THE COMBUSTION OF HYDROCARBONS

"I love the smell of napalm in the morning…smells like… victory!"

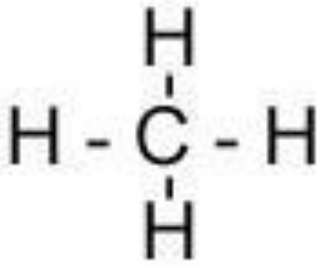
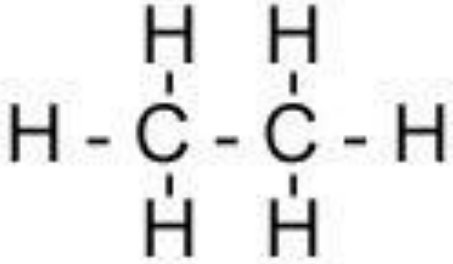
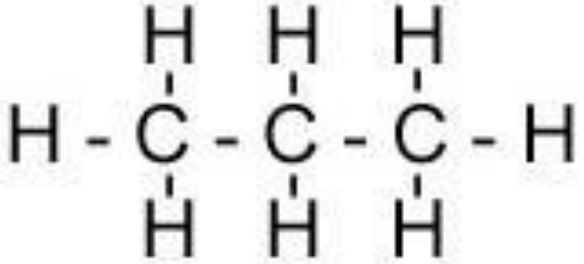
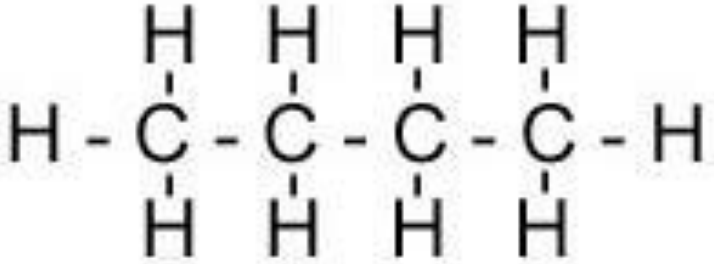
- Carbon monoxide is a toxic gas that can be produced during the combustion of a carbon-based fuel such as propane.
- Initial symptoms of carbon monoxide poisoning include drowsiness, impaired judgment, and unconsciousness.
- Prolonged exposure can be fatal.

- **Combustion** is a chemical reaction in which a fuel burns in oxygen, usually from air.
- Coal, propane, and gasoline are common fuels.
- The molecules of fuels like all compounds-are a source of chemical energy.
- Combustion releases this chemical energy as thermal energy and light.
- The other products of combustion vary depending on the type of fuel and how it was burned.
- Common products are carbon dioxide, water, and sometimes carbon monoxide.


OXYGEN
HEAT
FIRE
FUEL

- Carbon dioxide is a **greenhouse gas** (a gas that allows solar radiation to pass through the atmosphere but absorb radiation emitted by Earth, thereby trapping thermal energy and making Earth warmer) that contributes to global warming, as does water vapour.
- Propane is an example of an **organic compound**: a molecular compound containing one or more carbon-carbon bonds. Many organic compounds also contain one or more carbon-hydrogen bonds.
- The majority of fuels used today, including gasoline, are composed of organic compounds.
- Many fuels contain impurities such as sulfur compounds and heavy metals.

- Combustion releases these substances into the atmosphere as **air pollution** (chemicals and particles in the atmosphere that harm living organisms or damage the environment), unless they are removed by special pollution-control technologies.
- Many substances burn.
- We will focus on combustion of a special group of organic compounds called hydrocarbons.
- Hydrocarbons are made up of only two elements: hydrogen and carbon.
- Propane, C_3H_8, and butane, C_4H_{10}, are common examples of hydrocarbons.

Name	Formula	Structure
Methane	CH_4	
Ethane	C_2H_6	
Propane	C_3H_8	
Butane	C_4H_{10}	

- Gasoline is a mixture of mostly liquid hydrocarbons.
- Most hydrocarbons are extracted from coal, oil, and natural gas.
- Although some hydrocarbons are used in the synthesis of other compounds, most are
- burned for their energy content.
- Much of this energy is used for transportation.
- Other important uses of this energy are the generation of electricity and home heating.

