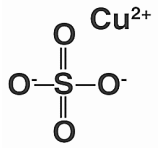
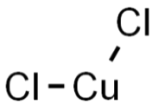
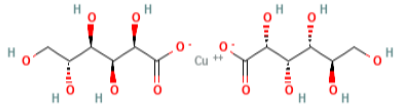
CHAPTER 4. CHEMICAL AND PHYSICAL INFORMATION

4.1 CHEMICAL IDENTITY

Copper, atomic number 29 on the periodic table, is a transition metal and a Group 11 essential element that can occur naturally in elemental form. Copper exists in four oxidation states: Cu(0), Cu(I), Cu(II), and Cu(III). The most common oxidation states are cupric Cu(I), with a +1 oxidation state, and cuprous Cu(II), with a +2 oxidation state (Conry 2006). Both types can form stable complex ions (i.e., salts). Cu(II) is classified as a borderline hard acid and can form complexes with hard ligands such as nitrogen- and oxygen-donating ligands as well as chloride- and sulfur-containing species; Cu(I) is considered a soft acid and typically forms salt complexes with softer ligands (Conry 2006). In physiological systems, Cu(II) is reduced to Cu(I) for transport across cellular membranes (Nishito and Kambe 2018). Copper industrial uses include electrical products and equipment, wiring, piping, sheet metal, building material, machinery, and motors. Copper is found in many foods and in some dietary supplements. Copper is essential to human health and among the most abundant trace elements in the human body. Because copper exhibits various oxidation states and can form numerous stable salts, there are many forms of copper. Copper sulfate ($CuSO_4$) is an inorganic compound that can occur in nature. It is the most common compound used in commercial applications. It is the most widely used copper salt and is an ingredient in pesticide formulations, and has been used as a micronutrient additive for fertilizer and animal feed (NLM 2024). Copper chloride is another important copper salt. It is used as a catalyst in chemical reactions; in dyeing and printing; and in fungicides, wood preservative, feed additives, and water purification (Budavari et al. 2001; NLM 2024). Copper oxide is used in some paints, glasses, porcelain glazes, and ceramics as a red pigment, and has been used as a fungicide (Conry 2006). Copper nanoparticles are formed through natural processes or can be manmade. They are primarily used as antimicrobial, antibacterial, and antifungal agents. A summary of copper nanoparticle toxicity is in Section 2.21. Information regarding the chemical identity of copper and copper compounds is presented in Table 4-1.

Table 4-1. Chemical Identity of Copper and Copper Compounds

Characteristic	Information		
Chemical Name	Copper	Copper sulfate	Copper chloride
Synonym(s) and Registered trade name(s)	M1; M2; M3; M4; Cuprum; Gold Bronze; 1721 Gold; Bronze powder; Cobre; Cuivre; Rame; Allbri Natural Copper; M3R; M3S; E 115; OFHC CU	Cupric sulfate; Copper (II) sulfate; cupric sulfate anhydrous; copper sulphate; Blue stone; copper monosulfate; Hylinec; Trinagle; Delcup, cupric sulphate; sulfuric acid copper (2+) salt (1:1); monocopper sulfate	Copper(II) chloride; cupric chloride; cupric chloride anhydrous; cupric chloride dihydrate
Chemical formula	Cu	$CuSO_4$	$CuCl_2$
SMILES	Cu	[O-]S(=O)(=O)[O-].[Cu+2]	Cl[Cu]Cl
Chemical structure	Cu		
CAS Registry Number	7440-50-8	7758-98-7	7447-39-4
Chemical Name	Copper (II) oxide	Copper gluconate	
Synonym(s) and Registered trade name(s)	Cupric oxide; copper oxide; copper monoxide; CuO; oxocopper	Copper(II) gluconate; copper di-D-gluconate; copper (II) D-gluconate; copper(2+) D-gluconate, (1:2)	
Chemical formula	CuO	$C_{12}H_{22}CuO_{14}$	
SMILES	[O-2].[Cu+2]	C(C(C(C(C(C(=O)[O-])O)O)O)O)O.C(C(C(C(C(C(=O)[O-])O)O)O)O)O.[Cu+2]	
Chemical structure	**Cu=O**		
CAS Registry Number	1317-38-0	527-09-3	

