Handbook of Inorganic Chemicals

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Preface

This handbook is an encyclopedic treatment of chemical elements and their most important compounds intended for professionals and students in many areas of chemistry throughout the manufacturing, academic, and consulting communities. Chemicals are presented in alphabetical order in a descriptive format highlighting pertinent information on physical, chemical, and thermodynamic properties of chemicals, methods of preparation, industrial applications, chemical analyses, and toxic and hazardous properties. Synonyms, CAS Registry Numbers, brief history of discovery and natural occurrence are provided for many entries. The objective is to provide readers a single source for instant information about important aspects each substance. In this sense it should serve as a combination handbook and encyclopedia.

Readers may note three unique features in this text. First, there is a substantial discussion of chemical reactions of all elements and many of their compounds, a practice abandoned nowadays by most modern reference and handbooks. Second, analytical methods are presented for identification and measurement of practically all entries. In many instances, the method is based on my own research and experience. Third, a preparation method is given for all entries. For most compounds, more than one preparative method is presented, covering both laboratory and commercial production. Also, a brief history of the discovery and early production of selected elements is presented to serve as background against which modern methods may be judged and historical perspective maintained.

It has been a hard task indeed to select a limited number of compounds from among over one hundred thousand inorganic chemicals used in industry. Because of space limitations, only a small number have been selected as main entries, but many more have been cited under each entry.

I hope that you find this book useful, and that you will let the publisher and me know how we may make it more useful to you.

Pradyot Patnaik,
Burlington, NJ.
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Acknowledgments

Introduction

All of the elements and many important compounds are presented in this reference. Substances are arranged in alphabetical order. Each entry topic is discussed briefly below.

Elements

Chemical names are followed by Chemical Abstract Service (CAS) registry numbers. This is followed by symbols, atomic numbers, atomic weights, group numbers in the Periodic Table (the older but more common CAS system and the present IUPAC Group numbers given in parentheses), electron configuration, valence states, most stable oxidation states, and atomic and ionic radii. Naturally occurring stable isotopes, abundance, artificial radioactive isotopes and longest- and shortest-lived radioisotopes with half-lives are presented for all elements. Additionally for many elements, electronegativity and standard electrode potential data are presented.

The next section under "Elements" is subtitled "History, Occurrence and Uses." This includes a brief history of chemical discoveries and the origin of their names and symbols, natural occurrence, principal minerals, abundance in the earth's crust and in sea water and principal uses. Uses include commercial applications, preparative reactions, analytical applications and other laboratory reactions. More general information is provided in this section.

The "Physical Properties" are listed next. Under this loose term a wide range of properties, including mechanical, electrical and magnetic properties of elements are presented. Such properties include color, odor, taste, refractive index, crystal structure, allotropic forms (if any), hardness, density, melting point, boiling point, vapor pressure, critical constants (temperature, pressure and volume/density), electrical resistivity, viscosity, surface tension, Young's modulus, shear modulus, Poisson's ratio, magnetic susceptibility and the thermal neutron cross section data for many elements. Also, solubilities in water, acids, alkalies, and salt solutions (in certain cases) are presented in this section.

Under the title "Thermochemical Properties," both thermodynamic and thermal properties appear. These include thermodynamic properties, enthalpies of formation, Gibbs free energy of formation, entropies and heat capacities, and

thermal properties such as thermal conductivities, coefficient of linear expansion, heat of fusion, and the heat of vaporization.

Under the "Recovery" or "Production" mining of ores, ore opening, separation, and isolation into pure elements are touched upon briefly.

The "Reactions" section highlights only important reactions that include formation of binary compounds, oxo salts, and complexes.

The "Analysis" section includes qualitative identification and quantitative measurement of the element in free elemental form or its compounds and alloys.

"Toxicity" or "Hazard" sections are presented last to illustrate dangerous properties of elements and compounds that are toxic, flammable, explosive, or otherwise harmful.

Compounds

Compounds of the elements are also presented in similar format. This includes CAS Registry Numbers, formulas, molecular weights and the hydrates they form (if any). This is followed by occurrence (for naturally occurring compounds) and industrial applications. The section on "Physical Properties" covers the color, crystal structure, density, melting and boiling points and solubilities of the compounds in water, acids, alkalies and organic solvents.

