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**Titanium**

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This article is about the chemical element. For other uses, see [Titanium (disambiguation)](https://en.wikipedia.org/wiki/Titanium_(disambiguation)).

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| --- | --- |
| Titanium,  22Ti | |
| [Titan-crystal bar.JPG](https://en.wikipedia.org/wiki/File:Titan-crystal_bar.JPG) | |
| **General properties** | |
| **Pronunciation** | [/tɪˈteɪniəm, taɪ-/](https://en.wikipedia.org/wiki/Help:IPA/English)[[1]](https://en.wikipedia.org/wiki/Titanium#cite_note-1) ​([*tə-TAY-nee-əm, ty-*](https://en.wikipedia.org/wiki/Help:Pronunciation_respelling_key)) |
| **Appearance** | silvery grey-white metallic |
| [**Standard atomic weight**](https://en.wikipedia.org/wiki/Standard_atomic_weight) **(*A*r, standard)** | 47.867(1)[[2]](https://en.wikipedia.org/wiki/Titanium#cite_note-CIAAW2016-2) |
| **Titanium in the** [**periodic table**](https://en.wikipedia.org/wiki/Periodic_table) | |
| |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 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[Neon](https://en.wikipedia.org/wiki/Neon) | | [Sodium](https://en.wikipedia.org/wiki/Sodium) | [Magnesium](https://en.wikipedia.org/wiki/Magnesium) |  | | | | | | | | | | | | | | | | | | | | | | | | [Aluminium](https://en.wikipedia.org/wiki/Aluminium) | [Silicon](https://en.wikipedia.org/wiki/Silicon) | [Phosphorus](https://en.wikipedia.org/wiki/Phosphorus) | [Sulfur](https://en.wikipedia.org/wiki/Sulfur) | [Chlorine](https://en.wikipedia.org/wiki/Chlorine) | [Argon](https://en.wikipedia.org/wiki/Argon) | | [Potassium](https://en.wikipedia.org/wiki/Potassium) | [Calcium](https://en.wikipedia.org/wiki/Calcium) | [Scandium](https://en.wikipedia.org/wiki/Scandium) |  | | | | | | | | | | | | | | Titanium | [Vanadium](https://en.wikipedia.org/wiki/Vanadium) | [Chromium](https://en.wikipedia.org/wiki/Chromium) | [Manganese](https://en.wikipedia.org/wiki/Manganese) | [Iron](https://en.wikipedia.org/wiki/Iron) | [Cobalt](https://en.wikipedia.org/wiki/Cobalt) | [Nickel](https://en.wikipedia.org/wiki/Nickel) | [Copper](https://en.wikipedia.org/wiki/Copper) | [Zinc](https://en.wikipedia.org/wiki/Zinc) | [Gallium](https://en.wikipedia.org/wiki/Gallium) | [Germanium](https://en.wikipedia.org/wiki/Germanium) | [Arsenic](https://en.wikipedia.org/wiki/Arsenic) | [Selenium](https://en.wikipedia.org/wiki/Selenium) | [Bromine](https://en.wikipedia.org/wiki/Bromine) | [Krypton](https://en.wikipedia.org/wiki/Krypton) | | [Rubidium](https://en.wikipedia.org/wiki/Rubidium) | [Strontium](https://en.wikipedia.org/wiki/Strontium) | [Yttrium](https://en.wikipedia.org/wiki/Yttrium) |  |  | | | | | | | | | | | | | [Zirconium](https://en.wikipedia.org/wiki/Zirconium) | [Niobium](https://en.wikipedia.org/wiki/Niobium) | [Molybdenum](https://en.wikipedia.org/wiki/Molybdenum) | [Technetium](https://en.wikipedia.org/wiki/Technetium) | [Ruthenium](https://en.wikipedia.org/wiki/Ruthenium) | [Rhodium](https://en.wikipedia.org/wiki/Rhodium) | [Palladium](https://en.wikipedia.org/wiki/Palladium) | [Silver](https://en.wikipedia.org/wiki/Silver) | [Cadmium](https://en.wikipedia.org/wiki/Cadmium) | [Indium](https://en.wikipedia.org/wiki/Indium) | [Tin](https://en.wikipedia.org/wiki/Tin) | [Antimony](https://en.wikipedia.org/wiki/Antimony) | [Tellurium](https://en.wikipedia.org/wiki/Tellurium) | [Iodine](https://en.wikipedia.org/wiki/Iodine) | [Xenon](https://en.wikipedia.org/wiki/Xenon) | | [Caesium](https://en.wikipedia.org/wiki/Caesium) | [Barium](https://en.wikipedia.org/wiki/Barium) | [Lanthanum](https://en.wikipedia.org/wiki/Lanthanum) | [Cerium](https://en.wikipedia.org/wiki/Cerium) | [Praseodymium](https://en.wikipedia.org/wiki/Praseodymium) | [Neodymium](https://en.wikipedia.org/wiki/Neodymium) | [Promethium](https://en.wikipedia.org/wiki/Promethium) | [Samarium](https://en.wikipedia.org/wiki/Samarium) | [Europium](https://en.wikipedia.org/wiki/Europium) | [Gadolinium](https://en.wikipedia.org/wiki/Gadolinium) | [Terbium](https://en.wikipedia.org/wiki/Terbium) | [Dysprosium](https://en.wikipedia.org/wiki/Dysprosium) | [Holmium](https://en.wikipedia.org/wiki/Holmium) | [Erbium](https://en.wikipedia.org/wiki/Erbium) | [Thulium](https://en.wikipedia.org/wiki/Thulium) | [Ytterbium](https://en.wikipedia.org/wiki/Ytterbium) | [Lutetium](https://en.wikipedia.org/wiki/Lutetium) | [Hafnium](https://en.wikipedia.org/wiki/Hafnium) | [Tantalum](https://en.wikipedia.org/wiki/Tantalum) | [Tungsten](https://en.wikipedia.org/wiki/Tungsten) | [Rhenium](https://en.wikipedia.org/wiki/Rhenium) | [Osmium](https://en.wikipedia.org/wiki/Osmium) | [Iridium](https://en.wikipedia.org/wiki/Iridium) | [Platinum](https://en.wikipedia.org/wiki/Platinum) | [Gold](https://en.wikipedia.org/wiki/Gold) | [Mercury (element)](https://en.wikipedia.org/wiki/Mercury_(element)) | [Thallium](https://en.wikipedia.org/wiki/Thallium) | [Lead](https://en.wikipedia.org/wiki/Lead) | [Bismuth](https://en.wikipedia.org/wiki/Bismuth) | [Polonium](https://en.wikipedia.org/wiki/Polonium) | [Astatine](https://en.wikipedia.org/wiki/Astatine) | [Radon](https://en.wikipedia.org/wiki/Radon) | | [Francium](https://en.wikipedia.org/wiki/Francium) | [Radium](https://en.wikipedia.org/wiki/Radium) | [Actinium](https://en.wikipedia.org/wiki/Actinium) | [Thorium](https://en.wikipedia.org/wiki/Thorium) | [Protactinium](https://en.wikipedia.org/wiki/Protactinium) | [Uranium](https://en.wikipedia.org/wiki/Uranium) | [Neptunium](https://en.wikipedia.org/wiki/Neptunium) | [Plutonium](https://en.wikipedia.org/wiki/Plutonium) | [Americium](https://en.wikipedia.org/wiki/Americium) | [Curium](https://en.wikipedia.org/wiki/Curium) | [Berkelium](https://en.wikipedia.org/wiki/Berkelium) | [Californium](https://en.wikipedia.org/wiki/Californium) | [Einsteinium](https://en.wikipedia.org/wiki/Einsteinium) | [Fermium](https://en.wikipedia.org/wiki/Fermium) | [Mendelevium](https://en.wikipedia.org/wiki/Mendelevium) | [Nobelium](https://en.wikipedia.org/wiki/Nobelium) | [Lawrencium](https://en.wikipedia.org/wiki/Lawrencium) | [Rutherfordium](https://en.wikipedia.org/wiki/Rutherfordium) | [Dubnium](https://en.wikipedia.org/wiki/Dubnium) | [Seaborgium](https://en.wikipedia.org/wiki/Seaborgium) | [Bohrium](https://en.wikipedia.org/wiki/Bohrium) | [Hassium](https://en.wikipedia.org/wiki/Hassium) | [Meitnerium](https://en.wikipedia.org/wiki/Meitnerium) | [Darmstadtium](https://en.wikipedia.org/wiki/Darmstadtium) | [Roentgenium](https://en.wikipedia.org/wiki/Roentgenium) | [Copernicium](https://en.wikipedia.org/wiki/Copernicium) | [Nihonium](https://en.wikipedia.org/wiki/Nihonium) | [Flerovium](https://en.wikipedia.org/wiki/Flerovium) | [Moscovium](https://en.wikipedia.org/wiki/Moscovium) | [Livermorium](https://en.wikipedia.org/wiki/Livermorium) | [Tennessine](https://en.wikipedia.org/wiki/Tennessine) | [Oganesson](https://en.wikipedia.org/wiki/Oganesson) | | – ↑ **Ti** ↓ [Zr](https://en.wikipedia.org/wiki/Zirconium) | | [scandium](https://en.wikipedia.org/wiki/Scandium) ← **titanium** → [vanadium](https://en.wikipedia.org/wiki/Vanadium) | | | | |
| [**Atomic number**](https://en.wikipedia.org/wiki/Atomic_number)(*Z*) | 22 |
| [**Group**](https://en.wikipedia.org/wiki/Group_(periodic_table)) | [group 4](https://en.wikipedia.org/wiki/Group_4_element) |
| [**Period**](https://en.wikipedia.org/wiki/Period_(periodic_table)) | [period 4](https://en.wikipedia.org/wiki/Period_(periodic_table)#Period_4) |
| [**Block**](https://en.wikipedia.org/wiki/Block_(periodic_table)) | [d-block](https://en.wikipedia.org/wiki/D-block) |
| [**Element category**](https://en.wikipedia.org/wiki/Names_for_sets_of_chemical_elements#Category) | [transition metal](https://en.wikipedia.org/wiki/Transition_metal) |
| [**Electron configuration**](https://en.wikipedia.org/wiki/Electron_configuration) | [[Ar](https://en.wikipedia.org/wiki/Argon)] 3d2 4s2 |
| Electrons per shell | 2, 8, 10, 2 |
| **Physical properties** | |
| [**Phase**](https://en.wikipedia.org/wiki/Phase_(matter)) **at**[**STP**](https://en.wikipedia.org/wiki/Standard_conditions_for_temperature_and_pressure) | [solid](https://en.wikipedia.org/wiki/Solid) |
| [**Melting point**](https://en.wikipedia.org/wiki/Melting_point) | 1941 [K](https://en.wikipedia.org/wiki/Kelvin) ​(1668 °C, ​3034 °F) |
| [**Boiling point**](https://en.wikipedia.org/wiki/Boiling_point) | 3560 K ​(3287 °C, ​5949 °F) |
| [**Density**](https://en.wikipedia.org/wiki/Density)(near r.t.) | 4.506 g/cm3 |
| when liquid (at m.p.) | 4.11 g/cm3 |
| [**Heat of fusion**](https://en.wikipedia.org/wiki/Enthalpy_of_fusion) | 14.15 [kJ/mol](https://en.wikipedia.org/wiki/Kilojoule_per_mole) |
| [**Heat of vaporization**](https://en.wikipedia.org/wiki/Enthalpy_of_vaporization) | 425 kJ/mol |
| [**Molar heat capacity**](https://en.wikipedia.org/wiki/Molar_heat_capacity) | 25.060 J/(mol·K) |
| [**Vapor pressure**](https://en.wikipedia.org/wiki/Vapor_pressure)   |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | ***P***(Pa) | **1** | **10** | **100** | **1 k** | **10 k** | **100 k** | | **at *T***(K) | 1982 | 2171 | (2403) | 2692 | 3064 | 3558 | | |
| **Atomic properties** | |
| [**Oxidation states**](https://en.wikipedia.org/wiki/Oxidation_state) | −2, −1, +1, +2, +3, **+4**[[3]](https://en.wikipedia.org/wiki/Titanium#cite_note-3) (an [amphoteric](https://en.wikipedia.org/wiki/Amphoterism) oxide) |
| [**Electronegativity**](https://en.wikipedia.org/wiki/Electronegativity) | Pauling scale: 1.54 |
| [**Ionization energies**](https://en.wikipedia.org/wiki/Ionization_energy) | * 1st: 658.8 kJ/mol * 2nd: 1309.8 kJ/mol * 3rd: 2652.5 kJ/mol * ([more](https://en.wikipedia.org/wiki/Molar_ionization_energies_of_the_elements#titanium)) |
| [**Atomic radius**](https://en.wikipedia.org/wiki/Atomic_radius) | empirical: 147 [pm](https://en.wikipedia.org/wiki/Picometre) |
| [**Covalent radius**](https://en.wikipedia.org/wiki/Covalent_radius) | 160±8 pm |
| [Color lines in a spectral range](https://en.wikipedia.org/wiki/File:Titanium_spectrum_visible.png)  [**Spectral lines**](https://en.wikipedia.org/wiki/Spectral_line) **of titanium** | |
| **Other properties** | |
| [**Crystal structure**](https://en.wikipedia.org/wiki/Crystal_structure) | ​[hexagonal close-packed](https://en.wikipedia.org/wiki/Close-packing_of_equal_spheres) (hcp)  [Hexagonal close packed crystal structure for titanium](https://en.wikipedia.org/wiki/File:Hexagonal_close_packed.svg) |
| [**Speed of sound**](https://en.wikipedia.org/wiki/Speed_of_sound)thin rod | 5090 m/s (at r.t.) |
| [**Thermal expansion**](https://en.wikipedia.org/wiki/Coefficient_of_thermal_expansion) | 8.6 µm/(m·K) (at 25 °C) |
| [**Thermal conductivity**](https://en.wikipedia.org/wiki/Thermal_conductivity) | 21.9 W/(m·K) |
| [**Electrical resistivity**](https://en.wikipedia.org/wiki/Electrical_resistivity_and_conductivity) | 420 nΩ·m (at 20 °C) |
| [**Magnetic ordering**](https://en.wikipedia.org/wiki/Magnetism) | [paramagnetic](https://en.wikipedia.org/wiki/Paramagnetic) |
| [**Magnetic susceptibility**](https://en.wikipedia.org/wiki/Magnetic_susceptibility) | +153.0·10−6 cm3/mol (293 K)[[4]](https://en.wikipedia.org/wiki/Titanium#cite_note-4) |
| [**Young's modulus**](https://en.wikipedia.org/wiki/Young%27s_modulus) | 116 GPa |
| [**Shear modulus**](https://en.wikipedia.org/wiki/Shear_modulus) | 44 GPa |
| [**Bulk modulus**](https://en.wikipedia.org/wiki/Bulk_modulus) | 110 GPa |
| [**Poisson ratio**](https://en.wikipedia.org/wiki/Poisson%27s_ratio) | 0.32 |
| [**Mohs hardness**](https://en.wikipedia.org/wiki/Mohs_scale_of_mineral_hardness) | 6.0 |
| [**Vickers hardness**](https://en.wikipedia.org/wiki/Vickers_hardness_test) | 830–3420 MPa |
| [**Brinell hardness**](https://en.wikipedia.org/wiki/Brinell_hardness_test) | 716–2770 MPa |
| [**CAS Number**](https://en.wikipedia.org/wiki/CAS_Registry_Number) | 7440-32-6 |
| **History** | |
| [**Discovery**](https://en.wikipedia.org/wiki/Timeline_of_chemical_element_discoveries) | [William Gregor](https://en.wikipedia.org/wiki/William_Gregor) (1791) |
| **First isolation** | [Jöns Jakob Berzelius](https://en.wikipedia.org/wiki/J%C3%B6ns_Jakob_Berzelius) (1825) |
| **Named by** | [Martin Heinrich Klaproth](https://en.wikipedia.org/wiki/Martin_Heinrich_Klaproth) (1795) |
| **Main** [**isotopes of titanium**](https://en.wikipedia.org/wiki/Isotopes_of_titanium) | |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | | [**Iso­tope**](https://en.wikipedia.org/wiki/Isotope) | [**Abun­dance**](https://en.wikipedia.org/wiki/Natural_abundance) | [**Half-life**](https://en.wikipedia.org/wiki/Half-life) **(*t*1/2)** | [**Decay mode**](https://en.wikipedia.org/wiki/Radioactive_decay) | [**Pro­duct**](https://en.wikipedia.org/wiki/Decay_product) | | **44Ti** | [syn](https://en.wikipedia.org/wiki/Synthetic_radioisotope) | 63 y | [ε](https://en.wikipedia.org/wiki/Electron_capture) | [44Sc](https://en.wikipedia.org/wiki/Scandium-44) | | [γ](https://en.wikipedia.org/wiki/Gamma_radiation) | – | | **46Ti** | 8.25% | [stable](https://en.wikipedia.org/wiki/Stable_isotope) | | | | **47Ti** | 7.44% | stable | | | | **48Ti** | 73.72% | stable | | | | **49Ti** | 5.41% | stable | | | | **50Ti** | 5.18% | stable | | | | |
| * [view](https://en.wikipedia.org/wiki/Template:Infobox_titanium) * [talk](https://en.wikipedia.org/wiki/Template_talk:Infobox_titanium) * [edit](https://en.wikipedia.org/w/index.php?title=Template:Infobox_titanium&action=edit)   | [references](https://en.wikipedia.org/wiki/List_of_data_references_for_chemical_elements) | |

