

= Titanium =

Titanium is a chemical element with symbol Ti and atomic number 22 . It is a lustrous transition metal with a silver color , low density and high strength . It is highly resistant to corrosion in sea water , aqua regia , and chlorine .

Titanium was discovered in Cornwall , Great Britain , by William Gregor in 1791 and named by Martin Heinrich Klaproth for the Titans of Greek mythology . The element occurs within a number of mineral deposits , principally rutile and ilmenite , which are widely distributed in the Earth 's crust and lithosphere , and it is found in almost all living things , rocks , water bodies , and soils . The metal is extracted from its principal mineral ores by the Kroll and Hunter processes . The most common compound , titanium dioxide , is a popular photocatalyst and is used in the manufacture of white pigments . Other compounds include titanium tetrachloride (TiCl_4) , a component of smoke screens and catalysts ; and titanium trichloride (TiCl_3) , which is used as a catalyst in the production of polypropylene .

Titanium can be alloyed with iron , aluminium , vanadium , and molybdenum , among other elements , to produce strong , lightweight alloys for aerospace (jet engines , missiles , and spacecraft) , military , industrial process (chemicals and petro @-@ chemicals , desalination plants , pulp , and paper) , automotive , agri @-@ food , medical prostheses , orthopedic implants , dental and endodontic instruments and files , dental implants , sporting goods , jewelry , mobile phones , and other applications .

The two most useful properties of the metal are corrosion resistance and the highest strength @-@ to @-@ density ratio of any metallic element . In its unalloyed condition , titanium is as strong as some steels , but less dense . There are two allotropic forms and five naturally occurring isotopes of this element , ^{46}Ti through ^{50}Ti , with ^{48}Ti being the most abundant (73 @. @ 8 %) . Although they have the same number of valence electrons and are in the same group in the periodic table , titanium and zirconium differ in many chemical and physical properties .

= = Characteristics = =

= = = Physical properties = = =

A metallic element , titanium is recognized for its high strength @-@ to @-@ weight ratio . It is a strong metal with low density that is quite ductile (especially in an oxygen @-@ free environment) , lustrous , and metallic @-@ white in color . The relatively high melting point (more than 1 @, @ 650 ° C or 3 @, @ 000 ° F) makes it useful as a refractory metal . It is paramagnetic and has fairly low electrical and thermal conductivity .

Commercial (99 @. @ 2 % pure) grades of titanium have ultimate tensile strength of about 434 MPa (63 @, @ 000 psi) , equal to that of common , low @-@ grade steel alloys , but are less dense . Titanium is 60 % denser than aluminium , but more than twice as strong as the most commonly used 6061 @-@ T6 aluminium alloy . Certain titanium alloys (e.g. , Beta C) achieve tensile strengths of over 1400 MPa (200000 psi) . However , titanium loses strength when heated above 430 ° C (806 ° F) .

Titanium is not as hard as some grades of heat @-@ treated steel , is non @-@ magnetic and a poor conductor of heat and electricity . Machining requires precautions , because the material might gall if sharp tools and proper cooling methods are not used . Like those made from steel , titanium structures have a fatigue limit that guarantees longevity in some applications . Titanium alloys have less stiffness than many other structural materials such as aluminium alloys and carbon fiber .

The metal is a dimorphic allotrope of an hexagonal ? form that changes into a body @-@ centered cubic (lattice) ? form at 882 ° C (1 @, @ 620 ° F) . The specific heat of the ? form increases dramatically as it is heated to this transition temperature but then falls and remains fairly constant for the ? form regardless of temperature . Similar to zirconium and hafnium , an additional omega phase exists , which is thermodynamically stable at high pressures , but is metastable at ambient

pressures . This phase is usually hexagonal (ideal) or trigonal (distorted) and can be considered to be due to a soft longitudinal acoustic phonon of the β phase causing collapse of (111) planes of atoms .

=== Chemical properties ===

Like aluminium and magnesium , titanium metal and its alloys oxidize immediately upon exposure to air . Titanium readily reacts with oxygen at 1 @, @ 200 ° C (2 @, @ 190 ° F) in air , and at 610 ° C (1 @, @ 130 ° F) in pure oxygen , forming titanium dioxide . It is , however , slow to react with water and air at ambient temperatures because it forms a passive oxide coating that protects the bulk metal from further oxidation . When it first forms , this protective layer is only 1 ? 2 nm thick but continues to grow slowly ; reaching a thickness of 25 nm in four years .

