The Science of Arson and Explosives
Fire

• Made of heat and light (photons)
• It is produced when an energy-containing compound combines with oxygen and gets oxidized.
• Oxygen gets reduced and becomes water.
• This is called combustion.

\[ \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} + \text{Energy / Heat / Light} \]

Methane contains energy in the form of electrons in the hydrogen atoms
Oxygen loves to grab electrons, so it grabs the electron-containing hydrogens from carbon
Carbon combines with leftover oxygen atoms to form carbon dioxide
The oxygen atoms that did grab the electron-containing hydrogens, become water
The breaking of the bonds in methane, releases energy, heat and light
Ignition Temperature

• The amount of heat required to “push” the combustion reaction over the energy barrier is known as the ignition temperature.

• Once the combustion starts, enough heat is created to keep the reaction going.

• For example: You need to use a match (extra heat) to light the methane gas on fire. But once that ignition occurs, the material keeps burning.
IGNITION DEVICES

• **Matches.** Juvenile arsonists and pyromaniacs seem to favor striking matches

• **Gasoline.** Gasoline and other accelerants are very popular with many different types of arsonists

• **Chemicals.** Various chemical combustions have been used to set fires
IGNITION DEVICES (cont'd)

• **Gas.** The combination of gas and the pilot light on the kitchen stoves of many residences is always a possibility

• **Electrical Systems.** Any wiring system, including doorbell and telephone circuits, can be used as a fire-setting tool

• **Mechanical Devices.** Alarm clocks were once a favored weapon of arsonists. Cell phones are often used now.
Heat Transfer

The three mechanisms of heat transfer are conduction, radiation, and convection.

- **Conduction** is the movement of heat through a solid object or two objects touching.

- **Radiation** is the transfer of heat energy by electromagnetic radiation. In open flames this is what you feel on the side of the flame.

- **Convection** is the transfer of heat energy by the movement of molecules within a liquid or gas. In open flames this moves heat UP!
Fire Investigation Terms

- **Fire** - Produced when a substance undergoes rapid oxidation involving heat and light.
- **Fire Triangle** – Shows the three elements needed to produce and sustain a fire.
- **Flash Point** – The lowest temperature to which a substance must be heated in order for the substance to give off vapors which will burn when exposed to a flame or ignition source.
- **Point of Origin** – The location where the fire started.
- **Burn patterns** – Noticeable patterns created by the fire as it burns.
- **Accelerants** – Substances, such as gasoline, paint thinner, and alcohol, that accelerate the burning process.
- **Arson** – A fire started deliberately.
Solid Fuels

• Wood for example, cannot generate a vapor easily.

• It has to *first* be exposed to enough heat to breakdown some of the solid organic material into gases that are combustible.

• The chemical breakdown of solids into gas is known as **pyrolysis**.
Glowing Combustion

- If there is not enough heat to pyrolyze the solid fuel to produce flames, the solid fuel does not combust through-and-through, only on the surface.

- This produces a glowing effect – Examples: embers, burning cigarette, etc.
Spontaneous Combustion

- Natural heat-producing process occurring in a poorly ventilated area.
- Very rare, but when it does occur, it is in fuel cans or other ignitable substances.
- Almost never in human bodies (more of a belief, right now).
Fire Investigation

- Locate origin of fire
  - Fire moves upwards, so source will be at the lowest point
  - The area will show the most intense burn damage

- Isolate and protect origin site for further investigations

- Look for signs of tampering or use of accelerants – Use hydrocarbon vapor detecting apparatus or “Sniffers”

- Dogs can be used as well to sniff-out accelerant residues
Fire Clues

• V-Patterns - Fire burns up, in a V-shaped pattern, so a fire that starts at an outlet against a wall leaves a char pattern that points to the origin.
  
  – A very narrow V-shape might indicate a fire that was hotter than normal, such as one helped along by an accelerant.
  
  – A wide V-shape might indicate a fire that was slow burning.
  
  – A U-shape could indicate that there was a "pool of origin" rather than a point of origin, such as might be caused by, say, a puddle of gasoline.
Pour patterns often are characterized by intermixed light, medium, and heavy burning in a puddle shape that corresponds to the shape of the original pool of the ignitable liquid.
**Heat Shadows** - Occur when heavy furniture shields part of a wall; can help determine the origin point.