"Thermochemical Properties" mostly covers heats of formation, Gibbs free energy, entropies, and heat capacities. For many compounds, heats of fusion and vaporization are included.

Under the heading "Preparation" or "Production," preparative processes are described briefly. Chemical equations are shown wherever applicable. While "Preparation" refers to laboratory method or a general preparative method, the term "Production" refers to commercial manufacturing processes. For many compounds both historical preparative methods and those in common use are described.

The section "Analysis" starts with elemental composition of the compound. Thus the composition of any compound can be determined from its elemental analysis, particularly the metal content. For practically all metal salts, atomic absorption and emission spectrophotometric methods are favored in this text for measuring metal content. Also, some other instrumental techniques such as x-ray fluorescence, x-ray diffraction, and neutron activation analyses are suggested. Many refractory substances and also a number of salts can be characterized nondestructively by x-ray methods. Anions can be measured in aqueous solutions by ion chromatography, ion-selective electrodes, titration, and colorimetric reactions. Water of crystallization can be measured by simple gravimetry or thermogravimetric analysis.

A section on "Toxicity" is presented in many entries for poisonous and carcinogenic substances. If a substance is flammable or explosive or toxic, the section is subtitled "Hazard." Only substances that manifest poisoning effects even at small doses or are highly corrosive, or highly flammable or reactive are mentioned in this section, although most substances can be hazardous at high doses or under unusual conditions.

Definitions

General and Physical Properties

Electron configuration of an atom indicates its extranuclear structure; that is, arrangement of electrons in shells and subshells. Chemical properties of elements (their valence states and reactivity) can be predicted from electron configuration.

Valence state of an atom indicates its power to combine to form compounds. It also determines chemical properties.

Electronegativity refers to tendency of an atom to pull electrons towards itself in a chemical bond. Nonmetals have high electronegativity, fluorine being the most electronegative while alkali metals possess least electronegativity. Electronegativity difference indicates polarity in the molecule.

Ionization potential is the energy required to remove a given electron from its atomic orbital. Its values are given in electron volts (eV).

Isotopes are atoms of the same elements having different mass numbers. Radioisotopes are the isotopes of an element that are radioactive or emit ionizing radiation. All elements are known to form artificial radioactive isotopes by nuclear bombardment.

Half-life of a radioactive isotope is the average time required for one-half the atoms in a sample of radioactive element to decay. It is expressed as $t_{1/2}$ and is equal to:

$$t_{1/2} = \ln 2/\lambda \text{ , where } \lambda \text{ is a decay constant.}$$

Atomic radius refers to relative size of an atom. Among the main group of elements, atomic radii mostly decrease from left to right across rows in the Periodic Table. Going down in each group, atoms get bigger. Ionic radius is a measure of ion size in a crystal lattice for a given coordination number (CN). Metal ions are smaller than their neutral atoms, and nonmetallic anions are larger than the atoms from which they are formed. Ionic radii depend on the element, its charge, and its coordination number in the crystal lattice. Atomic and ionic radii are expressed in angstrom units of length (Å).

Standard electrode potential is an important concept in electrochemistry. Standard potentials for many half-reactions have been measured or calculated. It is designated as EƳ and expressed in volts (V). From the values of $E°$ one can

predict if a species will be oxidized or reduced in solution (under acidic or basic conditions) and whether any oxidation-reduction reaction will take place.

Solubility data are presented for practically all entries. Quantitative data are also given for some compounds at different temperatures. In general, ionic substances are soluble in water and other polar solvents while the non-polar, covalent compounds are more soluble in the non-polar solvents. In sparingly soluble, slightly soluble or practically insoluble salts, degree of solubility in water and occurrence of any precipitation process may be determined from the solubility product, Ksp, of the salt. The smaller the Ksp value, the less its solubility in water.

Hardness measures ability of substances to abrade or indent one another. Several arbitrary scales have been developed to compare hardness of substances. Mohs hardness is based on a scale from 1 to 10 units in which diamond, the hardest substance, is given a value of 10 Mohs and talc given a value of 0.5.

Vapor pressure is exerted by a solid or liquid in equilibrium with its own vapor. All liquids have vapor pressures. Vapor pressure depends on temperature and is characteristic of each substance. The higher the vapor pressure at ambient temperature, the more volatile the substance. Vapor pressure of water at 20ºC is 17.535 torr.

