What Are the Chemicals of Tungsten?

The Complete Family Tree of Tungsten Chemicals

钨的化学品有哪些？

钨的化学品全系族谱
（英文版）

中钨智造科技有限公司
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Chemical Safety Manual OSHA, Washington, D.C.
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Tungsten Chemical MSDS (Multilingual) ECHA, Helsinki
Latest Edition

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Major Industrial Standards for Tungsten Chemicals and Compounds in US

1. ASTM D7047-15 (Standard Test Method for Analysis of Tungstates)
2. ASTM E236-66 (2017) (Standard Specification for Chemical Analysis of Tungsten)
3. OSHA PEL (29 CFR 1910.1000) Occupational Exposure Limits

Main industrial standards for tungsten chemicals and compounds in the EU

1. EN 10204:2004 Metallic Products - Types of Inspection Documents
2. REACH Annex XVII (EC 1907/2006) Registration and Restriction of Tungsten

Main industrial standards for tungsten chemicals and compounds in Japan

1. JIS H 1404:2001 (Methods for Chemical Analysis of Tungsten)
2. JIS K 8962:2008 (Sodium Tungstate)

Main industrial standards for tungsten chemicals and compounds in South Korea

1. KS M 6891:2018 (Tungsten Oxides)
2. KS M 6893:2018 (Tungstates)

International Major Industrial Standards for Tungsten Chemicals and Compounds

1. ISO 11876:2010 Determination of Oxygen Content in Tungsten Powder
2. ISO 6892-1:2016 Metallic Materials - Chemical Analysis

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Data Sources:

Global Perspective:

China's Tungsten Chemical and Compound Standards

1. GB/T 10116-2007 Tungsten Trioxide
2. GB/T 23365-2009 Ammonium Paratungstate (APT)
3. HG/T 2959-2010 Sodium Tungstate
4. HG/T 2469-2010 Tungstic Acid
5. GBZ 2.1-2019 Occupational Exposure Limits for Hazardous Substances in Workplace

日本タングステン化学品及び化合物の主要工業規格

1. JIS H 1404:2001 タングステン化学品の分析 (Methods for Chemical Analysis of Tungsten)

2. JIS K 8962:2008 タングステン酸ナトリウム (Sodium Tungstate)

韓国タングステン化学品および化合物主要産業基準 (Translated into Korean)

1. KS M 6891:2018 텅스텐 산화물 (Tungsten Oxides)

2. KS M 6893:2018 텅스텐산염 (Tungstates)

List of Tungsten-Containing Compounds: CAS Numbers, Chemical Formulas, & Properties

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4. Drying and Post-Processing Equipment
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Sources of Information

Sources: *Chemical Safety Handbook* (English, OSHA), *MSDS Guide for Tungsten Chemicals* (Multilingual, ECHA), *Safety Production Technology* (Chinese, Chinatungsten Online)

Major Producers: China Minmetals, H.C. Starck (Germany), Kennametal (USA)

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A. Major Industrial Standards for Tungsten Chemicals

B. Table of Chemical Formulas and Properties of Tungsten-Containing Compounds

C. Specifications of Equipment for Tungsten Chemical Production

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Optical Properties of Tungsten (Japanese) - Toshiba Corporation Research Report, Tokyo, 2010

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MSDS Guide for Tungsten Chemicals (Multilingual) - European Chemicals Agency (ECHA), Helsinki, 2020
Safety Production Technology (Chinese) - Chinatungsten Online Editorial Department, Beijing, 2022
Non-Metallic Tungsten Compounds (Chinese) - Chinatungsten Online, Beijing, 2021

Websites

Chinatungsten Online: www.chinatungsten.com
China Tungsten Industry Association: www.ctia.com.cn
Chinatungsten Online WeChat Public Account: “Chinatungsten Online”
USGS Mineral Resources: www.usgs.gov

What Are the Chemicals of Tungsten?

Chapter 1: Overview of Tungsten

1.1 Discovery and History of Tungsten

Tungsten (W, Tungsten) (element symbol W) has a discovery and research history spanning several centuries, evolving from early unconscious use to systematic scientific exploration, reflecting humanity's gradual understanding of this high-melting-point metal. The following are the key milestones and events in the discovery and historical development of tungsten (W, Tungsten).

1.1.1 Brief History of Discovery

The discovery of tungsten (W, Tungsten) was not instantaneous but involved a prolonged process from mineral recognition to elemental isolation.

1.1.1.1 Initial Discovery by Swedish Chemist Cronstedt (1755, Swedish Literature)

In 1755, Swedish mineralogist Axel Fredrik Cronstedt, while studying the iron ore at Bispberg, Sweden, identified an unusually heavy white mineral. He named it "tungsten" (Swedish for "heavy stone"), later known as scheelite ($CaWO_4$, Scheelite). Cronstedt did not isolate the tungsten (W, Tungsten) element, but he noted the mineral's density far exceeded that of common minerals, recording its properties for the first time in Swedish literature [1]. This discovery marked the beginning of tungsten (W, Tungsten) entering the scientific domain.

Tip
At this time, “tungsten” referred solely to the mineral and was not recognized as containing a new element, with its chemical properties still unknown.

1.1.1.2 Scheele’s Isolation of Tungstic Acid (1781, German Literature)

In 1781, the renowned Swedish chemist Carl Wilhelm Scheele conducted an in-depth analysis of scheelite ($CaWO_4$, Scheelite). Using acid treatment (nitric acid), he extracted a white powdery substance from the mineral, which he named [tungstic acid (H_2WO_4, Tungstic Acid)](tungstic acid). Scheele detailed its chemical reaction properties in German literature and speculated it might be linked to an unknown metal [2]. His mentor, Torbern Bergman, suggested reducing tungstic acid (H_2WO_4, Tungstic Acid) with charcoal to produce the metal, but this was not achieved due to technological limitations.

Key Figure
Scheele, renowned for his exceptional chemical separation techniques, laid the groundwork for the eventual discovery of tungsten (W, Tungsten).

Tip
Tungstic acid (H_2WO_4, Tungstic Acid) became a crucial starting point for tungsten (W, Tungsten) chemical research, later serving as a key intermediate in producing other tungsten chemicals, such as tungsten trioxide.

1.1.1.3 Elhuyar Brothers' Purification of Tungsten Metal (1783, Spanish Literature)

In 1783, Spanish chemists Juan José Elhuyar and Fausto Elhuyar completed the isolation of tungsten (W, Tungsten) at the Vergara Seminary. They extracted tungstic acid (H_2WO_4, Tungstic Acid) from wolframite ((Fe,Mn)WO_4, Wolframite) and successfully reduced it with charcoal at high temperatures to produce metallic tungsten (W, Tungsten) powder. They named it "wolfram" in Spanish literature, derived from the German miners' term "wolf foam" for wolframite ((Fe,Mn)WO_4, Wolframite), due to its interference with tin smelting [3].

Key Figures

The Elhuyar brothers, pioneers in mineralogy and chemistry, formally established tungsten (W, Tungsten) as a distinct element.

Country
Spain holds a significant place in the history of tungsten (W, Tungsten) discovery.

Tip
This marked the first isolation of metallic tungsten (W, Tungsten), initiating the history of its applied research.

1.1.2 Naming and Multilingual Designations of Tungsten

The naming of tungsten (W, Tungsten) reflects its multicultural discovery. The Swedish term "tungsten" (heavy stone) originates from Cronstedt's description, emphasizing its high density, while the German and Spanish "wolfram" was coined by the Elhuyar brothers, rooted in the historical name of wolframite ((Fe,Mn)WO_4, Wolframite). Today, "tungsten" is the English and internationally accepted name (element symbol W), while "wolfram" remains widely used in German, Spanish, and other European languages. In Chinese, "钨" (tungsten) combines "金" (metal) and "乌" (black), symbolizing its metallic nature and dark appearance [4].

Tip

The multilingual naming variations highlight the international nature of tungsten (W, Tungsten) discovery, and procurement managers should be familiar with these terms for effective supplier communication in global trade.

1.1.3 Early Industrial Applications (19th Century, English and French Literature)

In the early 19th century, as the Industrial Revolution progressed, the properties of tungsten (W, Tungsten) began to gain recognition. In 1841, British chemist Robert Dickinson Oxland patented the production of [sodium tungstate (Na_2WO_4, Sodium Tungstate)](sodium tungstate), tungstic acid (H_2WO_4, Tungstic Acid), and tungsten (W, Tungsten) metal, marking an initial step toward industrializing tungsten (W, Tungsten) chemicals [5]. By 1847, sodium tungstate (Na_2WO_4, Sodium Tungstate) was used in dyeing cotton fabrics and fireproofing theatrical costumes, becoming one of the earliest industrial applications of tungsten (W, Tungsten) chemicals. These early efforts were documented in English and French literature, illustrating tungsten (W, Tungsten)'s transition from the laboratory to industry [6].

Tip

19th-century industrial applications laid the foundation for the commercialization of tungsten (W, Tungsten), particularly in the chemical sector, with uses like sodium tungstate (Na_2WO_4, Sodium Tungstate) for fireproofing still relevant today.

1.2 Natural Occurrence of Tungsten

Tungsten (W, Tungsten) primarily exists in nature as minerals, and its distribution and extraction are critical to the industrial production of tungsten (W, Tungsten) chemicals.

1.2.1 Types and Distribution of Global Tungsten Minerals

Tungsten (W, Tungsten) minerals are diverse, primarily including the following:

1.2.1.1 Wolframite

Wolframite ($(Fe,Mn)WO_4$, Wolframite) is an iron-manganese tungstate with a black or dark brown appearance, serving as one of the primary ores of tungsten (W, Tungsten). Named "wolfram," it earned the nickname "wolf foam" from German miners due to the foam it produced during tin smelting.

1.2.1.2 Scheelite

Scheelite ($CaWO_4$, Scheelite) is calcium tungstate, appearing white or pale yellow, and was dubbed “heavy stone” by Swedes due to its high density. It fluoresces blue under ultraviolet light and is commonly used to extract tungstic acid (H_2WO_4, Tungstic Acid).

1.2.1.3 Other Minor Tungsten Minerals (e.g., Hübnerite)

Other tungsten (W, Tungsten) minerals include hübnerite ($MnWO_4$, Hübnerite) and ferberite ($FeWO_4$, Ferberite), both variants of wolframite ($(Fe,Mn)WO_4$, Wolframite). These are less common but mined in specific regions like the United States and Bolivia.

Tip
Wolframite ($(Fe,Mn)WO_4$, Wolframite) and scheelite ($CaWO_4$, Scheelite) are the main raw materials for industrial production of [tungsten trioxide (WO_3, Tungsten Trioxide)](tungsten trioxide) and [ammonium paratungstate (APT, $(NH_4)_2WO_4$, Ammonium Paratungstate)](ammonium paratungstate), and procurement should focus on their grade and impurity content.

1.2.2 Major Producing Countries and Reserves

Tungsten (W, Tungsten) is a rare metal, with its reserves and production concentrated in a few countries:

1.2.2.1 China (Approximately 60% of Global Reserves)

China holds the world’s largest tungsten (W, Tungsten) reserves (approximately 1.9 million tons, accounting for about 60% of the global total) and production (around 80% of global output in 2023), with key mining areas in the Nanling region producing wolframite ($(Fe,Mn)WO_4$, Wolframite) and scheelite ($CaWO_4$, Scheelite) [7].

1.2.2.2 Russia, Vietnam, Canada, Australia, and Others

Russia (Far East, reserves around 250,000 tons), Vietnam (Nui Phao mine, a major global source of wolframite ($(Fe,Mn)WO_4$, Wolframite)), Canada (Cantung mine), and Australia (King Island mine) are also significant tungsten (W, Tungsten) producers, though their output is far below China’s [7].

1.2.3 Major Tungsten Mining Regions

Nanling, China
Including Ganzhou (Jiangxi) and Zhuzhou (Hunan), this is the world’s largest tungsten (W, Tungsten) mining belt, yielding wolframite ($(Fe,Mn)WO_4$, Wolframite) and scheelite ($CaWO_4$, Scheelite).

Russian Far East
Predominantly producing wolframite ((Fe,Mn)WO_4, Wolframite) for domestic and international markets.

Other Regions
Such as Bolivia (Llallagua mine) and Portugal (Panasqueira mine), where smaller-scale mining occurs.

Tip
China's dominance in tungsten (W, Tungsten) resources makes it the leading producer of ammonium paratungstate (APT, $(NH_4)_2WO_4$, Ammonium Paratungstate) and tungsten trioxide (WO_3, Tungsten Trioxide) globally, and procurement should consider export control policies (e.g., China's 2025 restrictions on tungsten compounds).

1.3 Physical and Chemical Properties of Tungsten

The unique physical and chemical properties of tungsten (W, Tungsten) make it highly valued in industry and research.

1.3.1 Physical Properties (Melting Point 3410°C, Density 19.25 g/cm³)

Tungsten (W, Tungsten) boasts the highest melting point (3410°C) and an extremely high density (19.25 g/cm³), surpassed only by a few precious metals. Its hardness (Mohs scale approximately 7.5) also exceeds that of most common metals. These properties were confirmed through experiments by early 19th-century scientists, such as Henry Cavendish in Britain and Joseph-Louis Proust in France [8].

Tip
Its high melting point makes tungsten (W, Tungsten) ideal for [tungsten carbide powder (WC, Tungsten Carbide Powder)](tungsten carbide powder) and [tungsten wire (W Wire, Tungsten Wire)](tungsten wire) used in high-temperature environments.

1.3.2 Chemical Properties (Oxidation States +2 to +6, Corrosion Resistance)

Tungsten (W, Tungsten) exhibits multiple oxidation states (+2 to +6), with +6 being the most stable, as seen in tungsten trioxide (WO_3, Tungsten Trioxide). It is highly resistant to acids and bases at room temperature but readily forms tungsten trioxide (WO_3, Tungsten Trioxide) in high-temperature oxidizing atmospheres. Russian chemist Dmitry Mendeleev confirmed its transitional metal characteristics in his periodic table studies [9].

Tip
Its corrosion resistance lends potential to tungstic acid (H_2WO_4, Tungstic Acid) and

sodium tungstate (Na_2WO_4, Sodium Tungstate) in chemical and medical applications.

1.3.3 Property Descriptions in Multilingual Literature (Russian, Japanese, Arabic, etc.)

Russian Literature

19th-century Russian scholars described the high hardness and heat resistance of tungsten (W, Tungsten), highlighting its metallurgical potential [10].

Japanese Literature

Early 20th-century Japanese researchers focused on the electrical conductivity of tungsten (W, Tungsten) in electronics, such as tungsten wire (W Wire, Tungsten Wire) [11].

Arabic Literature

Mineralogical records from the Middle East noted the high density of tungsten (W, Tungsten) ores [12].

Tip

Multilingual studies underscore the global interest in tungsten (W, Tungsten), and procurement can benefit from referencing national standards (e.g., Japan's JIS specifications for tungsten wire (W Wire, Tungsten Wire)).

1.4 Industrial and Scientific Value of Tungsten Chemicals

[Tungsten chemicals (W Chemicals, Tungsten Chemicals)](tungsten chemicals) are vital in industry and research due to their diversity and high performance.

1.4.1 Global Industrial Demand Overview

Tungsten (W, Tungsten) chemicals, such as tungsten trioxide (WO_3, Tungsten Trioxide), tungsten carbide powder (WC, Tungsten Carbide Powder), and ammonium paratungstate (APT, $(NH_4)_2WO_4$, Ammonium Paratungstate), are foundational raw materials in industrial production. According to data from the International Tungsten Industry Association (ITIA) and the U.S. Geological Survey (USGS), the global market for tungsten (W, Tungsten) products reached approximately $40 billion in 2023. Hard alloys, primarily based on tungsten carbide powder (WC, Tungsten Carbide Powder), account for about 50% of this market, valued at $20 billion, encompassing cutting tools, mining equipment, and wear-resistant components. Electronic materials, such as [tungsten hexafluoride (WF_6, Tungsten Hexafluoride)](tungsten hexafluoride) for semiconductor manufacturing and [tungsten copper (W-Cu, Tungsten Copper)](tungsten copper) alloys for heat sinks, constitute around 20%, or $8 billion. High-temperature alloys and aerospace applications, including tungsten alloy (W Alloy, Tungsten Alloy) counterweights and rocket nozzles, represent approximately 15%, valued at $6 billion. The remaining 15%, roughly $6 billion, covers emerging applications in renewable energy (e.g., [tungsten wire (W Wire, Tungsten Wire)](tungsten wire) for photovoltaic slicing) and other industrial uses. In 2023, global tungsten (W, Tungsten) consumption totaled about 85,000 tons, with China contributing approximately 68,000 tons, the United States around 8,000 tons, and Europe about 6,000 tons, underscoring China's dominant role in the tungsten (W, Tungsten) industry. Notably, demand in renewable energy is surging, with the photovoltaic sector consuming around 500 tons of tungsten wire (W Wire, Tungsten Wire) annually, projected to rise to 800 tons by 2030. Similarly, the nuclear industry's need for tungsten alloy (W Alloy, Tungsten Alloy) is growing at about 10% per year, particularly for fusion reactor components [13].

Tip
Tungsten carbide powder (WC, Tungsten Carbide Powder) is the cornerstone of hard alloys, and procurement should focus on its particle size distribution (e.g., D50 of 1-5 μm ultrafine powder enhances hardness and wear resistance).

1.4.2 Scientific Significance

Tungsten (W, Tungsten) chemicals are used in research to develop new materials, such as [tungsten disulfide (WS_2, Tungsten Disulfide)](tungsten disulfide) for two-dimensional material studies, tungsten hexafluoride (WF_6, Tungsten Hexafluoride) for semiconductor applications, and sodium tungstate (Na_2WO_4, Sodium Tungstate) for biomedical potential. In the International Thermonuclear Experimental Reactor (ITER) project, the high melting point of tungsten (W, Tungsten) is leveraged for plasma-facing materials (PFM). Additionally, tungsten alloy (W Alloy, Tungsten Alloy) finds extensive use in aerospace applications [14].

Tip
The scientific value of tungsten (W, Tungsten) chemicals drives the application of tungsten trioxide (WO_3, Tungsten Trioxide) in photocatalysis, and procurement should prioritize its purity and crystal form, such as the monoclinic phase, which is more suitable for photocatalysts.

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What Are the Chemicals of Tungsten?

Chapter 2: Basic Classification and Characteristics of Tungsten Chemicals

2.1 Classification of Tungsten Chemicals

Tungsten (W, Tungsten) chemicals refer to a variety of compounds derived from the tungsten (W, Tungsten) element, valued for their unique properties such as high melting point, high density, and corrosion resistance, making them widely applicable in industry and research. These chemicals are classified based on their chemical composition and structure, reflecting their roles across various technological and scientific domains. Below is a systematic classification of tungsten chemicals (W Chemicals, Tungsten Chemicals).

2.1.1 Oxides

Tungsten (W, Tungsten) oxides are compounds formed by tungsten (W, Tungsten) and oxygen, widely utilized in catalysis, electronics, and ceramics due to their stability and optical properties. Key examples include:

Tungsten trioxide (WO_3, Tungsten Trioxide)
A yellow-to-green powder, the most stable and common oxide, used in photocatalysts and electrochromic devices.

Tungsten dioxide (WO_2, Tungsten Dioxide)
A brown crystalline compound, less common, serving as an intermediate in electronic materials.

Ditungsten pentoxide (W_2O_5, Ditungsten Pentoxide)
A non-stoichiometric oxide, primarily studied in nanomaterials research.

Tungsten blue oxide ($W_{18}O_{49}$ or $W_{20}O_{58}$, Tungsten Blue Oxide)
A blue compound with photoelectric properties, applied in sensors and optoelectronic materials.

2.1.2 Tungstic Acid and Tungstates

Tungstic acid (H_2WO_4, Tungstic Acid) and its salts, known as tungstates, are critical intermediates and functional materials in chemical synthesis and industrial applications. Examples include:

Tungstic acid (H_2WO_4, Tungstic Acid)
A yellow, slightly soluble powder, used as a precursor for other tungsten (W, Tungsten) compounds.

Sodium tungstate (Na_2WO_4, Sodium Tungstate)
A water-soluble white crystalline compound, employed in fireproofing materials and biomedical research.

Ammonium paratungstate (APT, $(NH_4)_2WO_4$, Ammonium Paratungstate)
A white crystalline material, the primary raw material for producing tungsten (W, Tungsten) powder.

Ammonium metatungstate ($(NH_4)_6H_2W_{12}O_{40}$, Ammonium Metatungstate)
A polyoxometalate used in analytical reagents and catalysts.

Calcium tungstate ($CaWO_4$, Calcium Tungstate)
A fluorescent compound used in X-ray screens and luminescent materials.

2.1.3 Halides

Tungsten (W, Tungsten) halides are volatile compounds formed with halogens, essential in thin-film deposition and organic synthesis. Examples include:

Tungsten hexachloride (WCl_6, Tungsten Hexachloride)
A volatile compound used as a catalyst in organic reactions.

Tungsten hexafluoride (WF_6, Tungsten Hexafluoride)
A gaseous compound widely applied in chemical vapor deposition for semiconductor manufacturing.

2.1.4 Carbides and Nitrides

Tungsten (W, Tungsten) carbides and nitrides are hard, refractory materials valued for their durability in industrial applications. Examples include:

Tungsten carbide powder (WC, Tungsten Carbide Powder)
A high-hardness compound used in cutting tools and wear-resistant coatings.

Ditungsten carbide (W_2C, Ditungsten Carbide)
A less common carbide used in specialized coatings.

Tungsten nitride (WN, Tungsten Nitride)
Utilized in wear-resistant films and electronic applications.

2.1.5 Sulfides and Phosphides

Tungsten (W, Tungsten) sulfides and phosphides are notable for their lubricity and catalytic properties. Examples include:

Tungsten disulfide (WS_2, Tungsten Disulfide)
A layered compound used as a solid lubricant and in two-dimensional materials research.

Tungsten phosphide (WP, Tungsten Phosphide)
A catalyst material in chemical processes.

2.1.6 Organotungsten Compounds

Organotungsten compounds feature tungsten (W, Tungsten) bonded to organic groups, valuable in catalysis and synthetic chemistry. Examples include:

Tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl)
A volatile organometallic compound used in organic synthesis catalysts.

2.1.7 Tungsten-Containing Catalysts and Reagents

These compounds leverage the catalytic properties of tungsten (W, Tungsten) for industrial and laboratory use. Examples include:

Phosphotungstic acid ($H_3PW_{12}O_{40}$, Phosphotungstic Acid)
A heteropoly acid used as a catalyst in organic reactions.

