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**Molybdenum**

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| --- | --- |
| Molybdenum,  42Mo | |
| [Molybdenum crystaline fragment and 1cm3 cube.jpg](https://en.wikipedia.org/wiki/File:Molybdenum_crystaline_fragment_and_1cm3_cube.jpg) | |
| **General properties** | |
| **Pronunciation** | [/məˈlɪbdənəm/](https://en.wikipedia.org/wiki/Help:IPA/English) ​([*mə-LIB-dən-əm*](https://en.wikipedia.org/wiki/Help:Pronunciation_respelling_key)) |
| **Appearance** | gray metallic |
| [**Standard atomic weight**](https://en.wikipedia.org/wiki/Standard_atomic_weight) **(*A*r, standard)** | 95.95(1)[[1]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-CIAAW2016-1) |
| **Molybdenum 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](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 | [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) | | [Cr](https://en.wikipedia.org/wiki/Chromium) ↑ **Mo** ↓ [W](https://en.wikipedia.org/wiki/Tungsten) | | [niobium](https://en.wikipedia.org/wiki/Niobium) ← **molybdenum** → [technetium](https://en.wikipedia.org/wiki/Technetium) | | | | |
| [**Atomic number**](https://en.wikipedia.org/wiki/Atomic_number)(*Z*) | 42 |
| [**Group**](https://en.wikipedia.org/wiki/Group_(periodic_table)) | [group 6](https://en.wikipedia.org/wiki/Group_6_element) |
| [**Period**](https://en.wikipedia.org/wiki/Period_(periodic_table)) | [period 5](https://en.wikipedia.org/wiki/Period_(periodic_table)#Period_5) |
| [**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) | [[Kr](https://en.wikipedia.org/wiki/Krypton)] 4d5 5s1 |
| Electrons per shell | 2, 8, 18, 13, 1 |
| **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) | 2896 [K](https://en.wikipedia.org/wiki/Kelvin) ​(2623 °C, ​4753 °F) |
| [**Boiling point**](https://en.wikipedia.org/wiki/Boiling_point) | 4912 K ​(4639 °C, ​8382 °F) |
| [**Density**](https://en.wikipedia.org/wiki/Density)(near r.t.) | 10.28 g/cm3 |
| when liquid (at m.p.) | 9.33 g/cm3 |
| [**Heat of fusion**](https://en.wikipedia.org/wiki/Enthalpy_of_fusion) | 37.48 [kJ/mol](https://en.wikipedia.org/wiki/Kilojoule_per_mole) |
| [**Heat of vaporization**](https://en.wikipedia.org/wiki/Enthalpy_of_vaporization) | 598 kJ/mol |
| [**Molar heat capacity**](https://en.wikipedia.org/wiki/Molar_heat_capacity) | 24.06 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) | 2742 | 2994 | 3312 | 3707 | 4212 | 4879 | | |
| **Atomic properties** | |
| [**Oxidation states**](https://en.wikipedia.org/wiki/Oxidation_state) | −4, −2, −1, +1,[[2]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-2) +2, +3, **+4**, +5, **+6** (a strongly [acidic](https://en.wikipedia.org/wiki/Acidic) oxide) |
| [**Electronegativity**](https://en.wikipedia.org/wiki/Electronegativity) | Pauling scale: 2.16 |
| [**Ionization energies**](https://en.wikipedia.org/wiki/Ionization_energy) | * 1st: 684.3 kJ/mol * 2nd: 1560 kJ/mol * 3rd: 2618 kJ/mol |
| [**Atomic radius**](https://en.wikipedia.org/wiki/Atomic_radius) | empirical: 139 [pm](https://en.wikipedia.org/wiki/Picometre) |
| [**Covalent radius**](https://en.wikipedia.org/wiki/Covalent_radius) | 154±5 pm |
| [Color lines in a spectral range](https://en.wikipedia.org/wiki/File:Molybdenum_spectrum_visible.png)  [**Spectral lines**](https://en.wikipedia.org/wiki/Spectral_line) **of molybdenum** | |
| **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 molybdenum](https://en.wikipedia.org/wiki/File:Cubic-body-centered.svg) |
| [**Speed of sound**](https://en.wikipedia.org/wiki/Speed_of_sound)thin rod | 5400 m/s (at r.t.) |
| [**Thermal expansion**](https://en.wikipedia.org/wiki/Coefficient_of_thermal_expansion) | 4.8 µm/(m·K) (at 25 °C) |
| [**Thermal conductivity**](https://en.wikipedia.org/wiki/Thermal_conductivity) | 138 W/(m·K) |
| [**Thermal diffusivity**](https://en.wikipedia.org/wiki/Thermal_diffusivity) | 54.3 mm2/s (at 300 K)[[3]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-3) |
| [**Electrical resistivity**](https://en.wikipedia.org/wiki/Electrical_resistivity_and_conductivity) | 53.4 nΩ·m (at 20 °C) |
| [**Magnetic ordering**](https://en.wikipedia.org/wiki/Magnetism) | [paramagnetic](https://en.wikipedia.org/wiki/Paramagnetic)[[4]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-4) |
| [**Magnetic susceptibility**](https://en.wikipedia.org/wiki/Magnetic_susceptibility) | +89.0·10−6 cm3/mol (298 K)[[5]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-5) |
| [**Young's modulus**](https://en.wikipedia.org/wiki/Young%27s_modulus) | 329 GPa |
| [**Shear modulus**](https://en.wikipedia.org/wiki/Shear_modulus) | 126 GPa |
| [**Bulk modulus**](https://en.wikipedia.org/wiki/Bulk_modulus) | 230 GPa |
| [**Poisson ratio**](https://en.wikipedia.org/wiki/Poisson%27s_ratio) | 0.31 |
| [**Mohs hardness**](https://en.wikipedia.org/wiki/Mohs_scale_of_mineral_hardness) | 5.5 |
| [**Vickers hardness**](https://en.wikipedia.org/wiki/Vickers_hardness_test) | 1400–2740 MPa |
| [**Brinell hardness**](https://en.wikipedia.org/wiki/Brinell_hardness_test) | 1370–2500 MPa |
| [**CAS Number**](https://en.wikipedia.org/wiki/CAS_Registry_Number) | 7439-98-7 |
| **History** | |
| [**Discovery**](https://en.wikipedia.org/wiki/Timeline_of_chemical_element_discoveries) | [Carl Wilhelm Scheele](https://en.wikipedia.org/wiki/Carl_Wilhelm_Scheele) (1778) |
| **First isolation** | [Peter Jacob Hjelm](https://en.wikipedia.org/wiki/Peter_Jacob_Hjelm) (1781) |
| **Main** [**isotopes of molybdenum**](https://en.wikipedia.org/wiki/Isotopes_of_molybdenum) | |
| |  |  |  |  |  | | --- | --- | --- | --- | --- | | [**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) | | **92Mo** | 14.65% | [stable](https://en.wikipedia.org/wiki/Stable_isotope) | | | | **93Mo** | [syn](https://en.wikipedia.org/wiki/Synthetic_radioisotope) | 4×103 y | [ε](https://en.wikipedia.org/wiki/Electron_capture) | [93Nb](https://en.wikipedia.org/wiki/Niobium-93) | | **94Mo** | 9.19% | stable | | | | **95Mo** | 15.87% | stable | | | | **96Mo** | 16.67% | stable | | | | **97Mo** | 9.58% | stable | | | | **98Mo** | 24.29% | stable | | | | **99Mo** | syn | 65.94 h | [β−](https://en.wikipedia.org/wiki/Beta_emission) | [99mTc](https://en.wikipedia.org/wiki/Technetium-99#technetium-99m) | | [γ](https://en.wikipedia.org/wiki/Gamma_ray) | – | | **100Mo** | 9.74% | 7.8×1018 y | β−β− | [100Ru](https://en.wikipedia.org/wiki/Ruthenium-100) | | |
| * [view](https://en.wikipedia.org/wiki/Template:Infobox_molybdenum) * [talk](https://en.wikipedia.org/wiki/Template_talk:Infobox_molybdenum) * [edit](https://en.wikipedia.org/w/index.php?title=Template:Infobox_molybdenum&action=edit)   | [references](https://en.wikipedia.org/wiki/List_of_data_references_for_chemical_elements) | |

