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**Vanadium**

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| --- | --- |
| Vanadium,  23V | |
| [Vanadium etched.jpg](https://en.wikipedia.org/wiki/File:Vanadium_etched.jpg) | |
| **General properties** | |
| **Pronunciation** | [/vəˈneɪdiəm/](https://en.wikipedia.org/wiki/Help:IPA/English) ​([*və-NAY-dee-əm*](https://en.wikipedia.org/wiki/Help:Pronunciation_respelling_key)) |
| **Appearance** | blue-silver-grey metal |
| [**Standard atomic weight**](https://en.wikipedia.org/wiki/Standard_atomic_weight) **(*A*r, standard)** | 50.9415(1)[[1]](https://en.wikipedia.org/wiki/Vanadium#cite_note-CIAAW2016-1) |
| **Vanadium 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](https://en.wikipedia.org/wiki/Titanium) | 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) | | – ↑ **V** ↓ [Nb](https://en.wikipedia.org/wiki/Niobium) | | [titanium](https://en.wikipedia.org/wiki/Titanium) ← **vanadium** → [chromium](https://en.wikipedia.org/wiki/Chromium) | | | | |
| [**Atomic number**](https://en.wikipedia.org/wiki/Atomic_number)(*Z*) | 23 |
| [**Group**](https://en.wikipedia.org/wiki/Group_(periodic_table)) | [group 5](https://en.wikipedia.org/wiki/Group_5_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)] 3d3 4s2 |
| Electrons per shell | 2, 8, 11, 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) | 2183 [K](https://en.wikipedia.org/wiki/Kelvin) ​(1910 °C, ​3470 °F) |
| [**Boiling point**](https://en.wikipedia.org/wiki/Boiling_point) | 3680 K ​(3407 °C, ​6165 °F) |
| [**Density**](https://en.wikipedia.org/wiki/Density)(near r.t.) | 6.0 g/cm3 |
| when liquid (at m.p.) | 5.5 g/cm3 |
| [**Heat of fusion**](https://en.wikipedia.org/wiki/Enthalpy_of_fusion) | 21.5 [kJ/mol](https://en.wikipedia.org/wiki/Kilojoule_per_mole) |
| [**Heat of vaporization**](https://en.wikipedia.org/wiki/Enthalpy_of_vaporization) | 444 kJ/mol |
| [**Molar heat capacity**](https://en.wikipedia.org/wiki/Molar_heat_capacity) | 24.89 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) | 2101 | 2289 | 2523 | 2814 | 3187 | 3679 | | |
| **Atomic properties** | |
| [**Oxidation states**](https://en.wikipedia.org/wiki/Oxidation_state) | −3, −1, +1, +2, +3, +4, **+5** (an [amphoteric](https://en.wikipedia.org/wiki/Amphoterism) oxide) |
| [**Electronegativity**](https://en.wikipedia.org/wiki/Electronegativity) | Pauling scale: 1.63 |
| [**Ionization energies**](https://en.wikipedia.org/wiki/Ionization_energy) | * 1st: 650.9 kJ/mol * 2nd: 1414 kJ/mol * 3rd: 2830 kJ/mol * ([more](https://en.wikipedia.org/wiki/Molar_ionization_energies_of_the_elements#vanadium)) |
| [**Atomic radius**](https://en.wikipedia.org/wiki/Atomic_radius) | empirical: 134 [pm](https://en.wikipedia.org/wiki/Picometre) |
| [**Covalent radius**](https://en.wikipedia.org/wiki/Covalent_radius) | 153±8 pm |
| [Color lines in a spectral range](https://en.wikipedia.org/wiki/File:Vanadium_spectrum_visible.png)  [**Spectral lines**](https://en.wikipedia.org/wiki/Spectral_line) **of vanadium** | |
| **Other properties** | |
| [**Crystal structure**](https://en.wikipedia.org/wiki/Crystal_structure) | ​[body-centered cubic](https://en.wikipedia.org/wiki/Cubic_crystal_system) (bcc)  [Body-centered cubic crystal structure for vanadium](https://en.wikipedia.org/wiki/File:Cubic-body-centered.svg) |
| [**Speed of sound**](https://en.wikipedia.org/wiki/Speed_of_sound)thin rod | 4560 m/s (at 20 °C) |
| [**Thermal expansion**](https://en.wikipedia.org/wiki/Coefficient_of_thermal_expansion) | 8.4 µm/(m·K) (at 25 °C) |
| [**Thermal conductivity**](https://en.wikipedia.org/wiki/Thermal_conductivity) | 30.7 W/(m·K) |
| [**Electrical resistivity**](https://en.wikipedia.org/wiki/Electrical_resistivity_and_conductivity) | 197 nΩ·m (at 20 °C) |
| [**Magnetic ordering**](https://en.wikipedia.org/wiki/Magnetism) | paramagnetic |
| [**Magnetic susceptibility**](https://en.wikipedia.org/wiki/Magnetic_susceptibility) | +255.0·10−6 cm3/mol (298 K)[[2]](https://en.wikipedia.org/wiki/Vanadium#cite_note-2) |
| [**Young's modulus**](https://en.wikipedia.org/wiki/Young%27s_modulus) | 128 GPa |
| [**Shear modulus**](https://en.wikipedia.org/wiki/Shear_modulus) | 47 GPa |
| [**Bulk modulus**](https://en.wikipedia.org/wiki/Bulk_modulus) | 160 GPa |
| [**Poisson ratio**](https://en.wikipedia.org/wiki/Poisson%27s_ratio) | 0.37 |
| [**Mohs hardness**](https://en.wikipedia.org/wiki/Mohs_scale_of_mineral_hardness) | 6.7 |
| [**Vickers hardness**](https://en.wikipedia.org/wiki/Vickers_hardness_test) | 628–640 MPa |
| [**Brinell hardness**](https://en.wikipedia.org/wiki/Brinell_hardness_test) | 600–742 MPa |
| [**CAS Number**](https://en.wikipedia.org/wiki/CAS_Registry_Number) | 7440-62-2 |
| **History** | |
| [**Discovery**](https://en.wikipedia.org/wiki/Timeline_of_chemical_element_discoveries) | [Andrés Manuel del Río](https://en.wikipedia.org/wiki/Andr%C3%A9s_Manuel_del_R%C3%ADo) (1801) |
| **First isolation** | [Nils Gabriel Sefström](https://en.wikipedia.org/wiki/Nils_Gabriel_Sefstr%C3%B6m) (1830) |
| **Named by** | Nils Gabriel Sefström (1830) |
| **Main** [**isotopes of vanadium**](https://en.wikipedia.org/wiki/Isotopes_of_vanadium) | |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | | [**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) | | **48V** | [syn](https://en.wikipedia.org/wiki/Synthetic_radioisotope) | 16 d | [β+](https://en.wikipedia.org/wiki/Positron_emission) | [48Ti](https://en.wikipedia.org/wiki/Titanium-48) | | **49V** | syn | 330 d | [ε](https://en.wikipedia.org/wiki/Electron_capture) | [49Ti](https://en.wikipedia.org/wiki/Titanium-49) | | **50V** | 0.25% | 1.5×1017 y | ε | [50Ti](https://en.wikipedia.org/wiki/Titanium-50) | | [β−](https://en.wikipedia.org/wiki/Beta_emission) | [50Cr](https://en.wikipedia.org/wiki/Chromium-50) | | **51V** | 99.75% | [stable](https://en.wikipedia.org/wiki/Stable_isotope) | | | | |
| * [view](https://en.wikipedia.org/wiki/Template:Infobox_vanadium) * [talk](https://en.wikipedia.org/wiki/Template_talk:Infobox_vanadium) * [edit](https://en.wikipedia.org/w/index.php?title=Template:Infobox_vanadium&action=edit)   | [references](https://en.wikipedia.org/wiki/List_of_data_references_for_chemical_elements) | |

**Vanadium** is a [chemical element](https://en.wikipedia.org/wiki/Chemical_element) with symbol **V** and [atomic number](https://en.wikipedia.org/wiki/Atomic_number) 23. It is a hard, silvery-grey, [ductile](https://en.wikipedia.org/wiki/Ductile), [malleable](https://en.wikipedia.org/wiki/Malleable) [transition metal](https://en.wikipedia.org/wiki/Transition_metal). The elemental metal is rarely found in nature, but once isolated artificially, the formation of an [oxide](https://en.wikipedia.org/wiki/Oxide) layer ([passivation](https://en.wikipedia.org/wiki/Passivation_(chemistry))) somewhat stabilizes the free metal against further [oxidation](https://en.wikipedia.org/wiki/Oxidation).

