CHAPTER 4. CHEMICAL AND PHYSICAL INFORMATION

4.1 CHEMICAL IDENTITY

Nickel is a transition metal in group 10 of the periodic table following iron and cobalt (Kerfoot 2012). Its outer shell of electrons has a $3d^8\,4s^2$ configuration (Haynes et al. 2015). Nickel occurs naturally in the Earth's crust. While nickel can exist in oxidation states -1, 0, +2, +3, and +4, its only important oxidation state is nickel (+2) under normal environmental conditions. Information regarding the chemical identity of nickel and nickel compounds is presented in Table 4-1.

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

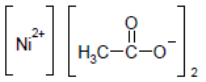
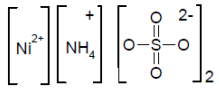
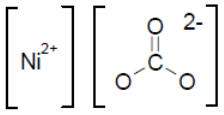
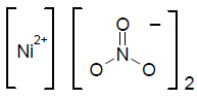
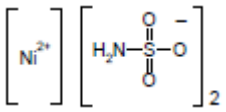
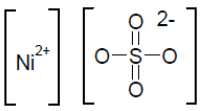
Characteristic	Nickel[a]	Nickel acetate[b]	Nickel ammonium sulfate[c]	Nickel carbonate[d]
Synonym(s) and Registered trade name(s)	CI 77775; NI 0901-S; NI 270; NI 4303T; Nickel 200; Nickel 201; Nickel 205; Nickel 207; Nickel 270; Nickel sponge; NI 0901-S (Harshaw); NP-2; Raney alloy; Raney nickel; RCH 55/5	Nickel (II) acetate; nickelous acetate; nickel diacetate; acetic acid, nickel(2+) salt; AI3-26110; nickel(2+) acetate	Nickel (II) ammonium sulfate; Diammonium nickel bis(sulphate); Ammonium disulfatonickelate(II); Sulfuric acid, ammonium nickel(2+) salt (2:2:1); diazanium; nickel(2+);disulfate; ammonium nickel sulfate (anhydrous); ammonium nickel(2+) sulfate (2/1/2)	CI 7779; Carbonic acid, nickel (2+) salt; nickel (II) carbonate; nickelous carbonate
Chemical formula	Ni	$C_4H_6NiO_4$	Ni $(NH_4)_2(SO_4)_2$[e]	$NiCO_3$
SMILES	[Ni]	CC(=O)[O-]. CC(=O)[O-].[Ni+2]	[NH4+].[NH4+]. [O-]S(=O)(=O)[O-]. [O-]S(=O)(=O) [O-].[Ni+2]	C(=O)([O-]) [O-].[Ni+2]
Chemical structure	Ni			
CAS registry number	7440-02-0	373-02-4; 14998-37-9 (EU)	15699-18-0	3333-67-3; 16337-84-1 (EU); 18195-55-6 (EU); 39380-74-0 (EU)

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

Characteristic	Nickel chloride[f]	Nickel cyanide[g]	Nickel oxide[h]	Nickel nitrate[i]
Synonym(s) and Registered trade name(s)	Nickel (2+) chloride; nickel dichloride; nickel(II) chloride; nickelous chloride	Dicyanonickel; Nickel dicyanide; Nickel (II) cyanide	Bunsenite; CI 77777; Green nickel oxide; mononickel oxide; nickel (II) oxide; nickel(2+) oxide; nickel protoxide	Nickel dinitrate; nickel (II) nitrate; nickel(2+) nitrate; nickelous nitrate; nitric acid, nickel(II) salt; nitric acid, nickel(2+) salt
Chemical formula	$NiCl_2$	C_2N_2Ni	NiO	$Ni(NO_3)_2$
SMILES	Cl[Ni]Cl	[C-]#N. [C-]#N.[Ni+2]	O=[Ni]	[N+](=O)([O-]) [O-].[N+](=O) ([O-])[O-].[Ni+2]
Chemical structure	Cl–Ni–Cl	CN–Ni–CN	Ni–O	
CAS registry number	7718-54-9; 37211-05-5 (EU and NZ)	557-19-7	1313-99-1; 34492-97-2; 11099-02-8	13138-45-9; 13478-00-7 (hexahydrate); 14216-75-2 (EU)

