= Ytterbium =

Ytterbium is a chemical element with symbol Yb and atomic number 70 . It is the fourteenth and penultimate element in the lanthanide series , which is the basis of the relative stability of its + 2 oxidation state . However , like the other lanthanides , its most common oxidation state is + 3 , seen in its oxide , halides and other compounds . In aqueous solution , like compounds of other late lanthanides , soluble ytterbium compounds form complexes with nine water molecules . Because of its closed @-@ shell electron configuration , its density and melting and boiling points differ from those of the other lanthanides .

In 1878 , the Swiss chemist Jean Charles Galissard de Marignac separated in the rare earth " erbia " another independent component , which he called " ytterbia " , for Ytterby , the village in Sweden near where he found the new component of erbium . He suspected that ytterbia was a compound of a new element that he called " ytterbium " (in total , four elements were named after the village , the others being yttrium , terbium and erbium) . In 1907 , the new earth " lutecia " was separated from ytterbia , from which the element " lutecium " (now lutetium) was extracted by Georges Urbain , Carl Auer von Welsbach , and Charles James . After some discussion , Marignac 's name " ytterbium " was retained . A relatively pure sample of the metal was obtained only in 1953 . At present , ytterbium is mainly used as a dopant of stainless steel or active laser media , and less often as a gamma ray source .

Natural ytterbium is a mixture of seven stable isotopes , which altogether are present at concentrations of 3 parts per million . This element is mined in China , the United States , Brazil , and India in form of the minerals monazite , euxenite , and xenotime . The ytterbium concentration is low , because the element is found among many other rare earth elements ; moreover , it is among the least abundant ones . Once extracted and prepared , ytterbium is somewhat hazardous as an eye and skin irritant . The metal is a fire and explosion hazard .

= = Characteristics = =

= = = Physical properties = = =

Ytterbium is a soft , malleable and ductile chemical element that displays a bright silvery luster when in its pure form . It is a rare earth element , and it is readily attacked and dissolved by the strong mineral acids . It reacts slowly with cold water and it oxidizes slowly in air .

Ytterbium has three allotropes labeled by the Greek letters alpha , beta and gamma ; their transformation temperatures are ? 13 ° C and 795 ° C , although the exact transformation temperature depends on the pressure and stress . The beta allotrope exists at room temperature , and it has a face @-@ centered cubic crystal structure . The high @-@ temperature gamma allotrope has a body @-@ centered cubic crystalline structure . The alpha allotrope has a hexagonal crystalline structure and is stable at low temperatures . Normally , the beta allotrope has a metallic electrical conductivity , but it becomes a semiconductor when exposed to a pressure of about 16 @,@ 000 atmospheres (1 @.@ 6 GPa) . Its electrical resistivity increases ten times upon compression to 39 @,@ 000 atmospheres (3 @.@ 9 GPa) , but then drops to about 10 % of its room @-@ temperature resistivity at about 40 @,@ 000 atm (4 @.@ 0 GPa) .

In contrast with the other rare @-@ earth metals , which usually have antiferromagnetic and / or ferromagnetic properties at low temperatures , ytterbium is paramagnetic at temperatures above 1 @.@ 0 kelvin . However , the alpha allotrope is diamagnetic . With a melting point of 824 ° C and a boiling point of 1196 ° C , ytterbium has the smallest liquid range of all the metals .

Contrary to most other lanthanides , which have a close @-@ packed hexagonal lattice , ytterbium crystallizes in the face @-@ centered cubic structure . As a result , its density (6 @.@ 973 g / cm3) is significantly lower than , e.g. , those of the neighboring elements thulium (9 @.@ 32 g / cm3) and lutetium (9 @.@ 841 g / cm3) . The melting and boiling points of ytterbium are also significantly lower than those of thulium and lutetium . These properties stem from the closed @-@

shell electron configuration of ytterbium ([Xe] 4f14 6s2) , which causes only the two 6s electrons to be available for metallic bonding (in contrast to the other lanthanides where three electrons are available) .

