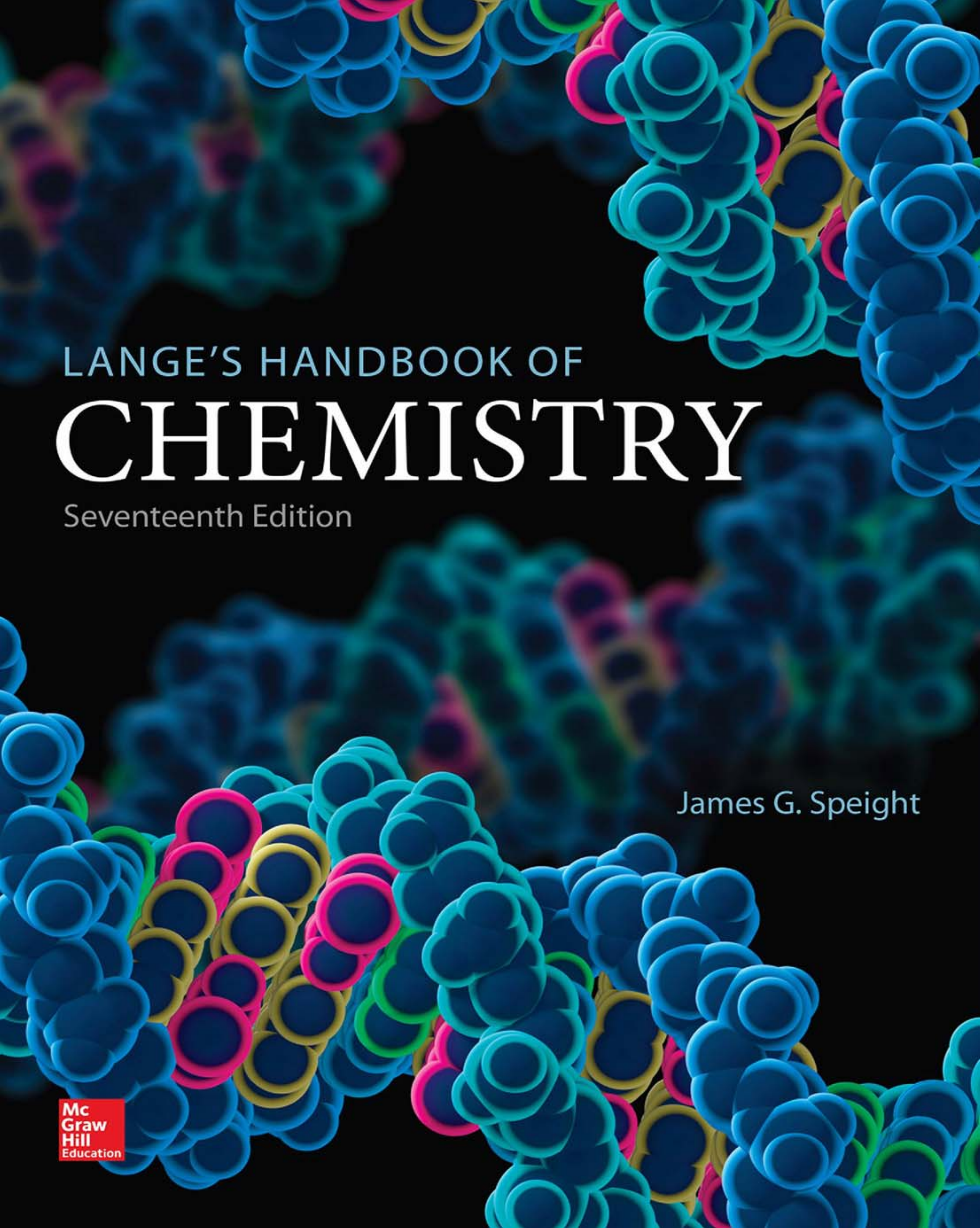

LANGE'S HANDBOOK OF CHEMISTRY

Seventeenth Edition

James G. Speight

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Education

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CHEMISTRY

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Dr. James G. Speight
CD&W Inc., Laramie, Wyoming

Seventeenth Edition

McGraw Hill Education

New York Chicago San Francisco Athens London
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ABOUT THE EDITOR

Dr. James G. Speight, CChem, FRSC, FCIC, FACS, earned his B.Sc. and Ph.D. degrees (in chemistry) from the University of Manchester, England. He also holds a D.Sc. (in geological sciences) from VINIGRI, St. Petersburg, Russia, and a Ph.D. (in petroleum engineering) from Dubna International University, Moscow, Russia.

Dr. Speight has more than 45 years of experience in areas associated with (1) the properties, recovery, and refining of reservoir fluids, conventional petroleum, heavy oil, and tar sands bitumen; (2) the properties and refining of natural gas and gaseous fuels; and (3) the properties and refining of biomass, biofuels, and biogas, and the generation of bioenergy. His work has also focused on safety issues, environmental effects, and remediation associated with the production and use of fuels and biofuels. Dr. Speight is the author of more than 65 books on petroleum science, petroleum engineering, biomass and biofuels, and environmental sciences.

He was elected to the Russian Academy of Sciences in 1996 and awarded the Gold Medal of Honor that same year for outstanding contributions to the field of petroleum sciences. Dr. Speight has also received the Scientists without Borders Medal of Honor from the Russian Academy of Sciences. In 2001, the Academy awarded him the Einstein Medal for outstanding contributions and service in the field of geological sciences.

