

# HANDLING AND DISPOSAL OF CHEMICALS IN LABORATORIES

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The following material has been extracted from two books prepared under the auspices of the Committee on Hazardous Substances in the Laboratory of the National Academy of Sciences – National Research Council. Readers are referred to these books for full details:

*Prudent Practices for Handling Hazardous Chemicals in Laboratories*, National Academy Press, Washington, 1981.

*Prudent Practices for Disposal of Chemicals from Laboratories*, National Academy Press, Washington, 1983.

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## INCOMPATIBLE CHEMICALS

The term “incompatible chemicals” refers to chemicals that can react with each other

- Violently
- With evolution of substantial heat
- To produce flammable products
- To produce toxic products

Good laboratory safety practice requires that incompatible chemicals be stored, transported, and disposed of in ways that will prevent their coming together in the event of an accident. Tables 1 and 2 give some basic guidelines for the safe handling of acids, bases, reactive metals, and other chemicals. Neither of these tables is exhaustive, and additional information on incompatible chemicals can be found in the following references.

1. Urben, P. G., Ed., *Bretherick's Handbook of Reactive Chemical Hazards*, 5th ed., Butterworth-Heinemann, Oxford, 1995.
2. Luxon, S. G., Ed., *Hazards in the Chemical Laboratory*, 5th ed., Royal Society of Chemistry, Cambridge, 1992.
3. *Fire Protection Guide to Hazardous Materials*, 11th ed., National Fire Protection Association, Quincy, MA, 1994.

TABLE 1. General Classes of Incompatible Chemicals

A	B
Acids	Bases, reactive metals
Oxidizing agents <sup>a</sup>	Reducing agents <sup>a</sup>
Chlorates	Ammonia, anhydrous and aqueous
Chromates	Carbon
Chromium trioxide	Metals
Dichromates	Metal hydrides
Halogens	Nitrites
Halogenating agents	Organic compounds
Hydrogen peroxide	Phosphorus
Nitric acid	Silicon
Nitrates	Sulfur
Perchlorates	
Peroxides	
Permanganates	
Persulfates	

<sup>a</sup> The examples of oxidizing and reducing agents are illustrative of common laboratory chemicals; they are not intended to be exhaustive.

TABLE 2. Examples of Incompatible Chemicals

Chemical	Is incompatible with
Acetic acid	Chromic acid, nitric acid, hydroxyl compounds, ethylene glycol, perchloric acid, peroxides, permanganates
Acetylene	Chlorine, bromine, copper, fluorine, silver, mercury
Acetone	Concentrated nitric and sulfuric acid mixtures
Alkali and alkaline earth metals (such as powdered aluminum or magnesium, calcium, lithium, sodium, potassium)	Water, carbon tetrachloride or other chlorinated hydrocarbons, carbon dioxide, halogens
Ammonia (anhydrous)	Mercury (in manometers, for example), chlorine, calcium hypochlorite, iodine, bromine, hydrofluoric acid (anhydrous)
Ammonium nitrate	Acids, powdered metals, flammable liquids, chlorates, nitrites, sulfur, finely divided organic or combustible materials
Aniline	Nitric acid, hydrogen peroxide
Arsenical materials	Any reducing agent
Azides	Acids

Chemical	Is incompatible with
Bromine	See Chlorine
Calcium oxide	Water
Carbon (activated)	Calcium hypochlorite, all oxidizing agents
Carbon tetrachloride	Sodium
Chlorates	Ammonium salts, acids, powdered metals, sulfur, finely divided organic or combustible materials
Chromic acid and chromium trioxide	Acetic acid, naphthalene, camphor, glycerol, alcohol, flammable liquids in general
Chlorine	Ammonia, acetylene, butadiene, butane, methane, propane (or other petroleum gases), hydrogen, sodium carbide, benzene, finely divided metals, turpentine
Chlorine dioxide	Ammonia, methane, phosphine, hydrogen sulfide
Copper	Acetylene, hydrogen peroxide
Cumene hydroperoxide	Acids (organic or inorganic)
Cyanides	Acids
Flammable liquids	Ammonium nitrate, chromic acid, hydrogen peroxide, nitric acid, sodium peroxide, halogens
Fluorine	Everything
Hydrocarbons (such as butane, propane, benzene)	Fluorine, chlorine, bromine, chromic acid, sodium peroxide
Hydrocyanic acid	Nitric acid, alkali
Hydrofluoric acid (anhydrous)	Ammonia (aqueous or anhydrous)
Hydrogen peroxide	Copper, chromium, iron, most metals or their salts, alcohols, acetone, organic materials, aniline, nitro-methane, combustible materials
Hydrogen sulfide	Fuming nitric acid, oxidizing gases
Hypochlorites	Acids, activated carbon
Iodine	Acetylene, ammonia (aqueous or anhydrous), hydrogen
Mercury	Acetylene, fulminic acid, ammonia
Nitrates	Sulfuric acid
Nitric acid (concentrated)	Acetic acid, aniline, chromic acid, hydrocyanic acid, hydrogen sulfide, flammable liquids, flammable gases, copper, brass, any heavy metals
Nitrites	Acids
Nitroparaffins	Inorganic bases, amines
Oxalic acid	Silver, mercury
Oxygen	Oils, grease, hydrogen, flammable liquids, solids, or gases
Perchloric acid	Acetic anhydride, bismuth and its alloys, alcohol, paper, wood, grease, oils
Peroxides, organic	Acids (organic or mineral), avoid friction, store cold
Phosphorus (white)	Air, oxygen, alkalis, reducing agents
Potassium	Carbon tetrachloride, carbon dioxide, water
Potassium chlorate	Sulfuric and other acids
Potassium perchlorate (see also chlorates)	Sulfuric and other acids
Potassium permanganate	Glycerol, ethylene glycol, benzaldehyde, sulfuric acid
Selenides	Reducing agents
Silver	Acetylene, oxalic acid, tartaric acid, ammonium compounds, fulminic acid
Sodium	Carbon tetrachloride, carbon dioxide, water
Sodium nitrite	Ammonium nitrate and other ammonium salts
Sodium peroxide	Ethyl or methyl alcohol, glacial acetic acid, acetic anhydride, benzaldehyde, carbon disulfide, glycerin, ethylene glycol, ethyl acetate, methyl acetate, furfural
Sulfides	Acids
Sulfuric acid	Potassium chlorate, potassium perchlorate, potassium permanganate (similar compounds of light metals, such as sodium, lithium)
Tellurides	Reducing agents

