CHAPTER 4. CHEMICAL AND PHYSICAL INFORMATION

4.1 CHEMICAL IDENTITY

Cobalt is a naturally occurring element in the earth's crust. It occurs in several minerals, often with nickel, silver, lead, copper, and iron ores (Haynes 2015). It is a member of Group 9 of the periodic table along with rhenium, iridium, and meitnerium, and adjacent to iron and nickel. There is only one stable isotope of cobalt, ^{59}Co. The other known isotopes of cobalt are not naturally occurring. Most of the radioactive forms have masses of 47–58 and 60–77 (NNDC 2023). The radioactive properties of cobalt isotopes are maintained in the United States by the National Nuclear Data Center. ^{60}Co, the most common radioisotope, is formed by the neutron activation of stable ^{59}Co, has a 5.27-year half-life. ^{60}Co is radioactive and emits beta particles (mean beta-energy 96.41 keV; total intensity 100%) and gamma radiation (1,173 keV 99.85%, 1,332 keV 99.98%) (NNDC 2023) forming a stable nickel isotope (^{60}Ni). It is used as a source of high energy gamma radiation in cancer therapy (e.g., in a gamma knife), food irradiation, and industrial radiography of welds used to detect internal flaws in metals (Clark 2023; Gregersen 2023). The cobalt isotopes ^{57}Co, ^{58}Co, and ^{60}Co are byproducts of nuclear reactor operations. Cobalt isotopes have half-lives that are specific to the isotope, and range from seconds to years (Clark 2023; NNDC 2023). Information regarding the chemical identity of cobalt and selected cobalt compounds is presented in Table 4-1.

Table 4-1. Chemical Identity of Cobalt and Selected Cobalt Compounds

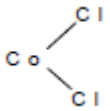
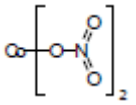
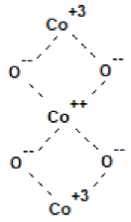
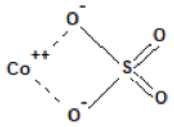
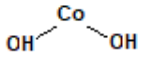
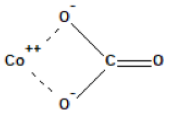
Characteristic	Cobalt	Cobalt (II) chloride	Cobalt (II) nitrate
Synonym(s) and Registered trade name(s)	CI 77320; kobalt; NCI-C60311; Aquacat; cobalt-59; Super Cobalt	Cobaltous chloride; cobalt dichloride; cobalt muriate; cobaltous dichloride; kobalt chloride	Cobaltous nitrate; cobalt bis(nitrate); cobalt dinitrate; cobalt (2+) nitrate; cobalt nitrate
Chemical formula	Co	$CoCl_2$	$Co(NO_3)_2$
SMILES	Co	Cl[Co]Cl	[N+](=O)([O-])[O-].[N+](=O)([O-])[O-].[Co+2]
Chemical structure	Co		
CAS registry number	7440-48-4	7646-79-9 (anhydrous)	10141-05-6 (anhydrous)

Table 4-1. Chemical Identity of Cobalt and Selected Cobalt Compounds

Characteristic	Cobalt (II) oxide	Cobalt tetraoxide	Cobalt (II) sulfate
Synonym(s) and Registered trade name(s)	Cobalt monoxide; Cobalt Black; Zaffre; Oxocobalt; cobaltous oxide; Mmonocobalt oxide; CI Pigment Black 13	Cobalt oxide; UNII-USK772NS56; cobaltosic oxide; cobalt oxide black; tricobalt tetroxide; cobalto-cobaltic oxide; cobaltic-cobaltous oxide; cobalto-cobaltic tetroxide; cobalt (II, III) oxide	Cobaltous sulfate; cobalt (II) sulphate; cobalt (II) sulfate (1:1); cobalt (2+) sulfate; cobalt sulfate; sulfuric acid, cobalt (2+) salt (1:1)
Chemical formula	CoO	Co_3O_4	$CoSO_4$
SMILES	O=[Co]	[O-2].[O-2].[O-2].[O-2].[Co+2].[Co+3].[Co+3]	[O-]S(=O)(=O)[O-].[Co+2]
Chemical structure	O=Co		
CAS registry number	1307-96-6	1308-06-1	10124-43-3 (anhydrous)