Characteristic	Nickel subsulfide[j]	Nickel sulfamate[k]	Nickel sulfate[l]
Synonym(s) and Registered trade name(s)	Trinickel disulfide; Heazlewoodite; nickel subsulphide; nickel sulfide; alpha-nickel sulfide (3:2) crystalline; nickel sulphide; nickel tritadisulphide	Nickel bis(sulphamidate); nickel (II) sulfamate; Aeronikl 250; Aeronikl 400; Aeronikl 575; sulfamic acid, nickel(2+) salt (2:1); Nickel aminosulfonate	NCI-C60344; Nickel (II) sulfate; nickelous sulfate; nickel(2+) sulfate; nickel sulphate; sulfuric acid, nickel(2+) salt; sulphuric acid, nickel (II) salt
Chemical formula	Ni_3S_2	$Ni(SO_3NH_2)_2$	$NiSO_4$
SMILES	[S-2].[S-2].[Ni].[Ni+2].[Ni+2]	NS(=O)(=O) [O-].NS(=O)(=O)[O-].[Ni+2]	[O-]S(=O)(=O)[O-].[Ni+2]
Chemical structure	Ni-Ni-Ni=S=S		
CAS registry number	12035-72-2	13770-89-3	7786-81-4; 15244-37-8 (EU)

[a]NLM 2024a unless otherwise specified.
[b]NLM 2024b unless otherwise specified.
[c]NLM 2024c unless otherwise specified.
[d]NLM 2024d unless otherwise specified.
[e]Haynes et al. 2015.
[f]NLM 2024e unless otherwise specified.
[g]NLM 2024f unless otherwise specified.
[h]NLM 2024g unless otherwise specified.
[i]NLM 2024h unless otherwise specified.
[j]NLM 2024i unless otherwise specified.
[k]NLM 2024j unless otherwise specified.
[l]NLM 2024k unless otherwise specified.

CAS = Chemical Abstract Service; EU = European Union; NZ = New Zealand; SMILES = simplified molecular-input line-entry system

4.2 PHYSICAL AND CHEMICAL PROPERTIES

Nickel exists in the solid state and is a hard, lustrous, silvery white metal that takes on a high polish (Haynes et al. 2015). Nickel has typical metallic properties; it is malleable, ductile, ferromagnetic, and a good conductor of both heat and electricity (Haynes et al. 2015). Nickel forms useful alloys with many metals. It is added to metals to increase their hardness, strength, and corrosion resistance. The most familiar are nickeliferous alloys used in stainless steel and copper nickel alloys used in coinage metal.

Nickel ammonium sulfate, nickel sulfate, nickel chloride, and nickel nitrate usually exist as hexahydrates, while nickel acetate, nickel cyanide, and nickel sulfamate are in the form of a tetrahydrate (Haynes et al. 2015). Nickel compounds are also solid, and colors include a yellow-brown or a blue-green color.

Metallic nickel is insoluble in water and slightly soluble in dilute acid. Nickel and its compounds are nonvolatile and exist in the atmosphere in particulate form. Information regarding physical and chemical properties of nickel and nickel compounds is presented in Table 4-2.

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

Property	Nickel[a]	Nickel acetate[b]	Nickel ammonium sulfate[c]	Nickel carbonate[d]
Molecular weight	58.7	176.78	286.9	118.70
Color	Silvery white	Green	Blue-green	Green
Physical state	Solid[e]	Solid[e,f]	Solid[e]	Solid[e]
Melting point	1,455°C[e]	Decomposes at 250°C[e,f]	Decomposes at 250°C[e]	Decomposes on heating
Boiling point	2,913°C[e]	16°C[e,f]	No data	No data
Density:	8.9[e]	1.74 g/cm^3[e,f]	1.92 g/cm^3[g]	4.39 g/cm^3
Odor	Odorless	Acetic acid odor[g]	Odorless[g]	No data
Odor threshold:				
Water	No data	No data	No data	No data
Air	No data	No data	No data	No data
Taste threshold	No data	No data	No data	No data
Solubility:				
Water	Insoluble in H_2O[e]	Very soluble in H_2O[e,f]; 17 pounds/ 100 pounds water at 68 °F	Slightly soluble in H_2O[e]; 10.4 g/100 g H_2O[g] at 20°C; 6.5 g/100 g H_2O at 68 °F[e,g]	0.0043 g/100 g H_2O[e]; 93 mg/L at 25°C
Organic solvent(s)	Slightly soluble in dilute acid	Soluble in ethanol[e,f]	Insoluble in alcohol[g]	Soluble in dilute acid[e]
Partition coefficients:				
Log K_{ow}	No data	No data	No data	No data
Log K_{oc}	No data	No data	No data	No data
Vapor pressure	0 mmHg (approximate)	No data	No data	No data
Henry's law constant	No data	No data	No data	No data
Autoignition temperature	No data	Nonflammable	Nonflammable	No data
Flashpoint	No data	Nonflammable	Nonflammable	No data
Flammability limits	No data	Nonflammable	Nonflammable	No data
Conversion factors	No data	No data	No data	No data
Explosive limits	No data	No data	No data	No data