## EXPLOSION HAZARDS

Table 3 lists some common classes of laboratory chemicals that have potential for producing a violent explosion when subjected to shock or friction. These chemicals should never be disposed of as such, but should be handled by procedures given in *Prudent Practices for Disposal of Chemicals from Laboratories*, National Academy Press, 1983, chapters 6 and 7. Additional information on these, as well as on some less common classes of explosives, can be found in L. Bretherick, *Handbook of Reactive Chemical Hazards*, 3rd ed., Butterworths, London–Boston, 1985.

Table 4 lists some illustrative combinations of common laboratory reagents that can produce explosions when they are brought together or that form reaction products that can explode without any apparent external initiating action. This list is not exhaustive, and additional information on potentially explosive reagent combinations can be found in *Manual of Hazardous Chemical Reactions, A Compilation of Chemical Reactions Reported to be Potentially Hazardous*, National Fire Protection Association, NFPA 491M, 1975, NFPA, 470 Atlantic Avenue, Boston, MA 02210.

## WATER-REACTIVE CHEMICALS

Table 5 lists some common laboratory chemicals that react violently with water and that should always be stored and handled so that they do not come into contact with liquid water or water vapor.

Procedures for decomposing laboratory quantities are given in *Prudent Practices for Disposal of Chemicals from Laboratories*, chapter 6; the pertinent section of that chapter is given in parentheses.

## PYROPHORIC CHEMICALS

Many members of the classes of readily oxidized, common laboratory chemicals listed in Table 6 ignite spontaneously in air. A more extensive list can be found in L. Bretherick, *Handbook of Reactive Chemical Hazards*, 3rd ed., Butterworths, London–Boston, 1985. Pyrophoric chemicals should be stored in tightly closed containers under an inert atmosphere (or, for some, an inert liquid),

and all transfers and manipulations of them must be carried out under an inert atmosphere or liquid. Suggested procedures for decomposing them are given in *Prudent Practices for Disposal of Chemicals from Laboratories*, chapter 6; the pertinent section of that chapter is given in parentheses.

## TABLE 3. Shock-Sensitive Compounds

Acetylenic compounds, especially polyacetylenes, haloacetylenes, and heavy metal salts of acetylenes (copper, silver, and mercury salts are particularly sensitive)
Acyl nitrates
Alkyl nitrates, particularly polyol nitrates such as nitrocellulose and nitroglycerine
Alkyl and acyl nitrites
Alkyl perchlorates
Ammine metal oxosalts: metal compounds with coordinated ammonia, hydrazine, or similar nitrogenous donors and ionic perchlorate, nitrate, permanganate, or other oxidizing group
Azides, including metal, nonmetal, and organic azides
Chlorite salts of metals, such as $\text{AgClO}_2$ and $\text{Hg}(\text{ClO}_2)_2$
Diazo compounds such as $\text{CH}_2\text{N}_2$
Diazonium salts, when dry
Fulminates (silver fulminate, $\text{AgCNO}$ , can form in the reaction mixture from the Tollens' test for aldehydes if it is allowed to stand for some time; this can be prevented by adding dilute nitric acid to the test mixture as soon as the test has been completed)
Hydrogen peroxide becomes increasingly treacherous as the concentration rises above 30%, forming explosive mixtures with organic materials and decomposing violently in the presence of traces of transition metals
<i>N</i> -Halogen compounds such as difluoroamino compounds and halogen azides
<i>N</i> -Nitro compounds such as <i>N</i> -nitromethylamine, nitrourea, nitroguanidine, and nitric amide
Oxo salts of nitrogenous bases: perchlorates, dichromates, nitrates, iodates, chlorites, chlorates, and permanganates of ammonia, amines, hydroxylamine, guanidine, etc.
Perchlorate salts. Most metal, nonmetal, and amine perchlorates can be detonated and may undergo violent reaction in contact with combustible materials
Peroxides and hydroperoxides, organic (see Chapter 6, Section II.P)
Peroxides (solid) that crystallize from or are left from evaporation of peroxidizable solvents (see Chapter 6 and Appendix I)
Peroxides, transition-metal salts
Picrates, especially salts of transition and heavy metals, such as Ni, Pb, Hg, Cu, and Zn; picric acid is explosive but is less sensitive to shock or friction than its metal salts and is relatively safe as a water-wet paste (see Chapter 7)
Polynitroalkyl compounds such as tetranitromethane and dinitroacetone nitrile
Polynitroaromatic compounds, especially polynitro hydrocarbons, phenols, and amines