CONTENTS

For the detailed contents of any section, consult the first page of that section. See also the alphabetical index in the back of this Handbook.

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PREFACE TO THE SEVENTEENTH EDITION

This new edition continues the tradition of previous editions by being a one-volume source of factual information for professional chemists, technicians, and students. The aim of *Lange's Handbook of Chemistry* is to provide sufficient data to satisfy the general needs of those working in the field of chemistry without their having to consult a multitude of scattered and diverse reference sources.

The book is divided into three main sections on inorganic chemistry, organic chemistry, and naturally occurring chemicals and chemical sources.

Section 1, Inorganic Chemistry, contains information relevant to the properties and behavior of elements and compounds. The data for each element and compound include (where available) name, naturally occurring isotopes, structural formula, formula weight, density, refractive index, melting point, and solubility in water.

Section 2, Organic Chemistry, contains the descriptive properties of approximately 5000 organic compounds. Entries are listed alphabetically to the extent possible, and the data for each compound include (where available) name, structural formula, formula weight, density, refractive index, melting point, boiling point, flash point, and solubility in water and various common organic solvents. Alternative names, as well as trivial names of long-standing usage, are listed as well.

Section 3, Naturally Occurring Chemicals and Chemical Sources, is new, and offers the reader details of the behavior and properties of the various fossil fuels (coal, crude oil, natural gas, tar sands, and oil shale) as well as details of the behavior and properties of biomass, biofuels, and minerals.

Two additional sections filled with useful information are available online at www.mhprofessional.com/Langes. The first, Spectroscopy, includes ultraviolet-visible spectroscopy, fluorescence, infrared and Raman spectroscopy, and X-ray spectrometry. Detection limits are listed for the elements when using flame emission, flame atomic absorption, electrothermal atomic absorption, argon induction-coupled plasma, and flame atomic fluorescence. Nuclear magnetic resonance embraces tables for the nuclear properties of the elements, proton chemical shifts and coupling constants, and similar material for carbon-13, boron-11, nitrogen-15, fluorine-19, silicon-29, and phosphorus-31. The second section, General Information and Conversion Tables, contains the general information and conversion tables required by the chemist.

Working professionals will find this *Handbook* appropriate for their needs. It is oriented toward scientists, engineers, or technologists who are employed by consultants, public works agencies, industry, regulatory agencies, universities, or equipment manufacturers, as well as planners, corporate managers, architects, elected officials, lawyers, students, or others seeking insight into the properties and behavior of chemicals.

It is hoped that users of this *Handbook* will continue to offer suggestions of material that might be included in, or even excluded from, future editions and call attention to errors. Such communications should be directed to the editor either directly or through the publisher, McGraw-Hill Education.

Dr. James G. Speight
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PREFACE TO THE SIXTEENTH EDITION

This Sixteenth Edition of *Lange's Handbook of Chemistry* takes on a new format under a new editor. Nevertheless, the Handbook remains the one-volume source of factual information for chemists and chemical engineers, both professionals and students. The aim of the Handbook remains to provide sufficient data to satisfy the general needs of the user without recourse to other reference sources. The many tables of numerical data that have been compiled, as well as additional tables, will provide the user with a valuable time-saver.

The new format involves division of the Handbook into four major sections, instead of the 11 sections that were part of previous editions. Section 1, Inorganic Chemistry, contains a group of tables relating to the physical properties of the elements (including recently discovered elements) and several thousand compounds. Likewise, Sec. 2, Organic Chemistry, contains a group of tables relating to the physical properties of the elements and several thousand compounds. Following these two sections, Sec. 3, Spectroscopy, presents the user with the fundamentals of the various spectroscopic techniques. This section also contains tables that are relevant to the spectroscopic properties of elements, inorganic compounds, and organic compounds. Section 4, General Information and Conversion Tables, contains all of the general information and conversion tables that were previously found in different sections of the Handbook.

In Secs. 1 and 2, the data for each compound include (where available) name, structural formula, formula weight, density, refractive index, melting point, boiling point, flash point, dielectric constant, dipole moment, solubility (if known) in water and relevant organic solvents, thermal conductivity, and electrical conductivity. The presentation of alternative names, as well as trivial names of long-standing use, has been retained. Section 2 also contains expanded information relating to the names and properties of condensed polynuclear aromatic compounds.

Enthalpies and Gibbs Energies of Formation, Entropies, and Heat Capacities of Organic and Inorganic Compounds, and Heats of Melting, Vaporization, and Sublimation and Specific Heat at Various Temperatures, are also presented in Secs. 1 and 2 for organic and inorganic compounds, as well as information on the critical properties (critical temperature, critical pressure, and critical volume).

As in the previous edition, Sec. 3, Spectroscopy, retains subsections on infrared spectroscopy, Raman spectroscopy, fluorescence spectroscopy, mass spectrometry, and X-ray spectrometry. The section on practical laboratory information (now Sec. 4) has been retained as it offers valuable information and procedures for laboratory methods.

As stated in the prefaces of earlier editions, every effort has been made to select the most useful and reliable information and to record it with accuracy. It is hoped that users of this Handbook will continue to offer suggestions of material that might be included in, or even excluded from, future editions and call attention to errors. These communications should be directed to the editor through the publisher, McGraw-Hill.