**Titanium** is a [chemical element](https://en.wikipedia.org/wiki/Chemical_element) with symbol **Ti** and [atomic number](https://en.wikipedia.org/wiki/Atomic_number) 22. It is a lustrous [transition metal](https://en.wikipedia.org/wiki/Transition_metal) with a silver color, low density, and high strength. Titanium is resistant to [corrosion](https://en.wikipedia.org/wiki/Corrosion) in [sea water](https://en.wikipedia.org/wiki/Sea_water), [aqua regia](https://en.wikipedia.org/wiki/Aqua_regia), and [chlorine](https://en.wikipedia.org/wiki/Chlorine).

Titanium was discovered in [Cornwall](https://en.wikipedia.org/wiki/Cornwall), [Great Britain](https://en.wikipedia.org/wiki/Kingdom_of_Great_Britain), by [William Gregor](https://en.wikipedia.org/wiki/William_Gregor) in 1791, and was named by [Martin Heinrich Klaproth](https://en.wikipedia.org/wiki/Martin_Heinrich_Klaproth) after the [Titans](https://en.wikipedia.org/wiki/Titan_(mythology)) of [Greek mythology](https://en.wikipedia.org/wiki/Greek_mythology). The element occurs within a number of [mineral](https://en.wikipedia.org/wiki/Mineral) deposits, principally [rutile](https://en.wikipedia.org/wiki/Rutile) and [ilmenite](https://en.wikipedia.org/wiki/Ilmenite), which are widely distributed in the [Earth's crust](https://en.wikipedia.org/wiki/Earth%27s_crust) and [lithosphere](https://en.wikipedia.org/wiki/Lithosphere), and it is found in almost all living things, water bodies, rocks, and soils.[[6]](https://en.wikipedia.org/wiki/Titanium#cite_note-EBC-6) The metal is extracted from its principal mineral ores by the [Kroll](https://en.wikipedia.org/wiki/Kroll_process)[[7]](https://en.wikipedia.org/wiki/Titanium#cite_note-LANL-7) and [Hunter processes](https://en.wikipedia.org/wiki/Hunter_process). The most common compound, [titanium dioxide](https://en.wikipedia.org/wiki/Titanium_dioxide), is a popular [photocatalyst](https://en.wikipedia.org/wiki/Photocatalysis) and is used in the manufacture of white pigments.[[8]](https://en.wikipedia.org/wiki/Titanium#cite_note-HistoryAndUse-8) Other compounds include [titanium tetrachloride](https://en.wikipedia.org/wiki/Titanium_tetrachloride) (TiCl4), a component of [smoke screens](https://en.wikipedia.org/wiki/Smoke_screen) and [catalysts](https://en.wikipedia.org/wiki/Catalyst); and [titanium trichloride](https://en.wikipedia.org/wiki/Titanium(III)_chloride) (TiCl3), which is used as a catalyst in the production of [polypropylene](https://en.wikipedia.org/wiki/Polypropylene).[[6]](https://en.wikipedia.org/wiki/Titanium#cite_note-EBC-6)

Titanium can be [alloyed](https://en.wikipedia.org/wiki/Alloy) with [iron](https://en.wikipedia.org/wiki/Iron), [aluminium](https://en.wikipedia.org/wiki/Aluminium), [vanadium](https://en.wikipedia.org/wiki/Vanadium), and [molybdenum](https://en.wikipedia.org/wiki/Molybdenum), among other elements, to produce strong, lightweight alloys for aerospace ([jet engines](https://en.wikipedia.org/wiki/Jet_engine), [missiles](https://en.wikipedia.org/wiki/Missile), and [spacecraft](https://en.wikipedia.org/wiki/Spacecraft)), military, industrial processes (chemicals and petrochemicals, [desalination plants](https://en.wikipedia.org/wiki/Desalination_plant), pulp, and paper), automotive, agri-food, medical [prostheses](https://en.wikipedia.org/wiki/Prostheses), orthopedic [implants](https://en.wikipedia.org/wiki/Implant_(medicine)), dental and endodontic instruments and files, [dental implants](https://en.wikipedia.org/wiki/Dental_implant), sporting goods, jewelry, [mobile phones](https://en.wikipedia.org/wiki/Mobile_phone), and other applications.[[6]](https://en.wikipedia.org/wiki/Titanium#cite_note-EBC-6)

The two most useful properties of the metal are corrosion resistance and strength-to-density ratio, the highest of any metallic element.[[9]](https://en.wikipedia.org/wiki/Titanium#cite_note-9) In its unalloyed condition, titanium is as strong as some [steels](https://en.wikipedia.org/wiki/Steel), but less dense.[[10]](https://en.wikipedia.org/wiki/Titanium#cite_note-Barksdale1968p738-10) There are two [allotropic](https://en.wikipedia.org/wiki/Allotropy) forms[[11]](https://en.wikipedia.org/wiki/Titanium#cite_note-TICE6th-11) and five naturally occurring [isotopes](https://en.wikipedia.org/wiki/Isotope) of this element, 46Ti through 50Ti, with 48Ti being the most [abundant](https://en.wikipedia.org/wiki/Natural_abundance) (73.8%).[[12]](https://en.wikipedia.org/wiki/Titanium#cite_note-EnvChem-12) Although they have the same number of [valence electrons](https://en.wikipedia.org/wiki/Valence_electron) and are in the same [group](https://en.wikipedia.org/wiki/Group_(periodic_table)) in the [periodic table](https://en.wikipedia.org/wiki/Periodic_table), titanium and [zirconium](https://en.wikipedia.org/wiki/Zirconium) differ in many chemical and physical properties.