**TABLE 4. Potentially Explosive Combinations of Some Common Reagents**

Acetone + chloroform in the presence of base  
 Acetylene + copper, silver, mercury, or their salts  
 Ammonia (including aqueous solutions) +  $\text{Cl}_2$ ,  $\text{Br}_2$ , or  $\text{I}_2$   
 Carbon disulfide + sodium azide  
 Chlorine + an alcohol  
 Chloroform or carbon tetrachloride + powdered Al or Mg  
 Decolorizing carbon + an oxidizing agent  
 Diethyl ether + chlorine (including a chlorine atmosphere)  
 Dimethyl sulfoxide + an acyl halide,  $\text{SOCl}_2$  or  $\text{POCl}_3$   
 Dimethyl sulfoxide +  $\text{CrO}_3$   
 Ethanol + calcium hypochlorite  
 Ethanol + silver nitrate  
 Nitric acid + acetic anhydride or acetic acid  
 Picric acid + a heavy-metal salt, such as of Pb, Hg, or Ag  
 Silver oxide + ammonia + ethanol  
 Sodium + a chlorinated hydrocarbon  
 Sodium hypochlorite + an amine

**TABLE 5. Water-Reactive Chemicals**

Alkali metals (III.D)  
 Alkali metal hydrides (III.C.2)  
 Alkali metal amides (III.C.7)  
 Metal alkyls, such as lithium alkyls and aluminum alkyls (IV.A)  
 Grignard reagents (IV.A)  
 Halides of nonmetals, such as  $\text{BCl}_3$ ,  $\text{BF}_3$ ,  $\text{PCl}_3$ ,  $\text{PCl}_5$ ,  $\text{SiCl}_4$ ,  $\text{S}_2\text{Cl}_2$  (III.F)  
 Inorganic acid halides, such as  $\text{POCl}_3$ ,  $\text{SOCl}_2$ ,  $\text{SO}_2\text{Cl}_2$  (III.F)  
 Anhydrous metal halides, such as  $\text{AlCl}_3$ ,  $\text{TiCl}_4$ ,  $\text{ZrCl}_4$ ,  $\text{SnCl}_4$  (III.E)  
 Phosphorus pentoxide (III.I)  
 Calcium carbide (IV.E)  
 Organic acid halides and anhydrides of low molecular weight (II.J)

**TABLE 6. Classes of Pyrophoric Chemicals**

Grignard reagents,  $\text{RMgX}$  (IV.A)  
 Metal alkyls and aryls, such as  $\text{RLi}$ ,  $\text{RNa}$ ,  $\text{R}_3\text{Al}$ ,  $\text{R}_2\text{Zn}$  (IV.A)  
 Metal carbonyls, such as  $\text{Ni}(\text{CO})_4$ ,  $\text{Fe}(\text{CO})_5$ ,  $\text{Co}_2(\text{CO})_8$  (IV.B)  
 Alkali metals such as Na, K (III.D.1)  
 Metal powders, such as Al, Co, Fe, Mg, Mn, Pd, Pt, Ti, Sn, Zn, Zr (III.D.2)  
 Metal hydrides, such as  $\text{NaH}$ ,  $\text{LiAlH}_4$  (IV.C.2)  
 Nonmetal hydrides, such as  $\text{B}_2\text{H}_6$  and other boranes,  $\text{PH}_3$ ,  $\text{AsH}_3$  (III.G)  
 Nonmetal alkyls, such as  $\text{R}_3\text{B}$ ,  $\text{R}_3\text{P}$ ,  $\text{R}_3\text{As}$  (IV.C)  
 Phosphorus (white) (III.H)

## HAZARDS FROM PEROXIDE FORMATION

Many common laboratory chemicals can form peroxides when allowed access to air over a period of time. A single opening of a container to remove some of the contents can introduce enough air for peroxide formation to occur. Some types of compounds form peroxides that are treacherously and violently explosive in concentrated solution or as solids. Accordingly, peroxide-containing liquids should never be evaporated near to or to dryness. Peroxide formation can also occur in many polymerizable unsaturated compounds, and these peroxides can initiate a runaway, sometimes explosive, polymerization reaction. Procedures for testing for peroxides and for removing small amounts from laboratory chemicals are given in *Prudent Practices for Disposal of Chemicals from Laboratories*, chapter 6, Section II.P.

Table 7 provides a list of structural characteristics in organic compounds that can peroxidize. These structures are listed in approximate order of decreasing hazard. Reports of serious incidents involving the last five structural types are extremely rare, but these structures are listed because laboratory workers should be aware that they can form peroxides that can influence the course of experiments in which they are used.

Table 8 gives examples of common laboratory chemicals that are prone to form peroxides on exposure to air. The lists are not exhaustive, and analogous organic compounds that have any of the structural features given in Table 7 should be tested for peroxides before being used as solvents or reagents, or before being distilled. The recommended retention times begin with the date of synthesis or of opening the original container.

## DISPOSAL OF TOXIC CHEMICALS

It is often desirable to precipitate toxic cations or hazardous anions from solution to facilitate recovery or disposal. Table 9 lists precipitants for many common cations, and Table 10 gives precipitants for some hazardous anions. Many cations can be precipitated as sulfides by adding sodium sulfide solution (preferable to the highly toxic hydrogen sulfide) to a neutral solution of the cation (Table 11). Control of pH is important because some sulfides will redissolve in excess sulfide ion. After precipitation, excess sulfide can be destroyed by addition of hypochlorite.

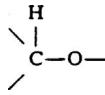
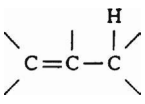
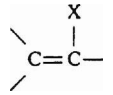
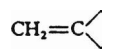
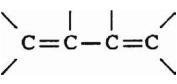
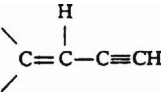
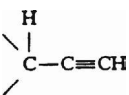


Most metal cations are precipitated as hydroxides or oxides at high pH. Since many of these precipitates will redissolve in excess

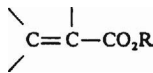
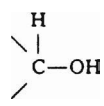
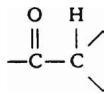

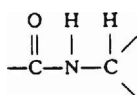
base, it is often necessary to control pH. Table 12 shows the recommended pH range for precipitating many cations in their most common oxidation state. The notation "1 N" in the right-hand column indicates that the precipitate will not dissolve in 1 N sodium hydroxide (pH 14).

