Hazmat Chemistry Quick Reference Card

(Second Edition)

Disclaimer: This document provides basic information designed to help you manage the initial response phase of a hazmat incident. This is not a substitute for developing preplans for your community or for checking reference sources at an incident. Remember that there are exceptions to every rule, that various factors may change the risks, and that if more than one product is involved, it may be difficult to accurately predict the hazards.

Phone: (800) 477-7151 or (408) 866-2081 • Fax: (408) 866-6108 • Web Site: www.firebelleproductions.com

Important Limitations of This Quick Reference Card

This card provides a condensed summary of the chemistry information taught in many hazmat technician classes throughout the country. It is designed as a study aid to help you remember the generalizations you may have learned in class. It can also be used at a hazmat incident to give you some quick information prior to checking more specific reference sources. However, do not rely solely on this quick reference card. It is a very limited tool. It must not be used in place of a proper risk assessment and hazard analysis.

The hazards identified herein are listed because either (1) they are true for the majority of chemicals within the given category or (2) they represent the hazards associated with some of the worst chemicals within the group.

At one extreme, it can be dangerous to assume that these generalizations apply to all chemicals in a given category. For example, most aromatic hydrocarbons are stable. However, styrene (C_8H_8) contains an unstable double bond between carbon atoms outside the resonant structure. That makes it subject to polymerization.

Conversely, you can easily blow an incident out of proportion by failing to recognize that not all products in a given category are equally hazardous. For example, sodium chloride (NaCl) is a binary salt, but if you failed to recognize that it is ordinary table salt, you might wrongly assume that it was very dangerous. There are many other such examples, most of which have names you might not recognize.

Chemicals don't always fit neatly into specific categories. For example, while salts are generally described as containing a metal element bonded to a nonmetal element, some salts contain no metal at all. The ammonium ion (NH_4) behaves like a metal element in the way that it bonds with nonmetal elements. Thus a handful of salts, such as ammonium nitrate (NH_4NO_3), contain no metal.

This quick reference card won't identify the multitude of exceptions that exist. It won't help you recognize when chemicals have multiple names. Nor does it show how hazards or risks can change based on form (solid, liquid, gas), concentration, external factors (such as temperature and humidity), or the presence of other chemicals. However, if you understand the limitations and use it accordingly, this quick reference card can be a valuable tool.

For More Information

Firebelle Productions offers two other products that cover hazmat chemistry in greater depth:

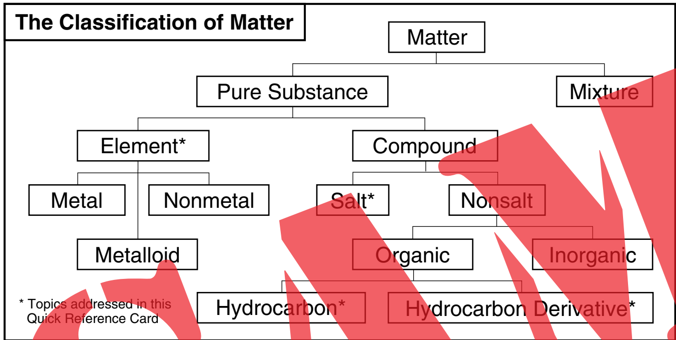
- Hazmat Chemistry Study Guide
- The Hazmat Chemistry Mini Review

Please visit our web site to get more information and see samples of these books.

www.firebelleproductions.com

The Classification of Matter

Matter is often classified as illustrated below. Although most hazardous materials we encounter are mixtures, hazmat chemistry classes usually focus on pure substances because it is far easier to make generalizations about them.



A **pure substance** is a homogenous one—one in which every sample of the same substance is identical in composition. A **mixture** consists of two or more elements or compounds that are physically mixed but not chemically bonded. Consequently, mixtures can vary from one sample to another.

A pure substance can be either a single **element** or a **compound** (molecule) comprised of two or more elements that are chemically bonded.

Elements are divided into metals, nonmetals, and metalloids (or semimetals). **Metals** generally have a lustrous (shiny) appearance and are good conductors of heat and electricity. They are malleable (can be hammered into sheets) and ductile (can be drawn into wires). **Nonmetals** generally are not lustrous, are not good conductors, and are neither malleable nor ductile. **Metalloids** tend to have properties of each. Metalloids are the elements immediately surrounding the dividing line between metals and nonmetals on the periodic table of elements.

Compounds are further divided into salts and nonsalts. *Most* **salt compounds** are comprised of a metal element bonded to one or more nonmetal elements. **Nonsalt compounds** are comprised solely of nonmetal elements.