Refractive index or index of refraction is the ratio of wavelength or phase velocity of an electromagnetic wave in a vacuum to that in the substance. It measures the amount of refraction a ray of light undergoes as it passes through a refraction interface. Refractive index is a useful physical property to identify a pure compound.

Temperature at the critical point (end of the vapor pressure curve in phase diagram) is termed critical temperature. At temperatures above critical temperature, a substance cannot be liquefied, no matter how great the pressure. Pressure at the critical point is called critical pressure. It is the minimum pressure required to condense gas to liquid at the critical temperature. A substance is still a fluid above the critical point, neither a gas nor a liquid, and is referred to as a supercritical fluid. The critical temperature and pressure are expressed in this text in ºC and atm, respectively.

Viscosity is a property of a fluid indicating its resistance to change of form (or resistance to flow). It is expressed as g/cm sec or Poise; 1 Poise = 100 centipoise.

Surface tension occurs when two fluids are in contact with each other. This is caused by molecular attractions between the molecules of two liquids at the surface of separation. It is expressed as dynes/cm or ergs/cm^2.

Modulus of elasticity is the stress required to produce unit strain to cause a change of length (Young's modulus), or a twist or shear (shear modulus), or a change of volume (bulk modulus). It is expressed as dynes/cm^2.

Thermochemical and Thermal Properties

The enthalpy of formation, $\Delta H_f°$, is the energy change or the heat of reaction in which a compound is formed from its elements. Two examples are shown below:

$$Ca(s) + O_2(g) + H_2(g) \rightarrow Ca(OH)_2(s) \qquad \Delta H_{rxn} = -235.68 \text{ kcal}$$

$$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g) \qquad\qquad \Delta H_{rxn} = -22.04 \text{ kcal}$$
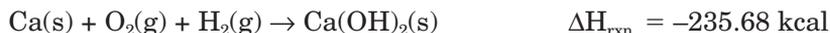
The ΔH_f° in the above reactions are –235.68 and –11.02 kcal/mol, respectively. In the second case, the value of ΔH_f° is one-half of ΔH_{rxn} since two moles of NH_3 are produced in the reaction. Also note that ΔH_f° refers to the formation of a compound from its elements only at the standard state (25°C and 1 atm), and not the formation from other compound(s).

The term ΔG_f° refers to the standard free energies of formation of compounds at 25°C and 1 atm. Its relation with enthalpy change, ΔH, and entropy change, ΔS, at a temperature T (in °K) can be expressed as:

$$\Delta G = \Delta H - T\Delta S$$

The value of ΔG_f° can be calculated from the above equation and from other equations also.

Entropy is a thermodynamic quantity that is a measure of disorder or randomness in a system. When a crystalline structure breaks down and a less ordered liquid structure results, entropy increases. For example, the entropy (disorder) increases when ice melts to water. The total entropy of a system and its surroundings always increases for a spontaneous process. The standard entropies, S° are entropy values for the standard states of substances.

Heat capacity, C_ρ is defined as the quantity of thermal energy needed to raise the temperature of an object by 1°C. Thus, the heat capacity is the product of mass of the object and its specific heat:

$$C_\rho = \text{mass} \times \text{specific heat}$$

Specific heat is the amount of heat required to raise the temperature of one gram of a substance by 1°C. The specific heat of water is 1 calorie or 4.184 Joule.

The heat of fusion, ΔH_{fus} is the amount of thermal energy required to melt one mole of the substance at the melting point. It is also termed as latent heat of fusion and expressed in kcal/mol or kJ/mol.

The heat of vaporization, ΔH_{vap}, is the amount of thermal energy needed to convert one mole of a substance to vapor at boiling point. It is also known as latent heat of vaporization and expressed kcal/mol or kJ/mol.

Thermal conductivity measures the rate of transfer of heat by conduction through unit thickness, across unit area for unit difference of temperature. It is measured as calories per second per square centimeter for a thickness of one centimeter and a temperature difference of 1°C. Its units are cal/cm sec.°K or W/cm°K.

The coefficient of linear thermal expansion is the ratio of the change in length per degree C to the length at 0°C.