[Andrés Manuel del Río](https://en.wikipedia.org/wiki/Andr%C3%A9s_Manuel_del_R%C3%ADo) discovered compounds of vanadium in 1801 in [Mexico](https://en.wikipedia.org/wiki/Mexico) by analyzing a new [lead](https://en.wikipedia.org/wiki/Lead)-bearing mineral he called "brown lead", and presumed its qualities were due to the presence of a new element, which he named *erythronium* (derived from Greek for "red") since, upon heating, most of the [salts](https://en.wikipedia.org/wiki/Salt_(chemistry)) turned red. Four years later, however, he was (erroneously) convinced by other scientists that erythronium was identical to [chromium](https://en.wikipedia.org/wiki/Chromium). [Chlorides](https://en.wikipedia.org/wiki/Chloride) of vanadium were generated in 1830 by [Nils Gabriel Sefström](https://en.wikipedia.org/wiki/Nils_Gabriel_Sefstr%C3%B6m) who thereby proved that a new element was involved, which he named "vanadium" after the Scandinavian goddess of beauty and fertility, [Vanadís](https://en.wikipedia.org/wiki/Vanad%C3%ADs) ([Freyja](https://en.wikipedia.org/wiki/Freyja)). Both names were attributed to the wide range of colors found in vanadium compounds. Del Rio's lead mineral was later renamed [vanadinite](https://en.wikipedia.org/wiki/Vanadinite) for its vanadium content. In 1867 [Henry Enfield Roscoe](https://en.wikipedia.org/wiki/Henry_Enfield_Roscoe) obtained the pure element.

Vanadium occurs naturally in about 65 [minerals](https://en.wikipedia.org/wiki/Mineral) and in [fossil fuel](https://en.wikipedia.org/wiki/Fossil_fuel) deposits. It is produced in [China](https://en.wikipedia.org/wiki/China) and [Russia](https://en.wikipedia.org/wiki/Russia) from steel smelter [slag](https://en.wikipedia.org/wiki/Slag); other countries produce it either from magnetite directly, flue dust of heavy oil, or as a byproduct of [uranium](https://en.wikipedia.org/wiki/Uranium) mining. It is mainly used to produce specialty [steel](https://en.wikipedia.org/wiki/Steel) [alloys](https://en.wikipedia.org/wiki/Alloy) such as [high-speed tool steels](https://en.wikipedia.org/wiki/High-speed_steel). The most important industrial vanadium compound, [vanadium pentoxide](https://en.wikipedia.org/wiki/Vanadium(V)_oxide), is used as a catalyst for the production of [sulfuric acid](https://en.wikipedia.org/wiki/Sulfuric_acid).

Large amounts of vanadium [ions](https://en.wikipedia.org/wiki/Ions) are found in a few organisms, possibly as a [toxin](https://en.wikipedia.org/wiki/Toxin). The oxide and some other salts of vanadium have moderate toxicity. Particularly in the ocean, vanadium is used by some life forms as an active center of [enzymes](https://en.wikipedia.org/wiki/Enzyme), such as the [vanadium bromoperoxidase](https://en.wikipedia.org/wiki/Vanadium_bromoperoxidase) of some ocean [algae](https://en.wikipedia.org/wiki/Algae).



**Contents**

* [1 History](https://en.wikipedia.org/wiki/Vanadium#History)
* [2 Characteristics](https://en.wikipedia.org/wiki/Vanadium#Characteristics)
  + [2.1 Isotopes](https://en.wikipedia.org/wiki/Vanadium#Isotopes)
* [3 Chemistry](https://en.wikipedia.org/wiki/Vanadium#Chemistry)
  + [3.1 Oxyanions](https://en.wikipedia.org/wiki/Vanadium#Oxyanions)
  + [3.2 Halide derivatives](https://en.wikipedia.org/wiki/Vanadium#Halide_derivatives)
  + [3.3 Coordination compounds](https://en.wikipedia.org/wiki/Vanadium#Coordination_compounds)
  + [3.4 Organometallic compounds](https://en.wikipedia.org/wiki/Vanadium#Organometallic_compounds)
* [4 Occurrence](https://en.wikipedia.org/wiki/Vanadium#Occurrence)
  + [4.1 Universe](https://en.wikipedia.org/wiki/Vanadium#Universe)
  + [4.2 Earth's crust](https://en.wikipedia.org/wiki/Vanadium#Earth's_crust)
  + [4.3 Water](https://en.wikipedia.org/wiki/Vanadium#Water)
* [5 Production](https://en.wikipedia.org/wiki/Vanadium#Production)
* [6 Applications](https://en.wikipedia.org/wiki/Vanadium#Applications)
  + [6.1 Alloys](https://en.wikipedia.org/wiki/Vanadium#Alloys)
  + [6.2 Other uses](https://en.wikipedia.org/wiki/Vanadium#Other_uses)
    - [6.2.1 Proposed](https://en.wikipedia.org/wiki/Vanadium#Proposed)
* [7 Biological role](https://en.wikipedia.org/wiki/Vanadium#Biological_role)
  + [7.1 Vanadoenzymes](https://en.wikipedia.org/wiki/Vanadium#Vanadoenzymes)
  + [7.2 Vanadium accumulation in tunicates and ascidians](https://en.wikipedia.org/wiki/Vanadium#Vanadium_accumulation_in_tunicates_and_ascidians)
  + [7.3 Fungi](https://en.wikipedia.org/wiki/Vanadium#Fungi)
  + [7.4 Mammals](https://en.wikipedia.org/wiki/Vanadium#Mammals)
  + [7.5 Research](https://en.wikipedia.org/wiki/Vanadium#Research)
* [8 Safety](https://en.wikipedia.org/wiki/Vanadium#Safety)
* [9 See also](https://en.wikipedia.org/wiki/Vanadium#See_also)
* [10 References](https://en.wikipedia.org/wiki/Vanadium#References)
* [11 Further reading](https://en.wikipedia.org/wiki/Vanadium#Further_reading)
* [12 External links](https://en.wikipedia.org/wiki/Vanadium#External_links)

**History**

Vanadium was [discovered](https://en.wikipedia.org/wiki/Discovery_of_the_chemical_elements) by [Andrés Manuel del Río](https://en.wikipedia.org/wiki/Andr%C3%A9s_Manuel_del_R%C3%ADo), a Spanish-Mexican mineralogist, in 1801. Del Río extracted the element from a sample of Mexican "brown lead" ore, later named [vanadinite](https://en.wikipedia.org/wiki/Vanadinite). He found that its salts exhibit a wide variety of colors, and as a result he named the element *panchromium* (Greek: παγχρώμιο "all colors"). Later, Del Río renamed the element *erythronium* (Greek: ερυθρός "red") because most of the salts turned red upon heating. In 1805, the French chemist [Hippolyte Victor Collet-Descotils](https://en.wikipedia.org/wiki/Hippolyte_Victor_Collet-Descotils), backed by del Río's friend Baron [Alexander von Humboldt](https://en.wikipedia.org/wiki/Alexander_von_Humboldt), incorrectly declared that del Río's new element was only an impure sample of [chromium](https://en.wikipedia.org/wiki/Chromium). Del Río accepted Collet-Descotils' statement and retracted his claim.[[3]](https://en.wikipedia.org/wiki/Vanadium#cite_note-Cintas-3)

In 1831, the Swedish chemist [Nils Gabriel Sefström](https://en.wikipedia.org/wiki/Nils_Gabriel_Sefstr%C3%B6m) rediscovered the element in a new oxide he found while working with [iron ores](https://en.wikipedia.org/wiki/Iron_ore). Later that same year, [Friedrich Wöhler](https://en.wikipedia.org/wiki/Friedrich_W%C3%B6hler) confirmed del Río's earlier work.[[4]](https://en.wikipedia.org/wiki/Vanadium#cite_note-sefs-4) Sefström chose a name beginning with V, which had not been assigned to any element yet. He called the element *vanadium* after [Old Norse](https://en.wikipedia.org/wiki/Old_Norse) [*Vanadís*](https://en.wikipedia.org/wiki/List_of_names_of_Freyja) (another name for the [Norse](https://en.wikipedia.org/wiki/Norse_mythology) [Vanr](https://en.wikipedia.org/wiki/Vanir) goddess [Freyja](https://en.wikipedia.org/wiki/Freyja), whose attributes include beauty and fertility), because of the many beautifully colored [chemical compounds](https://en.wikipedia.org/wiki/Chemical_compound) it produces.[[4]](https://en.wikipedia.org/wiki/Vanadium#cite_note-sefs-4) In 1831, the geologist [George William Featherstonhaugh](https://en.wikipedia.org/wiki/George_William_Featherstonhaugh) suggested that vanadium should be renamed "*rionium*" after del Río, but this suggestion was not followed.[[5]](https://en.wikipedia.org/wiki/Vanadium#cite_note-5)

[](https://en.wikipedia.org/wiki/File:1910Ford-T.jpg)

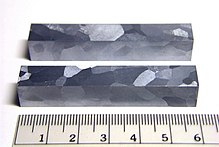
The [Model T](https://en.wikipedia.org/wiki/Model_T) used vanadium steel in its [chassis](https://en.wikipedia.org/wiki/Chassis).