Dr. James G. Speight
Laramie, Wyoming

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PREFACE TO THE FIRST EDITION

This book is the result of a number of years' experience in the compiling and editing of data useful to chemists. In it an effort has been made to select material to meet the needs of chemists who cannot command the unlimited time available to the research specialist, or who lack the facilities of a large technical library which so often is not conveniently located at many manufacturing centers. If the information contained herein serves this purpose, the compiler will feel that he has accomplished a worthy task. Even the worker with the facilities of a comprehensive library may find this volume of value as a time-saver because of the many tables of numerical data which have been especially computed for this purpose.

Every effort has been made to select the most reliable information and to record it with accuracy. Many years of occupation with this type of work bring a realization of the opportunities for the occurrence of errors, and while every endeavor has been made to prevent them, yet it would be remarkable if the attempts towards this end had always been successful. In this connection it is desired to express appreciation to those who in the past have called attention to errors, and it will be appreciated if this be done again with the present compilation for the publishers have given their assurance that no expense will be spared in making the necessary changes in subsequent printings.

It has been aimed to produce a compilation complete within the limits set by the economy of available space. One difficulty always at hand to the compiler of such a book is that he must decide what data are to be excluded in order to keep the volume from becoming unwieldy because of its size. He can hardly be expected to have an expert's knowledge of all branches of the science nor the intuition necessary to decide in all cases which particular value to record, especially when many differing values are given in the literature for the same constant. If the expert in a particular field will judge the usefulness of this book by the data which it supplies to him from fields other than his specialty and not by the lack of highly specialized information in which only he and his co-workers are interested (and with which he is familiar and for which he would never have occasion to consult this compilation), then an estimate of its value to him will be apparent. However, if such specialists will call attention to missing data with which they are familiar and which they believe others less specialized will also need, then works of this type can be improved in succeeding editions.

Many of the gaps in this volume are caused by the lack of such information in the literature. It is hoped that to one of the most important classes of workers in chemistry, namely the teachers, the book will be of value not only as an aid in answering the most varied questions with which they are confronted by interested students, but also as an inspiration through what it suggests by the gaps and inconsistencies, challenging as they do the incentive to engage in the creative and experimental work necessary to supply the missing information.

While the principal value of the book is for the professional chemist or student of chemistry, it should also be of value to many people not especially educated as chemists. Workers in the natural sciences—physicists, mineralogists, biologists, pharmacists, engineers, patent attorneys, and librarians—are often called upon to solve problems dealing with the properties of chemical products or materials of construction. For such needs this compilation supplies helpful information and will serve not only as an economical substitute for the costly accumulation of a large library of monographs on specialized subjects, but also as a means of conserving the time required to search for information so widely scattered throughout the literature. For this reason especial care has been taken in compiling a comprehensive index and in furnishing cross references with many of the tables.

It is hoped that this book will be of the same usefulness to the worker in science as is the dictionary to the worker in literature, and that its resting place will be on the desk rather than on the bookshelf.

N. A. Lange
Cleveland, Ohio
May 2, 1934

LANGE'S
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CHEMISTRY

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SECTION 1

INORGANIC CHEMISTRY

1.1 NOMENCLATURE OF INORGANIC COMPOUNDS

The following synopsis of rules for naming inorganic compounds and the examples given in explanation are not intended to cover all the possible cases.

Generally, there are two types of inorganic compounds that can be formed: ionic compounds and molecular compounds.

Compounds consisting of a metal and nonmetal are commonly known as ionic compounds, where the compound name has an ending of *-ide*. Cations have positive charges while anions have negative charges. The net charge of any ionic compound must be zero, which also means it must be electrically neutral. For example, one Na^+ is paired with one Cl^-, and one Ca^{2+} is paired with two Br^-. The rules of nomenclature state that (1) the cation (metal) is always named first with its name unchanged, and (2) the anion (nonmetal) is written after the cation, modified to end in *-ide*.

The transition metals may form more than one ion, thus it is needs to be specified which particular ion we are talking about. This is indicated by assigning a Roman numeral after the metal, which denotes the charge and the oxidation state of the transition metal ion. For example, iron can form two common ions: Fe^{2+} and Fe^{3+}. To distinguish between the two, Fe^{2+} is named iron (II) and Fe^{3+} is named iron (III).

However, some of the charges on transition metals have specific Latin names. Just like the other nomenclature rules, the ion of the transition metal that has the lower charge has the Latin name ending with *-ous* and the one with the higher charge has a Latin name ending with *-ic*.

Several exceptions apply to the Roman numeral assignment: aluminum, zinc, and silver. Although they belong to the transition metal category, these metals do not have Roman numerals written after their names because these metals only exist in one ion. Instead of using Roman numerals, the different ions can also be presented in plain words. The metal is changed to end in *-ous* or *-ic*.

Although HF can be named hydrogen fluoride, it is given a different name for emphasis that it is an acid—a substance that dissociates into hydrogen ions (H^+) and anions in water. A quick way to identify acids is to see if there is an H (denoting hydrogen) in front of the molecular formula of the compound. To name acids, the prefix *hydro-* is placed in front of the nonmetal modified to end with *-ic*. The state of acids is aqueous (aq) because acids are found in water. Some common binary acids include:

HF (g) (hydrogen fluoride) → HF (aq) (hydrofluoric acid)
HBr (g) (hydrogen bromide) → HBr (aq) (hydrobromic acid)
HCl (g) (hydrogen chloride) → HCl (aq) (hydrochloric acid)
H_2S (g) (hydrogen sulfide) → H_2S (aq) (hydrosulfuric acid)

Polyatomic ions (meaning two or more atoms) are joined together by covalent bonds. Although there may be an element with positive charge like H^+, it is not joined with another element with an ionic bond. This occurs because if the atoms formed an ionic bond, then it would have already become a compound, thus not needing to gain or lose any electrons. Polyatomic anions have negative charges while polyatomic cations have positive charges. To correctly specify how many oxygen atoms are in the ion, prefixes and suffixes are used.