Analysis

All metals at trace concentration, or in trace quantities, can be analyzed by atomic absorption (AA) spectrophotometry in flame or graphite furnace (electrothermal reduction) mode. A rapid, multi-element analysis may use

advanced instruments available commercially. Also, Inductively Coupled Plasma Atomic Emission Spectrophotometric methods (ICP-AES) are rapid, versatile, and multi-element analytical methods. They offer certain advantages over flame or furnace AA. ICP/MS (mass spectrometry) is the most sensitive technique because it provides a detection level over one hundred times lower than AA or ICP. For all such analyses, solid compounds must be dissolved in water by acid digestion or alkali fusion. Other instrumental techniques for metal analyses include x-ray fluorescence, x-ray diffraction, neutron activation analysis, and ion-specific electrode methods. Also, colorimetric methods that are prone to interference effects may be applied to identify metals in their pure salts.

Anions may be measured best by ion chromatography, using appropriate anion exchange resin columns that are available commercially. Salts may be diluted for such measurements. Ion-selective electrode methods also yield satisfactory results at trace concentrations. Numerous colorimetric methods are reported in literature. They are susceptible to erroneous results when impurities are present. Many titration methods are available in analytical chemistry. They may be applied successfully to measure certain anions, oxidizing and reducing substances, acids, and bases.

Thermogravimetric analysis (TGA) and the differential thermal analysis (DTA) may be used to measure the water of crystallization of a salt and the thermal decomposition of hydrates.

Substances also can be identified from physical properties such as density, melting and boiling points, and refractive index. Elemental analysis can confirm the identity of a compound.

Hazard

Toxicity of many entries are expressed quantitatively as LD_{50} (median lethal dose) or LC_{50} (median lethal concentration in air). The latter refers to inhalation toxicity of gaseous substances in air. Both these terms refer to the calculated concentration of a chemical that can kill 50% of test animals when administered.

A substance is usually termed "flammable" if its flash point is below 100°F (38°C).

Some Physical Constants

Velocity of light, c = 2.9979 × 10^8 m/s (in vacuum)
Planck's constant, h = 1.05457 × 10^{-34} J.s
Rydberg constant, R$_H$ = 2.17991 × 10^{-18} J
Boltzmann constant, k = 1.3807 × 10^{-16} erg/K
Acceleration of gravity, g = 980.6 cm/s
Electron mass, me = 9.1094 × 10^{-31} kg
Proton mass, m$_r$ = 1.6726 × 10^{-27} kg
Neutron mass, mn = 1.6749 × 10^{-27}kg
Proton-electron mass ratio = 1836
Atomic mass unit (amu) = 1.6605 × 10^{-27} kg
Electron charge, e = 1.60219 × 10^{-19} C
Faraday constant, F = 9.648456 × 10^4 C
Avogadro constant = 6.022 × 10^{23}/mol
Molar volume at STP = 22.41384 L
Molar gas constant, R = 0.08026 L. atm/mol. K
                          = 8.3145 J/mol. K
                          = 1.9872 cal/mol. K

Units and Conversion

Temperature

°C = (°F −32)/1.8
°F = 1.8°C + 32
°K = °C + 273.15

Pressure

1 atm = 101.365 KPa
       = 101,365 Pa
       = 0.101365 MPa
1 MPa = 9.87 atm
1 atm = 760 torr = 760 mm Hg
1 atm = 14.696 psi
1 KPa = 7.50 torr

Volume

1 L = 1,000 mL
1 mL = 1 cubic centimeter (cc)
1 m^3 = 1000 L
1 gal (US) = 3.784 L
1 quart (qt) = 946.4 mL
1 tablespoon = 14.79 mL
1 teaspoon = 4.93 mL

Energy

1 cal = 4.184 J
1 kcal = 1,000 cal
1 kJ = 1,000 J
1 eV = 1.602×10^{-19} J
1 MeV = 1.602×10^{-13} J

Distance, Bond Length and Atomic Radii

1 km = 1,000 m
1 m = 100 cm or 1,000 mm
1 mm = 1,000 μm
1 μm = 1,000 mm
1 nm = 1,000 pm
1 m = 10^6 mm or 10^9 nm
1 mho = 1 siemen (S)
1 Å = 10^{-10} m
1 Å = 10pm
1 micron = 1 micrometer (μm)

