Thorium

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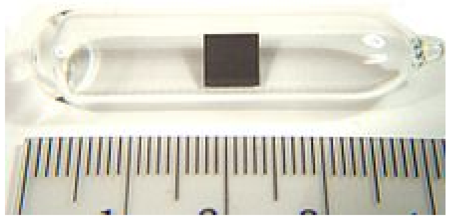
Thorium is a chemical element with symbol **Th** and atomic number 90. A radioactive actinide metal, thorium is one of only two significantly radioactive elements that still occur naturally in large quantities as a primordial element (the other being uranium).[a] It was discovered in 1829 by the Norwegian priest and amateur mineralogist Morten Thrane Esmark[3] and identified by the Swedish chemist Jöns Jacob Berzelius, who named it after Thor, the Norse god of thunder.

A thorium atom has 90 protons and therefore 90 electrons, of which four are valence electrons. Thorium metal is silvery and tarnishes black when exposed to air, forming the dioxide. Thorium is weakly radioactive: all its known isotopes are unstable. Thorium-232 (^{232}Th), which has 142 neutrons, is the most stable isotope of thorium and accounts for nearly all natural thorium, with six other natural isotopes occurring only as trace radioisotopes. Thorium has the longest half-life of all the significantly radioactive elements, 14.05 billion years, or about the age of the universe; it decays very slowly through alpha decay to radium-228 (^{228}Ra), starting a decay chain named the thorium series that ends at stable lead-208 (^{208}Pb). Thorium is estimated to be about three to four times more abundant than uranium in the Earth's crust, and is chiefly refined from monazite sands as a by-product of extracting rare earth metals.

Thorium was once commonly used as the light source in gas mantles and as an alloying material, but these applications have declined due to concerns about its radioactivity. Thorium is still widely used as an alloying element in TIG welding electrodes (at a rate of 1–2% mix with tungsten).[4] It remains popular as a material in high-end optics and scientific instrumentation; thorium and uranium are the only significantly radioactive elements with major commercial applications that do not rely on their radioactivity. Thorium is predicted to be able to replace uranium as nuclear fuel in nuclear reactors, but only a few thorium reactors have yet been completed.

Bulk properties

Thorium, $_{90}$Th



General properties	
Name, symbol	thorium, Th
Appearance	silvery, often with black tarnish
Thorium in the periodic table	
Atomic number (*Z*)	90
Group, block	group n/a, f-block
Period	period 7
Element category	actinide
Standard atomic weight (±) (A_r)	232.0377(4)[1]
Electron configuration	[Rn] $6d^2\ 7s^2$
per shell	2, 8, 18, 32, 18, 10, 2
Physical properties	
Phase	solid
Melting point	2023 K (1750 °C, 3182 °F)
Boiling point	5061 K (4788 °C,

Thorium is a soft, paramagnetic, bright silvery radioactive actinide metal. In the periodic table, it is located to the right of the actinide actinium, to the left of the actinide protactinium, and below the lanthanide cerium. Pure thorium is very ductile and, as normal for metals, can be cold-rolled, swaged, and drawn.[5] At room temperature, thorium metal has a face-centred cubic crystal structure; additionally, it has two other forms at exotic conditions, one at high temperature (over 1360 °C; body-centred cubic) and one at high pressure (around 100 GPa; body-centred tetragonal).[5]

The properties of thorium vary widely depending on the amount of impurities in the sample: the major impurity is usually thorium dioxide (ThO_2). The purest thorium specimens usually contain about a tenth of a percent of the dioxide.[5] Experimental measurements of its density give values between 11.5 and 11.66 g/cm^3: these are slightly lower than the theoretically expected value of 11.7 g/cm^3 calculated from thorium's lattice parameters, perhaps due to microscopic voids forming in the metal when it is cast.[5] These values lie intermediate between those of its neighbours actinium (10.1 g/cm^3) and protactinium (15.4 g/cm^3), showing the continuity of trends across the early actinides.[5]

Thorium's melting point of 1750 °C is above both that of actinium (1227 °C) and that of protactinium (approximately 1560 °C). In the beginning of period 7, from francium to thorium, the melting points of the elements increase (following the trend in the other periods): this is because the number of delocalised electrons that each atom contributes increases from one in francium to four in thorium, and there is a greater attraction between these electrons and the metal ions as their charge increases from one in francium to four in thorium. After thorium, there is a new smooth trend downward in the melting points of the early actinides from thorium to plutonium where the number of f electrons increases from about 0.4 to about 6, due to the itinerance of the f-orbitals, increasing hybridisation of the 5f and 6d orbitals and the formation of directional bonds in the metal resulting in increasingly complex crystal structures and weakened metallic bonding.[6][7] (The f-electron count for thorium is listed as a non-integer due to a 5f–6d overlap.)[7] Among the actinides, thorium has the highest melting and boiling points and second-lowest density