**Molybdenum** is a [chemical element](https://en.wikipedia.org/wiki/Chemical_element) with symbol **Mo** and [atomic number](https://en.wikipedia.org/wiki/Atomic_number) 42. The name is from [Neo-Latin](https://en.wikipedia.org/wiki/New_Latin) *molybdaenum*, from [Ancient Greek](https://en.wikipedia.org/wiki/Ancient_Greek) Μόλυβδος *molybdos*, meaning [lead](https://en.wikipedia.org/wiki/Lead), since its ores were confused with lead ores.[[7]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-CRCdescription-7) Molybdenum minerals have been known throughout history, but the element was discovered (in the sense of differentiating it as a new entity from the mineral salts of other metals) in 1778 by [Carl Wilhelm Scheele](https://en.wikipedia.org/wiki/Carl_Wilhelm_Scheele). The metal was first isolated in 1781 by [Peter Jacob Hjelm](https://en.wikipedia.org/wiki/Peter_Jacob_Hjelm).[[8]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-8)

Molybdenum does not occur naturally as a [free metal](https://en.wikipedia.org/wiki/Native_metal) on Earth; it is found only in various [oxidation states](https://en.wikipedia.org/wiki/Oxidation_state) in minerals. The free element, a silvery [metal](https://en.wikipedia.org/wiki/Metal) with a gray cast, has the [sixth-highest](https://en.wikipedia.org/wiki/List_of_elements_by_melting_point) [melting point](https://en.wikipedia.org/wiki/Melting_point) of any element. It readily forms hard, stable [carbides](https://en.wikipedia.org/wiki/Carbide) in [alloys](https://en.wikipedia.org/wiki/Alloy), and for this reason most of world production of the element (about 80%) is used in [steel](https://en.wikipedia.org/wiki/Steel) alloys, including high-strength alloys and [superalloys](https://en.wikipedia.org/wiki/Superalloy).

Most molybdenum compounds have low [solubility](https://en.wikipedia.org/wiki/Solubility) in water, but when molybdenum-bearing minerals contact [oxygen](https://en.wikipedia.org/wiki/Oxygen) and water, the resulting [molybdate](https://en.wikipedia.org/wiki/Molybdate) ion MoO2−  
4 is quite soluble. Industrially, molybdenum [compounds](https://en.wikipedia.org/wiki/Chemical_compound) (about 14% of world production of the element) are used in [high-pressure](https://en.wikipedia.org/wiki/High-pressure) and high-temperature applications as [pigments](https://en.wikipedia.org/wiki/Pigment) and [catalysts](https://en.wikipedia.org/wiki/Catalysis).

[Molybdenum-bearing enzymes](https://en.wikipedia.org/wiki/Category:Molybdenum_enzymes) are by far the most common bacterial catalysts for breaking the [chemical bond](https://en.wikipedia.org/wiki/Chemical_bond) in atmospheric molecular [nitrogen](https://en.wikipedia.org/wiki/Nitrogen) in the process of biological [nitrogen fixation](https://en.wikipedia.org/wiki/Nitrogen_fixation). At least 50 molybdenum enzymes are now known in bacteria, plants, and animals, although only bacterial and cyanobacterial enzymes are involved in nitrogen fixation. These [nitrogenases](https://en.wikipedia.org/wiki/Nitrogenase) contain molybdenum in a form different from other molybdenum enzymes, which all contain fully oxidized molybdenum in a [molybdenum cofactor](https://en.wikipedia.org/wiki/Molybdenum_cofactor). These various molybdenum cofactor enzymes are vital to the organisms, and molybdenum is an [essential element](https://en.wikipedia.org/wiki/Essential_element) for life in all higher [eukaryote](https://en.wikipedia.org/wiki/Eukaryote) organisms, though not in all bacteria.



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**Characteristics**

**Physical properties**

In its pure form, molybdenum is a silvery-grey metal with a [Mohs hardness](https://en.wikipedia.org/wiki/Mohs_scale_of_mineral_hardness) of 5.5, and a standard atomic weight of 95.95 g/mol.[[9]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-9)[[10]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-10) It has a [melting point](https://en.wikipedia.org/wiki/Melting_point) of 2,623 °C (4,753 °F); of the naturally occurring elements, only [tantalum](https://en.wikipedia.org/wiki/Tantalum), [osmium](https://en.wikipedia.org/wiki/Osmium), [rhenium](https://en.wikipedia.org/wiki/Rhenium), [tungsten](https://en.wikipedia.org/wiki/Tungsten), and [carbon](https://en.wikipedia.org/wiki/Carbon) have higher melting points.[[7]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-CRCdescription-7) It has one of the lowest coefficients of [thermal expansion](https://en.wikipedia.org/wiki/Thermal_expansion) among commercially used metals.[[11]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-nbb-11) The [tensile strength](https://en.wikipedia.org/wiki/Tensile_strength) of molybdenum wires increases about 3 times, from about 10 to 30 [GPa](https://en.wikipedia.org/wiki/Pascal_(unit)), when their diameter decreases from ~50–100 [nm](https://en.wikipedia.org/wiki/Nanometre) to 10 nm.[[12]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-12)

**Chemical properties**

Molybdenum is a [transition metal](https://en.wikipedia.org/wiki/Transition_metal) with an [electronegativity](https://en.wikipedia.org/wiki/Electronegativity) of 2.16 on the Pauling scale. It does not visibly react with oxygen or water at room temperature. Weak oxidation of molybdenum starts at 300 °C (572 °F); bulk oxidation occurs at temperatures above 600 °C, resulting in [molybdenum trioxide](https://en.wikipedia.org/wiki/Molybdenum_trioxide). Like many heavier transition metals, molybdenum shows little inclination to form a cation in aqueous solution, although the Mo3+ cation is known under carefully controlled conditions.[[13]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-13)