Characteristic	Cobalt (II) sulfide	Cobalt arsenide
Synonym(s) and Registered trade name(s)	Cobalt sulfide; sulfanylidenecobalt; cobalt sulphide; cobalto monosulfide; cobalt (2+) sulfide; cobaltous sulfide	Arsanylidynecobalt; cobalt monoarsenide; cobalt (III) arsenide
Chemical formula	CoS	CoAs
SMILES	S=[Co]	[Co]#[As]
Chemical structure	S=Co	Co≡As
CAS registry number	1317-42-6	27016-73-5

Table 4-1. Chemical Identity of Cobalt and Selected Cobalt Compounds

Characteristic	Cobalt (II) hydroxide	Cobalt (II) carbonate
Synonym(s) and Registered trade name(s)	Cobaltous hydroxide; cobalt hydroxide; cobalt (2+) hydroxide	Cobalt carbonate; cobalt (2+) carbonate; cobalt carbonate (1:1); cobalt (II) carbonate hydrate; carbonic acid, cobalt (2+) salt; cobalt spar; cobalt monocarbonate; carbonic acid, cobalt salt
Chemical formula	$Co(OH)_2$	$CoCO_3$
SMILES	[OH-].[OH-].[Co+2]	C(=O)([O-])[O-].[Co+2]
Chemical structure		
CAS registry number	21041-93-0	513-79-1

CAS = Chemical Abstracts Service; SMILES = simplified molecular-input line-entry system

Sources: NLM (2023a, 2023b, 2023c, 2023d, 2023e, 2023f, 2023g, 2023h, 2023i, 2023j)

4.2 PHYSICAL AND CHEMICAL PROPERTIES

Cobalt is a magnetic, hard, gray metal that is resistant to oxidation (Haynes 2015; Lenntech 2023). While it can be brittle, it is also ductile and somewhat malleable, and its natural magnetic properties are enhanced by alloying with other metals. Cobalt's physical and chemical properties make it ideal for a variety of applications. Cobalt exists in nature mainly as cobalt (II) with a +2 oxidation state and, to a lesser extent, cobalt (III) in the +3 oxidation state. Cobalt may also display oxidation states of +4, +1, and −1. The most common and stable ionic species is cobalt (II). Both cobalt (II) and cobalt (III) can form stable complexes (NTP 2016). Alloys containing cobalt can maintain their strength at high temperatures, making them useful in gas turbine engines, chemical and petroleum plants, and power plants (USGS 2011). Cobalt and cobalt compounds are nonvolatile and are emitted to the atmosphere in particulate form. Cobalt is also an essential trace element found in vitamin B_{12}. In biological systems, the chemistry of cobalt is facilitated by various enzymes that can cycle cobalt ions between cobalt (III), cobalt (II), and cobalt (I) species (NTP 2016; Osman et al. 2021).

Cobalt (III) is a strong oxidizer and accepts electron easily in aqueous solutions to form cobalt (II) (ionization potentials: $Co3^{+}/2^{+}$=+1.8V; $Co2^{+}/Co_{(s)}$=-0.28) (Haynes 2015; Lenntech 2023). Metallic cobalt does not react with water at room temperature; however, reactions with acids produce hydrogen gas (Clark 2023).

Information regarding physical and chemical properties of cobalt and cobalt compounds is presented in Table 4-2.

Table 4-2. Physical and Chemical Properties of Cobalt and Selected Cobalt Compounds

Property	Cobalt	Cobalt (II) chloride	Cobalt (II) nitrate
Molecular weight	58.933[a]	129.8[a]	182.9[a]
Color	Gray, silvery bluish-white[a,b]	Blue[a]	Pale red[a]
Physical state	Solid[c]	Solid	Solid[g]
Melting point	1,495°C[a]	737°C[a]	Decomposes at 100–105°C[g]
Boiling point	2,927°C[a]	1,049°C[a]	No data
Density at 20°C/4°C	8.9 g/cm^3[a]	3.36 g/cm^3[a]	2.49 g/cm^3[a]
Odor	Odorless[c]	Slight sharp odor[f]	Odorless[g]
Odor threshold:			
Water	No data	No data	No data
Air	No data	No data	No data
Taste threshold	No data	No data	No data
Solubility:			
Water	No data	Soluble in water[f]	Soluble in water[g]
Organic solvent(s)	Soluble in dilute acids; readily soluble in dilute nitric acid[a,d]	Soluble in alcohols, acetone, ether, glycerol, and pyridine[f]	No data
Partition coefficients:			
Log K_{ow}	No data	No data	No data
Log K_{oc}	No data	No data	No data
Vapor pressure:			
At 726 mmHg and 85°C	2.09x10^{-10} mmHg[a]	No data	No data
Approximately	0 mmHg[c]	No data	No data
Henry's law constant	No data	No data	No data
Autoignition temperature	No data	No data	No data
Flashpoint	No data	No data	No data
Flammability limits	No data	No data	No data
Conversion factors	1 ppm = 2.4 mg/m^3[e]	No data	No data
Explosive limits	No data	Reacts violently with alkali metals such as potassium or sodium causing fire and explosion hazard[f]	No data