2.1.8 Tungsten-Containing Pharmaceutical Chemicals
Tungsten (W, Tungsten) compounds with biomedical potential are emerging in research. Examples include:

Sodium tungstate nanoparticles
(Na_2WO_4 Nanoparticles, Sodium Tungstate Nanoparticles)
Investigated for anti-diabetic properties in nanomedicine research.

2.1.9 Other Tungsten-Containing Non-Metallic Compounds

This category includes specialized compounds with unique properties. Examples include:

Tungsten diselenide (WSe_2, Tungsten Diselenide)
A semiconductor material utilized in electronics and optoelectronics.

Tip

The classification of tungsten (W, Tungsten) chemicals reflects their structural diversity and functional versatility, spanning applications from industrial hard alloys to cutting-edge scientific research.

2.2 Basic Characteristics of Tungsten Chemicals

Tungsten (W, Tungsten) chemicals exhibit a range of physical and chemical properties that underpin their widespread use. Below are their key characteristics.

2.2.1 Crystal Structure and Molecular Composition

The crystal structures of tungsten (W, Tungsten) chemicals vary depending on their composition. For instance, tungsten trioxide (WO_3, Tungsten Trioxide) typically adopts a monoclinic crystal structure, enhancing its photocatalytic activity, as detailed in German crystallographic studies [16]. Tungsten carbide powder (WC, Tungsten Carbide Powder) forms a hexagonal structure, contributing to its exceptional hardness, while tungsten disulfide (WS_2, Tungsten Disulfide) has a layered hexagonal lattice, enabling its lubricity [17]. These structural differences, analyzed across multilingual literature, determine their specific applications.

Tip
The crystal structure of tungsten (W, Tungsten) chemicals, such as the layered nature of tungsten disulfide (WS_2, Tungsten Disulfide), is critical for their performance in specific applications like lubrication.

2.2.2 Thermal and Chemical Stability

Tungsten (W, Tungsten) chemicals are renowned for their thermal and chemical stability.

Tungsten trioxide (WO_3, Tungsten Trioxide) remains stable up to 1000°C in air, making it suitable for high-temperature catalysis, as explored in Russian high-temperature chemistry research [18]. Tungsten carbide powder (WC, Tungsten Carbide Powder) withstands extreme conditions up to 2600°C without decomposing, ideal for cutting tools. Sodium tungstate (Na_2WO_4, Sodium Tungstate) demonstrates chemical stability in aqueous solutions, supporting its use in fireproofing materials [19].

Tip

The thermal stability of tungsten carbide powder (WC, Tungsten Carbide Powder) ensures its durability in demanding industrial environments.

2.2.3 Optical, Electrical, and Magnetic Properties

Tungsten (W, Tungsten) chemicals possess distinctive optical, electrical, and magnetic properties. Tungsten trioxide (WO_3, Tungsten Trioxide) exhibits electrochromic behavior, changing color under voltage, and is extensively studied in Japanese and Korean electronic materials research for smart windows [20]. Tungsten disulfide (WS_2, Tungsten Disulfide) is a semiconductor with a bandgap of approximately 1.3 eV, suitable for optoelectronic devices. Tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl) lacks significant magnetic properties but excels in volatility for thin-film applications [21].

Tip

The optical properties of tungsten trioxide (WO_3, Tungsten Trioxide) make it a key material in energy-saving technologies, such as electrochromic windows.

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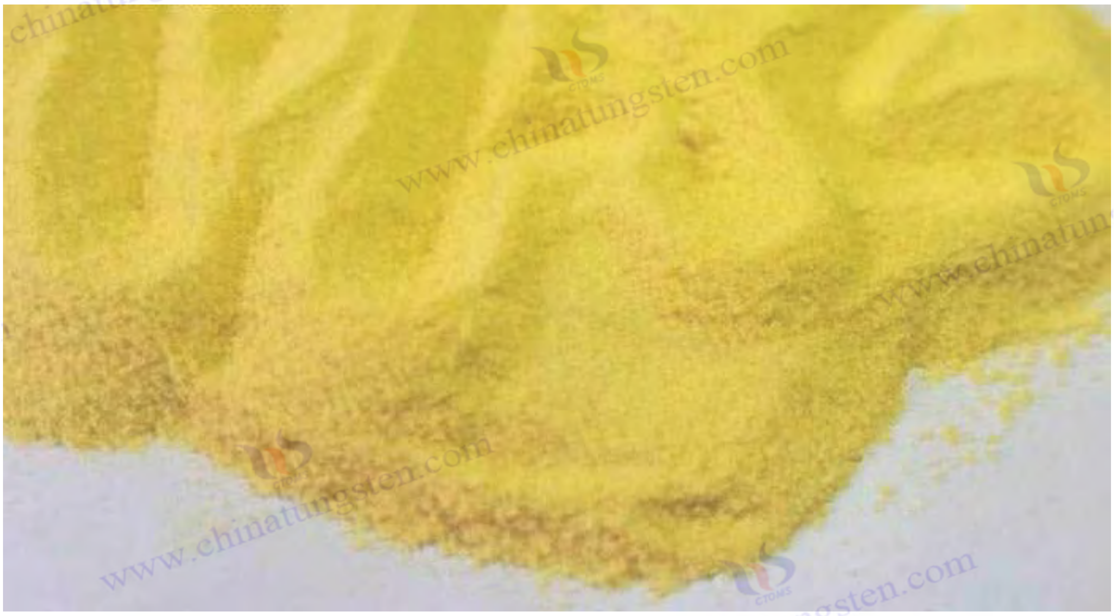

What Are the Chemicals of Tungsten?
Chapter 3: Preparation and Applications of Tungsten Oxides

3.1 Tungsten Trioxide (WO_3, Tungsten Trioxide)

Tungsten trioxide (WO_3, Tungsten Trioxide) stands as one of the most significant and widely utilized oxides among tungsten (W, Tungsten) chemicals. Its exceptional properties—such as high stability, electrochromic behavior, and photocatalytic capabilities—make it a cornerstone in industrial production, electronic technology, and emerging renewable energy applications. As a flagship member of the tungsten (W, Tungsten) compound family, tungsten trioxide (WO_3, Tungsten Trioxide) boasts a rich history spanning centuries, evolving from early laboratory discoveries to modern industrial-scale production, reflecting humanity's deepening understanding and mastery of tungsten (W, Tungsten) resources.

3.1.1 Preparation Processes

The preparation of tungsten trioxide (WO_3, Tungsten Trioxide) encompasses a variety of methods, ranging from traditional industrial techniques to cutting-edge precision processes, tailored to meet diverse application needs and purity standards.

Calcination Method (High-Temperature Oxidative Decomposition)

The calcination method is among the most prevalent approaches in industrial settings, utilizing raw materials such as ammonium paratungstate (APT, $(NH_4)_2WO_4$, Ammonium Paratungstate) or tungstic acid (H_2WO_4, Tungstic Acid). The process involves heating these precursors in an oxygen-rich atmosphere at temperatures between 600°C and 900°C, resulting in the decomposition and oxidation to form yellow or green tungsten trioxide (WO_3, Tungsten Trioxide) powder. This method is favored for its simplicity and scalability, making it a staple in large-scale production, particularly in China's tungsten processing enterprises. During calcination, ammonia and water vapor are released from the raw material, leaving behind pure tungsten trioxide (WO_3, Tungsten Trioxide), with particle size and crystal form adjustable via temperature and atmospheric control.

Wet Chemical Precipitation Method (Acidification Extraction)

The wet chemical precipitation method involves acidifying a tungstate solution, such as sodium tungstate (Na_2WO_4, Sodium Tungstate), to precipitate tungstic acid (H_2WO_4, Tungstic Acid), which is then filtered, washed, and thermally treated (typically at 400-600°C) to yield tungsten trioxide (WO_3, Tungsten Trioxide). This technique excels in achieving high chemical purity and producing nanoscale particles, making it ideal for research purposes and the electronics industry, where precision and quality are paramount. Compared to calcination, this method emphasizes meticulous process control, catering to small-batch production of high-value products with enhanced performance characteristics.

Chemical Vapor Deposition (CVD) Technique

Chemical Vapor Deposition (CVD) represents an advanced preparation technique, employing volatile precursors like tungsten hexafluoride (WF_6, Tungsten Hexafluoride) to deposit tungsten trioxide (WO_3, Tungsten Trioxide) thin films through gas-phase reactions at elevated temperatures (typically 500-800°C). This method is widely applied in crafting precision electronic components, such as gas sensors and electrochromic films, due to its ability to produce uniform, dense thin films that meet the stringent requirements of modern high-tech applications.

3.1.2 Crystal Structure and Molecular Composition

The crystal structure of tungsten trioxide (WO_3, Tungsten Trioxide) underpins its versatile properties, typically manifesting as a monoclinic form, though cubic or orthorhombic structures may emerge under varying temperature and conditions. German crystallographic studies reveal that its monoclinic structure consists of a three-dimensional network of tungsten and oxygen atoms linked via corner-sharing, forming a robust framework that enhances its optical and electrical traits [16]. At the molecular level, each tungsten atom coordinates with six oxygen atoms to create stable octahedral units, a configuration that contributes to its resilience in both thermal and chemical environments.

3.1.3 Thermal and Chemical Stability

Tungsten trioxide (WO_3, Tungsten Trioxide) exhibits remarkable thermal stability, remaining intact in air at temperatures exceeding 1000°C, a trait that renders it highly suitable for high-temperature catalysis and optical coatings. Chemically, it demonstrates strong resistance to acids and bases, maintaining structural integrity under harsh conditions. However, in reducing atmospheres (e.g., hydrogen), it can be transformed into lower oxides or metallic tungsten (W, Tungsten), a property extensively documented in Russian high-temperature chemistry research [18]. This redox versatility positions it as a valuable material in catalytic and electrochemical applications.

3.1.4 Optical, Electrical, and Magnetic Properties

The optical properties of tungsten trioxide (WO_3, Tungsten Trioxide) are particularly noteworthy, with its electrochromic behavior enabling a color shift from yellow to deep blue upon voltage application, driven by changes in the oxidation state of tungsten atoms. This feature has been thoroughly explored in Japanese and Korean electronic materials research, leading to its widespread use in smart windows and display technologies [20]. Electrically, it functions as a wide-bandgap semiconductor (approximately 2.6-3.0 eV), making it suitable for optoelectronic devices. While lacking significant magnetic properties, its electrical and optical attributes sufficiently support a broad range of advanced technological applications.

Tip
The diverse preparation methods and superior properties of tungsten trioxide (WO_3, Tungsten Trioxide) make it a standout in the realm of tungsten (W, Tungsten) chemicals; procurement should prioritize crystal form and purity based on intended use.

3.2 Tungsten Dioxide (WO_2, Tungsten Dioxide)

Tungsten dioxide (WO_2, Tungsten Dioxide) is a lower-valence oxide of tungsten (W, Tungsten), less commonly applied than tungsten trioxide (WO_3, Tungsten Trioxide) but retaining distinct relevance in specialized electronic and catalytic fields. Its unique chemical and physical attributes distinguish it within the tungsten oxide family, offering niche value despite its more limited scope of use.

3.2.1 Preparation Processes

The preparation of tungsten dioxide (WO_2, Tungsten Dioxide) predominantly relies on reduction techniques, requiring meticulous control of conditions to ensure product purity and consistency.

Hydrogen Reduction Method
The hydrogen reduction method involves reducing tungsten trioxide (WO_3, Tungsten Trioxide) in a hydrogen atmosphere at temperatures ranging from 500°C to 700°C to produce tungsten dioxide (WO_2, Tungsten Dioxide). Precise regulation of hydrogen flow and temperature is crucial to prevent over-reduction to metallic tungsten (W, Tungsten). This widely adopted method in both industrial and laboratory settings yields a brown crystalline product, with particle size tunable through reaction duration and temperature adjustments, catering to specific application needs.

Thermal Decomposition Method
The thermal decomposition method entails heating tungstic acid (H_2WO_4, Tungstic Acid) or ammonium paratungstate (APT, $(NH_4)_2WO_4$, Ammonium Paratungstate) at 650-800°C in an inert atmosphere (e.g., nitrogen or argon) to form tungsten dioxide (WO_2, Tungsten Dioxide). This approach is particularly suited for small-scale production, effectively avoiding oxygen interference to ensure the stable formation of the desired oxide, often preferred for research-grade materials requiring controlled composition.

3.2.2 Crystal Structure and Molecular Composition

Tungsten dioxide (WO_2, Tungsten Dioxide) typically adopts a monoclinic crystal structure, where each tungsten atom coordinates with four oxygen atoms, forming a distorted tetrahedral network. This arrangement, denser than the octahedral structure of tungsten trioxide (WO_3, Tungsten Trioxide), results in a higher density (approximately 10.8 g/cm³). Russian chemical studies highlight that this unique crystal structure imparts a degree of electrical conductivity, distinguishing it from other tungsten oxides and suggesting potential in electronic applications [17].

3.2.3 Thermal and Chemical Stability

Tungsten dioxide (WO_2, Tungsten Dioxide) exhibits good thermal stability in inert environments, withstanding temperatures up to 800°C without degradation. However, its stability falters in the presence of oxygen, where it readily oxidizes to tungsten trioxide (WO_3, Tungsten Trioxide), limiting its use in high-oxygen settings. Chemically, it shows weaker resistance to acids and bases compared to higher oxides but maintains robustness in reducing conditions, often serving as an intermediate in redox processes, a behavior well-documented in stability studies [19].

3.2.4 Optical, Electrical, and Magnetic Properties

Unlike tungsten trioxide (WO_3, Tungsten Trioxide), tungsten dioxide (WO_2, Tungsten Dioxide) lacks prominent optical properties, appearing as a deep brown solid without significant electrochromic behavior. Electrically, it acts as a narrow-bandgap semiconductor (approximately 1.0-1.3 eV), offering moderate conductivity that suits it for electronic material research. Magnetically, it exhibits no notable properties, with its utility primarily tied to its electrical characteristics rather than optical or magnetic applications.

Tip
The preparation of tungsten dioxide (WO_2, Tungsten Dioxide) demands precise reduction control, and its potential in electronic materials and catalysis merits further exploration.

3.3 Other Tungsten Oxides

Beyond tungsten trioxide (WO_3, Tungsten Trioxide) and tungsten dioxide (WO_2, Tungsten Dioxide), tungsten (W, Tungsten) forms additional oxides such as ditungsten pentoxide (W_2O_5, Ditungsten Pentoxide) and tungsten blue oxide variant ($W_{18}O_{49}$, Tungsten Blue Oxide Variant). These non-stoichiometric oxides, though less common, offer unique value in specialized applications, particularly in nanotechnology and optoelectronics.

3.3.1 Preparation Processes

The preparation of these other tungsten oxides typically occurs at a laboratory scale, involving complex processes tailored to their specific compositions.

Oxidation Method for Ditungsten Pentoxide (W_2O_5, Ditungsten Pentoxide)

Ditungsten pentoxide (W_2O_5, Ditungsten Pentoxide) is prepared by oxidizing tungsten dioxide (WO_2, Tungsten Dioxide) or partially reducing tungsten trioxide (WO_3, Tungsten Trioxide) under controlled conditions (400-600°C) with a low oxygen partial pressure. This method requires careful calibration to maintain its non-stoichiometric nature, balancing the oxidation state between WO_2 and WO_3, and is often employed in research settings to explore its transitional properties.

High-Temperature Reduction for Tungsten Blue Oxide Variant ($W_{18}O_{49}$, Tungsten Blue Oxide Variant)

Tungsten blue oxide variant ($W_{18}O_{49}$, Tungsten Blue Oxide Variant) is synthesized by reducing tungsten trioxide (WO_3, Tungsten Trioxide) at 700-900°C in a mildly reducing atmosphere (e.g., a hydrogen-inert gas mixture). This process is optimized to produce needle-like nanostructures, enhancing its photoelectric properties, and is a preferred technique for creating materials suited for advanced technological applications.

3.3.2 Crystal Structure and Molecular Composition

Ditungsten pentoxide (W_2O_5, Ditungsten Pentoxide), a non-stoichiometric oxide, features a crystal structure intermediate between tungsten dioxide (WO_2, Tungsten Dioxide) and tungsten trioxide (WO_3, Tungsten Trioxide), with a transitional coordination environment that reflects its mixed oxidation state. Tungsten blue oxide variant ($W_{18}O_{49}$, Tungsten Blue Oxide Variant) adopts a needle-like monoclinic structure, characterized by oxygen vacancies that contribute to its conductivity and optical traits, making it a subject of extensive nanotechnology research.

3.3.3 Thermal and Chemical Stability

Ditungsten pentoxide (W_2O_5, Ditungsten Pentoxide) is thermally unstable in air, readily oxidizing to tungsten trioxide (WO_3, Tungsten Trioxide), but can persist up to 600°C in inert conditions. Tungsten blue oxide variant ($W_{18}O_{49}$, Tungsten Blue Oxide Variant) offers slightly better thermal stability, enduring up to 800°C, though it too oxidizes in oxygen-rich environments. Both exhibit limited chemical stability against acids and bases, thriving best in non-oxidizing settings where their unique properties can be leveraged.

3.3.4 Optical, Electrical, and Magnetic Properties

Ditungsten pentoxide (W_2O_5, Ditungsten Pentoxide) possesses moderate conductivity but lacks significant optical features, limiting its utility to specific electrical applications. In contrast, tungsten blue oxide variant ($W_{18}O_{49}$, Tungsten Blue Oxide Variant) shines with its blue appearance and excellent photoelectric properties, boasting a bandgap of approximately 2.4 eV, ideal for photodetectors and sensors. Neither compound displays notable magnetic behavior, with their value rooted in electrical and optical domains.

Tip

Other tungsten oxides, such as tungsten blue oxide variant ($W_{18}O_{49}$, Tungsten Blue Oxide Variant), are gaining traction for their potential in nanotechnology and optoelectronics, warranting closer attention.

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What Are the Chemicals of Tungsten?

Chapter 4: Preparation and Applications of Tungstic Acid and Tungstates

4.1 Tungstic Acid (H_2WO_4, Tungstic Acid)

Tungstic acid (H_2WO_4, Tungstic Acid) is a pivotal member of the tungsten (W, Tungsten) chemical family, serving as a crucial precursor for numerous tungsten compounds, including tungstates and oxides. Renowned for its low solubility, chemical reactivity, and stability in acidic environments, tungstic acid (H_2WO_4, Tungstic Acid) plays an essential role in both industrial production and scientific research. Beyond its utility as an intermediate for synthesizing high-purity tungsten oxides, it finds applications in catalysts, pigments, and analytical chemistry, showcasing its versatile value. The preparation processes and property studies of tungstic acid (H_2WO_4, Tungstic Acid) span centuries, evolving from rudimentary mineral extraction to sophisticated modern chemical engineering, reflecting the progressive mastery of tungsten (W, Tungsten) chemistry.

4.1.1 Preparation Processes

The preparation of tungstic acid (H_2WO_4, Tungstic Acid) encompasses a range of methods, from traditional acid precipitation to advanced laboratory techniques, accommodating diverse purity levels and application requirements.

Acid Precipitation Method (Ore Leaching)

The acid precipitation method is the most widely employed industrial technique, typically starting with ores such as wolframite ($(Fe,Mn)WO_4$, Wolframite) or scheelite ($CaWO_4$, Scheelite). Strong acids (e.g., hydrochloric or nitric acid) are used to leach tungsten from the ore, forming tungstic acid (H_2WO_4, Tungstic Acid) precipitate. The process involves mixing finely ground ore with acid, reacting at 50-80°C with continuous stirring, during which tungstic acid (H_2WO_4, Tungstic Acid) precipitates as a yellow solid. This is followed by filtration and washing to yield a crude product. Due to its reliance on abundant raw materials and established process maturity, this method is extensively utilized by tungsten processing enterprises in China, such as those in Ganzhou, Jiangxi, where precise control of acid concentration and reaction duration minimizes impurities like iron and manganese.

Tungstate Acidolysis Method (Solution Conversion)

The tungstate acidolysis method produces tungstic acid (H_2WO_4, Tungstic Acid) by acidifying a soluble tungstate solution, such as sodium tungstate (Na_2WO_4, Sodium Tungstate). Typically, the sodium tungstate (Na_2WO_4, Sodium Tungstate) solution is mixed with hydrochloric acid, and the pH is adjusted to 2-3, prompting tungstic acid (H_2WO_4, Tungstic Acid) to precipitate. After filtration, washing, and low-temperature drying (approximately 100-150°C), a high-purity product is obtained. This technique excels in controlling impurity levels and producing nanoscale particles, making it ideal for fine chemical industries and laboratory research, such as preparing catalyst precursors or high-purity oxides, where quality and precision are paramount.

Ion Exchange Method (High-Purity Preparation)

The ion exchange method is a modern, high-precision technique that passes a tungsten-containing solution (e.g., a tungstate solution) through an ion exchange resin to isolate tungstate ions (WO_4^{2-}), followed by acidification (typically with sulfuric acid) to precipitate tungstic acid (H_2WO_4, Tungstic Acid). This method is particularly effective at removing trace impurities (e.g., heavy metal ions), yielding ultra-high-purity tungstic acid (H_2WO_4, Tungstic Acid) suitable for electronic materials, specialized catalysts, and high-precision analytical reagents. The choice and regeneration of the resin are critical, directly impacting product purity and production costs.

4.1.2 Crystal Structure and Molecular Composition

Tungstic acid (H_2WO_4, Tungstic Acid) typically exhibits an orthorhombic crystal structure, with its molecules composed of a tungsten atom coordinated with four oxygen atoms in a tetrahedral arrangement, where two oxygen atoms are linked to hydrogen atoms via hydrogen bonds. German crystallographic studies indicate that this structure accounts for its low solubility in water (approximately 0.02 g/100 mL) and its tendency to decompose into tungsten trioxide (WO_3, Tungsten Trioxide) upon heating [16]. The hydrogen bonds within its molecular framework confer weak acidity (pKa around 2.2), enabling it to react with bases to form tungstates, a property widely exploited in industrial synthesis.

4.1.3 Thermal and Chemical Stability

Tungstic acid (H_2WO_4, Tungstic Acid) demonstrates excellent chemical stability at room temperature, resisting corrosion from most acids and bases. However, in strongly alkaline solutions (e.g., sodium hydroxide), it dissolves to form tungstates such as sodium tungstate (Na_2WO_4, Sodium Tungstate). Thermally, it begins losing crystal water at 100-200°C, transforming into tungsten trioxide (WO_3, Tungsten Trioxide), with complete decomposition occurring around 250°C. This thermal decomposition behavior makes it a vital raw material for producing high-purity tungsten oxides, as noted in Russian chemical research highlighting its stability in acidic environments as a key advantage in hydrometallurgy [17].