The isolation of vanadium metal proved difficult. In 1831, [Berzelius](https://en.wikipedia.org/wiki/J%C3%B6ns_Jakob_Berzelius) reported the production of the metal, but [Henry Enfield Roscoe](https://en.wikipedia.org/wiki/Henry_Enfield_Roscoe) showed that Berzelius had in fact produced the nitride, [vanadium nitride](https://en.wikipedia.org/wiki/Vanadium_nitride) (VN). Roscoe eventually produced the metal in 1867 by reduction of [vanadium(II) chloride](https://en.wikipedia.org/wiki/Vanadium(II)_chloride), VCl2, with [hydrogen](https://en.wikipedia.org/wiki/Hydrogen).[[6]](https://en.wikipedia.org/wiki/Vanadium#cite_note-Roscoe-6) In 1927, pure vanadium was produced by reducing [vanadium pentoxide](https://en.wikipedia.org/wiki/Vanadium_pentoxide) with [calcium](https://en.wikipedia.org/wiki/Calcium).[[7]](https://en.wikipedia.org/wiki/Vanadium#cite_note-Marden-7)

The first large-scale industrial use of vanadium was in the [steel](https://en.wikipedia.org/wiki/Steel) alloy chassis of the [Ford Model T](https://en.wikipedia.org/wiki/Ford_Model_T), inspired by French race cars. Vanadium steel allowed for reduced weight while simultaneously increasing [tensile strength](https://en.wikipedia.org/wiki/Tensile_strength) (ca. 1905).[[8]](https://en.wikipedia.org/wiki/Vanadium#cite_note-8) For the first decade most of the vanadium ore was mined by [American Vanadium Company](https://en.wikipedia.org/wiki/American_Vanadium_Company) from the [Minas Ragra](https://en.wikipedia.org/wiki/Minas_Ragra) in Peru. With the rising demands for uranium which was partially mined as [carnotite](https://en.wikipedia.org/wiki/Carnotite), a vanadium mineral the uranium mining supplied a large share of the needed vanadium.[[9]](https://en.wikipedia.org/wiki/Vanadium#cite_note-Busch1961-9)[[10]](https://en.wikipedia.org/wiki/Vanadium#cite_note-10)

German chemist [Martin Henze](https://en.wikipedia.org/wiki/Friedrich_Wolfgang_Martin_Henze) discovered vanadium in the [hemovanadin](https://en.wikipedia.org/wiki/Hemovanadin) proteins found in [blood cells](https://en.wikipedia.org/wiki/Blood_cell) (or [coelomic](https://en.wikipedia.org/wiki/Coelom) cells) of [Ascidiacea](https://en.wikipedia.org/wiki/Ascidiacea) (sea squirts) in 1911.[[11]](https://en.wikipedia.org/wiki/Vanadium#cite_note-11)[[12]](https://en.wikipedia.org/wiki/Vanadium#cite_note-michibata2002-12)

**Characteristics**

[](https://en.wikipedia.org/wiki/File:Vanadium-bar.jpg)

High-purity (99.95%) vanadium cuboids, [ebeam remelted](https://en.wikipedia.org/wiki/Electron_beam_technology) and macro-etched

Vanadium is a medium-hard, [ductile](https://en.wikipedia.org/wiki/Ductility), steel-blue metal. It is electrically [conductive](https://en.wikipedia.org/wiki/Conductive) and thermally [insulating](https://en.wikipedia.org/wiki/Thermal_insulation). Some sources describe vanadium as "soft", perhaps because it is ductile, [malleable](https://en.wikipedia.org/wiki/Malleable), and not [brittle](https://en.wikipedia.org/wiki/Brittle).[[13]](https://en.wikipedia.org/wiki/Vanadium#cite_note-13)[[14]](https://en.wikipedia.org/wiki/Vanadium#cite_note-14) Vanadium is harder than most metals and steels (see [Hardnesses of the elements (data page)](https://en.wikipedia.org/wiki/Hardnesses_of_the_elements_(data_page)) and [iron](https://en.wikipedia.org/wiki/Iron#Mechanical_properties)). It has good resistance to [corrosion](https://en.wikipedia.org/wiki/Corrosion) and it is stable against [alkalis](https://en.wikipedia.org/wiki/Alkali) and [sulfuric](https://en.wikipedia.org/wiki/Sulfuric_acid) and [hydrochloric acids](https://en.wikipedia.org/wiki/Hydrochloric_acid).[[15]](https://en.wikipedia.org/wiki/Vanadium#cite_note-HollemanAF-15) It is [oxidized](https://en.wikipedia.org/wiki/Oxidation) in air at about 933 [K](https://en.wikipedia.org/wiki/Kelvin) (660 °C, 1220 °F), although an oxide [passivation](https://en.wikipedia.org/wiki/Passivation_(chemistry)) layer forms even at room temperature.

**Isotopes**

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

Naturally occurring vanadium is composed of one stable [isotope](https://en.wikipedia.org/wiki/Isotope), 51V, and one radioactive isotope, 50V. The latter has a [half-life](https://en.wikipedia.org/wiki/Half-life) of 1.5×1017 years and a natural abundance of 0.25%. 51V has a [nuclear spin](https://en.wikipedia.org/wiki/Nuclear_spin) of ​7⁄2, which is useful for [NMR spectroscopy](https://en.wikipedia.org/wiki/NMR_spectroscopy).[[16]](https://en.wikipedia.org/wiki/Vanadium#cite_note-NUBASE-16) Twenty-four artificial [radioisotopes](https://en.wikipedia.org/wiki/Radioisotope) have been characterized, ranging in [mass number](https://en.wikipedia.org/wiki/Mass_number) from 40 to 65. The most stable of these isotopes are 49V with a half-life of 330 days, and 48V with a half-life of 16.0 days. The remaining [radioactive](https://en.wikipedia.org/wiki/Radioactive) isotopes have half-lives shorter than an hour, most below 10 seconds. At least four isotopes have [metastable excited states](https://en.wikipedia.org/wiki/Nuclear_isomer).[[16]](https://en.wikipedia.org/wiki/Vanadium#cite_note-NUBASE-16) [Electron capture](https://en.wikipedia.org/wiki/Electron_capture) is the main [decay mode](https://en.wikipedia.org/wiki/Decay_mode) for isotopes lighter than 51V. For the heavier ones, the most common mode is [beta decay](https://en.wikipedia.org/wiki/Beta_decay). The electron capture reactions lead to the formation of element 22 ([titanium](https://en.wikipedia.org/wiki/Titanium)) isotopes, while beta decay leads to element 24 ([chromium](https://en.wikipedia.org/wiki/Chromium)) isotopes.

**Chemistry**

See also: [Category:Vanadium compounds](https://en.wikipedia.org/wiki/Category:Vanadium_compounds).

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

From left: [V(H2O)6]2+ (lilac), [V(H2O)6]3+ (green), [VO(H2O)5]2+ (blue) and [VO(H2O)5]3+ (yellow).