**Isotopes**

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

There are 35 known [isotopes](https://en.wikipedia.org/wiki/Isotopes) of molybdenum, ranging in [atomic mass](https://en.wikipedia.org/wiki/Atomic_mass) from 83 to 117, as well as four metastable [nuclear isomers](https://en.wikipedia.org/wiki/Nuclear_isomer). Seven isotopes occur naturally, with atomic masses of 92, 94, 95, 96, 97, 98, and 100. Of these naturally occurring isotopes, only molybdenum-100 is unstable.[[14]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Audi-14)

Molybdenum-98 is the most [abundant](https://en.wikipedia.org/wiki/Isotopic_abundance) isotope, comprising 24.14% of all molybdenum. Molybdenum-100 has a [half-life](https://en.wikipedia.org/wiki/Half-life) of about 1019 [y](https://en.wikipedia.org/wiki/Year) and undergoes [double beta decay](https://en.wikipedia.org/wiki/Double_beta_decay) into [ruthenium](https://en.wikipedia.org/wiki/Ruthenium)-100. Molybdenum isotopes with mass numbers from 111 to 117 all have half-lives of approximately 150 ns.[[14]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Audi-14)[[15]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-CRCisotopes-15) All unstable isotopes of molybdenum decay into isotopes of [niobium](https://en.wikipedia.org/wiki/Niobium), [technetium](https://en.wikipedia.org/wiki/Technetium), and [ruthenium](https://en.wikipedia.org/wiki/Ruthenium).[[15]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-CRCisotopes-15)

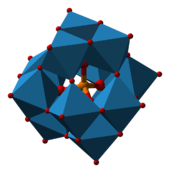
As also noted below, the most common isotopic molybdenum application involves [molybdenum-99](https://en.wikipedia.org/wiki/Molybdenum-99), which is a fission product. It is a parent radioisotope to the short-lived gamma-emitting daughter radioisotope [technetium-99m](https://en.wikipedia.org/wiki/Technetium-99m), a [nuclear isomer](https://en.wikipedia.org/wiki/Nuclear_isomer) used in various imaging applications in medicine.[[16]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-armstrong-16) In 2008, the [Delft University of Technology](https://en.wikipedia.org/wiki/Delft_University_of_Technology) applied for a patent on the molybdenum-98-based production of molybdenum-99.[[17]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-17)

**Compounds**

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

Molybdenum forms chemical compounds in oxidation states from -II to +VI. Higher oxidation states are more relevant to its terrestrial occurrence and its biological roles, mid-level oxidation states are often associated with [metal clusters](https://en.wikipedia.org/wiki/Metal_cluster), and very low oxidation states are typically associated with [organomolybdenum compounds](https://en.wikipedia.org/wiki/Organomolybdenum_compound). Mo and W chemistry shows strong similarities. The relative rarity of molybdenum(III), for example, contrasts with the pervasiveness of the chromium(III) compounds. The highest oxidation state is seen in [molybdenum(VI) oxide](https://en.wikipedia.org/wiki/Molybdenum(VI)_oxide) (MoO3), whereas the normal sulfur compound is [molybdenum disulfide](https://en.wikipedia.org/wiki/Molybdenum_disulfide) MoS2.[[18]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Holl-18)

|  |  |
| --- | --- |
| **Oxidation  state** | **Example**[**[19]**](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Schmidt-19) |
| −2 | Na 2[Mo 2(CO) 10] |
| 0 | [Mo(CO) 6](https://en.wikipedia.org/wiki/Molybdenum_hexacarbonyl) |
| +1 | Na[C 6H 6Mo] |
| +2 | [MoCl 2](https://en.wikipedia.org/wiki/Molybdenum(II)_chloride) |
| +3 | Na 3[Mo(CN)] 6 |
| **+4** | [MoS 2](https://en.wikipedia.org/wiki/Molybdenum_disulfide) |
| +5 | [MoCl 5](https://en.wikipedia.org/wiki/Molybdenum(V)_chloride) |
| **+6** | [MoF 6](https://en.wikipedia.org/wiki/Molybdenum(VI)_fluoride) |

[](https://en.wikipedia.org/wiki/File:Phosphotungstate-3D-polyhedra.png)

[Keggin structure](https://en.wikipedia.org/wiki/Keggin_structure) of the phosphomolybdate anion (P[Mo12O40]3−), an example of a [polyoxometalate](https://en.wikipedia.org/wiki/Polyoxometalate)

From the perspective of commerce, the most important compounds are molybdenum disulfide (MoS  
2) and molybdenum trioxide (MoO  
3). The black disulfide is the main mineral. It is roasted in air to give the trioxide:[[18]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Holl-18)

2 MoS  
2 + 7 O  
2 → 2 MoO  
3 + 4 SO  
2

The trioxide, which is volatile at high temperatures, is the precursor to virtually all other Mo compounds as well as alloys. Molybdenum has several [oxidation states](https://en.wikipedia.org/wiki/Oxidation_state), the most stable being +4 and +6 (bolded in the table at left).

Molybdenum(VI) oxide is soluble in strong [alkaline](https://en.wikipedia.org/wiki/Base_(chemistry)) water, forming molybdates (MoO42−). Molybdates are weaker oxidants than [chromates](https://en.wikipedia.org/wiki/Chromates). They tend to form structurally complex [oxyanions](https://en.wikipedia.org/wiki/Oxyanion) by condensation at lower [pH](https://en.wikipedia.org/wiki/PH) values, such as [Mo7O24]6− and [Mo8O26]4−. Polymolybdates can incorporate other ions, forming [polyoxometalates](https://en.wikipedia.org/wiki/Polyoxometalate).[[20]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-20) The dark-blue [phosphorus](https://en.wikipedia.org/wiki/Phosphorus)-containing heteropolymolybdate P[Mo12O40]3− is used for the [spectroscopic](https://en.wikipedia.org/wiki/Ultraviolet-visible_spectroscopy) detection of phosphorus.[[21]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-21) The broad range of [oxidation states](https://en.wikipedia.org/wiki/Oxidation_state) of molybdenum is reflected in various molybdenum chlorides:[[18]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Holl-18)

* [Molybdenum(II) chloride](https://en.wikipedia.org/wiki/Molybdenum(II)_chloride) MoCl2, which exists as the hexamer Mo6Cl12 and the related dianion [Mo6Cl14]2-.
* Molybdenum(III) chloride MoCl3, a dark red solid, which converts to the anion trianionic complex [MoCl6]3-.
* [Molybdenum(IV) chloride](https://en.wikipedia.org/wiki/Molybdenum_tetrachloride) MoCl4, a black solid, which adopts a polymeric structure.
* [Molybdenum(V) chloride](https://en.wikipedia.org/wiki/Molybdenum(V)_chloride) MoCl5 dark green solid that adopts a dimeric structure.