The distinctions between high and low toxicity or hazard are based on toxicological and other data, and are relative. There is no implication of a sharp distinction between high and low, or that any cations or anions are totally without hazard.

TABLE 7. Types of Chemicals That Are Prone to Form Peroxides

## A. Organic structures (in approximate order of decreasing hazard)

1.		Ethers and acetals with $\alpha$ hydrogen atoms
2.		Olefins with allylic hydrogen atoms
3.		Chloroolefins and fluoroolefins
4.		Vinyl halides, esters, and ethers
5.		Dienes
6.		Vinylacetylenes with $\alpha$ hydrogen atoms
7.		Alkylacetylenes with $\alpha$ hydrogen atoms
8.		Alkylarenes that contain tertiary hydrogen atoms
9.		Alkanes and cycloalkanes that contain tertiary hydrogen atoms

10.		Acrylates and methacrylates
11.		Secondary alcohols
12.		Ketones that contain $\alpha$ hydrogen atoms
13.		Aldehydes
14.		Ureas, amides, and lactams that have a hydrogen atom on a carbon atom attached to nitrogen

**B. Inorganic substances**

1. Alkali metals, especially potassium, rubidium, and cesium (see Chapter 6, Section III.D)
2. Metal amides (see Chapter 6, Section III.C.7)
3. Organometallic compounds with a metal atom bonded to carbon (see Chapter 6, Section IV)
4. Metal alkoxides

**TABLE 8. Common Peroxide-Forming Chemicals****LIST A****Severe Peroxide Hazard on Storage with Exposure to Air***Discard within 3 months*

- Diisopropyl ether (isopropyl ether)
- Divinylacetylene (DVA)<sup>a</sup>
- Potassium metal
- Potassium amide
- Sodium amide (sodamide)
- Vinylidene chloride (1,1-dichloroethylene)<sup>a</sup>

**LIST B****Peroxide Hazard on Concentration; Do Not Distill or Evaporate Without First Testing for the Presence of Peroxides***Discard or test for peroxides after 6 months*

- Acetaldehyde diethyl acetal (acetal)
- Cumene (isopropylbenzene)
- Cyclohexene
- Cyclopentene
- Decalin (decahydronaphthalene)
- Diacetylene
- Dicyclopentadiene
- Diethyl ether (ether)
- Diethylene glycol dimethyl ether (diglyme)
- Dioxane
- Ethylene glycol dimethyl ether (glyme)
- Ethylene glycol ether acetates
- Ethylene glycol monoethers (cellosolves)
- Furan
- Methylacetylene
- Methylcyclopentane
- Methyl isobutyl ketone
- Tetrahydrofuran (THF)
- Tetralin (tetrahydronaphthalene)
- Vinyl ethers<sup>a</sup>

**LIST C****Hazard of Rapid Polymerization Initiated by Internally Formed Peroxides<sup>a</sup>****a. Normal Liquids; discard or test for peroxides after 6 months<sup>b</sup>**

- Chloroprene (2-chloro-1,3-butadiene)<sup>c</sup>
- Styrene
- Vinyl acetate
- Vinylpyridine

**b. Normal Gases; discard after 12 months<sup>d</sup>**

- Butadiene<sup>c</sup>
- Tetrafluoroethylene (TFE)<sup>c</sup>
- Vinylacetylene (MVA)<sup>c</sup>
- Vinyl chloride

<sup>a</sup> Polymerizable monomers should be stored with a polymerization inhibitor from which the monomer can be separated by distillation just before use.<sup>b</sup> Although common acrylic monomers such as acrylonitrile, acrylic acid, ethyl acrylate, and methyl methacrylate can form peroxides, they have not been reported to develop hazardous levels in normal use and storage.<sup>c</sup> The hazard from peroxides in these compounds is substantially greater when they are stored in the liquid phase, and if so stored without an inhibitor they should be considered as in LIST A.<sup>d</sup> Although air will not enter a gas cylinder in which gases are stored under pressure, these gases are sometimes transferred from the original cylinder to another in the laboratory, and it is difficult to be sure that there is no residual air in the receiving cylinder. An inhibitor should be put into any such secondary cylinder before one of these gases is transferred into it; the supplier can suggest inhibitors to be used. The hazard posed by these gases is much greater if there is a liquid phase in such a secondary container, and even inhibited gases that have been put into a secondary container under conditions that create a liquid phase should be discarded within 12 months.

Note: Laboratory workers should label all containers of peroxidizable solvents or reagents with one of the following:

[LIST A]

Date	Peroxidizable compound	
	Received	Opened
	Discard 3 months after opening	

[LISTS B AND C]

Date	Peroxidizable compound	
	Received	Opened
	Discard or test for peroxides 6 months after opening	