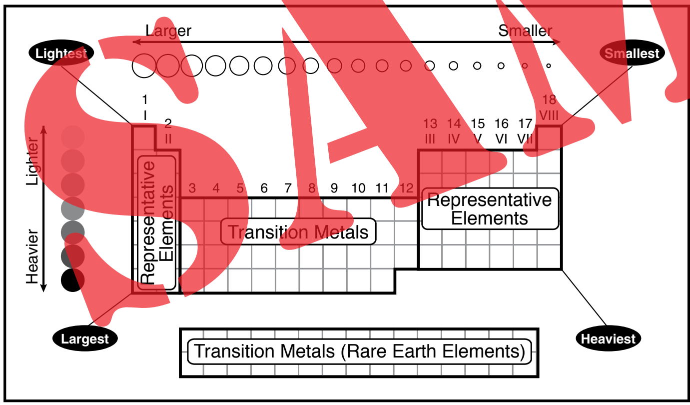
Nonsalt compounds are either organic or inorganic. **Organic compounds** are derived from living (or once living) organisms. Almost all of them contain carbon-hydrogen bonds. **Inorganic compounds** are *not* derived from living (or once living) organisms and do *not* contain carbon-hydrogen bonds. (Most known compounds are organic and contain carbon, not because carbon is more abundant than other elements, but because carbon is so versatile in the way it bonds with other elements.)

Organic compounds are either hydrocarbons or hydrocarbon derivatives. **Hydrocarbons** contain only carbon and hydrogen atoms. *Most* **hydrocarbon derivatives** contain carbon and hydrogen, along with other nonmetal elements.

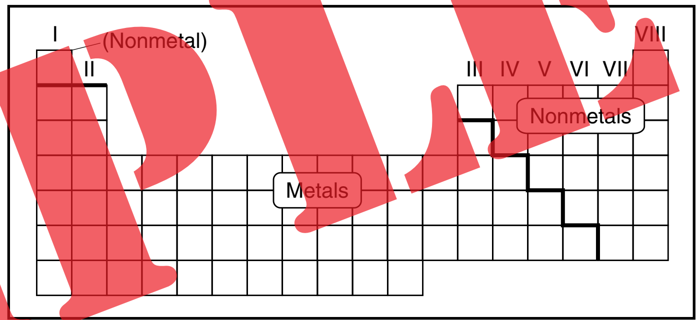
Elements on the Periodic Table

Elements on the periodic table are arranged according to their atomic structure. The complete periodic table is printed on the back panel of this reference card, where you can view it easily anytime. Here we'll look at how an element's position on the periodic table provides some basic information about its characteristics.

The elements become heavier as you look lower on the table, which is significant with respect to vapor density, specific gravity, and related properties. The **representative elements** on either side of the table are the most important to the study of hazardous materials because, in general, they're more chemically active than the **transition metals** or **rare earth elements**.



Metals are located on the left side of the dividing line on the periodic table; **nonmetals**, on the right. (Hydrogen, in the upper left-hand corner above the thick dividing line, is also a nonmetal.)



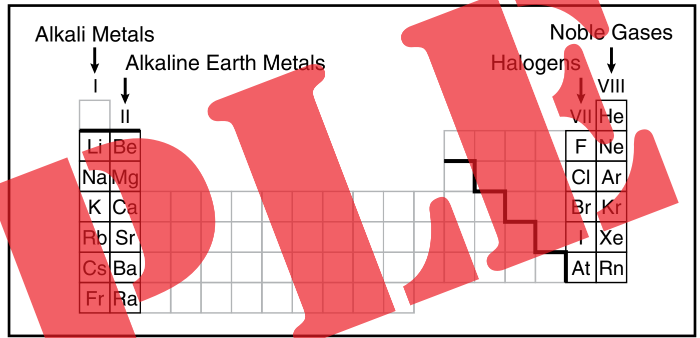
The Roman numerals above each column in the representative elements indicates the number of outer shell electrons for each element in that column. The number of electrons in the outermost shell is the characteristic that most influences chemical bonding (reactivity).

Most elements exist as solids in their natural states. The elements that exist as gases are hydrogen, nitrogen, oxygen, chlorine, fluorine, and the noble gases (Group VIII). Periodic tables generally identify bromine, cesium, francium, and mercury as liquids. Some elements are borderline and may exist in different forms, depending on ambient temperature.

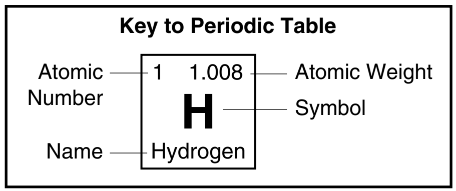
Elements on the Periodic Table (continued)

Elements are grouped vertically in families based on their chemical behaviors. All members of the same family have similar chemical characteristics because each has the same number of electrons in the outermost shell. However, each will also have its own unique properties. Four families are significant from a hazmat standpoint. They are identified below, along with the common characteristics for the group:

- **Group I - Alkali Metals**
  (lithium, sodium, potassium, rubidium, cesium, francium)
  These elements are flammable and highly reactive. When in contact with water, they produce flammable hydrogen gas, a strong caustic runoff, and excessive heat.
- **Group II - Alkaline Earth Metals**
  (beryllium, magnesium, calcium, strontium, barium, radium)
  These elements are flammable and water-reactive, although less so than the elements in Group I.
- **Group VII - Halogens**
  (fluorine, chlorine, bromine, iodine, astatine)
  These elements are highly reactive, toxic, and powerful oxidizers. They are nonflammable.
- **Group VIII - Noble (Inert) Gases**
  (helium, neon, argon, krypton, xenon, radon)
  These gases are inert, nonreactive simple asphyxiants that are often stored and transported as cryogenic liquids.