Molybdenum(VI) chloride MoCl6 is not known, although the [molybdenum hexafluoride](https://en.wikipedia.org/wiki/Molybdenum_hexafluoride) is well characterized.

Like [chromium](https://en.wikipedia.org/wiki/Chromium) and some other transition metals, molybdenum forms [quadruple bonds](https://en.wikipedia.org/wiki/Quadruple_bond), such as in Mo2(CH3COO)4 and [Mo2Cl8]4−, which also has a quadruple bond.[[18]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Holl-18)[[22]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-22)

The oxidation state 0 is possible with carbon monoxide as ligand, such as in [molybdenum hexacarbonyl](https://en.wikipedia.org/wiki/Molybdenum_hexacarbonyl), Mo(CO)6.[[18]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Holl-18)

**History**

[Molybdenite](https://en.wikipedia.org/wiki/Molybdenite)—the principal ore from which molybdenum is now extracted—was previously known as molybdena. Molybdena was confused with and often utilized as though it were [graphite](https://en.wikipedia.org/wiki/Graphite). Like graphite, molybdenite can be used to blacken a surface or as a solid lubricant.[[23]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Lansdown1999-23) Even when molybdena was distinguishable from graphite, it was still confused with the common [lead](https://en.wikipedia.org/wiki/Lead) ore PbS (now called [galena](https://en.wikipedia.org/wiki/Galena)); the name comes from [Ancient Greek](https://en.wikipedia.org/wiki/Ancient_Greek) Μόλυβδος *molybdos*, meaning *lead*.[[11]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-nbb-11) (The Greek word itself has been proposed as a [loanword](https://en.wikipedia.org/wiki/Loanword) from [Anatolian](https://en.wikipedia.org/wiki/Anatolian_languages) [Luvian](https://en.wikipedia.org/wiki/Luvian_language) and [Lydian](https://en.wikipedia.org/wiki/Lydian_language) languages).[[24]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-melchert-24)

Although (reportedly) molybdenum was deliberately alloyed with steel in one 14th-century Japanese sword (mfd. ca. 1330), that art was never employed widely and was later lost.[[25]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-25)[[26]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-26) In the West in 1754, [Bengt Andersson Qvist](https://en.wikipedia.org/wiki/Bengt_Andersson_Qvist) examined a sample of molybdenite and determined that it did not contain lead and thus was not galena.[[27]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-vanderkrogt-27)

By 1778 [Swedish](https://en.wikipedia.org/wiki/Sweden) chemist [Carl Wilhelm Scheele](https://en.wikipedia.org/wiki/Carl_Wilhelm_Scheele) stated firmly that molybdena was (indeed) neither galena nor graphite.[[28]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-elemental-28)[[29]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-29) Instead, Scheele correctly proposed that molybdena was an ore of a distinct new element, named *molybdenum* for the mineral in which it resided, and from which it might be isolated. [Peter Jacob Hjelm](https://en.wikipedia.org/wiki/Peter_Jacob_Hjelm) successfully isolated molybdenum using [carbon](https://en.wikipedia.org/wiki/Carbon) and [linseed oil](https://en.wikipedia.org/wiki/Linseed_oil) in 1781.[[11]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-nbb-11)[[30]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-30)

For the next century, molybdenum had no industrial use. It was relatively scarce, the pure metal was difficult to extract, and the necessary techniques of metallurgy were immature.[[31]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Hoyt1921-31)[[32]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Krupp1888-32)[[33]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Gupta1992-33) Early molybdenum steel alloys showed great promise of increased hardness, but efforts to manufacture the alloys on a large scale were hampered with inconsistent results, a tendency toward brittleness, and recrystallization. In 1906, [William D. Coolidge](https://en.wikipedia.org/wiki/William_D._Coolidge) filed a patent for rendering molybdenum [ductile](https://en.wikipedia.org/wiki/Ductility), leading to applications as a heating element for high-temperature furnaces and as a support for tungsten-filament light bulbs; oxide formation and degradation require that molybdenum be physically sealed or held in an inert gas.[[34]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-34) In 1913, [Frank E. Elmore](https://en.wikipedia.org/w/index.php?title=Frank_E._Elmore&action=edit&redlink=1) developed a [froth flotation process](https://en.wikipedia.org/wiki/Froth_flotation_process) to recover [molybdenite](https://en.wikipedia.org/wiki/Molybdenite) from ores; flotation remains the primary isolation process.[[35]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-35)

During [World War I](https://en.wikipedia.org/wiki/World_War_I), demand for molybdenum spiked; it was used both in [armor plating](https://en.wikipedia.org/wiki/Vehicle_armor) and as a substitute for tungsten in [high speed steels](https://en.wikipedia.org/wiki/High_speed_steel). Some British tanks were protected by 75 mm (3 in) [manganese steel](https://en.wikipedia.org/wiki/Mangalloy) plating, but this proved to be ineffective. The manganese steel plates were replaced with much lighter 25 mm (1.0 in) molybdenum steel plates allowing for higher speed, greater maneuverability, and better protection.[[11]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-nbb-11) The Germans also used molybdenum-doped [steel](https://en.wikipedia.org/wiki/Steel) for heavy artillery, like in the super-heavy howitzer [Big Bertha](https://en.wikipedia.org/wiki/Big_Bertha_(howitzer)),[[36]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-36) because traditional steel melts at the temperatures produced by the propellant of the [one ton](https://en.wikipedia.org/wiki/Ton) shell.[[37]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-37) After the war, demand plummeted until metallurgical advances allowed extensive development of peacetime applications. In [World War II](https://en.wikipedia.org/wiki/World_War_II), molybdenum again saw strategic importance as a substitute for tungsten in steel alloys.[[38]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Millholland1941-38)

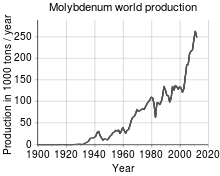
**Occurrence and production**

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

[Molybdenite](https://en.wikipedia.org/wiki/Molybdenite) on quartz

Molybdenum is the [54th most abundant element in the Earth's crust](https://en.wikipedia.org/wiki/Abundance_of_elements_in_Earth%27s_crust) and the 25th most abundant element in its oceans, with an average of 10 parts per billion; it is the 42nd most abundant element in the Universe.[[11]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-nbb-11)[[39]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Nostrand-39) The Russian [Luna 24](https://en.wikipedia.org/wiki/Luna_24) mission discovered a molybdenum-bearing grain (1 × 0.6 µm) in a [pyroxene](https://en.wikipedia.org/wiki/Pyroxene) fragment taken from [Mare Crisium](https://en.wikipedia.org/wiki/Mare_Crisium) on the [Moon](https://en.wikipedia.org/wiki/Moon).[[40]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-40) The comparative rarity of molybdenum in the Earth's crust is offset by its concentration in a number of water-insoluble ores, often combined with sulfur in the same way as copper, with which it is often found. Though molybdenum is found in such [minerals](https://en.wikipedia.org/wiki/Mineral) as [wulfenite](https://en.wikipedia.org/wiki/Wulfenite) (PbMoO4) and [powellite](https://en.wikipedia.org/wiki/Powellite) (CaMoO4), the main commercial source is [molybdenite](https://en.wikipedia.org/wiki/Molybdenite) (Mo[S](https://en.wikipedia.org/wiki/Sulfur)2). Molybdenum is mined as a principal ore and is also recovered as a byproduct of copper and tungsten mining.[[7]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-CRCdescription-7)