TYPES OF HYDROCARBON COMBUSTION

- All hydrocarbons burn, provided they are hot enough and have sufficient oxygen.
- We classify the combustion of hydrocarbons as either complete or incomplete, depending on the products that form.

COMPLETE COMBUSTION

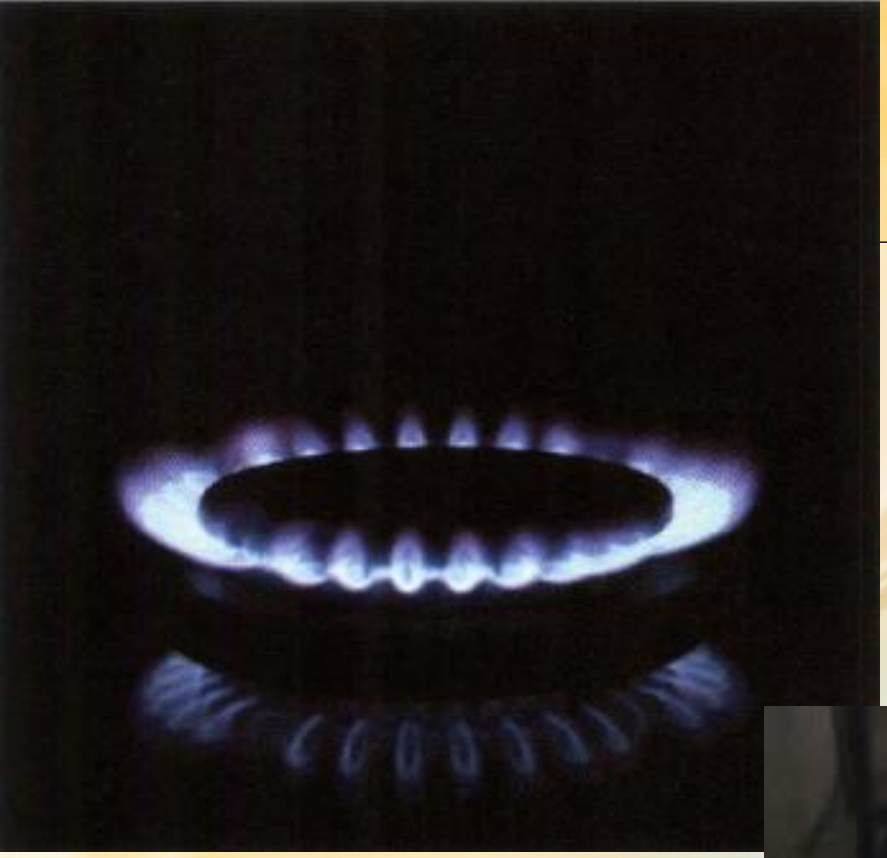
- The **complete combustion** of a hydrocarbon occurs when the oxygen supply is plentiful.
- The products are energy, carbon dioxide, and water vapour.
- The general unbalanced chemical equation for the combustion of a hydrocarbon, C_XH_Y is

$$C_XH_Y + O_{2(g)} \longrightarrow CO_{2(g)} + H_2O_{(g)} + \text{energy}$$

- This general equation applies to all hydrocarbons. For example, natural gas is mostly methane, CH_4
- The chemical equation for the complete combustion of methane is

$$CH_{4(g)} + 2\,O_{2(g)} \longrightarrow CO_{2(g)} + 2\,H_2O_{(g)} + \text{energy}$$

- Complete combustion usually occurs under carefully controlled conditions in which excess (more than enough) oxygen is present.
- Complete combustion is the ideal way to burn a fuel because it releases the most energy from the fuel molecules.
- As a result, complete combustion produces the cleanest (least sooty) and hottest flames.
- The blue flame of a gas stove is evidence of complete combustion.
- Keeping a natural gas furnace well maintained ensures that the gas is burned as completely as possible and produces the most thermal energy.
- This helps to reduce the cost of home heating.



- Ethyne, C_2H_2, is another well-known hydrocarbon fuel.
- It is more commonly known as acetylene. When ethyne burns with a good supply of oxygen, it generates the high temperatures needed to cut steel.
- An oxyacetylene torch is supplied by two gas cylinders:
  - one containing acetylene and the other containing oxygen.
- The steelworker controls the temperature of the flame by adjusting the flow of oxygen to the torch nozzle.
- As more oxygen reaches the flame, combustion of acetylene becomes more complete.