The periodic table on the back panel of this reference card shows each element by name, symbol, and atomic number. (The atomic weight was rounded to three decimal points where the number was less than 100. Atomic weights over 100 were rounded to two decimal points.)



Chemical Bonding

The noble gases (Group VIII) have filled outer shells. Thus they have no reason to react (bond) with other elements. All the other elements have outer shells that aren't filled to maximum capacity, so they must bond with other atoms to create a filled outer shell. Hydrogen, with only one shell, needs one more electron for a total of two. The rest need eight electrons in their outermost shells. To determine how many electrons any representative element needs, look at the Roman numeral above its column on the periodic table. Subtract that number (the number of electrons on the outermost shell) from eight (the maximum capacity the outermost shell can hold).

Ionic bonds are formed by the *transfer* of electrons from a metal element to a nonmetal element. When the metal element donates electrons to the nonmetal element, it leaves the metal element with a net positive charge (protons outnumber electrons). Conversely, when the nonmetal element accepts electrons from the metal element, it ends up with a net negative charge (electrons outnumber protons). A charged atom is called an *ion*.

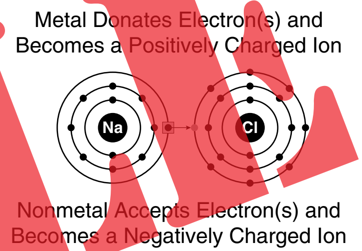
Oppositely charged ions attract each other, forming a strong bond that holds them together. The atoms cannot stray far apart because ions (charged atoms) cannot exist by themselves. The union of a metal element and one or more nonmetal elements creates a *salt compound*.

The Roman numerals above each column of representative elements on the periodic table also reflect the electrical charge associated with each element in an ionic bond. Metal ions will have a positive charge equal to the number of electrons the element can donate (e.g., sodium is 1^+). Nonmetal ions will have a negative charge equal to the number of electrons the element can accept (e.g., chlorine is 1^-). Elements bond in ratios that result in a neutral charge (e.g., sodium chloride).

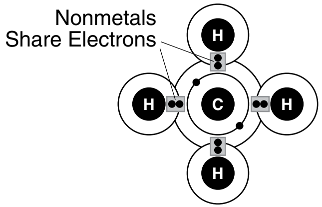
Covalent bonds are formed between two or more nonmetal elements that *share* electrons. Their outer shells overlap to the point that the electrons seem to belong to each atom at the same time. The union creates a *nonsalt compound* with weaker bonds than those seen in salt compounds.

When compounds (such as the aromatic hydrocarbons) contain **resonant bonds**, the electrons *rotate* rapidly between the carbon atoms.

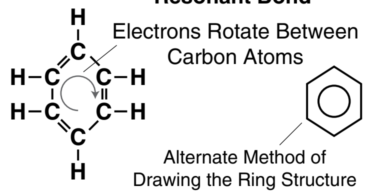
Ionic Bond (Salt Compound)



Covalent Bond (Nonsalt Compound)



Resonant Bond



Salts

The summary chart on the next page identifies six types of salts, their composition, how they're named, and the common hazards associated with the worst salts in each category. However, the following are characteristics common to *most* salts:

- Salts are solid.
- Salts are nonflammable.
- Most are water-soluble.
- Many are water-reactive and produce a flammable gas, a toxic gas, a caustic solution, and/or heat when in contact with water.
- Salts are electrolytes; they conduct electricity when in a molten state or when dissolved in water.
- Salts range from being mildly toxic to very toxic.
- Some cause severe environmental damage.

Elements in a salt compound bond in ratios that create a neutral electrical charge. With binary and oxide salts, the electrical charges are based on the number of electrons each element can donate or accept (as explained on the previous page).

The other salts contain *polyatomic (complex) ions* in which two or more atoms act as a single unit. Peroxide, cyanide, and hydroxide salts are simple. The charges for those ions are shown below.

- Peroxide (O_2): 2^-
- Cyanide (CN): 1^-
- Hydroxide (OH): 1^-

The polyatomic ions (oxyradicals) in oxysalts vary, as do their electrical charges. The following chart provides examples.