The world's production of molybdenum was 250,000 tonnes in 2011, the largest producers being China (94,000 t), the United States (64,000 t), Chile (38,000 t), Peru (18,000 t) and Mexico (12,000 t). The total reserves are estimated at 10 million tonnes, and are mostly concentrated in China (4.3 Mt), the US (2.7 Mt) and Chile (1.2 Mt). By continent, 93% of world molybdenum production is about evenly shared between North America, South America (mainly in Chile), and China. Europe and the rest of Asia (mostly Armenia, Russia, Iran and Mongolia) produce the remainder.[[41]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-USGS-41)

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

World production trend

In molybdenite processing, the ore is first roasted in air at a temperature of 700 °C (1,292 °F). The process gives gaseous sulfur dioxide and the [molybdenum(VI) oxide](https://en.wikipedia.org/wiki/Molybdenum(VI)_oxide):[[18]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Holl-18)

2 MoS2 + 7 O2 → 2 MoO3 + 4 SO2

The oxidized ore is then usually extracted with aqueous ammonia to give ammonium molybdate:

MoO3 + 2 NH3 + H2O → (NH4)2(MoO4)

Copper, an impurity in molybdenite, is less soluble in ammonia. To completely remove it from the solution, it is precipitated with [hydrogen sulfide](https://en.wikipedia.org/wiki/Hydrogen_sulfide).[[18]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Holl-18) Ammonium molybdate converts to [ammonium dimolybdate](https://en.wikipedia.org/wiki/Ammonium_dimolybdate), which is isolated as a solid. Heating this solid gives molybdenum trioxide:[[42]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-ullmann-42)

(NH4)2Mo2O7 → 2 MoO3 + 2 NH3 + H2O

Crude trioxide can be further purified by sublimation at 1,100 °C (2,010 °F).

Metallic molybdenum is produced by reduction of the oxide with hydrogen:

MoO3 + 3 H2 → Mo + 3 H2O

The molybdenum for steel production is reduced by the [aluminothermic reaction](https://en.wikipedia.org/wiki/Aluminothermic_reaction) with addition of iron to produce [ferromolybdenum](https://en.wikipedia.org/wiki/Ferromolybdenum). A common form of ferromolybdenum contains 60% molybdenum.[[18]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Holl-18)[[43]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-43)

Molybdenum had a value of approximately $30,000 per tonne as of August 2009. It maintained a price at or near $10,000 per tonne from 1997 through 2003, and reached a peak of $103,000 per tonne in June 2005.[[44]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-44) In 2008, the [London Metal Exchange](https://en.wikipedia.org/wiki/London_Metal_Exchange) announced that molybdenum would be traded as a commodity.[[45]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-45)

**History of molybdenum mining**

Historically, the [Knaben](https://en.wikipedia.org/wiki/Knaben) mine in southern Norway, opened in 1885, was the first dedicated molybdenum mine. It was closed in 1973 but was reopened in 2007.[[46]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-46) and now produces 100,000 kilograms (98 long tons; 110 short tons) of molybdenum disulfide per year. Large mines in Colorado (such as the [Henderson mine](https://en.wikipedia.org/wiki/Henderson_molybdenum_mine) and the [Climax mine](https://en.wikipedia.org/wiki/Climax_mine))[[47]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-47) and in British Columbia yield molybdenite as their primary product, while many [porphyry copper](https://en.wikipedia.org/wiki/Porphyry_copper) deposits such as the [Bingham Canyon Mine](https://en.wikipedia.org/wiki/Bingham_Canyon_Mine) in Utah and the [Chuquicamata](https://en.wikipedia.org/wiki/Chuquicamata) mine in northern Chile produce molybdenum as a byproduct of copper mining.

**Applications**

**Alloys**

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

A plate of molybdenum copper alloy

About 86% of molybdenum produced is used in [metallurgy](https://en.wikipedia.org/wiki/Metallurgy), with the rest used in chemical applications. The estimated global use is structural steel 35%, [stainless steel](https://en.wikipedia.org/wiki/Stainless_steel) 25%, chemicals 14%, tool & high-speed steels 9%, [cast iron](https://en.wikipedia.org/wiki/Cast_iron) 6%, molybdenum elemental metal 6%, and [superalloys](https://en.wikipedia.org/wiki/Superalloy) 5%.[[48]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-48)

Molybdenum can withstand extreme temperatures without significantly expanding or softening, making it useful in environments of intense heat, including military armor, aircraft parts, electrical contacts, industrial motors, and filaments.[[11]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-nbb-11)[[49]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-azom-49)

Most high-strength steel [alloys](https://en.wikipedia.org/wiki/Alloy) (for example, [41xx steels](https://en.wikipedia.org/wiki/41xx_steel)) contain 0.25% to 8% molybdenum.[[7]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-CRCdescription-7) Even in these small portions, more than 43,000 tonnes of molybdenum are used each year in [stainless steels](https://en.wikipedia.org/wiki/Stainless_steel), [tool steels](https://en.wikipedia.org/wiki/Tool_steel), cast irons, and high-temperature [superalloys](https://en.wikipedia.org/wiki/Superalloy).[[39]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Nostrand-39)

Molybdenum is also valued in steel alloys for its high [corrosion](https://en.wikipedia.org/wiki/Corrosion) resistance and [weldability](https://en.wikipedia.org/wiki/Weldability).[[39]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Nostrand-39)[[41]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-USGS-41) Molybdenum contributes corrosion resistance to type-300 stainless steels (specifically type-316) and especially so in the so-called super[austenitic](https://en.wikipedia.org/wiki/Austenitic) stainless steels (such as alloy [AL-6XN](https://en.wikipedia.org/wiki/AL-6XN), 254SMO and 1925hMo). Molybdenum increases lattice strain, thus increasing the energy required to dissolve iron atoms from the surface.[[*contradictory*](https://en.wikipedia.org/wiki/Category:Articles_contradicting_other_articles)] Molybdenum is also used to enhance the corrosion resistance of ferritic (for example grade 444) and martensitic (for example 1.4122 and 1.4418) stainless steels.[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)]