Atmospheric passivation gives titanium excellent resistance to corrosion , almost equivalent to platinum , capable of withstanding attack by dilute sulfuric and hydrochloric acids , chloride solutions , and most organic acids . However , titanium is corroded by concentrated acids . As indicated by its negative redox potential , titanium is thermodynamically a very reactive metal that burns in normal atmosphere at lower temperatures than the melting point . Melting is possible only in an inert atmosphere or in a vacuum . At 550 ° C (1 @, @ 1022 ° F) , it combines with chlorine . It also reacts with the other halogens and absorbs hydrogen .

Titanium is one of the few elements that burns in pure nitrogen gas , reacting at 800 ° C (1 @, @ 470 ° F) to form titanium nitride , which causes embrittlement . Because of its high reactivity with oxygen , nitrogen , and some other gases , titanium filaments are applied in titanium sublimation pumps as scavengers for these gases . Such pumps inexpensively and reliably produce extremely low pressures in ultra @-@ high vacuum systems .

=== Occurrence ===

Titanium is the ninth @-@ most abundant element in Earth 's crust (0 @. @ 63 % by mass) and the seventh @-@ most abundant metal . It is present as oxides in most igneous rocks , in sediments derived from them , in living things , and natural bodies of water . Of the 801 types of igneous rocks analyzed by the United States Geological Survey , 784 contained titanium . Its proportion in soils is approximately 0 @. @ 5 to 1 @. @ 5 % .

It is widely distributed and occurs primarily in the minerals anatase , brookite , ilmenite , perovskite , rutile and titanite (sphene) . Of these minerals , only rutile and ilmenite have economic importance , yet even they are difficult to find in high concentrations . About 6 @. @ 0 and 0 @. @ 7 million tonnes of those minerals were mined in 2011 , respectively . Significant titanium @-@ bearing ilmenite deposits exist in western Australia , Canada , China , India , Mozambique , New Zealand , Norway , Ukraine and South Africa . About 186 @, @ 000 tonnes of titanium metal sponge were produced in 2011 , mostly in China (60 @, @ 000 t) , Japan (56 @, @ 000 t) , Russia (40 @, @ 000 t) , United States (32 @, @ 000 t) and Kazakhstan (20 @, @ 700 t) . Total reserves of titanium are estimated to exceed 600 million tonnes .

The concentration of Ti is about 4 picomolar in the ocean . At 100 ° C , the concentration of titanium in water is estimated to be less than 10 ? 7 M at pH 7 . The identity of titanium species in aqueous solution remains unknown because of its low solubility and the lack of sensitive spectroscopic methods , although only the 4 + oxidation state is stable in air . No evidence exists for a biological role , although rare organisms are known to accumulate high concentrations of titanium .

Titanium is contained in meteorites and has been detected in the Sun and in M @-@ type stars (the coolest type) with a surface temperature of 3 @, @ 200 ° C (5 @, @ 790 ° F) . Rocks brought back from the Moon during the Apollo 17 mission are composed of 12 @. @ 1 % TiO₂ . It is also found in coal ash , plants , and even the human body . Native titanium (pure metallic) is very rare .

=== Isotopes ===

Naturally occurring titanium is composed of 5 stable isotopes : ^{46}Ti , ^{47}Ti , ^{48}Ti , ^{49}Ti , and ^{50}Ti , with ^{48}Ti being the most abundant (73 @. @ 8 % natural abundance) . Eleven radioisotopes have been characterized , the most stable being ^{44}Ti with a half @- @ life of 63 years ; ^{45}Ti , 184 @. @ 8 minutes ; ^{51}Ti , 5 @. @ 76 minutes ; and ^{52}Ti , 1 @. @ 7 minutes . All the other radioactive isotopes have half @- @ lives less than 33 seconds and the majority , less than half a second .

The isotopes of titanium range in atomic weight from 39 @. @ 99 u (^{40}Ti) to 57 @. @ 966 u (^{58}Ti) . The primary decay mode before the most abundant stable isotope , ^{48}Ti , is electron capture and the primary mode after is beta emission . The primary decay products before ^{48}Ti are element 21 (scandium) isotopes and the primary products after are element 23 (vanadium) isotopes .

Titanium becomes radioactive upon bombardment with deuterons , emitting mainly positrons and hard gamma rays .