Density

Solid = g/cm^3
Liquid = g/mL
Gas = g/L
Density of gas/vapor at STP = molecular wt(g)/22.4 L
Vapor density (times heavier than air) = molecular wt/29

Concentration

1ppm (w/w) = 1mg/L (in aqueous solution)
1M = mol/L
1N = gram equivalent weight/L
1 m = mol/kg solvent

Miscellaneous

1dyne/cm^2 = 0.10 Pa
1 erg = 10^{-7} J
1 erg/s = 10^{-7}watt (W)
1 Faraday = 96,495 coulomb (C)
1 inch = 2.54 cm
1 mho = 1 siemen (S)
1 ohm.cm = 10^{-2} ohm.cm
1 ohm.cm = 10^6 microhm.cm
1 centipoise = 0.001 Pascal-second
1 centistoke = 1×10^{-6} m^2/sec

Bibliography

Some general bibliographic references follow. Additional references from journals and historical literature have been cited in the text.

1. *Kirk-Othmer Encyclopedia of Chemical Technology*, 3rd ed., Vol 1-23, 1970-86; New York: John Wiley & Sons
2. *The Encyclopedia of Chemical Elements*, ed. Clifford A. Hempel, 1968, New York: Reinhold Book Corporation
3. *CRC Handbook of Chemistry and Physics*, 77th ed., edited. David R. Lide, 1999, Boca Raton: CRC Press
4. Cotton, F.A., Wilkinson, G., Murillo, C.A. and M. Bochmann. 1999. *Advanced Inorganic Chemistry*, 6th ed., New York: John Wiley & Sons
5. Patnaik, P. 1999. *A Comprehensive Guide to the Hazardous Properties of Chemical Substances*, 2nd ed. New York: John Wiley & Sons
6. Lewis(Sr.), R.J. 1996 *Sax's Dangerous Properties of Industrial Materials*, 9th ed. New York: Van Nostrand Reinhold
7. *The Merck Index*, 12thed, edited. Susan Budavery, 1995 Rahway, NJ: The Merk and Company, Inc.
8. American Public Health Association, American Water Works Association and Water Environment Federation. 1999. *Standard Methods for the Examination of Water and Wastewater*, 20th ed. Edited Arnold E. Greenberg, Lenore S. Clesceri, and Andrew D. Easton. Washington, DC: American Public Health Association.
9. *The Merck Index*, 12th ed, edited. Susan Budavery, 1995 Rahway, NJ: The Merck and Company, Inc.
10. American Public Health Association, American Water Works Association and Water Environment Federation. 1999. *Standard Methods for the Examination of Water and Wastewater*, 20th ed. Edited Arnold E. Greenberg, Lenore S. Clesceri and Andrew D. Easton. Washington, DC: American Public Health Association
11. Patnaik, P. 1997. *Handbook of Environmental Analysis*, Boca Raton: CRC Press
12. Skoog, D.A. West, D.M. and F. James Holler. 1992. *Fundamentals of Analytical Chemistry*, 6th ed. 1992. New York: Saunders College Publishing
13. Silberberg, M. 1996. *Chemistry, The Molecular Nature of Matter and Change*, St. Louis: Mosby
14. H. Remy. 1956. *Treatise on Theoretical and Inorganic Chemistry*, Amsterdam: Elsevier Publishing Company

ABBREVIATIONS AND STANDARD LETTER SYMBOLS

Absorbance (decaidic)	A
Absorption coefficient, linear decaidic	a
Activation energy	E_a
Activity (radioactive)	A
Adjusted retention time	t'_R
Adjusted retention volume	V'_R
Alcohol	alc
Alkaline	alk
Alpha particle	α
Alternating current	ac
Amorphous	am
Amount concentration	c
Amount of substance	n
Ampere	A
Angle of optical rotation	α
Angstrom	Å
Angular dispersion	$d\theta/d\lambda$
Angular velocity	ω
Anhydrous	anhyd
Approximate	ca.
Aqueous solution phase	aq
Area	A
Atmosphere, unit of pressure	atm
Atomic mass unit	amu
Atomic percent	at.%
Atomic weight	at. wt.
Average	av
Average linear gas velocity	μ
Band width	σ^2
Bar, unit of pressure	bar
Barn, cross section (radioactivity)	b
Base of natural logarithms	e
Becquerel	Bq
Bed volume	V_g
Beta particle	β
Bohr magneton	μ_B
Boiling point	bp
Boltzmann constant	k_B
Bragg angle	θ
Butyl	Bu
Calorie, unit of energy	cal
Capacitance	C
Celsius temperature	t
Charge number of an ion	z