**Contents**

* [1 Characteristics](https://en.wikipedia.org/wiki/Titanium#Characteristics)
  + [1.1 Physical properties](https://en.wikipedia.org/wiki/Titanium#Physical_properties)
  + [1.2 Chemical properties](https://en.wikipedia.org/wiki/Titanium#Chemical_properties)
  + [1.3 Occurrence](https://en.wikipedia.org/wiki/Titanium#Occurrence)
  + [1.4 Isotopes](https://en.wikipedia.org/wiki/Titanium#Isotopes)
* [2 Compounds](https://en.wikipedia.org/wiki/Titanium#Compounds)
  + [2.1 Oxides, sulfides, and alkoxides](https://en.wikipedia.org/wiki/Titanium#Oxides,_sulfides,_and_alkoxides)
  + [2.2 Nitrides and carbides](https://en.wikipedia.org/wiki/Titanium#Nitrides_and_carbides)
  + [2.3 Halides](https://en.wikipedia.org/wiki/Titanium#Halides)
  + [2.4 Organometallic complexes](https://en.wikipedia.org/wiki/Titanium#Organometallic_complexes)
  + [2.5 Anticancer therapy](https://en.wikipedia.org/wiki/Titanium#Anticancer_therapy)
* [3 History](https://en.wikipedia.org/wiki/Titanium#History)
* [4 Production and fabrication](https://en.wikipedia.org/wiki/Titanium#Production_and_fabrication)
* [5 Applications](https://en.wikipedia.org/wiki/Titanium#Applications)
  + [5.1 Pigments, additives, and coatings](https://en.wikipedia.org/wiki/Titanium#Pigments,_additives,_and_coatings)
  + [5.2 Aerospace and marine](https://en.wikipedia.org/wiki/Titanium#Aerospace_and_marine)
  + [5.3 Industrial](https://en.wikipedia.org/wiki/Titanium#Industrial)
  + [5.4 Consumer and architectural](https://en.wikipedia.org/wiki/Titanium#Consumer_and_architectural)
  + [5.5 Jewelry](https://en.wikipedia.org/wiki/Titanium#Jewelry)
  + [5.6 Medical](https://en.wikipedia.org/wiki/Titanium#Medical)
  + [5.7 Nuclear waste storage](https://en.wikipedia.org/wiki/Titanium#Nuclear_waste_storage)
* [6 Bioremediation](https://en.wikipedia.org/wiki/Titanium#Bioremediation)
* [7 Precautions](https://en.wikipedia.org/wiki/Titanium#Precautions)
* [8 See also](https://en.wikipedia.org/wiki/Titanium#See_also)
* [9 References](https://en.wikipedia.org/wiki/Titanium#References)
* [10 Bibliography](https://en.wikipedia.org/wiki/Titanium#Bibliography)
* [11 External links](https://en.wikipedia.org/wiki/Titanium#External_links)

**Characteristics**

**Physical properties**

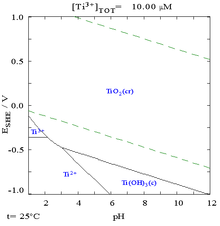
As a [metal](https://en.wikipedia.org/wiki/Metal), titanium is recognized for its high [strength-to-weight ratio](https://en.wikipedia.org/wiki/Strength-to-weight_ratio).[[11]](https://en.wikipedia.org/wiki/Titanium#cite_note-TICE6th-11) It is a strong metal with low [density](https://en.wikipedia.org/wiki/Density) that is quite [ductile](https://en.wikipedia.org/wiki/Ductility) (especially in an [oxygen](https://en.wikipedia.org/wiki/Oxygen)-free environment),[[6]](https://en.wikipedia.org/wiki/Titanium#cite_note-EBC-6) lustrous, and metallic-white in [color](https://en.wikipedia.org/wiki/Color).[[13]](https://en.wikipedia.org/wiki/Titanium#cite_note-Stwertka1998-13) The relatively high melting point (more than 1,650 °C or 3,000 °F) makes it useful as a [refractory metal](https://en.wikipedia.org/wiki/Refractory_metals). It is [paramagnetic](https://en.wikipedia.org/wiki/Paramagnetism) and has fairly low [electrical](https://en.wikipedia.org/wiki/Electrical_conductivity) and [thermal conductivity](https://en.wikipedia.org/wiki/Thermal_conductivity).[[6]](https://en.wikipedia.org/wiki/Titanium#cite_note-EBC-6)

Commercially pure (99.2% pure) [grades](https://en.wikipedia.org/wiki/Titanium_alloy#Grades_of_titanium) of titanium have [ultimate tensile strength](https://en.wikipedia.org/wiki/Ultimate_tensile_strength) of about 434 [MPa](https://en.wikipedia.org/wiki/Megapascal) (63,000 [psi](https://en.wikipedia.org/wiki/Pounds_per_square_inch)), 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[[10]](https://en.wikipedia.org/wiki/Titanium#cite_note-Barksdale1968p738-10) as the most commonly used [6061-T6 aluminium alloy](https://en.wikipedia.org/wiki/6061_aluminium_alloy). Certain titanium alloys (e.g., [Beta C](https://en.wikipedia.org/wiki/Titanium_Beta_C)) achieve tensile strengths of over 1,400 MPa (200,000 psi).[[14]](https://en.wikipedia.org/wiki/Titanium#cite_note-14) However, titanium loses strength when heated above 430 °C (806 °F).[[15]](https://en.wikipedia.org/wiki/Titanium#cite_note-Barksdale1968p734-15)

Titanium is not as hard as some grades of heat-treated steel; it is non-magnetic and a poor conductor of heat and electricity. Machining requires precautions, because the material can [gall](https://en.wikipedia.org/wiki/Galling) unless sharp tools and proper cooling methods are used. Like steel structures, those made from titanium have a [fatigue limit](https://en.wikipedia.org/wiki/Fatigue_limit) that guarantees longevity in some applications.[[13]](https://en.wikipedia.org/wiki/Titanium#cite_note-Stwertka1998-13)

The metal is a dimorphic [allotrope](https://en.wikipedia.org/wiki/Allotropy) of an hexagonal α form that changes into a body-centered cubic (lattice) β form at 882 °C (1,620 °F).[[15]](https://en.wikipedia.org/wiki/Titanium#cite_note-Barksdale1968p734-15) The [specific heat](https://en.wikipedia.org/wiki/Specific_heat_capacity) of the α form increases dramatically as it is heated to this transition temperature but then falls and remains fairly constant for the β form regardless of temperature.[[15]](https://en.wikipedia.org/wiki/Titanium#cite_note-Barksdale1968p734-15)

**Chemical properties**

[](https://en.wikipedia.org/wiki/File:Titanium_in_water_Pourbaix_diagram.png)

The [Pourbaix diagram](https://en.wikipedia.org/wiki/Pourbaix_diagram) for titanium in pure water, perchloric acid, or sodium hydroxide[[16]](https://en.wikipedia.org/wiki/Titanium#cite_note-medusa-16)

Like [aluminium](https://en.wikipedia.org/wiki/Aluminium) and [magnesium](https://en.wikipedia.org/wiki/Magnesium), titanium metal and its alloys [oxidize](https://en.wikipedia.org/wiki/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](https://en.wikipedia.org/wiki/Titanium_dioxide).[[11]](https://en.wikipedia.org/wiki/Titanium#cite_note-TICE6th-11) It is, however, slow to react with water and air at ambient temperatures because it forms a [passive](https://en.wikipedia.org/wiki/Passivation_(chemistry)) oxide coating that protects the bulk metal from further oxidation.[[6]](https://en.wikipedia.org/wiki/Titanium#cite_note-EBC-6) When it first forms, this protective layer is only 1–2 [nm](https://en.wikipedia.org/wiki/Nanometre) thick but continues to grow slowly; reaching a thickness of 25 nm in four years.[[17]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p453-17)

Atmospheric passivation gives titanium excellent resistance to corrosion, almost equivalent to [platinum](https://en.wikipedia.org/wiki/Platinum). Titanium is capable of withstanding attack by dilute [sulfuric](https://en.wikipedia.org/wiki/Sulfuric_acid) and [hydrochloric acids](https://en.wikipedia.org/wiki/Hydrochloric_acid), chloride solutions, and most organic acids.[[7]](https://en.wikipedia.org/wiki/Titanium#cite_note-LANL-7) However, titanium is corroded by concentrated acids.[[18]](https://en.wikipedia.org/wiki/Titanium#cite_note-18) 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 (1,022 °F), it combines with chlorine.[[7]](https://en.wikipedia.org/wiki/Titanium#cite_note-LANL-7) It also reacts with the other halogens and absorbs hydrogen.[[8]](https://en.wikipedia.org/wiki/Titanium#cite_note-HistoryAndUse-8)

Titanium is one of the few elements that burns in pure nitrogen gas, reacting at 800 °C (1,470 °F) to form [titanium nitride](https://en.wikipedia.org/wiki/Titanium_nitride), which causes embrittlement.[[19]](https://en.wikipedia.org/wiki/Titanium#cite_note-titaniumindustry-19) Because of its high reactivity with oxygen, nitrogen, and some other gases, titanium [filaments](https://en.wikipedia.org/wiki/Electrical_filament) are applied in [titanium sublimation pumps](https://en.wikipedia.org/wiki/Titanium_sublimation_pump) as scavengers for these gases. Such pumps inexpensively and reliably produce extremely low pressures in [ultra-high vacuum](https://en.wikipedia.org/wiki/Ultra-high_vacuum) systems.

**Occurrence**

|  |  |  |
| --- | --- | --- |
| 2011 production of rutile and ilmenite[[20]](https://en.wikipedia.org/wiki/Titanium#cite_note-USGS-20) | | |
| **Country** | **thousand  tonnes** | **% of total** |
| [Australia](https://en.wikipedia.org/wiki/Australia) | 1,300 | 19.4 |
| [South Africa](https://en.wikipedia.org/wiki/South_Africa) | 1,160 | 17.3 |
| [Canada](https://en.wikipedia.org/wiki/Canada) | 700 | 10.4 |
| [India](https://en.wikipedia.org/wiki/India) | 574 | 8.6 |
| [Mozambique](https://en.wikipedia.org/wiki/Mozambique) | 516 | 7.7 |
| [China](https://en.wikipedia.org/wiki/China) | 500 | 7.5 |
| [Vietnam](https://en.wikipedia.org/wiki/Vietnam) | 490 | 7.3 |
| [Ukraine](https://en.wikipedia.org/wiki/Ukraine) | 357 | 5.3 |
| **World** | **6,700** | **100** |

Titanium is the ninth-most [abundant](https://en.wikipedia.org/wiki/Abundance_of_elements_in_Earth%27s_crust) element in [Earth](https://en.wikipedia.org/wiki/Earth)'s crust (0.63% by [mass](https://en.wikipedia.org/wiki/Mass))[[21]](https://en.wikipedia.org/wiki/Titanium#cite_note-Barksdale1968p732-21) and the seventh-most abundant metal. It is present as oxides in most [igneous rocks](https://en.wikipedia.org/wiki/Igneous_rock), in [sediments](https://en.wikipedia.org/wiki/Sedimentary_rock) derived from them, in living things, and natural bodies of water.[[6]](https://en.wikipedia.org/wiki/Titanium#cite_note-EBC-6)[[7]](https://en.wikipedia.org/wiki/Titanium#cite_note-LANL-7) Of the 801 types of igneous rocks analyzed by the [United States Geological Survey](https://en.wikipedia.org/wiki/United_States_Geological_Survey), 784 contained titanium. Its proportion in soils is approximately 0.5 to 1.5%.[[21]](https://en.wikipedia.org/wiki/Titanium#cite_note-Barksdale1968p732-21)