= = Compounds = =

The + 4 oxidation state dominates titanium chemistry , but compounds in the + 3 oxidation state are also common . Commonly , titanium adopts an octahedral coordination geometry in its complexes , but tetrahedral TiCl_4 is a notable exception . Because of its high oxidation state , titanium (IV) compounds exhibit a high degree of covalent bonding . Unlike most other transition metals , simple aquo Ti (IV) complexes are unknown .

= = = Oxides , sulfides , and alkoxides = = =

The most important oxide is TiO_2 , which exists in three important polymorphs ; anatase , brookite , and rutile . All of these are white diamagnetic solids , although mineral samples can appear dark (see rutile) . They adopt polymeric structures in which Ti is surrounded by six oxide ligands that link to other Ti centers .

Titanates usually refer to titanium (IV) compounds , as represented barium titanate (BaTiO_3) . With a perovskite structure , this material exhibits piezoelectric properties and is used as a transducer in the interconversion of sound and electricity . Many minerals are titanates , e.g. ilmenite (FeTiO_3) . Star sapphires and rubies get their asterism (star @- @ forming shine) from the presence of titanium dioxide impurities .

A variety of reduced oxides of titanium are known . Ti_3O_5 , described as a Ti (IV) - Ti (III) species , is a purple semiconductor produced by reduction of TiO_2 with hydrogen at high temperatures , and is used industrially when surfaces need to be vapour @- @ coated with titanium dioxide : it evaporates as pure TiO , whereas TiO_2 evaporates as a mixture of oxides and deposits coatings with variable refractive index . Also known is Ti_2O_3 , with the corundum structure , and TiO , with the rock salt structure , although often nonstoichiometric .

The alkoxides of titanium (IV) , prepared by reacting TiCl_4 with alcohols , are colourless compounds that convert to the dioxide on reaction with water . They are industrially useful for depositing solid TiO_2 via the sol @- @ gel process . Titanium isopropoxide is used in the synthesis of chiral organic compounds via the Sharpless epoxidation .

Titanium forms a variety of sulfides , but only TiS_2 has attracted significant interest . It adopts a layered structure and was used as a cathode in the development of lithium batteries . Because Ti (IV) is a " hard cation " , the sulfides of titanium are unstable and tend to hydrolyze to the oxide with release of hydrogen sulfide .

= = = Nitrides , carbides = = =

Titanium nitride (TiN) has a hardness equivalent to sapphire and carborundum (9 @. @ 0 on the Mohs Scale) , and is often used to coat cutting tools , such as drill bits . It is also used as a gold @- @ colored decorative finish and as a barrier metal in semiconductor fabrication . Titanium carbide , which is also very hard , is found in cutting tools and coatings .

== Halides ==

Titanium tetrachloride (titanium (IV) chloride , TiCl_4) is a colorless volatile liquid (commercial samples are yellowish) that , in air , hydrolyzes with spectacular emission of white clouds . Via the Kroll process , TiCl_4 is produced in the conversion of titanium ores to titanium dioxide , e.g. , for use in white paint . It is widely used in organic chemistry as a Lewis acid , for example in the Mukaiyama aldol condensation . In the van Arkel process , titanium tetraiodide (TiI_4) is generated in the production of high purity titanium metal .

Titanium (III) and titanium (II) also form stable chlorides . A notable example is titanium (III) chloride (TiCl_3) , which is used as a catalyst for production of polyolefins (see Ziegler @-@ Natta catalyst) and a reducing agent in organic chemistry .

== Organometallic complexes ==

Owing to the important role of titanium compounds as polymerization catalyst , compounds with Ti @-@ C bonds have been intensively studied . The most common organotitanium complex is titanocene dichloride ((C_5H_5) 2TiCl_2) . Related compounds include Tebbe 's reagent and Petasis reagent . Titanium forms carbonyl complexes , e.g. (C_5H_5) $2\text{Ti} (\text{CO})_2$.

== History ==

Titanium was discovered as an inclusion of a mineral in Cornwall , Great Britain , in 1791 by the clergyman and amateur geologist William Gregor , then vicar of Creed parish . He recognized the presence of a new element in ilmenite when he found black sand by a stream in the nearby parish of Manaccan and noticed the sand was attracted by a magnet . Analyzing the sand , he determined the presence of two metal oxides : iron oxide (explaining the attraction to the magnet) and 45 @. 25 % of a white metallic oxide he could not identify . Realizing that the unidentified oxide contained a metal that did not match any known element , Gregor reported his findings to the Royal Geological Society of Cornwall and in the German science journal Crell 's Annalen .