Cations and Anions

+1 Charge	+2 Charge	−1 Charge	−2 Charge	−3 Charge	−4 Charge
Hydrogen: H^+	Beryllium: Be^{2+}	Hydride: H^-	Oxide: O^{2-}	Nitride: N^{3-}	Carbide: C^{4-}
Lithium: Li^+	Magnesium: Mg^{2+}	Fluoride: F^-	Sulfide: S^{2-}	Phosphide: P^{3-}	
Sodium: Na^+	Calcium: Ca^{2+}	Chloride: Cl^-			
Potassium: K^+	Strontium: Sr^{2+}	Bromide: Br^-			
Rubidium: Rb^+	Barium: Ba^{2+}	Iodide: I^-			
Cesium: Cs^+					

Transition Metals and Metal Cations

+1 Charge	+2 Charge	+3 Charge	+4 Charge
Copper(I): Cu^{+} Silver: Ag^{+}	Copper(II): Cu^{2+} Iron(II): Fe^{2+} Cobalt(II): Co^{2+} Tin(II): Sn^{2+} Lead(II): Pb^{2+} Nickel: Ni^{2+} Zinc: Zn^{2+}	Aluminum: Al^{3+} Iron(III): Fe^{3+} Cobalt(III): Co^{3+}	Lead(IV): Pb^{4+} Tin(IV): Sn^{4+}

Common Polyatomic Ions

Cation or Anion	Formula
Ammonium ion	NH_4^+
Hydronium ion	H_3O^+
Acetate ion	$C_2H_3O_2^-$
Arsenate ion	AsO_4^{3-}
Carbonate ion	CO_3^{2-}
Hypochlorite ion	ClO^-
Chlorite ion	ClO_2^-
Chlorate ion	ClO_3^-
Perchlorate ion	ClO_4^-
Chromate ion	CrO_4^{2-}
Dichromate ion	$Cr_2O_7^{2-}$
Cyanide ion	CN^-
Hydroxide ion	OH^-
Nitrite ion	NO_2^-
Nitrate ion	NO_3^-
Oxalate ion	$C_2O_4^{2-}$
Permanganate ion	MnO_4^-
Phosphate ion	PO_4^{3-}
Sulfite ion	SO_3^{2-}
Sulfate ion	SO_4^{2-}
Thiocyanate ion	SCN^-
Thiosulfate ion	$S_2O_3^{2-}$

1.1.1 Writing Formulas

1.1.1.1 Mass Number, Atomic Number, Number of Atoms, and Ionic Charge. The mass number, atomic number, number of atoms, and ionic charge of an element are indicated by means of four indices placed around the symbol:

$$\begin{matrix}\text{mass number} \\ \text{atomic number}\end{matrix}\ \textbf{SYMBOL}\ \begin{matrix}\text{ionic charge} \\ \text{number of atoms}\end{matrix} \qquad {}^{15}_{7}N_2^{3-}$$

Ionic charge should be indicated by an Arabic superscript numeral preceding the plus or minus sign: Mg^{2+}, PO_4^{3-}

1.1.1.2 Placement of Atoms in a Formula. The electropositive constituent (cation) is placed first in a formula. If the compound contains more than one electropositive or more than one electronegative constituent, the sequence within each class should be in alphabetical order of their symbols. The alphabetical order may be different in formulas and names; for example, $NaNH_4HPO_4$, ammonium sodium hydrogen phosphate.

Acids are treated as hydrogen salts. Hydrogen is cited last among the cations.

When there are several types of ligands, anionic ligands are cited before the neutral ligands.

1.1.1.3 Binary Compounds between Nonmetals. For binary compounds between nonmetals, that constituent should be placed first which appears earlier in the sequence:

Rn, Xe, Kr, Ar, Ne, He, B, Si, C, Sb, As, P, N, H, Te, Se, S, At, I, Br, Cl, O, F

Examples: $AsCl_3$, SbH_3, H_3Te, BrF_3, OF_2, and N_4S_4.

1.1.1.4 Chain Compounds. For chain compounds containing three or more elements, the sequence should be in accordance with the order in which the atoms are actually bound in the molecule or ion.

Examples: SCN^- (thiocyanate), HSCN (hydrogen thiocyanate or thiocyanic acid), HNCO (hydrogen isocyanate), HONC (hydrogen fulminate), and HPH_2O_2 (hydrogen phosphinate).

1.1.1.5 Use of Centered Period. A centered period is used to denote water of hydration, other solvates, and addition compounds; for example, $CuSO_4 \cdot 5H_2O$, copper(II) sulfate 5-water (or pentahydrate).

1.1.1.6 Free Radicals. In the formula of a polyatomic radical an unpaired electron(s) is (are) indicated by a dot placed as a right superscript to the parentheses (or square bracket for coordination compounds). In radical ions the dot precedes the charge. In structural formulas, the dot may be placed to indicate the location of the unpaired electron(s).