The chemistry of vanadium is noteworthy for the accessibility of the four adjacent [oxidation states](https://en.wikipedia.org/wiki/Oxidation_state) 2–5. In [aqueous solution](https://en.wikipedia.org/wiki/Metal_ions_in_aqueous_solution), vanadium forms [metal aquo complexes](https://en.wikipedia.org/wiki/Metal_aquo_complex) of which the colours are lilac [V(H2O)6]2+, green [V(H2O)6]3+, blue [VO(H2O)5]2+, yellow VO3−. Vanadium(II) compounds are reducing agents, and vanadium(V) compounds are oxidizing agents. Vanadium(IV) compounds often exist as [vanadyl](https://en.wikipedia.org/wiki/Vanadyl_ion) derivatives, which contain the VO2+ center.[[15]](https://en.wikipedia.org/wiki/Vanadium#cite_note-HollemanAF-15)

[Ammonium vanadate(V)](https://en.wikipedia.org/wiki/Ammonium_metavanadate) (NH4VO3) can be successively reduced with elemental [zinc](https://en.wikipedia.org/wiki/Zinc) to obtain the different colors of vanadium in these four oxidation states. Lower oxidation states occur in compounds such as V(CO)6, [V(CO)  
6]−  
and substituted derivatives.[[15]](https://en.wikipedia.org/wiki/Vanadium#cite_note-HollemanAF-15)

The most commercially important compound is [vanadium pentoxide](https://en.wikipedia.org/wiki/Vanadium(V)_oxide). It is used as a catalyst for the production of sulfuric acid.[[15]](https://en.wikipedia.org/wiki/Vanadium#cite_note-HollemanAF-15) This compound oxidizes [sulfur dioxide](https://en.wikipedia.org/wiki/Sulfur_dioxide) (SO  
2) to the [trioxide](https://en.wikipedia.org/wiki/Sulfur_trioxide) (SO  
3). In this [redox reaction](https://en.wikipedia.org/wiki/Redox_reaction), sulfur is oxidized from +4 to +6, and vanadium is reduced from +5 to +4:

V2O5 + SO2 → 2 VO2 + SO3[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)]

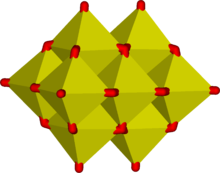
The catalyst is regenerated by oxidation with air:

4 VO2 + O2 → 2 V2O5

Similar oxidations are used in the production of [maleic anhydride](https://en.wikipedia.org/wiki/Maleic_anhydride), [phthalic anhydride](https://en.wikipedia.org/wiki/Phthalic_anhydride), and several other bulk organic compounds.[[17]](https://en.wikipedia.org/wiki/Vanadium#cite_note-Ullmann-17)

The [vanadium redox battery](https://en.wikipedia.org/wiki/Vanadium_redox_battery) utilizes all four oxidation states; one electrode uses the +5/+4 couple and the other uses the +3/+2 couple. Conversion of these oxidation states is illustrated by the reduction of a strongly acidic solution of a vanadium(V) compound with zinc dust or amalgam. The initial yellow color characteristic of the pervanadyl ion [VO2(H2O)4]+ is replaced by the blue color of [VO(H2O)5]2+, followed by the green color of [V(H2O)6]3+ and then the violet color of [V(H2O)6]2+.[[15]](https://en.wikipedia.org/wiki/Vanadium#cite_note-HollemanAF-15)

**Oxyanions**

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

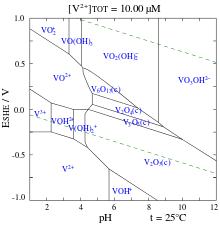
The [decavanadate](https://en.wikipedia.org/wiki/Decavanadate) structure

In aqueous solution, vanadium(V) forms an extensive family of [oxyanions](https://en.wikipedia.org/wiki/Oxyanion). The interrelationships in this family are described by the [predominance diagram](https://en.wikipedia.org/wiki/Predominance_diagram), which shows at least 11 species, depending on pH and concentration.[[18]](https://en.wikipedia.org/wiki/Vanadium#cite_note-18) The tetrahedral orthovanadate ion, VO3−  
4, is the principal species present at pH 12-14. Similar in size and charge to phosphorus(V), vanadium(V) also parallels its chemistry and crystallography. [Orthovanadate](https://en.wikipedia.org/wiki/Sodium_orthovanadate) VO3−  
4 is used in [protein crystallography](https://en.wikipedia.org/wiki/Protein_crystallography)[[19]](https://en.wikipedia.org/wiki/Vanadium#cite_note-19) to study the [biochemistry](https://en.wikipedia.org/wiki/Biochemistry) of phosphate.[[20]](https://en.wikipedia.org/wiki/Vanadium#cite_note-20) The tetrathiovanadate [VS4]3− is analogous to the orthovanadate ion.[[21]](https://en.wikipedia.org/wiki/Vanadium#cite_note-21)

At lower pH values, the monomer [HVO4]2− and dimer [V2O7]− are formed, with the monomer predominant at vanadium concentration of less than c. 10−2M (pV > 2, where pV is equal to the minus value of the logarithm of the total vanadium concentration/M). The formation of the divanadate ion is analogous to the formation of the [dichromate](https://en.wikipedia.org/wiki/Dichromate) ion. As the pH is reduced, further protonation and condensation to [polyvanadates](https://en.wikipedia.org/wiki/Vanadate) occur: at pH 4-6 [H2VO4]− is predominant at pV greater than ca. 4, while at higher concentrations trimers and tetramers are formed. Between pH 2-4 [decavanadate](https://en.wikipedia.org/wiki/Decavanadate) predominates, its formation from orthovanadate is represented by this condensation reaction:

10 [VO4]3− + 24 H+ → [V10O28]6− + 12 H2O

In decavanadate, each V(V) center is surrounded by six oxide [ligands](https://en.wikipedia.org/wiki/Ligand).[[15]](https://en.wikipedia.org/wiki/Vanadium#cite_note-HollemanAF-15) Vanadic acid, H3VO4 exists only at very low concentrations because protonation of the tetrahedral species [H2VO4]− results in the preferential formation of the octahedral [VO2(H2O)4]+ species. In strongly acidic solutions, pH<2. [VO2(H2O)4]+ is the predominant species, while the oxide V2O5 precipitates from solution at high concentrations. The oxide is formally the [acid anhydride](https://en.wikipedia.org/wiki/Acidic_oxide) of vanadic acid. The structures of many [vanadate](https://en.wikipedia.org/wiki/Vanadate) compounds have been determined by X-ray crystallography.

[](https://en.wikipedia.org/wiki/File:VinwaterPourbaixdiagram2.svg)

The [Pourbaix diagram](https://en.wikipedia.org/wiki/Pourbaix_diagram) for vanadium in water

The [Pourbaix diagram](https://en.wikipedia.org/wiki/Pourbaix_diagram) for vanadium in water, which shows the [redox](https://en.wikipedia.org/wiki/Redox) potentials between various vanadium species in different oxidation states, is also complex.[[22]](https://en.wikipedia.org/wiki/Vanadium#cite_note-22)

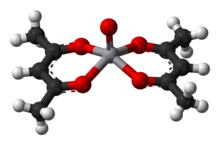
Vanadium(V) forms various peroxo complexes, most notably in the active site of the vanadium-containing [bromoperoxidase](https://en.wikipedia.org/wiki/Bromoperoxidase) enzymes. The species VO(O)2(H2O)4+ is stable in acidic solutions. In alkaline solutions, species with 2, 3 and 4 peroxide groups are known; the last forms violet salts with the formula M3V(O2)4 nH2O (M= Li, Na, etc.), in which the vanadium has an 8-coordinate dodecahedral structure.[[23]](https://en.wikipedia.org/wiki/Vanadium#cite_note-23)[[24]](https://en.wikipedia.org/wiki/Vanadium#cite_note-24)

**Halide derivatives**

Twelve binary [halides](https://en.wikipedia.org/wiki/Halides), compounds with the formula VXn (n=2..5), are known. VI4, VCl5, VBr5, and VI5 do not exist or are extremely unstable. In combination with other reagents, [VCl4](https://en.wikipedia.org/wiki/Vanadium(IV)_chloride) is used as a catalyst for polymerization of [dienes](https://en.wikipedia.org/wiki/Diene). Like all binary halides, those of vanadium are [Lewis acidic](https://en.wikipedia.org/wiki/Lewis_acid), especially those of V(IV) and V(V). Many of the halides form octahedral complexes with the formula VX*n*L6−*n* (X= halide; L= other ligand).

Many vanadium [oxyhalides](https://en.wikipedia.org/wiki/Oxyhalide) (formula VOmXn) are known.[[25]](https://en.wikipedia.org/wiki/Vanadium#cite_note-25) The oxytrichloride and oxytrifluoride ([VOCl3](https://en.wikipedia.org/wiki/Vanadium_oxytrichloride) and [VOF3](https://en.wikipedia.org/w/index.php?title=Vanadium_oxytrifluoride&action=edit&redlink=1)) are the most widely studied. Akin to POCl3, they are volatile, adopt tetrahedral structures in the gas phase, and are Lewis acidic.