TABLE 9. Relative Toxicity of Cations

High toxic hazard	Precipitant <sup>a</sup>	Low toxic hazard	Precipitant <sup>a</sup>
Antimony	OH <sup>-</sup> , S <sup>2-</sup>	Aluminum	OH <sup>-</sup>
Arsenic	S <sup>2-</sup>	Bismuth	OH <sup>-</sup> , S <sup>2-</sup>
Barium	SO <sub>4</sub> <sup>2-</sup> , CO <sub>3</sub> <sup>2-</sup>	Calcium	SO <sub>4</sub> <sup>2-</sup> , CO <sub>3</sub> <sup>2-</sup>
Beryllium	OH <sup>-</sup>	Cerium	OH <sup>-</sup>
Cadmium	OH <sup>-</sup> , S <sup>2-</sup>	Cesium	
Chromium (III) <sup>b</sup>	OH <sup>-</sup>	Copper <sup>c</sup>	OH <sup>-</sup> , S <sup>2-</sup>
Cobalt (II) <sup>b</sup>	OH <sup>-</sup> , S <sup>2-</sup>	Gold	OH <sup>-</sup> , S <sup>2-</sup>
Gallium	OH <sup>-</sup>	Iron <sup>c</sup>	OH <sup>-</sup> , S <sup>2-</sup>
Germanium	OH <sup>-</sup> , S <sup>2-</sup>	Lanthanides	OH <sup>-</sup>
Hafnium	OH <sup>-</sup>	Lithium	
Indium	OH <sup>-</sup> , S <sup>2-</sup>	Magnesium	OH <sup>-</sup>
Iridium	OH <sup>-</sup> , S <sup>2-</sup>	Molybdenum (VI) <sup>b,d</sup>	
Lead	OH <sup>-</sup> , S <sup>2-</sup>	Niobium (V)	OH <sup>-</sup>
Manganese (II) <sup>b</sup>	OH <sup>-</sup> , S <sup>2-</sup>	Palladium	OH <sup>-</sup> , S <sup>2-</sup>
Mercury	OH <sup>-</sup> , S <sup>2-</sup>	Potassium	
Nickel	OH <sup>-</sup> , S <sup>2-</sup>	Rubidium	
Osmium (IV) <sup>b,e</sup>	OH <sup>-</sup> , S <sup>2-</sup>	Scandium	OH <sup>-</sup>
Platinum (II) <sup>b</sup>	OH <sup>-</sup> , S <sup>2-</sup>	Sodium	
Rhenium (VII) <sup>b</sup>	S <sup>2-</sup>	Strontium	SO <sub>4</sub> <sup>2-</sup> , CO <sub>3</sub> <sup>2-</sup>
Rhodium (III) <sup>b</sup>	OH <sup>-</sup> , S <sup>2-</sup>	Tantalum	OH <sup>-</sup>
Ruthenium (III) <sup>b</sup>	OH <sup>-</sup> , S <sup>2-</sup>	Tin	OH <sup>-</sup> , S <sup>2-</sup>
Selenium	S <sup>2-</sup>	Titanium	OH <sup>-</sup>
Silver	Cl <sup>-</sup> , OH <sup>-</sup> , S <sup>2-</sup>	Yttrium	OH <sup>-</sup>
Tellurium	S <sup>2-</sup>	Zinc <sup>c</sup>	OH <sup>-</sup> , S <sup>2-</sup>
Thallium	OH <sup>-</sup> , S <sup>2-</sup>	Zirconium	OH <sup>-</sup>
Tungsten (VI) <sup>b,d</sup>			
Vanadium	OH <sup>-</sup> , S <sup>2-</sup>		

<sup>a</sup> Precipitants are listed in order of preference:  
 OH<sup>-</sup> = base (sodium hydroxide or sodium carbonate)  
 S<sup>2-</sup> = sulfide  
 Cl<sup>-</sup> = chloride  
 SO<sub>4</sub><sup>2-</sup> = sulfate  
 CO<sub>3</sub><sup>2-</sup> = carbonate

<sup>b</sup> The precipitant is for the indicated valence state.

<sup>c</sup> Maximum tolerance levels have been set for these low-toxicity ions by the U.S. Public Health Service, and large amounts should not be put into public sewer systems. The small amounts typically used in laboratories will not normally affect water supplies.

<sup>d</sup> These ions are best precipitated as calcium molybdate or calcium tungstate.

<sup>e</sup> CAUTION: OsO<sub>4</sub>, a volatile, extremely poisonous substance, is formed from almost any osmium compound under acid conditions in the presence of air.

TABLE 10. Relative Hazard of Anions

High-hazard anions			Low-hazard anions
Ion	Hazard type <sup>a</sup>	Precipitant	
Aluminum hydride, $\text{AlH}_4^-$	F	—	Bisulfite, $\text{HSO}_3^-$
Amide, $\text{NH}_2^-$	F, E <sup>b</sup>	—	Borate, $\text{BO}_3^{3-}$ , $\text{B}_4\text{O}_7^{2-}$
Arsenate, $\text{AsO}_3^-$ , $\text{AsO}_4^{3-}$	T	$\text{Cu}^{2+}$ , $\text{Fe}^{2+}$	Bromide, $\text{Br}^-$
Arsenite, $\text{AsO}_2^-$ , $\text{AsO}_3^{3-}$	T	$\text{Pb}^{2+}$	Carbonate, $\text{CO}_3^{2-}$
Azide, $\text{N}_3^-$	E, T	—	Chloride, $\text{Cl}^-$
Borohydride, $\text{BH}_4^-$	F	—	Cyanate, $\text{OCN}^-$
Bromate, $\text{BrO}_3^-$	O, E	—	Hydroxide, $\text{OH}^-$
Chlorate, $\text{ClO}_3^-$	O, E	—	Iodide, $\text{I}^-$
Chromate, $\text{CrO}_4^{2-}$ , $\text{Cr}_2\text{O}_7^{2-}$	T, O	<sup>c</sup>	Oxide, $\text{O}^{2-}$
Cyanide, $\text{CN}^-$	T	—	Phosphate, $\text{PO}_4^{3-}$
Ferricyanide, $\text{Fe}(\text{CN})_6^{3-}$	T	$\text{Fe}^{2+}$	Sulfate, $\text{SO}_4^{2-}$
Ferrocyanide, $\text{Fe}(\text{CN})_6^{4-}$	T	$\text{Fe}^{3+}$	Sulfite, $\text{SO}_3^{2-}$
Fluoride, $\text{F}^-$	T	$\text{Ca}^{2+}$	Thiocyanate, $\text{SCN}^-$
Hydride, $\text{H}^-$	F	—	
Hydroperoxide, $\text{O}_2\text{H}^-$	O, E	—	
Hydrosulfide, $\text{SH}^-$	T	—	
Hypochlorite, $\text{OCl}^-$	O	—	
Iodate, $\text{IO}_3^-$	O, E	—	
Nitrate, $\text{NO}_3^-$	O	—	
Nitrite, $\text{NO}_2^-$	T, O	—	
Perchlorate, $\text{ClO}_4^-$	O, E	—	
Permanganate, $\text{MnO}_4^-$	T, O	<sup>d</sup>	
Peroxide, $\text{O}_2^{2-}$	O, E	—	
Persulfate, $\text{S}_2\text{O}_8^{2-}$	O	—	
Selenate, $\text{SeO}_4^{2-}$	T	$\text{Pb}^{2+}$	
Selenide, $\text{Se}^{2-}$	T	$\text{Cu}^{2+}$	
Sulfide, $\text{S}^{2-}$	T	<sup>e</sup>	