	8650 °F)
Density near r.t.	11.7 g/cm^3
Heat of fusion	13.81 kJ/mol
Heat of vaporisation	514 kJ/mol
Molar heat capacity	26.230 J/(mol·K)

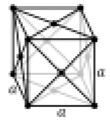
Vapour pressure

P (Pa)	**1**	**10**	**100**	**1 k**	**10 k**	**100 k**
at T (K)	2633	2907	3248	3683	4259	5055

Atomic properties

Oxidation states	**4**, 3, 2, 1
Electronegativity	Pauling scale: 1.3
Ionisation energies	1st: 587 kJ/mol 2nd: 1110 kJ/mol 3rd: 1930 kJ/mol
Atomic radius	empirical: 179.8 pm
Covalent radius	206±6 pm

Miscellanea

Crystal structure	face-centred cubic (fcc) 
Speed of sound thin rod	2490 m/s (at 20 °C)
Thermal expansion	11.0 µm/(m·K) (at 25 °C)
Thermal conductivity	54.0 W/(m·K)
Electrical resistivity	157 nΩ·m (at 0 °C)
Magnetic ordering	paramagnetic[2]
Young's modulus	79 GPa

(second only to actinium) Its boiling point of 4788 °C is the fifth-highest among all the elements with known boiling points, behind only osmium, tantalum, tungsten, and rhenium.[5]

Thorium has a bulk modulus of 54 GPa, comparable to those of tin and scandium. The hardness of thorium is similar to that of soft steel, so heated pure thorium can be rolled in sheets and pulled into wire.[6] Nevertheless, while thorium is nearly half as dense as uranium and plutonium, it is harder than either of them.[6] Thorium becomes superconductive below 1.4 K.[5]

Thorium can also form alloys with many other metals. Addition of small amounts of thorium improves the mechanical strength of magnesium, and thorium-aluminium alloys have been considered as a way to store thorium in proposed future thorium nuclear reactors. With chromium and uranium, it forms eutectic mixtures, and thorium is completely miscible in both solid and liquid states with its lighter congener cerium.[5]

Shear modulus	31 GPa
Bulk modulus	54 GPa
Poisson ratio	0.27
Mohs hardness	3.0
Vickers hardness	295–685 MPa
Brinell hardness	390–1500 MPa
CAS Number	7440-29-1
History	
Naming	after Thor, the Norse god of thunder
Discovery	Jöns Jakob Berzelius (1829)