**Coordination compounds**

[](https://en.wikipedia.org/wiki/File:Vanadyl-acetylacetonate-from-xtal-3D-balls.png)

A [ball-and-stick model](https://en.wikipedia.org/wiki/Ball-and-stick_model) of VO5(C5H7)2

Complexes of vanadium(II) and (III) are relatively exchange inert and reducing. Those of V(IV) and V(V) are oxidants. Vanadium ion is rather large and some complexes achieve coordination numbers greater than 6, as is the case in [V(CN)7]4−. Oxovanadium(V) also forms 7 coordinate coordination complexes with tetradentate ligands and peroxides and these complexes are used for oxidative brominations and thioether oxidations. The coordination chemistry of V4+ is dominated by the [vanadyl](https://en.wikipedia.org/wiki/Vanadyl) center, VO2+, which binds four other ligands strongly and one weakly (the one trans to the vanadyl center). An example is [vanadyl acetylacetonate](https://en.wikipedia.org/wiki/Vanadyl_acetylacetonate) (V(O)(O2C5H7)2). In this complex, the vanadium is 5-coordinate, square pyramidal, meaning that a sixth ligand, such as pyridine, may be attached, though the [association constant](https://en.wikipedia.org/wiki/Association_constant) of this process is small. Many 5-coordinate vanadyl complexes have a trigonal bypyramidal geometry, such as VOCl2(NMe3)2.[[26]](https://en.wikipedia.org/wiki/Vanadium#cite_note-26) The coordination chemistry of V5+ is dominated by the relatively stable dioxovanadium coordination complexes which are often formed by aerial oxidation of the vanadium(IV) precursors indicating the stability of the +5 oxidation state and ease of interconversion between the +4 and +5 states.

**Organometallic compounds**

Main article: [Organovanadium chemistry](https://en.wikipedia.org/wiki/Organovanadium_chemistry)

Organometallic chemistry of vanadium is well developed, although it has mainly only academic significance. [Vanadocene dichloride](https://en.wikipedia.org/wiki/Vanadocene_dichloride) is a versatile starting reagent and even finds some applications in organic chemistry.[[27]](https://en.wikipedia.org/wiki/Vanadium#cite_note-wilkinson-27) [Vanadium carbonyl](https://en.wikipedia.org/wiki/Vanadium_carbonyl), V(CO)6, is a rare example of a paramagnetic [metal carbonyl](https://en.wikipedia.org/wiki/Metal_carbonyl). Reduction yields V(CO)−  
6 ([isoelectronic](https://en.wikipedia.org/wiki/Isoelectronic) with [Cr(CO)6](https://en.wikipedia.org/wiki/Hexacarbonylchromium)), which may be further reduced with sodium in liquid ammonia to yield V(CO)3−  
5 (isoelectronic with Fe(CO)5).[[28]](https://en.wikipedia.org/wiki/Vanadium#cite_note-28)[[29]](https://en.wikipedia.org/wiki/Vanadium#cite_note-29)

**Occurrence**

[](https://en.wikipedia.org/wiki/File:Vanadinite,_goethite(2).jpg)

[Vanadinite](https://en.wikipedia.org/wiki/Vanadinite)

**Universe**

The [cosmic abundance](https://en.wikipedia.org/wiki/Abundance_of_the_chemical_elements#Abundance_of_elements_in_the_Universe) of vanadium in the universe is 0.0001%, making the element nearly as common as [copper](https://en.wikipedia.org/wiki/Copper) or [zinc](https://en.wikipedia.org/wiki/Zinc).[[30]](https://en.wikipedia.org/wiki/Vanadium#cite_note-Dieter-30) Vanadium is detected [spectroscopically](https://en.wikipedia.org/wiki/Optical_spectrometer) in light from the [Sun](https://en.wikipedia.org/wiki/Sun) and sometimes in the light from other [stars](https://en.wikipedia.org/wiki/Star).[[31]](https://en.wikipedia.org/wiki/Vanadium#cite_note-31)

**Earth's crust**

See also: [Category:Vanadate minerals](https://en.wikipedia.org/wiki/Category:Vanadate_minerals).

Vanadium is the 20th most abundant element in the earth's crust;[[32]](https://en.wikipedia.org/wiki/Vanadium#cite_note-32) metallic vanadium is rare in nature (known as the mineral vanadium, [native vanadium](https://en.wikipedia.org/wiki/Native_vanadium)),[[33]](https://en.wikipedia.org/wiki/Vanadium#cite_note-33)[[34]](https://en.wikipedia.org/wiki/Vanadium#cite_note-34) but vanadium compounds occur naturally in about 65 different [minerals](https://en.wikipedia.org/wiki/Mineral).

At the beginning of the 20th century a large deposit of vanadium ore was discovered. For several years this [patrónite](https://en.wikipedia.org/wiki/Patr%C3%B3nite) (VS4)[[35]](https://en.wikipedia.org/wiki/Vanadium#cite_note-35) deposit was a economically significant source for vanadium ore. With the production of radium in the 1910s and 1920s from [carnotite](https://en.wikipedia.org/wiki/Carnotite) (K2(UO2)2(VO4)2·3H2O) vanadium became available as a side product of radium and uranium production. [Vanadinite](https://en.wikipedia.org/wiki/Vanadinite) (Pb5(VO4)3Cl) and other vanadium bearing minerals are only mined in exceptional cases. With the rising demand, now much of the world's vanadium production is sourced from vanadium-bearing [magnetite](https://en.wikipedia.org/wiki/Magnetite) found in [ultramafic](https://en.wikipedia.org/wiki/Ultramafic) [gabbro](https://en.wikipedia.org/wiki/Gabbro) bodies. If this [titanomagnetite](https://en.wikipedia.org/wiki/Titanomagnetite) is used to produce iron most of the vanadium is ending in the [slag](https://en.wikipedia.org/wiki/Slag) and is extracted from there.[[36]](https://en.wikipedia.org/wiki/Vanadium#cite_note-36)[[37]](https://en.wikipedia.org/wiki/Vanadium#cite_note-37)

Vanadium is mined mostly in [South Africa](https://en.wikipedia.org/wiki/South_Africa), north-western [China](https://en.wikipedia.org/wiki/China), and eastern [Russia](https://en.wikipedia.org/wiki/Russia). In 2013 these three countries mined more than 97% of the 79,000 [tonnes](https://en.wikipedia.org/wiki/Tonne) of produced vanadium.[[38]](https://en.wikipedia.org/wiki/Vanadium#cite_note-38)

Vanadium is also present in [bauxite](https://en.wikipedia.org/wiki/Bauxite) and in deposits of [crude oil](https://en.wikipedia.org/wiki/Crude_oil), [coal](https://en.wikipedia.org/wiki/Coal), [oil shale](https://en.wikipedia.org/wiki/Oil_shale), and [tar sands](https://en.wikipedia.org/wiki/Tar_sand). In crude oil, concentrations up to 1200 ppm have been reported. When such oil products are burned, traces of vanadium may cause [corrosion](https://en.wikipedia.org/wiki/Corrosion) in engines and boilers.[[39]](https://en.wikipedia.org/wiki/Vanadium#cite_note-39) An estimated 110,000 tonnes of vanadium per year are released into the atmosphere by burning fossil fuels.[[40]](https://en.wikipedia.org/wiki/Vanadium#cite_note-40)

**Water**

The [vanadyl ion](https://en.wikipedia.org/wiki/Vanadyl_ion) is abundant in [seawater](https://en.wikipedia.org/wiki/Seawater), having an average concentration of 30 [nM](https://en.wikipedia.org/wiki/Molar_concentration#Units).[[30]](https://en.wikipedia.org/wiki/Vanadium#cite_note-Dieter-30) Some [mineral water](https://en.wikipedia.org/wiki/Mineral_water) [springs](https://en.wikipedia.org/wiki/Spring_(hydrology)) also contain the ion in high concentrations. For example, springs near [Mount Fuji](https://en.wikipedia.org/wiki/Mount_Fuji) contain as much as 54 [μg](https://en.wikipedia.org/wiki/Microgram) per [liter](https://en.wikipedia.org/wiki/Liter).[[30]](https://en.wikipedia.org/wiki/Vanadium#cite_note-Dieter-30)

**Production**

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

Vacuum sublimed vanadium [dendritic](https://en.wikipedia.org/wiki/Dendrite_(crystal)) crystals (99.9%)

[](https://en.wikipedia.org/wiki/File:Vanadium_crystal_bar_and_1cm3_cube.jpg)