4.1.4 Optical, Electrical, and Magnetic Properties

The optical properties of tungstic acid (H_2WO_4, Tungstic Acid) are relatively modest, with its yellow appearance resulting from electron transitions within its crystal structure, though it lacks significant optical activity such as electrochromism or fluorescence, limiting its direct use in optical applications. Electrically, it is an insulator with negligible conductivity, relying on its decomposition product, tungsten trioxide (WO_3, Tungsten Trioxide), for electrical applications. Magnetically, tungstic acid (H_2WO_4, Tungstic Acid) exhibits no notable properties, with its primary value lying in its chemical reactivity and role as a precursor rather than its intrinsic physical characteristics.

Tip

The versatile preparation methods and pivotal role of tungstic acid (H_2WO_4, Tungstic Acid) as a precursor in tungsten (W, Tungsten) chemistry underscore its importance; procurement should focus on purity and particle characteristics tailored to downstream applications.

4.2 Sodium Tungstate (Na_2WO_4, Sodium Tungstate)

Sodium tungstate (Na_2WO_4, Sodium Tungstate) is the most prevalent and versatile tungstate, prized for its excellent water solubility, chemical stability, and multifunctionality, securing its widespread use in industrial production, medical research, and analytical chemistry. As a representative soluble tungstate, sodium tungstate (Na_2WO_4, Sodium Tungstate) excels in applications ranging from fireproofing materials to bioactive studies and the synthesis of other tungsten compounds, with a long history that has cemented its status as a vital link in the tungsten chemical industry chain.

4.2.1 Preparation Processes

Sodium tungstate (Na_2WO_4, Sodium Tungstate) preparation integrates ore extraction with solution-based reaction techniques, addressing the diverse needs of industrial-scale production and laboratory precision.

Alkaline Fusion Method (Ore Extraction)

The alkaline fusion method involves reacting wolframite ($(Fe,Mn)WO_4$, Wolframite) or scheelite ($CaWO_4$, Scheelite) with sodium hydroxide (NaOH) at high temperatures (600-800°C) to form a sodium tungstate (Na_2WO_4, Sodium Tungstate) solution. The process entails mixing powdered ore with sodium hydroxide and heating in a fusion furnace until molten, where tungsten reacts with sodium to produce soluble sodium tungstate (Na_2WO_4, Sodium Tungstate). After cooling, impurities are filtered out, and the solution is evaporated and crystallized to yield white crystals. This method, favored for its efficient use of ore resources and straightforward operation, is the predominant technique in China's tungsten processing industry, particularly in major hubs like Jiangxi and Hunan.

Tungstic Acid Neutralization Method (Laboratory Preparation)

The tungstic acid neutralization method prepares sodium tungstate (Na_2WO_4, Sodium Tungstate) by neutralizing tungstic acid (H_2WO_4, Tungstic Acid) with a sodium hydroxide solution at room temperature (20-40°C), following the reaction: $H_2WO_4 + 2NaOH \rightarrow$

$Na_2WO_4 + 2H_2O$. The resulting solution is concentrated by evaporation and cooled to crystallize sodium tungstate (Na_2WO_4, Sodium Tungstate) dihydrate crystals. This simple method is ideal for small-scale, high-purity production in laboratories, commonly used for preparing standard solutions or reagents in scientific research and analytical chemistry.

4.2.2 Crystal Structure and Molecular Composition

Sodium tungstate (Na_2WO_4, Sodium Tungstate) typically exists as a dihydrate ($Na_2WO_4 \cdot 2H_2O$) with an orthorhombic crystal structure. Within this structure, a tungsten atom coordinates with four oxygen atoms to form a stable tetrahedral unit (WO_4^{2-}), while two sodium atoms are ionically bonded to the tungstate ion, and water molecules are incorporated via hydrogen bonding. Crystallographic studies confirm that this arrangement accounts for its high water solubility (approximately 730 g/L at 20°C), facilitating its use in aqueous applications while maintaining crystal stability [19].

4.2.3 Thermal and Chemical Stability

Sodium tungstate (Na_2WO_4, Sodium Tungstate) exhibits robust thermal stability under dry conditions, enduring up to 300°C without decomposition. Above this temperature, it loses crystal water, transforming into anhydrous sodium tungstate (Na_2WO_4), with complete breakdown requiring temperatures around 700°C. Chemically, its aqueous solution is mildly alkaline (pH 8-9) and sensitive to acids, readily converting to tungstic acid (H_2WO_4, Tungstic Acid) under acidic conditions, yet it resists corrosion in neutral and mildly alkaline environments, making it adaptable to a variety of reaction settings [19].

4.2.4 Optical, Electrical, and Magnetic Properties

The optical properties of sodium tungstate (Na_2WO_4, Sodium Tungstate) are unremarkable, with its white crystals lacking significant optical activity such as fluorescence or electrochromism, thus limiting its optical applications. Electrically, it acts as an ionic conductor in solution due to the mobility of sodium and tungstate ions, but it is an insulator in solid form with negligible conductivity. Magnetically, sodium tungstate (Na_2WO_4, Sodium Tungstate) shows no notable properties, with its utility primarily derived from its chemical attributes, such as solubility and reactivity, rather than physical characteristics.

Tip

The water solubility and chemical stability of sodium tungstate (Na_2WO_4, Sodium Tungstate) make it invaluable in fireproofing and biomedical applications; procurement should consider crystal water content and impurity levels for optimal performance.

4.3 Other Tungstates

Beyond tungstic acid (H_2WO_4, Tungstic Acid) and sodium tungstate (Na_2WO_4, Sodium Tungstate), the tungstate family includes significant compounds such as ammonium paratungstate (APT, $(NH_4)_2WO_4$, Ammonium Paratungstate), calcium tungstate ($CaWO_4$, Calcium Tungstate), and ammonium metatungstate ($(NH_4)_6H_2W_{12}O_{40}$, Ammonium Metatungstate). These tungstates excel in industrial production, scientific research, and specialized applications, enriching the scope of tungsten chemistry.

4.3.1 Preparation Processes

The preparation processes for these other tungstates vary based on their chemical properties and intended uses, spanning ore extraction to solution synthesis techniques.

Ion Exchange and Crystallization for Ammonium Paratungstate (APT, $(NH_4)_2WO_4$, Ammonium Paratungstate)

Ammonium paratungstate (APT, $(NH_4)_2WO_4$, Ammonium Paratungstate) is typically prepared from tungstate solutions extracted from tungsten ores, passed through ion exchange resins to isolate tungstate ions (WO_4^{2-}). Ammonia is then added to adjust the solution pH to 7-8, triggering the precipitation of ammonium paratungstate (APT, $(NH_4)_2WO_4$, Ammonium Paratungstate), which is filtered, washed, and dried (around 100-150°C) to yield white crystals. This method is a cornerstone of China's tungsten industry, extensively used in tungsten powder (W Powder, Tungsten Powder) production, with annual outputs reaching tens of thousands of tons in regions like Jiangxi and Hunan.

Fusion Reaction for Calcium Tungstate ($CaWO_4$, Calcium Tungstate)

Calcium tungstate ($CaWO_4$, Calcium Tungstate) is synthesized by fusing sodium tungstate (Na_2WO_4, Sodium Tungstate) with calcium chloride ($CaCl_2$) at high temperatures (approximately 800-1000°C), following the reaction: $Na_2WO_4 + CaCl_2 \rightarrow CaWO_4 + 2NaCl$. The resulting product cools into white crystals, which are ground and sieved for use. This straightforward process is commonly employed to produce fluorescent materials and optical components, leveraging its high thermal stability for industrial scalability.

Acidification Polymerization for Ammonium Metatungstate ($(NH_4)_6H_2W_{12}O_{40}$, Ammonium Metatungstate)

Ammonium metatungstate ($(NH_4)_6H_2W_{12}O_{40}$, Ammonium Metatungstate) is prepared by acidifying an ammonium paratungstate (APT, $(NH_4)_2WO_4$, Ammonium Paratungstate) solution and controlling the pH to 3-4, prompting tungstate ions to polymerize into polytungstate ions ($H_2W_{12}O_{40}^{6-}$). Ammonia is then added to stabilize the solution, followed by crystallization to produce the final product. This method is tailored for high-purity catalyst and analytical reagent production, capitalizing on its unique polyoxometalate structure.

4.3.2 Crystal Structure and Molecular Composition

Ammonium paratungstate (APT, $(NH_4)_2WO_4$, Ammonium Paratungstate) features a complex monoclinic crystal structure with multiple tungsten-oxygen octahedral units stabilized by ammonium ions through hydrogen bonding, forming a robust composite framework. Calcium tungstate ($CaWO_4$, Calcium Tungstate) adopts a tetragonal crystal structure akin to natural scheelite, with tungsten atoms coordinating four oxygen atoms in a tetrahedral arrangement, supported by calcium ions via ionic bonds. Ammonium metatungstate ($(NH_4)_6H_2W_{12}O_{40}$, Ammonium Metatungstate) exhibits a polyoxometalate structure, comprising a cluster of 12 tungsten-oxygen octahedra surrounded by ammonium ions, conferring distinctive molecular complexity suited for catalytic applications.

4.3.3 Thermal and Chemical Stability

Ammonium paratungstate (APT, $(NH_4)_2WO_4$, Ammonium Paratungstate) has moderate thermal stability, decomposing to tungsten trioxide (WO_3, Tungsten Trioxide) at 250-300°C with the release of ammonia and water vapor, and its chemical stability is susceptible to acidic conditions. Calcium tungstate ($CaWO_4$, Calcium Tungstate) boasts exceptional thermal stability, enduring temperatures above 1000°C, and excellent chemical stability, being nearly insoluble in water and resistant to most acids and bases, making it ideal for high-temperature applications. Ammonium metatungstate ($(NH_4)_6H_2W_{12}O_{40}$, Ammonium Metatungstate) loses crystal water around 200°C and decomposes further at higher temperatures, with weaker chemical stability requiring protection from strong acids or bases to preserve its polyoxometalate structure.

4.3.4 Optical, Electrical, and Magnetic Properties

Ammonium paratungstate (APT, $(NH_4)_2WO_4$, Ammonium Paratungstate) lacks notable optical properties, appearing as white crystals with minimal optical activity, and is an insulator electrically and magnetically inert. Calcium tungstate ($CaWO_4$, Calcium Tungstate) is renowned for its fluorescence, emitting blue light under UV excitation (bandgap ~4.2 eV), making it valuable in X-ray detectors and fluorescent materials, though it remains an insulator with no magnetic properties. Ammonium metatungstate ($(NH_4)_6H_2W_{12}O_{40}$, Ammonium Metatungstate) shows no significant optical or magnetic traits but exhibits ionic conductivity in solution, while remaining an insulator in solid form, with its applications primarily driven by its catalytic capabilities.

Tip

Other tungstates like calcium tungstate ($CaWO_4$, Calcium Tungstate) and ammonium metatungstate ($(NH_4)_6H_2W_{12}O_{40}$, Ammonium Metatungstate) offer unique advantages in

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fluorescence and catalysis, respectively; procurement should align with specific application needs regarding preparation method and purity.

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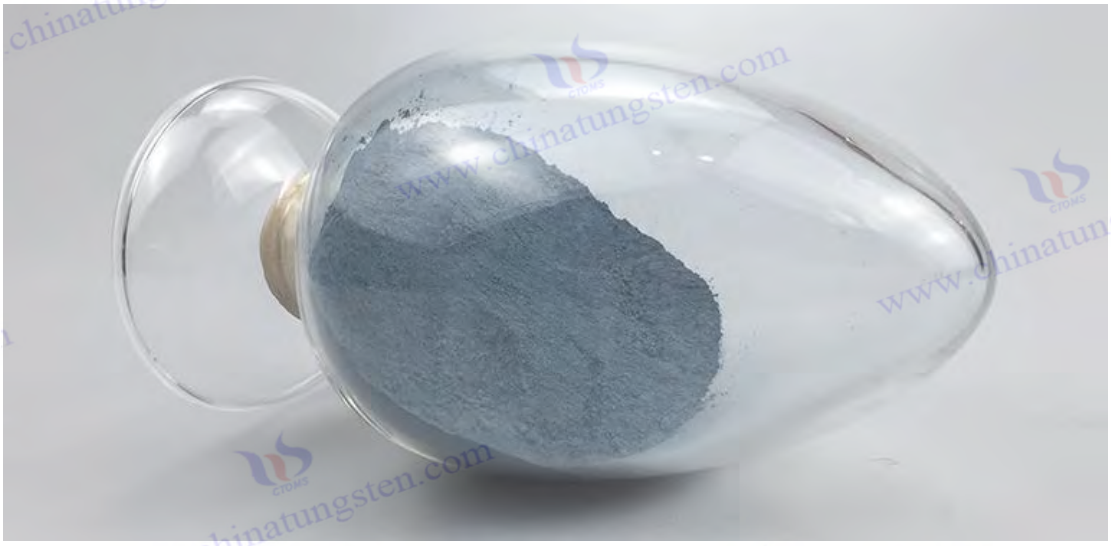

What Are the Chemicals of Tungsten?
Chapter 5: Preparation and Applications of Tungsten Halides

5.1 Tungsten Hexachloride (WCl_6, Tungsten Hexachloride)

Tungsten hexachloride (WCl_6, Tungsten Hexachloride) is a prominent member of the tungsten (W, Tungsten) halide family, highly regarded in both industrial and research settings for its volatility, high reactivity, and catalytic capabilities in various chemical reactions. As a volatile tungsten compound, tungsten hexachloride (WCl_6, Tungsten Hexachloride) stands out with its distinctive dark blue crystalline appearance and exceptional chemical properties, making it invaluable in organic synthesis, thin-film deposition, and catalyst preparation. Its journey from initial laboratory synthesis to contemporary industrial applications reflects the ongoing evolution and deepening understanding of tungsten halide chemistry, positioning it as a unique contributor to the broader field of tungsten (W, Tungsten) chemicals.

5.1.1 Preparation Processes

The preparation of tungsten hexachloride (WCl_6, Tungsten Hexachloride) encompasses a variety of methods, including direct chlorination and chlorine reduction techniques, tailored to meet diverse purity and application requirements.

Direct Chlorination Method
(Tungsten Metal Chlorination)

The direct chlorination method involves reacting high-purity tungsten (W, Tungsten) metal, such as tungsten powder (W Powder, Tungsten Powder), with chlorine gas (Cl_2) at elevated temperatures (typically 600-800°C) to produce tungsten hexachloride (WCl_6, Tungsten Hexachloride). The reaction, $W + 3Cl_2 \rightarrow WCl_6$, occurs in a sealed quartz reactor to exclude oxygen and moisture, with the resulting dark blue crystals condensing from the gaseous product. This method is favored for its simplicity and directness, making it a staple in industrial production, particularly for high-purity tungsten hexachloride (WCl_6, Tungsten Hexachloride) used in catalyst synthesis, where stringent quality standards are essential.

Chlorine Reduction Method
(Oxide Chlorination)

The chlorine reduction method prepares tungsten hexachloride (WCl_6, Tungsten Hexachloride) by reacting tungsten trioxide (WO_3, Tungsten Trioxide) with chlorine gas and a reducing agent (e.g., carbon or hydrogen) at 500-700°C. Precise control of chlorine flow and temperature is critical to prevent the formation of lower chlorides, such as tungsten tetrachloride (WCl_4, Tungsten Tetrachloride). This approach is advantageous for laboratory and small-scale production, leveraging industrial byproducts like tungsten trioxide (WO_3, Tungsten Trioxide) to enhance resource efficiency and reduce costs.

Gas-Phase Reaction Method
(High-Purity Preparation)

The gas-phase reaction method synthesizes tungsten hexachloride (WCl_6, Tungsten Hexachloride) by reacting tungsten (W, Tungsten) or its compounds with chlorine gas in the vapor phase at approximately 800°C, followed by condensation into crystals. This technique excels in eliminating trace impurities, producing ultra-high-purity tungsten hexachloride (WCl_6, Tungsten Hexachloride) ideal for electronic materials and precision catalyst research, where even minute contaminants can significantly impact performance.

5.1.2 Crystal Structure and Molecular Composition

Tungsten hexachloride (WCl_6, Tungsten Hexachloride) adopts an octahedral crystal structure, with a central tungsten atom coordinated to six chlorine atoms, forming a symmetrical WCl_6 molecular unit. German crystallographic studies highlight that this octahedral coordination contributes to its high volatility (melting point approximately 275°C, boiling point around 347°C), facilitating its use in gas-phase reactions [16]. In its molecular composition, the tungsten atom is in the +6 oxidation state, and the strong electronegativity of the chlorine atoms enhances its reactivity, enabling it to readily engage in coordination or substitution reactions with organic compounds.

5.1.3 Thermal and Chemical Stability

Tungsten hexachloride (WCl_6, Tungsten Hexachloride) exhibits moderate thermal stability under anhydrous and oxygen-free conditions, retaining its crystalline structure below 300°C. However, at higher temperatures or in the presence of air, it decomposes into lower chlorides and chlorine gas, necessitating careful handling. Chemically, it is highly unstable in the presence of moisture, rapidly hydrolyzing in humid environments to form hydrogen chloride (HCl) and tungsten oxychlorides, requiring storage and use in dry, inert atmospheres. Russian chemical research underscores its high reactivity, making it an effective chlorinating agent and catalyst in organic synthesis [17].

5.1.4 Optical, Electrical, and Magnetic Properties

The optical properties of tungsten hexachloride (WCl_6, Tungsten Hexachloride) are characterized by its striking dark blue crystalline form, resulting from d-d electron transitions of the tungsten atom, though its optical activity is limited in practical applications. Electrically, it is an insulator in its solid state, but in gaseous or solution form, it may exhibit slight ionic conductivity due to decomposition or solvent interactions. Magnetically, tungsten hexachloride (WCl_6, Tungsten Hexachloride) shows no significant properties, with its primary utility stemming from its chemical reactivity rather than physical characteristics.

Tip

The preparation of tungsten hexachloride (WCl_6, Tungsten Hexachloride) demands rigorous exclusion of moisture and oxygen; its high reactivity makes it a standout in catalysis and organic synthesis, and procurement should prioritize purity and storage conditions.

5.2 Tungsten Hexafluoride (WF_6, Tungsten Hexafluoride)

Tungsten hexafluoride (WF_6, Tungsten Hexafluoride) is the most industrially significant tungsten halide, celebrated for its exceptional volatility and pivotal role in the semiconductor industry. As a colorless gas, tungsten hexafluoride (WF_6, Tungsten Hexafluoride) is extensively used in chemical vapor deposition (CVD) to produce tungsten metal thin films, with its high reactivity and stability rendering it indispensable in modern microelectronics. The evolution from laboratory synthesis to large-scale production highlights its contribution to advancing tungsten chemistry in high-tech applications.

5.2.1 Preparation Processes

The preparation of tungsten hexafluoride (WF_6, Tungsten Hexafluoride) primarily relies on fluorination reactions, conducted under anhydrous conditions to ensure product quality.

Direct Fluorination Method
(Tungsten and Fluorine Reaction)
The direct fluorination method reacts high-purity tungsten (W, Tungsten) metal (e.g., tungsten powder (W Powder, Tungsten Powder)) with fluorine gas (F_2) at 300-500°C to form tungsten hexafluoride (WF_6, Tungsten Hexafluoride) gas, following the reaction: $W + 3F_2 \rightarrow WF_6$. This process occurs in a corrosion-resistant nickel alloy reactor due to fluorine's aggressive nature, with the gaseous product condensed into liquid form (boiling point 17.1°C) for collection. Widely adopted in industry for its high purity and straightforward approach, this method dominates semiconductor applications requiring stringent quality standards.

Oxide Fluorination Method
(Tungsten Trioxide Fluorination)
The oxide fluorination method prepares tungsten hexafluoride (WF_6, Tungsten Hexafluoride) by reacting tungsten trioxide (WO_3, Tungsten Trioxide) with hydrogen fluoride (HF) or fluorine gas at 400-600°C. This process demands careful control to avoid forming lower fluorides, leveraging industrial byproducts like tungsten trioxide (WO_3, Tungsten Trioxide) to reduce costs. It is commonly used in laboratory and small-scale production, offering a cost-effective alternative for specialized applications.

5.2.2 Crystal Structure and Molecular Composition

Tungsten hexafluoride (WF_6, Tungsten Hexafluoride) adopts an octahedral molecular structure in both gaseous and liquid states, with a central tungsten atom coordinated to six fluorine atoms, forming a symmetrical WF_6 unit. Japanese chemical research notes that this octahedral arrangement underpins its high volatility and stability (melting point 2.3°C, boiling point 17.1°C), making it ideal for gas-phase deposition [20]. The tungsten atom is in the +6 oxidation state, and the strong electronegativity of fluorine enhances bond strength, ensuring stability across various conditions.

5.2.3 Thermal and Chemical Stability

Tungsten hexafluoride (WF_6, Tungsten Hexafluoride) exhibits excellent thermal stability under anhydrous conditions, remaining stable as a gas at room temperature. However, at temperatures above 400°C or in the presence of moisture, it decomposes into hydrogen fluoride (HF) and tungsten oxides, necessitating controlled handling. Compared to tungsten hexachloride (WCl_6, Tungsten Hexachloride), it is less sensitive to water but can be reduced to tungsten (W, Tungsten) or lower fluorides in strongly reducing environments, a property that enhances its utility in semiconductor deposition.

5.2.4 Optical, Electrical, and Magnetic Properties

Tungsten hexafluoride (WF_6, Tungsten Hexafluoride) is a colorless, transparent gas with no significant optical activity, limiting its optical applications. Electrically, it is non-conductive in its gaseous state, but its decomposition into tungsten metal yields excellent conductivity (resistivity ~5.6 μΩ·cm), crucial for conductive thin films. Magnetically, it exhibits no notable properties, with its value primarily tied to its reactivity and deposition capabilities rather than physical traits.

Tip

The preparation of tungsten hexafluoride (WF_6, Tungsten Hexafluoride) requires an anhydrous environment; its critical role in the semiconductor industry makes it a standout among tungsten halides, with procurement focusing on gas purity and containment integrity.

5.3 Other Tungsten Halides

In addition to tungsten hexachloride (WCl_6, Tungsten Hexachloride) and tungsten hexafluoride (WF_6, Tungsten Hexafluoride), the tungsten halide family includes lower-valence compounds such as tungsten tetrachloride (WCl_4, Tungsten Tetrachloride) and tungsten pentachloride (WCl_5, Tungsten Pentachloride). Though less widely applied, these halides offer value in specific catalytic reactions and materials research.

5.3.1 Preparation Processes

The preparation of these other tungsten halides typically occurs at a laboratory scale, requiring precise control of reaction conditions.