Around the same time , Franz @-@ Joseph Müller von Reichenstein produced a similar substance , but could not identify it . The oxide was independently rediscovered in 1795 by Prussian chemist Martin Heinrich Klaproth in rutile from Boinik (German name of unknown place) village of Hungary (now in Slovakia) . Klaproth found that it contained a new element and named it for the Titans of Greek mythology . After hearing about Gregor 's earlier discovery , he obtained a sample of manaccanite and confirmed it contained titanium .

The currently known processes for extracting titanium from its various ores are laborious and costly ; it is not possible to reduce the ore by heating with carbon (as in iron smelting) because titanium combines with the carbon to produce titanium carbide . Pure metallic titanium (99 @. 9 %) was first prepared in 1910 by Matthew A. Hunter at Rensselaer Polytechnic Institute by heating TiCl_4 with sodium at 700 ? 800 ° C under great pressure in a batch process known as the Hunter process . Titanium metal was not used outside the laboratory until 1932 when William Justin Kroll proved that it could be produced by reducing titanium tetrachloride (TiCl_4) with calcium . Eight years later he refined this process with magnesium and even sodium in what became known as the Kroll process . Although research continues into more efficient and cheaper processes (e.g. , FFC Cambridge , Armstrong) , the Kroll process is still used for commercial production .

Titanium of very high purity was made in small quantities when Anton Eduard van Arkel and Jan Hendrik de Boer discovered the iodide , or crystal bar , process in 1925 , by reacting with iodine and decomposing the formed vapors over a hot filament to pure metal .

In the 1950s and 1960s the Soviet Union pioneered the use of titanium in military and submarine applications (Alfa class and Mike class) as part of programs related to the Cold War . Starting in the early 1950s , titanium came into use extensively in military aviation , particularly in high @-@ performance jets , starting with aircraft such as the F100 Super Sabre and Lockheed A @-@ 12 and SR @-@ 71 .

Recognizing the strategic importance of titanium the U.S. Department of Defense supported early efforts of commercialization .

Throughout the period of the Cold War , titanium was considered a strategic material by the U.S. government , and a large stockpile of titanium sponge was maintained by the Defense National Stockpile Center , which was finally depleted in the 2000s . According to 2006 data , the world 's largest producer , Russian @-@ based VSMPO @-@ Avisma , was estimated to account for about 29 % of the world market share . As of 2015 , titanium sponge metal was produced in six countries : China , Japan , Russia , Kazakhstan , the USA , Ukraine and India . (in order of output) .

In 2006 , the U.S. Defense Advanced Research Projects Agency (DARPA) awarded \$ 5 @.@ 7 million to a two @-@ company consortium to develop a new process for making titanium metal powder . Under heat and pressure , the powder can be used to create strong , lightweight items ranging from armor plating to components for the aerospace , transport , and chemical processing industries .

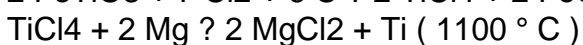
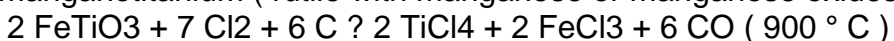
= = Production and fabrication = =

The processing of titanium metal occurs in 4 major steps : reduction of titanium ore into " sponge " , a porous form ; melting of sponge , or sponge plus a master alloy to form an ingot ; primary fabrication , where an ingot is converted into general mill products such as billet , bar , plate , sheet , strip , and tube ; and secondary fabrication of finished shapes from mill products .

Because it cannot be readily produced by reduction of its dioxide , titanium metal is obtained by reduction of TiCl_4 with magnesium metal in the Kroll Process . The complexity of this batch production in the Kroll process explains the relatively high market value of titanium , despite the Kroll process is less expensive than the Hunter process . To produce the TiCl_4 required by the Kroll process , the dioxide is subjected to carbothermic reduction in the presence of chlorine . In this process , the chlorine gas is passed over a red @-@ hot mixture of rutile or ilmenite in the presence of carbon . After extensive purification by fractional distillation , the TiCl_4 is reduced with 800°C molten magnesium in an argon atmosphere . Titanium metal can be further purified by the van Arkel ? de Boer process , which involves thermal decomposition of titanium tetraiodide .