Because of its lower density and more stable price, molybdenum is sometimes used in place of tungsten.[[39]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Nostrand-39) An example is the 'M' series of high-speed steels such as M2, M4 and M42 as substitution for the 'T' steel series, which contain tungsten. Molybdenum can also be used as a flame-resistant coating for other metals. Although its melting point is 2,623 °C (4,753 °F), molybdenum rapidly oxidizes at temperatures above 760 °C (1,400 °F) making it better-suited for use in vacuum environments.[[49]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-azom-49)

TZM (Mo (~99%), Ti (~0.5%), Zr (~0.08%) and some C) is a corrosion-resisting molybdenum superalloy that resists molten fluoride salts at temperatures above 1,300 °C (2,370 °F). It has about twice the strength of pure Mo, and is more ductile and more weldable, yet in tests it resisted corrosion of a standard eutectic salt ([FLiBe](https://en.wikipedia.org/wiki/FLiBe)) and salt vapors used in [molten salt reactors](https://en.wikipedia.org/wiki/Molten_salt_reactor) for 1100 hours with so little corrosion that it was difficult to measure.[[50]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-50)[[51]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-51)

Other molybdenum-based alloys that do not contain iron have only limited applications. For example, because of its resistance to molten zinc, both pure molybdenum and molybdenum-[tungsten](https://en.wikipedia.org/wiki/Tungsten) alloys (70%/30%) are used for piping, stirrers and pump impellers that come into contact with molten zinc.[[52]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-52)

**Other applications as a pure element**

* Molybdenum powder is used as a fertilizer for some plants, such as cauliflower[[39]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Nostrand-39)
* Elemental molybdenum is used in NO, NO2, NOx analyzers in power plants for pollution controls. At 350 °C (662 °F), the element acts as a catalyst for NO2/NOx to form NO molecules for detection by infrared light.[[53]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-53)
* Molybdenum anodes replace tungsten in certain low voltage X-ray sources for specialized uses such as [mammography](https://en.wikipedia.org/wiki/Mammography)[[54]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-54)
* The radioactive isotope [molybdenum-99](https://en.wikipedia.org/wiki/Molybdenum-99) is used to generate [technetium-99m](https://en.wikipedia.org/wiki/Technetium-99m), used for medical imaging[[55]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-55) The isotope is handled and stored as the molybdate.[[56]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-56)

**Compounds (14% of global use)**

* [Molybdenum disulfide](https://en.wikipedia.org/wiki/Molybdenum_disulfide) (MoS2) is used as a solid lubricant and a high-pressure high-temperature (HPHT) anti-wear agent. It forms strong films on metallic surfaces and is a common additive to HPHT greases — in the event of a catastrophic grease failure, a thin layer of molybdenum prevents contact of the lubricated parts.[[57]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-57) It also has semiconducting properties with distinct advantages over traditional silicon or [graphene](https://en.wikipedia.org/wiki/Graphene) in electronics applications.[[58]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-physorg-58) MoS2 is also used as a catalyst in [hydrocracking](https://en.wikipedia.org/wiki/Hydrocracking) of petroleum fractions containing nitrogen, sulfur and oxygen.[[59]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-59)
* [Molybdenum disilicide](https://en.wikipedia.org/wiki/Molybdenum_disilicide) (MoSi2) is an electrically conducting [ceramic](https://en.wikipedia.org/wiki/Ceramic) with primary use in [heating elements](https://en.wikipedia.org/wiki/Heating_element) operating at temperatures above 1500 °C in air.[[60]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-60)
* [Molybdenum trioxide](https://en.wikipedia.org/wiki/Molybdenum_trioxide) (MoO3) is used as an adhesive between [enamels](https://en.wikipedia.org/wiki/Vitreous_enamel) and metals.[[28]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-elemental-28) [Lead molybdate](https://en.wikipedia.org/wiki/Lead_molybdate) (wulfenite) co-precipitated with lead chromate and lead sulfate is a bright-orange pigment used with ceramics and plastics.[[61]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-61)
* The molybdenum-based mixed oxides are versatile catalysts in the chemical industry. Some examples are the catalysts for the selective oxidation of propylene to acrolein and acrylic acid, the ammoxidation of propylene to acrylonitrile.[[62]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-62)[[63]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-63) Suitable catalysts and process for the direct selective oxidation of propane to acrylic acid are being researched.[[64]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-64)[[65]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-65)[[66]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-66)[[67]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-67)
* [Ammonium heptamolybdate](https://en.wikipedia.org/wiki/Ammonium_heptamolybdate) is used in biological staining.
* Molybdenum coated soda lime glass is used in CIGS ([copper indium gallium selenide](https://en.wikipedia.org/wiki/Copper_indium_gallium_selenide)) [solar cells](https://en.wikipedia.org/wiki/Solar_cell), called [CIGS solar cells](https://en.wikipedia.org/wiki/Copper_indium_gallium_selenide_solar_cells).
* [Phosphomolybdic acid](https://en.wikipedia.org/wiki/Phosphomolybdic_acid) is a stain used in [thin-layer chromatography](https://en.wikipedia.org/wiki/Thin-layer_chromatography).

**Biological role**

**Mo-containing enzymes**

Molybdenum is an essential element in most organisms. In fact a scarcity of molybdenum in the Earth's early oceans may have strongly influenced evolution of [eukaryotic life](https://en.wikipedia.org/wiki/Eukaryote) (which includes all plants and animals).[[68]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Scottetal-68)

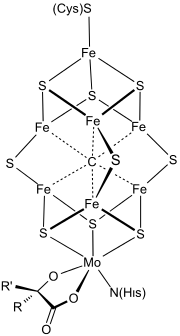
At least 50 molybdenum-containing enzymes have been identified, mostly in bacteria.[[69]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-69)[[70]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-70) those enzymes include [aldehyde oxidase](https://en.wikipedia.org/wiki/Aldehyde_oxidase), [sulfite oxidase](https://en.wikipedia.org/wiki/Sulfite_oxidase) and [xanthine oxidase](https://en.wikipedia.org/wiki/Xanthine_oxidase).[[11]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-nbb-11) With one exception, Mo in proteins is bound by [molybdopterin](https://en.wikipedia.org/wiki/Molybdopterin) to give the [molybdenum cofactor](https://en.wikipedia.org/wiki/Molybdenum_cofactor).[[71]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-71)