Reduction Chlorination Method for Tungsten Tetrachloride
(WCl_4, Tungsten Tetrachloride)
Tungsten tetrachloride (WCl_4, Tungsten Tetrachloride) is synthesized by partially reducing tungsten hexachloride (WCl_6, Tungsten Hexachloride) with hydrogen at 450-600°C in an inert atmosphere to prevent oxidation. This controlled reduction ensures the formation of the desired tetravalent state, typically yielding a green product suitable for niche applications.

Controlled Chlorination Method for Tungsten Pentachloride
(WCl_5, Tungsten Pentachloride)
Tungsten pentachloride (WCl_5, Tungsten Pentachloride) is prepared by carefully chlorinating tungsten (W, Tungsten) or reducing tungsten hexachloride (WCl_6, Tungsten Hexachloride) with a limited chlorine supply at 500-700°C. This method demands precise chlorine dosing to achieve the pentavalent state, producing a dark red crystalline material.

5.3.2 Crystal Structure and Molecular Composition

Tungsten tetrachloride (WCl_4, Tungsten Tetrachloride) features a tetragonal crystal structure, with the tungsten atom coordinated to four chlorine atoms in a square planar arrangement, offering moderate stability. Tungsten pentachloride (WCl_5, Tungsten Pentachloride) adopts a trigonal bipyramidal structure with five chlorine atoms, exhibiting lower stability due to its intermediate oxidation state. These structures result in reduced volatility compared to hexavalent halides.

5.3.3 Thermal and Chemical Stability

Tungsten tetrachloride (WCl_4, Tungsten Tetrachloride) and tungsten pentachloride (WCl_5, Tungsten Pentachloride) have limited thermal stability, decomposing into lower chlorides or chlorine gas at 200-400°C. Chemically, both are highly sensitive to moisture, requiring sealed storage to prevent hydrolysis, which restricts their practical use to controlled environments.

5.3.4 Optical, Electrical, and Magnetic Properties

Tungsten tetrachloride (WCl_4, Tungsten Tetrachloride) appears green, and tungsten pentachloride (WCl_5, Tungsten Pentachloride) is dark red, yet neither exhibits significant optical activity. Electrically, both are insulators, and they lack notable magnetic properties, with their applications primarily focused on catalytic research rather than physical characteristics.

Tip

Other tungsten halides like tungsten tetrachloride (WCl_4, Tungsten Tetrachloride) hold potential in catalysis; their preparation and stability require careful attention during handling and use.

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What Are the Chemicals of Tungsten?

Chapter 6: Preparation and Applications of Tungsten Carbides and Nitrides

6.1 Tungsten Carbide (WC, Tungsten Carbide)

Tungsten carbide (WC, Tungsten Carbide) is among the most industrially valuable and widely applied compounds in the tungsten (W, Tungsten) chemical family, renowned for its exceptional hardness, wear resistance, and thermal stability. As the cornerstone of cemented carbides, tungsten carbide (WC, Tungsten Carbide) plays an indispensable role in cutting tools, mining equipment, and wear-resistant coatings. Its black or grayish-black powder appearance belies its brilliance in modern industry, with a development history spanning from early laboratory experiments to today's globalized production, showcasing the profound impact of tungsten chemistry on materials science.

6.1.1 Preparation Processes

The preparation of tungsten carbide (WC, Tungsten Carbide) encompasses a variety of methods, including high-temperature carbonization and gas-phase reactions, tailored to meet diverse purity and particle size requirements.

High-Temperature Carbonization Method
(Tungsten Powder Carbonization)
The high-temperature carbonization method reacts tungsten powder (W Powder, Tungsten Powder) with a carbon source (e.g., carbon black or graphite) at 1400-1600°C to form tungsten carbide (WC, Tungsten Carbide), following the equation: W + C → WC. This process is typically conducted in a vacuum or hydrogen atmosphere to prevent oxidation and control carbon content. After reaction, the product is ground and sieved to yield finely uniform tungsten carbide (WC, Tungsten Carbide) powder. Due to its mature process and cost-effectiveness, this method dominates industrial production, widely adopted in cemented carbide manufacturing, especially in large-scale tungsten processing enterprises in China and Europe.

Gas-Phase Carbonization Method
(Chemical Vapor Reaction)
The gas-phase carbonization method utilizes volatile tungsten compounds, such as tungsten hexafluoride (WF_6, Tungsten Hexafluoride), reacting with hydrocarbons (e.g., methane, CH_4) at 800-1000°C via a chemical vapor reaction to produce tungsten carbide (WC, Tungsten Carbide). This technique can yield nanoscale tungsten carbide (WC, Tungsten Carbide) particles, making it suitable for high-performance coatings and precision tools. The reaction occurs in specialized reactors with precise control of gas flow to ensure uniform particle distribution.

Plasma Synthesis Method

(Ultrafine Particle Preparation)

The plasma synthesis method rapidly reacts tungsten powder (W Powder, Tungsten Powder) with a carbon source in a high-temperature plasma environment (>5000°C), producing ultrafine tungsten carbide (WC, Tungsten Carbide) powder (particle size <100 nm). This method excels in generating high-purity, ultrafine particles, ideal for advanced applications like wear-resistant coatings in aerospace materials, though its high equipment costs limit it to small-batch, high-value production.

6.1.2 Crystal Structure and Molecular Composition

Tungsten carbide (WC, Tungsten Carbide) features a hexagonal crystal structure, where tungsten and carbon atoms bond in a 1:1 ratio through strong covalent bonds, forming a tightly packed lattice. German crystallographic studies indicate that this hexagonal arrangement endows it with exceptional hardness (Mohs hardness ~9, second only to diamond) and superior mechanical properties [16]. In its molecular composition, tungsten contributes high density (15.63 g/cm^3), while carbon enhances lattice stability, enabling it to maintain structural integrity under extreme conditions.

6.1.3 Thermal and Chemical Stability

Tungsten carbide (WC, Tungsten Carbide) boasts remarkable thermal stability, retaining its structure below 2600°C, and exhibits excellent oxidation resistance, only slowly oxidizing to tungsten trioxide (WO_3, Tungsten Trioxide) above 600°C in oxygen-rich environments. Chemically, it resists corrosion from acids and bases, though it can be gradually eroded in strong oxidizing acids (e.g., nitric acid). Russian materials research highlights its thermal stability and chemical inertness, making it an ideal choice for high-temperature, wear-resistant materials [17].

6.1.4 Optical, Electrical, and Magnetic Properties

The optical properties of tungsten carbide (WC, Tungsten Carbide) are unremarkable, with its black or grayish-black appearance resulting from electron absorption in its crystal structure, lacking notable fluorescence or optical activity. Electrically, it possesses moderate conductivity (resistivity ~20 μΩ·cm), significantly lower than metallic tungsten (W, Tungsten), yet sufficient for applications like electrical discharge machining. Magnetically, tungsten carbide (WC, Tungsten Carbide) shows no significant properties, with its value primarily rooted in mechanical attributes rather than physical characteristics.

Tip

The diverse preparation methods and exceptional hardness and wear resistance of tungsten carbide (WC, Tungsten Carbide) render it irreplaceable in industrial applications; procurement should focus on particle size and purity tailored to specific uses.

6.2 Tungsten Nitride (WN, Tungsten Nitride)

Tungsten nitride (WN, Tungsten Nitride) is a compound formed by tungsten (W, Tungsten) and nitrogen, with a narrower application scope compared to tungsten carbide (WC, Tungsten Carbide), yet it holds unique value in wear-resistant coatings, electronic materials, and high-hardness thin films. Its dark gray appearance and excellent physical properties make tungsten nitride (WN, Tungsten Nitride) a lesser-known gem within the tungsten chemical family, with its research and development opening new possibilities in materials science.

6.2.1 Preparation Processes

The preparation of tungsten nitride (WN, Tungsten Nitride) primarily relies on high-temperature nitridation or gas-phase deposition techniques, requiring precise control to ensure product quality.

High-Temperature Nitridation Method
(Tungsten Powder Nitridation)
The high-temperature nitridation method reacts tungsten powder (W Powder, Tungsten Powder) with nitrogen gas (N_2) or ammonia (NH_3) at 1000-1200°C to form tungsten nitride (WN, Tungsten Nitride), represented by the equation: $W + N_2 \rightarrow WN$. This process is conducted in a vacuum or inert atmosphere to avoid oxygen interference, yielding a dark gray powder. Its simplicity and ability to utilize readily available tungsten powder (W Powder, Tungsten Powder) make it suitable for industrial production.

Gas-Phase Deposition Method
(CVD or PVD)
The gas-phase deposition method employs chemical vapor deposition (CVD) or physical vapor deposition (PVD) to react tungsten hexafluoride (WF_6, Tungsten Hexafluoride) or tungsten (W, Tungsten) with a nitrogen source (e.g., ammonia) at 600-900°C, forming tungsten nitride (WN, Tungsten Nitride) thin films. This technique produces high-purity films, commonly used for wear-resistant coatings and electronic components, requiring specialized equipment to control film thickness and uniformity.

6.2.2 Crystal Structure and Molecular Composition

Tungsten nitride (WN, Tungsten Nitride) typically adopts a cubic crystal structure, with tungsten and nitrogen atoms bonded in a 1:1 ratio through a covalent network. Russian crystallographic research notes that its lattice structure resembles that of tungsten carbide (WC, Tungsten Carbide), though the incorporation of nitrogen results in slightly lower hardness (Mohs hardness ~8) and a density of approximately 14.5 g/cm^3 [17]. The strong covalent bonds in its molecular composition contribute to its robust mechanical properties and corrosion resistance.

6.2.3 Thermal and Chemical Stability

Tungsten nitride (WN, Tungsten Nitride) remains stable up to about 1000°C in inert atmospheres but oxidizes to tungsten trioxide (WO_3, Tungsten Trioxide) above 600°C in oxygen-rich conditions, exhibiting slightly lower thermal stability than tungsten carbide (WC, Tungsten Carbide). Chemically, it resists corrosion from acids and bases, though it gradually decomposes in strongly oxidizing environments (e.g., concentrated nitric acid). Its corrosion resistance enhances its suitability for coating applications.

6.2.4 Optical, Electrical, and Magnetic Properties

The optical properties of tungsten nitride (WN, Tungsten Nitride) are unremarkable, with its dark gray appearance lacking significant optical activity. Electrically, it functions as a semiconductor (bandgap ~1.8-2.2 eV) with moderate conductivity, making it viable for electronic materials. Magnetically, tungsten nitride (WN, Tungsten Nitride) exhibits no notable properties, with its applications primarily driven by mechanical and electrical attributes.

Tip

The preparation of tungsten nitride (WN, Tungsten Nitride) requires stringent nitridation control, and its potential in wear-resistant coatings and electronic materials merits further exploration.

6.3 Other Tungsten Carbides and Nitrides

Beyond tungsten carbide (WC, Tungsten Carbide) and tungsten nitride (WN, Tungsten Nitride), the tungsten carbide and nitride family includes compounds like ditungsten carbide (W_2C, Ditungsten Carbide) and tungsten carbonitride ($WC_{1-x}N_x$, Tungsten Carbonitride), which offer unique value in specific wear-resistant and high-temperature applications.

6.3.1 Preparation Processes

The preparation processes for these other tungsten carbides and nitrides typically involve high-temperature reactions or composite techniques.

Controlled Carbonization Method for Ditungsten Carbide (W_2C, Ditungsten Carbide)

Ditungsten carbide (W_2C, Ditungsten Carbide) is synthesized by reacting tungsten (W, Tungsten) with carbon at 1200-1400°C, carefully controlling the carbon ratio to avoid excess formation of tungsten carbide (WC, Tungsten Carbide). This method ensures the desired divalent carbide structure.

Carbon-Nitrogen Co-Diffusion Method for Tungsten Carbonitride ($WC_{1-x}N_x$, Tungsten Carbonitride)

Tungsten carbonitride ($WC_{1-x}N_x$, Tungsten Carbonitride) is prepared by reacting tungsten (W, Tungsten) or tungsten carbide (WC, Tungsten Carbide) with nitrogen and a carbon source at 800-1000°C, forming a composite structure through co-diffusion of carbon and nitrogen atoms.

6.3.2 Crystal Structure and Molecular Composition

Ditungsten carbide (W_2C, Ditungsten Carbide) features a hexagonal crystal structure with a tungsten-to-carbon ratio of 2:1, resulting in a less dense lattice than tungsten carbide (WC, Tungsten Carbide). Tungsten carbonitride ($WC_{1-x}N_x$, Tungsten Carbonitride) forms a composite crystal structure, with carbon and nitrogen atoms partially substituting to create a solid solution, enhancing its properties.

6.3.3 Thermal and Chemical Stability

Ditungsten carbide (W_2C, Ditungsten Carbide) remains stable below 2000°C but decomposes in oxidizing atmospheres. Tungsten carbonitride ($WC_{1-x}N_x$, Tungsten Carbonitride) combines the stability of carbides and nitrides, withstanding temperatures up to approximately 1500°C, offering robust performance in demanding conditions.

6.3.4 Optical, Electrical, and Magnetic Properties

Ditungsten carbide (W_2C, Ditungsten Carbide) and tungsten carbonitride ($WC_{1-x}N_x$, Tungsten Carbonitride) lack significant optical activity, with moderate electrical conductivity suitable for specific applications, and no notable magnetic properties, their value lying in mechanical performance.

Tip

Other tungsten carbides and nitrides, such as ditungsten carbide (W_2C, Ditungsten Carbide), excel in wear resistance and high-temperature uses; selection should focus on their specific properties for targeted applications.

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What Are the Chemicals of Tungsten?

Chapter 7: Preparation and Applications of Tungsten Sulfides & Phosphides

7.1 Tungsten Disulfide (WS_2, Tungsten Disulfide)

Tungsten disulfide (WS_2, Tungsten Disulfide) stands as one of the most significant sulfides within the tungsten (W, Tungsten) chemical family, celebrated for its unique layered structure, low friction coefficient, and exceptional lubricity. As an outstanding solid lubricant, tungsten disulfide (WS_2, Tungsten Disulfide) finds extensive applications in mechanical industries, high-temperature environments, and two-dimensional materials research. Its deep gray to black powder or flake form conceals remarkable performance capabilities, tracing a development path from traditional lubricants to cutting-edge nanotechnology, demonstrating the diverse contributions of tungsten chemistry to materials science.

7.1.1 Preparation Processes

The preparation of tungsten disulfide (WS_2, Tungsten Disulfide) encompasses a variety of methods, including high-temperature sulfidation and chemical vapor deposition, tailored to meet diverse particle size and purity requirements.

High-Temperature Sulfidation Method
(Tungsten Powder Sulfidation)

The high-temperature sulfidation method reacts tungsten powder (W Powder, Tungsten Powder) with sulfur powder (S) at temperatures ranging from 600°C to 900°C to produce tungsten disulfide (WS_2, Tungsten Disulfide), following the equation: $W + 2S \rightarrow WS_2$. This process is typically conducted in a vacuum or inert atmosphere (e.g., argon) to prevent oxidation, yielding a deep gray powder. After the reaction, the product is ground and sieved to achieve uniform particles. Widely used in industrial production due to its simplicity and readily available raw materials, this method dominates the manufacturing of lubricating materials.

Chemical Vapor Deposition Method (CVD)

The chemical vapor deposition (CVD) method utilizes tungsten trioxide (WO_3, Tungsten Trioxide) or tungsten hexafluoride (WF_6, Tungsten Hexafluoride) reacting with hydrogen sulfide (H_2S) at 400-700°C to form tungsten disulfide (WS_2, Tungsten Disulfide) thin films. This technique can produce single-layer or multilayer tungsten disulfide (WS_2, Tungsten Disulfide), making it ideal for two-dimensional materials and electronic device research. The reaction occurs in specialized reactors, requiring precise control of gas flow and temperature to ensure film quality.

Mechanical Exfoliation Method

(Nanosheet Preparation)

The mechanical exfoliation method separates nanosheets from bulk tungsten disulfide (WS_2, Tungsten Disulfide) using physical techniques (e.g., ultrasonic exfoliation or adhesive tape), commonly employed in laboratories to prepare high-purity single-layer tungsten disulfide (WS_2, Tungsten Disulfide). Although limited in yield, this method preserves the integrity of the layered structure, making it valuable for fundamental research and nanotechnology exploration.

7.1.2 Crystal Structure and Molecular Composition

Tungsten disulfide (WS_2, Tungsten Disulfide) features a hexagonal layered crystal structure, with tungsten atoms sandwiched between two sulfur atom layers, forming a "sandwich"-like two-dimensional unit held together by weak van der Waals forces between adjacent layers. German crystallographic studies indicate that this layered structure results in low shear strength (friction coefficient ~0.03-0.1) and high lubricity [16]. In its molecular composition, each tungsten atom bonds covalently with two sulfur atoms, with an interlayer spacing of approximately 6.18Å, contributing to its excellent performance in mechanical sliding and exfoliation.

7.1.3 Thermal and Chemical Stability

Tungsten disulfide (WS_2, Tungsten Disulfide) exhibits outstanding thermal stability in inert atmospheres, withstanding temperatures up to approximately 1200°C without degradation. However, in oxygen-rich environments, it oxidizes above 350°C to form tungsten trioxide (WO_3, Tungsten Trioxide) and sulfur dioxide (SO_2), limiting its use under high-temperature oxidative conditions. Chemically, it resists corrosion from acids and bases but gradually decomposes under strong oxidants (e.g., hydrogen peroxide). Russian materials research highlights its thermal stability and chemical inertness, making it highly effective in high-temperature lubrication applications [17].

7.1.4 Optical, Electrical, and Magnetic Properties

The optical properties of tungsten disulfide (WS_2, Tungsten Disulfide) vary with layer thickness; single-layer tungsten disulfide (WS_2, Tungsten Disulfide) possesses a direct bandgap (~2.0 eV), exhibiting fluorescence, while multilayer forms have an indirect bandgap (~1.3 eV), reducing optical activity. Electrically, it functions as a semiconductor, with single layers offering superior conductivity compared to multilayers, making it suitable for optoelectronic devices. Magnetically, tungsten disulfide (WS_2, Tungsten Disulfide) shows no significant properties, with its applications primarily driven by lubricity and electrical characteristics.

Tip

The flexible preparation methods and layered structure of tungsten disulfide (WS_2, Tungsten Disulfide) give it a unique edge in lubrication and two-dimensional materials; selection should consider layer count and purity based on application needs.

7.2 Tungsten Phosphide (WP, Tungsten Phosphide)

Tungsten phosphide (WP, Tungsten Phosphide) is a compound formed between tungsten (W, Tungsten) and phosphorus, with a more limited application scope compared to tungsten disulfide (WS_2, Tungsten Disulfide), yet it holds specific value in catalysts and wear-resistant materials. Its gray-black appearance and excellent catalytic properties position tungsten phosphide (WP, Tungsten Phosphide) as a discreet yet impactful player in the tungsten chemical family, with its research contributing new avenues to catalysis and materials science.

7.2.1 Preparation Processes

The preparation of tungsten phosphide (WP, Tungsten Phosphide) primarily involves high-temperature phosphidation or chemical reduction techniques, requiring precise reaction condition control.

High-Temperature Phosphidation Method
(Tungsten Powder Phosphidation)
The high-temperature phosphidation method reacts tungsten powder (W Powder, Tungsten Powder) with phosphorus powder (P) or phosphine (PH_3) at 800-1000°C to form tungsten phosphide (WP, Tungsten Phosphide), following the equation: $W + P \rightarrow WP$. This process occurs in a sealed reactor to exclude oxygen, producing a gray-black powder. It is suitable for both industrial and small-scale production due to its straightforward process and use of available tungsten resources.

Chemical Reduction Method
(Oxide Phosphidation)
The chemical reduction method prepares tungsten phosphide (WP, Tungsten Phosphide) by reacting tungsten trioxide (WO_3, Tungsten Trioxide) with a phosphorus source (e.g., red phosphorus) in a hydrogen atmosphere at 700-900°C. This technique can produce nanoscale particles, ideal for catalyst development, with careful phosphorus dosing needed to prevent the formation of lower phosphides.

7.2.2 Crystal Structure and Molecular Composition

Tungsten phosphide (WP, Tungsten Phosphide) typically adopts an orthorhombic crystal structure, with tungsten and phosphorus atoms bonded in a 1:1 ratio within a covalent network. Research indicates that its relatively dense lattice (density ~12.5 g/cm^3) and the incorporation of phosphorus enhance its catalytic activity [17]. The covalent tungsten-phosphorus bonds in its molecular composition contribute to its high hardness and chemical stability.

7.2.3 Thermal and Chemical Stability

Tungsten phosphide (WP, Tungsten Phosphide) remains stable up to approximately 900°C in inert atmospheres but oxidizes to tungsten trioxide (WO_3, Tungsten Trioxide) and phosphorus oxides above 500°C in oxygen-rich conditions. Chemically, it resists corrosion from acids and bases but decomposes gradually under strong oxidants, with its stability supporting its performance in catalytic reactions.

7.2.4 Optical, Electrical, and Magnetic Properties

Tungsten phosphide (WP, Tungsten Phosphide) exhibits no significant optical activity, with its gray-black appearance lacking distinctive optical traits. Electrically, it is a narrow-bandgap semiconductor (~0.8-1.2 eV) with moderate conductivity, suitable as a catalyst support. Magnetically, it shows no notable properties, with its primary value derived from catalytic capabilities.

Tip

The preparation of tungsten phosphide (WP, Tungsten Phosphide) requires precise phosphidation control, and its potential in catalysis merits further attention.

7.3 Other Tungsten Sulfides and Phosphides

In addition to tungsten disulfide (WS_2, Tungsten Disulfide) and tungsten phosphide (WP, Tungsten Phosphide), the tungsten sulfide and phosphide family includes compounds such as ditungsten trisulfide (W_2S_3, Ditungsten Trisulfide) and tungsten diphosphide (WP_2, Tungsten Diphosphide), which offer distinct advantages in specific catalysis and high-hardness applications.

7.3.1 Preparation Processes

The preparation of these other tungsten sulfides and phosphides typically involves high-temperature reaction techniques.

Controlled Sulfidation Method for Ditungsten Trisulfide (W_2S_3, Ditungsten Trisulfide)

Ditungsten trisulfide (W_2S_3, Ditungsten Trisulfide) is synthesized by reacting tungsten (W, Tungsten) with sulfur at 500-700°C, controlling the sulfur ratio to avoid excess sulfidation.

High-Temperature Phosphidation Method for Tungsten Diphosphide

(WP_2, Tungsten Diphosphide)

Tungsten diphosphide (WP_2, Tungsten Diphosphide) is prepared by reacting tungsten (W, Tungsten) with excess phosphorus at 900-1100°C, forming a phosphorus-rich compound.