- This results in a hotter flame.
- The temperature of an oxyacetylene torch flame can reach 3500 ^{o}C - hot enough to slice through steel like a knife through butter.
- The chemical equation for the complete combustion of ethyne (acetylene) is

$$2\ C_2H_{2(g)} + 5\ O_{2(g)} \longrightarrow 4\ CO_{2(g)} + 2\ H_2O_{(g)} + \text{energy}$$

INCOMPLETE COMBUSTION

- **Incomplete combustion** of hydrocarbons occurs when the supply of oxygen is limited.
- This situation can occur while burning a hydrocarbon in an enclosed space, such as when operating a car or barbeque in a garage.
- Incomplete combustion often occurs in uncontrolled or less than ideal conditions.
- The mixture of air and fuel that results in incomplete combustion is said to be “fuel rich.”
  - A log in a wood-burning stove is an example of a fuel-rich condition: there is lots of fuel (wood) and limited oxygen.
  - The lack of oxygen prevents "ideal" or complete combustion from occurring, limiting the quantity of energy released.

- Flames resulting from incomplete combustion are often sooty, yellow, and cooler than flames from complete combustion.
- Incomplete combustion is usually undesirable.
- However, it can be useful in some applications.
- For example, incomplete combustion is used to start gasoline-powered devices such as lawn mowers.

- A cold lawn mower is much easier to start if a fuel-rich mixture enters its engine than if there is less fuel and more air. The volume of air entering the engine is controlled by a valve on the lawn mower called the choke. Before starting a cold lawn mower, adjust the choke so that it is in the closed position. This restricts the air flow into the engine. The result is a fuel-rich mixture that is easier to ignite. Once the engine starts, you might see sooty exhaust produced. This is evidence of incomplete combustion. After warming up the lawn mower for a few seconds, open the choke, allowing more air to mix with the fuel. The result is combustion that is more complete.

- Incomplete combustion produces a greater variety of combustion products than complete combustion.
- Carbon dioxide, water, and energy can be produced.
- However, incomplete combustion also releases either carbon monoxide or soot, or both.
- Soot is a solid black ash observed when a carbon-based fuel burns.
- Soot is actually a mixture of solid carbon-rich molecules.
- This is why soot is often represented in chemical equations as C(s).

- Because so many reaction products are possible, incomplete combustion cannot be represented by a single chemical equation.
- For example, both of the following chemical equations represent the incomplete combustion of heptane, a hydrocarbon in gasoline:

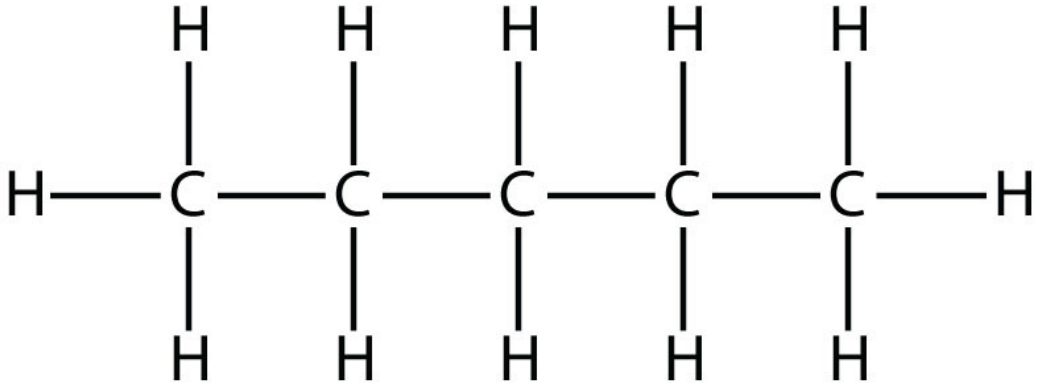
$$C_7H_{16(l)} + 7\ O_{2(g)} \longrightarrow 3\ C_{(s)} + 2\ CO_{(g)} + 2\ CO_{2(g)} + 8\ H_2O_{(g)} + \text{energy}$$

$$2\ C_7H_{16(l)} + 11\ O_{2(g)} \longrightarrow 14\ CO_{(g)} + 8\ H_2O_{(g)} + \text{energy}$$

- By comparison, there is only one chemical equation for the complete combustion of heptane.
- This reaction does not produce either soot or carbon monoxide:

$$C_7H_{16(l)} + 11\ O_{2(g)} \longrightarrow 7\ CO_{2(g)} + 8\ H_2O_{(g)} + \text{energy}$$

- Note that more molecules of oxygen are required per molecule of heptane for complete combustion to occur.