<sup>a</sup> Toxic, T; oxidant, O; flammable, F; explosive, E.

<sup>b</sup> Metal amides readily form explosive peroxides on exposure to air.

<sup>c</sup> Reduce and precipitate as Cr(III); see Table 9.

<sup>d</sup> Reduce and precipitate as Mn(II); see Table 9.

<sup>e</sup> See Table 11.

TABLE 11. Precipitation of Sulfides

Precipitated at pH 7	Not precipitated at low pH	Forms a soluble complex at high pH
$\text{Ag}^+$		
$\text{As}^{3+a}$		X
$\text{Au}^{+a}$		X
$\text{Bi}^{3+}$		
$\text{Cd}^{2+}$		
$\text{Co}^{2+}$	X	
$\text{Cr}^{3+a}$		
$\text{Cu}^{2+}$		
$\text{Fe}^{2+a}$	X	
$\text{Ge}^{2+}$		X
$\text{Hg}^{2+}$		X
$\text{In}^{3+}$	X	
$\text{Ir}^{4+}$		X
$\text{Mn}^{2+a}$	X	
$\text{Mo}^{3+}$		X
$\text{Ni}^{2+}$	X	
$\text{Os}^{4+}$		
$\text{Pb}^{2+}$		
$\text{Pd}^{2+a}$		
$\text{Pt}^{2+a}$		X
$\text{Re}^{4+}$		
$\text{Rh}^{2+a}$		
$\text{Ru}^{4+}$		



TABLE 11. Precipitation of Sulfides

Precipitated at pH 7	Not precipitated at low pH	Forms a soluble complex at high pH
Sb <sup>3+ a</sup>		X
Se <sup>2+</sup>		X
Sn <sup>2+</sup>		X
Te <sup>4+</sup>		X
Tl <sup>1+ a</sup>	X	
V <sup>4+ a</sup>		
Zn <sup>2+</sup>	X	

<sup>a</sup> Higher oxidation states of this ion are reduced by sulfide ion and precipitated as this sulfide.