Chemical shift	δ
Citrate	Cit
Compare (confer)	cf.
Concentration at peak maximum	C_{max}
Concentration of solute in mobile phase	C_M
Concentration of solute in stationary phase	C_S
Conductance	G
Conductivity	κ
Coulomb	C
Critical temperature	t_c
Cross section	σ
Curie	Ci
Cycles per second	Hz
Dalton (atomic mass unit)	Da
Decay constant (radioactive)	λ
Decompose	dec
Degree of dissociation	α
Degrees Celsius	°C
Density, critical	d_c
Detect, determine(d)	det(d)
Diffusion coefficient	D
Diffusion coefficient, mobile phase	D_M
Diffusion coefficient, stationary phase	D_S
Diffusion current	i_d
Dilute	dil
Direct current	dc
Disintegration per minute	dpm
Distribution ratio	D
Dropping mercury electrode	dme
Electric current	I
Electric potential	V
Electrical resistance	R
Electromotive force	E, emf
Electron	e^-, e
Electronvolt	eV
Equivalent weight	equiv wt, eq wt
et alii (and others)	et al.
et cetera (and so forth)	etc.
Ethyl	Et
Ethylenediamine-N,N,N',N'-tetra-acetic acid	EDTA

Exempli gratia	e.g.	Oxidant	ox
Exponential	exp	Page(s)	p. (pp.)
Faraday constant	F	Partition ratio	k'
Flowrate, column chromatography	F_c	Parts per billion, volume	ng/mL
Freezing point	fp	Parts per billion, weight	ng/g
Gamma radiation	γ	Parts per million, volume	μg/mL
Gas (physical state)	g	Parts per million, weight	μg/g
Gas constant	R	Pascal	Pa
Gauss	G	Peak resolution	Rs
Gram	g	pH, expressed in activity	paH
Half-life	$t_{1/2}$	expressed in molarity	pH
Half-wave potential	$E_{1/2}$	Phenyl	Ph
Hertz	Hz	Plate number, effective	N_{eff}
Hour	h	Pounds per square inch	psi
Hygroscopic	hygr	Pressure, critical	p_c
ibidem (in the same place)	ibid.	Propyl	Pr
id est (that is)	i.e.	Pyridine	py
Inch	in*	Radiofrequency	rf
Inorganic	inorg	Reductant	red
Inside diameter	i.d.	Retardation factor	R_f
Insoluble	insol	Retention time	t_R
In the same place	ibid.	Retention volume	V_R
In the work cited	op. cit.	Saturated	satd
Joule	J	Saturated calomel electrode	SCE
Kelvin	K	Second	s
Kilo-	k-	Signal-to-noise ratio	S/N
Liter	L	Slightly	sl
Logarithm, common	log	Solid	c, s
Logarithm, base e	ln	Soluble	sol
Mass absorption coefficient	$\mu/\rho, \mu_m$	Solution	soln
Maximum	max	Solvent	solv
Melting point	mp	Standard	std
Meter	m	Tartrate	tart
Milliequivalent	meq	Transit time of nonretained solute	t_M, t_0
Millimeters of mercury, pressure unit	mmHg	Ultraviolet	uv
Millimole	mM	Vacuum	vac
Minute	m, min	Velocity	u, w
Molar	M	Versus	vs
Mole	mol	Volt	V
Mole percent	mol %	Volume	V, v
Molecular weight	mol wt	Volume mobile phase in volume	V_M
Neutron	n	Volume per volume	v/v
Nuclear magnetic resonance	NMR	Weight	W
Ohm	Ω	Weight percent	wt %
Organic	org	Weight per volume	w/v
Outer diameter	o.d.	Zone width at base	W_b
Oxalate	Ox	Zone width at one-half peak height	$W_{1/2}$

About the Author

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