[Crystal-bar](https://en.wikipedia.org/wiki/Crystal_bar_process) vanadium, showing different textures and surface oxidation; 99.95%-pure cube for comparison

Vanadium metal is obtained by a multistep process that begins with the roasting of crushed ore with [NaCl](https://en.wikipedia.org/wiki/Sodium_chloride) or [Na2CO3](https://en.wikipedia.org/wiki/Sodium_carbonate) at about 850 °C to give [sodium metavanadate](https://en.wikipedia.org/wiki/Sodium_metavanadate) (NaVO3). An aqueous extract of this solid is acidified to give "red cake", a polyvanadate salt, which is reduced with [calcium](https://en.wikipedia.org/wiki/Calcium) metal. As an alternative for small-scale production, vanadium pentoxide is reduced with [hydrogen](https://en.wikipedia.org/wiki/Hydrogen) or [magnesium](https://en.wikipedia.org/wiki/Magnesium). Many other methods are also in use, in all of which vanadium is produced as a [byproduct](https://en.wikipedia.org/wiki/Byproduct) of other processes.[[41]](https://en.wikipedia.org/wiki/Vanadium#cite_note-Moskalyk-41) Purification of vanadium is possible by the [crystal bar process](https://en.wikipedia.org/wiki/Crystal_bar_process) developed by [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) in 1925. It involves the formation of the metal iodide, in this example [vanadium(III) iodide](https://en.wikipedia.org/wiki/Vanadium(III)_iodide), and the subsequent decomposition to yield pure metal:[[42]](https://en.wikipedia.org/wiki/Vanadium#cite_note-42)

2 V + 3 I2 ⇌ 2 VI3

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

Ferrovanadium chunks

Most vanadium is used as a [steel](https://en.wikipedia.org/wiki/Steel) alloy called [ferrovanadium](https://en.wikipedia.org/wiki/Ferrovanadium). Ferrovanadium is produced directly by reducing a mixture of vanadium oxide, iron oxides and iron in an electric furnace. The vanadium ends up in [pig iron](https://en.wikipedia.org/wiki/Pig_iron) produced from vanadium-bearing magnetite. Depending on the ore used, the slag contains up to 25% of vanadium.[[41]](https://en.wikipedia.org/wiki/Vanadium#cite_note-Moskalyk-41)

**Applications**

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

Tool made from vanadium steel

**Alloys**

Approximately 85% of vanadium produced is used as [ferrovanadium](https://en.wikipedia.org/wiki/Ferroalloy#Ferrovanadium) or as a [steel](https://en.wikipedia.org/wiki/Steel) additive.[[41]](https://en.wikipedia.org/wiki/Vanadium#cite_note-Moskalyk-41) The considerable increase of strength in steel containing small amounts of vanadium was discovered in the early 20th century. Vanadium forms stable nitrides and carbides, resulting in a significant increase in the strength of steel.[[43]](https://en.wikipedia.org/wiki/Vanadium#cite_note-Chandler-43) From that time on, vanadium steel was used for applications in [axles](https://en.wikipedia.org/wiki/Axle), bicycle frames, [crankshafts](https://en.wikipedia.org/wiki/Crankshaft), gears, and other critical components. There are two groups of vanadium steel alloys. Vanadium high-carbon steel alloys contain 0.15% to 0.25% vanadium, and [high-speed tool steels](https://en.wikipedia.org/wiki/High-speed_steel) (HSS) have a vanadium content of 1% to 5%. For high-speed tool steels, a hardness above [HRC](https://en.wikipedia.org/wiki/Rockwell_hardness) 60 can be achieved. HSS steel is used in [surgical instruments](https://en.wikipedia.org/wiki/Surgical_instrument) and [tools](https://en.wikipedia.org/wiki/Tool).[[44]](https://en.wikipedia.org/wiki/Vanadium#cite_note-44) [Powder-metallurgic](https://en.wikipedia.org/wiki/Powder_metallurgy) alloys contain up to 18% percent vanadium. The high content of vanadium carbides in those alloys increases wear resistance significantly. One application for those alloys is tools and knives.[[45]](https://en.wikipedia.org/wiki/Vanadium#cite_note-45)

Vanadium stabilizes the beta form of titanium and increases the strength and temperature stability of titanium. Mixed with [aluminium](https://en.wikipedia.org/wiki/Aluminium) in [titanium](https://en.wikipedia.org/wiki/Titanium) alloys, it is used in [jet engines](https://en.wikipedia.org/wiki/Jet_engine), high-speed airframes and [dental implants](https://en.wikipedia.org/wiki/Dental_implant). The most common alloy for seamless tubing is [Titanium 3/2.5](https://en.wikipedia.org/wiki/Titanium_alloy#Grades_of_titanium) containing 2.5% vanadium, the titanium alloy of choice in the aerospace, defense, and bicycle industries.[[46]](https://en.wikipedia.org/wiki/Vanadium#cite_note-46) Another common alloy, primarily produced in sheets, is [Titanium 6AL-4V](https://en.wikipedia.org/wiki/Titanium_6AL-4V), a titanium alloy with 6% aluminium and 4% vanadium.[[47]](https://en.wikipedia.org/wiki/Vanadium#cite_note-47)

Several vanadium alloys show superconducting behavior. The first [A15 phase](https://en.wikipedia.org/wiki/A15_phase) superconductor was a vanadium compound, V3Si, which was discovered in 1952.[[48]](https://en.wikipedia.org/wiki/Vanadium#cite_note-48) [Vanadium-gallium](https://en.wikipedia.org/wiki/Vanadium-gallium) tape is used in [superconducting](https://en.wikipedia.org/wiki/Superconductivity) magnets (17.5 [teslas](https://en.wikipedia.org/wiki/Tesla_(unit)) or 175,000 [gauss](https://en.wikipedia.org/wiki/Gauss_(unit))). The structure of the superconducting A15 phase of V3Ga is similar to that of the more common [Nb3Sn](https://en.wikipedia.org/wiki/Niobium-tin) and [Nb3Ti](https://en.wikipedia.org/wiki/Niobium-titanium).[[49]](https://en.wikipedia.org/wiki/Vanadium#cite_note-49)

It has been proposed that a small amount, 40 to 270 ppm, of vanadium in [Wootz steel](https://en.wikipedia.org/wiki/Wootz_steel) and [Damascus steel](https://en.wikipedia.org/wiki/Damascus_steel) significantly improved the strength of the product, though the source of the vanadium is unclear.[[50]](https://en.wikipedia.org/wiki/Vanadium#cite_note-50)

**Other uses**

[](https://en.wikipedia.org/wiki/File:Vanadium(V)_oxide.jpg)

[Vanadium(V) oxide](https://en.wikipedia.org/wiki/Vanadium(V)_oxide) is a catalyst in the [contact process](https://en.wikipedia.org/wiki/Contact_process) for producing sulfuric acid

Vanadium compounds are used extensively as catalysts;[[51]](https://en.wikipedia.org/wiki/Vanadium#cite_note-51) for example, the most common oxide of vanadium, [vanadium pentoxide](https://en.wikipedia.org/wiki/Vanadium(V)_oxide) V2O5, is used as a [catalyst](https://en.wikipedia.org/wiki/Catalyst) in manufacturing sulfuric acid by the [contact process](https://en.wikipedia.org/wiki/Contact_process)[[52]](https://en.wikipedia.org/wiki/Vanadium#cite_note-52) and as an oxidizer in [maleic anhydride](https://en.wikipedia.org/wiki/Maleic_anhydride) production.[[53]](https://en.wikipedia.org/wiki/Vanadium#cite_note-53) Vanadium pentoxide is used in [ceramics](https://en.wikipedia.org/wiki/Ceramic).[[54]](https://en.wikipedia.org/wiki/Vanadium#cite_note-rubber-54) Vanadium is an important component of mixed metal oxide catalysts used in the oxidation of propane and propylene to acrolein, acrylic acid or the ammoxidation of propylene to acrylonitrile.[[55]](https://en.wikipedia.org/wiki/Vanadium#cite_note-55)[[56]](https://en.wikipedia.org/wiki/Vanadium#cite_note-56)[[57]](https://en.wikipedia.org/wiki/Vanadium#cite_note-57) In service, the oxidation state of vanadium changes dynamically and reversibly with the oxygen and the steam content of the reacting feed mixture.[[58]](https://en.wikipedia.org/wiki/Vanadium#cite_note-58)[[59]](https://en.wikipedia.org/wiki/Vanadium#cite_note-59) Another oxide of vanadium, [vanadium dioxide](https://en.wikipedia.org/wiki/Vanadium_dioxide) VO2, is used in the production of glass coatings, which blocks [infrared radiation](https://en.wikipedia.org/wiki/Infrared_radiation) (and not visible light) at a specific temperature.[[60]](https://en.wikipedia.org/wiki/Vanadium#cite_note-60) Vanadium oxide can be used to induce color centers in [corundum](https://en.wikipedia.org/wiki/Corundum) to create simulated [alexandrite](https://en.wikipedia.org/wiki/Alexandrite) jewelry, although alexandrite in nature is a [chrysoberyl](https://en.wikipedia.org/wiki/Chrysoberyl).[[61]](https://en.wikipedia.org/wiki/Vanadium#cite_note-61)