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

Property	Nickel chloride[h]	Nickel cyanide[i]	Nickel oxide[j]	Nickel nitrate[k]
Molecular weight	129.60	110.73	74.69	182.7
Color	Yellow[e]; green[e,g]	Yellow-brown; green[e,g]	Green; black	Green
Physical state	Solid	Solid	Solid	Solid
Melting point	1,031°C[e]	>200°C	1,957°C[e]	Decomposes at 56°C[e,g]
Boiling point	Sublimation point 985°C[e]	Decomposes	No data	No data
Density	3.51 g/cm^3	2.393 g/cm^3	6.72 g/cm^{3e}	2.05 g/cm^{3e,g}
Odor	Odorless	Weak almond odor	Odorless	No data
Odor threshold:				
Water	No data	No data	No data	No data
Air	No data	No data	No data	No data
Taste threshold	No data	No data	No data	No data
Solubility:				
Water	67.5 g/100 g H_2O[e]	Insoluble in H_2O	Insoluble in H_2O[e] 0.11 mg/100 mL H_2O at 20°C	99.2 g/100 g H_2O[e,g]
Organic solvent(s)	Soluble in ethanol	Soluble in aqueous alkali cyanides and other bases	Soluble in acid	Soluble in ethanol
Partition coefficients:				
Log K_{ow}	No data	No data	No data	No data
Log K_{oc}	No data	No data	No data	No data
Vapor pressure	No data	No data	No data	No data
Henry's law constant	No data	No data	No data	No data
Autoignition temperature	Nonflammable	Nonflammable	No data	No data
Flashpoint	Nonflammable	Nonflammable	Flammable as dust or fume	No data
Flammability limits	Nonflammable	Nonflammable	No data	No data
Conversion factors	No data	No data	No data	No data
Explosive limits	Mixture of potassium and $NiCl_2$ produces strong explosion on impact	No data	No data	May explode after prolonged exposure to fire or heat

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

Property	Nickel subsulfide[l]	Nickel sulfamate[m]	Nickel sulfate[n]
Molecular weight	240.21	250.87	154.76
Color	Yellow[e]	Blue-green	Greenish-yellow; blue-green[g], green[o]
Physical state	Solid[e]	Liquid	Solid
Melting point	789°C[e]	No data	Decomposes at 840°C Decomposes at 100°C[e,g]
Boiling point	No data	No data	No data
Density	5.87 g/cm^3[e]	No data	4.01 g/cm^3; 2.03 g/cm^3[g]; 1.98 g/cm^3[o]
Odor	No data	No data	Odorless
Odor threshold: Water Air	No data No data	No data No data	No data No data
Taste threshold	No data	No data	Sweet astringent taste
Solubility: Water Organic solvent(s)	 No data No data	 Highly soluble[f,p] No data	 40.4 g/100 g H_2O[e,g,o] Insoluble in alcohol; slightly soluble[g] or soluble[o] in ethanol
Partition coefficients: Log K_{ow} Log K_{oc}	 No data No data	 No data 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	Nonflammable
Flashpoint	No data	No data	Nonflammable
Flammability limits	No data	No data	Nonflammable
Conversion factors	No data	No data	No data
Explosive limits	No data	No data	No data

[a]NLM 2024a unless otherwise specified.
[b]NLM 2024b unless otherwise specified.
[c]NLM 2024c unless otherwise specified.
[d]NLM 2024d unless otherwise specified.
[e]Haynes et al. 2015.
[f]Data are for the tetrahydrate.
[g]Data are for the hexahydrate.
[h]NLM 2024e unless otherwise specified.
[i]NLM 2024f unless otherwise specified.
[j]NLM 2024g unless otherwise specified.
[k]NLM 2024h unless otherwise specified.
[l]NLM 2024i unless otherwise specified.
[m]NLM 2024j unless otherwise specified.
[n]NLM 2024k unless otherwise specified.
[o]Data are for the heptahydrate.
[p]Lascelles et al. 2019.