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

Source: NLM 2024

4.2 PHYSICAL AND CHEMICAL PROPERTIES

Copper is a metallic solid that is malleable and has high thermal conductivity, high electrical conductivity, low corrosivity, and alloying ability. Its malleability is attributed to its relatively low number of electrons on its outer shell. The properties of copper typically vary with purity. Metallic copper is naturally a reddish color, and when exposed to oxygen in the air, it forms copper oxide, which is black (Haynes et al. 2015). As copper reacts with carbon dioxide in the air, copper carbonates, which are

usually green, form. Copper is positioned below hydrogen in the electromotive-force series (lower reactivity); therefore, it will not displace hydrogen ions in water, and thus has no single displacement interaction with water. It is soluble in dilute acid and in ammonia with the presence of an oxidizing agent. Copper will undergo galvanic corrosion when in contact with other metals. Copper sulfate is typically produced by treating hot copper with sulfuric acid. The resulting material is a white-green solid when anhydrous and blue crystals when hydrated ($CuSO_4.5H_2O$) (Haynes et al. 2015). Copper chloride is produced by reaction of metallic copper with chlorine. It is a yellow-brown powder in the anhydrous form. Information regarding physical and chemical properties of copper and copper compounds is presented in Table 4-2.

Table 4-2. Physical and Chemical Properties of Copper and Copper Compounds

Property	Information		
Chemical name	Copper	Copper (II) sulfate	Copper (II) chloride
Molecular weight	63.55 g/mol	159.61 g/mol	134.45 g/mol
Color	Reddish, lustrous	White, off-white when dehydrated; blue crystals when hydrated	Yellow to brown
Physical state	Solid	Solid	Solid
Melting point	1,083°C	590°C	630°C
Boiling point	2,595°C	650°C	993°C
Density at 20°C/4°C	8.94	3.6	3.39
Odor	Odorless	Pleasant odor	Odorless
Odor threshold: Water Air	 No data No data	 No data No data	 No data No data
Taste threshold	No data	No data	No data
Solubility: Water Organic solvent(s)	 Insoluble Slightly soluble in dilute acid and ammonia water	 Soluble Soluble in methanol Insoluble in ethanol	 Soluble in acetone, ethanol
Partition coefficients: Log K_{ow} Log K_{oc}	 No data No data	 No data No data	 No data No data
Vapor pressure at 20°C	1 mm Hg at 1,628°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	Since these substances exist in the atmosphere in the particulate state, the concentration is expressed as mg/m^3.		
Explosive limits	No data	No data	No data

Table 4-2. Physical and Chemical Properties of Copper and Copper Compounds

Property	Information	
Chemical name	Copper (II) oxide	Copper gluconate
Molecular weight	79.55 g/mol	453.84 g/mol
Color	Steel-grey to black solid; black to brownish-black amorphous or crystalline powder or granules	Light blue crystalline powder
Physical state	Solid	Solid
Melting point	1,326°C (decomposes)	155–157°C (D-form)
Boiling point	1,026°C (decomposes)	No data
Density at 20°C/4°C	6.315 at 14°C/4°C	No data
Odor	Odorless	Odorless
Odor threshold:		
Water	No data	No data
Air	No data	No data
Taste threshold	No data	No data
Solubility:		
Water	Insoluble	30 g/100 mL water at 25°C
Organic and inorganic solvent(s)	Soluble in acids, and ammonia and ammonium carbonate solutions; soluble in alkali cyanides	Slightly soluble in alcohol; practically insoluble in most organic solvents
Partition coefficients:		
Log K_{ow}	No data	No data
Log K_{oc}	No data	No data
Vapor pressure at 20°C	1 mm Hg at 1,628°C	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	Since these substances exist in the atmosphere in the particulate state, the concentration is expressed as mg/m^3.	
Explosive limits	No data	No data

Sources: Haynes et al. 2015; NLM 2024