In terms of function, molybdoenzymes catalyze the oxidation and sometimes reduction of certain small molecules in the process of regulating [nitrogen](https://en.wikipedia.org/wiki/Nitrogen_cycle), [sulfur](https://en.wikipedia.org/wiki/Sulfur_cycle), and [carbon](https://en.wikipedia.org/wiki/Carbon_cycle).[[72]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-72) In some animals, and in humans, the oxidation of [xanthine](https://en.wikipedia.org/wiki/Xanthine) to [uric acid](https://en.wikipedia.org/wiki/Uric_acid), a process of [purine](https://en.wikipedia.org/wiki/Purine) [catabolism](https://en.wikipedia.org/wiki/Catabolism), is catalyzed by [xanthine oxidase](https://en.wikipedia.org/wiki/Xanthine_oxidase), a molybdenum-containing enzyme. The activity of xanthine oxidase is directly proportional to the amount of molybdenum in the body. However, an extremely high concentration of molybdenum reverses the trend and can act as an inhibitor in both purine catabolism and other processes. Molybdenum concentration also affects [protein synthesis](https://en.wikipedia.org/wiki/Protein_synthesis), [metabolism](https://en.wikipedia.org/wiki/Metabolism), and growth.[[73]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-IMOAoverview-73)

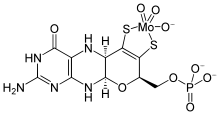
Mo is as a component in most [nitrogenases](https://en.wikipedia.org/wiki/Nitrogenase). Among molybdoenzymes, nitrogenases are unique in lacking the molybdopterin.[[74]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-74)[[75]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-75) Nitrogenases catalyze the production of ammonia from atmospheric nitrogen:

N 2 + 8   H + + 8   e − + 16   A T P + 16   H 2 O ⟶ 2   N H 3 + H 2 + 16   A D P + 16   P i {\displaystyle \mathrm {N\_{2}+8\ H^{+}+8\ e^{-}+16\ ATP+16\ H\_{2}O\longrightarrow 2\ NH\_{3}+H\_{2}+16\ ADP+16\ P\_{i}} }

The [biosynthesis](https://en.wikipedia.org/wiki/Biosynthesis) of the [FeMoco](https://en.wikipedia.org/wiki/FeMoco) [active site](https://en.wikipedia.org/wiki/Active_site) is highly complex.[[76]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-76)

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

Structure of the [FeMoco](https://en.wikipedia.org/wiki/FeMoco) active site of [nitrogenase](https://en.wikipedia.org/wiki/Nitrogenase).

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

The [molybdenum cofactor](https://en.wikipedia.org/wiki/Molybdenum_cofactor) (pictured) is composed of a molybdenum-free organic complex called [molybdopterin](https://en.wikipedia.org/wiki/Molybdopterin), which has bound an oxidized molybdenum(VI) atom through adjacent sulfur (or occasionally selenium) atoms. Except for the ancient nitrogenases, all known Mo-using enzymes use this cofactor.

Molybdate is transported in the body as MoO42−.[[73]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-IMOAoverview-73)

**Human metabolism and deficiency**

Molybdenum is an essential trace [dietary element](https://en.wikipedia.org/wiki/Dietary_element).[[77]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-77) Four mammalian Mo-dependent enzymes are known, all of them harboring a [pterin](https://en.wikipedia.org/wiki/Pterin)-based [molybdenum cofactor](https://en.wikipedia.org/wiki/Molybdenum_cofactor) (Moco) in their active site: [sulfite oxidase](https://en.wikipedia.org/wiki/Sulfite_oxidase), [xanthine oxidoreductase](https://en.wikipedia.org/wiki/Xanthine_oxidase), [aldehyde oxidase](https://en.wikipedia.org/wiki/Aldehyde_oxidase), and mitochondrial amidoxime reductase.[[78]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-78) People severely deficient in molybdenum have poorly functioning sulfite oxidase and are prone to toxic reactions to sulfites in foods.[[79]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-79)[[80]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-80) The human body contains about 0.07 mg of molybdenum per kilogram of body weight,[[81]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-81) with higher concentrations in the liver and kidneys and lower in the vertebrae.[[39]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Nostrand-39) Molybdenum is also present within human [tooth enamel](https://en.wikipedia.org/wiki/Tooth_enamel) and may help prevent its decay.[[82]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-82)

Acute toxicity has not been seen in humans, and the toxicity depends strongly on the chemical state. Studies on rats show a [median lethal dose](https://en.wikipedia.org/wiki/Median_lethal_dose) (LD50) as low as 180[mg/kg](https://en.wikipedia.org/w/index.php?title=Mg/kg&action=edit&redlink=1) for some Mo compounds.[[83]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-ORNL-83) Although human toxicity data is unavailable, animal studies have shown that chronic ingestion of more than 10 mg/day of molybdenum can cause diarrhea, growth retardation, [infertility](https://en.wikipedia.org/wiki/Infertility), low birth weight, and [gout](https://en.wikipedia.org/wiki/Gout); it can also affect the lungs, kidneys, and liver.[[84]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Coug-84)[[85]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-85) [Sodium tungstate](https://en.wikipedia.org/wiki/Sodium_tungstate) is a [competitive inhibitor](https://en.wikipedia.org/wiki/Competitive_inhibition) of molybdenum. Dietary tungsten reduces the concentration of molybdenum in tissues.[[39]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Nostrand-39)

Low soil concentration of molybdenum in a geographical band from northern China to Iran results in a general dietary [molybdenum deficiency](https://en.wikipedia.org/wiki/Molybdenum_deficiency), and is associated with increased rates of [esophageal cancer](https://en.wikipedia.org/wiki/Esophageal_cancer).[[86]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-86)[[87]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-87) Compared to the United States, which has a greater supply of molybdenum in the soil, people living in those areas have about 16 times greater risk for [esophageal](https://en.wikipedia.org/wiki/Esophageal_cancer) [squamous cell carcinoma](https://en.wikipedia.org/wiki/Squamous_cell_carcinoma).[[88]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-88)

Molybdenum deficiency has also been reported as a consequence of non-molybdenum supplemented [total parenteral nutrition](https://en.wikipedia.org/wiki/Total_parenteral_nutrition) (complete intravenous feeding) for long periods of time. It results in high blood levels of [sulfite](https://en.wikipedia.org/wiki/Sulfite) and [urate](https://en.wikipedia.org/wiki/Urate), in much the same way as [molybdenum cofactor deficiency](https://en.wikipedia.org/wiki/Molybdenum_cofactor_deficiency). However (presumably since pure molybdenum deficiency from this cause occurs primarily in adults), the neurological consequences are not as marked as in cases of congenital cofactor deficiency.[[89]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-89)

**Related diseases**

A congenital [molybdenum cofactor deficiency](https://en.wikipedia.org/wiki/Molybdenum_cofactor_deficiency) disease, seen in infants, is an inability to synthesize [molybdenum cofactor](https://en.wikipedia.org/wiki/Molybdenum_cofactor), the heterocyclic molecule discussed above that binds molybdenum at the active site in all known human enzymes that use molybdenum. The resulting deficiency results in high levels of [sulfite](https://en.wikipedia.org/wiki/Sulfite) and [urate](https://en.wikipedia.org/wiki/Urate), and neurological damage.[[90]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-90)[[91]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-91)

