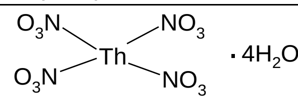
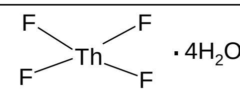
CHAPTER 4. CHEMICAL AND PHYSICAL INFORMATION

4.1 CHEMICAL IDENTITY

Data pertaining to the chemical identity (that is, the common terms or symbols used for the identification of the element) of thorium are listed in Table 4-1.

Table 4-1. Chemical Identity of Thorium and Compounds[a]

Characteristic	Thorium	Thorium dioxide	Thorium nitrate (tetrahydrate)	Thorium fluoride (tetrahydrate)
Synonym(s)[b] and registered trade name(s)	^{232}Th, thorium metal, pyrophoric	Thoria, Thorotrast	No data	Thorium tetrafluoride
Chemical formula	Th	ThO_2	$Th(NO_3)_4$ ● $4H_2O$	ThF_4 ● 4H
Chemical structure[c]	Th[d]	O=Th=O		
CAS Registry Number	7440-29-1[c]	1314-20-1[c]	13470-07-0	13709-59-6

Characteristic	Thorium dicarbonate	Thorium chloride[e]	Thorium sulfate[e]
Synonym(s)[b] and registered trade name(s)	Thorium carbonate[f]	Thorium tetrachloride; thorium(IV) chloride; thorium chloride; tetrachlorothorium	Thorium disulphate; sulfuric acid, thorium; thorium sulfate nonahydrate; thorium sulfate 9water; thorium (IV) sulfate 9-water
Chemical formula	$Th(CO_3)_2$	$ThCl_4$	$Th(SO_4)_2 \cdot 9H_2O$
Chemical structure[c]	$O_3C=Th=CO_3$		
CAS Registry Number	19024-62-5	10026-08-1, 54327-76-3	10381-37-0

[a]All information obtained from HSDB 1990, except where noted.
[b]Structures are based on tetra valency of thorium unless otherwise stated.
[c]CAS 1990.
[d]SANSS 1988.
[e]Web_elements 2014a, 2014b.
[f]NIH 2018.

CAS = Chemical Abstracts Service

4.2 PHYSICAL AND CHEMICAL PROPERTIES

The physical and chemical properties of elemental thorium and a few representative water-soluble and insoluble thorium compounds are presented in Table 4-2. Water-soluble thorium compounds include the chloride, fluoride, nitrate, and sulfate salts (Weast 1983). These compounds dissolve fairly readily in water. Soluble thorium compounds, as a class, have greater bioavailability than the insoluble thorium compounds. Water-insoluble thorium compounds include the dioxide, dicarbonate, hydroxide, oxalate, and phosphate salts. Thorium dicarbonate is soluble in concentrated sodium carbonate (Weast 1983). Thorium metal and several of its compounds are commercially available. No general specifications for commercially prepared thorium metal or compounds have been established. Manufacturers prepare thorium products according to contractual specifications (Hedrick 1985).

Thorium is a metallic element of the actinide series. It exists in several isotopic forms. The isotope ^{232}Th is a naturally occurring element that is radioactive. It decays through the emission of a series of alpha and beta particles, gamma radiation, and the formation of daughter products, finally yielding the stable isotope of lead, ^{208}Pb. The decay series of ^{232}Th, together with that of ^{238}U and ^{235}U, are shown in Figure 4-1. It can be seen from Figure 4-1 that the isotopes ^{234}Th and ^{230}Th are produced during the decay of naturally occurring ^{238}U, the isotope ^{228}Th during the decay of ^{232}Th, and the isotopes ^{231}Th and ^{227}Th during the decay of naturally occurring ^{235}U. Of these naturally produced isotopes of thorium, only ^{232}Th, ^{230}Th, and ^{228}Th have long enough half-lives to be environmentally significant. More than 99.99% of natural thorium is ^{232}Th; the rest is ^{230}Th and ^{228}Th.

Including artificially produced isotopes, there are 12 isotopes of thorium with atomic masses ranging from 223 to 234. All are radioactive and decay with the emission of alpha or beta particles and/or gamma radiation (Weast 1983). The percent occurrence and the energies of the major alpha and beta particles emitted by these isotopes are shown in Table 4-3. In general, the alpha particles are more intensely ionizing and less penetrating than the beta particles. The gamma radiation is the most penetrating of the three, but it has the least ionizing intensity. Alpha particles do not penetrate external skin to a sufficient depth to produce biological damage due to the protective effect of the epidermis. However, alpha particles emitted from thorium deposited in the lung are able to penetrate lung tissue and produce adverse biological damage since the protective coating of the lung tissue is very thin. In turn, beta particles are able to penetrate the skin to a sufficient depth to cause biological effects in the skin just below the epidermis. Likewise, they penetrate lung tissues to a greater depth. Gamma rays can generally pass through all tissue and interact with tissue at any depth.