1- Charge		2- Charge		3- Charge	
Hypochlorite	ClO	Carbonate	CO_3	Phosphate	PO_4
Chlorite	ClO_2	Sulfite	SO_3	Arsenate	AsO_4
Chlorate *	ClO_3	Sulfate *	SO_4	Borate	BO_3
Perchlorate	ClO_4	Persulfate	S_2O_8		
Nitrite	NO_2	Chromate *	CrO_4		
Nitrate *	NO_3	Dichromate	Cr_2O_7		
Permanganate	MnO_4	Oxylate	C_2O_4		
Bicarbonate	HCO_3	* Asterisk indicates the base state (most stable state) of any similar oxyradicals listed above.			
Acetate	CH_3COO				
Bisulfate	HSO_4				
Bromate	BrO_3				

The normal (most stable) state of an oxyradical is its *base state*. So, for example, although chlorine and oxygen can combine to create hypochlorite (ClO), chlorite (ClO_2), chlorate (ClO_3), or perchlorate (ClO_4), the chlorate ion (ClO_3) is the most stable.

Most salt compounds are formed through an ionic bond between a metal element and one or more nonmetal elements. Only a few salts don't contain a metal element. Examples include ammonium chloride (NH_4Cl) and ammonium nitrate (NH_4NO_3). That's because the ammonium ion (NH_4^{1+}) behaves like a metal element in the way it forms an ionic bond with other nonmetals.

Summary of Salts

Salt	Composition	Naming	Example	Common Hazards of Some of the Worst Salts in Each Category *
Binary Salts	metal + nonmetal (not otherwise listed below)	metal + nonmetal root (ends in "ide")	CaC_2 calcium carbide	Toxic. May be water-reactive. Produce a flammable and/or toxic gas when mixed with water (e.g., calcium carbide produces flammable acetylene gas, and aluminum chloride produces nonflammable toxic hydrogen chloride gas). Metal sulfides (metal + sulfur) react with acids to produce toxic hydrogen sulfide gas.
Metal Cyanide	metal + cyanide	metal + "cyanide"	KCN potassium cyanide	Toxic. React with acids to produce toxic hydrogen cyanide gas.
Metal Oxide (Binary Oxide)	metal + oxygen	metal + "oxide"	Na_2O sodium oxide	Water-reactive. Produce heat and a caustic solution when mixed with water. Metal oxides containing alkali metals (Group I) are extremely destructive to skin and metal. (Despite the name, most metal oxides are not oxidizers and do not offgas when exposed to water.)
Metal Hydroxide	metal + hydroxide	metal + "hydroxide" (or alkali, caustic, base)	NaOH sodium hydroxide	Very caustic and destructive. Water-reactive. Will react with moisture on skin. Extremely destructive to human skin and other body tissues.
Metal Peroxide	metal (Group I or II) + peroxide	metal + "peroxide"	Na_2O_2 sodium peroxide	Very strong oxidizers; react with reducing agents (fuel). Water-reactive; can react violently. Produce a caustic solution, heat, and oxygen gas when mixed with water.
Metal Oxysalts	metal + element + oxygen	metal + oxyradical (ends in "ate" or "ite") (may include prefix "per" or "hypo")	$NaNO_3$ sodium nitrate	Very strong oxidizers; react with reducing agents (fuel). The ending "ate," particularly when preceded by the prefix "per" (e.g., perchlorate), signifies a high oxygen content. Oxysalts formed with halogens (e.g., chlorates or bromates) or nitrogen (nitrates) are the most hazardous.

* These generalizations apply primarily to salts containing alkali metals (Group I) and alkaline earth metals (Group II). In general, when salts contain transition metals, toxicity and environmental damage are common concerns; reactivity is usually less of a problem.

Hydrocarbons

Types of Hydrocarbons				
Type	**Ending**	**Bond**	**Formula**	**Common Characteristics**
Alkane	-ane	single	C_nH_{2n+2}	Stable.
Alkene	-ene	double (pi)	C_nH_{2n}	Less stable. Subject to polymerization.
Alkyne	-yne	triple	C_nH_{2n-2}	Highly unstable. Could explode.
Aromatic	-ene	resonant (ring)	C_nH_{2n-6} $(n \geq 6)$ (except styrene)	Stable (except styrene). Burn with sooty smoke. Toxic. Some are carcinogenic.

The Aromatics	
Name	**Formula**
Benzene	C_6H_6
Toluene	C_7H_8
Xylene	C_8H_{10}
Styrene	C_8H_8
Cumene	C_9H_{12}

Hydrocarbons can often be identified by name and formula. Most use specific prefixes to indicate the number of carbon atoms (lower right chart) and specific endings to identify the type of hydrocarbon (upper left chart). However, there are exceptions. For example, despite the *-ene* ending, acetylene (C_2H_2) is an alkyne. (Acetylene is also known as *ethyne*.) The aromatics (upper right chart) use different prefixes than do the other hydrocarbons. There are exceptions to some of the formulas too. For example, the formula for styrene (C_8H_8) does not follow the normal pattern for aromatics.