= = = Chemical properties = = =

Ytterbium metal tarnishes slowly in air . Finely dispersed ytterbium readily oxidizes in air and under oxygen . Mixtures of powdered ytterbium with polytetrafluoroethylene or hexachloroethane burn with a luminous emerald @-@ green flame . Ytterbium reacts with hydrogen to form various non @-@ stoichiometric hydrides . Ytterbium dissolves slowly in water , but quickly in acids , liberating hydrogen gas .

Ytterbium is quite electropositive , and it reacts slowly with cold water and quite quickly with hot water to form ytterbium (III) hydroxide :

2 Yb (s) + 6 H2O (l) ? 2 Yb (OH) 3 (aq) + 3 H2 (g)

Ytterbium reacts with all the halogens :

2 Yb (s) + 3 F2 (g) ? 2 YbF3 (s) [white]

2 Yb (s) + 3 Cl2 (g) ? 2 YbCl3 (s) [white]

2 Yb (s) + 3 Br2 (g) ? 2 YbBr3 (s) [white]

2 Yb (s) + 3 I2 (g) ? 2 YbI3 (s) [white]

The ytterbium (III) ion absorbs light in the near infrared range of wavelengths , but not in visible light , so the mineral ytterbia , Yb2O3 , is white in color and the salts of ytterbium are also colorless . Ytterbium dissolves readily in dilute sulfuric acid to form solutions that contain the colorless Yb (III) ions , which exist as nonahydrate complexes :

2 Yb (s) + 3 H2SO4 (aq) ? 2 [Yb (H2O) 9] 3 + (aq) + 3 SO2 ?

4 (aq) + 3 H2 (g)

= = = Yb (II) vs. Yb (III) = = =

Although usually trivalent , ytterbium readily forms divalent compounds . This behavior is unusual to most lanthanides , which almost exclusively form compounds with an oxidation state of + 3 . The + 2 state has a valence electron configuration of 4f14 because the fully filled f @-@ shell gives more stability . The yellow @-@ green ytterbium (II) ion is a very strong reducing agent and decomposes water , releasing hydrogen gas , and thus only the colorless ytterbium (III) ion occurs in aqueous solution . Samarium and thulium also behave this way in the + 2 state , but europium (II) is stable in aqueous solution . Ytterbium metal behaves similarly to europium metal and the alkaline earth metals , dissolving in ammonia to form blue electride salts .

= = = Isotopes = = =

Natural ytterbium is composed of seven stable isotopes : 168Yb , 170Yb , 171Yb , 172Yb , 173Yb , 174Yb , and 176Yb , with 174Yb being the most abundant isotope , at 31 @.@ 8 % of the natural abundance) . 27 radioisotopes have been observed , with the most stable ones being 169Yb with a half @-@ life of 32 @.@ 0 days , 175Yb with a half @-@ life of 4 @.@ 18 days , and 166Yb with a half @-@ life of 56 @.@ 7 hours . All of its remaining radioactive isotopes have half @-@ lives that are less than two hours and most of these have half @-@ lives are less than 20 minutes . Ytterbium also has 12 meta states , with the most stable being 169mYb (t1 / 2 46 seconds) .

The isotopes of ytterbium range in atomic weight from 147 @.@ 9674 atomic mass unit (u) for 148Yb to 180 @.@ 9562 u for 181Yb . The primary decay mode of ytterbium isotopes lighter than the most abundant stable isotope , 174Yb , is electron capture , and the primary decay mode for those heavier than 174Yb is beta decay . The primary decay products of ytterbium isotopes lighter than 174Yb are thulium isotopes , and the primary decay products of ytterbium isotopes with heavier than 174Yb are lutetium isotopes .