Examples: $(HO)^{\cdot}$ $(O_2)^{2\cdot}$ $(\dot{N}H^+{}_3)$

1.1.1.7 Enclosing Marks. Where it is necessary in an inorganic formula, enclosing marks (parentheses, braces, and brackets) are nested within square brackets as follows:

[( )], [{ ( ) }], [{ [( )] }], [{ { [( )] } }]

1.1.1.8 Molecular Formula. For compounds consisting of discrete molecules, a formula in accordance with the correct molecular weight of the compound should be used.

Examples: S_2Cl_2, S_8, N_2O_4, and $H_4P_2O_6$; not SCl, S, NO_2, and H_2PO_3.

1.1.1.9 Structural Formula and Prefixes. In the structural formula the sequence and spatial arrangement of the atoms in a molecule are indicated.

Examples: NaO(O═C)H (sodium formate), Cl—S—S—Cl (disulfur dichloride).

Structural prefixes should be italicized and connected with the chemical formula by a hyphen: *cis-, trans-, anti-, syn-, cyclo-, catena-, o-* or *ortho-, m-* or *meta-, p-* or *para-, sec-* (secondary), *tert-* (tertiary), *v-* (vicinal), *meso-, as-* for asymmetrical, and *s-* for symmetrical.

The sign of optical rotation is placed in parentheses, (+) for dextrorotary, (–) for levorotary, and (±) for racemic, and placed before the formula. The wavelength (in nanometers is indicated by a right subscript; unless indicated otherwise, it refers to the sodium D-line.

The italicized symbols *d*- (for deuterium) and *t*- (for tritium) are placed after the formula and connected to it by a hyphen. The number of deuterium or tritium atoms is indicated by a subscript to the symbol.

Examples:	*cis*-$[PtCl_2(NH_3)_2]$	methan-d_3-ol
	di-*tert*-butyl sulfate	$(+)_{589}$ $[Co(en)_3]Cl_2$
	methan-ol-*d*	

1.1.2 Naming Compounds

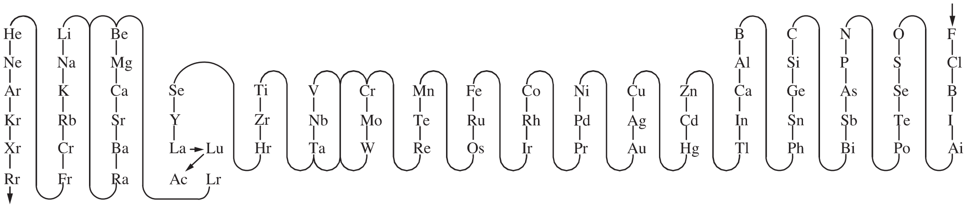
1.1.2.1 Names and Symbols for Elements. Names and symbols for the elements are given in Table 1.3. Wolfram is preferred to tungsten but the latter is used in the United States. In forming a complete name of a compound, the name of the electropositive constituent is left unmodified except when it is necessary to indicate the valency (see oxidation number and charge number, formerly the Stock and Ewens-Bassett systems). The order of citation follows the alphabetic listing of the names of the cations followed by the alphabetical listing of the anions and ligands. The alphabetical citation is maintained regardless of the number of each ligand.

Example: $K[AuS(S_2)]$ is potassium (disulfido)thioaurate (1–).

1.1.2.2 Electronegative Constituents. The name of a monatomic electronegative constituent is obtained from the element name with its ending (-en, -ese, -ic, -ine, -ium, -ogen, -on, -orus, -um, -ur, -y, or -ygen) replaced by -ide. The elements bismuth, cobalt, nickel, zinc, and the noble gases are used unchanged with the ending -ide. Homopolyatomic ligands will carry the appropriate prefix. A few Latin names are used with affixes: cupr- (copper), aur- (gold), ferr- (iron), plumb- (lead), argent- (silver), and stann- (tin).

For binary compounds, the name of the element standing later in the sequence in Sec. 1.1.1.3 is modified to end in -ide. Elements other than those in the sequence of Sec. 1.1.1.3 are taken in the reverse order of the following sequence, and the name of the element occurring last is modified to end in -ide; e.g., calcium stannide.

ELEMENT SEQUENCE



1.1.2.3 Stoichiometric Proportions. The stoichiometric proportions of the constituents in a formula may be denoted by Greek numerical prefixes: mono-, di-, tri-, tetra-, penta-, hexa-, hepta-, octa-, nona- (Latin), deca-, undeca- (Latin), dodeca-, …, icosa- (20), henicosa- (21), …, triconta- (30), tetraconta- (40), …, hecta- (100), and so on, preceding without a hyphen the names of the elements to which they refer. The prefix mono can usually be omitted; occasionally hemi- (1/2) and sesqui- (3/2) are used. No elisions are made when using numerical prefixes except in the case of icosa- when the letter “i” is elided in docosa- and tricosa-. Beyond 10, prefixes may be replaced by Arabic numerals.

When it is required to indicate the number of entire groups of atoms, the multiplicative numerals bis-, tris-, tetrakis-, pentakis-, and so on, are used (i.e., -kis is added starting from tetra-). The entity to which they refer is placed in parentheses.

Examples: $Ca[PF_6]_2$, calcium bis(hexafluorophosphate); and $(C_{10}H_{21})_3PO_4$, tris(decyl) phosphate instead of tridecyl which is $(C_{13}H_{27}–)$.

Composite numeral prefixes are built up by citing units first, then tens, then hundreds, and so on. For example, 43 is written tritetraconta- (or tritetracontakis-).