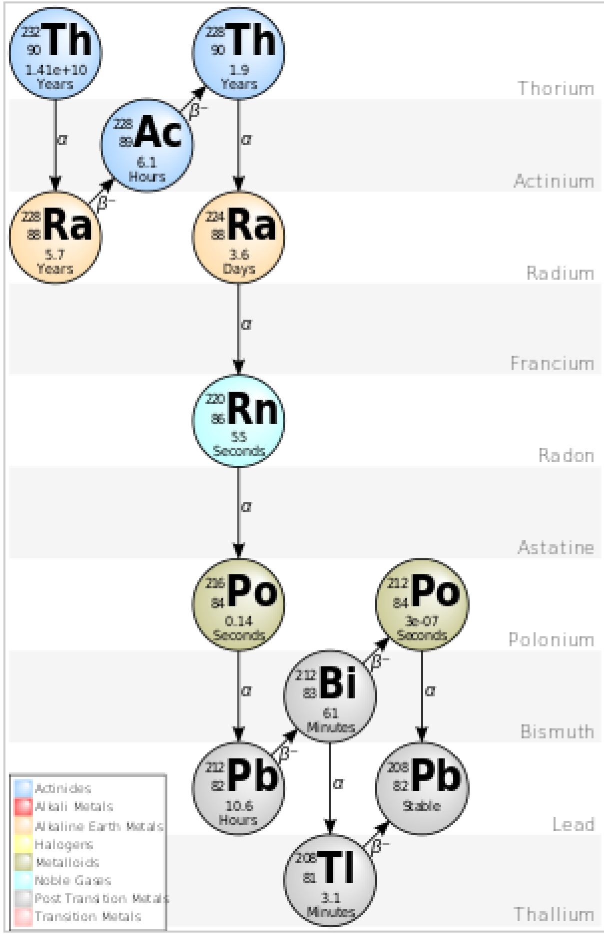
Most stable isotopes of thorium

iso	NA	half-life	DM	DE (MeV)	DP
^{227}Th	trace	18.68 d	α	6.038 5.978	^{223}Ra
^{228}Th	trace	1.9116 y	α	5.520	^{224}Ra
^{229}Th	trace	7917 y	α	5.168	^{225}Ra
^{230}Th	0.02%	75400 y	α	4.770	^{226}Ra
^{231}Th	trace	25.5 h	β^-	0.39	^{231}Pa
^{232}Th	99.98%	1.405×10^{10} y	α	4.083	^{228}Ra
^{234}Th	trace	24.1 d	β^-	0.27	^{234}Pa

Isotopes

Although every element up to bismuth (element 83) has an isotope that is practically stable for all purposes ("classically stable"), with the exceptions of technetium and promethium (elements 43 and 61), all elements from polonium (element 84) onward are noticeably radioactive. Of these, thorium (element 90) is the most stable, closely followed by uranium (element 92): the isotope ^{232}Th has a half-life of 14.05 billion years, about three times the age of the earth, and even slightly longer than the generally accepted age of the universe (about 13.8 billion years). As such, ^{232}Th still occurs naturally today: four-fifths of the thorium present at Earth's formation has survived to the present.[8][9][10] Thorium and uranium are thus the most well-studied of all the radioactive elements.[11]

The heaviest three primordial nuclides, ^{232}Th, ^{235}U, and ^{238}U, are the only isotopes beyond bismuth that have half-lives measured in billions of years. Thus, they are the only such heavy isotopes to have survived since their production around ten billion years ago. Hence, thorium and uranium are the only important primordial radioactive elements. Even then, the half-life of ^{232}Th is only a billionth that of ^{209}Bi, the last classically stable nuclide. ^{232}Th is the only isotope of thorium occurring in significant quantities in nature today, and thus thorium is usually considered to be a mononuclidic element.[8] The reason for the existence of this "island of relative stability" at thorium and uranium, where the longest-lived isotopes have half-lives of millions or billions of years, is because the most stable isotopes of these elements have closed nuclear shells;[12][13] nevertheless, since thorium and uranium have more protons than bismuth, their nuclei are thus still susceptible to alpha decay because the strong nuclear force is not strong enough to overcome the electromagnetic repulsion between their protons.[14]



The 4*n* decay chain of ^{232}Th, commonly called the "thorium series"

^{232}Th is the longest-lived isotope in the 4*n* decay chain which includes isotopes with a mass number divisible by 4 (hence the name: it is also called the thorium series after its progenitor). The chain begins with the alpha decay of ^{232}Th to ^{228}Ra, and terminates at stable ^{208}Pb.[8] (^{232}Th very occasionally undergoes spontaneous fission rather than alpha decay, and has left evidence in doing so in its minerals, but the partial half-life of this process is very large at over 10^{21} years and hence alpha decay predominates.)[15][16] Because ^{232}Th is so long-lived, its daughters still exist in nature as radiogenic nuclides despite their much shorter half-lives, the longest among them being the 5.7-year half-life of ^{228}Ra, the immediate alpha daughter of ^{232}Th. Any sample of thorium or its compounds contain traces of these daughters, which are isotopes of thallium, lead, bismuth, polonium, radon, radium, and actinium.[8] As such, natural thorium samples can be chemically purified to extract its useful daughter nuclides, such as ^{212}Pb, which is used in nuclear medicine for cancer therapy.[17][18]

Thirty radioisotopes have been characterised, which range in mass number from 209[19] to 238.[15] The most stable of them (after ^{232}Th) are ^{230}Th with a half-life of 75,380 years, ^{229}Th with a half-life of 7,340 years, ^{228}Th with a half-life of 1.92 years, ^{234}Th with a half-life of 24.10 days, and ^{227}Th with a half-life of 18.68 days: all of these isotopes occur in nature as trace radioisotopes due to their presence in the decay chains of ^{232}Th, ^{235}U, ^{238}U, and ^{237}Np (produced in minute traces in nuclear reactions in uranium ores). All of the remaining thorium isotopes have half-lives that are less than thirty days and the majority of these have half-lives that are less than ten minutes.[8]

