Essentials of Fire Fighting
6th Edition
Firefighter I

Chapter 5 — Fire Behavior

Learning Objective 1

Explain the science of fire as it relates to energy, forms of ignition, and modes of combustion.

5–1

Reality Check

13:28:05 Time =0

Time = 6 seconds

Time = 48 seconds

Time = 120 seconds

Understanding the physical science of fire can help firefighter safety.

Fire – Variety of forms

- Heat-producing chemical reaction between fuel and oxidizer

Knowledge can help

- Translate into practical knowledge of fire behavior
- Recognize what is happening – Predict potential behavior

5–3

There are two types of changes firefighters should understand.

Physical change	Chemical reaction
Substance chemically same	Substance changes
Changes in size, shape, appearance	From one type of matter to another

5–4

The concept of energy is also important for firefighters to know.

In heat defined as

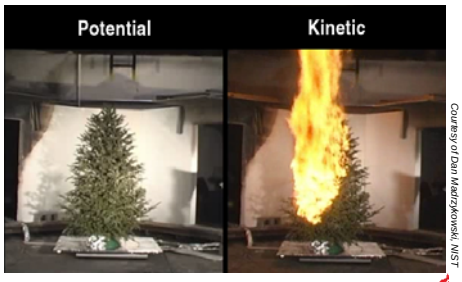
- Increasing temperature of substance

Work occurs when

- Force is applied to object over distance
- Substance undergoes chemical, biological, physical change

5–5

There are two forms of energy that firefighters should know about.



Courtesy of Dan Madrzykowski, NIST

5–6

There are many types of energy and all can change from one type to another.

Types	• Chemical • Thermal • Mechanical • Electrical • Light • Nuclear • Sound
In fire behavior potential chemical energy is	• Converted to thermal • Released as heat

5–7

You should also know about how to measure and the exchange of energy.

Measurement	Chemical, physical changes involve exchange of energy

• Joules (J) in SI
• British thermal unit (Btu) in customary
	• Potential energy
	  • Released during combustion
	  • Converted to kinetic energy

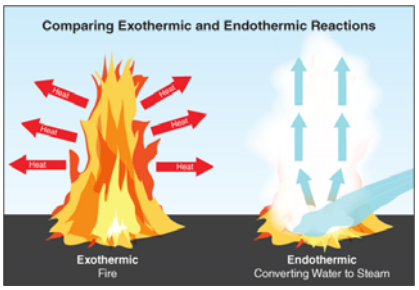
5–8

POWER….

..is the Rate at which energy is expended.

- Expressed as Watts
- 1 watt = 1 joule / second
- Kilowatts and Megawatts commonly used
- 1 horsepower = 745 watts

There are two types of energy reactions that you should understand.



5–10

The process of ignition follows a sequence of steps.

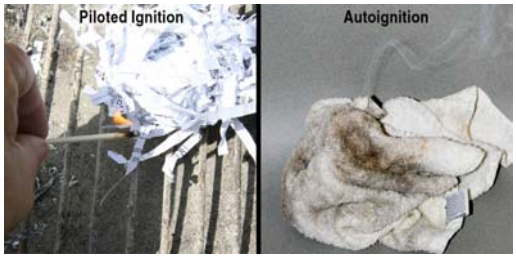
Fuel heated – Temperature increases → Sufficient heat transfer
- Causes pyrolysis (solid fuels); vaporization (liquid fuels)
- Releases ignitable vapors or gases

Energy necessary for ignition
- Provided by external source
- Fuel can be heated until ignites

→ Continues production, ignition so combustion reaction sustained

5–11

Piloted and autoignition are the two forms of ignition.



5–12

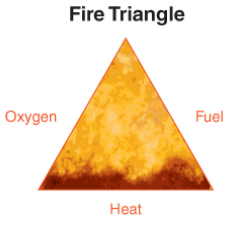
Fire and combustion require similar conditions to occur.