In indexing it may be convenient to italicize a numerical prefix at the beginning of the name and connect it to the rest of the name with a hyphen; e.g., *di*-nitrogen pentaoxide (indexed under the letter "n").

1.1.2.4 Oxidation and Charge Numbers. The *oxidation number* (Stock system) of an element is indicated by a Roman numeral placed in parentheses immediately following the name of the element. For zero, the cipher 0 is used. When used in conjunction with symbols, the Roman numeral may be placed above and to the right. The *charge number* of an ion (Ewens-Bassett system) rather than the oxidation state is indicated by an Arabic numeral followed by the sign of the charge cited and is placed in parentheses immediately following the name of the ion.

Examples: P_2O_5, diphosphorus pentaoxide or phosphorus(V) oxide; Hg_2^{2+}. mercury(I) ion or dimercury (2+) ion; $K_2[Fe(CN)_6]$, potassium hexacyanoferrate(II) or potassium hexacyanoferrate(4–); $Pb^{II}_2Pb^{IV}O_4$, dilead(II) lead(IV) oxide or trilead tetraoxide.

Where it is not feasible to define an oxidation state for each individual member of a group, the overall oxidation level of the group is defined by a formal ionic charge to avoid the use of fractional oxidation states; for example, O_2^-.

1.1.2.5 Collective Names. Collective names include:

Halogens (F, Cl, Br, I, At)
Chalcogens (O, S, Se, Te, Po)
Alkali metals (Li, Na, K, Rb, Cs, Fr)
Alkaline-earth metals (Ca, Sr, Ba, Ra)
Lanthanoids or lanthanides (La to Lu)
Rare-earth metals (Sc, Y, and La to Lu inclusive)
Actinoids or actinides (Ac to Lr, those whose 5*f* shell is being filled)
Noble gases (He to Rn)

A transition element is an element whose atom has an incomplete *d* subshell, or which gives rise to a cation or cations with an incomplete *d* subshell.

1.1.2.6 Isotopically Labeled Compounds. The hydrogen isotopes are given special names: ^1H (protium), ^2H or D (deuterium), and ^3H or T (tritium). The superscript designation is preferred because D and T disturb the alphabetical ordering in formulas.

Other isotopes are designated by mass numbers: ^{10}B (boron-10).

Isotopically labeled compounds may be described by inserting the italic symbol of the isotope in brackets into the name of the compound; for example, $H^{36}Cl$ is hydrogen chloride[^{36}Cl] or hydrogen chloride-36, and $^2H^{38}Cl$ is hydrogen [^2H] chloride[^{38}Cl] or hydrogen-2 chloride-38.

1.1.2.7 Allotropes. Systematic names for gaseous and liquid modifications of elements are sometimes needed. Allotropic modifications of an element bear the name of the atom together with the descriptor to specify the modification. The following are a few common examples:

Symbol	Trivial name	Systematic name
H	Atomic hydrogen	Monohydrogen
O_2	(Common oxygen)	Dioxygen
O_3	Ozone	Trioxygen
P_4	White phosphorus	Tetraphosphorus
S_8	α-Sulfur, β-Sulfur	Octasulfur
S_n	μ-Sulfur (plastic sulfur)	Polysulfur

Trivial (customary) names are used for the amorphous modification of an element.

1.1.2.8 ***Heteroatomic and Other Anions.*** A few heteroatomic anions have names ending in -ide. These are

—OH, hydroxide ion (not hydroxyl)
—CN, cyanide ion
—NH_2^- hydrogen difluoride ion
—NH_2, amide ion
—NH—, imide ion
—NH—NH_2, hydrazide ion
—NHOH, hydroxylamide ion
—HS^-, hydrogen sulfide ion

Added to these anions are

—triiodide ion
—N_3, axide ion
—O_3, ozonide ion
—O—O—, peroxide ion
—S—S—, disulfide ion

1.1.2.9 ***Binary Compounds of Hydrogen.*** Binary compounds of hydrogen with the more electropositive elements are designated hydrides (NaH, sodium hydride).

Volatile hydrides, except those of Periodic Group VII and of oxygen and nitrogen, are named by citing the root name of the element (penultimate consonant and Latin affixes, Sec. 1.1.2.2) followed by the suffix -ane. Exceptions are water, ammonia, hydrazine, phosphine, arsine, stibine, and bismuthine.

Examples: B_2H_6, diborane; $B_{10}H_{14}$, decaborane (14); $B_{10}H_{16}$, decaborane (16); P_2H_4, diphosphane; Sn_2H_6, distannane; H_2Se_2, diselane; H_2Te_2, ditellane; H_2S_5, pentasulfane; and pbH_4, plumbane.

1.1.2.10 ***Neutral Radicals.*** Certain neutral radicals have special names ending in -yl:

HO	hydroxyl
CO	carbonyl
ClO	chlorosyl[1]
ClO_2	chloryl[1]
ClO_3	perchloryl[1]
CrO_2	chromyl
NO	nitrosyl
NO_2	nitryl (nitroyl)
PO	phosphoryl
SO	sulfinyl (thionyl)
SO_2	sulfonyl (sulfuryl)
S_2O_5	disulfuryl
SeO	seleninyl
SeO_2	selenoyl
UO_2	uranyl
NpO_2	neptunyl[2]

Radicals analogous to the above containing other chalcogens in place of oxygen are named by adding the prefixes thio-, seleno-, and so on; for example, PS, thiophosphoryl; CS, thiocarbonyl.