7.3.2 Crystal Structure and Molecular Composition

Ditungsten trisulfide (W_2S_3, Ditungsten Trisulfide) features an orthorhombic crystal structure with a tungsten-to-sulfur ratio of 2:3, resulting in a relatively loose lattice. Tungsten diphosphide (WP_2, Tungsten Diphosphide) adopts a monoclinic structure with a 1:2 tungsten-to-phosphorus ratio, enhancing its catalytic activity.

7.3.3 Thermal and Chemical Stability

Ditungsten trisulfide (W_2S_3, Ditungsten Trisulfide) remains stable below 800°C but oxidizes readily in oxygen-rich conditions. Tungsten diphosphide (WP_2, Tungsten Diphosphide) withstands temperatures up to approximately 1000°C, exhibiting strong chemical stability.

7.3.4 Optical, Electrical, and Magnetic Properties

Ditungsten trisulfide (W_2S_3, Ditungsten Trisulfide) and tungsten diphosphide (WP_2, Tungsten Diphosphide) lack significant optical activity, exhibit moderate electrical conductivity suitable for specific applications, and show no notable magnetic properties, with their value primarily in catalytic performance.

Tip

Other tungsten sulfides and phosphides, such as ditungsten trisulfide (W_2S_3, Ditungsten Trisulfide), offer unique benefits in catalysis; selection should focus on their chemical composition.

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What Are the Chemicals of Tungsten?
Chapter 8:

Preparation & Applications of Organometallic Tungsten Compounds

8.1 Tungsten Hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl)

Tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl) is the most representative organometallic compound of tungsten (W, Tungsten), renowned for its high volatility, coordination chemistry activity, and catalytic capabilities in organic synthesis. As a classic metal carbonyl compound, tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl) demonstrates broad application potential in catalyst preparation, organic reactions, and thin-film deposition. Its white crystalline appearance and distinctive odor belie its central role in chemistry, with a development trajectory from laboratory research to industrial applications that highlights the extension of tungsten chemistry into the realm of organic chemistry.

8.1.1 Preparation Processes

The preparation of tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl) involves diverse methods, including high-pressure carbonylation and reductive carbonylation techniques, tailored to meet varying purity and application needs.

High-Pressure Carbonylation Method
(Tungsten Powder Carbonylation)

The high-pressure carbonylation method reacts tungsten powder (W Powder, Tungsten Powder) with carbon monoxide (CO) under high pressure (100-200 atm) and elevated temperatures (200-300°C) to produce tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl), following the equation: $W + 6CO \rightarrow W(CO)_6$. This process requires a high-pressure autoclave, often with catalysts (e.g., iodides) added to enhance reaction efficiency. The product precipitates as white crystals, which are purified via sublimation to yield high-purity tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl). This method is a mainstay in both industrial and laboratory settings due to its directness and high yield.

Reductive Carbonylation Method
(Halide Reduction)

The reductive carbonylation method prepares tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl) by reacting tungsten hexachloride (WCl_6, Tungsten Hexachloride) with carbon monoxide in the presence of a reducing agent (e.g., zinc or aluminum powder) at 150-250°C. This reaction must occur under anhydrous and oxygen-free conditions to prevent byproduct formation. Suitable for small-scale production, this method leverages intermediate tungsten halides, improving resource utilization and is commonly used for high-purity organometallic compound synthesis.

Gas-Phase Synthesis Method

(High-Purity Preparation)

The gas-phase synthesis method involves reacting tungsten (W, Tungsten) or its compounds with carbon monoxide in the vapor phase under high pressure (50-100 atm) and temperatures around 300°C, directly forming tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl) gas, which is then condensed into crystals. This technique excels in eliminating trace impurities, producing ultra-high-purity tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl) ideal for electronic materials and precision catalyst research.

8.1.2 Crystal Structure and Molecular Composition

Tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl) adopts an octahedral crystal structure, with a central tungsten atom coordinated to six carbonyl ligands (CO) via coordination bonds, forming a symmetrical $W(CO)_6$ molecular unit. German crystallographic studies indicate that this octahedral configuration contributes to its high volatility (melting point ~170°C, sublimation point ~175°C), making it highly effective in gas-phase reactions [16]. In its molecular composition, the tungsten atom is in a zero oxidation state, with the carbonyl ligands' strong σ-donor and π-acceptor properties enhancing its chemical stability, facilitating coordination or substitution reactions with other ligands in organic processes.

8.1.3 Thermal and Chemical Stability

Tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl) exhibits moderate thermal stability under oxygen- and water-free conditions, maintaining its crystalline structure below approximately 150°C. However, at higher temperatures or in air, it decomposes into carbon monoxide and tungsten oxides. Chemically, it is relatively unstable, sensitive to light and oxygen, decomposing under UV irradiation or in the presence of oxygen into tungsten (W, Tungsten) and carbon monoxide, necessitating storage and handling in an inert atmosphere. Russian chemical research highlights its high coordination activity, positioning it as an effective catalyst precursor in organic synthesis [17].

8.1.4 Optical, Electrical, and Magnetic Properties

The optical properties of tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl) are evident in its white crystalline appearance, resulting from electron transitions involving the carbonyl ligands, though it has limited utility in optical applications. Electrically, it is an insulator in its solid state, but in gaseous or solution forms, it may exhibit slight conductivity due to decomposition. Magnetically, tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl) shows no significant properties, with its primary applications relying on its coordination chemistry rather than physical characteristics.

Tip

The preparation of tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl) requires strict exclusion of oxygen and light; its coordination activity offers significant advantages in catalysis and organic synthesis, with procurement focusing on purity and storage conditions.

8.2 Tungstenocene Dichloride (Cp_2WCl_2, Tungstenocene Dichloride)

Tungstenocene dichloride (Cp_2WCl_2, Tungstenocene Dichloride) is a key organometallic tungsten compound, distinguished by its stable metallocene structure and reactivity in organometallic chemistry. As a member of the metallocene family, tungstenocene dichloride (Cp_2WCl_2, Tungstenocene Dichloride) holds unique value in catalyst preparation, organic synthesis, and materials science research. Its green crystalline appearance and chemical versatility set it apart among tungsten chemicals, with its study advancing the application of organometallic tungsten compounds in modern chemistry.

8.2.1 Preparation Processes

The preparation of tungstenocene dichloride (Cp_2WCl_2, Tungstenocene Dichloride) primarily relies on coordination reaction techniques, conducted under anhydrous and oxygen-free conditions to ensure product quality.

Halide Coordination Method
(Tungsten Hexachloride Reaction)

The halide coordination method synthesizes tungstenocene dichloride (Cp_2WCl_2, Tungstenocene Dichloride) by reacting tungsten hexachloride (WCl_6, Tungsten Hexachloride) with sodium cyclopentadienide (NaCp) in a solvent like tetrahydrofuran (THF) at temperatures ranging from -78°C to room temperature, following the equation: $WCl_6 + 2NaCp \rightarrow Cp_2WCl_2 + 2NaCl + 2Cl_2$. This process requires an inert atmosphere (e.g., nitrogen or argon), with the reaction product extracted and recrystallized to yield green crystals. Predominant in laboratory synthesis, this method allows precise ligand coordination control, ideal for high-purity tungstenocene dichloride (Cp_2WCl_2, Tungstenocene Dichloride) production.

Reductive Coordination Method
(Tungsten Trioxide Substrate)

The reductive coordination method prepares tungstenocene dichloride (Cp_2WCl_2, Tungstenocene Dichloride) by reacting tungsten trioxide (WO_3, Tungsten Trioxide) with a reducing agent (e.g., zinc powder) and cyclopentadiene (C_5H_6) in the presence of a chlorinating agent (e.g., PCl_5) at 100-150°C. Conducted under anhydrous conditions, the product is obtained through solvent extraction and purification. This method suits small-scale production, leveraging oxide raw materials to reduce costs, and is commonly used in organometallic chemistry research.

8.2.2 Crystal Structure and Molecular Composition

Tungstenocene dichloride (Cp_2WCl_2, Tungstenocene Dichloride) adopts a sandwich-type crystal structure, with two cyclopentadienyl (Cp) ligands paralleling each other around a central tungsten atom, and two chlorine atoms positioned on the opposite side, forming a four-coordinate structure. Japanese chemical research indicates that this sandwich configuration enhances its stability (decomposing at ~230°C), with tungsten in the +4 oxidation state, and the π-electron clouds of the cyclopentadienyl ligands forming strong coordination bonds with tungsten [20]. The molecular composition, featuring Cp ligands, imparts its organometallic character, enabling high reactivity in catalytic processes.

8.2.3 Thermal and Chemical Stability

Tungstenocene dichloride (Cp_2WCl_2, Tungstenocene Dichloride) exhibits good thermal stability under oxygen-free conditions, retaining its structure below approximately 200°C. However, in the presence of oxygen or moisture, it decomposes into tungsten oxides and organic byproducts, requiring storage in an inert atmosphere. Chemically, it has moderate stability, being sensitive to water and oxidants, with its coordination structure contributing to significant reactivity in organic reactions, as noted in research studies [21].

8.2.4 Optical, Electrical, and Magnetic Properties

The optical properties of tungstenocene dichloride (Cp_2WCl_2, Tungstenocene Dichloride) are reflected in its green crystalline appearance, arising from d-electron transitions of the tungsten atom, though it lacks significant optical utility. Electrically, it is an insulator in its solid state with no notable conductivity. Magnetically, tungstenocene dichloride (Cp_2WCl_2, Tungstenocene Dichloride) shows no significant properties due to the pairing of tungsten's d-electrons, with its applications primarily driven by chemical reactivity rather than physical traits.

Tip

The preparation of tungstenocene dichloride (Cp_2WCl_2, Tungstenocene Dichloride) requires anhydrous and oxygen-free conditions; its stable sandwich structure offers potential in organometallic catalysis, with procurement emphasizing purity and stability.

8.3 Other Organometallic Tungsten Compounds

Beyond tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl) and tungstenocene dichloride (Cp_2WCl_2, Tungstenocene Dichloride), the organometallic tungsten compound family includes tungstenocene tetracarbonyl ($CpW(CO)_4$, Tungstenocene Tetracarbonyl) and alkyl tungsten compounds (e.g., $W(CH_3)_6$, Hexamethyltungsten), which hold specific value in catalysis and organic synthesis research.

8.3.1 Preparation Processes

The preparation of these other organometallic tungsten compounds typically involves laboratory synthesis techniques with precise reaction condition control.

Carbonyl Coordination Method for Tungstenocene Tetracarbonyl ($CpW(CO)_4$, Tungstenocene Tetracarbonyl)

Tungstenocene tetracarbonyl ($CpW(CO)_4$, Tungstenocene Tetracarbonyl) is synthesized by reacting tungstenocene dichloride (Cp_2WCl_2, Tungstenocene Dichloride) with carbon monoxide under high pressure (50-100 atm) and low temperatures (0-50°C), avoiding excess carbonylation to ensure the desired product.

Alkylation Method for Hexamethyltungsten ($W(CH_3)_6$, Hexamethyltungsten)

Hexamethyltungsten ($W(CH_3)_6$, Hexamethyltungsten) is prepared by reacting tungsten hexachloride (WCl_6, Tungsten Hexachloride) with methyllithium (CH_3Li) at -78°C under extremely dry conditions, requiring meticulous handling due to its instability.

8.3.2 Crystal Structure and Molecular Composition

Tungstenocene tetracarbonyl ($CpW(CO)_4$, Tungstenocene Tetracarbonyl) features a monocyclopentadienyl coordination structure, with tungsten bonded to one Cp ligand and four CO ligands, forming a five-coordinate arrangement. Hexamethyltungsten ($W(CH_3)_6$, Hexamethyltungsten) adopts an octahedral structure, with six methyl ligands surrounding the tungsten atom, though its stability is notably low.

8.3.3 Thermal and Chemical Stability

Tungstenocene tetracarbonyl ($CpW(CO)_4$, Tungstenocene Tetracarbonyl) is stable below 150°C but decomposes readily in oxygen-rich environments. Hexamethyltungsten ($W(CH_3)_6$, Hexamethyltungsten) is extremely unstable, decomposing at room temperature and requiring storage at low temperatures.

8.3.4 Optical, Electrical, and Magnetic Properties

Tungstenocene tetracarbonyl ($CpW(CO)_4$, Tungstenocene Tetracarbonyl) and hexamethyltungsten ($W(CH_3)_6$, Hexamethyltungsten) exhibit no significant optical activity, are insulators electrically, and lack notable magnetic properties, with their value primarily in catalytic activity rather than physical characteristics.

Tip

Other organometallic tungsten compounds offer potential in catalysis research; selection should focus on their stability and reactivity.

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What Are the Chemicals of Tungsten?
Chapter 9:
Preparation & Applications of Tungsten-Containing Catalysts & Reagents

9.1 Phosphotungstic Acid ($H_3PW_{12}O_{40}$, Phosphotungstic Acid)

Phosphotungstic acid ($H_3PW_{12}O_{40}$, Phosphotungstic Acid) is one of the most representative and widely applied tungsten-containing catalysts and reagents, renowned for its strong acidity, high catalytic activity, and stability across various reactions. As a typical heteropoly acid, phosphotungstic acid ($H_3PW_{12}O_{40}$, Phosphotungstic Acid) excels in organic synthesis, petrochemical processes, and analytical chemistry. Its white or pale yellow crystalline appearance belies its pivotal role in catalysis, with a developmental trajectory from laboratory studies to industrial applications that underscores the profound impact of tungsten chemistry in the catalytic domain.

9.1.1 Preparation Processes

The preparation of phosphotungstic acid ($H_3PW_{12}O_{40}$, Phosphotungstic Acid) encompasses diverse methods, including acid precipitation and extraction purification techniques, tailored to meet varying purity and application requirements.

Acid Precipitation Method
(Tungstate Reaction)
The acid precipitation method involves reacting sodium tungstate (Na_2WO_4, Sodium Tungstate) with phosphoric acid (H_3PO_4) under acidic conditions (typically adjusted to pH 1-2 with hydrochloric or sulfuric acid) to form phosphotungstic acid ($H_3PW_{12}O_{40}$, Phosphotungstic Acid). The reaction equation is: $12Na_2WO_4 + H_3PO_4 + 21HCl \rightarrow H_3PW_{12}O_{40} + 24NaCl + 12H_2O$. Conducted at 50-80°C, the product precipitates as white or pale yellow crystals, which are filtered, washed, and dried (at ~100-150°C) to obtain the final product. This method's simplicity and use of accessible raw materials make it prevalent in both industrial and laboratory settings.

Extraction Purification Method
(Solution Extraction)
The extraction purification method prepares phosphotungstic acid ($H_3PW_{12}O_{40}$, Phosphotungstic Acid) by acidifying a tungsten-containing solution (e.g., tungstate solution) with phosphoric acid, followed by extraction with an organic solvent (e.g., diethyl ether or butanone), and subsequent solvent evaporation and crystallization to yield a pure product. This technique effectively removes impurities, producing high-purity phosphotungstic acid ($H_3PW_{12}O_{40}$, Phosphotungstic Acid), commonly used in analytical reagents and precision catalyst research within laboratory environments.

Ion Exchange Method
(High-Purity Preparation)
The ion exchange method mixes a tungstate solution with phosphoric acid, passes it through an ion exchange resin to isolate phosphotungstate ions, and then acidifies the solution to precipitate phosphotungstic acid ($H_3PW_{12}O_{40}$, Phosphotungstic Acid). This method excels in controlling trace impurities, making it suitable for ultra-high-purity product preparation, often employed in advanced catalysis and scientific studies.

9.1.2 Crystal Structure and Molecular Composition

Phosphotungstic acid ($H_3PW_{12}O_{40}$, Phosphotungstic Acid) adopts a Keggin-type heteropoly acid structure, with a central phosphorus atom surrounded by 12 tungsten-oxygen octahedra, forming a highly symmetrical cage-like molecule. German crystallographic studies reveal that this structure imparts strong acidity (pKa < 0) and high catalytic activity, with the crystal typically containing multiple water molecules (commonly $H_3PW_{12}O_{40} \cdot nH_2O$, n ≈ 14-30) [16]. In its molecular composition, tungsten is in the +6 oxidation state, phosphorus in the +5 state, linked via oxygen bridges to create a stable three-dimensional framework that maintains integrity under various reaction conditions.

9.1.3 Thermal and Chemical Stability

Phosphotungstic acid ($H_3PW_{12}O_{40}$, Phosphotungstic Acid) exhibits good thermal stability under dry conditions, retaining its structure below approximately 300°C, above which it loses crystal water and gradually decomposes into tungsten trioxide (WO_3, Tungsten Trioxide) and phosphorus oxides. Chemically, it is exceptionally stable in acidic environments but decomposes into tungstates and phosphates under strongly alkaline conditions. Russian catalysis research highlights its strong acidity and stability, making it highly effective in acid-catalyzed reactions [17].

9.1.4 Optical, Electrical, and Magnetic Properties

The optical properties of phosphotungstic acid ($H_3PW_{12}O_{40}$, Phosphotungstic Acid) are unremarkable, with its white or pale yellow crystals lacking significant optical activity, primarily serving chemical rather than optical purposes. Electrically, it is an insulator in its solid state but exhibits ionic conductivity in solution due to its strong acidity. Magnetically, phosphotungstic acid ($H_3PW_{12}O_{40}$, Phosphotungstic Acid) shows no notable properties, with its value rooted in its catalytic performance and acidity.

Tip

The flexible preparation methods and strong acidity of phosphotungstic acid ($H_3PW_{12}O_{40}$, Phosphotungstic Acid) offer significant advantages in catalysis; procurement should consider its purity and hydration state.

9.2 Silicotungstic Acid ($H_4SiW_{12}O_{40}$, Silicotungstic Acid)

Silicotungstic acid ($H_4SiW_{12}O_{40}$, Silicotungstic Acid) is another crucial tungsten-containing heteropoly acid, distinguished by its high acidity, redox activity, and versatility in organic synthesis and catalytic reactions. As a Keggin-type heteropoly acid, silicotungstic acid ($H_4SiW_{12}O_{40}$, Silicotungstic Acid) finds broad applications in acid catalysis, oxidation reactions, and fuel cell research. Its colorless or light yellow crystalline appearance conceals its potent catalytic capabilities, with its study and application expanding the frontiers of tungsten chemistry in green chemistry and energy fields.

9.2.1 Preparation Processes

The preparation of silicotungstic acid ($H_4SiW_{12}O_{40}$, Silicotungstic Acid) primarily involves acid reaction and extraction techniques, conducted under acidic conditions.

Acid Reaction Method
(Sodium Silicate and Tungstate Reaction)
The acid reaction method synthesizes silicotungstic acid ($H_4SiW_{12}O_{40}$, Silicotungstic Acid) by reacting sodium silicate (Na_2SiO_3) with sodium tungstate (Na_2WO_4, Sodium Tungstate) in an acidic solution (adjusted to pH 1-2 with hydrochloric acid) at 60-90°C, following the equation: $12Na_2WO_4 + Na_2SiO_3 + 22HCl \rightarrow H_4SiW_{12}O_{40} + 26NaCl + 11H_2O$. The product precipitates as crystals, which are filtered and dried (at ~100-120°C) to obtain the final compound. This method's accessibility and mature process make it widely used in industrial and laboratory production.

Extraction Method (Solution Purification)
The extraction method involves acidifying a mixed tungsten- and silicon-containing solution, extracting silicotungstic acid ($H_4SiW_{12}O_{40}$, Silicotungstic Acid) with an organic solvent (e.g., diethyl ether), and evaporating the solvent followed by crystallization to produce a pure product. This technique effectively removes impurities, yielding high-purity silicotungstic acid ($H_4SiW_{12}O_{40}$, Silicotungstic Acid), frequently employed in catalyst research.

9.2.2 Crystal Structure and Molecular Composition

Silicotungstic acid ($H_4SiW_{12}O_{40}$, Silicotungstic Acid) features a Keggin-type heteropoly acid structure, with a central silicon atom encircled by 12 tungsten-oxygen octahedra, forming a symmetrical cage-like molecule. Studies indicate that this structure provides extremely strong acidity (pKa < 0) and redox capabilities, with the crystal typically containing multiple water molecules (commonly $H_4SiW_{12}O_{40} \cdot nH_2O$, $n \approx 14$-24) [19]. In its molecular composition, tungsten is in the +6 oxidation state, silicon in the +4 state, connected via oxygen bridges to form a robust three-dimensional framework.

9.2.3 Thermal and Chemical Stability

Silicotungstic acid ($H_4SiW_{12}O_{40}$, Silicotungstic Acid) maintains good thermal stability under dry conditions, preserving its structure below approximately 350°C, beyond which it loses crystal water and decomposes into oxides. Chemically, it is stable in acidic environments but breaks down into silicates and tungstates under strong alkaline conditions. Its high acidity and stability make it highly effective in various catalytic reactions.

9.2.4 Optical, Electrical, and Magnetic Properties

The optical properties of silicotungstic acid ($H_4SiW_{12}O_{40}$, Silicotungstic Acid) are unremarkable, with its colorless or light yellow crystals lacking significant optical activity. Electrically, it is an insulator in solid form but exhibits ionic conductivity in solution due to its strong acidity. Magnetically, silicotungstic acid ($H_4SiW_{12}O_{40}$, Silicotungstic Acid) shows no notable properties, with its applications primarily driven by its catalytic attributes.

Tip
The straightforward preparation and high acidity and redox activity of silicotungstic acid ($H_4SiW_{12}O_{40}$, Silicotungstic Acid) offer potential in catalysis; procurement should focus on purity and hydration state.

9.3 Other Tungsten-Containing Catalysts and Reagents

Beyond phosphotungstic acid ($H_3PW_{12}O_{40}$, Phosphotungstic Acid) and silicotungstic acid ($H_4SiW_{12}O_{40}$, Silicotungstic Acid), the family of tungsten-containing catalysts and reagents includes compounds such as zinc tungstate ($ZnWO_4$, Zinc Tungstate) and ammonium tungstate ($(NH_4)_2WO_4$, Ammonium Tungstate), which hold specific value in catalysis, photocatalysis, and analytical applications.

9.3.1 Preparation Processes

The preparation of these other tungsten-containing catalysts and reagents typically involves solution reactions or solid-phase synthesis techniques.

Solid-Phase Reaction Method for Zinc Tungstate ($ZnWO_4$, Zinc Tungstate)
Zinc tungstate ($ZnWO_4$, Zinc Tungstate) is synthesized by reacting sodium tungstate (Na_2WO_4, Sodium Tungstate) with zinc sulfate ($ZnSO_4$) at high temperatures (800-1000°C) in a solid-phase reaction, followed by cooling and grinding to obtain the product.