Common titanium-containing [minerals](https://en.wikipedia.org/wiki/Mineral) are [anatase](https://en.wikipedia.org/wiki/Anatase), [brookite](https://en.wikipedia.org/wiki/Brookite), [ilmenite](https://en.wikipedia.org/wiki/Ilmenite), [perovskite](https://en.wikipedia.org/wiki/Perovskite), [rutile](https://en.wikipedia.org/wiki/Rutile), and [titanite](https://en.wikipedia.org/wiki/Titanite) (sphene).[[17]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p453-17) [Akaogiite](https://en.wikipedia.org/wiki/Akaogiite) is an extremely rare mineral consisting of titanium dioxide. 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.[[20]](https://en.wikipedia.org/wiki/Titanium#cite_note-USGS-20) Significant titanium-bearing ilmenite deposits exist in western [Australia](https://en.wikipedia.org/wiki/Australia), [Canada](https://en.wikipedia.org/wiki/Canada), [China](https://en.wikipedia.org/wiki/China), [India](https://en.wikipedia.org/wiki/India), [Mozambique](https://en.wikipedia.org/wiki/Mozambique), [New Zealand](https://en.wikipedia.org/wiki/New_Zealand), [Norway](https://en.wikipedia.org/wiki/Norway), [Sierra Leone](https://en.wikipedia.org/wiki/Sierra_Leone), [South Africa](https://en.wikipedia.org/wiki/South_Africa), and [Ukraine](https://en.wikipedia.org/wiki/Ukraine).[[17]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p453-17) About 186,000 tonnes of titanium [metal sponge](https://en.wikipedia.org/wiki/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.[[20]](https://en.wikipedia.org/wiki/Titanium#cite_note-USGS-20)

The concentration of titanium 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.[[22]](https://en.wikipedia.org/wiki/Titanium#cite_note-22)

Titanium is contained in [meteorites](https://en.wikipedia.org/wiki/Meteorite), and it has been detected in the [Sun](https://en.wikipedia.org/wiki/Sun) and in [M-type](https://en.wikipedia.org/wiki/Stellar_classification) [stars](https://en.wikipedia.org/wiki/Star)[[7]](https://en.wikipedia.org/wiki/Titanium#cite_note-LANL-7) (the coolest type) with a surface temperature of 3,200 °C (5,790 °F).[[23]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p451-23) [Rocks](https://en.wikipedia.org/wiki/Rock_(geology)) brought back from the [Moon](https://en.wikipedia.org/wiki/Moon) during the [Apollo 17](https://en.wikipedia.org/wiki/Apollo_17) mission are composed of 12.1% TiO2.[[7]](https://en.wikipedia.org/wiki/Titanium#cite_note-LANL-7) It is also found in [coal](https://en.wikipedia.org/wiki/Coal) ash, [plants](https://en.wikipedia.org/wiki/Plant), and even the [human](https://en.wikipedia.org/wiki/Human) body. Native titanium (pure metallic) is very rare.[[24]](https://en.wikipedia.org/wiki/Titanium#cite_note-24)

**Isotopes**

Main article: [Isotopes of titanium](https://en.wikipedia.org/wiki/Isotopes_of_titanium)

Naturally occurring titanium is composed of 5 stable [isotopes](https://en.wikipedia.org/wiki/Isotope): 46Ti, 47Ti, 48Ti, 49Ti, and 50Ti, with 48Ti being the most abundant (73.8% [natural abundance](https://en.wikipedia.org/wiki/Natural_abundance)). Eleven [radioisotopes](https://en.wikipedia.org/wiki/Radioisotope) have been characterized, the most stable being 44Ti with a [half-life](https://en.wikipedia.org/wiki/Half-life) of 63 years; 45Ti, 184.8 minutes; 51Ti, 5.76 minutes; and 52Ti, 1.7 minutes. All the other [radioactive](https://en.wikipedia.org/wiki/Radioactive) isotopes have half-lives less than 33 seconds and the majority, less than half a second.[[12]](https://en.wikipedia.org/wiki/Titanium#cite_note-EnvChem-12)

The isotopes of titanium range in [atomic weight](https://en.wikipedia.org/wiki/Atomic_weight) from 39.99 [u](https://en.wikipedia.org/wiki/Unified_atomic_mass_unit) (40Ti) to 57.966 u (58Ti). The primary [decay mode](https://en.wikipedia.org/wiki/Decay_mode) before the most abundant stable isotope, 48Ti, is [electron capture](https://en.wikipedia.org/wiki/Electron_capture) and the primary mode after is [beta emission](https://en.wikipedia.org/wiki/Beta_emission). The primary [decay products](https://en.wikipedia.org/wiki/Decay_product) before 48Ti are element 21 ([scandium](https://en.wikipedia.org/wiki/Scandium)) isotopes and the primary products after are element 23 ([vanadium](https://en.wikipedia.org/wiki/Vanadium)) isotopes.[[12]](https://en.wikipedia.org/wiki/Titanium#cite_note-EnvChem-12)

Titanium becomes radioactive upon bombardment with [deuterons](https://en.wikipedia.org/wiki/Deuterons), emitting mainly [positrons](https://en.wikipedia.org/wiki/Positrons) and hard [gamma rays](https://en.wikipedia.org/wiki/Gamma_rays).[[7]](https://en.wikipedia.org/wiki/Titanium#cite_note-LANL-7)

**Compounds**

See also: the categories [Titanium compounds](https://en.wikipedia.org/wiki/Category:Titanium_compounds) and [Titanium minerals](https://en.wikipedia.org/wiki/Category:Titanium_minerals).

[A steel colored twist drill bit with the spiral groove colored in a golden shade.](https://en.wikipedia.org/wiki/File:Titanium_nitride_coating.jpg)

TiN-coated [drill](https://en.wikipedia.org/wiki/Drill) bit

The +4 [oxidation state](https://en.wikipedia.org/wiki/Oxidation_state) dominates titanium chemistry,[[25]](https://en.wikipedia.org/wiki/Titanium#cite_note-Greenwood1997p958-25) but compounds in the +3 [oxidation state](https://en.wikipedia.org/wiki/Oxidation_state) are also common.[[26]](https://en.wikipedia.org/wiki/Titanium#cite_note-Greenwood1997p970-26) Commonly, titanium adopts an [octahedral coordination geometry](https://en.wikipedia.org/wiki/Octahedral_coordination_geometry) in its complexes, but tetrahedral TiCl4 is a notable exception. Because of its high oxidation state, titanium(IV) compounds exhibit a high degree of [covalent bonding](https://en.wikipedia.org/wiki/Covalent_bond). Unlike most other transition metals, simple [aquo Ti(IV) complexes](https://en.wikipedia.org/wiki/Transition_metal_aquo_complex) are unknown.

**Oxides, sulfides, and alkoxides**

The most important oxide is TiO2, which exists in three important [polymorphs](https://en.wikipedia.org/wiki/Polymorphism_(materials_science)); [anatase](https://en.wikipedia.org/wiki/Anatase), [brookite](https://en.wikipedia.org/wiki/Brookite), and [rutile](https://en.wikipedia.org/wiki/Rutile). All of these are white diamagnetic solids, although mineral samples can appear dark (see [rutile](https://en.wikipedia.org/wiki/Rutile)). They adopt polymeric structures in which Ti is surrounded by six [oxide](https://en.wikipedia.org/wiki/Oxide) ligands that link to other Ti centers.

The term [*titanates*](https://en.wikipedia.org/wiki/Titanate) usually refers to titanium(IV) compounds, as represented by [barium titanate](https://en.wikipedia.org/wiki/Barium_titanate) (BaTiO3). With a [perovskite](https://en.wikipedia.org/wiki/Perovskite) structure, this material exhibits [piezoelectric](https://en.wikipedia.org/wiki/Piezoelectric) properties and is used as a transducer in the interconversion of [sound](https://en.wikipedia.org/wiki/Sound) and [electricity](https://en.wikipedia.org/wiki/Electricity).[[11]](https://en.wikipedia.org/wiki/Titanium#cite_note-TICE6th-11) Many minerals are titanates, e.g. [ilmenite](https://en.wikipedia.org/wiki/Ilmenite) (FeTiO3). [Star sapphires](https://en.wikipedia.org/wiki/Star_sapphire_(jewel)) and [rubies](https://en.wikipedia.org/wiki/Ruby) get their [asterism](https://en.wikipedia.org/wiki/Asterism_(gemmology)) (star-forming shine) from the presence of titanium dioxide impurities.[[17]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p453-17)

A variety of reduced oxides ([suboxides](https://en.wikipedia.org/wiki/Suboxide)) of titanium are known, mainly reduced [stoichiometries](https://en.wikipedia.org/wiki/Stoichiometry) of [titanium dioxide](https://en.wikipedia.org/wiki/Titanium_dioxide) obtained by [atmospheric plasma spraying](https://en.wikipedia.org/wiki/Atmospheric_plasma_spraying).Ti3O5, described as a Ti(IV)-Ti(III) species, is a purple semiconductor produced by reduction of TiO2 with hydrogen at high temperatures,[[27]](https://en.wikipedia.org/wiki/Titanium#cite_note-27) and is used industrially when surfaces need to be vapour-coated with titanium dioxide: it evaporates as pure TiO, whereas TiO2 evaporates as a mixture of oxides and deposits coatings with variable refractive index.[[28]](https://en.wikipedia.org/wiki/Titanium#cite_note-28) Also known is [Ti2O3](https://en.wikipedia.org/wiki/Titanium(III)_oxide), with the [corundum](https://en.wikipedia.org/wiki/Corundum) structure, and [TiO](https://en.wikipedia.org/wiki/Titanium(II)_oxide), with the rock salt structure, although often nonstoichiometric.[[29]](https://en.wikipedia.org/wiki/Titanium#cite_note-29)

The [alkoxides](https://en.wikipedia.org/wiki/Alkoxide) of titanium(IV), prepared by reacting TiCl4 with alcohols, are colourless compounds that convert to the dioxide on reaction with water. They are industrially useful for depositing solid TiO2 via the [sol-gel process](https://en.wikipedia.org/wiki/Sol-gel_process). [Titanium isopropoxide](https://en.wikipedia.org/wiki/Titanium_isopropoxide) is used in the synthesis of chiral organic compounds via the [Sharpless epoxidation](https://en.wikipedia.org/wiki/Sharpless_epoxidation).

Titanium forms a variety of sulfides, but only [TiS2](https://en.wikipedia.org/wiki/Titanium_disulfide) has attracted significant interest. It adopts a layered structure and was used as a cathode in the development of [lithium batteries](https://en.wikipedia.org/wiki/Lithium_batteries). Because Ti(IV) is a ["hard cation"](https://en.wikipedia.org/wiki/HSAB_theory), the sulfides of titanium are unstable and tend to hydrolyze to the oxide with release of hydrogen sulfide.