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

Property	Thorium (Th)	Thorium dioxide (ThO_2)	Thorium nitrate, tetrahydrate ($Th(NO_3)_4 \bullet 4H_2O$)	Thorium fluoride, tetrahydrate ($ThF_4 \bullet 4H$)
Molecular weight	232.04[a]	264.04[a]	552.12[a]	380.09[a]
Color	Gray[a]	White[b]	Colorless[a]	Not known
Physical state	Solid[a]	Powdery solid[b]	Crystalline solid[a]	Crystalline solid[a]
Odor	Not known	Not known	Not known	Not known
Melting point, °C	≈1,700[b]	3,220±50[a]	500 (decomposes)	100 ($-H_2O$)[a]
Boiling point, °C	≈4,500[b]	4,400[b]	Not applicable	140–100 ($-2H_2O$)[a]
Autoignition temperature	Not applicable	Not applicable	Not applicable	Not applicable
Solubility:				
Water	Insoluble[a]	Insoluble[b]	Very soluble[b]	0.017 g/100 cc H_2O (25°C)[a]
Organic solvents	Soluble in HCl, H_2SO_4, slightly soluble in HNO_3[a]	Soluble in hot H_2SO_4; insoluble in dilute acid alkali[a]	Very soluble in alcohol; slightly soluble in acetone[a]	Insoluble in HF[a]
Density (g/cm^3)	11.7[a]	9.7[b]	Not known	Not known
Partition coefficients	Not applicable	Not applicable	Not applicable	Not applicable
Vapor pressure at 20 °C	Not applicable	Not applicable	Not applicable	Not applicable
Henry's law constant at 25 °C	Not applicable	Not applicable	Not applicable	Not applicable
Refractive index	Not applicable	2.20 (liquid)[a]	Not applicable	Not applicable
Flashpoint	Not applicable	Not applicable	Not applicable	Not applicable
Flammability limits	Not applicable	Not applicable	Not applicable	Not applicable
Conversion factors	1 pCi=1.2 fg[c] of ^{228}Th 1 pCi=9.1 µg of ^{232}Th 1 pCi=48 fg[c] of ^{230}Th	1 pCi=1.2 fg[c] of ^{228}Th 1 pCi=9.1 µg of ^{232}Th 1 pCi=48 fg[c] of ^{2230}Th	1 pCi=1.2 fg[c] of ^{228}Th 1 pCi=9.1 µg of ^{232}Th 1 pCi=48 fg[c] of ^{230}Th	1 pCi=1.2 fg[c] of ^{228}Th 1 pCi=9.1 µg of ^{232}Th 1 pCi=48 fg[c] of ^{230}Th

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

Property	Thorium carbonate $Th(CO_3)_2$	Thorium chloride[d] $ThCl_4$	Thorium sulfate[d] $Th(SO_4)_2\ 9H_2O$
Molecular weight	352.06[a]	373.849	586.303
Color	Not known	White to gray	White
Physical state	Not known	Crystalline solid	Crystalline solid
Odor	Not known	Not known	Not known
Melting point, °C	Not known	770	400 (dehydrates)
Boiling point, °C	Not known	921	Not known
Autoignition temperature	Not applicable	Not known	Not known
Solubility:			
Water	Insoluble[a]	Soluble	4.2 g/100 g H_2O
Organic solvents	Soluble in HCl, H_2SO_4, slightly soluble in HNO_3[a]	Not known	Not known
Density (g/cm^3)	Not known	4.59	2.8
Partition coefficients	Not applicable	Not known	Not known
Vapor pressure at 20 °C	Not applicable	Not known	Not known
Henry's law constant at 25 °C	Not applicable	Not known	Not known
Refractive index	Not applicable	Not known	Not known
Flashpoint	Not applicable	Not known	Not known
Flammability limits	Not applicable	Not known	Not known
Conversion factors	1 pCi=1.2 fg[c] of ^{228}Th 1 pCi=9.1 µg of ^{232}Th 1 pCi=48 fg[c] of ^{230}Th		

[a]Weast 1983.
[b]Hawley 1981.
[c]1 fg = 10^{-9} µg; 1 pCi = 10^{-12} Ci.
[d]Web_elements 2014a, 2014b.