Combustion – Chemical reaction, can occur without fire

Fire – One possible result of combustion

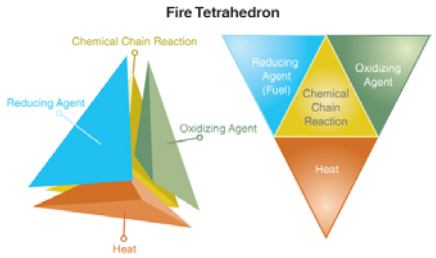
5–13

The fire triangle is the oldest and simplest fire model.



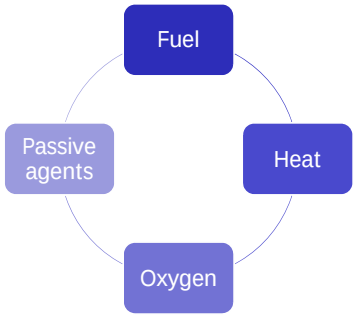
5–14

The fire tetrahedron represents the uninhibited chain reaction that must be present for fire to occur.



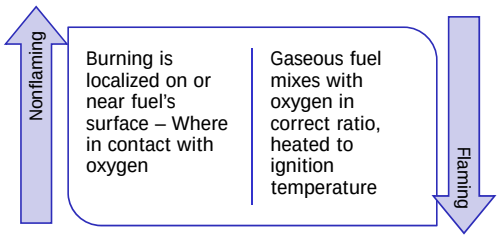
5–15

There are several materials that affect both ignition and fire development.



5–16

The two types of combustion occur under different circumstances.



5–17

The products of combustion generate as fuel burns and changes chemical composition.

- Thermal energy
- Toxic smoke
- Smoke

(Cont.)

5–18

The products of combustion generate as fuel burns and changes chemical composition.

- Carbon monoxide (CO)
- Hydrogen cyanide (HCN)
- Carbon dioxide (CO_2)

(Cont.)

5–19

WARNING

Smoke is fuel and is always potentially flammable. Wear full PPE and SCBA anytime you work in smoke.

5–20

The products of combustion generate as fuel burns and changes chemical composition.

Flame

5–21

REVIEW QUESTION

How does the science of fire relate to energy, forms of ignition, and modes of combustion?

5–22

Learning Objective 2

Describe the impact of thermal energy on heat, temperature, and heat transfer.

5–23

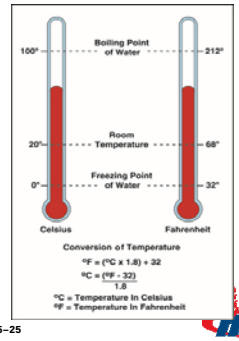
Thermal energy (heat) is the energy element in both fire models.

Kinetic energy transfers from high-temperature to low-temperature substance	Always in transit
Thermal kinetic needed to release potential chemical energy in fuel	Vibrates molecules in fuel leading to break down, release of vapors

5–24

You should understand the relationship between heat and temperature.

- **Heat- a form of energy capable of initiating and supporting chemical changes and changes of state**



5–25

Tempurature

Measure of a materials ability to transfer heat energy to other objects- the greater the energy, the higher the temperature.

Measured in terms of degrees on a Standard Scale- Celsius or Fahrenheight

- What is the difference between the scales?

1–26

The concept of transfer rate is influenced by several factors.

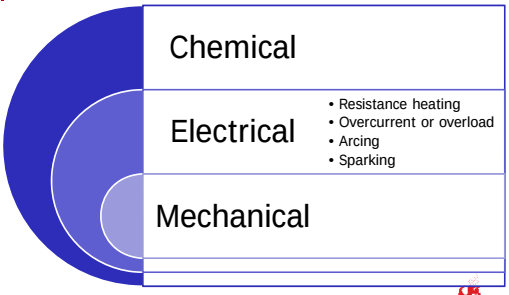
Related to temperature differential – Thermal conductivity

Greater temperature difference – Greater transfer rate

Heat flux

5–27

There are several sources of thermal energy you should recognize.



5–28

Understanding the concept of heat transfer can help in several ways.