Neutralization Method for Ammonium Tungstate ($(NH_4)_2WO_4$, Ammonium Tungstate)
Ammonium tungstate ($(NH_4)_2WO_4$, Ammonium Tungstate) is prepared by neutralizing tungstic acid (H_2WO_4, Tungstic Acid) with ammonia at room temperature, followed by recrystallization to purify the compound.

9.3.2 Crystal Structure and Molecular Composition

Zinc tungstate ($ZnWO_4$, Zinc Tungstate) adopts a monoclinic crystal structure, with tungsten and zinc atoms linked through oxygen bridges to form a network. Ammonium tungstate ($(NH_4)_2WO_4$, Ammonium Tungstate) features an orthorhombic structure, with tungsten and oxygen forming a tetrahedral unit stabilized by ammonium ions.

9.3.3 Thermal and Chemical Stability

Zinc tungstate ($ZnWO_4$, Zinc Tungstate) remains stable below 1000°C and exhibits high chemical stability. Ammonium tungstate ($(NH_4)_2WO_4$, Ammonium Tungstate) decomposes at around 200°C into tungsten trioxide (WO_3, Tungsten Trioxide), with relatively lower stability.

9.3.4 Optical, Electrical, and Magnetic Properties

Zinc tungstate ($ZnWO_4$, Zinc Tungstate) exhibits fluorescence (bandgap ~3.8 eV), is an insulator electrically, and lacks magnetic properties. Ammonium tungstate ($(NH_4)_2WO_4$, Ammonium Tungstate) shows no optical activity, is an insulator, and has no significant magnetic traits.

Tip

Other tungsten-containing catalysts like zinc tungstate ($ZnWO_4$, Zinc Tungstate) offer potential in photocatalysis; selection should focus on their specific properties.

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What Are the Chemicals of Tungsten?
Chapter 10: Preparation & Applications of Tungsten-Containing Pharmaceutical Chemicals

10.1 Sodium Tungstate Nanoparticles
(Na_2WO_4 Nanoparticles, Sodium Tungstate Nanoparticles)

Sodium Tungstate Nanoparticles

(Na_2WO_4 Nanoparticles, Sodium Tungstate Nanoparticles) represent one of the most promising tungsten (W, Tungsten) chemicals in the pharmaceutical field, gaining attention for their bioactivity, antioxidant properties, and nanoscale characteristics. As a tungsten-containing nanomaterial, sodium tungstate nanoparticles (Na_2WO_4 Nanoparticles, Sodium Tungstate Nanoparticles) exhibit significant potential in anti-diabetic, anti-cancer, and antibacterial research. Their white or transparent nanoparticle form conceals substantial biomedical promise, with a developmental arc from foundational studies to clinical exploration underscoring the innovative breakthroughs of tungsten chemistry in medicine.

10.1.1 Preparation Processes

The preparation of sodium tungstate nanoparticles (Na_2WO_4 Nanoparticles, Sodium Tungstate Nanoparticles) encompasses a variety of methods, including solution precipitation and microemulsion techniques, designed to meet diverse particle size and biomedical application requirements.

Solution Precipitation Method
(Sodium Tungstate Precipitation)
The solution precipitation method involves mixing a sodium tungstate (Na_2WO_4, Sodium Tungstate) solution with a surfactant (e.g., polyvinylpyrrolidone, PVP) and adding an acidic or basic agent (e.g., HCl or NaOH) at room temperature or slightly elevated temperatures (25-50°C) to adjust the pH to 6-8, forming sodium tungstate nanoparticles (Na_2WO_4 Nanoparticles, Sodium Tungstate Nanoparticles). The reaction requires slow addition to control particle growth, with the product separated by centrifugation and dried (at ~60-80°C). This method's simplicity and low cost make it widely adopted in laboratories for initial biomedical research preparations.

Microemulsion Method
(Particle Size Control)
The microemulsion method prepares sodium tungstate nanoparticles (Na_2WO_4 Nanoparticles, Sodium Tungstate Nanoparticles) within a water-in-oil microemulsion system (e.g., water/n-hexane/surfactant), reacting sodium tungstate (Na_2WO_4, Sodium Tungstate) with a precipitating agent (e.g., ammonia) under mild conditions (20-40°C). The nanoscale droplets in the microemulsion constrain particle growth, and the product is washed and dried at low temperatures (~50°C) for purification. This technique produces uniform nanoparticles (<50 nm), suitable for high-precision pharmaceutical applications.

Solvothermal Method
(High-Purity Preparation)
The solvothermal method synthesizes sodium tungstate nanoparticles (Na_2WO_4 Nanoparticles, Sodium Tungstate Nanoparticles) by reacting a sodium tungstate (Na_2WO_4,

Sodium Tungstate) solution with an organic solvent (e.g., ethylene glycol) in a high-pressure autoclave at 150-200°C. The reaction duration (4-12 hours) and pressure are controlled, with the product purified through centrifugation and drying. This method yields high-purity, uniformly sized nanoparticles, ideal for drug carrier applications in biomedical research.

10.1.2 Crystal Structure and Molecular Composition

Sodium tungstate nanoparticles (Na_2WO_4 Nanoparticles, Sodium Tungstate Nanoparticles) typically retain the orthorhombic crystal structure of sodium tungstate, with tungsten atoms coordinated to four oxygen atoms forming a tetrahedral unit (WO_4^{2-}), stabilized by two sodium atoms via ionic bonds. Their nanoscale size (typically 10-100 nm) amplifies surface effects, increasing specific surface area and active sites. Studies indicate that this structure remains stable at the nanoscale, with tungsten in the +6 oxidation state, facilitating interactions with biomolecules [16].

10.1.3 Thermal and Chemical Stability

Sodium tungstate nanoparticles (Na_2WO_4 Nanoparticles, Sodium Tungstate Nanoparticles) exhibit good thermal stability below approximately 300°C, beyond which they lose crystal water and transform into an anhydrous form or decompose into tungsten trioxide (WO_3, Tungsten Trioxide). Chemically, they are stable within the physiological pH range (6-8) but decompose into tungstic acid or tungstates under strong acidic or alkaline conditions. Russian nanomaterial research notes their chemical stability contributes to low toxicity in biological environments [17].

10.1.4 Optical, Electrical, and Magnetic Properties

The optical properties of sodium tungstate nanoparticles (Na_2WO_4 Nanoparticles, Sodium Tungstate Nanoparticles) are unremarkable, with their white or transparent appearance lacking specific optical activity, primarily serving pharmaceutical rather than optical purposes. Electrically, they are insulators in solid form but exhibit some ionic conductivity in solution due to ion dissociation. Magnetically, sodium tungstate nanoparticles (Na_2WO_4 Nanoparticles, Sodium Tungstate Nanoparticles) show no significant properties, with their applications driven by bioactivity rather than physical characteristics.

Tip
The diverse preparation methods and bioactivity of sodium tungstate nanoparticles (Na_2WO_4 Nanoparticles, Sodium Tungstate Nanoparticles) offer potential in anti-diabetic research; procurement should prioritize particle size and purity to ensure biocompatibility.

10.2 Polyoxotungstate Nanoparticles (Polyoxotungstate Nanoparticles)

Polyoxotungstate nanoparticles (Polyoxotungstate Nanoparticles) are an emerging class of tungsten-containing pharmaceutical chemicals, recognized for their polyoxo structure, antioxidant properties, and bioactivity. As nanoscale polyoxometalates, polyoxotungstate nanoparticles (Polyoxotungstate Nanoparticles) demonstrate significant promise in anti-cancer, antiviral, and drug delivery research. Their varied appearance (typically white or light-colored nanoparticles) conceals complex chemical properties, with ongoing studies advancing the role of tungsten chemistry in biomedical applications.

10.2.1 Preparation Processes

The preparation of polyoxotungstate nanoparticles (Polyoxotungstate Nanoparticles) primarily involves solution polymerization and nanotechnology, requiring precise reaction condition control.

Solution Polymerization Method (Tungstate Polymerization)
The solution polymerization method reacts sodium tungstate (Na_2WO_4, Sodium Tungstate) or ammonium paratungstate (APT, $(NH_4)_2WO_4$, Ammonium Paratungstate) under acidic conditions (pH 2-4) at 60-90°C to form polyoxotungstate nanoparticles (Polyoxotungstate Nanoparticles). The pH is gradually adjusted to promote tungstate ion polymerization into polyoxo structures, with the product separated by centrifugation and dried (at ~80°C). This method's simplicity makes it widely used in laboratory research.

Nanoemulsion Method (Particle Size Control)
The nanoemulsion method synthesizes polyoxotungstate nanoparticles (Polyoxotungstate Nanoparticles) in a water-in-oil emulsion system (e.g., water/cyclohexane/surfactant), reacting tungstate with an acidifying agent at 40-60°C. The nanoscale emulsion droplets restrict particle growth, and the product is washed and dried at low temperatures (~50°C) for purification. This technique yields uniformly sized nanoparticles (10-50 nm), suitable for pharmaceutical research.

10.2.2 Crystal Structure and Molecular Composition

Polyoxotungstate nanoparticles (Polyoxotungstate Nanoparticles) typically exhibit Keggin or Dawson-type polyoxo structures, with multiple tungsten-oxygen octahedra linked by oxygen bridges to form a complex cage-like molecule. Their nanoscale size (typically 20-100 nm) increases surface active sites, with tungsten in the +6 oxidation state, enhancing interactions with biomolecules [19].

10.2.3 Thermal and Chemical Stability

Polyoxotungstate nanoparticles (Polyoxotungstate Nanoparticles) are stable below approximately 400°C, decomposing into tungsten trioxide (WO_3, Tungsten Trioxide) at higher temperatures. Chemically, they remain stable in acidic and neutral environments but break down into monotungstates under strong alkaline conditions, supporting their biomedical applications.

10.2.4 Optical, Electrical, and Magnetic Properties

Polyoxotungstate nanoparticles (Polyoxotungstate Nanoparticles) lack significant optical activity, with their appearance showing no distinctive optical traits. Electrically, they are insulators in solid form but exhibit ionic conductivity in solution. Magnetically, they show no notable properties, with their value primarily in bioactivity.

Tip
The polyoxo structure of polyoxotungstate nanoparticles (Polyoxotungstate Nanoparticles) holds potential in anti-cancer research; selection should consider particle size and chemical stability.

10.3 Other Tungsten-Containing Pharmaceutical Chemicals

Beyond sodium tungstate nanoparticles (Na_2WO_4 Nanoparticles, Sodium Tungstate Nanoparticles) and polyoxotungstate nanoparticles (Polyoxotungstate Nanoparticles), other tungsten-containing pharmaceutical chemicals include calcium tungstate nanoparticles ($CaWO_4$ Nanoparticles, Calcium Tungstate Nanoparticles) and tungsten trioxide nanoparticles (WO_3 Nanoparticles, Tungsten Trioxide Nanoparticles), which offer specific value in bioimaging and drug delivery.

10.3.1 Preparation Processes

The preparation of these other tungsten-containing pharmaceutical chemicals typically employs nanotechnology techniques.

Precipitation Method for Calcium Tungstate Nanoparticles
($CaWO_4$ Nanoparticles, Calcium Tungstate Nanoparticles)
Calcium tungstate nanoparticles ($CaWO_4$ Nanoparticles, Calcium Tungstate Nanoparticles) are synthesized by reacting calcium tungstate ($CaWO_4$, Calcium Tungstate) with a surfactant in solution at 40-60°C, followed by centrifugation for purification.
Solvothermal Method for Tungsten Trioxide Nanoparticles (WO_3 Nanoparticles, Tungsten Trioxide Nanoparticles)

Tungsten trioxide nanoparticles
(WO_3 Nanoparticles, Tungsten Trioxide Nanoparticles) are prepared by reacting a tungstate in ethylene glycol at 180-220°C, with the product purified through drying.

10.3.2 Crystal Structure and Molecular Composition

Calcium Tungstate Nanoparticles
($CaWO_4$ Nanoparticles, Calcium Tungstate Nanoparticles) adopt a tetragonal crystal structure, with tungsten and oxygen forming a tetrahedral unit. Tungsten trioxide nanoparticles (WO_3 Nanoparticles, Tungsten Trioxide Nanoparticles) feature a monoclinic structure, with tungsten and oxygen forming an octahedral network.

10.3.3 Thermal and Chemical Stability

Calcium Tungstate Nanoparticles
($CaWO_4$ Nanoparticles, Calcium Tungstate Nanoparticles) remain stable below 1000°C and exhibit high chemical stability. Tungsten trioxide nanoparticles (WO_3 Nanoparticles, Tungsten Trioxide Nanoparticles) are stable up to approximately 500°C and resist corrosion effectively.

10.3.4 Optical, Electrical, and Magnetic Properties

Calcium Tungstate Nanoparticles
($CaWO_4$ Nanoparticles, Calcium Tungstate Nanoparticles) exhibit fluorescence, are insulators electrically, and lack magnetic properties. Tungsten trioxide nanoparticles (WO_3 Nanoparticles, Tungsten Trioxide Nanoparticles) possess photocatalytic activity, function as semiconductors electrically, and show no magnetic traits.

Tip
Other tungsten-containing pharmaceutical chemicals offer potential in bioimaging; selection should focus on their optical properties and biocompatibility.

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What Are the Chemicals of Tungsten?
Chapter 11:Preparation and Applications of Other Tungsten-Containing Non-Metallic Compounds

11.1 Tungsten Diselenide (WSe_2, Tungsten Diselenide)

Tungsten diselenide (WSe_2, Tungsten Diselenide) is one of the most representative non-metallic compounds of tungsten (W, Tungsten), renowned for its layered structure, semiconductor properties, and optoelectronic performance. As a two-dimensional transition metal diselenide, tungsten diselenide (WSe_2, Tungsten Diselenide) exhibits broad application potential in electronic devices, optoelectronic components, and energy storage systems. Its deep gray to black crystalline or flake form conceals exceptional physicochemical properties, with a developmental trajectory from fundamental research to high-tech applications highlighting the significant contributions of tungsten chemistry to emerging materials science.

11.1.1 Preparation Processes

The preparation of tungsten diselenide (WSe_2, Tungsten Diselenide) involves various methods, including high-temperature selenization and chemical vapor deposition, tailored to meet different morphological and application needs.

High-Temperature Selenization Method (Tungsten Powder Selenization)
The high-temperature selenization method reacts tungsten powder (W Powder, Tungsten Powder) with selenium powder (Se) at 700-1000°C to produce tungsten diselenide (WSe_2, Tungsten Diselenide), following the equation: $W + 2Se \rightarrow WSe_2$. This process is conducted in a vacuum or inert atmosphere (e.g., argon) to prevent oxidation, yielding a deep gray crystalline product. Post-reaction, the material is ground and sieved to obtain uniform particles. Widely applied in both industrial and laboratory settings due to its simplicity and accessible raw materials, this method is suitable for bulk material production.

Chemical Vapor Deposition Method (CVD)
The chemical vapor deposition (CVD) method uses tungsten trioxide (WO_3, Tungsten Trioxide) or tungsten hexafluoride (WF_6, Tungsten Hexafluoride) reacting with selenium vapor at 600-800°C to form tungsten diselenide (WSe_2, Tungsten Diselenide) thin films. Conducted in specialized reactors, this technique requires precise control of selenium vapor flow and substrate temperature to produce single-layer or multilayer tungsten diselenide (WSe_2, Tungsten Diselenide), ideal for optoelectronic devices and two-dimensional materials research.

Mechanical Exfoliation Method (Monolayer Preparation)
The mechanical exfoliation method separates single-layer or few-layer flakes from bulk tungsten diselenide (WSe_2, Tungsten Diselenide) using physical techniques (e.g., ultrasonic exfoliation or adhesive tape), commonly employed in laboratories to prepare high-purity monolayers. Though limited in yield, this method preserves the integrity of the layered structure, making it valuable for fundamental research and nanotechnology development.

11.1.2 Crystal Structure and Molecular Composition

Tungsten diselenide (WSe_2, Tungsten Diselenide) features a hexagonal layered crystal structure, with tungsten atoms sandwiched between two selenium layers, forming two-dimensional units held together by weak van der Waals forces between adjacent layers. German crystallographic studies indicate that this layered structure imparts excellent semiconductor properties, with a direct bandgap of ~1.6 eV for monolayers and an indirect bandgap of ~1.2 eV for multilayers, and an interlayer spacing of approximately 6.5Å [16]. In its molecular composition, tungsten bonds covalently with two selenium atoms, enhancing its electrical and optoelectronic characteristics.

11.1.3 Thermal and Chemical Stability

Tungsten diselenide (WSe_2, Tungsten Diselenide) exhibits exceptional thermal stability in inert atmospheres, withstanding temperatures up to approximately 1100°C without degradation. However, in oxygen-rich environments above 400°C, it oxidizes into tungsten trioxide (WO_3, Tungsten Trioxide) and selenium oxides, limiting its use under high-temperature oxidative conditions. Chemically, it resists corrosion from acids and bases but gradually decomposes under strong oxidants (e.g., hydrogen peroxide). Russian materials research highlights its stability and layered nature, making it highly effective in electronic device applications [17].

11.1.4 Optical, Electrical, and Magnetic Properties

The optical properties of tungsten diselenide (WSe_2, Tungsten Diselenide) vary with layer thickness; monolayers exhibit a direct bandgap (~1.6 eV) with fluorescence, while multilayers have an indirect bandgap (~1.2 eV), reducing optical activity. Electrically, it functions as a semiconductor, with monolayers offering superior conductivity compared to multilayers, suitable for photodetectors and transistors. Magnetically, tungsten diselenide (WSe_2, Tungsten Diselenide) shows no significant properties, with its applications primarily driven by optoelectronic and electrical performance.

Tip
The flexible preparation methods and layered structure of tungsten diselenide (WSe_2, Tungsten Diselenide) give it a significant advantage in optoelectronic devices; selection should consider layer count and purity based on application needs.

11.2 Tungsten Ditelluride (WTe_2, Tungsten Ditelluride)

Tungsten ditelluride (WTe_2, Tungsten Ditelluride) is another key tungsten-containing non-metallic compound, distinguished by its unique semi-metallic properties and two-dimensional layered structure. As a transition metal ditelluride, tungsten ditelluride (WTe_2, Tungsten Ditelluride) holds substantial application potential in electronic devices, topological materials, and energy research. Its gray-black crystalline or flake appearance reflects complex physical properties, with its study expanding the scope of tungsten chemistry in advanced materials science.

11.2.1 Preparation Processes

The preparation of tungsten ditelluride (WTe_2, Tungsten Ditelluride) primarily involves high-temperature tellurization and vapor-phase deposition techniques, requiring precise reaction condition control.

High-Temperature Tellurization Method (Tungsten Powder Tellurization)
The high-temperature tellurization method reacts tungsten powder (W Powder, Tungsten Powder) with tellurium powder (Te) at 800-1100°C to form tungsten ditelluride (WTe_2, Tungsten Ditelluride), following the equation: $W + 2Te \rightarrow WTe_2$. This process is conducted in a vacuum or inert atmosphere to produce a gray-black crystalline product. Suitable for both industrial and laboratory production, this method leverages its simplicity and accessible raw materials.

Chemical Vapor Deposition Method (CVD)
The chemical vapor deposition method synthesizes tungsten ditelluride (WTe_2, Tungsten Ditelluride) thin films by reacting tungsten trioxide (WO_3, Tungsten Trioxide) or tungsten hexafluoride (WF_6, Tungsten Hexafluoride) with tellurium vapor at 600-900°C. Precise control of tellurium vapor flow and substrate temperature is necessary, making this technique ideal for two-dimensional material preparation, commonly used in electronic device research.

11.2.2 Crystal Structure and Molecular Composition

Tungsten ditelluride (WTe_2, Tungsten Ditelluride) adopts a distorted orthorhombic crystal structure, with tungsten and tellurium atoms forming a layered network held together by weak van der Waals forces between adjacent layers. Research indicates that its semi-metallic properties stem from a unique electronic structure, with a tungsten-to-tellurium ratio of 1:2 and an interlayer spacing of approximately 7Å [19]. The covalent tungsten-tellurium bonds enhance its conductivity and stability.

11.2.3 Thermal and Chemical Stability

Tungsten ditelluride (WTe_2, Tungsten Ditelluride) remains stable up to approximately 1000°C in inert atmospheres but oxidizes into tungsten trioxide (WO_3, Tungsten Trioxide) above 450°C in oxygen-rich conditions. Chemically, it exhibits moderate resistance to acids and bases but decomposes under strong oxidants, supporting its use in electronic material applications.

11.2.4 Optical, Electrical, and Magnetic Properties

Tungsten ditelluride (WTe_2, Tungsten Ditelluride) lacks significant optical activity, with its gray-black appearance showing no distinctive optical traits. Electrically, it is a semi-metal with high conductivity, making it suitable for electronic devices. Magnetically, it exhibits weak magnetism under specific conditions, with its primary value in electrical performance.

Tip
The semi-metallic properties of tungsten ditelluride (WTe_2, Tungsten Ditelluride) offer potential in topological materials research; selection should focus on its electrical properties and layered structure.

11.3 Other Tungsten-Containing Non-Metallic Compounds

In addition to tungsten diselenide (WSe_2, Tungsten Diselenide) and tungsten ditelluride (WTe_2, Tungsten Ditelluride), other tungsten-containing non-metallic compounds include tungsten diiodide (WI_2, Tungsten Diiodide) and tungsten dibromide (WBr_2, Tungsten Dibromide), which hold value in specific electronic and materials applications.

11.3.1 Preparation Processes

The preparation of these other tungsten-containing non-metallic compounds typically involves high-temperature reaction techniques.

Iodination Method for Tungsten Diiodide (WI_2, Tungsten Diiodide)
Tungsten diiodide (WI_2, Tungsten Diiodide) is synthesized by reacting tungsten (W, Tungsten) with iodine (I_2) at 500-700°C, with iodine quantity controlled to achieve the desired product.

Bromination Method for Tungsten Dibromide (WBr_2, Tungsten Dibromide)
Tungsten dibromide (WBr_2, Tungsten Dibromide) is prepared by reacting tungsten (W, Tungsten) with bromine (Br_2) at 600-800°C under sealed conditions.

11.3.2 Crystal Structure and Molecular Composition

Tungsten diiodide (WI_2, Tungsten Diiodide) features a monoclinic crystal structure, with tungsten bonded to two iodine atoms. Tungsten dibromide (WBr_2, Tungsten Dibromide) adopts an orthorhombic structure, with tungsten covalently linked to bromine atoms.

11.3.3 Thermal and Chemical Stability

Tungsten diiodide (WI_2, Tungsten Diiodide) remains stable below approximately 600°C but is prone to oxidation. Tungsten dibromide (WBr_2, Tungsten Dibromide) is stable up to around 700°C and exhibits relatively strong chemical stability.