A more recently developed batch production method , the FFC Cambridge process , consumes titanium dioxide powder (a refined form of rutile) as feedstock and produces titanium metal , either powder or sponge . The process involves fewer steps than the Kroll process and takes less time . If mixed oxide powders are used , the product is an alloy .

Common titanium alloys are made by reduction . For example , cuprotitanium (rutile with copper added is reduced) , ferrocarbon titanium (ilmenite reduced with coke in an electric furnace) , and manganotitanium (rutile with manganese or manganese oxides) are reduced .



About 50 grades of titanium and titanium alloys are designed and currently used , although only a couple of dozen are readily available commercially . The ASTM International recognizes 31 Grades of titanium metal and alloys , of which Grades 1 through 4 are commercially pure (unalloyed) . Those four vary in tensile strength as a function of oxygen content , with Grade 1 being the most ductile (lowest tensile strength with an oxygen content of 0 @.@ 18 %) , and Grade 4 the least ductile (highest tensile strength with an oxygen content of 0 @.@ 40 %) . The remaining grades are alloys , each designed for specific properties of ductility , strength , hardness , electrical resistivity , creep resistance , specific corrosion resistance , and combinations thereof .

In addition to the ASTM specifications , titanium alloys are also produced to meet Aerospace and Military specifications (SAE @-@ AMS , MIL @-@ T) , ISO standards , and country @-@ specific specifications , as well as proprietary end @-@ user specifications for aerospace , military , medical , and industrial applications .

Titanium powder is manufactured using a flow production process known as the Armstrong process that is similar to the batch production Hunter process . A stream of titanium tetrachloride gas is added to a stream of molten sodium metal ; the products (sodium chloride salt and titanium

particles) is filtered from the extra sodium . Titanium is then separated from the salt by water washing . Both sodium and chlorine are recycled to produce and process more titanium tetrachloride .

All welding of titanium must be done in an inert atmosphere of argon or helium to shield it from contamination with atmospheric gases (oxygen , nitrogen , and hydrogen) . Contamination causes a variety of conditions , such as embrittlement , which reduces the integrity of the assembly welds and leads to joint failure .

Commercially pure flat product (sheet , plate) can be formed readily , but processing must take into account the fact that the metal has a " memory " and tends to spring back . This is especially true of certain high @-@ strength alloys . Titanium cannot be soldered without first pre @-@ plating it in a metal that is solderable . The metal can be machined with the same equipment and the same processes as stainless steel .

= = Applications = =

Titanium is used in steel as an alloying element (ferro @-@ titanium) to reduce grain size and as a deoxidizer , and in stainless steel to reduce carbon content . Titanium is often alloyed with aluminium (to refine grain size) , vanadium , copper (to harden) , iron , manganese , molybdenum , and other metals . Titanium mill products (sheet , plate , bar , wire , forgings , castings) find application in industrial , aerospace , recreational , and emerging markets . Powdered titanium is used in pyrotechnics as a source of bright @-@ burning particles .

= = = Pigments , additives and coatings = = =

About 95 % of all titanium ore is destined for refinement into titanium dioxide (TiO_2) , an intensely white permanent pigment used in paints , paper , toothpaste , and plastics . It is also used in cement , in gemstones , as an optical opacifier in paper , and a strengthening agent in graphite composite fishing rods and golf clubs .

TiO_2

TiO_2 powder is chemically inert , resists fading in sunlight , and is very opaque : it imparts a pure and brilliant white color to the brown or gray chemicals that form the majority of household plastics . In nature , this compound is found in the minerals anatase , brookite , and rutile . Paint made with titanium dioxide does well in severe temperatures and marine environments . Pure titanium dioxide has a very high index of refraction and an optical dispersion higher than diamond . In addition to being a very important pigment , titanium dioxide is also used in sunscreens .