Figure 4-1. Uranium and Thorium Isotope Decay Series Showing the Sources and Decay Products of the Two Naturally Occurring Isotopes of Thorium

^{238}U Series

NP							
U	^{238}U 4.5x10^{9} years		^{234}U 2.5x10^{5} years				
Pa	↓	^{234}Pa^{m} 1.2 minutes	↓				
Th	^{234}Th 24 days		^{230}Th 7.5x10^{4} years				
Ac			↓				
Ra			^{226}Ra 1,600 years				
Fr			↓				
Rn			^{222}Rn 3.82 days				
At			↓				
Po			^{218}Po 3.1 minutes		^{214}Po 1.6x10^{-4} seconds		^{210}Po 138 days
Bi			↓	^{214}Bi 19.9 minutes	↓	^{210}Bi 5.0 days	↓
Pb			^{214}Pb 27.1 minutes		^{210}Pb 22.2 years		^{206}Pb stable
Tl							

^{232}Th Series

NP					
U					
Pa					
Th	^{232}Th 1.4x10^{10} years		^{228}Th 1.91 years		
Ac	↓	^{228}Ac 6.15 hours	↓		
Ra	^{228}Ra 5.8 years		^{224}Ra 3.63 days		
Fr			↓		
Rn			^{220}Rn 55.6 seconds		
At			↓		
Po			^{216}Po 0.15 seconds		^{212}Po 3.0x10^{-7} seconds
Bi			↓	^{212}Bi 60.6 minutes	↓
Pb			^{212}Pb 10.6 hours	↓	^{208}Pb stable
Tl				^{208}Tl 3.1 minutes	

^{235}U Series

NP					
U	^{235}U 7.04x10^{8} years				
Pa	↓	^{231}Pa 3.3x10^{4} years			
Th	^{231}Th 25.5 hours	↓	^{227}Th 18.7 days		
Ac		^{227}Ac 21.8 years	↓		
Ra			^{223}Ra 11.4 days		
Fr			↓		
Rn			^{219}Rn 4.0 seconds		
At			↓		
Po			^{215}Po 1.8x10^{-3} seconds		
Bi			↓	^{211}Bi 2.14 minutes	
Pb			^{211}Pb 36.1 minutes	↓	^{207}Pb stable
Tl				^{207}Ti 4.79 minutes	

Table 4-3. Percent Occurrence and the Energies of the Major Alpha Particles Emitted by Thorium Isotopes with Atomic Masses Ranging from 223 to 234

Isotope	Percentage in natural thorium	Major alpha energies[a] MEV (abundances)	Half-life
^{223}Th	0	7.286 (26%) 7.298 (66%) 7.323 (13%)	0.60 seconds
^{224}Th	0	7.000 (19%) 7.170 (79%)	1.04 seconds
^{225}Th	0	6.441 (13.5%) 6.478 (39%) 6.501 (12.6%) 6.797 (8.1%)	8.75 minutes
^{226}Th	0	6.234 (22.8%) 6.337 (75.5%)	30.57 minutes
^{227}Th	0	5.757 (20.4%) 5.987 (23.5%) 6.038 (24.2%)	18.70 days
^{228}Th	Very small	5.340 (26.0%) 5.423 (73.4%)	1.91 years
^{229}Th	0	4.815 (9.3%) 4.845 (56.2%) 4.901 (10.2%)	7.93×10^3 years
^{230}Th	Very small	4.621 (23.4%) 4.687 (76.3%)	7.54×10^4 years
^{231}Th	0	Beta-only emitter[b] (0.392 MeV total)	25.52 hours
^{232}Th	>99.99%	3.947 (21.7%) 4.012 (78.2%)	1.40×10^{10} years
^{233}Th	0	Beta-only emitter[b] (1.243 MeV total)	21.8 minutes
^{234}Th	0	Beta-only emitter[b] (0.27e MeV total)	24.10 days

[a]All but a few of these isotopes also emit gamma radiation.
[b]The values in parentheses are the decay energies for the beta particles.

MeV = million electron volt

Source: Weast 1983; NNDC 2018

Alpha particles give up all of their energy in a very short distance and, hence, produce ionization. Beta particles produce less dense ionization, and gamma rays produce less yet. In general, the severity of biological effects of exposures to ionizing radiations is proportional to the density of the ionization produced by their passage through tissue.

Finely divided thorium metal is pyrophoric in air, and thorium ribbon burns in air to give the oxide. The metal also reacts vigorously with hydrogen, nitrogen, the halogens, and sulfur. Thorium compounds are stable in +4 oxidation state (Katzin 1983). Details of thorium chemistry are given by Katzin (1983).

When the solubility of a low-solubility thorium compound is different than expected or reported, the cause could be differences in surface form due to external factors, such as pH or concentrations of two thorium forms at grain boundaries. Vandenborre et al. (2010) scanned the surface of sintered thorium oxide using x-ray photoelectron spectroscopy (XPS) and found it to consist of two forms, 80% ThO_2 and 20% $ThO_x(OH)_y(H_2O)_z$, which have different solubilities. The rate of surface detachment for this oxide was measured, then ^{239}Th was added and the surface attachment rate was determined. The net balance disagreed with the thermodynamic calculation for pure ThO_2.