**Glass** - Glass fragments, windows, and light bulbs can provide clues to a fire.
- Light bulbs tend to melt toward the heat source, so the "direction of melt" can indicate the direction of the fire.
- The shattered or cracked glass of the windows can provide indications as to how a fire burned. A dark soot layer on the glass could indicate a slow, smoldering fire.
- Clear glass with an abnormal pattern of cracking could imply a very hot fire, possibly due to an accelerant.

**Chimney Effect** - Since fire burns upwards, there can be a "chimney effect" where the fire ignites at a point, the superheated gases rise upward and form a fireball, which continues straight up to burn a hole in the ceiling. If the roof is not entirely burnt, and the fire investigator finds such a hole, the origin of the fire could be directly underneath.

**Color of smoke** – Determine what type material was burning

**Color of flames** – Indicates at what temperature the fire was burning.
Investigation of Fire Scenes

Search for Causes:

- An important objective of the scene investigation is to determine the cause of the fire.
- Determining the cause of a fire is basically a reconstruction.
- Accidental causes include electrical short circuit, cooking accidents, and careless smoking.
Fire Clues

- **Point of Origin** – Burn patterns and other damage can help determine the point of origin, or the location where the fire started.

- **Char Patterns** – Created by very hot fires that burn very quickly and move fast along its path, so that there can be sharp lines between what is burned and what isn't.
  - A char pattern on a door would help an investigator determine which side of the door the fire was on.
  - A char pattern on the floor would help investigators determine the use of an accelerant and its path.
One effective way to determine fire causes is to determine the point of origin.

The investigator should check for the level of origin by examining:
- the bottoms of shelves, ledges, moldings
- furniture and all sides of the legs, arms, and framework of reconstructed furniture

The floor and lower areas of the room produce the most clues to the cause for the fire, because they are living area.
WHERE AND HOW DID THE FIRE START?

Two Factors Needed to Cause Fire

During the investigation, it should be borne in mind that a fire always has two causes: a source of heat and material ignited. Video

Accidental Fires

Once the point of origin has been discovered the next step is to determine how the fire started. Even though arson may be suspected, the investigator must first investigate and rule out all possible accidental or natural causes. Web Link
Accident or Arson?

- **Accidental Nature**
  - Heating System
  - Electrical appliances
  - Lightning
  - Children playing with matches
  - Smoking

- **Non-Accident**
  - Odors – Gas, kerosene, or other accelerants
  - Furnishing – Removal of personal objects and valuables
  - Clothing – Check debris for buttons, zippers, etc
  - Locked windows, blocked doors
  - Two or more points of origin
  - Look for inverted v-patterns (can be a sign that an accelerant was used)
  - Floors charred – Can indicate use of an accelerant
  - Trailers that lead the fire from one place to another

Image: Havana Rural Fire Department
COMMON CAUSES FOR ACCIDENTAL OR NATURAL FIRES

- The electric system
- Electrical appliance and equipment
- Gas
- Heating units
- Sunlight
- Matches
- Smoking
BURN INDICATORS

• Burn indicators are the effects of heat or partial burning that indicate a fire’s rate of development, points of origin, temperature, duration, and time of occurrence and the presence of flammable liquids. Interpretation of burn indicators is the principle means for determining the cause of a fire, especially arson.
EXAMPLES OF BURN INDICATORS

- Alligatoring
- Depth of char
- Breaking of glass
- Collapsed furniture springs
- Spalling
- Distorted light bulbs
- Temperature determination
Alligatoring and Spalling

- **Spalling** is the heat-induced crumbling of concrete, as the moisture in concrete heats up to steam levels and expands & explodes.

- **Alligatoring** is the appearance of blisters on the surface of burned wood, points to a fire’s origin.
LINE OF DEMARCATION IN A WOOD SECTION

• Depth of char
  – is used for evaluating fire spread
  – is used to estimate the duration of a fire
  – the rate of charring of wood varies widely

(Source: Factory Mutual Engineering Corporation, Norwood, Massachusetts. Reprinted with permission.)
Fire Debris

• Fire debris is submitted to laboratories for analysis by the fire marshal, crime scene investigators, forensic scientists, and insurance investigators.