= = Occurrence = =

Ytterbium is found with other rare earth elements in several rare minerals . It is most often recovered commercially from monazite sand (0 @.@ 03 % ytterbium) . The element is also found in euxenite and xenotime . The main mining areas are China , the United States , Brazil , India , Sri Lanka , and Australia ; and reserves of ytterbium are estimated as one million tonnes . Ytterbium is normally difficult to separate from other rare earths , but ion @-@ exchange and solvent extraction techniques developed in the mid- to late 20th century have simplified separation . Known compounds of ytterbium are rare and have not yet been well characterized . The abundance of ytterbium in the Earth 's crust is about 3 mg / kg .

As an even @-@ numbered lanthanide , in accordance with the Oddo @-@ Harkins rule , ytterbium is significantly more abundant than its immediate neighbors , thulium and lutetium , which occur in the same concentrate at levels of about 0 @.@ 5 % each . The world production of ytterbium is only about 50 tonnes per year , reflecting the fact that ytterbium has few commercial applications . Microscopic traces of ytterbium are used as a dopant in the Yb : YAG laser , a solid @-@ state laser in which ytterbium is the element that undergoes stimulated emission of electromagnetic radiation .

= = Production = =

It is somewhat difficult to separate ytterbium from other lanthanides due to its similar properties . As a result , the process is somewhat long . First , minerals such as monazite or xenotime are dissolved into various acids , such as sulfuric acid . Ytterbium can then be separated from other lanthanides by ion exchange , as can other lanthanides . The solution is then applied to a resin , which different lanthanides bond to in different matters . This is then dissolved using complexing agents , and due to the different types of bonding exhibited by the different lanthanides , it is possible to isolate the compounds .

Ytterbium is separated from other rare earths either by ion exchange or by reduction with sodium amalgam . In the latter method , a buffered acidic solution of trivalent rare earths is treated with molten sodium @-@ mercury alloy , which reduces and dissolves Yb3 + . The alloy is treated with hydrochloric acid . The metal is extracted from the solution as oxalate and converted to oxide by heating . The oxide is reduced to metal by heating with lanthanum , aluminium , cerium or zirconium in high vacuum . The metal is purified by sublimation and collected over a condensed plate .

= = Compounds = =

The chemical behavior of ytterbium is similar to that of the rest of the lanthanides . Most ytterbium compounds are found in the + 3 oxidation state and its salts in this oxidation state are nearly colorless . Like europium , samarium , and thulium , the trihalides of ytterbium can be reduced to the dihalides by hydrogen , zinc dust , or by the addition of metallic ytterbium . The + 2 oxidation state only occurs in solid compounds and reacts in some ways similarly to the alkaline earth metal compounds ; for example , ytterbium (II) oxide (YbO) shows the same structure as calcium oxide (CaO) .

= = = Halides = = =

Ytterbium forms both dihalides and trihalides with the halogens fluorine , chlorine , bromine , and iodine . The dihalides are susceptible to oxidation to the trihalides at room temperature and disproportionate to the trihalides and metallic ytterbium at high temperature :

3 YbX2 ? 2 YbX3 + Yb (X = F , Cl , Br , I)

Some ytterbium halides are used as reagents in organic synthesis . For example , ytterbium (III) chloride (YbCl3) is a Lewis acid and can be used as a catalyst in the Aldol and Diels ? Alder reactions . Ytterbium (II) iodide (YbI2) may be used , like samarium (II) iodide , as a reducing agent for coupling reactions . Ytterbium (III) fluoride (YbF3) is used as an inert and non @-@

toxic tooth filling as it continuously releases fluoride ions , which are good for dental health , and is also a good X @-@ ray contrast agent .

= = = Oxides = = =

Ytterbium reacts with oxygen to form ytterbium (III) oxide (Yb2O3) , which crystallizes in the " rare @-@ earth C @-@ type sesquioxide " structure which is related to the fluorite structure with one quarter of the anions removed , leading to ytterbium atoms in two different six coordinate (non @-@ octahedral) environments . Ytterbium (III) oxide can be reduced to ytterbium (II) oxide (YbO) with elemental ytterbium , which crystallizes in the same structure as sodium chloride .