**Copper-molybdenum antagonism**

High levels of molybdenum can interfere with the body's uptake of [copper](https://en.wikipedia.org/wiki/Copper), producing [copper deficiency](https://en.wikipedia.org/wiki/Copper_deficiency). Molybdenum prevents plasma proteins from binding to copper, and it also increases the amount of copper that is excreted in [urine](https://en.wikipedia.org/wiki/Urine). [Ruminants](https://en.wikipedia.org/wiki/Ruminant) that consume high levels of molybdenum suffer from [diarrhea](https://en.wikipedia.org/wiki/Diarrhea), stunted growth, [anemia](https://en.wikipedia.org/wiki/Anemia), and [achromotrichia](https://en.wikipedia.org/wiki/Human_hair_color#Aging_or_achromotrichia) (loss of fur pigment). These symptoms can be alleviated by copper supplements, either dietary and injection.[[92]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-suttle-92) The effective copper deficiency can be aggravated by excess [sulfur](https://en.wikipedia.org/wiki/Sulfur).[[39]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Nostrand-39)[[93]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-93)

Copper reduction or deficiency can also be deliberately induced for therapeutic purposes by the compound [ammonium tetrathiomolybdate](https://en.wikipedia.org/wiki/Ammonium_tetrathiomolybdate), in which the bright red anion **tetrathiomolybdate** is the copper-chelating agent. Tetrathiomolybdate was first used therapeutically in the treatment of [copper toxicosis](https://en.wikipedia.org/wiki/Copper_toxicosis) in animals. It was then introduced as a treatment in [Wilson's disease](https://en.wikipedia.org/wiki/Wilson%27s_disease), a hereditary copper metabolism disorder in humans; it acts both by competing with copper absorption in the bowel and by increasing excretion. It has also been found to have an inhibitory effect on [angiogenesis](https://en.wikipedia.org/wiki/Angiogenesis), potentially by inhibiting the membrane translocation process that is dependent on copper ions.[[94]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-94) This is a promising avenue for investigation of treatments for [cancer](https://en.wikipedia.org/wiki/Cancer), [age-related macular degeneration](https://en.wikipedia.org/wiki/Age-related_macular_degeneration), and other diseases that involve a pathologic proliferation of blood vessels.[[95]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-95)[[96]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-96)

**Dietary recommendations**

In 2000, the then U.S. Institute of Medicine (now the [National Academy of Medicine](https://en.wikipedia.org/wiki/National_Academy_of_Medicine), NAM) updated its Estimated Average Requirements (EARs) and Recommended Dietary Allowances (RDAs) for molybdenum. If there is not sufficient information to establish EARs and RDAs, an estimate designated [Adequate Intake](https://en.wikipedia.org/wiki/Adequate_Intake) (AI) is used instead.

An AI of 2 [micrograms](https://en.wikipedia.org/wiki/Microgram) (μg) of molybdenum per day was established for infants up to 6 months of age, and 3 μg/day from 7 to 12 months of age, both for males and females. For older children and adults, the following daily RDAs have been established for molybdenum: 17 μg from 1 to 3 years of age, 22 μg from 4 to 8 years, 34 μg from 9 to 13 years, 43 μg from 14 to 18 years, and 45 μg for persons 19 years old and older. All these RDAs are valid for both sexes. [Pregnant](https://en.wikipedia.org/wiki/Pregnancy) or [lactating](https://en.wikipedia.org/wiki/Breastfeeding) females from 14 to 50 years of age have a higher daily RDA of 50 μg of molybdenum.

As for safety, the NAM sets [tolerable upper intake levels](https://en.wikipedia.org/wiki/Tolerable_upper_intake_level) (ULs) for vitamins and minerals when evidence is sufficient. In the case of molybdenum, the UL is 2000 μg/day. Collectively the EARs, RDAs, AIs and ULs are referred to as [Dietary Reference Intakes](https://en.wikipedia.org/wiki/Dietary_Reference_Intake) (DRIs).[[97]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-97)

The [European Food Safety Authority](https://en.wikipedia.org/wiki/European_Food_Safety_Authority) (EFSA) refers to the collective set of information as Dietary Reference Values, with Population Reference Intake (PRI) instead of RDA, and Average Requirement instead of EAR. AI and UL defined the same as in United States. For women and men ages 15 and older the AI is set at 65 μg/day. Pregnant and lactating women have the same AI. For children aged 1–14 years, the AIs increase with age from 15 to 45 μg/day. The adult AIs are higher than the U.S. RDAs,[[98]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-98) but on the other hand, the European Food Safety Authority reviewed the same safety question and set its UL at 600 μg/day, which is much lower than the U.S. value.[[99]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-99)

For U.S. food and dietary supplement labeling purposes, the amount in a serving is expressed as a percent of Daily Value (%DV). For molybdenum labeling purposes 100% of the Daily Value was 75 μg, but as of May 27, 2016 it was revised to 45 μg.[[100]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-FedReg-100) A table of the old and new adult Daily Values is provided at [Reference Daily Intake](https://en.wikipedia.org/wiki/Reference_Daily_Intake). The original deadline to be in compliance was July 28, 2018, but on September 29, 2017 the [Food and Drug Administration](https://en.wikipedia.org/wiki/Food_and_Drug_Administration) (FDA) released a proposed rule that extended the deadline to January 1, 2020 for large companies and January 1, 2021 for small companies.[[101]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-FDAdelay-101)

**Food sources**

Average daily intake varies between 120 and 240 μg/day, which is higher than dietary recommendations.[[84]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-Coug-84) Pork, lamb, and beef [liver](https://en.wikipedia.org/wiki/Liver) each have approximately 1.5 parts per million of molybdenum. Other significant dietary sources include green beans, eggs, sunflower seeds, wheat flour, lentils, cucumbers, and cereal grain.[[11]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-nbb-11)

**Precautions**

Molybdenum dusts and fumes, generated by mining or metalworking, can be toxic, especially if ingested (including dust trapped in the [sinuses](https://en.wikipedia.org/wiki/Paranasal_sinuses) and later swallowed).[[83]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-ORNL-83) Low levels of prolonged exposure can cause irritation to the eyes and skin. Direct inhalation or ingestion of molybdenum and its oxides should be avoided.[[102]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-102)[[103]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-103) [OSHA](https://en.wikipedia.org/wiki/Occupational_Safety_and_Health_Administration) regulations specify the maximum permissible molybdenum exposure in an 8-hour day as 5 mg/m3. Chronic exposure to 60 to 600 mg/m3 can cause symptoms including fatigue, headaches and joint pains.[[104]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-104) At levels of 5000 mg/m3, molybdenum is [immediately dangerous to life and health](https://en.wikipedia.org/wiki/IDLH).[[105]](https://en.wikipedia.org/wiki/Molybdenum#cite_note-105)

**See also**

* [List of molybdenum mines](https://en.wikipedia.org/wiki/List_of_molybdenum_mines)
* [Molybdenum mining in the United States](https://en.wikipedia.org/wiki/Molybdenum_mining_in_the_United_States)

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