CONCERNS RELATED TO INCOMPLETE COMBUSTION

- Incomplete combustion of hydrocarbons can be a problem in enclosed places where there is poor ventilation.
- Even the candles burning in places of worship can pose a number of health concerns.
- Incomplete combustion in such places, and in gas powered engines, is undesirable for a variety of reasons.

1. Incomplete combustion releases only a portion of the energy that may be obtained from hydrocarbon fuels such as gasoline. Automobile engines rarely burn gasoline completely. However, the combustion of gasoline is more complete while travelling at highway speeds than when driving in the city. The most incomplete combustion of gasoline occurs while a vehicle is idling. This is because an idling engine operates below its optimal temperature. As a result, gasoline is burned less completely than when the engine operates at higher temperatures. Also, fuel residue may form on engine components, making them work less efficiently.

2. Soot particles from incomplete combustion are an inhalation hazard. Many of the chemicals in soot are toxic. Furthermore, soot particles are often too small to be filtered by the upper respiratory tract. As a result, these particles may penetrate deep into the lungs and irritate sensitive tissue. This can lead to respiratory problems, including asthma. Soot can also foul moving engine parts, making the engine even less efficient.

3. Carbon monoxide produced during incomplete combustion is also an inhalation hazard. This toxic gas is often called the "silent killer" because it has no colour, taste, or odour. Carbon monoxide is dangerous because it binds tightly with the hemoglobin in blood. This prevents hemoglobin from binding with inhaled oxygen. During a rush -hour traffic jam, the carbon monoxide concentration in the air can be high enough to cause headaches- a symptom of mild carbon monoxide poisoning. Carbon monoxide poisoning can also occur in the home. According to the Canadian Safety Council, carbon monoxide is the leading cause of fatal poisonings in North America. Each year, several Canadians die needlessly due to faulty home heating equipment. Many of these deaths could have been prevented if a carbon monoxide detector had been installed.

OTHER COMBUSTION HAZARDS

- Firefighting has always been a risky profession.
- However, the increased use of synthetic materials in recent decades has made the job even more hazardous.
- Many veteran firefighters describe domestic fires as being hotter and more toxic than ever before .

- Synthetic materials have unusual combustion properties.
- As synthetic materials burn, they can produce toxic gases and particulate matter.
- Firefighters wear sealed breathing apparatus to avoid inhaling these toxins.
- However, studies have shown that some of the chemicals may be absorbed through the skin.
- Not surprisingly, fire departments in many countries are seeing a rise in the incidence of certain types of cancer among their workers and retirees.


Head Harness
Goggle Elastic
Chin Strap
Drag Rescue Device
Camera Strap
SCBA Harness
FR Suspenders
Belt
Zipper Tape
Integrated Body Harness
Adjustment Straps
Boot Straps
Escape Rope

- Even natural substances can produce potentially hazardous chemicals when they burn.
- For example, conservation areas routinely conduct controlled burns of vegetation.
- Before they do, notices are often sent to nearby residents warning people with asthma to avoid prolonged exposure to the smoke and that the smoke may carry small droplets of poison ivy oil.

- Forest fires can affect air quality on a much larger scale.
- In a recent study of the effect of forest fires on air quality, scientists found that burning pine forests release large quantities of chemicals called alkaloids into the air.
- Alkaloids are naturally occurring substances produced by plants.
- Some, like morphine, are beneficial to humans.
- In small doses, pine tree alkaloids are not a risk.
- However, in larger doses, the alkaloids produced from burning pine trees can be potent toxins.
- As this research continues, it could change our perceptions of the health risks faced by communities downwind from a forest fire.