= = History = =

Ytterbium was discovered by the Swiss chemist Jean Charles Galissard de Marignac in the year 1878 . While examining samples of gadolinite , Marignac found a new component in the earth then known as erbia , and he named it ytterbia , for Ytterby , the Swedish village near where he found the new component of erbium . Marignac suspected that ytterbia was a compound of a new element that he called " ytterbium " .

In 1907 , the French chemist Georges Urbain separated Marignac 's ytterbia into two components : neoytterbia and lutecia . Neoytterbia would later become known as the element ytterbium , and lutecia would later be known as the element lutetium . The Austrian chemist Carl Auer von Welsbach independently isolated these elements from ytterbia at about the same time , but he called them aldebaranium and cassiopeium ; the American chemist Charles James also independently isolated these elements at about the same time . Urbain and Welsbach accused each other of publishing results based on the other party . The Commission on Atomic Mass , consisting of Frank Wigglesworth Clarke , Wilhelm Ostwald , and Georges Urbain , which was then responsible for the attribution of new element names , settled the dispute in 1909 by granting priority to Urbain and adopting his names as official ones , based on the fact that the separation of lutetium from Marignac 's ytterbium was first described by Urbain ; after Urbain 's names were recognized , neoytterbium was reverted to ytterbium .

The chemical and physical properties of ytterbium could not be determined with any precision until 1953 , when the first nearly pure ytterbium metal was produced by using ion @-@ exchange processes . The price of ytterbium was relatively stable between 1953 and 1998 at about US $ 1 @,@ 000 / kg .

= = Applications = =

= = = Source of gamma rays = = =

The 169Yb isotope (with a half @-@ life of 32 days) , which is created along with the short @-@ lived 175Yb isotope (half @-@ life 4 @.@ 2 days) by neutron activation during the irradiation of ytterbium in nuclear reactors , has been used as a radiation source in portable X @-@ ray machines . Like X @-@ rays , the gamma rays emitted by the source pass through soft tissues of the body , but are blocked by bones and other dense materials . Thus , small 169Yb samples (which emit gamma rays) act like tiny X @-@ ray machines useful for radiography of small objects . Experiments show that radiographs taken with a 169Yb source are roughly equivalent to those taken with X @-@ rays having energies between 250 and 350 keV . 169Yb is also used in nuclear medicine .

= = = World 's most stable atomic clock = = =

Ytterbium clocks hold the record for stability with ticks stable to within less than two parts in 1

quintillion (2 × 10 ? 18) . The clocks developed at the National Institute of Standards and Technology (NIST) rely on about 10 @,@ 000 rare @-@ earth atoms cooled to 10 microkelvin (10 millionths of a degree above absolute zero) and trapped in an optical lattice ? a series of pancake @-@ shaped wells made of laser light . Another laser that " ticks " 518 trillion times per second provokes a transition between two energy levels in the atoms . The large number of atoms is key to the clocks ' high stability .

= = = Doping of stainless steel = = =

Ytterbium can also be used as a dopant to help improve the grain refinement , strength , and other mechanical properties of stainless steel . Some ytterbium alloys have rarely been used in dentistry .

= = = Ytterbium as dopant of active media = = =

The ytterbium + 3 ion is used as a doping material in active laser media , specifically in solid state lasers and double clad fiber lasers . Ytterbium lasers are highly efficient , have long lifetimes and can generate short pulses ; ytterbium can also easily be incorporated into the material used to make the laser . Ytterbium lasers commonly radiate in the 1 @.@ 06 ? 1 @.@ 12 μm band being optically pumped at wavelength 900 nm ? 1 μm , dependently on the host and application . The small quantum defect makes ytterbium a prospective dopant for efficient lasers and power scaling .