Table 4-2. Physical and Chemical Properties of Cobalt and Selected Cobalt Compounds

Property	Cobalt (II) oxide	Cobalt tetraoxide	Cobalt (II) sulfate
Molecular weight	74.932[a]	240.8[a]	155[a]
Color	Gray[a]	Black[a]	Red[a]
Physical state	Solid[a]	Solid[a]	Solid[h]
Melting point	1,830°C[a]	Decomposes at 900°C[a]	>700°C[a]
Boiling point	No data	No data	No data
Density at 20°C/4°C	4.63 g/cm^{3}[a]	6.11 g/cm^{3}[a]	3.71 g/cm^{3}[a]
Odor	No data	No data	Odorless[i]
Odor threshold:			
Water	No data	No data	No data
Air	No data	No data	No data
Taste threshold	No data	No data	No data
Solubility:			
Water	Insoluble in water[a]	Insoluble in water[a]	330 g/L at 20°C[h]
Organic solvent(s)	Soluble in acid solutions[a]	Soluble in acid solutions and alkaline solutions[a]	1.04 g/11 mL methanol at 18°C[h]
Partition coefficients:			
Log K_{ow}	No data	No data	No data
Log K_{oc}	No data	No data	No data
Vapor pressure	No data	No data	No data
Henry’s law constant	No data	No data	No data
Autoignition temperature	No data	No data	No data
Flashpoint	No data	No data	No data
Flammability limits	No data	No data	No data
Conversion factors	No data	No data	No data
Explosive limits	No data	No data	No data

Table 4-2. Physical and Chemical Properties of Cobalt and Selected Cobalt Compounds

Property	Cobalt (II) sulfide	Cobalt arsenide
Molecular weight	90.998[a]	133.855[a]
Color	Black[a]	No data
Physical state	Solid[a]	Solid[a]
Melting point	1,117°C[a]	1,180°C[a]
Boiling point	No data	No data
Density at 20°C/4°C	5.45 g/cm^{3}[a]	8.22 g/cm^{3}[a]
Odor	No data	No data
Odor threshold:		
Water	No data	No data
Air	No data	No data
Taste threshold	No data	No data
Solubility:		
Water	Insoluble in water[a]	No data
Organic solvent(s)	Soluble in acid solutions[a]	No data
Partition coefficients:		
Log K_{ow}	No data	No data
Log K_{oc}	No data	No data
Vapor pressure	No data	No data
Henry’s law constant	No data	No data
Autoignition temperature	No data	No data
Flashpoint	No data	No data
Flammability limits	No data	No data
Conversion factors	No data	No data
Explosive limits	No data	No data

Table 4-2. Physical and Chemical Properties of Cobalt and Selected Cobalt Compounds

Property	Cobalt (II) hydroxide	Cobalt (II) carbonate
Molecular weight	92.948[a]	118.942[a]
Color	Blue-green crystals[a]	Pink crystals[a]
Physical state	Solid[a]	Solid[a]
Melting point	~160°C[a] (decomposes)[a]	280°C (decomposes)[a]
Boiling point	No data	No data
Density at 20°C/4°C	3.60 g/cm^{3a}	4.2 g/cm^{3a}
Odor	No data	No data
Odor threshold:		
Water	No data	No data
Air	No data	No data
Taste threshold	No data	No data
Solubility:		
Water	Slightly soluble in water[a]	0.00014 g/100g H_2O at 20°C
Organic solvent(s)	Soluble in acid solutions[a]	Insoluble in ethanol
Partition coefficients:		
Log K_{ow}	No data	No data
Log K_{oc}	No data	No data
Vapor pressure	No data	No data
Henry's law constant	No data	No data
Autoignition temperature	No data	No data
Flashpoint	No data	No data
Flammability limits	No data	No data
Conversion factors	No data	No data
Explosive limits	No data	No data

[a]Haynes 2015.
[b]Browning 1969.
[c]NIOSH 2019b.
[d]O'Neil 2013.
[e]EPA 2000.
[f]NLM 2023bc.
[g]NLM 2023c.
[h]NLM 2023f.
[i]NLM 2023f.