• Investigators determine the best locations at the scene to collect samples, based on suspicious details.
Collecting Fire Debris

• Once an appropriate area has been identified for sampling, samples are collected for later analysis.

• Samples are collected in a tightly sealed container (glass jar or metal can).
Collecting Fire Debris

- Sample should fill 2/3 of the container.
- Top 1/3 of container is used for sampling headspace.
Passive Headspace Sampling

• In passive headspace sampling the container is heated to volatilize any ignitable liquids remaining in the sample.

• Activated charcoal is suspended in the headspace to absorb the volatilized liquid.

• The charcoal is then removed from the sample container and the liquid is removed from it by solvent extraction.
Headspace vapor

- The debris is placed in an airtight container and the container is heated.

- If the debris contains any volatiles or hydrocarbons (from accelerants), the vapors will rise to the top of the container.

- This risen vapor or headspace is removed with a syringe and injected into a GC.
Fire Debris Sampling

- Sample areas likely to contain traces of ignitable liquid:
  - insulated areas within the pattern
  - porous substrates in contact with the pattern
    - cloth
    - paper products
    - wood
  - seams or cracks
  - lightly burned edges of the pattern
  - lowest regions of burned area
Presumptive Testing

• GC-MS analysis can be time consuming and expensive.

• A presumptive test can be performed quickly in the field to indicate the presence of an ignitable liquid.

• Colorimetric gas detection tubes are used for this purpose.
Presumptive Testing

• Colorimetric gas detection tubes are filled with a compound designed to react with a specific compound of interest (gasoline, diesel fuel, etc.)

• To perform the test, both ends of the glass tube are broken off.

• Air from the scene is drawn through the tube with a pump.
Presumptive Testing

• In the presence of specific vapors, the compound within the tube will change color.

• The concentration of the compound may be estimated but this technique is not very accurate.
Presumptive Testing

• If the presumptive test is positive, then samples will be collected for GC-MS analysis.

• In some labs, this is used for preliminary screening of samples.
Solvent Extraction

• **Carbon disulfide** is frequently used in solvent extraction because it produces excellent desorption of most accelerants.

• It also produces a low detector response when analyzed by a gas chromatograph using a flame ionization detector.

• Unfortunately, carbon disulfide is a health hazard because it can cause nervous system damage.
Gas Chromatography, Mass Spectroscopy

• Analysis of materials collected at a suspected arson site is done using GC-MS.
• The chromatogram is compared to known petroleum standards.
• One such standard is called the “gasoline standard”
• But first, the debris has to be prepped.
• After the solvent is extracted it is analyzed with a gas chromatograph – mass spectrometer (GC-MS).

• The liquid is injected into the GC and carried through the instrument by an inert carrier gas (called the mobile phase).

• The liquid then permeates a column (long thin tubing) which binds the liquid to a polymer coating on the inside (called the stationary phase). This separates the liquid components by volatility.
• More volatile components move faster through the column.

• The components come off of the column separately during the elution step and enter the mass spectrometer.

• The mass spectrometer separates each component based upon the mass-to-charge ratio of their particles.

• The mass spectrum of the sample is then compared to a library of known compounds to identify the compound in the sample.
This is a Gasoline Standard Gas Chromatograph

This is a Gas Chromatograph from suspicious fire debris
Introduction to Explosives

- Most bombing incidents involve homemade explosive devices
- There are a great many types of explosives and explosive devices
- Lab must determine type of explosives and, if possible, reconstruct the explosive device
Explosives

- An explosive is a material that undergoes rapid exothermic oxidation reaction (combustion), producing immense quantities of gas.

- The build-up of gas pressure in a confined space is the actual “Explosion”. The damage is caused by rapidly escaping gases and confinement.

- The ignition of an explosive is called Detonation
Explosives

• Combustion (or decomposition) of explosives occurs so rapidly, that there isn’t enough time for the oxygen in the surrounding atmosphere to combine with the fuel.