The [Vanadium redox battery](https://en.wikipedia.org/wiki/Vanadium_redox_battery), a type of [flow battery](https://en.wikipedia.org/wiki/Flow_battery), is an electrochemical cell consisting of aqueous vanadium ions in different oxidation states.[[62]](https://en.wikipedia.org/wiki/Vanadium#cite_note-62)[[63]](https://en.wikipedia.org/wiki/Vanadium#cite_note-RychcikSkyllas-Kazacos1988-63) Batteries of the type were first proposed in the 1930s and developed commercially from the 1980s onwards. Cells use +5 and +2 formal oxidization state ions. Vanadium redox batteries are used commercially for [grid energy storage](https://en.wikipedia.org/wiki/Grid_energy_storage).

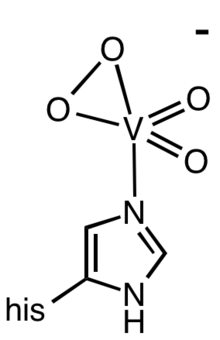
[Vanadate](https://en.wikipedia.org/wiki/Vanadate) can be used for protecting steel against rust and corrosion by [conversion coating](https://en.wikipedia.org/wiki/Conversion_coating).[[64]](https://en.wikipedia.org/wiki/Vanadium#cite_note-64) Vanadium foil is used in [cladding](https://en.wikipedia.org/wiki/Cladding_(metalworking)) titanium to steel because it is compatible with both iron and titanium.[[65]](https://en.wikipedia.org/wiki/Vanadium#cite_note-65) The moderate [thermal neutron-capture cross-section](https://en.wikipedia.org/wiki/Neutron_capture) and the short half-life of the isotopes produced by neutron capture makes vanadium a suitable material for the inner structure of a [fusion reactor](https://en.wikipedia.org/wiki/Fusion_reactor).[[66]](https://en.wikipedia.org/wiki/Vanadium#cite_note-66)[[67]](https://en.wikipedia.org/wiki/Vanadium#cite_note-67)

**Proposed**

Lithium vanadium oxide has been proposed for use as a high energy density anode for [lithium ion batteries](https://en.wikipedia.org/wiki/Lithium-ion_battery), at 745 Wh/L when paired with a [lithium cobalt oxide](https://en.wikipedia.org/wiki/Lithium_cobalt_oxide) cathode.[[68]](https://en.wikipedia.org/wiki/Vanadium#cite_note-68) Vanadium phosphates have been proposed as the cathode in the [lithium vanadium phosphate battery](https://en.wikipedia.org/wiki/Lithium_vanadium_phosphate_battery), another type of lithium-ion battery.[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)]

**Biological role**

Health benefits of vanadium and its potential as an anticancer agent have been reviewed.[[69]](https://en.wikipedia.org/wiki/Vanadium#cite_note-69) Vanadium is more important in marine environments than terrestrial.[[70]](https://en.wikipedia.org/wiki/Vanadium#cite_note-70)

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

Active site of the enzyme [vanadium bromoperoxidase](https://en.wikipedia.org/wiki/Vanadium_bromoperoxidase), which produces the preponderance of naturally-occurring [organobromine compounds](https://en.wikipedia.org/wiki/Organobromine_compound).

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

[Tunicates](https://en.wikipedia.org/wiki/Tunicate) such as this bluebell tunicate contain vanadium as [vanabin](https://en.wikipedia.org/wiki/Vanabin).

[](https://en.wikipedia.org/wiki/File:Amanita_muscaria_3_vliegenzwammen_op_rij.jpg)

[*Amanita muscaria*](https://en.wikipedia.org/wiki/Amanita_muscaria) contains [amavadin](https://en.wikipedia.org/wiki/Amavadin).

**Vanadoenzymes**

A number of species of marine [algae](https://en.wikipedia.org/wiki/Algae) produce [vanadium bromoperoxidase](https://en.wikipedia.org/wiki/Vanadium_bromoperoxidase) as well as the closely related [chloroperoxidase](https://en.wikipedia.org/wiki/Chloroperoxidase) (which may use a [heme](https://en.wikipedia.org/wiki/Heme) or vanadium cofactor) and [iodoperoxidases](https://en.wikipedia.org/w/index.php?title=Iodoperoxidase&action=edit&redlink=1). The bromoperoxidase produces an estimated 1–2 million tons of [bromoform](https://en.wikipedia.org/wiki/Bromoform) and 56,000 tons of [bromomethane](https://en.wikipedia.org/wiki/Bromomethane) annually.[[71]](https://en.wikipedia.org/wiki/Vanadium#cite_note-71) Most naturally occurring [organobromine compounds](https://en.wikipedia.org/wiki/Organobromine_compound) are produced by this enzyme,[[72]](https://en.wikipedia.org/wiki/Vanadium#cite_note-72) catalyzing the following reaction (R-H is hydrocarbon substrate):

R-H + Br− + H2O2 → R-Br + H2O + OH−

A [vanadium nitrogenase](https://en.wikipedia.org/wiki/Vanadium_nitrogenase) is used by some [nitrogen-fixing](https://en.wikipedia.org/wiki/Nitrogen_fixation) micro-organisms, such as [*Azotobacter*](https://en.wikipedia.org/wiki/Azotobacter). In this role, vanadium replaces more-common [molybdenum](https://en.wikipedia.org/wiki/Molybdenum) or [iron](https://en.wikipedia.org/wiki/Iron), and gives the [nitrogenase](https://en.wikipedia.org/wiki/Nitrogenase) slightly different properties.[[73]](https://en.wikipedia.org/wiki/Vanadium#cite_note-73)

**Vanadium accumulation in tunicates and ascidians**

Vanadium is essential to [ascidians](https://en.wikipedia.org/wiki/Ascidiacea) and [tunicates](https://en.wikipedia.org/wiki/Tunicate), where it is stored in the highly acidified [vacuoles](https://en.wikipedia.org/wiki/Vacuole) of certain blood cell types, designated "vanadocytes". [Vanabins](https://en.wikipedia.org/wiki/Vanabin) (vanadium binding proteins) have been identified in the cytoplasm of such cells. The concentration of vanadium in the blood of ascidians is as much as ten million times higher[[*specify*](https://en.wikipedia.org/wiki/Wikipedia:Citing_sources)][[74]](https://en.wikipedia.org/wiki/Vanadium#cite_note-74)[[75]](https://en.wikipedia.org/wiki/Vanadium#cite_note-75) than the surrounding seawater, which normally contains 1 to 2 µg/l.[[76]](https://en.wikipedia.org/wiki/Vanadium#cite_note-76)[[77]](https://en.wikipedia.org/wiki/Vanadium#cite_note-77) The function of this vanadium concentration system and these vanadium-bearing proteins is still unknown, but the vanadocytes are later deposited just under the outer surface of the tunic where they may deter [predation](https://en.wikipedia.org/wiki/Predation).[[78]](https://en.wikipedia.org/wiki/Vanadium#cite_note-78)

**Fungi**

[*Amanita muscaria*](https://en.wikipedia.org/wiki/Amanita_muscaria) and related species of macrofungi accumulate vanadium (up to 500 mg/kg in dry weight). Vanadium is present in the [coordination complex](https://en.wikipedia.org/wiki/Coordination_complex) [amavadin](https://en.wikipedia.org/wiki/Amavadin)[[79]](https://en.wikipedia.org/wiki/Vanadium#cite_note-79) in fungal fruit-bodies. The biological importance of the accumulation is unknown.[[80]](https://en.wikipedia.org/wiki/Vanadium#cite_note-80)[[81]](https://en.wikipedia.org/wiki/Vanadium#cite_note-81) Toxic or [peroxidase](https://en.wikipedia.org/wiki/Peroxidase) enzyme functions have been suggested.[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)]

