend to be in the top layer, while the cooler gases form the lower layers
• Smoke rises {duh-huh}, if a hole is cut in a roof, smoke will rise to the outside
• Thermal layering is critical to firefighting – As long as the hottest air and gases are allowed to rise, the lower levels will be safer for firefighters
Thermal Layering of Gases

• The thermal layering process can be disrupted if water is applied directly into the hottest layer.

• When water is applied to the upper level of the layer, the rapid conversion to steam can cause the gases to mix rapidly.

• This causes hot gases to mix throughout the compartment and is referred to as disrupting the thermal balance or creating a thermal imbalance.
  – Many firefighters have been burned when thermal layering was disrupted.

• The proper procedure is to ventilate and direct the fire stream at the base of the fire so as not to disrupt the thermal balance
Backdraft

- As a fire grown in a compartment, large volumes of hot, unburned gases can collect in unventilated spaces
- These gases may be at or above their ignition temperature but have insufficient oxygen to ignite
- Any thin we do to allow air to mix with these host gases can result in an explosive ignition called *backdraft*
- Many firefighters have been injured or killed as a result of backdrafts
- Proper vertical ventilation can reduce the chance of a backdraft occurring
Backdraft

• The following conditions may indicate the potential for a backdraft situation
  – Pressurized smoke exiting small openings
  – Black smoke becoming dense gray yellow
  – Confinement and excessive heat
  – Little or no visible flame
  – Smoke leaving the building in puffs or at intervals
    {appearance of breathing}
  – Smoke stained windows
Products of Combustion

• Fire changes the chemical composition of the materials that burn

• This result in the production of new substances and the generation of energy
  – The Law of Conservation of Mass tells us that any mass lost converts to energy

• In a fire, this energy is in the form of heat and light
  – Fire also results in the generation of airborne fire gases, particles, and liquids often referred to as smoke
Products of Combustion

• Heat in a fire is one product of combustion
  – In addition to spreading the fire, heat also cause burns, dehydration, heat exhaustion, and injury to a person’s respiratory tract

• Heat energy is a danger to anyone directly exposed to it, but smoke causes most deaths in fires

• The materials that make up smoke vary from fuel to fuel, but all smoke can be considered toxic

• Smoke contains narcotic {asphyxiant} gases and irritants that cause central nervous system depression, resulting in reduced awareness, intoxication, and can lead to loss of consciousness and death
Products of Combustion

• Most common narcotic gases found in smoke are carbon monoxide, hydrogen cyanide, and carbon dioxide

• Reduced oxygen levels will also cause a narcotic effect in humans

• Irritants in smoke cause breathing discomfort and inflammation of the eyes, respiratory tract, and skin

• Depending on involved fuels, smoke will contain numerous substances considered as irritants

• The most common hazardous substance is CO
Products of Combustion

- CO is not the most dangerous of the materials found, but it is almost always present when combustion occurs.
- A variety of toxic substances in smoke may cause death, but CO is the one that is most easily detected in the blood, and most often reported.
- Flame is the visible body of a burning gas.
- It becomes hotter and less luminous during more complete combustion of the carbon.
- It is not present in types of combustion that do not produce a flame, such as smoldering fires.
Fire Extinguishment Theory

• Extinguishment is done by limiting or interrupting one or more of the essential elements in the combustion process

• A fire may be extinguished by reducing its temperature, eliminating fuel or oxygen, or stopping the self-sustained chemical chain reaction
Temperature Reduction

• Cooling with water is one of the most common methods of extinguishment

• This reduces the temperature of a fuel to a point where it no longer produces sufficient vapors to burn
  – Solid fuels and liquid fuels with high flash points can be extinguished by cooling
  – It will not work on fires with low flash point liquids or flammable gases
  – Cooling with water also works on smoldering fires

• To use this method, enough water must be applied to absorb the heat being generated by the fire
Fuel Removal

• Some fires can be extinguished by removing fuel source

• This can be done by stopping the flow of a liquid or gaseous fuel or by removing a solid fuel in the path of a fire

• Another method of fuel removal is to allow a fire to consume all of the fuel and burn itself out
Oxygen Exclusion

• In its simplest form, this method is used to extinguish cooking stove fires when a cover is placed over a pan of burning food.