**Nitrides and carbides**

[Titanium nitride](https://en.wikipedia.org/wiki/Titanium_nitride) (TiN) is a member of a family of refractory transition metal nitrides and exhibits properties similar to both covalent compounds including; thermodynamic stability, extreme hardness, thermal/electrical conductivity, and a high melting point.[[30]](https://en.wikipedia.org/wiki/Titanium#cite_note-30) TiN has a hardness equivalent to [sapphire](https://en.wikipedia.org/wiki/Sapphire) and [carborundum](https://en.wikipedia.org/wiki/Carborundum) (9.0 on the [Mohs Scale](https://en.wikipedia.org/wiki/Mohs_Scale)),[[31]](https://en.wikipedia.org/wiki/Titanium#cite_note-31) and is often used to coat cutting tools, such as [drill bits](https://en.wikipedia.org/wiki/Drill_bit).[[32]](https://en.wikipedia.org/wiki/Titanium#cite_note-32) It is also used as a gold-colored decorative finish and as a [barrier metal](https://en.wikipedia.org/wiki/Copper-based_chips#Barrier_metal) in [semiconductor fabrication](https://en.wikipedia.org/wiki/Semiconductor_fabrication).[[33]](https://en.wikipedia.org/wiki/Titanium#cite_note-33) [Titanium carbide](https://en.wikipedia.org/wiki/Titanium_carbide), which is also very hard, is found in cutting tools and coatings.[[34]](https://en.wikipedia.org/wiki/Titanium#cite_note-34)

[](https://en.wikipedia.org/wiki/File:TiCl3.jpg)

Titanium(III) compounds are characteristically violet, illustrated by this aqueous solution of [titanium trichloride](https://en.wikipedia.org/wiki/Titanium_trichloride).

**Halides**

[Titanium tetrachloride](https://en.wikipedia.org/wiki/Titanium_tetrachloride) (titanium(IV) chloride, TiCl4[[35]](https://en.wikipedia.org/wiki/Titanium#cite_note-35)) is a colorless volatile liquid (commercial samples are yellowish) that, in air, hydrolyzes with spectacular emission of white clouds. Via the [Kroll process](https://en.wikipedia.org/wiki/Kroll_process), TiCl4 is produced in the conversion of titanium ores to titanium dioxide, e.g., for use in white paint.[[36]](https://en.wikipedia.org/wiki/Titanium#cite_note-36) It is widely used in [organic chemistry](https://en.wikipedia.org/wiki/Organic_chemistry) as a [Lewis acid](https://en.wikipedia.org/wiki/Lewis_acids_and_bases), for example in the [Mukaiyama aldol condensation](https://en.wikipedia.org/wiki/Mukaiyama_aldol_condensation).[[37]](https://en.wikipedia.org/wiki/Titanium#cite_note-37) In the [van Arkel process](https://en.wikipedia.org/wiki/Van_Arkel_process), [titanium tetraiodide](https://en.wikipedia.org/wiki/Titanium_tetraiodide) (TiI4) 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](https://en.wikipedia.org/wiki/Titanium(III)_chloride) (TiCl3), which is used as a [catalyst](https://en.wikipedia.org/wiki/Catalyst) for production of [polyolefins](https://en.wikipedia.org/wiki/Polyolefin) (see [Ziegler-Natta catalyst](https://en.wikipedia.org/wiki/Ziegler-Natta_catalyst)) and a reducing [agent](https://en.wikipedia.org/wiki/Reagent) in organic chemistry.

**Organometallic complexes**

Main article: [Organotitanium chemistry](https://en.wikipedia.org/wiki/Organotitanium_chemistry)

Owing to the important role of titanium compounds as [polymerization](https://en.wikipedia.org/wiki/Polymerization) catalyst, compounds with Ti-C bonds have been intensively studied. The most common organotitanium complex is [titanocene dichloride](https://en.wikipedia.org/wiki/Titanocene_dichloride) ((C5H5)2TiCl2). Related compounds include [Tebbe's reagent](https://en.wikipedia.org/wiki/Tebbe%27s_reagent) and [Petasis reagent](https://en.wikipedia.org/wiki/Petasis_reagent). Titanium forms [carbonyl complexes](https://en.wikipedia.org/wiki/Metal_carbonyl), e.g. [(C5H5)2Ti(CO)2](https://en.wikipedia.org/wiki/Titanocene_dicarbonyl).[[38]](https://en.wikipedia.org/wiki/Titanium#cite_note-38)

**Anticancer therapy**

Following the success of [platinum-based](https://en.wikipedia.org/wiki/Cisplatin) chemotherapy, titanium(IV) complexes were among the first non-platinum compounds to be tested for cancer treatment. The advantage of titanium compounds lies in their high efficacy and low toxicity. In biological environments, hydrolysis leads to the safe and inert titanium dioxide. Despite these advantages the first candidate compounds failed clinical trials. Further development resulted in the creation of potentially effective, selective, and stable titanium-based drugs.[[39]](https://en.wikipedia.org/wiki/Titanium#cite_note-39) Their mode of action is not yet well understood.

**History**

[](https://en.wikipedia.org/wiki/File:Martin_Heinrich_Klaproth.jpg)

[Martin Heinrich Klaproth](https://en.wikipedia.org/wiki/Martin_Heinrich_Klaproth) named titanium for the [Titans](https://en.wikipedia.org/wiki/Titan_(mythology)) of [Greek mythology](https://en.wikipedia.org/wiki/Greek_mythology)

Titanium was [discovered](https://en.wikipedia.org/wiki/Discovery_of_the_chemical_elements) in 1791 by the [clergyman](https://en.wikipedia.org/wiki/Clergy) and amateur geologist, [William Gregor](https://en.wikipedia.org/wiki/William_Gregor), as an [inclusion](https://en.wikipedia.org/wiki/Inclusion_(mineral)) of a [mineral](https://en.wikipedia.org/wiki/Mineral) in [Cornwall](https://en.wikipedia.org/wiki/Cornwall), Great Britain.[[40]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p452-40) Gregor recognized the presence of a new element in [ilmenite](https://en.wikipedia.org/wiki/Ilmenite)[[8]](https://en.wikipedia.org/wiki/Titanium#cite_note-HistoryAndUse-8) when he found black sand by a stream and noticed the sand was attracted by a [magnet](https://en.wikipedia.org/wiki/Magnet).[[40]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p452-40) Analyzing the sand, he determined the presence of two metal oxides: [iron oxide](https://en.wikipedia.org/wiki/Iron_oxide) (explaining the attraction to the magnet) and 45.25% of a white metallic oxide he could not identify.[[21]](https://en.wikipedia.org/wiki/Titanium#cite_note-Barksdale1968p732-21) 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](https://en.wikipedia.org/wiki/Royal_Geological_Society_of_Cornwall) and in the German science journal [*Crell's Annalen*](https://en.wikipedia.org/wiki/Crell%27s_Annalen).[[40]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p452-40)[[41]](https://en.wikipedia.org/wiki/Titanium#cite_note-41)[[42]](https://en.wikipedia.org/wiki/Titanium#cite_note-42)

Around the same time, [Franz-Joseph Müller von Reichenstein](https://en.wikipedia.org/wiki/Franz-Joseph_M%C3%BCller_von_Reichenstein) produced a similar substance, but could not identify it.[[8]](https://en.wikipedia.org/wiki/Titanium#cite_note-HistoryAndUse-8) The oxide was independently rediscovered in 1795 by [Prussian](https://en.wikipedia.org/wiki/Prussia) chemist [Martin Heinrich Klaproth](https://en.wikipedia.org/wiki/Martin_Heinrich_Klaproth) in rutile from Boinik (German name Bajmócska), a village in Hungary (now Bojničky in Slovakia).[[40]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p452-40)[[43]](https://en.wikipedia.org/wiki/Titanium#cite_note-43) Klaproth found that it contained a new element and named it for the [Titans](https://en.wikipedia.org/wiki/Titan_(mythology)) of [Greek mythology](https://en.wikipedia.org/wiki/Greek_mythology).[[23]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p451-23) After hearing about Gregor's earlier discovery, he obtained a sample of manaccanite and confirmed that 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](https://en.wikipedia.org/wiki/Carbon) (as in iron smelting) because titanium combines with the carbon to produce [titanium carbide](https://en.wikipedia.org/wiki/Titanium_carbide).[[40]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p452-40) Pure metallic titanium (99.9%) was first prepared in 1910 by [Matthew A. Hunter](https://en.wikipedia.org/wiki/Matthew_A._Hunter) at [Rensselaer Polytechnic Institute](https://en.wikipedia.org/wiki/Rensselaer_Polytechnic_Institute) by heating TiCl4 with [sodium](https://en.wikipedia.org/wiki/Sodium) at 700–800 °C under great pressure[[44]](https://en.wikipedia.org/wiki/Titanium#cite_note-Roza2008p9-44) in a [batch process](https://en.wikipedia.org/wiki/Batch_production) known as the [Hunter process](https://en.wikipedia.org/wiki/Hunter_process).[[7]](https://en.wikipedia.org/wiki/Titanium#cite_note-LANL-7) Titanium metal was not used outside the laboratory until 1932 when [William Justin Kroll](https://en.wikipedia.org/wiki/William_Justin_Kroll) proved that it can be produced by reducing [titanium tetrachloride](https://en.wikipedia.org/wiki/Titanium_tetrachloride) (TiCl4) with [calcium](https://en.wikipedia.org/wiki/Calcium).[[45]](https://en.wikipedia.org/wiki/Titanium#cite_note-Greenwood1997p955-45) Eight years later he refined this process with [magnesium](https://en.wikipedia.org/wiki/Magnesium) and even sodium in what became known as the [Kroll process](https://en.wikipedia.org/wiki/Kroll_process).[[45]](https://en.wikipedia.org/wiki/Titanium#cite_note-Greenwood1997p955-45) Although research continues into more efficient and cheaper processes (e.g., [FFC Cambridge](https://en.wikipedia.org/wiki/FFC_Cambridge), [Armstrong](https://en.wikipedia.org/w/index.php?title=Armstrong_process&action=edit&redlink=1)), the Kroll process is still used for commercial production.[[7]](https://en.wikipedia.org/wiki/Titanium#cite_note-LANL-7)[[8]](https://en.wikipedia.org/wiki/Titanium#cite_note-HistoryAndUse-8)

[](https://en.wikipedia.org/wiki/File:TitaniumMetal_jpg.jpg)

Titanium sponge, made by the [Kroll process](https://en.wikipedia.org/wiki/Kroll_process)

Titanium of very high purity was made in small quantities when [Anton Eduard van Arkel](https://en.wikipedia.org/wiki/Anton_Eduard_van_Arkel) and [Jan Hendrik de Boer](https://en.wikipedia.org/wiki/Jan_Hendrik_de_Boer) discovered the iodide, or [crystal bar](https://en.wikipedia.org/wiki/Crystal_bar_process), process in 1925, by reacting with iodine and decomposing the formed vapours over a hot filament to pure metal.[[46]](https://en.wikipedia.org/wiki/Titanium#cite_note-46)

In the 1950s and 1960s, the [Soviet Union](https://en.wikipedia.org/wiki/Soviet_Union) pioneered the use of titanium in military and submarine applications[[44]](https://en.wikipedia.org/wiki/Titanium#cite_note-Roza2008p9-44) ([Alfa class](https://en.wikipedia.org/wiki/Alfa-class_submarine) and [Mike class](https://en.wikipedia.org/wiki/Soviet_submarine_K-278_Komsomolets))[[47]](https://en.wikipedia.org/wiki/Titanium#cite_note-47) as part of programs related to the Cold War.[[48]](https://en.wikipedia.org/wiki/Titanium#cite_note-48) Starting in the early 1950s, titanium came into use extensively in military aviation, particularly in high-performance jets, starting with aircraft such as the [F-100 Super Sabre](https://en.wikipedia.org/wiki/F-100_Super_Sabre) and [Lockheed A-12](https://en.wikipedia.org/wiki/Lockheed_A-12) and [SR-71](https://en.wikipedia.org/wiki/SR-71).