All hydrocarbons have common characteristics. All burn, though some are flammable and others are combustible. All have some degree of toxicity. All are floaters. Differences between the types of hydrocarbons are based primarily on the types of bonds between carbon atoms. Most alkanes (single bonds) and aromatics (resonant bonds) are relatively stable. Alkenes are less stable because of their double bonds; they are subject to polymerization. Alkynes are highly unstable because of their triple bonds.

Naming Hydrocarbons		
# Carbons	**Prefix(es)**	**Examples**
1	Meth- (Form-)	Methane, Formaldehyde
2	Eth- (Acet-) (Vinyl-)	Ethane, Acetylene, Vinyl Chloride
3	Prop- (Allyl-) (Acryl-)	Propane, Acrylonitrile
4	But-	Butane
5	Pent- (Amyl-)	Pentane, Amyl Acetate
6	Hex- (Ben-) (Phen-)	Hexane, Benzene, Phenol
7	Hept-	Heptane
8	Oct-	Octane
9	Non-	Nonane
10	Dec-	Decane

Hydrocarbon Radicals and Hydrocarbon Derivatives

Hydrocarbon derivatives are comprised of a *hydrocarbon radical* attached to a functional group. A **hydrocarbon radical** is a hydrocarbon compound in which one or more hydrogen atoms have been removed (upper right chart).

Hydrocarbon derivatives can be divided into groups based on the elements that comprise them (below). Part 1 hydrocarbon derivatives contain only carbon, hydrogen, and oxygen. The group is further divided by general structure. The *carbonyls* all have a double bond between the carbon and oxygen within their structures; the others do not. Part 2 hydrocarbon derivatives may contain carbon, hydrogen, or oxygen, but they also contain other elements.

The next two pages show the general structure and functional group of each hydrocarbon derivative. (The "R" in each structure stands for "hydrocarbon radical.") The functional group (e.g., OH or CO) remains consistent for each type of derivative. Changing the hydrocarbon radicals (e.g., CH_3 or C_2H_5) changes the compound (e.g., methyl alcohol or ethyl alcohol). While these compounds can have many names, the common names often include the words, prefixes, or suffixes shown on the next two pages. The hazards listed are common hazards for some of worst chemicals in each category.

Original Hydrocarbon		Hydrocarbon Radical	
Methane	CH_4	Methyl	$CH_3–$
		Form-	$H(C)\equiv$
Ethane	C_2H_6	Ethyl	$C_2H_5–$
		Acet-	$CH_3(C)\equiv$
Ethene	C_2H_4	Vinyl	$C_2H_3–$
Propane	C_3H_8	Propyl	$C_3H_7–$
Propene	C_3H_6	Allyl, Acryl	$C_2H_3(C)\equiv$
Butane	C_4H_{10}	Butyl	$C_4H_9–$
Benzene	C_6H_6	Phenyl	$C_6H_5–$

Part 1 Hydrocarbon Derivatives (contain only carbon, hydrogen, and oxygen)		Part 2 Hydrocarbon Derivatives (contain other elements)	
Carbonyls Ketones Aldehydes Organic Acids Esters	**Other** Alcohols Glycols Glycerols Ethers Organic Peroxides	**Contain Nitrogen** Nitros Amines Nitriles Carbamates Amides	**Contain Other** Thiols Alkyl Halides Organophosphates Hi-Tech Compounds

Key to Chemical Symbols on Next Page

As = Arsenic	N = Nitrogen
B = Boron	O = Oxygen
Be = Beryllium	P = Phosphorus
Br = Bromine	S = Sulfur
C = Carbon	Si = Silicon
Cl = Chlorine	Sn = Tin
F = Fluorine	Ti = Titanium
H = Hydrogen	X = Alkyl Halide
I = Iodine	

R = Hydrocarbon Radical

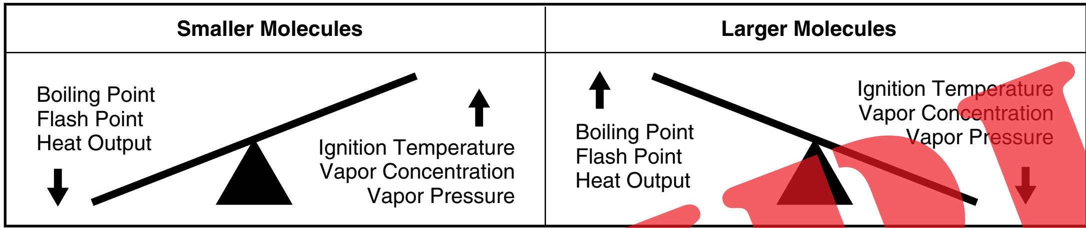
Summary of Hydrocarbon Derivatives (Part 1)