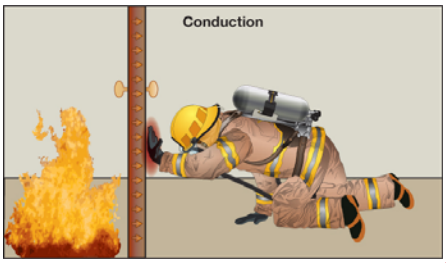
Understand transfer from initial fuel package to others

Estimate size of fire before attacking – Evaluate effectiveness of attack

Transfer occurs from warmer to cooler – In a room full of fire, if you are in it- heat is transferred to you

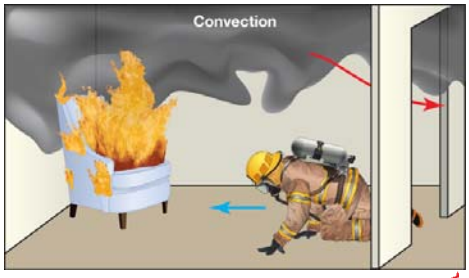
5–29

Conduction is the transfer of heat through and between solids.



5–30

Convection is the transfer of thermal energy by circulation or movement of fluid (liquid or gas).



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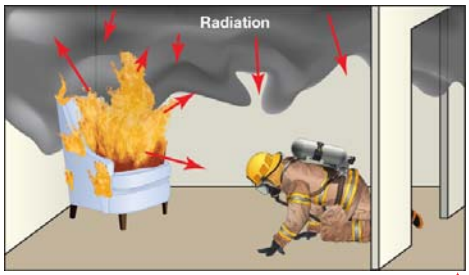
Radiation is the transmission of energy as an electromagnetic wave, without an intervening medium.



5–32

REVIEW QUESTION

What impact does thermal energy have on heat, temperature, and heat transfer?

5–33

Learning Objective 3

Recognize the physical states of fuel.

5–34

Fuel is the material or substance oxidized or burned in combustion.

Inorganic – Do not contain carbon

Organic – Contain carbon, other elements

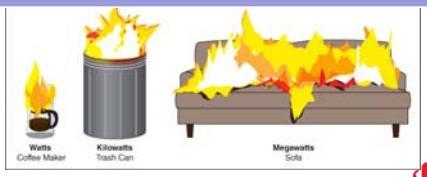
5–35

The chemical content of fuel influences heat of combustion and heat release rate.

Heat of combustion

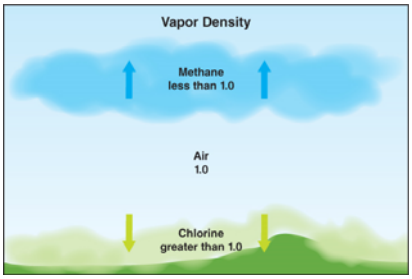
- Total amount of thermal energy released when specific amount of fuel oxidized (burned)

Heat release rates



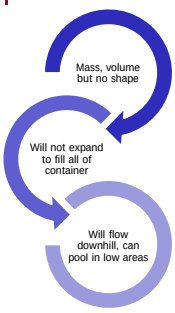
5–36

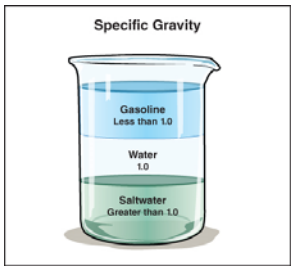
Gaseous fuel can be the most dangerous of all fuel types.



5–37

The properties of liquid fuel are important to understand.

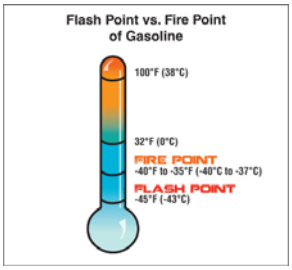




5–38

Vaporization is the transformation of a liquid to a vapor or gaseous state.

Flammable liquids with high vapor pressure present special hazard



5–39

Solubility is a factor to consider regarding liquid fuels.

Solubility – Extent to which substance will mix with water

- Miscible – Mix in any proportion
- Hydrocarbon – Do not mix
- Polar solvents – Readily mix

5–40

Density is also a factor to consider regarding liquid fuels.