Recognizing the strategic importance of titanium,[[49]](https://en.wikipedia.org/wiki/Titanium#cite_note-49) the U.S. [Department of Defense](https://en.wikipedia.org/wiki/United_States_Department_of_Defense) supported early efforts of commercialization.[[50]](https://en.wikipedia.org/wiki/Titanium#cite_note-50)

Throughout the period of the Cold War, titanium was considered a [strategic material](https://en.wikipedia.org/wiki/Strategic_material) by the U.S. government, and a large stockpile of titanium sponge was maintained by the [Defense National Stockpile Center](https://en.wikipedia.org/wiki/Defense_National_Stockpile_Center), which was finally depleted in the 2000s.[[51]](https://en.wikipedia.org/wiki/Titanium#cite_note-51) According to 2006 data, the world's largest producer, Russian-based [VSMPO-AVISMA](https://en.wikipedia.org/wiki/VSMPO-AVISMA), was estimated to account for about 29% of the world market share.[[52]](https://en.wikipedia.org/wiki/Titanium#cite_note-52) As of 2015, titanium sponge metal was produced in six countries: China, Japan, Russia, Kazakhstan, the US, Ukraine, and India. (in order of output).[[53]](https://en.wikipedia.org/wiki/Titanium#cite_note-53)[[54]](https://en.wikipedia.org/wiki/Titanium#cite_note-54)

In 2006, the U.S. [Defense Advanced Research Projects Agency](https://en.wikipedia.org/wiki/DARPA) (DARPA) awarded $5.7 million to a two-company consortium to develop a new process for making titanium metal [powder](https://en.wikipedia.org/wiki/Powder_metallurgy). Under heat and pressure, the powder can be used to create strong, lightweight items ranging from armour plating to components for the aerospace, transport, and chemical processing industries.[[55]](https://en.wikipedia.org/wiki/Titanium#cite_note-55)

**Production and fabrication**

[](https://en.wikipedia.org/wiki/File:TitaniumUSGOV.jpg)

Titanium (mineral concentrate)

[](https://en.wikipedia.org/wiki/File:Titanium_products.jpg)

Basic titanium products: plate, tube, rods, and powder

The processing of titanium metal occurs in four major steps:[[56]](https://en.wikipedia.org/wiki/Titanium#cite_note-56) 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](https://en.wikipedia.org/wiki/Bar_stock), bar, [plate](https://en.wikipedia.org/wiki/Plate_(metal)), [sheet](https://en.wikipedia.org/wiki/Sheet_metal), strip, and [tube](https://en.wikipedia.org/wiki/Tube_(fluid_conveyance)); and secondary fabrication of finished shapes from mill products.

Main article: [Kroll process](https://en.wikipedia.org/wiki/Kroll_process)

Because it cannot be readily produced by [reduction](https://en.wikipedia.org/wiki/Reduction_(chemistry)) of its dioxide,[[13]](https://en.wikipedia.org/wiki/Titanium#cite_note-Stwertka1998-13) titanium metal is obtained by reduction of [TiCl4](https://en.wikipedia.org/wiki/Titanium_tetrachloride) 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,[[57]](https://en.wikipedia.org/wiki/Titanium#cite_note-Barksdale1968p733-57) despite the Kroll process being less expensive than the Hunter process.[[44]](https://en.wikipedia.org/wiki/Titanium#cite_note-Roza2008p9-44) To produce the TiCl4 required by the Kroll process, the dioxide is subjected to [carbothermic reduction](https://en.wikipedia.org/wiki/Carbothermic_reduction) in the presence of [chlorine](https://en.wikipedia.org/wiki/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](https://en.wikipedia.org/wiki/Fractional_distillation), the TiCl4 is [reduced](https://en.wikipedia.org/wiki/Reduction_(chemistry)) with 800 °C molten [magnesium](https://en.wikipedia.org/wiki/Magnesium) in an [argon](https://en.wikipedia.org/wiki/Argon) atmosphere.[[11]](https://en.wikipedia.org/wiki/Titanium#cite_note-TICE6th-11) Titanium metal can be further purified by the [van Arkel–de Boer process](https://en.wikipedia.org/wiki/Van_Arkel%E2%80%93de_Boer_process), which involves [thermal decomposition](https://en.wikipedia.org/wiki/Chemical_vapor_transport) of titanium tetraiodide.

Main article: [FFC Cambridge process](https://en.wikipedia.org/wiki/FFC_Cambridge_process)

A more recently developed batch production method, the FFC Cambridge process,[[58]](https://en.wikipedia.org/wiki/Titanium#cite_note-58) 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.[[59]](https://en.wikipedia.org/wiki/Titanium#cite_note-Roza2008p23-59) If mixed oxide powders are used, the product is an [alloy](https://en.wikipedia.org/wiki/Alloy).

Common titanium alloys are made by reduction. For example, cuprotitanium (rutile with [copper](https://en.wikipedia.org/wiki/Copper) added is reduced), ferrocarbon titanium (ilmenite reduced with [coke](https://en.wikipedia.org/wiki/Coke_(fuel)) in an electric furnace), and manganotitanium (rutile with manganese or manganese oxides) are reduced.[[60]](https://en.wikipedia.org/wiki/Titanium#cite_note-TI_Encarta2005-60)

2 FeTiO3 + 7 Cl2 + 6 C → 2 TiCl4 + 2 FeCl3 + 6 CO (900 °C)

TiCl4 + 2 Mg → 2 MgCl2 + Ti (1,100 °C)

About fifty [grades](https://en.wikipedia.org/wiki/Titanium_alloy#Grades) of titanium and titanium alloys are designed and currently used, although only a couple of dozen are readily available commercially.[[61]](https://en.wikipedia.org/wiki/Titanium#cite_note-61) The [ASTM International](https://en.wikipedia.org/wiki/ASTM_International) recognizes 31 [grades of titanium](https://en.wikipedia.org/wiki/Titanium_alloy) metal and alloys, of which grades one through four are commercially pure (unalloyed). Those four vary in tensile strength as a function of [oxygen](https://en.wikipedia.org/wiki/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%).[[17]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p453-17) The remaining grades are alloys, each designed for specific properties of ductility, strength, hardness, electrical resistivity, [creep](https://en.wikipedia.org/wiki/Creep_(deformation)) resistance, specific corrosion resistance, and combinations thereof.[[62]](https://en.wikipedia.org/wiki/Titanium#cite_note-62)

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.[[63]](https://en.wikipedia.org/wiki/Titanium#cite_note-63)

Titanium powder is manufactured using a [flow production](https://en.wikipedia.org/wiki/Flow_production) process known as the [Armstrong process](https://en.wikipedia.org/w/index.php?title=Armstrong_process&action=edit&redlink=1)[[64]](https://en.wikipedia.org/wiki/Titanium#cite_note-Roza2008p25-64) that is similar to the batch production Hunter process. A stream of titanium tetrachloride gas is added to a stream of [molten](https://en.wikipedia.org/wiki/Molten) sodium metal; the products (sodium chloride [salt](https://en.wikipedia.org/wiki/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.[[65]](https://en.wikipedia.org/wiki/Titanium#cite_note-ECI_online-65)

All [welding](https://en.wikipedia.org/wiki/Welding) of titanium must be done in an inert atmosphere of [argon](https://en.wikipedia.org/wiki/Argon) or [helium](https://en.wikipedia.org/wiki/Helium) to shield it from contamination with atmospheric gases (oxygen, [nitrogen](https://en.wikipedia.org/wiki/Nitrogen), and [hydrogen](https://en.wikipedia.org/wiki/Hydrogen)).[[15]](https://en.wikipedia.org/wiki/Titanium#cite_note-Barksdale1968p734-15) Contamination causes a variety of conditions, such as [embrittlement](https://en.wikipedia.org/wiki/Embrittlement), which reduce the integrity of the assembly welds and lead 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.[[66]](https://en.wikipedia.org/wiki/Titanium#cite_note-66)[[67]](https://en.wikipedia.org/wiki/Titanium#cite_note-67) Titanium cannot be [soldered](https://en.wikipedia.org/wiki/Solder) without first pre-[plating](https://en.wikipedia.org/wiki/Plating) it in a metal that is [solderable](https://en.wikipedia.org/wiki/Solderability).[[68]](https://en.wikipedia.org/wiki/Titanium#cite_note-68) The metal can be machined with the same equipment and the same processes as [stainless steel](https://en.wikipedia.org/wiki/Stainless_steel).[[15]](https://en.wikipedia.org/wiki/Titanium#cite_note-Barksdale1968p734-15)

**Applications**

[](https://en.wikipedia.org/wiki/File:Titanzylinder.jpg)

A titanium cylinder of "grade 2" quality

Titanium is used in [steel](https://en.wikipedia.org/wiki/Steel) as an alloying element ([ferro-titanium](https://en.wikipedia.org/wiki/Ferro-titanium)) to reduce [grain size](https://en.wikipedia.org/wiki/Crystallite) and as a deoxidizer, and in stainless steel to reduce carbon content.[[6]](https://en.wikipedia.org/wiki/Titanium#cite_note-EBC-6) Titanium is often alloyed with aluminium (to refine grain size), [vanadium](https://en.wikipedia.org/wiki/Vanadium), copper (to harden), [iron](https://en.wikipedia.org/wiki/Iron), [manganese](https://en.wikipedia.org/wiki/Manganese), [molybdenum](https://en.wikipedia.org/wiki/Molybdenum), and other metals.[[69]](https://en.wikipedia.org/wiki/Titanium#cite_note-ECE738-69) Titanium mill products (sheet, plate, bar, wire, forgings, castings) find application in industrial, aerospace, recreational, and emerging markets. Powdered titanium is used in [pyrotechnics](https://en.wikipedia.org/wiki/Pyrotechnics) as a source of bright-burning particles.

**Pigments, additives, and coatings**

[](https://en.wikipedia.org/wiki/File:Titanium(IV)_oxide.jpg)

[Titanium dioxide](https://en.wikipedia.org/wiki/Titanium_dioxide) is the most commonly used compound of titanium

About 95% of all titanium ore is destined for refinement into [titanium dioxide](https://en.wikipedia.org/wiki/Titanium_dioxide) (Ti[O](https://en.wikipedia.org/wiki/Oxygen)  
2), an intensely white permanent [pigment](https://en.wikipedia.org/wiki/Pigment) used in paints, paper, toothpaste, and plastics.[[20]](https://en.wikipedia.org/wiki/Titanium#cite_note-USGS-20) It is also used in cement, in gemstones, as an optical opacifier in paper,[[70]](https://en.wikipedia.org/wiki/Titanium#cite_note-70) and a strengthening agent in graphite composite fishing rods and golf clubs.