= = = Aerospace and marine = = =

Because of their high tensile strength to density ratio , high corrosion resistance , fatigue resistance , high crack resistance , and ability to withstand moderately high temperatures without creeping , titanium alloys are used in aircraft , armor plating , naval ships , spacecraft , and missiles . For these applications , titanium is alloyed with aluminium , zirconium , nickel , vanadium , and other elements to manufacture a variety of components including critical structural parts , fire walls , landing gear , exhaust ducts (helicopters) , and hydraulic systems . In fact , about two thirds of all titanium metal produced is used in aircraft engines and frames . The SR @-@ 71 " Blackbird " was one of the first aircraft frames where titanium was used , paving the way for much wider use in modern military and commercial aircraft . An estimated 59 metric tons (130 @,@ 000 pounds) are used in the Boeing 777 , 45 in the Boeing 747 , 18 in the Boeing 737 , 32 in the Airbus A340 , 18 in the Airbus A330 , and 12 in the Airbus A320 . The Airbus A380 may use 77 metric tons , including about 11 tons in the engines . In engine applications , titanium is used for rotors , compressor blades , hydraulic system components , and nacelles . The titanium 6AL @-@ 4V alloy accounts for almost 50 % of all alloys used in aircraft applications .

Because it is highly resistant to corrosion by sea water , titanium is used to make propeller shafts ,

rigging , and heat exchangers in desalination plants ; heater @-@ chillers for salt water aquariums , fishing line and leader , and divers ' knives . Titanium is used in the housings and components of ocean @-@ deployed surveillance and monitoring devices for science and the military . The former Soviet Union developed techniques for making submarines with hulls of titanium alloys forging titanium in huge vacuum tubes .

= = = Industrial = = =

Welded titanium pipe and process equipment (heat exchangers , tanks , process vessels , valves) are used in the chemical and petrochemical industries primarily for corrosion resistance . Specific alloys are used in downhole and nickel hydrometallurgy for their high strength (e. g. : titanium Beta C alloy) , corrosion resistance , or both . The pulp and paper industry uses titanium in process equipment exposed to corrosive media , such as sodium hypochlorite or wet chlorine gas (in the bleachery) . Other applications include : ultrasonic welding , wave soldering , and sputtering targets .

Titanium tetrachloride (TiCl_4) , a colorless liquid , is important as an intermediate in the process of making TiO_2 and is also used to produce the Ziegler - Natta catalyst . Titanium tetrachloride is also used to iridize glass and , because it fumes strongly in moist air , it is used to make smoke screens .

= = = Consumer and architectural = = =

Titanium metal is used in automotive applications , particularly in automobile and motorcycle racing where low weight and high strength and rigidity are critical . The metal is generally too expensive for the general consumer market , though some late model Corvettes have been manufactured with titanium exhausts , and the new Corvette Z06 's LT4 supercharged engine uses lightweight , solid titanium intake valves for greater strength and resistance to heat .

Titanium is used in many sporting goods : tennis rackets , golf clubs , lacrosse stick shafts ; cricket , hockey , lacrosse , football helmet grills , and bicycle frames and components . Although not a mainstream material for bicycle production , titanium bikes have been used by racing teams and adventure cyclists .

Titanium alloys are used in spectacle frames that are rather expensive but highly durable , long lasting , light weight , and cause no skin allergies . Many backpackers use titanium equipment , including cookware , eating utensils , lanterns , and tent stakes . Though slightly more expensive than traditional steel or aluminium alternatives , titanium products can be significantly lighter without compromising strength . Titanium horseshoes are preferred to steel by farriers because it is lighter and more durable .

Titanium has occasionally been used in architecture . The 40 m (131 foot) memorial to Yuri Gagarin , the first man to travel in space , ($55^\circ 42' 29'' \text{ N } 37^\circ 34' 57'' \text{ E}$) , as well as the 110 m (360 @.@ 9 feet) Monument to the Conquerors of Space on top of the Cosmonaut Museum in Moscow are made of titanium for the metal 's attractive color and association with rocketry . The Guggenheim Museum Bilbao and the Cerritos Millennium Library were the first buildings in Europe and North America , respectively , to be sheathed in titanium panels . Titanium sheathing was used in the Frederic C. Hamilton Building in Denver , Colorado .

Because of its superior strength and light weight relative to other metals (steel , stainless steel , and aluminium) , and because of recent advances in metalworking techniques , titanium has become more widespread in the manufacture of firearms . Primary uses include pistol frames and revolver cylinders . For the same reasons , it is used in the body of laptop computers (for example , in Apple 's PowerBook line) .

Some upmarket lightweight and corrosion @-@ resistant tools , such as shovels and flashlights , are made of titanium or titanium alloys .

= = = Jewelry = = =

Because of its durability , titanium has become more popular for designer jewelry (particularly , titanium rings) . Its inertness makes it a good choice for those with allergies or those who will be wearing the jewelry in environments such as swimming pools . Titanium is also alloyed with gold to produce an alloy that can be marketed as 24 @-@ carat gold because the 1 % of alloyed Ti is insufficient to require a lesser mark . The resulting alloy is roughly the hardness of 14 @-@ carat gold and is more durable than pure 24 @-@ carat gold .