Type	Structure	Key to Formula	Common Names	Common Hazards and Other Behaviors
Ketones	O ‖ R-C-R	CO	ketone or -one	Toxic. Flammable. Burn with yellow flame and blue base. Can have narcotic effect on central nervous system. Water-soluble.
Aldehydes	O ‖ R-C-H	CHO	aldehyde or -al	Toxic. Flammable. Burn with yellow flame and blue base. May have wide flammable ranges. May eventually form unstable, explosive peroxides if exposed to air. Have choking, suffocating odors. Water-soluble.
Organic Acids	O ‖ R-C-O-H	COOH	-ic acid or -oic acid	Toxic. Corrosive. Combustible. Burn with blue and yellow flame and clean smoke. Water-soluble.
Esters	O ‖ R-C-O-R	COO or CO_2	-ate or acetate or acrylate	Flammable. Burn with yellow flame and blue base. May be toxic. May be subject to polymerization. Slightly soluble.
Alcohols	R-O-H	OH	alcohol or -ol	Generally toxic. Flammable or combustible. Burn with clean blue flame. May have wide flammable ranges. Water-soluble.
Glycols	R-$(O\text{-}H)_2$	$(OH)_2$	glycol	Toxic. Combustible. Highly soluble. Relatively nonvolatile.
Glycerols	R-$(O\text{-}H)_3$	$(OH)_3$	glycerol or glycerin	(The most common one, glycerin, is relatively harmless. Others should be considered toxic and combustible until proven otherwise.)
Ethers	R-O-R	O	ether or oxide	Very volatile. Flammable. Burn with invisible flames. May have flash points below 0˚F. May have wide flammable ranges. May be subject to polymerization. Limited shelf lives; form explosive organic peroxides if exposed to air. May have anesthetic properties. Insoluble (floaters).
Organic Peroxides	R-O-O-R	OO or O_2	peroxide or peroxy-	Explosive. Extremely unstable. Very sensitive to heat and friction (possibly to contamination also). Prone to runaway polymerization if heated. Flammable. Oxidizing. Highly reactive with other chemicals. May be toxic. May be corrosive. Insoluble (floaters).

Summary of Hydrocarbon Derivatives (Part 2)

Type	Structure	Key to Formula	Common Names	Common Hazards and Other Behaviors
Nitros	R-N(O)(O)	NO_2	nitro-	Explosive. Highly flammable. May be sensitive to shock or heat. Toxic. May be vasodilators. May or may not be water-soluble.
Amines	R-N(H(R))(H(R))	NH_2	amine	Toxic. Flammable. Burn with yellow flame. May be corrosive. Water-soluble. Have characteristically foul odors.
Nitriles (Cyanides)	R-C≡N	CN	nitrile or cyanide	Toxic. Flammable. Burn with yellow flame and blue base. May be subject to polymerization. Water-soluble.
Carbamates	((R)H)((R)H)N-C(=O)-O-R	NH_2COO	carba-	Toxic (commonly used in pesticides, often in place of the more toxic organophosphate compounds). Combustible.
Amides	R-C(=O)-N(H(R))(H(R))	$CONH_2$	-amide	Low to moderate toxicity. Flammable. May be subject to polymerization.
Thiols (Mercaptans)	R-S-H	SH	-thiol or mercaptan	Flammable. Toxic. Strong irritants. Have skunk-like odors.
Alkyl Halides (Halogenated Hydrocarbons)	R-X	F, Cl, Br, or I (a halogen versus a specific functional group)	-ide or -methane	Generally toxic. May be flammable. (Most do not burn. Some are used as extinguishing agents.) May break down at relatively low temperatures, giving off toxic decomposition products. Insoluble (sinkers).
Organo-phosphates	R-P(<	P (double bonded to sulfur or oxgen)	varies	Toxic (often used in insecticides). May be mixed with flammable liquids for dissemination.
Hi-Tech Compounds	May vary greatly	B, Si, As, Be, Sn, or Ti	varies	May be reactive, pyrophoric, and/or toxic. May be flammable. Should be treated as very dangerous until proven otherwise.

The Effect of Molecular Size on "Like" Compounds

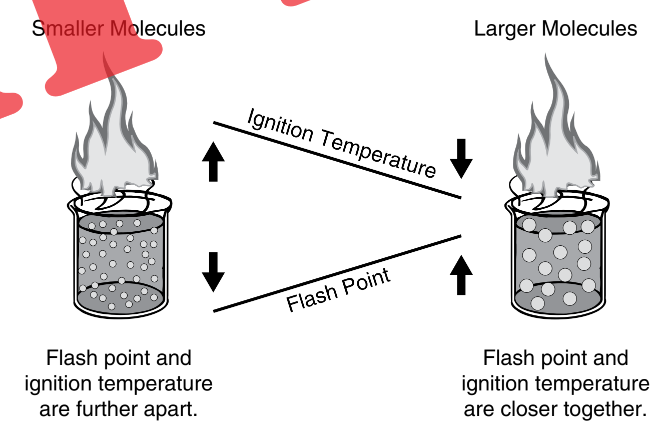


Molecular size has a direct effect on physical and chemical properties when comparing "like" compounds. Many of these properties are directly or indirectly proportional to one another (left).