Liquids less dense than water difficult to extinguish with water alone

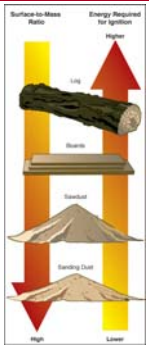
- Fuel will not mix with water – Adding may disperse burning liquid
- Extinguish with appropriate agent

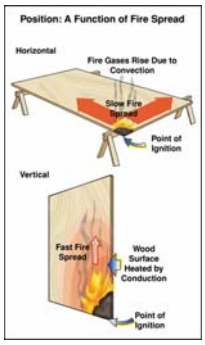
Water-soluble mix with agent – Become less effective

- Avoid use with foams specifically designed for polar solvents

5–41

The properties of solid fuel influence the process of pyrolysis.





REVIEW QUESTION

What are the physical states that fuel can be found in?

5–43

Learning Objective 4

Explain the relationship between oxygen and life safety.

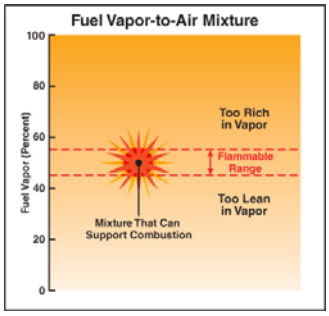
5–44

Oxygen is the primary oxidizing agent present at most fires.

- 21 percent oxygen typical
- At normal temperatures
  - Materials can ignite, burn at concentrations as low as 14 percent
- Limited oxygen diminishes flaming combustion
- Ambient temperature impacts
  - Nonflaming
  - Flaming
- Higher oxygen concentrations than normal

5–45

Combustion occurs after a fuel has been converted to a gaseous state and mixed with an oxidizer in proper ratio.



5–46

REVIEW QUESTION

How do oxygen and life safety relate to one another?

5–47

Learning Objective 5

Identify the products of self-sustained chemical reactions.

5–48

Self-sustained chemical reactions create several products.

Combustion of methane and oxygen	Flaming combustion
• Production of CO_2, water • Release of energy in form of heat, light • Production of CO, formaldehyde • Different free radicals	• Free radicals • Will burn until fuel or oxygen exhausted • Chemical flame inhibition occurs when extinguishing agent applied

5–49

REVIEW QUESTION

What products of self-sustained chemical reactions combine to make flammable and toxic substances?

5–50

Learning Objective 6

Explain the factors that affect fire development.

5–51

Learning Objective 7

Describe the stages of fire development.

5–52

The stages of fire development occur in both unconfined and confined fires.

Click image to play

Courtesy of Dan Madrzykowski, NIST

(Cont.)

Traditional – Lab development

5–53

The stages of fire development occur in both unconfined and confined fires.

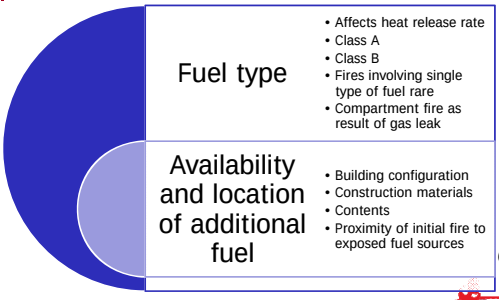
Click image to play

Courtesy of Dan Madrzykowski, NIST

Actual – Real world development

5–54

There are several factors that will affect fire development.



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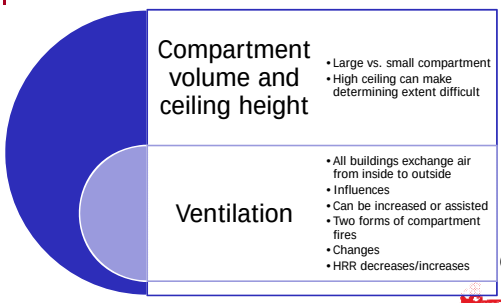