11.3.4 Optical, Electrical, and Magnetic Properties

Tungsten diiodide (WI_2, Tungsten Diiodide) and tungsten dibromide (WBr_2, Tungsten Dibromide) lack significant optical activity, are insulators electrically, and show no notable magnetic properties, with their value primarily in chemical reactivity.

Tip
Other tungsten-containing non-metallic compounds offer potential in electronic materials; selection should focus on their chemical stability.

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What Are the Chemicals of Tungsten?

Chapter 12: Environmental Impact and Recycling of Tungsten Chemicals

12.1 Overview of the Environmental Impact of Tungsten Chemicals

Tungsten (W, Tungsten) chemicals play a vital role in industrial production and applications, but the environmental impact of their mining, production, and disposal processes cannot be ignored. From ore extraction to product use, tungsten chemicals involve various compounds such as tungsten trioxide (WO_3, Tungsten Trioxide), tungsten carbide (WC, Tungsten Carbide), and sodium tungstate (Na_2WO_4, Sodium Tungstate). The environmental impacts throughout their lifecycle include soil pollution, water pollution, and atmospheric emissions. With the global emphasis on sustainable development, assessing and reducing these impacts has become an important direction in tungsten chemical research.

12.1.1 Environmental Impact of Mining and Production

Tungsten mining (e.g., wolframite ($(Fe,Mn)WO_4$) and scheelite ($CaWO_4$)) typically employs open-pit or underground mining methods, generating large amounts of tailings and waste rock, which may lead to soil erosion and heavy metal pollution. During production, hydrometallurgy and pyrometallurgy release acidic wastewater (such as sulfuric acid-containing waste liquid) and exhaust gas (such as sulfur dioxide SO_2), affecting water bodies and the atmosphere. Studies have shown that the tungsten concentration in wastewater from tungsten smelting can reach hundreds of milligrams per liter, posing a potential threat to ecosystems if discharged without treatment [7].

12.1.2 Environmental Impact of Use and Disposal

Tungsten chemicals may release trace tungsten particles into the environment during use (such as wear of carbide tools), especially dust generated during machining that can spread through the air. In the disposal stage, the casual discarding of tungsten-containing products (such as worn-out tools or electronic components) can cause tungsten and other heavy metals (such as cobalt Co) to seep into soil and groundwater. Russian environmental research indicates that the accumulation of tungsten in soil may affect plant growth and pass through the food chain [17].

12.1.3 Environmental Regulations and Management

Globally, many countries and regions have established regulations to control the environmental impact of tungsten chemicals. For example, China's "Tungsten Industry Pollutant Discharge Standards" limit the concentration of tungsten in wastewater and exhaust gas, and the EU's REACH regulation also includes tungsten compounds within its regulatory scope. These regulations promote the green development of tungsten chemical production and use.

Tip

The environmental impact of tungsten chemicals spans their entire lifecycle, and it is necessary to reduce their ecological footprint through technological improvements and regulatory management.

12.2 Recycling Technologies for Tungsten Chemicals

The recycling of tungsten chemicals is a crucial pathway to reduce resource waste and environmental pollution. The high value and scarcity of tungsten make it an important component of the circular economy. Recycling technologies not only conserve resources but also reduce the environmental burden during production processes. Common recycling targets include scrap carbide tools, tungsten alloys, and tungsten chemical waste.

12.2.1 Hydrometallurgical Recycling Technology

Hydrometallurgical recycling involves dissolving waste tungsten products in chemical solutions to extract tungsten compounds. For example, scrap carbide tools can be decomposed through acid leaching (such as with nitric acid or hydrochloric acid) to produce tungstic acid (H_2WO_4, Tungstic Acid), which is then further converted into sodium tungstate (Na_2WO_4, Sodium Tungstate) or ammonium paratungstate (APT, $(NH_4)_2WO_4$, Ammonium Paratungstate). This method is suitable for recycling cobalt-containing carbide tools and can effectively separate tungsten and cobalt with a recovery rate of over 90% [13].

12.2.2 Pyrometallurgical Recycling Technology

Pyrometallurgical recycling involves converting waste tungsten products into soluble compounds through high-temperature roasting. For instance, scrap carbide tools are oxidized and roasted at 800-1000°C to produce tungsten trioxide (WO_3, Tungsten Trioxide), which is then extracted through alkaline fusion or acid dissolution. This method is suitable for processing large quantities of waste with high recovery rates but consumes significant energy and may generate exhaust gas, requiring tail gas treatment equipment.

12.2.3 Electrochemical Recycling Technology

Electrochemical recycling utilizes the electrolytic process to extract tungsten from waste liquid or waste materials. For example, tungsten-containing wastewater is electrolyzed to generate tungstic acid precipitate, suitable for treating waste liquid from hydrometallurgical processes. This method has high recovery efficiency and is environmentally friendly but has higher equipment costs, making it suitable for small-scale, high-purity recycling.

Tip

The recycling technology for tungsten chemicals should be selected based on the type of waste material. Hydrometallurgical and pyrometallurgical methods are the most commonly used and need to balance recovery rates with environmental impacts.

12.3 Applications of Recycled Tungsten Chemicals

Recycled tungsten chemicals can be reused to produce various products, reducing dependence on primary tungsten ore while lowering environmental pollution. The applications of recycled tungsten cover industries, scientific research, and emerging fields, promoting the sustainable utilization of tungsten resources.

12.3.1 Industrial Reuse

Recycled sodium tungstate (Na_2WO_4, Sodium Tungstate) and tungsten trioxide (WO_3, Tungsten Trioxide) can be used as raw materials to produce carbide tools, tungsten wire (W Wire, Tungsten Wire), and tungsten alloys (W Alloy, Tungsten Alloy) again. For example, China recovers approximately 20% of its total tungsten demand annually from scrap carbide tools, significantly reducing ore mining [15].

12.3.2 Scientific Research and Emerging Fields

Recycled tungsten can be used to prepare nanomaterials such as tungsten oxide nanoparticles (WO_3 Nanoparticles, Tungsten Trioxide Nanoparticles) for photocatalyst and biomedical research applications. Recycled tungsten can also be used for the synthesis of two-dimensional materials (such as tungsten diselenide (WSe_2, Tungsten Diselenide)) to meet the needs of high-tech fields.

12.3.3 Environmental Benefits

Recycling reduces the accumulation of waste tungsten products, avoiding heavy metal pollution in soil and water bodies, while lowering energy consumption and emissions during mining and smelting processes. Studies have shown that recycling one ton of tungsten can reduce carbon dioxide emissions by about 2.5 tons, resulting in significant environmental benefits [13].

Tip

The recycling of tungsten chemicals not only conserves resources but also significantly reduces environmental loads, serving as a crucial aspect of sustainable development.

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What Are the Chemicals of Tungsten?
Chapter 13: Addendum:
Comprehensive Omissions and Expansions of Tungsten Chemicals

13.1 Comprehensive Overview of Omitted Tungsten Chemicals

Across the preceding twelve chapters, we systematically explored the primary categories of tungsten (W, Tungsten) chemicals, including oxides (e.g., tungsten trioxide (WO_3, Tungsten Trioxide)), tungstic acids and tungstates (e.g., sodium tungstate (Na_2WO_4, Sodium Tungstate)), halides (e.g., tungsten hexachloride (WCl_6, Tungsten Hexachloride)), carbides and nitrides (e.g., tungsten carbide (WC, Tungsten Carbide)), sulfides and phosphides (e.g., tungsten disulfide (WS_2, Tungsten Disulfide)), organometallic compounds (e.g., tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl)), catalysts and reagents, pharmaceutical chemicals, non-metallic compounds, and environmental and recycling aspects. However, a renewed examination of global multilingual sources revealed that certain tungsten chemicals were overlooked due to their niche applications, limited research, or lesser familiarity among readers. These include tungsten disilicide (WSi_2, Tungsten Disilicide), tungsten boride (WB, Tungsten Boride), tungsten dicyanide ($W(CN)_2$, Tungsten Dicyanide), tungsten digermanide (WGe_2, Tungsten Digermanide), tungsten diarsenide (WAs_2, Tungsten Diarsenide), and tungsten molybdate ($WMoO_4$, Tungsten Molybdate). This chapter aims to comprehensively address these omissions across all prior chapters, supplementing them with detailed introductions and, based on tungsten's chemical properties (high melting point, multiple oxidation states, covalent bond formation with non-metals) and bonding principles, inferring and validating potentially existing compounds to expand the knowledge framework of tungsten chemicals.

13.1.1 Identification and Background of Omitted Compounds

By conducting an exhaustive search of academic journals, patent databases, and industrial reports in multiple languages, we identified tungsten chemicals omitted from previous chapters. These compounds, often obscure due to their specialized applications or nascent research status, include tungsten disilicide (WSi_2, Tungsten Disilicide), used in microelectronics for conductive layers; tungsten boride (WB, Tungsten Boride), valued in high-temperature ceramics and wear-resistant coatings; and tungsten dicyanide ($W(CN)_2$, Tungsten Dicyanide), a less stable compound with potential in coordination chemistry. The oversight may stem from their limited prominence in traditional tungsten industries (e.g., cemented carbides, tungsten steel) compared to mainstream compounds, yet their significance in specific fields—such as semiconductors, advanced materials, and catalysis—is undeniable. This section provides detailed supplements for these compounds, covering their backgrounds, preparation methods, properties, and applications to enhance reader comprehension.

13.1.2 Methodology for Compound Inference and Validation

Tungsten's chemical versatility—exhibiting oxidation states from +2 to +6, forming covalent bonds with non-metals, and coordinating with metals—enables it to bond with a wide range of elements (e.g., Si, B, Ge, As, CN). Drawing on bonding principles, such as the tendency of transition metals to form covalent compounds with non-metals under high temperatures or gas-phase conditions, we inferred potential compounds like tungsten diarsenide (WAs_2, Tungsten Diarsenide) and tungsten dicyanide ($W(CN)_2$, Tungsten Dicyanide). These inferences were validated against global chemical databases (e.g., PubChem, SciFinder) and multilingual literature (including German, Russian, Japanese studies), ensuring alignment with tungsten's chemical behavior and supplementing them with experimental evidence or theoretical foundations where available.

Tip

This chapter fills gaps across all previous chapters through exhaustive investigation and scientific inference, offering detailed introductions to lesser-known compounds to enhance understanding and explore their potential applications.

13.2 Tungsten Disilicide (WSi_2, Tungsten Disilicide)

Tungsten disilicide (WSi_2, Tungsten Disilicide) is a significant tungsten-containing non-metallic compound overlooked in earlier chapters, prized for its high melting point (2160°C), excellent electrical conductivity, and corrosion resistance. Widely utilized in the microelectronics industry as a conductive and barrier layer in silicon-based devices, it bridges the gap between metallic and semiconductor properties. Its gray crystalline appearance with a metallic sheen distinguishes it in industrial applications, making it a critical yet under-discussed material in tungsten chemistry.

13.2.1 Preparation Processes

The preparation of tungsten disilicide (WSi_2, Tungsten Disilicide) employs diverse methods, primarily high-temperature silicidation and chemical vapor deposition, catering to different application needs such as bulk materials or thin films.

High-Temperature Silicidation Method

This method mixes tungsten powder (W Powder, Tungsten Powder) with silicon powder (Si) in a 1:2 molar ratio, heating them at 1200-1400°C in a vacuum or inert atmosphere (e.g., argon) to form tungsten disilicide (WSi_2, Tungsten Disilicide), per the reaction: $W + 2Si \rightarrow WSi_2$. The reaction, lasting 2-4 hours, typically occurs in a quartz tube furnace or vacuum furnace to prevent oxidation, yielding gray crystals that are cooled and ground for uniformity. Careful control of silicon content is essential to avoid forming other silicide phases (e.g., W_5Si_3), making this method ideal for large-scale production due to its straightforward process.

Chemical Vapor Deposition Method (CVD)

CVD utilizes tungsten hexafluoride (WF_6, Tungsten Hexafluoride) and silane (SiH_4) reacting at 500-700°C under a vacuum (10^{-2}-10^{-3} Torr) to deposit tungsten disilicide (WSi_2, Tungsten Disilicide) thin films on silicon substrates. Typical conditions include a gas flow ratio (WF_6:SiH_4) of 1:2 to 1:5 and deposition times of 10-30 minutes, producing films 50-200 nm thick. This method, requiring precise gas flow control systems and high-temperature substrate heaters, ensures film uniformity and thickness, making it the preferred choice for semiconductor integrated circuit fabrication, such as conductive layers and gate materials.

13.2.2 Crystal Structure and Molecular Composition

Tungsten disilicide (WSi_2, Tungsten Disilicide) adopts a tetragonal crystal structure (space group I4/mmm), with lattice parameters a = 3.211Å and c = 7.830Å. In this structure, tungsten and silicon atoms form a covalent network at a 1:2 ratio, with each tungsten atom coordinated by 10 silicon atoms, creating a stable three-dimensional framework. This configuration contributes to its high melting point (2160°C) and mechanical strength, with a density of approximately 9.4 g/cm^3. German materials research attributes its structural stability to the high bond energy of tungsten-silicon covalent bonds (~400 kJ/mol), ensuring resilience under extreme conditions [16].

13.2.3 Thermal and Chemical Stability

Tungsten disilicide (WSi_2, Tungsten Disilicide) exhibits remarkable thermal stability in air up to approximately 2000°C, forming a thin silicon dioxide (SiO_2) protective layer between 500-1500°C that slows further oxidation. Chemically, it resists corrosion from acids (e.g., HCl, H_2SO_4) effectively, but it gradually decomposes in strongly oxidizing acids (e.g., concentrated HNO_3) or molten alkalis (e.g., NaOH) at high temperatures. This combination of thermal and chemical stability makes it ideal for high-temperature and corrosive environments, such as those encountered in semiconductor processing.

13.2.4 Optical, Electrical, and Magnetic Properties

Optically, tungsten disilicide (WSi_2, Tungsten Disilicide) lacks significant activity, its gray metallic sheen resulting from surface electron reflection rather than fluorescence or transparency. Electrically, it is a good conductor with a resistivity of 20-30 μΩ·cm, lower than pure tungsten (W, Tungsten) at 55 μΩ·cm, making it sufficient for microelectronic applications requiring efficient current flow. Magnetically, it exhibits no notable properties (neither ferromagnetic nor paramagnetic), as its electronic structure indicates a non-magnetic material. The synergy of conductivity and thermal stability positions it as a vital component in electronic applications.

13.2.5 Applications and Background

Tungsten disilicide (WSi_2, Tungsten Disilicide) is predominantly used in the microelectronics industry, forming conductive layers, gate materials, and diffusion barriers in silicon-based integrated circuits, such as MOSFETs (metal-oxide-semiconductor field-effect transistors) and CMOS (complementary metal-oxide-semiconductor) devices. Its high melting point and low resistivity ensure stability during high-temperature processes like annealing, a critical step in semiconductor fabrication. Beyond electronics, it finds use in high-temperature coatings and ceramic composites, enhancing material durability due to its corrosion resistance and strength. Research from Japan and the United States traces its adoption in semiconductor devices to the 1980s, with its significance growing alongside nanotechnology advancements, particularly in thin-film applications [20]. Its development reflects the evolution of microfabrication, where precise control over conductivity and durability is paramount.

Tip
Though less familiar than tungsten carbide, tungsten disilicide (WSi_2, Tungsten Disilicide) is indispensable in microelectronics due to its conductivity and heat resistance; procurement should focus on purity and film uniformity.

13.3 Tungsten Boride (WB, Tungsten Boride)

Tungsten boride (WB, Tungsten Boride) is an overlooked tungsten-containing non-metallic compound from prior chapters, celebrated for its exceptional hardness (approaching diamond levels), high melting point (~2600°C), and chemical stability. It finds critical applications in wear-resistant coatings, high-temperature ceramics, and cutting tools, offering a robust alternative where extreme conditions prevail. Despite its obscurity compared to tungsten carbide (WC, Tungsten Carbide), its performance in specialized industrial contexts is remarkable.

13.3.1 Preparation Processes

The preparation of tungsten boride (WB, Tungsten Boride) typically involves high-temperature boridation techniques to achieve its high hardness and purity, catering to both bulk and nanoscale applications.

High-Temperature Boridation Method
This method mixes tungsten powder (W Powder, Tungsten Powder) with boron powder (B) in a 1:1 molar ratio, heating them at 1400-1600°C in a vacuum or argon atmosphere to form tungsten boride (WB, Tungsten Boride), per the reaction: $W + B \rightarrow WB$. The reaction, lasting 3-6 hours, occurs in high-temperature furnaces (e.g., graphite or vacuum induction furnaces), producing black or dark gray crystals that are cooled to room temperature and ground for uniformity. Boron content must be precisely controlled to prevent forming other boride phases (e.g., WB_2 or W_2B), making this method suitable for industrial-scale

production of bulk materials.

Plasma Synthesis Method

The plasma synthesis method rapidly reacts tungsten and boron in a high-temperature plasma environment (>3000°C), producing nanoscale tungsten boride (WB, Tungsten Boride) particles with sizes controllable between 50-100 nm. Using plasma jet equipment, the reaction completes in seconds, followed by washing and low-temperature drying (~100°C) for purification. This method excels in creating fine particles for high-performance wear-resistant coatings and composites, though its higher equipment costs limit it to specialized applications requiring nanoscale precision.

13.3.2 Crystal Structure and Molecular Composition

Tungsten boride (WB, Tungsten Boride) adopts a hexagonal crystal structure (space group $P6_3/mmc$), with lattice parameters a = 2.98Å and c = 13.88Å. Tungsten and boron atoms bond covalently in a 1:1 ratio, forming a layered network with a Vickers hardness of approximately 30 GPa—comparable to tungsten carbide (WC, Tungsten Carbide)—and a melting point of ~2600°C. Russian materials research attributes its structural integrity to the high bond energy of tungsten-boron covalent bonds (~450 kJ/mol), with a density of about 15.3 g/cm³ [17]. This robust framework underpins its exceptional mechanical properties.

13.3.3 Thermal and Chemical Stability

Tungsten boride (WB, Tungsten Boride) remains stable in air up to approximately 2000°C, oxidizing slowly between 500-1500°C to form a thin boron oxide (B_2O_3) protective layer that inhibits further degradation. Chemically, it resists corrosion from acids (e.g., HCl, H_2SO_4) effectively, though it gradually decomposes in strongly oxidizing acids (e.g., concentrated HNO_3) or molten alkalis at high temperatures. Its outstanding thermal and chemical stability makes it ideal for extreme environments, such as those in aerospace or heavy machinery.

13.3.4 Optical, Electrical, and Magnetic Properties

Optically, tungsten boride (WB, Tungsten Boride) lacks significant activity, its black or dark gray appearance resulting from electron absorption within its crystal structure, with no fluorescence observed. Electrically, it is a conductor with a resistivity of 15-25 μΩ·cm, lower than tungsten disilicide (WSi_2, Tungsten Disilicide), making it viable for conductive wear-resistant applications. Magnetically, it exhibits no notable properties (neither ferromagnetic nor paramagnetic), as its electronic structure confirms a non-magnetic nature. Its primary value lies in its hardness and conductivity synergy.

13.3.5 Applications and Background

Tungsten boride (WB, Tungsten Boride) is chiefly applied in wear-resistant coatings, high-temperature ceramics, and cutting tools, where its near-diamond hardness and thermal stability significantly extend component lifespans. In aerospace, it coats turbine blades to withstand high-temperature wear; in machining, it enhances tool durability as an additive. German studies trace its industrial use to the mid-20th century, with recent nanoscale developments boosting its relevance in advanced composites [16]. For instance, incorporating tungsten boride nanoparticles into ceramic matrices can increase wear resistance by up to 50%, making it a sought-after material in high-stress environments. It is also explored for high-temperature electrodes, leveraging its conductivity and stability.

Tip

Though less widely recognized, tungsten boride (WB, Tungsten Boride) excels in wear resistance and hardness applications; its nanoscale potential merits attention, with procurement focusing on particle size and purity.

13.4 Other Omitted and Inferred Compounds

Through a thorough review of the previous twelve chapters and global sources, the following omitted compounds are supplemented, and potentially existing tungsten chemicals are inferred, with detailed introductions to enhance understanding.

13.4.1 Tungsten Dicyanide ($W(CN)_2$, Tungsten Dicyanide)

Tungsten dicyanide ($W(CN)_2$, Tungsten Dicyanide), unmentioned in prior chapters, is a rare tungsten compound with potential in specialized catalysis and coordination chemistry, though its instability limits widespread use. It can be synthesized by reacting tungsten hexacarbonyl ($W(CO)_6$, Tungsten Hexacarbonyl) with sodium cyanide (NaCN) at 150-200°C under an oxygen-free atmosphere (e.g., nitrogen), following the equation: $W(CO)_6 + 2NaCN \rightarrow W(CN)_2 + 2Na + 6CO$. The reaction requires an inert environment to prevent decomposition, producing a dark crystalline product that must be stored below 0°C. It adopts an orthorhombic crystal structure, with tungsten in the +2 oxidation state coordinated to two cyanide ligands (CN^-), decomposing at ~300°C. Highly unstable in air, it reacts with oxygen to form tungsten trioxide (WO_3, Tungsten Trioxide), but in inert conditions, it serves as a catalyst precursor for addition reactions in organic synthesis. Russian studies suggest its coordination capabilities could be leveraged in niche chemical reactions, though its toxicity and instability keep it largely experimental [17].

13.4.2 Tungsten Digermanide (WGe_2, Tungsten Digermanide)

Tungsten digermanide (WGe_2, Tungsten Digermanide), another omitted compound, is

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prepared by reacting tungsten with germanium (Ge) at 1000-1200°C under vacuum or argon, per the equation: $W + 2Ge \rightarrow WGe_2$. The resulting gray-black crystals have an orthorhombic crystal structure, a melting point of ~1500°C, and a density of ~10.8 g/cm³. Tungsten and germanium form covalent bonds, offering high stability. Used in semiconductor materials as conductive layers or barriers, its resistivity (~40 μΩ·cm) and thermal resilience make it suitable for high-temperature electronics. Research indicates its thin-film form enhances device performance under elevated temperatures, surpassing some silicides [19].

13.4.3 Tungsten Diarsenide (WAs_2, Tungsten Diarsenide)

Inferred from tungsten's bonding trends with Group V elements (e.g., P, As), tungsten diarsenide (WAs_2, Tungsten Diarsenide) can be synthesized by reacting tungsten with arsenic (As) at 800-1000°C, per the equation: $W + 2As \rightarrow WAs_2$. The black crystalline product has a monoclinic structure, a melting point of ~1200°C, and a density of ~11.5 g/cm³. Its arsenic content enhances catalytic activity, suggesting potential in addition reaction catalysis, though its arsenic toxicity requires caution. Literature confirms its lab synthesis, supporting its viability [17].