Flash point and ignition temperature are inversely proportional. **Smaller molecules** produce *more* vapor. Therefore, flash point is *lower*—it takes *less heat* to raise the temperature of the liquid to the point where it produces sufficient vapor to form an ignitable mixture in air. However, it takes *more heat energy* to ignite those vapors because they contain less hydrogen (fuel) than do the vapors produced by a larger molecule. The flash point and ignition temperature are further apart in relation to each other (right).

Larger molecules, by comparison, produce *less* vapor. The flash point is *higher*—it takes *more heat* to raise the temperature of the liquid to the point where it produces sufficient vapor to form an ignitable mixture in air. However, when the ignitable mixture is produced, the vapors are closer to their ignition temperature. It takes *less heat energy* to cause ignition. The flash point and ignition temperature are closer together in relation to each other. Because these larger molecules contain more hydrogen (fuel), they will also generate more heat than smaller molecules do.

The Relation Between Flash Point and Ignition Temperature



Behavioral Clues

The following are some clues about chemicals and their hazards based on observable behaviors. However, these are broad generalizations only and should not be used as a substitute for proper field identification or reference checking.

Water Behavior

Liquids that float on water are hydrocarbons. Expect floaters to be flammable or combustible, with low to moderate toxicity. Using water for fire control or vapor suppression will usually spread floaters. If possible, use foam instead (e.g., AFFF). Consider letting hydrocarbon fires burn.

The most common liquids that sink in water are alkyl halides (halogenated hydrocarbons). Other possibilities include some of the newer solvents as well as organic materials containing phosphorus or sulfur. Expect sinkers to have moderate to high toxicity.

Fire Behavior

Black sooty smoke indicates incomplete combustion. Expect these products to have moderate to high toxicity. Any unusual flame or smoke colors (e.g., reddish brown smoke associated with nitrous oxides or bromine) should also be considered a sign of toxicity.

If a fire intensifies when you apply water, consider the product to be water-reactive.

Evaporation Rate (Volatility) / Vapor Pressure

Evaporation rate (volatility) is an indication of vapor pressure. The faster something evaporates, the higher its vapor pressure. In general, products with high vapor pressures are more hazardous than those with low vapor pressures because they produce more vapor and because that vapor will travel further from the source.

The normal frame of reference for evaporation rate is water. Water has a relatively low vapor pressure of 17.5 mmHg at 68˚F (20˚C). (Vapor pressure is temperature-dependent. The higher the temperature, the higher the vapor pressure.) If the vapor pressure of a product is equal to or greater than 760 mmHg at sea level, the product is a gas in its normal state. The closer the vapor pressure of a liquid is to 760 mmHg, the more vapors that liquid produces. (Note: 760 mmHg = 1 atm = 14.7 psi)

Since vapor pressure is closely related to other chemical and physical properties (see page 13), you can begin to predict other hazards based on the rate at which the product evaporates.

Viscosity

In general, the more viscous a liquid is, the lower the vapor pressure and the more difficult it will be to decon contaminated people or equipment. The less viscous the liquid, the higher the vapor pressure and the further the contaminant can spread.

Contaminant Concentration

Contaminant concentration is often cited in percent by volume in air (%) or in parts per million (ppm) or parts per billion (ppb). A concentration of 1% is equal to 10,000 parts per million (ppm) or 10,000,000 parts per billion (ppb).

The middle chart on this page shows the relation between contaminant concentration and oxygen concentration. At the point where OSHA defines an atmosphere as being oxygen-deficient (19.5%), there can be 70,000 ppm of a contaminant. Many substances are deadly at far lower concentrations.

The third chart shows **common toxic fire gases**. Carbon monoxide (CO) and carbon dioxide (CO_2) are usually produced in large quantities at most fires. (Carbon dioxide is not toxic, but it will displace oxygen in a confined area.) Other products of combustion vary, depending on the fuel.

% by volume	ppm	ppb
0.1%	1,0000	1,000,000
1%	10,000	10,000,000
10%	100,000	100,000,000

Contaminant Concentration	Oxygen Concentration
1% (10,000 ppm)	20.7%
2% (20,000 ppm)	20.5%
3% (30,000 ppm)	20.3%
4% (40,000 ppm)	20.1%
5% (50,000 ppm)	19.9%
6% (60,000 ppm)	19.7%
7% (70,000 ppm)	19.5%

Common Toxic Fire Gas	Source Materials
Carbon Monoxide (CO)	Materials containing carbon
Hydrogen Cyanide (HCN) Nitrogen Dioxide (NO_2) Nitrogen Oxide (NO)	Materials containing nitrogen (e.g., wool, silk, nylon, polyurethane)
Hydrogen Chloride (HCl)	Materials containing chlorine (e.g., PVC)
Acrolein (CH_2:CHCHO)	Cellulosic materials

Vapor density is the relative weight of a vapor or a gas compared with a like volume of air. (The molecular weight of air is 29.) All vapors and most gases are heavier than air. Only a handful of gases are lighter than air, and many of those are so close to the density of air that the difference is negligible to the emergency responder.