TiO  
2 pigment is chemically inert, resists fading in sunlight, and is very opaque: it imparts a pure and brilliant white colour to the brown or grey chemicals that form the majority of household plastics.[[8]](https://en.wikipedia.org/wiki/Titanium#cite_note-HistoryAndUse-8) In nature, this compound is found in the minerals [anatase](https://en.wikipedia.org/wiki/Anatase), [brookite](https://en.wikipedia.org/wiki/Brookite), and rutile.[[6]](https://en.wikipedia.org/wiki/Titanium#cite_note-EBC-6) Paint made with titanium dioxide does well in severe temperatures and marine environments.[[8]](https://en.wikipedia.org/wiki/Titanium#cite_note-HistoryAndUse-8) Pure titanium dioxide has a very high [index of refraction](https://en.wikipedia.org/wiki/Refractive_index) and an [optical dispersion](https://en.wikipedia.org/wiki/Optical_dispersion) higher than [diamond](https://en.wikipedia.org/wiki/Diamond).[[7]](https://en.wikipedia.org/wiki/Titanium#cite_note-LANL-7) In addition to being a very important pigment, titanium dioxide is also used in sunscreens.[[13]](https://en.wikipedia.org/wiki/Titanium#cite_note-Stwertka1998-13)

**Aerospace and marine**

Because titanium alloys have high [tensile strength](https://en.wikipedia.org/wiki/Tensile_strength) to density ratio,[[11]](https://en.wikipedia.org/wiki/Titanium#cite_note-TICE6th-11) high [corrosion resistance](https://en.wikipedia.org/wiki/Corrosion_resistance),[[7]](https://en.wikipedia.org/wiki/Titanium#cite_note-LANL-7) fatigue resistance, high crack resistance,[[71]](https://en.wikipedia.org/wiki/Titanium#cite_note-Moiseyev-71) and ability to withstand moderately high temperatures without [creeping](https://en.wikipedia.org/wiki/Creep_(deformation)), they are used in aircraft, armour plating, naval ships, spacecraft, and missiles.[[7]](https://en.wikipedia.org/wiki/Titanium#cite_note-LANL-7)[[8]](https://en.wikipedia.org/wiki/Titanium#cite_note-HistoryAndUse-8) For these applications, [titanium is alloyed](https://en.wikipedia.org/wiki/Titanium_alloy) with aluminium, zirconium, nickel,[[72]](https://en.wikipedia.org/wiki/Titanium#cite_note-NYT7513-72) vanadium, and other elements to manufacture a variety of components including critical structural parts, fire walls, [landing gear](https://en.wikipedia.org/wiki/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.[[73]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p454-73) The [titanium 6AL-4V](https://en.wikipedia.org/wiki/Titanium_6AL-4V) alloy accounts for almost 50% of all alloys used in aircraft applications.[[74]](https://en.wikipedia.org/wiki/Titanium#cite_note-74)

The [Lockheed A-12](https://en.wikipedia.org/wiki/Lockheed_A-12) and its development the [SR-71 "Blackbird"](https://en.wikipedia.org/wiki/SR-71_Blackbird) were two 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](https://en.wikipedia.org/wiki/Boeing_777), 45 in the [Boeing 747](https://en.wikipedia.org/wiki/Boeing_747), 18 in the [Boeing 737](https://en.wikipedia.org/wiki/Boeing_737), 32 in the [Airbus A340](https://en.wikipedia.org/wiki/Airbus_A340), 18 in the [Airbus A330](https://en.wikipedia.org/wiki/Airbus_A330), and 12 in the [Airbus A320](https://en.wikipedia.org/wiki/Airbus_A320). The [Airbus A380](https://en.wikipedia.org/wiki/Airbus_A380) may use 77 metric tons, including about 11 tons in the engines.[[75]](https://en.wikipedia.org/wiki/Titanium#cite_note-75) In aero engine applications, titanium is used for rotors, compressor blades, hydraulic system components, and [nacelles](https://en.wikipedia.org/wiki/Nacelle). An early use in jet engines was for the [Orenda Iroquois](https://en.wikipedia.org/wiki/Orenda_Iroquois) in the 1950s.[[76]](https://en.wikipedia.org/wiki/Titanium#cite_note-76):412

Because titanium is resistant to corrosion by sea water, it is used to make propeller shafts, rigging, and [heat exchangers](https://en.wikipedia.org/wiki/Heat_exchanger) in [desalination plants](https://en.wikipedia.org/wiki/Desalination_plant);[[7]](https://en.wikipedia.org/wiki/Titanium#cite_note-LANL-7) 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](https://en.wikipedia.org/wiki/Soviet_Union) developed techniques for making submarines with hulls of titanium alloys[[77]](https://en.wikipedia.org/wiki/Titanium#cite_note-77) forging titanium in huge vacuum tubes.[[72]](https://en.wikipedia.org/wiki/Titanium#cite_note-NYT7513-72)

Titanium is used in the walls of the Juno spacecraft's [vault](https://en.wikipedia.org/wiki/Juno_Radiation_Vault) to shield on-board electronics.[[78]](https://en.wikipedia.org/wiki/Titanium#cite_note-78)

**Industrial**

[](https://en.wikipedia.org/wiki/File:Hochreines_Titan_(99.999)_mit_sichtbarer_Kristallstruktur.jpg)

High-purity (99.999%) titanium with visible [crystallites](https://en.wikipedia.org/wiki/Crystallite)

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 oil and gas downhole applications and [nickel](https://en.wikipedia.org/wiki/Nickel) [hydrometallurgy](https://en.wikipedia.org/wiki/Hydrometallurgy) for their high strength (e. g.: titanium beta C alloy), corrosion resistance, or both. The [pulp and paper industry](https://en.wikipedia.org/wiki/Pulp_and_paper_industry) uses titanium in process equipment exposed to corrosive media, such as sodium hypochlorite or wet chlorine gas (in the bleachery).[[79]](https://en.wikipedia.org/wiki/Titanium#cite_note-79) Other applications include [ultrasonic welding](https://en.wikipedia.org/wiki/Ultrasonic_welding), [wave soldering](https://en.wikipedia.org/wiki/Wave_soldering),[[80]](https://en.wikipedia.org/wiki/Titanium#cite_note-80) and [sputtering](https://en.wikipedia.org/wiki/Sputtering) targets.[[81]](https://en.wikipedia.org/wiki/Titanium#cite_note-81)

[Titanium tetrachloride](https://en.wikipedia.org/wiki/Titanium_tetrachloride) (TiCl4), a colorless liquid, is important as an intermediate in the process of making TiO2 and is also used to produce the [Ziegler–Natta catalyst](https://en.wikipedia.org/wiki/Ziegler%E2%80%93Natta_catalyst). Titanium tetrachloride is also used to iridize [glass](https://en.wikipedia.org/wiki/Glass) and, because it fumes strongly in moist air, it is used to make smoke screens.[[13]](https://en.wikipedia.org/wiki/Titanium#cite_note-Stwertka1998-13)

**Consumer and architectural**

[](https://en.wikipedia.org/wiki/File:Titanium-stamps.jpg)

Titanium [sealing stamps](https://en.wikipedia.org/wiki/Seal_(East_Asia))

Titanium metal is used in automotive applications, particularly in automobile and motorcycle racing where low weight and high strength and rigidity are critical.[[82]](https://en.wikipedia.org/wiki/Titanium#cite_note-82) The metal is generally too expensive for the general consumer market, though some late model [Corvettes](https://en.wikipedia.org/wiki/Chevrolet_Corvette) have been manufactured with titanium exhausts,[[83]](https://en.wikipedia.org/wiki/Titanium#cite_note-83) and a [Corvette Z06's LT4](https://en.wikipedia.org/wiki/GM_small-block_engine) supercharged engine uses lightweight, solid titanium intake valves for greater strength and resistance to heat.[[84]](https://en.wikipedia.org/wiki/Titanium#cite_note-84)

Titanium is used in many sporting goods: tennis rackets, golf clubs, lacrosse stick shafts; cricket, hockey, lacrosse, and 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](https://en.wikipedia.org/wiki/Adventure_Cycling).[[85]](https://en.wikipedia.org/wiki/Titanium#cite_note-85)

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](https://en.wikipedia.org/wiki/Farrier) because they are lighter and more durable.[[86]](https://en.wikipedia.org/wiki/Titanium#cite_note-Donachie2000-86)

[](https://en.wikipedia.org/wiki/File:El_Guggenheim_vizca%C3%ADno._(1454058701).jpg)

Titanium cladding of [Frank Gehry](https://en.wikipedia.org/wiki/Frank_Gehry)'s [Guggenheim Museum](https://en.wikipedia.org/wiki/Guggenheim_Museum_Bilbao), [Bilbao](https://en.wikipedia.org/wiki/Bilbao)

Titanium has occasionally been used in architecture. The 42.5 m (139 ft) [Monument to Yuri Gagarin](https://en.wikipedia.org/wiki/Monument_to_Yuri_Gagarin), the first man to travel in space ([55°42′29.7″N 37°34′57.2″E](https://tools.wmflabs.org/geohack/geohack.php?pagename=Titanium&params=55_42_29.7_N_37_34_57.2_E_region:CN-62_type:landmark)), as well as the 110 m (360 ft) [Monument to the Conquerors of Space](https://en.wikipedia.org/wiki/Monument_to_the_Conquerors_of_Space) on top of the [Cosmonaut Museum](https://en.wikipedia.org/wiki/Memorial_Museum_of_Cosmonautics) in Moscow are made of titanium for the metal's attractive colour and association with rocketry.[[87]](https://en.wikipedia.org/wiki/Titanium#cite_note-87)[[88]](https://en.wikipedia.org/wiki/Titanium#cite_note-88) The [Guggenheim Museum Bilbao](https://en.wikipedia.org/wiki/Guggenheim_Museum_Bilbao) and the [Cerritos Millennium Library](https://en.wikipedia.org/wiki/Cerritos_Millennium_Library) were the first buildings in Europe and North America, respectively, to be sheathed in titanium panels.[[73]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p454-73) Titanium sheathing was used in the Frederic C. Hamilton Building in Denver, Colorado.[[89]](https://en.wikipedia.org/wiki/Titanium#cite_note-89)

Because of titanium's superior strength and light weight relative to other metals (steel, stainless steel, and aluminium), and because of recent advances in metalworking techniques, its use 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](https://en.wikipedia.org/wiki/Apple_Inc.)'s PowerBook line).[[90]](https://en.wikipedia.org/wiki/Titanium#cite_note-90)

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

**Jewelry**

[](https://en.wikipedia.org/wiki/File:Anodized_titanium_table.jpg)

Relation between voltage and color for anodized titanium. (Cateb, 2010).