TABLE 12. pH Range for Precipitation of Metal Hydroxides and Oxides

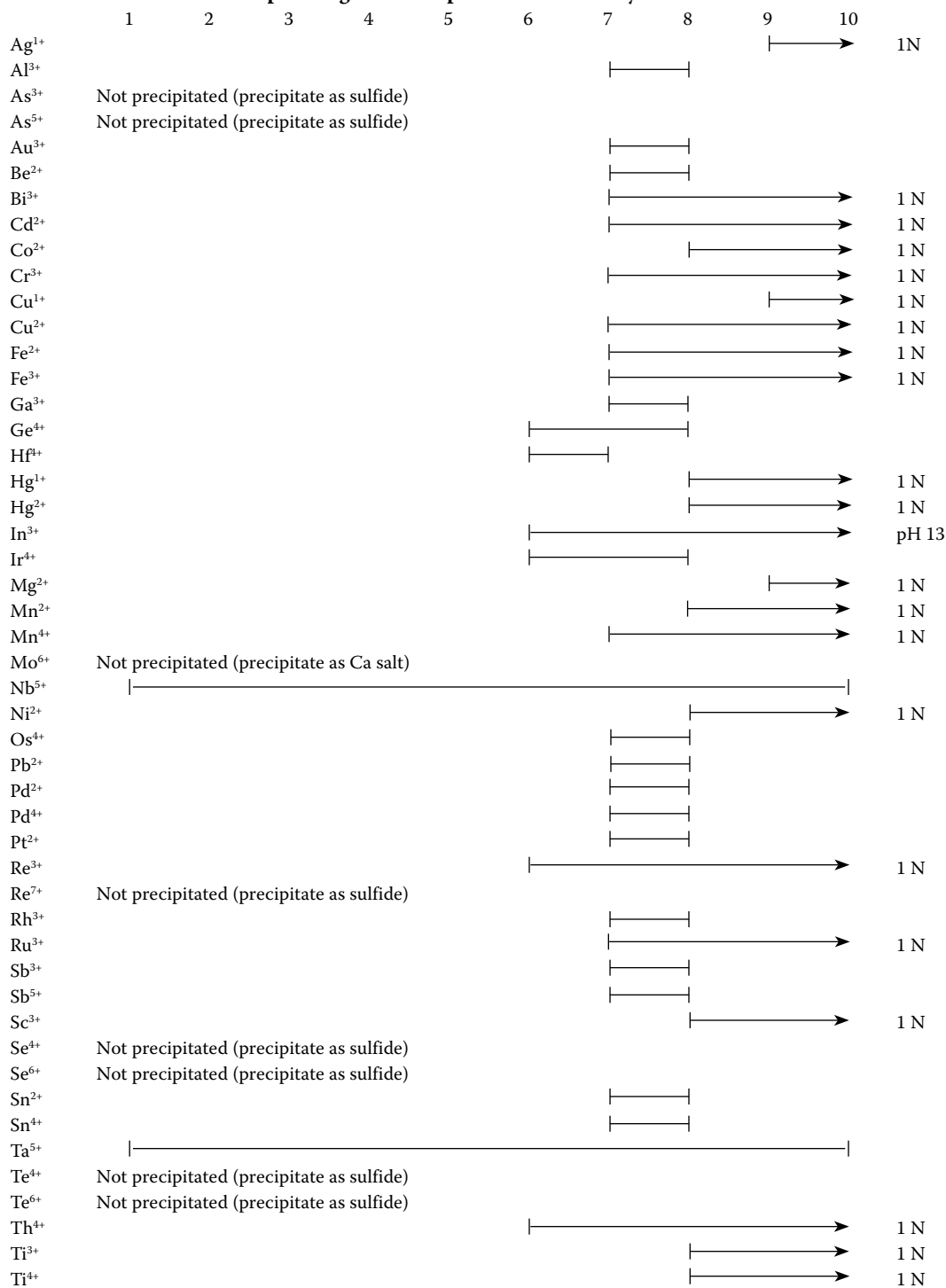


TABLE 12. pH Range for Precipitation of Metal Hydroxides and Oxides

	1	2	3	4	5	6	7	8	9	10	1 N
Tl <sup>3+</sup>									→		
V <sup>4+</sup>							—	—			
V <sup>5+</sup>							—	—			
W <sup>6+</sup>	Not precipitated (precipitate as Ca salt)										
Zn <sup>2+</sup>							—	—			
Zr <sup>4+</sup>						—	—				

### References

- L. Erdey, *Gravimetric Analysis*, Part II, Pergamon Press, New York, 1965.  
 D. T. Burns, A. Towsend, and A. H. Carter, *Inorganic Reaction Chemistry*, Vol. 2, Ellis Horwood, New York, 1981.

## FIRE HAZARDS

Flammable solvents are a common source of laboratory fires. The relative ease with which some common laboratory solvents can be ignited is indicated by the following properties.

**Flash Point** — The lowest temperature, as determined by standard tests, at which a liquid emits vapor in sufficient concentration to form an ignitable mixture with air near the surface of the liquid in a test vessel. Note that many of these common chemicals have flash points below room temperature.

**Ignition Temperature** — The minimum temperature required to initiate self-sustained combustion, regardless of the heat source.

**Flammable Limits** — The lower flammable limit is the minimum concentration (percent by volume) of a vapor in air below which a

flame is not propagated when an ignition source is present. Below this concentration the mixture is too lean to burn. The upper flammable limit is the maximum concentration (percent by volume) of the vapor in air above which a flame is not propagated. Above this concentration the mixture is too rich to burn. The flammable range comprises all concentrations between these two limits. This range becomes wider with increasing temperature and in oxygen-rich atmospheres. Table 13 lists these properties for a few common laboratory chemicals.

## GLOVE MATERIALS

It is good safety practice (and mandated in some laboratories) to wear rubber gloves while handling chemicals that can cause injury when in contact with, or absorbed through, the skin. The various

common rubbers are not equally resistant to all chemicals. Table 14 provides guidelines for selecting the best, and avoiding the poorest, glove material for handling a given chemical.

## RESPIRATORS

In the event of a laboratory accident or spill, it will be necessary for someone to enter the contaminated area for cleanup. If significant quantities of a chemical are spilled, or even minor quantities of a known toxic material, it is essential to wear the correct kind of respirator equipment when entering the area. If it is not known

whether the contamination is of a chemical “immediately dangerous to life or health”, the prudent course is to assume that it is, and to use the corresponding type of respirator. Guidelines are presented in Table 15.

TABLE 13. Flash Points, Boiling Points, Ignition Temperatures, and Flammable Limits of Some Common Laboratory Chemicals

Chemical	Flash point (°C)	Boiling point (°C)	Ignition temp. (°C)	Flammable limit (percent by volume in air)	
				Lower	Upper
Acetaldehyde	-37.8	21.1	175.0	4.0	60.0
Acetone	-19.0	56.0	538.0	2.6	12.8
Benzene	-11.1	80.1	560.0	1.4	8.0
Carbon disulfide	-30.0	45.8	90.0	1.0	44.0
Cyclohexane	-18.0	80.7	260.0	1.3	8.0
Diethyl ether	-45.0	34.4	160.0	1.8	48.0
Ethanol	12.0	78.3	363.0	3.3	19.0
<i>n</i> -Heptane	-3.9	98.4	204.0	1.0	6.7
<i>n</i> -Hexane	-21.7	68.7	223.0	1.2	7.5
Isopropyl alcohol	11.7	82.2	398.9	2.0	12.0
Methanol	11.1	64.5	385.0	6.0	36.5
Methyl ethyl ketone	-6.1	79.6	515.6	1.9	11.0

TABLE 13. Flash Points, Boiling Points, Ignition Temperatures, and Flammable Limits of Some Common Laboratory Chemicals

Chemical	Flash point (°C)	Boiling point (°C)	Ignition temp. (°C)	Flammable limit (percent by volume in air)	
				Lower	Upper
Pentane	-40.0	36.1	260.0	1.4	7.8
Styrene	31.0	145.0	490.0	1.1	6.1
Toluene	4.4	110.6	530.0	1.3	7.0
<i>p</i> -Xylene	25.0	132.4	529.0	1.1	7.0

Note: For a more extensive listing, see the table "Properties of Common Solvents" in Section 15.