Gases Lighter Than Air	Vapor Density
Hydrogen	0.07
Helium	0.138
Natural Gas	0.550
Methane	0.553
Ammonia	0.589
Hydrogen Fluoride	0.690
Neon	0.696
Acetylene	0.898
Hydrogen Cyanide	0.932
Diborane	0.954
Nitrogen	0.966
Ethylene	0.967
Carbon Monoxide	0.967

The Periodic Table of Elements

Alkali Metals 1 • I	Alkaline Earth Metals 2 • II	3	4	5	6	7	8	9	10	11	12	13 • III	14 • IV	15 • V	16 • VI	Halogens 17 • VII	Noble Gases 18 • VIII
1 1.008 H Hydrogen																	2 4.003 He Helium
3 6.941 Li Lithium	4 9.012 Be Beryllium											5 10.811 B Boron	6 12.011 C Carbon	7 14.007 N Nitrogen	8 15.999 O Oxygen	9 18.998 F Fluorine	10 20.180 Ne Neon
11 22.990 Na Sodium	12 24.305 Mg Magnesium											13 26.982 Al Aluminum	14 28.086 Si Silicon	15 30.974 P Phosphorus	16 32.065 S Sulfur	17 35.453 Cl Chlorine	18 39.948 Ar Argon
19 39.098 K Potassium	20 40.078 Ca Calcium	21 44.956 Sc Scandium	22 47.867 Ti Titanium	23 50.942 V Vanadium	24 51.996 Cr Chromium	25 54.938 Mn Manganese	26 55.845 Fe Iron	27 58.933 Co Cobalt	28 58.693 Ni Nickel	29 63.546 Cu Copper	30 65.409 Zn Zinc	31 69.723 Ga Gallium	32 72.64 Ge Germanium	33 74.922 As Arsenic	34 78.960 Se Selenium	35 79.904 Br Bromine	36 83.798 Kr Krypton
37 85.468 Rb Rubidium	38 87.620 Sr Strontium	39 88.906 Y Yttrium	40 91.224 Zr Zirconium	41 92.906 Nb Niobium	42 95.940 Mo Molybdenum	43 98.0 Tc Technetium	44 101.07 Ru Ruthenium	45 102.91 Rh Rhodium	46 106.42 Pd Palladium	47 107.87 Ag Silver	48 112.41 Cd Cadmium	49 114.82 In Indium	50 118.71 Sn Tin	51 121.76 Sb Antimony	52 127.60 Te Tellurium	53 126.90 I Iodine	54 131.29 Xe Xenon
55 132.91 Cs Cesium	56 137.33 Ba Barium	57-71	72 178.49 Hf Hafnium	73 180.95 Ta Tantalum	74 183.84 W Tungsten	75 186.21 Re Rhenium	76 190.23 Os Osmium	77 192.22 Ir Iridium	78 195.08 Pt Platinum	79 196.97 Au Gold	80 200.59 Hg Mercury	81 204.38 Tl Thallium	82 207.20 Pb Lead	83 208.98 Bi Bismuth	84 209 Po Polonium	85 210 At Astatine	86 222 Rn Radon
87 223 Fr Francium	88 226 Ra Radium	89-103	104 261 Rf Rutherfordium	105 262 Db Dubnium	106 266 Sg Seaborgium	107 264 Bh Bohrium	108 277 Hs Hassium	109 268 Mt Meitnerium	110 271 Ds Darmstadtium	111 272 Rg Roentgenium							

57 138.91 La Lanthanum	58 140.12 Ce Cerium	59 140.91 Pr Praseodymium	60 144.24 Nd Neodymium	61 145 Pm Promethium	62 150.36 Sm Samarium	63 151.96 Eu Europium	64 157.25 Gd Gadolinium	65 158.93 Tb Terbium	66 162.50 Dy Dysprosium	67 164.93 Ho Holmium	68 167.26 Er Erbium	69 168.93 Tm Thulium	70 173.04 Yb Ytterbium	71 174.97 Lu Lutetium
89 227 Ac Actinium	90 232.04 Th Thorium	91 231.04 Pa Protactinium	92 238.03 U Uranium	93 2371 Np Neptunium	94 244 Pu Plutonium	95 243 Am Americium	96 247 Cm Curium	97 247 Bk Berkelium	98 251 Cf Californium	99 252 Es Einsteinium	100 257 Fm Fermium	101 258 Md Mendelevium	102 259 No Nobelium	103 262 Lr Lawrencium