• Therefore, many explosives must have their own source of oxygen – or oxidizing agents
Types of Explosives

• Low explosives
  • Combustion is relatively slow - 1000 meters per second
  • The speed of explosion is called the **speed of deflagration**
  • Crucial element is physical mixture of oxygen and fuel
  • Examples are black and smokeless powders
    • Black powder is mixture of potassium nitrate, charcoal and sulphur
    • Smokeless powder is nitrocellulose and perhaps nitro-glycerine
Shock Wave

• It is this sudden buildup of gas pressure that constitutes the nature of an explosion.
• The speed at which explosives decompose permits their classification as high or low explosives.
Black Powder (Low Explosive)

• Black powder contains:
  – 75% Potassium Nitrate (KNO$_3$)
  – 15% Charcoal (C)
  – 10% Sulfur (S)

The KNO$_3$ is the oxidizing agent.
  – When heat is applied to the powder, the oxygen from KNO$_3$ is liberated.
  – It combines with the carbon (fuel) and sulfur (for stable combustion).
  – The combustion of charcoal and sulfur produces 2 gases – CO$_2$ and N$_2$.
  – The buildup of gases in the cartridge, propels the bullet forward in bullet cartridges.
Smokeless Powder

- Used as propellant in firearms and other weapons.

- There are 3 types:
  - Single-base – contains nitrocellulose
  - Double-base – contains nitrocellulose and nitroglycerine
  - Triple-base – contains nitrocellulose, nitroglycerine and nitroguanidine

- Produce very little smoke when burned, unlike black powder.

- The reason that they are smokeless is that the combustion products are mainly gaseous, compared to around 55% solid products for black powder (potassium carbonate, potassium sulfate residues).
Types of Explosives II

- High explosives – they detonate (explode) rather than deflagrate (burn)
  - Combustion can range from 1000 mps to 10,000 mps
  - Oxygen usually contained in fuel molecule
    - Two types
      - **Initiating (or primary explosives)**
        - Sensitive, will detonate readily when subjected to heat or shock.
        - Used to detonate other explosives in explosive train (a triggering sequence that ends up in a detonation of explosives)
        - Includes Nitroglycerine
      - **Noninitiating (Secondary or base explosives)**
        - relatively insensitive, to heat, friction or shock, need special detonators such as low explosives.
        - Includes *Dynamite*, *TNT* or *PETN*
        - *ANFOs or* (Ammonium Nitrate Fuel Oil) (These are actually tertiary)
Nitroglycerin (Initiating or primary high explosive)

- In its pure form, it is a contact explosive (physical shock can cause it to explode) and degrades over time to even more unstable forms.
- This makes it highly dangerous to transport or use.
- In this undiluted form, it is one of the most powerful high explosives, comparable to the newer military explosives.
- Believe it or not, it is also used as heart medication – it is a vasodilator.
How does it work?

- The explosive power of nitroglycerin is derived from detonation: energy from the initial decomposition causes a pressure gradient that detonates the surrounding fuel.
Ingredients of Dynamite

• Original dynamite consisted of three parts nitroglycerin, one part diatomaceous earth and a small admixture of sodium carbonate.

• This mixture was formed into short sticks and wrapped in paper, with a “fuse” or a cord with a core of powder, that will transport the fire to the cylinder.

• Today, ammonium nitrate based dynamite is made and the fuse has been replaced with electronic detonators called blasting caps.
Electric Blasting Caps (Detonators)
High Explosives Acronyms

• **TNT** = *Trinitro Toluene*

• **PETN** = *PentaErythritol TetraNitrate*, also known as *pentrite*. PETN is also used as a vasodilator, similar to nitroglycerin. Used as medicine for heart diseases.

• **RDX** = *Cyclotrimethylenetrinitramine*

• **HMX** or **Octagon** = *Cyclotetramethylene-tetranitramine* (related to RDX)
PETN

• PETN and TNT used together to make small-caliber projectiles
• Commercially used (mining, demolition, etc.)
• PETN is used in detonation cords or Primacords. These cords are used to create a series of explosions.
PETN primacords attached to demolition explosives.
Ammonium Nitrate Based Explosives

- They are:
  - Water gels
  - Emulsions
  - ANFOs (Ammonium Nitrate Fuel Oil)
Water Gels