The kinetic of excitations in ytterbium @-@ doped materials is simple and can be described within the concept of effective cross @-@ sections ; for most ytterbium @-@ doped laser materials (as for many other optically pumped gain media) , the McCumber relation holds , although the application to the ytterbium @-@ doped composite materials was under discussion .

Usually , low concentrations of ytterbium are used . At high concentrations , the ytterbium @-@ doped materials show photodarkening (glass fibers) or even a switch to broadband emission (crystals and ceramics) instead of efficient laser action . This effect may be related with not only overheating , but also with conditions of charge compensation at high concentrations of ytterbium ions .

Much progress has been made in the power scaling Lasers and Amplifiers produced with ytterbium (Yb) doped optical fibers . Power levels have increased from the 1 kW regimes due to the advancements in components as well as the Yb doped fibers themselves . Fabrication of Low NA , Large Mode Area (LMA) fibers enable achievement of near perfect beam qualities (M2 < 1 @.@ 1) at power levels of 1 @.@ 5 kW to greater than 2 kW at ~ 1064 nm in a broadband configuration . Ytterbium @-@ doped LMA fibers also have the advantages of a larger mode field diameter (MFD) which negates the impacts of nonlinear effects such as stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS) , which limit the achievement of higher power levels , and provides a distinct advantage over single mode ytterbium @-@ doped fibers .

In order to achieve even higher power levels in ytterbium @-@ based fiber systems all factors of the fiber must be considered . These can only be achieved via optimization of all the ytterbium fiber parameters , ranging from the core background losses to the geometrical properties , in order to reduce the splice losses within the cavity . Power scaling also requires optimization of matching passive fibers within the optical cavity . The optimization of the ytterbium @-@ doped glass itself through host glass modification of various dopants also plays a large part in reducing the background loss of the glass , improvements in slope efficiency of the fiber and improved photodarkening performance . All of which contribute to increased power levels in 1 μm systems .

= = = Others = = =

Ytterbium metal increases its electrical resistivity when subjected to high stresses . This property is used in stress gauges to monitor ground deformations from earthquakes and explosions .

Visible light waves oscillate faster than microwaves , and therefore optical clocks can be more precise than caesium atomic clocks . The Physikalisch @-@ Technische Bundesanstalt (PTB) is

working on several such optical clocks . The model with one single ytterbium ion caught in an ion trap is highly accurate . The optical clock based on it is exact to 17 digits after the decimal point . A pair of experimental atomic clocks based on ytterbium atoms at the National Institute of Standards and Technology (NIST) has set a new record for stability . NIST physicists report in the August 22 , 2013 issue of Science Express that the ytterbium clocks ' ticks are stable to within less than two parts in 1 quintillion (1 followed by 18 zeros) , roughly 10 times better than the previous best published results for other atomic clocks . The clocks would be accurate within a second for a period comparable to the age of the universe .

Currently , ytterbium is being investigated as a possible replacement for magnesium in high density pyrotechnic payloads for kinematic infrared decoy flares . As ytterbium (III) oxide has a significantly higher emissivity in the infrared range than magnesium oxide , a higher radiant intensity is obtained with ytterbium @-@ based payloads in comparison to those commonly based on magnesium / Teflon / Viton (MTV) .

= = Precautions = =

Although ytterbium is fairly stable chemically , it is stored in airtight containers and in an inert atmosphere such as a nitrogen @-@ filled dry box to protect the metal from air and moisture . All compounds of ytterbium are treated as highly toxic , although initial studies appear to indicate that the danger is minimal . Ytterbium compounds are , however , known to cause irritation to the human skin and eyes , and some might be teratogenic . Metallic ytterbium dust can spontaneously combust , and the resulting fumes are hazardous . Ytterbium fires cannot be extinguished using water , and only dry chemical class D fire extinguishers can extinguish the fires .