EE-527: MicroFabrication

Flammability of Compounds

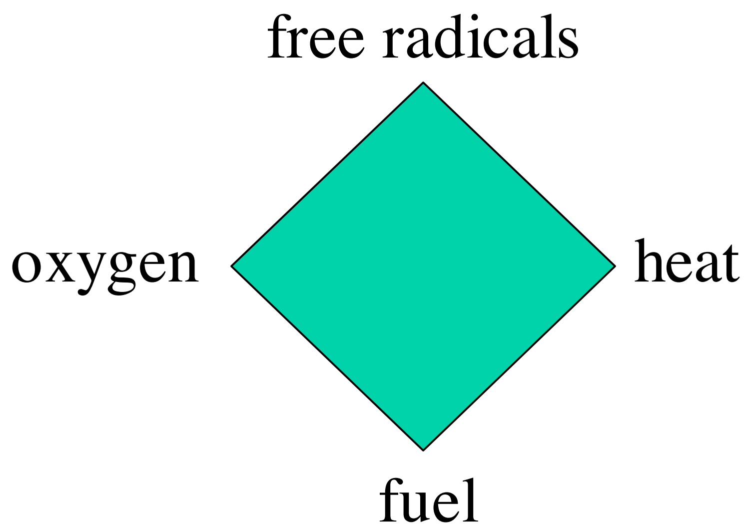
Flammability Range

- Upper Explosive Limit (UEL)
- Lower Explosive Limit (LEL)
  - volume percent of substance in air that will sustain combustion
- Flammable Range: UEL - LEL, in percent
  - Example: xylene
    - UEL = 7.0% above this concentration, mixture is too rich to burn
    - LEL = 1.1% below this concentration, mixture is too lean to burn

Flammability Points

- Flash Point: minimum temperature where a spark or flame will cause an instantaneous flash in the vapor space above a liquid
- Fire Point: minimum temperature of a liquid to support continuous combustion after ignition via a spark or flame
- Autoignition Point: minimum temperature at which a liquid spontaneously ignites without the introduction of a spark or flame
  - Example: xylene
    - autoignition point (AP) = 496 C
    - boiling point (BP) = 138 C
    - fire point = 44 C [usually about 20 C higher than FP]
    - flash point (FP) = 25 C

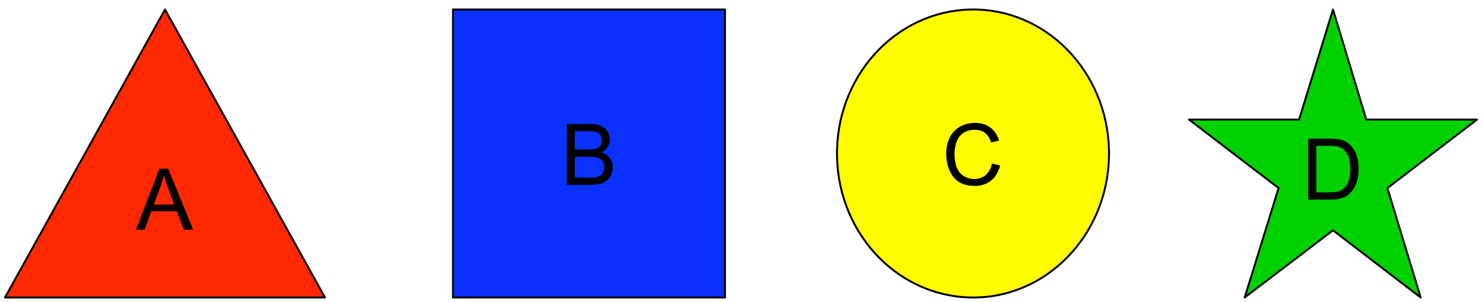
Fire Tetrahedron



BLEVE: boiling liquid expanding vapor explosion
---gas cylinders with liquefied contents

Fire Classifications

- Class A - common combustibles that leave coals or embers
- Class B - flammable liquids and gases
- Class C - fires in energized electrical equipment
- Class D - combustible metals: Al, Mg, Li, Na, K, Ti, Zr



Fire Extinguishants

- Water - Class A fires only
- Carbon Dioxide - Class A or B fires only
  - 2-25 lb. 830 psi cylinders of liquefied CO_2
  - soda-acid extinguishers (sodium bicarbonate)
    - spray: $2NaHCO_3 + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O + 2CO_2$
    - foam: $6NaHCO_3 + Al_2(SO_4)_3 \rightarrow 3Na_2SO_4 + 2Al(OH)_3 + 6CO_2$
- Carbon Tetrachloride - Class A-B-C
  - no longer used; can produce phosgene gas; CCl_4 is carcinogenic
    - $CCl_4 + H_2O \rightarrow COCl_2 + 2HCl$
- Halogenated Hydrocarbons - Class A-B-C
- Dry Chemical Extinguishers - Class A-B-C

Halogen Fire Extinguishants

- Halogenated Hydrocarbons (Halogens)
  - Halon numbering system:
    - 1st digit: no. of carbon atoms
    - 2nd digit: no. of fluorine atoms
    - 3rd digit: no. of chlorine atoms
    - 4th digit: no. of bromine atoms
    - 5th digit: no. of iodine atoms
  - Examples:
    - Halon 104 = CCl_4, carbon tetrachloride
    - Halon 1011 = CH_2ClBr, bromochloromethane
    - Halon 1301 = CF_3Br, bromotrifluoromethane
    - Halon 1211 = CF_2ClBr, bromochlorodifluoromethane

Halogen Fire Extinguishants

- Halons 1301 and 1211 are most commonly used
  - gases at room temperature
  - heavier than air
  - produce Br atoms which scavenge free radicals
  - toxicity is controversial, but short term exposure appears safe
- Halons are "clean" extinguishants
  - do not leave any solid or liquid by-products
  - only alternative for vaults, museums, libraries, aircraft, and sensitive electronics
- Halons are greenhouse gases- displace atmospheric ozone
  - many halons are no longer manufactured; existing supply is all there is...

Dry Chemical Fire Extinguishants

- Granular sodium chloride: NaCl, melts at 801 C
- Graphite: C, usually used for class D fires
- Sodium bicarbonate: $NaHCO_3$
- Potassium bicarbonate: $KHCO_3$, "purple K"
- ABC: ammonium dihydrogen phosphate, $NH_4H_2PO_4$
  - $2NH_4H_2PO_4 \rightarrow P_2O_5 + 2NH_3 + H_2O$
  - endothermic reaction absorbs heat
  - NH_3 scavenges OH radicals
  - most commonly used in household fire extinguishers
  - H_3PO_4 is produced which is is corrosive to metals

Principles of Fire Extinguishants

- Fuel must pyrolize into free radicals before combustion will occur:
  - H_2 and O_2 do not react until a spark is introduced to ignite them
  - HCl as a gas will not combust until exposed to sunlight
  - CH_4 will not combust until ignited
- Halon extinguishants are broken into free radicals with combine with and eliminate the free radicals of the fuel.
- CO_2 fire extinguishants are most effective in laboratory situations when used properly
- Fire sprinklers are not intended to extinguish fires!!!
  - Their purpose is lay down a fog and suppress the smoke so that people can escape from a burning room