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5–56

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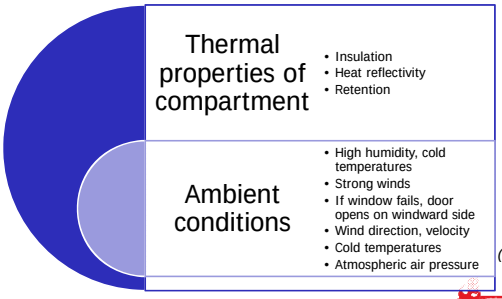

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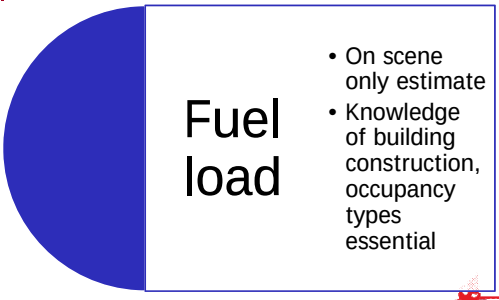


5–58

REVIEW QUESTION

What different factors can impact fire development?

5–59

The incipient stage starts when the elements of the fire triangle come together and combustion begins.

Courtesy of Dan Madrzykowski, NIST

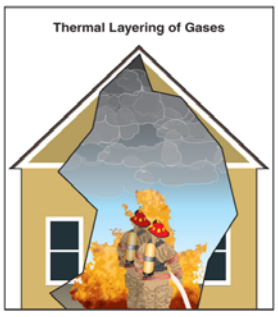
5–60

The growth stage occurs as the fire transitions and is influenced by air in the compartment.

Courtesy of Dan Madrzykowski, NIST

5–61

Thermal layering can also occur during the growth stage.



5–62

Isolated flames and rapid transitions may also be a part of the growth stage.

Courtesy of Dan Madrzykowski, NIST

5–63

The fully developed stage occurs when all combustible materials are burning.

Courtesy of Dan Madrzykowski, NIST

5–64

The decay stage brings combustion to a complete stop through two means.

Courtesy of Dan Madrzykowski, NIST

5–65

REVIEW QUESTION

What are the stages of fire development?

5–66

Learning Objective 8

Recognize signs, causes, and effects of rapid fire development.

5–67

Rapid fire development is responsible for numerous deaths and injuries.

Protect yourself and your crew

- Recognize indicators
- Know conditions created by
- Determine best action to take before

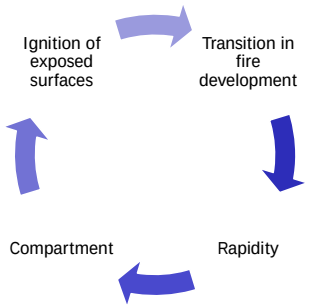
5–68

Flashover occurs when combustible materials in a compartment ignite almost simultaneously.

- Typically occurs during growth stage – May occur during fully developed stage
- Environment of room changes from two-layer condition to single well mixed, untenable hot gas condition
- Transition between pre-flashover to post-flashover can occur rapidly
- Conditions during
  - Volume of fire can increase to fill entire room
  - Burning gases push out of openings

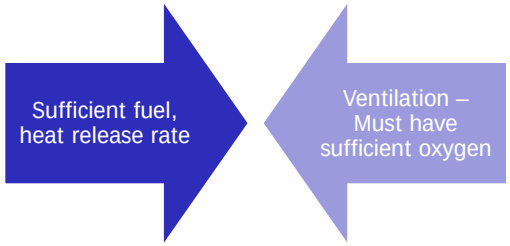
5–69

There are several common elements in flashover to be aware of.



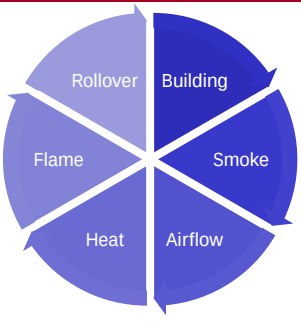
5–70

Progression to a flashover is determined by two factors.



5–71

Firefighters should be aware of several flashover indicators.