• The oxygen content can be reduced by using an inert gas such as carbon dioxide to displace the oxygen and disrupt the combustion process.

• We can separate oxygen from fuel by blanketing the fuel with foam.

• None of these methods will work on fuels that are self oxidizing.
Chemical Flame Inhibition

- Some agents such as some dry chemicals and halogenated agents interrupt the combustion reaction and stop flaming.
- This is effective on gas and liquid fuels because they must flame to burn.
- Smoldering fires are not easily extinguished by these agents.
- Most ignitable liquids have a specific gravity of less than 1.
  - If water is used, the fuel can float on it and continue to burn.
  - If unconfined, this could spread a fire.
Chemical Flame Inhibition

• The solubility of a liquid fuel in water is also an issue

• Liquids of similar molecular structure tend to be soluble in each other while those with different structure and electrical charge tend not to mix

• Liquids that readily mix with water are called polar solvents

• Alcohol and other polar solvents dissolve in water
  – If large amounts of water are used, polar solvents may dilute to the point where they will not burn
Chemical Flame Inhibition

• As a rule, hydrocarbon liquids do not dissolve in water and float on top of water
• Vapor density also affects extinguishment of both ignitable liquids and gaseous fuels
• Gases with a vapor density less than 1 ten to rise and dissipate
• Gases with vapor density greater than 1 tend to hug the ground and travel as directed by terrain and wind
  – Examples of different gases and their properties
    • Ethane and Propane are heavier than air
    • Natural gas is lighter than air
Classification of Fires

• This is important to the firefighter when discussing extinguishment

• Each class of fire has its own requirements for extinguishment

• There are four classes of fire and we will discuss each class individually
Class A Fires

– Involve ordinary combustible materials such as wood, cloth, paper, rubber, and may plastics
– Water is used to cool or quench the burning material below ignition temperature
– Class A foams {wet-water} can enhance water’s ability to extinguish class A fires, especially deep seated fires in bulk materials such as hay bales, sawdust piles, etc.
– The wetting agent reduces the water’s surface tension, allowing it to penetrate more easily into piles of the material
– These fires are difficult to extinguish with oxygen exclusion methods because those methods do not help cool the fuel
Class B Fires

• These are fires involving flammable and combustible liquids and gases such as gasoline, oil, lacquer, paint, mineral spirits, and alcohol

• Oxygen exclusion is the most effective extinguishing method for these types of fires and it helps reduce the production of additional vapors

• Other extinguishing methods include removal of fuel, temperature reduction when possible, and the interruption of the chain reaction with dry chemical agents such as a Purple K®
Class C Fires

- These fires involve energized electrical equipment
- Household appliances, computers, transformers, and overhead transmission lines are examples
- Control these fires with a non-conducting extinguishing agent such as halon, dry chemical, or carbon dioxide
- Fastest procedure is to first de-energize high voltage circuits and then fight the fire appropriately depending upon the fuel involved
- After the power is off it will become a class A, B, or D fire
Class D Fires

• These fires involve combustible metals such as aluminum, magnesium, titanium, zirconium, sodium, and potassium

• They are particularly hazardous in their powdered form

• Proper airborne concentrations of metal dusts can cause powerful explosions

• The extremely high temperature of some burning metals makes water and other common extinguishing agents ineffective

• No single agent controls fires in all combustible metal fires
Class D Fires

• Special extinguishing agent are available for control of fire in each type of metal and are marked specifically for the metal fire they can extinguish

• We may find these materials in a variety of industrial or storage facilities

• Use caution with Class D fires

• Isolate the materials and treat it as recommended in its MSDS sheet or if you do not have that, use the North American Emergency Response Guidebook for instructions on this material.
Video Tape Time

Please view the video tape entitled:

Fire Behavior – 18:33 minutes

Essentials of Firefighting

Firefighter 1 – Volume 3