Titanium 's durability , light weight , dent and corrosion resistance makes it useful for watch cases . Some artists work with titanium to produce sculptures , decorative objects and furniture .

Titanium may be anodized to vary the thickness of the surface oxide layer , causing optical interference fringes and a variety of bright colors . With this coloration and chemical inertness , titanium is a popular metal for body piercing .

Titanium has a minor use in dedicated non @-@ circulating coins and medals . In 1999 , Gibraltar released world 's first titanium coin for the millennium celebration . The Gold Coast Titans , an Australian rugby league team , award a medal of pure titanium to their player of the year .

= = = Medical = = =

Titanium biocompatibility : Because it is biocompatible (non @-@ toxic and not rejected by the body) , titanium has many medical uses , including surgical implements and implants , such as hip balls and sockets (joint replacement) and dental implants that can stay in place for up to 20 years . The titanium is often alloyed with about 4 % aluminium or 6 % Al and 4 % vanadium .

Titanium has the inherent ability to osseointegrate , enabling use in dental implants that can last for over 30 years . This property is also useful for orthopedic implant applications . These benefit from titanium 's lower modulus of elasticity (Young 's modulus) to more closely match that of the bone that such devices are intended to repair . As a result , skeletal loads are more evenly shared between bone and implant , leading to a lower incidence of bone degradation due to stress shielding and periprosthetic bone fractures , which occur at the boundaries of orthopedic implants . However , titanium alloys ' stiffness is still more than twice that of bone , so adjacent bone bears a greatly reduced load and may deteriorate .

Because titanium is non @-@ ferromagnetic , patients with titanium implants can be safely examined with magnetic resonance imaging (convenient for long @-@ term implants) . Preparing titanium for implantation in the body involves subjecting it to a high @-@ temperature plasma arc which removes the surface atoms , exposing fresh titanium that is instantly oxidized .

Titanium is also used for the surgical instruments used in image @-@ guided surgery , as well as wheelchairs , crutches , and any other products where high strength and low weight are desirable .

Titanium dioxide nanoparticles are widely used in electronics and the delivery of pharmaceuticals and cosmetics .

= = = Nuclear waste storage = = =

Because of its excellent corrosion resistance , titanium containers have been studied for the long @-@ term storage of nuclear waste . Containers lasting more than 100 @,@ 000 years are possible with manufacturing conditions that minimize material defects . A titanium " drip shield " could also be installed over containers of other types to enhance their longevity .

= = Bioremediation = =

The fungal species *Marasmius oreades* and *Hypholoma capnoides* can bio convert titanium in titanium polluted soils .

= = Precautions = =

Titanium is non-toxic even in large doses and does not play any natural role inside the human body . An estimated quantity of 0.8 milligrams of titanium is ingested by humans each day , but most passes through without being absorbed in the tissues . It does , however , sometimes bioaccumulate in tissues that contain silica . One study indicates a possible connection between titanium and yellow nail syndrome . An unknown mechanism in plants may use titanium to stimulate the production of carbohydrates and encourage growth . This may explain why most plants contain about 1 part per million (ppm) of titanium , food plants have about 2 ppm , and horsetail and nettle contain up to 80 ppm .

As a powder or in the form of metal shavings , titanium metal poses a significant fire hazard and , when heated in air , an explosion hazard . Water and carbon dioxide are ineffective for extinguishing a titanium fire ; Class D dry powder agents must be used instead .

When used in the production or handling of chlorine , titanium should not be exposed to dry chlorine gas because it may result in a titanium / chlorine fire . Even wet chlorine presents a fire hazard when extreme weather conditions cause unexpected drying .

Titanium can catch fire when a fresh , non-oxidized surface comes in contact with liquid oxygen . Fresh metal may be exposed when the oxidized surface is struck or scratched with a hard object , or when mechanical strain causes a crack . This poses a limitation to its use in liquid oxygen systems , such as those in the aerospace industry . Because titanium tubing impurities can cause fires when exposed to oxygen , titanium is prohibited in gaseous oxygen respiration systems . Steel tubing is used for high pressure systems (3,000 p.s.i.) and aluminium tubing for low pressure systems .