TABLE 14. Resistance to Chemicals of Common Glove Materials (E = Excellent, G = Good, F = Fair, P = Poor)

Chemical	Natural rubber	Neoprene	Nitrile	Vinyl
Acetaldehyde	G	G	E	G
Acetic acid	E	E	E	E
Acetone	G	G	G	F
Acrylonitrile	P	G	—	F
Ammonium hydroxide (sat)	G	E	E	E
Aniline	F	G	E	G
Benzaldehyde	F	F	E	G
Benzene <sup>a</sup>	P	F	G	F
Benzyl chloride <sup>a</sup>	F	P	G	P
Bromine	G	G	—	G
Butane	P	E	—	P
Butyraldehyde	P	G	—	G
Calcium hypochlorite	P	G	G	G
Carbon disulfide	P	P	G	F
Carbon tetrachloride <sup>a</sup>	P	F	G	F
Chlorine	G	G	—	G
Chloroacetone	F	E	—	P
Chloroform <sup>a</sup>	P	F	G	P
Chromic acid	P	F	F	E
Cyclohexane	F	E	—	P
Dibenzyl ether	F	G	—	P
Dibutyl phthalate	F	G	—	P
Diethanolamine	F	E	—	E
Diethyl ether	F	G	E	P
Dimethyl sulfoxide <sup>b</sup>	—	—	—	—
Ethyl acetate	F	G	G	F
Ethylene dichloride <sup>a</sup>	P	F	G	
Ethylene glycol	G	G	E	E
Ethylene trichloride <sup>a</sup>	P	P	—	P
Fluorine	G	G	—	G
Formaldehyde	G	E	E	E
Formic acid	G	E	E	E
Glycerol	G	G	E	E
Hexane	P	E	—	P
Hydrobromic acid (40%)	G	E	—	E
Hydrochloric acid (conc)	G	G	G	E
Hydrofluoric acid (30%)	G	G	G	E
Hydrogen peroxide	G	G	G	E
Iodine	G	G	—	G
Methylamine	G	G	E	E
Methyl cellosolve	F	E	—	P
Methyl chloride <sup>a</sup>	P	E	—	P
Methyl ethyl ketone	F	G	G	P
Methylene chloride <sup>a</sup>	F	F	G	F
Monoethanolamine	F	E	—	E
Morpholine	F	E	—	E
Naphthalene <sup>a</sup>	G	G	E	G
Nitric acid (conc)	P	P	P	G
Perchloric acid	F	G	F	E

**TABLE 14. Resistance to Chemicals of Common Glove Materials (E = Excellent, G = Good, F = Fair, P = Poor)**

Chemical	Natural rubber	Neoprene	Nitrile	Vinyl
Phenol	G	E	—	E
Phosphoric acid	G	E	—	E
Potassium hydroxide (sat)	G	G	G	E
Propylene dichloride <sup>a</sup>	P	F	—	P
Sodium hydroxide	G	G	G	E
Sodium hypochlorite	G	P	F	G
Sulfuric acid (conc)	G	G	F	G
Toluene <sup>a</sup>	P	F	G	F
Trichloroethylene <sup>a</sup>	P	F	G	F
Tricresyl phosphate	P	F	—	F
Triethanolamine	F	E	E	E
Trinitrotoluene	P	E	—	P

<sup>a</sup> Aromatic and halogenated hydrocarbons will attack all types of natural and synthetic glove materials. Should swelling occur, the user should change to fresh gloves and allow the swollen gloves to dry and return to normal.

<sup>b</sup> No data on the resistance to dimethyl sulfoxide of natural rubber, neoprene, nitrile rubber, or vinyl materials are available; the manufacturer of the substance recommends the use of butyl rubber gloves.

**TABLE 15. Guide for Selection of Respirators**

Type of hazard	Type of respirator
Oxygen deficiency	Self-contained breathing apparatus Hose mask with blower Combination of air-line respirator and auxiliary self-contained air supply or air-storage receiver with alarm
Gas and vapor contaminants	Self-contained breathing apparatus
Immediately dangerous to life or health	Hose mask with blower Air-purifying full-facepiece respirator with chemical canister (gas mask) Self-rescue mouthpiece respirator (for escape only) Combination of air-line respirator and auxiliary self-contained air supply or air-storage receiver with alarm
Not immediately dangerous to life or health	Air-line respirator Hose mask with blower Air-purifying half-mask or mouthpiece respirator with chemical cartridge
Particulate Contaminants	Self-contained breathing apparatus
Immediately dangerous to life or health	Hose mask with blower Air-purifying full-facepiece respirator with appropriate filter Self-rescue mouthpiece respirator (for escape only) Combination of air-line respirator and auxiliary self-contained air supply or air-storage receiver with alarm
Not immediately dangerous to life or health	Air-purifying half-mask or mouthpiece respirator with filter pad or cartridge Air-line respirator Air-line abrasive-blasting respirator Hose mask with blower
Combination of gas, vapor, and particulate contaminants	Self-contained breathing apparatus
Immediately dangerous to life or health	Hose mask with blower Air-purifying full-facepiece respirator with chemical canister and appropriate filter (gas mask with filter) Self-rescue mouthpiece respirator (for escape only) Combination of air-line respirator and auxiliary self-contained air supply or air-storage receiver with alarm
Not immediately dangerous to life or health	Air-line respirator Hose mask without blower Air-purifying half-mask or mouthpiece respirator with chemical cartridge and appropriate filter

Source: ANSI Standard Z88.2 (1969).