Because of its durability, titanium has become more popular for designer jewelry (particularly, [titanium rings](https://en.wikipedia.org/wiki/Titanium_ring)).[[86]](https://en.wikipedia.org/wiki/Titanium#cite_note-Donachie2000-86) 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](https://en.wikipedia.org/wiki/Titanium_gold) to produce an alloy that can be marketed as [24-carat](https://en.wikipedia.org/wiki/Carat_(purity)) 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.[[91]](https://en.wikipedia.org/wiki/Titanium#cite_note-91)

Titanium's durability, light weight, and dent and corrosion resistance make it useful for [watch](https://en.wikipedia.org/wiki/Watch) cases.[[86]](https://en.wikipedia.org/wiki/Titanium#cite_note-Donachie2000-86) Some artists work with titanium to produce sculptures, decorative objects and furniture.[[92]](https://en.wikipedia.org/wiki/Titanium#cite_note-92)

Titanium may be [anodized](https://en.wikipedia.org/wiki/Anodising) to vary the thickness of the surface oxide layer, causing optical [interference fringes](https://en.wikipedia.org/wiki/Interference_fringe) and a variety of bright colors.[[93]](https://en.wikipedia.org/wiki/Titanium#cite_note-93) With this coloration and chemical inertness, titanium is a popular metal for [body piercing](https://en.wikipedia.org/wiki/Body_piercing).[[94]](https://en.wikipedia.org/wiki/Titanium#cite_note-94)

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.[[95]](https://en.wikipedia.org/wiki/Titanium#cite_note-95) The [Gold Coast Titans](https://en.wikipedia.org/wiki/Gold_Coast_Titans), an Australian rugby league team, award a medal of pure titanium to their player of the year.[[96]](https://en.wikipedia.org/wiki/Titanium#cite_note-96)

**Medical**

Main article: [Titanium biocompatibility](https://en.wikipedia.org/wiki/Titanium_biocompatibility)

Because titanium is [biocompatible](https://en.wikipedia.org/wiki/Biocompatibility) (non-toxic and not rejected by the body), it has many medical uses, including surgical implements and implants, such as hip balls and sockets ([joint replacement](https://en.wikipedia.org/wiki/Joint_replacement)) and [dental implants](https://en.wikipedia.org/wiki/Dental_implant) that can stay in place for up to 20 years.[[40]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p452-40) The titanium is often alloyed with about 4% aluminium or 6% Al and 4% vanadium.[[97]](https://en.wikipedia.org/wiki/Titanium#cite_note-97)

[](https://en.wikipedia.org/wiki/File:Titanium_plaatje_voor_pols.jpg)

Medical screws and plate used for repair fracture of the wrist, scale is in centimeters.

Titanium has the inherent ability to [osseointegrate](https://en.wikipedia.org/wiki/Osseointegration), enabling use in [dental implants](https://en.wikipedia.org/wiki/Dental_implants) that can last for over 30 years. This property is also useful for [orthopedic implant](https://en.wikipedia.org/wiki/Internal_fixator) applications.[[40]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p452-40) These benefit from titanium's lower modulus of elasticity ([Young's modulus](https://en.wikipedia.org/wiki/Young%27s_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](https://en.wikipedia.org/wiki/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.[[98]](https://en.wikipedia.org/wiki/Titanium#cite_note-98)[[99]](https://en.wikipedia.org/wiki/Titanium#cite_note-99)

Because titanium is non-[ferromagnetic](https://en.wikipedia.org/wiki/Ferromagnetic), patients with titanium implants can be safely examined with [magnetic resonance imaging](https://en.wikipedia.org/wiki/Magnetic_resonance_imaging) (convenient for long-term implants). Preparing titanium for implantation in the body involves subjecting it to a high-temperature [plasma](https://en.wikipedia.org/wiki/Plasma_(physics)) arc which removes the surface atoms, exposing fresh titanium that is instantly oxidized.[[40]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p452-40)

Titanium is used for the [surgical instruments](https://en.wikipedia.org/wiki/Surgical_instrument) used in [image-guided surgery](https://en.wikipedia.org/wiki/Image-guided_surgery), as well as wheelchairs, crutches, and any other products where high strength and low weight are desirable.

Titanium dioxide [nanoparticles](https://en.wikipedia.org/wiki/Nanoparticle) are widely used in electronics and the delivery of [pharmaceuticals](https://en.wikipedia.org/wiki/Pharmaceutical_drug) and cosmetics.[[100]](https://en.wikipedia.org/wiki/Titanium#cite_note-100)

**Nuclear waste storage**

Because of it is corrosion resistance, containers made of titanium have been studied for the long-term storage of nuclear waste. Containers lasting more than 100,000 years are thought possible with manufacturing conditions that minimize material defects.[[101]](https://en.wikipedia.org/wiki/Titanium#cite_note-101) A titanium "drip shield" could also be installed over containers of other types to enhance their longevity.[[102]](https://en.wikipedia.org/wiki/Titanium#cite_note-102)

**Bioremediation**

The fungal species [*Marasmius oreades*](https://en.wikipedia.org/wiki/Marasmius_oreades) and [*Hypholoma capnoides*](https://en.wikipedia.org/wiki/Hypholoma_capnoides) can bioconvert titanium in titanium polluted soils.[[103]](https://en.wikipedia.org/wiki/Titanium#cite_note-103)

**Precautions**

[](https://en.wikipedia.org/wiki/File:Kopiva.JPG)

[Nettles](https://en.wikipedia.org/wiki/Urtica_dioica) contain up to 80 parts per million of titanium.

Titanium is non-toxic even in large doses and does not play any natural role inside the [human body](https://en.wikipedia.org/wiki/Human_body).[[23]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p451-23) 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.[[23]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p451-23) It does, however, sometimes [bio-accumulate](https://en.wikipedia.org/wiki/Bioaccumulation) in tissues that contain [silica](https://en.wikipedia.org/wiki/Silica). One study indicates a possible connection between titanium and [yellow nail syndrome](https://en.wikipedia.org/wiki/Yellow_nail_syndrome).[[104]](https://en.wikipedia.org/wiki/Titanium#cite_note-104) An unknown mechanism in [plants](https://en.wikipedia.org/wiki/Plant) may use titanium to stimulate the production of [carbohydrates](https://en.wikipedia.org/wiki/Carbohydrate) and encourage growth. This may explain why most plants contain about 1 [part per million](https://en.wikipedia.org/wiki/Part_per_million) (ppm) of titanium, food plants have about 2 ppm, and [horsetail](https://en.wikipedia.org/wiki/Horsetail) and [nettle](https://en.wikipedia.org/wiki/Urtica) contain up to 80 ppm.[[23]](https://en.wikipedia.org/wiki/Titanium#cite_note-Emsley2001p451-23)

As a powder or in the form of metal shavings, titanium metal poses a significant fire hazard and, when heated in [air](https://en.wikipedia.org/wiki/Air), an explosion hazard.[[105]](https://en.wikipedia.org/wiki/Titanium#cite_note-105) Water and [carbon dioxide](https://en.wikipedia.org/wiki/Carbon_dioxide) are ineffective for extinguishing a titanium fire; [Class D](https://en.wikipedia.org/wiki/Fire_classes) dry powder agents must be used instead.[[8]](https://en.wikipedia.org/wiki/Titanium#cite_note-HistoryAndUse-8)

When used in the production or handling of [chlorine](https://en.wikipedia.org/wiki/Chlorine), titanium should not be exposed to dry chlorine gas because it may result in a titanium–chlorine fire.[[106]](https://en.wikipedia.org/wiki/Titanium#cite_note-106) 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](https://en.wikipedia.org/wiki/Liquid_oxygen).[[107]](https://en.wikipedia.org/wiki/Titanium#cite_note-107) 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.

**See also**

* [List of countries by titanium production](https://en.wikipedia.org/wiki/List_of_countries_by_titanium_production)
* [Suboxide](https://en.wikipedia.org/wiki/Suboxide)
* [Titanium in Africa](https://en.wikipedia.org/wiki/Titanium_in_Africa)
* [Titanium alloy](https://en.wikipedia.org/wiki/Titanium_alloy)
* [Titanium coating](https://en.wikipedia.org/wiki/Titanium_nitride)
* [Titanium Man](https://en.wikipedia.org/wiki/Titanium_Man)
* [Titanium Metals Corporation](https://en.wikipedia.org/wiki/Titanium_Metals_Corporation)
* [Titanium ring](https://en.wikipedia.org/wiki/Titanium_ring)
* [Titanium sublimation pump](https://en.wikipedia.org/wiki/Titanium_sublimation_pump)
* [VSMPO-AVISMA](https://en.wikipedia.org/wiki/VSMPO-AVISMA)
* [Titanium in zircon geothermometry](https://en.wikipedia.org/wiki/Titanium_in_zircon_geothermometry)

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|  | |
| [**Portals**](https://en.wikipedia.org/wiki/Portal:Contents/Portals) Access related topics | * [Papapishu-Lab-icon-6.svg](https://en.wikipedia.org/wiki/File:Papapishu-Lab-icon-6.svg)[***Chemistry portal***](https://en.wikipedia.org/wiki/Portal:Chemistry) |

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  [Donachie 1988](https://en.wikipedia.org/wiki/Titanium#CITEREFDonachie1988), p. 11

  [Barksdale 1968](https://en.wikipedia.org/wiki/Titanium#CITEREFBarksdale1968), p. 738

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* [Biomaterials](https://en.wikipedia.org/wiki/Category:Biomaterials)

**Navigation menu**

* Not logged in
* [Talk](https://en.wikipedia.org/wiki/Special:MyTalk)
* [Contributions](https://en.wikipedia.org/wiki/Special:MyContributions)
* [Create account](https://en.wikipedia.org/w/index.php?title=Special:CreateAccount&returnto=Titanium)
* [Log in](https://en.wikipedia.org/w/index.php?title=Special:UserLogin&returnto=Titanium)
* [Article](https://en.wikipedia.org/wiki/Titanium)
* [Talk](https://en.wikipedia.org/wiki/Talk:Titanium)
* [Read](https://en.wikipedia.org/wiki/Titanium)
* [View source](https://en.wikipedia.org/w/index.php?title=Titanium&action=edit)
* [View history](https://en.wikipedia.org/w/index.php?title=Titanium&action=history)

**Search**

Top of Form

Bottom of Form

* [Main page](https://en.wikipedia.org/wiki/Main_Page)
* [Contents](https://en.wikipedia.org/wiki/Portal:Contents)
* [Featured content](https://en.wikipedia.org/wiki/Portal:Featured_content)
* [Current events](https://en.wikipedia.org/wiki/Portal:Current_events)
* [Random article](https://en.wikipedia.org/wiki/Special:Random)
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* [Wikipedia store](https://shop.wikimedia.org)

**Interaction**

* [Help](https://en.wikipedia.org/wiki/Help:Contents)
* [About Wikipedia](https://en.wikipedia.org/wiki/Wikipedia:About)
* [Community portal](https://en.wikipedia.org/wiki/Wikipedia:Community_portal)
* [Recent changes](https://en.wikipedia.org/wiki/Special:RecentChanges)
* [Contact page](https://en.wikipedia.org/wiki/Wikipedia:Contact_us)

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* [What links here](https://en.wikipedia.org/wiki/Special:WhatLinksHere/Titanium)
* [Related changes](https://en.wikipedia.org/wiki/Special:RecentChangesLinked/Titanium)
* [Upload file](https://en.wikipedia.org/wiki/Wikipedia:File_Upload_Wizard)
* [Special pages](https://en.wikipedia.org/wiki/Special:SpecialPages)
* [Permanent link](https://en.wikipedia.org/w/index.php?title=Titanium&oldid=875881814)
* [Page information](https://en.wikipedia.org/w/index.php?title=Titanium&action=info)
* [Wikidata item](https://www.wikidata.org/wiki/Special:EntityPage/Q716)
* [Cite this page](https://en.wikipedia.org/w/index.php?title=Special:CiteThisPage&page=Titanium&id=875881814)

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* [Download as PDF](https://en.wikipedia.org/w/index.php?title=Special:ElectronPdf&page=Titanium&action=show-download-screen)
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* [Español](https://es.wikipedia.org/wiki/Titanio)
* [Français](https://fr.wikipedia.org/wiki/Titane)
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* [Русский](https://ru.wikipedia.org/wiki/%D0%A2%D0%B8%D1%82%D0%B0%D0%BD_(%D1%8D%D0%BB%D0%B5%D0%BC%D0%B5%D0%BD%D1%82))
* [Tagalog](https://tl.wikipedia.org/wiki/Titanyo)
* [Tiếng Việt](https://vi.wikipedia.org/wiki/Titan)
* [中文](https://zh.wikipedia.org/wiki/%E9%92%9B)

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