**Mammals**

Deficiencies in vanadium result in reduced growth in rats.[[82]](https://en.wikipedia.org/wiki/Vanadium#cite_note-82) The U.S. Institute of Medicine has not confirmed that vanadium is an essential nutrient for humans, so neither a Recommended Dietary Intake nor an Adequate Intake have been established. Dietary intake is estimated at 6 to 18 µg/day, with less than 5% absorbed. The [Tolerable Upper Intake Level](https://en.wikipedia.org/wiki/Tolerable_upper_intake_level) (UL) of dietary vanadium, beyond which adverse effects may occur, is set at 1.8 mg/day.[[83]](https://en.wikipedia.org/wiki/Vanadium#cite_note-83)

**Research**

Vanadyl sulfate as a dietary supplement has been researched as a means of increasing insulin sensitivity or otherwise improving glycemic control in people who are diabetic. Some of the trials had significant treatment effects, but were deemed as being of poor study quality. The amounts of vanadium used in these trials (30 to 150 mg) far exceeded the safe upper limit.[[84]](https://en.wikipedia.org/wiki/Vanadium#cite_note-Smith2008-84)[[85]](https://en.wikipedia.org/wiki/Vanadium#cite_note-85) The conclusion of the systemic review was "There is no rigorous evidence that oral vanadium supplementation improves glycaemic control in type 2 diabetes. The routine use of vanadium for this purpose cannot be recommended."[[84]](https://en.wikipedia.org/wiki/Vanadium#cite_note-Smith2008-84)

In [astrobiology](https://en.wikipedia.org/wiki/Astrobiology), it has been suggested that discrete vanadium accumulations on [Mars](https://en.wikipedia.org/wiki/Mars) could be a potential microbial [biosignature](https://en.wikipedia.org/wiki/Biosignature), when used in conjunction with [Raman spectroscopy](https://en.wikipedia.org/wiki/Raman_spectroscopy) and morphology.[[86]](https://en.wikipedia.org/wiki/Vanadium#cite_note-Biosignature_Vanadium-86)[[87]](https://en.wikipedia.org/wiki/Vanadium#cite_note-Vanadium_Craig-87)

**Safety**

All vanadium compounds should be considered toxic. Tetravalent [VOSO4](https://en.wikipedia.org/wiki/Vanadyl_sulfate) has been reported to be at least 5 times more toxic than trivalent V2O3.[[88]](https://en.wikipedia.org/wiki/Vanadium#cite_note-88) The [Occupational Safety and Health Administration](https://en.wikipedia.org/wiki/Occupational_Safety_and_Health_Administration) (OSHA) has set an exposure limit of 0.05 mg/m3 for vanadium pentoxide dust and 0.1 mg/m3 for vanadium pentoxide fumes in workplace air for an 8-hour workday, 40-hour work week.[[89]](https://en.wikipedia.org/wiki/Vanadium#cite_note-OSHA-89) The [National Institute for Occupational Safety and Health](https://en.wikipedia.org/wiki/National_Institute_for_Occupational_Safety_and_Health) (NIOSH) has recommended that 35 mg/m3 of vanadium be considered immediately dangerous to life and health, that is, likely to cause permanent health problems or death.[[89]](https://en.wikipedia.org/wiki/Vanadium#cite_note-OSHA-89)

Vanadium compounds are poorly absorbed through the gastrointestinal system. Inhalation of vanadium and vanadium compounds results primarily in adverse effects on the respiratory system.[[90]](https://en.wikipedia.org/wiki/Vanadium#cite_note-90)[[91]](https://en.wikipedia.org/wiki/Vanadium#cite_note-ress-91)[[92]](https://en.wikipedia.org/wiki/Vanadium#cite_note-92) Quantitative data are, however, insufficient to derive a subchronic or chronic inhalation reference dose. Other effects have been reported after oral or inhalation exposures on blood parameters,[[93]](https://en.wikipedia.org/wiki/Vanadium#cite_note-93)[[94]](https://en.wikipedia.org/wiki/Vanadium#cite_note-94) liver,[[95]](https://en.wikipedia.org/wiki/Vanadium#cite_note-95) neurological development,[[96]](https://en.wikipedia.org/wiki/Vanadium#cite_note-96) and other organs[[97]](https://en.wikipedia.org/wiki/Vanadium#cite_note-97) in rats.

There is little evidence that vanadium or vanadium compounds are reproductive toxins or [teratogens](https://en.wikipedia.org/wiki/Teratogen). Vanadium pentoxide was reported to be carcinogenic in male rats and in male and female mice by inhalation in an NTP study,[[91]](https://en.wikipedia.org/wiki/Vanadium#cite_note-ress-91) although the interpretation of the results has recently been disputed.[[98]](https://en.wikipedia.org/wiki/Vanadium#cite_note-98) The carcinogenicity of vanadium has not been determined by the [United States Environmental Protection Agency](https://en.wikipedia.org/wiki/United_States_Environmental_Protection_Agency).[[99]](https://en.wikipedia.org/wiki/Vanadium#cite_note-99)

Vanadium traces in [diesel fuels](https://en.wikipedia.org/wiki/Diesel_fuel) are the main fuel component in [high temperature corrosion](https://en.wikipedia.org/wiki/High_temperature_corrosion). During combustion, vanadium oxidizes and reacts with sodium and sulfur, yielding [vanadate](https://en.wikipedia.org/wiki/Vanadate) compounds with melting points as low as 530 °C, which attack the [passivation layer](https://en.wikipedia.org/wiki/Passivation_(chemistry)) on steel and render it susceptible to corrosion. The solid vanadium compounds also abrade engine components.[[100]](https://en.wikipedia.org/wiki/Vanadium#cite_note-100)[[101]](https://en.wikipedia.org/wiki/Vanadium#cite_note-101)

**See also**

* [Flow battery](https://en.wikipedia.org/wiki/Flow_battery)
* [Green Giant mine](https://en.wikipedia.org/wiki/Green_Giant_mine)
* [Grid energy storage](https://en.wikipedia.org/wiki/Grid_energy_storage)
* [Vanadium carbide](https://en.wikipedia.org/wiki/Vanadium_carbide)
* [Vanadium redox battery](https://en.wikipedia.org/wiki/Vanadium_redox_battery)
* [Vanadium tetrachloride](https://en.wikipedia.org/wiki/Vanadium_tetrachloride)
* [Vanadium(V) oxide](https://en.wikipedia.org/wiki/Vanadium(V)_oxide)

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* [Dietary minerals](https://en.wikipedia.org/wiki/Category:Dietary_minerals)
* [Restorative dentistry](https://en.wikipedia.org/wiki/Category:Restorative_dentistry)
* [Transition metals](https://en.wikipedia.org/wiki/Category:Transition_metals)

**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=Vanadium)
* [Log in](https://en.wikipedia.org/w/index.php?title=Special:UserLogin&returnto=Vanadium)
* [Article](https://en.wikipedia.org/wiki/Vanadium)
* [Talk](https://en.wikipedia.org/wiki/Talk:Vanadium)
* [Read](https://en.wikipedia.org/wiki/Vanadium)
* [Edit](https://en.wikipedia.org/w/index.php?title=Vanadium&action=edit)
* [View history](https://en.wikipedia.org/w/index.php?title=Vanadium&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)

**Tools**

* [What links here](https://en.wikipedia.org/wiki/Special:WhatLinksHere/Vanadium)
* [Related changes](https://en.wikipedia.org/wiki/Special:RecentChangesLinked/Vanadium)
* [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=Vanadium&oldid=875843528)
* [Page information](https://en.wikipedia.org/w/index.php?title=Vanadium&action=info)
* [Wikidata item](https://www.wikidata.org/wiki/Special:EntityPage/Q722)
* [Cite this page](https://en.wikipedia.org/w/index.php?title=Special:CiteThisPage&page=Vanadium&id=875843528)

**Print/export**

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* [Español](https://es.wikipedia.org/wiki/Vanadio)
* [Français](https://fr.wikipedia.org/wiki/Vanadium)
* [한국어](https://ko.wikipedia.org/wiki/%EB%B0%94%EB%82%98%EB%93%90)
* [Italiano](https://it.wikipedia.org/wiki/Vanadio)
* [Русский](https://ru.wikipedia.org/wiki/%D0%92%D0%B0%D0%BD%D0%B0%D0%B4%D0%B8%D0%B9)
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[Edit links](https://www.wikidata.org/wiki/Special:EntityPage/Q722#sitelinks-wikipedia)

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* [Cookie statement](https://foundation.wikimedia.org/wiki/Cookie_statement)
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