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[1] Similarly for the other halogens.

[2] Similarly for the other actinide elements.

1.1.3 Cations

1.1.3.1 Monatomic Cations. Monatomic cations are named as the corresponding element; for example, Fe^{2+}, iron(II) ion; Fe^{3+}, iron(III) ion.

This principle also applies to polyatomic cations corresponding to radicals with special names ending in -yl (Sec. 1.1.2.10); for example, PO^+, phosphoryl cation; NO^+, nitrosyl cation; NO_2^{2+}, nitryl cation; O_2^{2+} oxygenyl cation.

Use of the oxidation number and charge number extends the range for radicals; for example, UO_2^{2+} uranyl(VI) or uranyl(2+) cation; UO_2^+ , uranyl(V) or uranyl(1+) cation.

1.1.3.2 Polyatomic Cations. Polyatomic cations derived by addition of more protons than required to give a neutral unit to polyatomic anions are named by adding the ending -onium to the root of the name of the anion element; for example, PH_4^+ phosphonium ion; H_2I^+, iodonium ion; H_3O^+, oxonium ion; $CH_3OH_2^+$ methyl oxonium ion.

Exception: The name ammonium is retained for the NH_4^+ ion; similarly for substituted ammonium ions; for example, NF_4^+, tetrafluoroammonium ion.

Substituted ammonium ions derived from nitrogen bases with names ending in -amine receive names formed by changing -amine into -ammonium. When known by a name not ending in -amine, the cation name is formed by adding the ending -ium to the name of the base (eliding the final vowel); e.g., anilinium, hydrazinium, imidazolium, acetonium, dioxanium.

Exceptions are the names uronium and thiouronium derived from urea and thiourea, respectively.

1.1.3.3 Multiple Ions from One Base. Where more than one ion is derived from one base, the ionic charges are indicated in their names: $N_2H_5^+$, hydrazinium(1+) ion; $N_2H_6^{2+}$, hydrazinium(2+) ion.

1.1.4 Anions

See Secs. 1.1.2.2 and 1.1.2.8 for naming monatomic and certain polyatomic anions. When an organic group occurs in an inorganic compound, organic nomenclature (*q.v.*) is followed to name the organic part.

1.1.4.1 Protonated Anions. Ions such as HSO_4^- are recommended to be named hydrogensulfate with the two words written as one following the usual practice for polyatomic anions.

1.1.4.2 Other Polyatomic Anions. Names for other polyatomic anions consist of the root name of the central atom with the ending -ate and followed by the valence of the central atom expressed by its oxidation number. Atoms and groups attached to the central atom are treated as ligands in a complex.

Examples: $[Sb(OH)_6^-]$, hexahydroxoantimonate(V); $[Fe(CN_6]^{3-}$, hexacyanoferrate(III); $[Co(NO_2)_6]^{3-}$, hexanitritocobaltate(III); $[TiO(C_2O_4)_2(H_2O)_2]^{2-}$, oxobisoxalatodiaquatitanate (IV); $[PCl_6]^-$, hexachlorophosphate(V).

Exceptions to the use of the root name of the central atom are antimonate, bismuthate, carbonate, cobaltate, nickelate (or niccolate), nitrate, phosphate, tungstate (or wolframate), and zincate.

1.1.4.3 Anions of Oxygen. Oxygen is treated in the same manner as other ligands with the number of -oxo groups indicated by a suffix; for example, SO_3^{2-}, trioxosulfate.

The ending -ite, formerly used to denote a lower state of oxidation, may be retained in trivial names in these cases (note Sec. 1.1.5.3 also):

AsO_3^{3-}	arsenite	NOO_2^-	peroxonitrite
BrO^-	hypobromite	PO_3^{3-}	phosphite[3]
ClO^-	hypochlorite	SO_3^{2-}	sulfite
ClO_2^-	chlorite	$S_2O_5^{2-}$	disulfite
IO^-	hypoiodite	$S_2O_4^{2-}$	dithionite
NO_2^-	nitrite	$S_2O_2^{2-}$	thiosulfite
$N_2O_2^{2-}$	hyponitrite	SeO_3^{2-}	selenite

However, compounds known to be double oxides in the solid state are named as such; for example, Cr_2CuO_4 (actually $Cr_2O_3 \cdot CuO$) is chromium(III) copper(II) oxide (and not copper chromite).

1.1.4.4 Isopolyanions. Isopolyanions are named by indicating with numerical prefixes the number of atoms of the characteristic element. It is not necessary to give the number of oxygen atoms when the charge of the anion or the number of cations is indicated.

Examples: $Ca_3Mo_7O_{24}$, tricalcium 24-oxoheptamolybdate, may be shortened to tricalcium heptamolybdate; the anion, $Mo_7O_{24}^{6-}$, is heptamolybdate(6–); $S_2O_7^{2-}$, disulfate(2–); $P_2O_7^{4-}$, diphosphate(V)(4–).

When the characteristic element is partially or wholly present in a lower oxidation state than corresponds to its Periodic Group number, oxidation numbers are used; for example, $[O_2HP—O—PO_3H]^{2-}$, dihydrogendiphosphate(III, V)(2–).

A bridging group should be indicated by adding the Greek letter μ immediately before its name and separating this from the rest of the complex by a hyphen. The atom or atoms of the characteristic element to which the bridging atom is bonded, is indicated by numbers.