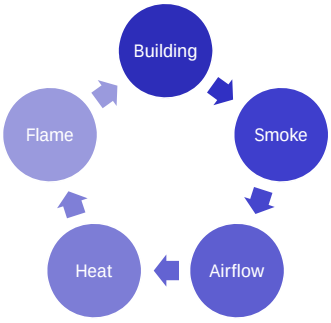
5–72

Backdraft is a change in ventilation that results in explosively rapid combustion of flammable gases.

Courtesy of Bob Esposito

5–73

Firefighters should know about several backdraft indicators as well.



5–74

Backdraft effects vary depending on several factors and will not always occur immediately after the opening is made.

Factors	Not always occur immediately	Violence depends on
• Volume of smoke • Degree of confinement • Pressure • Speed with which fuel and air are mixed • Location where ignition occurs	• If mix of hot flammable products, air is slow – Unlikely to occur • May not occur until air is fully introduced	• Extent of confinement • More confined – More violent

5–75

A smoke explosion may occur before or after the decay stage as unburned fuel gases contact an ignition source.

Cooling smoke can accumulate in other areas, mix with air

Violent because involve premixed fuel, oxygen

Smoke
- Generally cool – Less than 1,112° F (600° C)
- Located in void spaces or uninvolved areas

5–76

REVIEW QUESTION

What are the signs and causes of a backdraft?

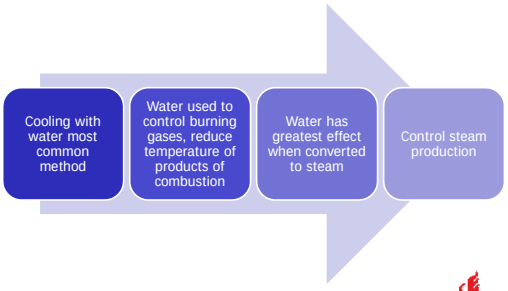
5–77

Learning Objective 9

Describe the methods through which fire fighting operations can influence fire behavior.

5–78

Firefighters can influence fire behavior through temperature reduction.



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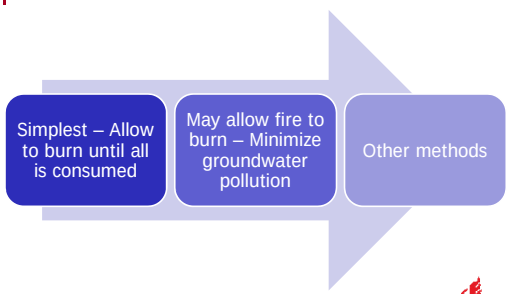
Firefighters can influence fire behavior through fuel removal.



5–80

Oxygen exclusion reduces a fire's growth and may extinguish it over time.

- Methods – Will not work if fuel is self-oxidizing
- Closing doors can limit air supply, help prevent flashover

5–81

Chemical flame inhibition uses agents to interrupt the combustion reaction.

- Effective on gas, liquid fuels
- Do not easily extinguish nonflaming fires
- Not practical for smoldering fires

5–82

Unplanned ventilation may occur before or after suppression operations start.

Can be result wind outside structure

- Increase pressure inside structure
- Drive smoke, flames into unburned portions
- Upset tactical ventilation

(Cont.)

5–83

WARNING

Wind driven conditions can occur in any type of structure. Wind speeds as low as 10 mph (16 kph) can create wind-driven conditions.

5–84

Unplanned ventilation may occur before or after suppression operations start.

May be result of

- Occupant action
- Fire effects on building
- Action outside of planned ventilation

5–85

Tactical ventilation is planned, systematic, and coordinated.

Must be coordinated with suppression operations

Influence behavior based on

- HHR increased when ventilation increased
- Can be simple or complex

Increase in combustion rate when controlled

5–86

WARNING

Even coordinated tactical ventilation increases the combustion rate in ventilation controlled fires.

5–87

REVIEW QUESTION

How can fire fighting operations impact fire behavior?

5–88

Summary

- You need to understand the combustion process, how fire behaves, and how to select appropriate extinguishing agents.
- Understanding fire behavior can help you recognize developing fire conditions and respond safely to mitigate hazards present in the fire environment.

5–89