- Consistency of gel or toothpaste
- Water-resistant, so good for explosions in or under bodies of water and wet conditions
- Contains:
  - Oxidizers: a mixture of ammonium nitrate and sodium nitrate, gelled together with a carbohydrate like guar gum (food thickener and emulsifier)
  - The fuel: is usually a combustible substance such as aluminum
Emulsion Explosives

• Have 2 distinct phases
  – An oil phase
  – A water phase

• These emulsions contain
  – An ammonium nitrate solution (oxidizer) surrounded by
  – A hydrocarbon (fuel)
  – An emulsifier such as glass, resin or ceramic microspheres to make the explosive less sensitive
ANFO

- Ammonium nitrate (oxidizer) or urea nitrate, soaked in a highly combustible hydrocarbon (fuel) – usually a fuel oil.
- Easy to make, safe to handle
- Ammonium nitrate is found in fertilizers, so ANFOs are a favorite type of homemade bombs.
Homemade Explosives

- Molotov Cocktails
- TATP (Triacetone triperoxide) – a favorite amongst Middle Eastern Terrorists.
Molotov cocktail

- In its simplest form, a Molotov cocktail is a glass bottle containing petrol fuel usually with a source of ignition such as a burning, fuel soaked, rag wick held in place by the bottle's stopper.

- In action the fuse is lit and the bottle hurled at a target such as a vehicle or fortification. When the bottle smashes on impact, the ensuing cloud of petrol droplets and vapor is ignited, causing an immediate fireball followed by a raging fire as the remainder of the fuel is consumed.

- Other flammable liquids such as wood alcohol and turpentine have been used in place of petrol.

- Thickening agents such as motor oil have been added to the fuel, analogously to the use of napalm, to help the burning liquid adhere to the target and create clouds of thick choking smoke.
The Role of Forensic Science in the Investigation of Major Acts of Terrorism
The World Trade Center Bombing
The Scenario

- Urea nitrate bomb put into truck and driven into underground WTC garage and parked at 4th level down
- Subsequent explosion did extensive damage to several levels of the garage and less damage to other levels
- Although goal was to topple WTC, little structural damage was done
- Some loss of life
Goals of Investigation

- Identify victims
- Identify explosive
- Recover bomb and timing device
- Determine method of delivery
Evidence Sought

- Investigators had to remove large quantities of concrete, steel and cars to get to bomb seat
- Bomb seat contained most of the important evidence
- Bomb parts; timer, casing, etc.
- Explosive residue
- Parts of truck that contained explosive
Areas of Forensic Science

- Explosives
- Engineering
- Questioned documents
- Fingerprints
- Pathology
- DNA
The Murrah Building, Oklahoma City
The Scenario

• ANFO explosive and timer packed into a rented truck, which was then parked outside Murrah building
• Explosive confined to closed space such as truck is much more powerful
• Resulting explosion caused severe damage to building and loss of more than 100 lives
Goals of Investigation

- Identify victims
- Identify explosive
- Find timer and bomb parts
- Determine method of delivery
Evidence Sought

- Easier to find than in WTC because bomb seat outside building
- Explosive residues
- Bomb parts
- Bodies and body parts; cadaver dogs, flies
- Personal effects; helps in identification of human remains
Areas of Forensic Science

- Anthropology
- DNA and serology
- Pathology
- Entomology
- Explosives
- Trace evidence
- Engineering
- Questioned documents
- Fingerprints
WTC Destruction
The Scenario

- Large airplanes, loaded with fuel, crash into WTC buildings
- Raging fires ignite everything in building above crash sites.
- Metal supports melt from heat
- Building collapses due to inability to support its own weight after structural damage
- Thousands of people killed
Goals of Investigation

• Cause known, no need to determine how destruction occurred
• Recover and identify bodies, parts of bodies and charred remains
• Recover personal effects that might help identify victims or perpetrators
• Evidence that might determine how hijackings occurred.
Evidence Sought

- Bodies and body parts; cadaver dogs, flies
- Charred remains
- Personal effects
- Trace evidence such as charred papers
- Weapons such as knives
- Constraining devices such as wire
Areas of Forensic Science

- Anthropology
- DNA and serology
- Odontology
- Pathology
- Entomology
- Trace evidence
- Questioned documents
- Fingerprints
- Tools and toolmarks