In deep seawaters the isotope ^{230}Th becomes significant enough that the International Union of Pure and Applied Chemistry (IUPAC) reclassified thorium as a binuclidic element in 2013, as it can then make up to 0.04% of natural thorium, with ^{232}Th being the remainder.[20] The reason for this is that while its parent ^{238}U is soluble in water, ^{230}Th is insoluble and thus precipitates to form part of the sediment, and may be observed doing so. Uranium ores with low thorium concentrations can be purified to produce gram-sized thorium samples of which over a quarter is the ^{230}Th isotope, since ^{230}Th is one of the daughters of ^{238}U.[15] Thorium thus has a characteristic terrestrial isotopic composition, and so an atomic mass can be given, which is 232.0377(4) u. Thorium is one of only three significantly radioactive elements (the others being protactinium and uranium) that occur in large enough quantities on Earth for this to be possible.[20]

Thorium also has three known nuclear isomers (or metastable states), ^{216m1}Th, ^{216m2}Th, and ^{229m}Th. ^{229m}Th has the lowest known excitation energy of any isomer,[21] measured to be (7.6 ± 0.5) eV. This is so low that when it undergoes isomeric transition, the emitted gamma radiation is in the ultraviolet range.[22][23][24][b]

In the early history of the study of radioactivity, the different natural isotopes of thorium were given different names. In this scheme, ^{227}Th was named radioactinium (RdAc), ^{228}Th radiothorium (RdTh), ^{230}Th ionium (Io), ^{231}Th uranium Y (UY), ^{232}Th thorium (Th), and ^{234}Th uranium X1 (UX_1).[15] This reflects that ^{227}Th and ^{231}Th occur in the decay chain of natural ^{235}U (the actinium series), ^{228}Th occurs in the decay chain of ^{232}Th (the thorium series), and that ^{230}Th occurs in the decay chain of ^{238}U (the uranium or radium series). The remaining natural thorium isotope, ^{229}Th, occurs in minute traces as part of the decay chain of ^{237}Np, the neptunium series, which is much less abundant than the other decay chains in nature and was hence discovered much later: therefore it does not have a historical name. When it was realised that all of these are isotopes of thorium, many of these names fell out of use, and "thorium" came to refer to all isotopes, not just ^{232}Th.[15] The name ionium is still encountered for ^{230}Th in the context of ionium-thorium dating.[26][27]

Different isotopes of thorium behave identically chemically, but have slightly differing physical properties: for example, the densities of isotopically pure ^{228}Th, ^{229}Th, ^{230}Th, and ^{232}Th in g/cm^3 are respectively expected to be 11.5, 11.6, 11.6, and 11.7.[28] The isotope ^{229}Th is expected to be fissionable with a bare critical mass of 2839 kg, although with steel reflectors this value could drop to 994 kg.[28][c] While ^{232}Th is not fissionable, it is fertile as it can be converted to fissile ^{233}U using neutron capture.[28][29]

Radiometric dating

Two radiometric dating methods involve thorium isotopes: uranium-thorium dating, involving the decay of ^{234}U to ^{230}Th (ionium), and ionium-thorium dating, which measures the ratio of ^{232}Th to ^{230}Th. These rely on the fact that ^{232}Th is a primordial radioisotope, but ^{230}Th only occurs as an intermediate decay product in the decay chain of ^{238}U.[30] Uranium-thorium dating is a relatively short-range process because of the short half-lives of ^{234}U and ^{230}Th relative to the age of the Earth: it is also accompanied by a sister process involving the alpha decay of ^{235}U into ^{231}Th, which very quickly becomes the longer-lived ^{231}Pa, and this process is often used to check the results of uranium-thorium dating. Uranium-thorium dating is commonly used to determine the age of calcium carbonate materials such as speleothem or coral, because while uranium is rather soluble in water, thorium and protactinium are not, and so they are selectively precipitated into ocean-floor sediments, from which their ratios are measured. The scheme has a range of several hundred thousand years.[30][31] Ionium-thorium dating is a related process, which exploits the insolubility of thorium (both ^{232}Th and ^{230}Th) and thus its presence in ocean sediments to date these sediments by measuring the ratio of ^{232}Th to ^{230}Th.[26][27] Both of these dating methods assume that the proportion of ^{230}Th to ^{232}Th is a constant during the time period when the sediment layer was formed, that the sediment did not already contain thorium before contributions from the decay of uranium, and that the thorium cannot shift within the sediment layer.[26][27]

Source

- Wikipedia: Thorium (https://en.wikipedia.org/wiki/Thorium)