Examples: $[O_3P—S—PO_2—O—PO_3]^{5-}$, 1, 2-$\mu$-thiotriphosphate(5–)
$[S_3P—O—PS_2—O—PS_3]^{5-}$, di-$\mu$-oxo-octathiotriphosphate(5–)

1.1.5 Acids

1.1.5.1 Acids and -ide Anions. Acids giving rise to the -ide anions (Sec. 1.1.2.2) should be named as hydrogen … -ide; for example, HCl, hydrogen chloride; HN_3, hydrogen azide.

Names such as hydrobromic acid refer to an aqueous solution, and percentages such as 48% HBr denote the weight/volume of hydrogen bromide in the solution.

1.1.5.2 Acids and -ate Anions. Acids giving rise to anions bearing names ending in -ate are treated as in Sec. 1.1.5.1; for example, H_2GeO_4, hydrogen germanate; $H_4[Fe(CN)_6]$, hydrogen hexacyanoferrate(II).

1.1.5.3 Trivial Names. Acids given in Table 1.1 retain their trivial names due to long-established usage. Anions may be formed from these trivial names by changing -ous acid to -ite, and -ic acid to -ate. The prefix hypo- is used to denote a lower oxidation state and the prefix per- designates a higher oxidation state. The prefixes ortho- and meta- distinguish acids of differing water content; for example, H_4SiO_4 is orthosilicic acid and H_2SiO_3 is metasilicic acid. The anions would be named silicate (4–) and silicate(2–), respectively.

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[3] Named for esters formed from the hypothetical acid $P(OH)_3$.

1.1.5.4 Peroxo- Group. When used in conjunction with the trivial names of acids, the prefix peroxo- indicates substitution of —O—by—O—O—.

1.1.5.5 Replacement of Oxygen by Other Chalcogens. Acids derived from oxoacids by replacement of oxygen by sulfur are called thioacids, and the number of replacements are given by prefixes di-, tri-, and so on. The affixes seleno- and telluro- are used analogously.

Examples: HOO—C═S, thiocarbonic acid; HSS—C═S, trithiocarbonic acid.

1.1.5.6 Ligands Other than Oxygen and Sulfur. See Sec. 1.1.7, Coordination Compounds, for acids containing ligands other than oxygen and sulfur (selenium and tellurium).

1.1.5.7 Differences between Organic and Inorganic Nomenclature. Organic nomenclature is largely built upon the scheme of substitution, that is, the replacement of hydrogen atoms by other atoms or groups. Although rare in inorganic nomenclature: NH_2Cl is called chloramine and $NHCl_2$ dichloroamine. Other substitutive names are fluorosulfonic acid and chlorosulfonic acid derived from HSO_3H. These and the names aminosulfonic acid (sulfamic acid), iminodisulfonic acid, and nitrilotrisulfonic acid should be replaced by the following based on the concept that these names are formed by adding hydroxyl, amide, imide, and so on, groups together with oxygen atoms to a sulfur atom:

HSO_3F	fluorosulfuric acid	$NH(SO_3H)_2$	imidobis(sulfuric) acid
HSO_3Cl	chlorosulfuric acid	$N(SO_3H)_3$	nitridotris(sulfuric) acid
NH_2SO_3H	amidosulfuric acid		

1.1.6 Salts and Functional Derivatives of Acids

1.1.6.1 Acid Halogenides. For acid halogenides the name is formed from the corresponding acid radical if this has a special name (Sec. 1.1.2.10); for example, NOCl, nitrosyl chloride. In other cases these compounds are named as halogenide oxides with the ligands listed alphabetically; for example, BiClO, bismuth chloride oxide; VCl_2O, vanadium(IV) dichloride oxide.

1.1.6.2 Anhydrides. Anhydrides of inorganic acids are named as oxides; for example, N_2O_5, dinitrogen pentaoxide.

1.1.6.3 Esters. Esters of inorganic acids are named as the salts; for example, $(CH_3)_2SO_4$, dimethyl sulfate. However, if it is desired to specify the constitution of the compound, the nomenclature for coordination compounds should be used.

1.1.6.4 Amides. Names for amides are derived from the names of the acid radicals (or from the names of acids by replacing acid by amide); for example, $SO_2(NH_2)_2$, sulfonyl diamide (or sulfuric diamide); NH_2SO_3H, sulfamidic acid (or amidosulfuric acid).

1.1.6.5 Salts. Salts containing acid hydrogen are named by adding the word hydrogen before the name of the anion (however, see Sec. 1.1.4.1), for example, KH_2PO_4, potassium dihydrogen phosphate; $NaHCO_3$, sodium hydrogen carbonate (not bicarbonate); $NaHPHO_3$, sodium hydrogen phosphonate (only one acid hydrogen remaining).

Salts containing O^{2-} and HO^- anions are named oxide and hydroxide, respectively. Anions are cited in alphabetical order which may be different in formulas and names.

Examples: FeO(OH), iron(III) hydroxide oxide; $VO(SO_4)$, vanadium(IV) oxide sulfate.

1.1.6.6 Multiplicative Prefixes. The multiplicative prefixes bis, tris, etc., are used with certain anions for indicating stoichiometric proportions when di, tri, etc., have been preempted to designate condensed anions; for example, $AlK(SO_4)_2 \cdot 12H_2O$, aluminum potassium bis(sulfate) 12-water (recall that disulfate refers to the anion $S_2O_7^{2-}$).