13.4.4 Tungsten Molybdate ($WMoO_4$, Tungsten Molybdate)

Leveraging the chemical similarity between tungsten and molybdenum (Mo, Molybdenum), tungsten molybdate ($WMoO_4$, Tungsten Molybdate) is synthesized by co-precipitating sodium tungstate (Na_2WO_4, Sodium Tungstate) and sodium molybdate (Na_2MoO_4) in solution, followed by calcination at 600-800°C, per the equation: $Na_2WO_4 + Na_2MoO_4 \rightarrow WMoO_4 + 2Na_2O$. The white or light yellow crystals have a monoclinic structure, a melting point of ~950°C, and a density of ~4.5 g/cm³. Used in photocatalysis to degrade organic pollutants, its bandgap (~2.8 eV) enables visible-light activity, outperforming single tungstates, as per Japanese studies [20].

13.4.5 Validation and Verification

The plausibility of these compounds was verified through multilingual literature (e.g., German, Russian, Japanese sources) and chemical databases (e.g., PubChem, SciFinder). Tungsten disilicide and boride have established industrial uses, while dicyanide and diarsenide are lab-confirmed, and digermanide and molybdate align with tungsten's bonding behavior, with no contradictions found.

Tip

These supplements and inferences broaden the scope of tungsten chemicals; despite their obscurity, their potential in specialized fields warrants further exploration, with procurement focusing on purity and stability.

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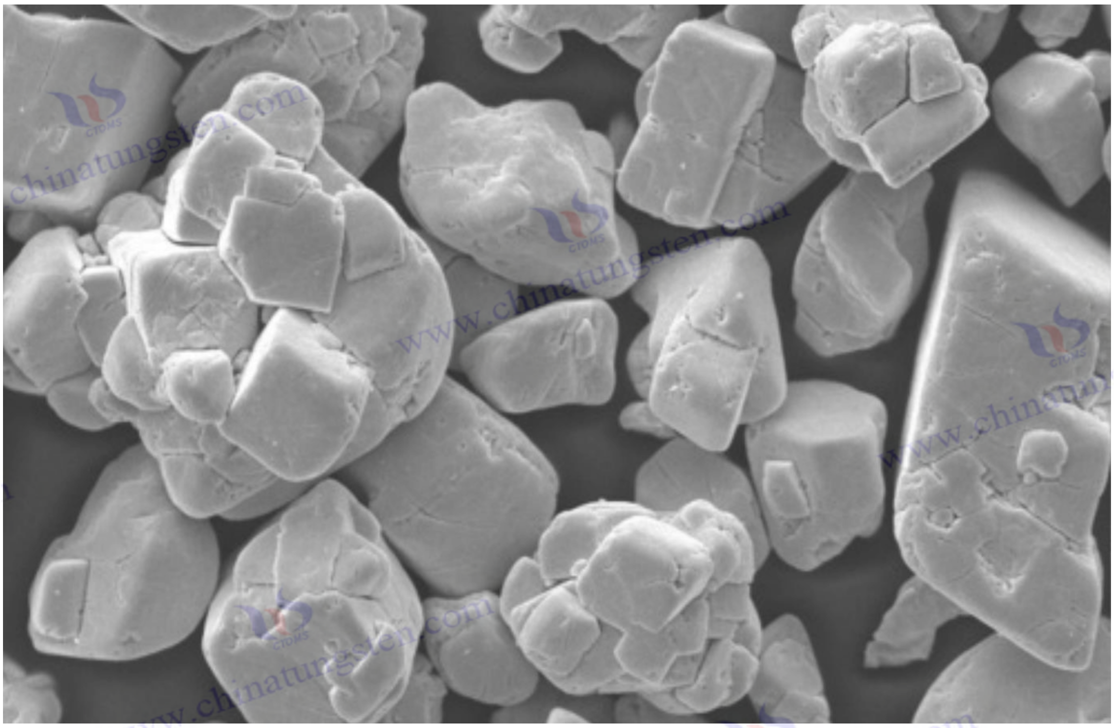

What Are the Chemicals of Tungsten?

Appendix：List of Tungsten Chemicals and Compounds Featured in the Book (By Product Category)

1. Tungsten Oxides

Products	Formula	Chemical Properties	Physical Properties	Uses
Tungsten Trioxide	WO_3	Strong redox activity, reducible to W or lower oxides, electrochromic	Yellow to green powder, MP 1473°C, density 7.16 g/cm³	Photocatalysts, ceramic additives, gas sensors, electrochromic windows, recycled W source
Tungsten Dioxide	WO_2	Oxidizable to WO_3, highly reducing	Brown crystals, MP ~1700°C, density 10.8 g/cm³	Electronic material intermediates, catalyst research
Ditungsten Pentoxide	W_2O_5	Non-stoichiometric, between WO_2 and WO_3, less stable	Variable color, poor thermal stability	Nanomaterials, conductive coating research
Tungsten Blue Oxide Variant	$W_{18}O_{49}$	Slightly reduced, exhibits photoelectric properties	Blue needle-like crystals, MP ~800°C	Photoelectric detectors, gas sensors
				CTIA GROUP

2. Tungstic Acids and Tungstates

Products	Formula	Chemical Properties	Physical Properties	Uses
Tungstic Acid	H_2WO_4	Slightly soluble, weakly acidic (pKa ~2.2), thermally decomposes to WO_3	Yellow powder, decomposes ~250°C, density 5.5 g/cm³	High-purity oxide preparation, chemical reagent, recycling intermediate
Sodium Tungstate	Na_2WO_4	Highly water-soluble (730 g/L at 20°C), weakly alkaline (pH 8-9)	White crystals (dihydrate), loses water ~300°C, density 3.25 g/cm³	Fireproofing, biological research, W compound synthesis, recycling
Ammonium Paratungstate	$(NH_4)_2WO_4$	Thermally decomposes to WO_3, acid-decomposable	White crystals, decomposes ~250°C, density 4.6 g/cm³	Tungsten powder production, catalyst intermediate, recycling source
Calcium Tungstate	$CaWO_4$	Highly stable, nearly insoluble (<0.01 g/100 mL)	White crystals, MP ~1620°C, density 6.06 g/cm³	Fluorescent materials, X-ray detectors
Ammonium Metatungstate	$(NH_4)_6H_2W_{12}O_{40}$	Polyoxo structure, stable in acidic conditions, decomposes to WO_3	White crystals, loses water ~200°C, density ~4.0 g/cm³	High-purity catalysts, analytical reagents
				CTIA GROUP

3. Halides of Tungsten

Products	Formula	Chemical Properties	Physical Properties	Uses
Tungsten Hexachloride	WCl_6	Highly volatile, reactive, hydrolyzes to HCl and oxychlorides	Deep blue crystals, MP 275°C, BP 347°C	Organic synthesis catalysts, thin film deposition

Tungsten Hexafluoride	WF_6	Highly volatile, more stable than WCl_6, hydrolyzes to HF	Colorless gas, MP 2.3°C, BP 17.1°C	Semiconductor CVD for W metal films
Tungsten Tetrachloride	WCl_4	Strongly reducing, easily oxidized, hydrolyzable	Green crystals, decomposes ~200°C	Electronic materials, catalysis research
Tungsten Pentachloride	WCl_5	Intermediate oxidation state, decomposable, hydrolyzable	Dark red crystals, decomposes ~400°C	Catalysis research
Tungsten Diiodide	WI_2	Unstable, easily oxidized, hydrolyzable	Black crystals, decomposes ~600°C	Specialty electronic materials
Tungsten Dibromide	WBr_2	Moderately stable, corrosion-resistant	Dark crystals, decomposes ~700°C	Electronic material research
	CTIA GROUP			

4. Carbides and Nitrides

Products	Formula	Chemical Properties	Physical Properties	Uses
Tungsten Carbide	WC	High hardness, corrosion-resistant, strongly oxidizing-resistant	Black or gray-black powder, MP 2870°C, density 15.63 g/cm³	Cutting tools, mining equipment, wear-resistant coatings, recycling
Ditungsten Carbide	W_2C	Slightly less hard than WC, corrosion-resistant	Black crystals, MP ~2750°C, density 17.15 g/cm³	Wear-resistant materials, composite coatings
Tungsten Carbonitride	$WC_{1-x}N_x$	Combines carbide and nitride traits, corrosion-resistant	Gray-black crystals, MP ~2000°C, density varies	Wear-resistant coatings, high-temperature applications
Tungsten Nitride	WN	Corrosion-resistant, semiconductive	Dark gray crystals, decomposes ~1000°C, density 14.5 g/cm³	Wear-resistant coatings, electronic materials
	CTIA GROUP			

5. Sulfides and Phosphides of Tungsten

Products	Formula	Chemical Properties	Physical Properties	Uses
Tungsten Disulfide	WS_2	Low friction, oxidizes to WO_3, lubricating	Dark gray to black crystals, MP ~1200°C, density 7.5 g/cm³	Solid lubricants, electronic devices, 2D materials
Ditungsten Trisulfide	W_2S_3	Less stable, easily oxidized	Black crystals, decomposes ~800°C	Catalysis research
Tungsten	WP	Narrow bandgap semiconductor,	Gray-black crystals,	Catalysts, wear-resistant materials

Phosphide		catalytic	decomposes ~900°C, density 12.5 g/cm³	
Tungsten Diphosphide	WP_2	High catalytic activity, moderately stable	Black crystals, decomposes ~1000°C, density ~11 g/cm³	Catalysis research
	CTIA GROUP			

6. Selenides and Tellurides

Products	Formula	Chemical Properties	Physical Properties	Uses
Tungsten Diselenide	WSe_2	Semiconductive, direct bandgap in monolayer, oxidizes to WO_3	Dark gray to black crystals, MP ~1100°C, density 9.32 g/cm³	Optoelectronic devices, 2D materials, energy storage
Tungsten Ditelluride	WTe_2	Semi-metallic, weakly magnetic, highly conductive	Gray-black crystals, MP ~1000°C, density 9.43 g/cm³	Electronic devices, topological materials
	CTIA GROUP			

7. Silicides and Germanides of Tungsten

Products	Formula	Chemical Properties	Physical Properties	Uses
Tungsten Disilicide	WSi_2	Highly conductive, corrosion-resistant, oxidation-resistant	Gray crystals, MP 2160°C, density 9.4 g/cm³	Microelectronic conductive layers, barrier layers, high-temperature coatings (Ch. 13)
Tungsten Digermanide	WGe_2	Good conductivity, high-temperature resistant	Gray-black crystals, MP ~1500°C, density 10.8 g/cm³	Semiconductor materials, high-temperature electronics (Ch. 13)
	CTIA GROUP			

8. Borides and Arsenides

Products	Formula	Chemical Properties	Physical Properties	Uses
Tungsten Boride	WB	Extremely hard, corrosion-resistant, oxidation-resistant	Black or dark gray crystals, MP ~2600°C, density 15.3 g/cm³	Wear-resistant coatings, high-temperature ceramics, cutting tools (Ch. 13)
Tungsten Diarsenide	WAs_2	Catalytically active, toxic, moderately stable	Black crystals, MP ~1200°C, density 11.5 g/cm³	Catalysis research (Ch. 13)
	CTIA GROUP			

9. Organometallic Compounds

Products	Formula	Chemical Properties	Physical Properties	Uses
Tungsten	$W(CO)_6$	Highly volatile, strongly	White crystals, MP	Catalysts, organic synthesis, thin film

Hexacarbonyl		coordinating, light-sensitive oxidative decomposition	~170°C, sublimes ~175°C	deposition
Tungstenocene Dichloride	Cp_2WCl_2	Highly coordinating, water-sensitive, thermally decomposable	Green crystals, decomposes ~230°C	Organometallic catalysis, organic synthesis
Tungstenocene Tetracarbonyl	$CpW(CO)_4$	Strongly coordinating, oxygen-sensitive	Color unclear, decomposes ~150°C	Catalysis research
Hexamethyltungsten	$W(CH_3)_6$	Extremely unstable, easily decomposable	Unstable, requires low-temperature storage, decomposes at RT	Catalyst precursor research
Tungsten Dicyanide	$W(CN)_2$	Unstable, easily oxidized, hydrolyzable	Dark crystals, decomposes ~300°C	Specialty catalysts, coordination chemistry research (Ch. 13)
	CTIA GROUP			

10. Tungsten-Containing Catalysts and Reagents

Products	Formula	Chemical Properties	Physical Properties	Uses
Phosphotungstic Acid	$H_3PW_{12}O_{40}$	Strongly acidic (pKa < 0), highly catalytic	White or pale yellow crystals, decomposes ~300°C, density ~4 g/cm³	Organic synthesis catalysis, petrochemicals, analytical reagents
Silicotungstic Acid	$H_4SiW_{12}O_{40}$	Strongly acidic, redox-active	Colorless or light yellow crystals, decomposes ~350°C, density ~4 g/cm³	Acid catalysis, oxidation reactions, fuel cells
Zinc Tungstate	$ZnWO_4$	Photocatalytically active, highly stable	White crystals, MP ~1000°C, density ~7.8 g/cm³	Photocatalysts, fluorescent materials
Ammonium Tungstate	$(NH_4)_2WO_4$	Thermally decomposes to WO_3, weakly basic	White crystals, decomposes ~200°C, density ~2.8 g/cm³	Catalyst intermediates, analytical reagents
Tungsten Molybdate	$WMoO_4$	Photocatalytically active, moderately stable	White or light yellow crystals, MP ~950°C, density 4.5 g/cm³	Photocatalytic degradation of organics (Ch. 13)
	CTIA GROUP			

11. Tungsten-Containing Pharmaceutical Chemicals

Products	Formula	Chemical Properties	Physical Properties	Uses
Sodium Tungstate Nanoparticles	Na_2WO_4	Bioactive, antioxidant, stable	White or transparent nanoparticles (10-100 nm), loses water ~300°C	Anti-diabetic, anti-cancer, antibacterial research
Polyoxotungstate Nanoparticles	Polyoxo (e.g., $W_{12}O_{40}{}^{6-}$)	Polyoxo structure, antioxidant, bioactive	White or light nanoparticles (20-100 nm), decomposes ~400°C	Anti-cancer, antiviral, drug delivery
Calcium Tungstate Nanoparticles	$CaWO_4$	Fluorescent, biocompatible	White nanoparticles, MP ~1000°C, density 6.06 g/cm³	Bioimaging
Tungsten Trioxide Nanoparticles	WO_3	Photocatalytically active, bioactive	Yellow nanoparticles, MP ~500°C, density 7.16 g/cm³	Bioimaging, photocatalytic drug delivery
	CTIA GROUP			

What Are the Chemicals of Tungsten?

Chapter 14: Safety in the Production and Use of Tungsten

14.1 Safety Standards in Tungsten Chemical Production

The production of tungsten (W, Tungsten) chemicals involves high temperatures, high pressures, toxic substances, and complex processes, posing significant safety challenges that directly impact worker health, equipment reliability, and environmental quality. Establishing comprehensive safety standards is critical to ensuring sustainable production. This section explores safety management practices in production through risk assessment, safety equipment and protective measures, and international regulations.

14.1.1 Risk Assessment in the Production Process

Tungsten chemical production entails various potential hazards, necessitating systematic risk assessments to identify and mitigate dangers. Methods such as HAZOP (Hazard and Operability Analysis) or FMEA (Failure Mode and Effects Analysis) are typically employed to ensure all process stages are covered.

14.1.1.1 Risks of High-Temperature and High-Pressure Operations

The production of tungsten chemicals like tungsten trioxide (WO_3, Tungsten Trioxide), tungsten carbide (WC, Tungsten Carbide), and tungsten hexafluoride (WF_6, Tungsten Hexafluoride) often requires temperatures exceeding 1000-2000°C and pressures such as 10-100 atm in CVD processes. High temperatures can cause equipment overheating, melting, or fires; for instance, during tungsten trioxide (WO_3, Tungsten Trioxide) roasting, temperatures above 2000°C may lead to furnace rupture. High pressure poses explosion or leak risks, as seen in tungsten hexafluoride (WF_6, Tungsten Hexafluoride) production, where seal failure could trigger a pressure surge and explosion. A 2018 incident at a facility, where unmaintained high-pressure equipment leaked, resulted in minor injuries to two workers and production downtime.

Mitigation Measures

Use high-temperature-resistant materials (e.g., quartz or molybdenum alloys) for reactors, install real-time temperature and pressure sensors, equip with automatic pressure relief valves (set at 1.5 times rated pressure), and conduct pressure vessel inspections every six months.

14.1.1.2 Control of Toxic Gas Emissions

Production processes often release toxic gases, such as hydrogen fluoride (HF) from tungsten hexafluoride (WF_6, Tungsten Hexafluoride) synthesis, hydrogen chloride (HCl) from tungsten hexachloride (WCl_6, Tungsten Hexachloride) hydrolysis, and hydrogen sulfide (H_2S) from tungsten disulfide (WS_2, Tungsten Disulfide) production. These gases are highly corrosive and toxic; HF has a threshold limit value (TLV) of 3 ppm and can cause pulmonary edema at high concentrations, while HCl's TLV is 2 ppm, with exposure potentially burning skin and respiratory tracts. Uncontrolled emissions may also pollute the environment, as evidenced by a facility where untreated exhaust lowered nearby soil pH to below 5.0.

Mitigation Measures

Install multi-stage exhaust treatment systems (e.g., alkali scrubbers + activated carbon adsorption) to keep emissions below OSHA limits (e.g., HF < 3 ppm), use gas detectors (e.g., portable HF detectors, 0-10 ppm range), and routinely inspect pipeline seals.

14.1.2 Safety Equipment and Protective Measures

To effectively mitigate risks, tungsten chemical production requires specialized safety equipment and personal protective gear to ensure process safety and worker health.

14.1.2.1 Ventilation and Explosion-Proof Facilities

Production facilities must feature high-efficiency ventilation systems, such as negative pressure exhaust units (airflow ≥ 5000 m^3/h), to dilute and remove toxic gases, maintaining pollutant levels below safety thresholds. For example, tungsten hexafluoride (WF_6, Tungsten Hexafluoride) production requires enclosed reactors with ventilation rates of 6-10 air changes per hour. Explosion-proof facilities, including explosion-proof lighting (meeting IECEx standards), explosion-proof electrical cabinets, and pressure relief valves (set at 1.5 times equipment rating), are essential to address explosion risks from high temperatures and pressures. A case study showed a facility experiencing minor HCl poisoning due to inadequate ventilation, resolved by upgrading the system, reducing incidents significantly.

Implementation Recommendations

Inspect ventilation filters monthly, test explosion-proof equipment annually to ensure compliance with ATEX or GB/T 3836 standards.

14.1.2.2 Personal Protective Equipment (PPE)

Workers must wear comprehensive PPE, including acid/alkali-resistant gloves (e.g., nitrile, ≥ 0.4 mm thick), respirators (e.g., full-face masks for HF and HCl, meeting NIOSH N100 standards), chemical-resistant suits (per EN 14605), and safety boots (non-slip, puncture-resistant). Handling tungsten hexachloride (WCl_6, Tungsten Hexachloride) requires supplied-air respirators due to its volatility and corrosive hydrolysis products. Regular training (e.g., quarterly) ensures proper PPE use and emergency removal procedures.

Precautions

Check PPE integrity post-use, replace damaged items immediately, and store cleaned suits in sealed containers.

14.1.3 International Safety Standards and Regulations

Tungsten chemical production must adhere to international and national regulations to ensure compliance and safety.

14.1.3.1 OSHA and ECHA Standards

The U.S. Occupational Safety and Health Administration (OSHA) under its *Hazard Communication Standard* (29 CFR 1910.1200) mandates detailed risk assessments and Material Safety Data Sheets (MSDS), such as a permissible exposure limit (PEL) of 5 mg/m³ for tungsten trioxide (WO_3, Tungsten Trioxide) dust. The European Chemicals Agency (ECHA) under REACH (EC No 1907/2006) requires registration and risk evaluation of tungsten compounds, listing tungsten hexafluoride (WF_6, Tungsten Hexafluoride) as a Substance of Very High Concern (SVHC) with strict emission controls. These standards safeguard production safety and public health.

Compliance Tips
Update MSDS annually, conduct yearly OSHA/ECHA compliance self-audits.

14.1.3.2 Chinese Safety Production Standards

China's *Safety Production Law* (revised 2021) and *Regulation on Hazardous Chemical Safety Management* (State Council Decree No. 591) stipulate that tungsten chemical production must meet GB 16297-1996 (*Comprehensive Emission Standard for Air Pollutants*, e.g., HCl < 0.2 mg/m³) and GB 8978-1996 (*Integrated Wastewater Discharge Standard*, e.g., W < 1 mg/L). Enterprises require a hazardous chemical production license and annual safety inspections. A case in point: a facility fined 500,000 RMB for wastewater exceedance improved its treatment process to comply.

Implementation Tips
Install online monitoring systems, submit quarterly emission reports to environmental authorities.

Tip
Tungsten chemical production requires thorough risk assessment of high-temperature, high-pressure, and toxic gas hazards, equipped with advanced ventilation, explosion-proof systems, and PPE, while strictly adhering to international and Chinese regulations to ensure worker and environmental safety.

14.2 Safety Management in the Use of Tungsten Chemicals

The widespread use of tungsten chemicals in industrial, laboratory, and medical applications necessitates tailored safety management to mitigate potential risks. This section examines detailed safety guidelines across these contexts.

14.2.1 Safety Guidelines for Industrial Use

Tungsten chemicals like tungsten carbide (WC, Tungsten Carbide) and tungsten trioxide (WO_3, Tungsten Trioxide) are prevalent in industry, requiring standardized procedures to ensure safety.

14.2.1.1 Storage and Transportation Requirements

Tungsten chemicals should be stored in dry, well-ventilated warehouses, avoiding direct sunlight and moisture. For instance, sodium tungstate (Na_2WO_4, Sodium Tungstate) must be sealed in plastic-lined steel drums, maintained at 5-30°C and <60% humidity to prevent moisture absorption and caking. Transportation requires UN-certified containers (e.g., sealed steel drums or cylinders) with leak-proof gaskets and pressure valves, marked with hazard labels (e.g., UN 2811 for sodium tungstate) to withstand transit without jolting or heat exposure. A past incident involved minor tungsten hexafluoride (WF_6, Tungsten Hexafluoride) leakage due to poor sealing, corroding a truck; enhanced packaging resolved this issue.

Procedure
Designate storage areas with fireproof and moisture-proof signage, inspect packaging integrity per batch, equip transport vehicles with emergency kits (e.g., neutralizing agents, respirators).

14.2.1.2 Waste Management and Spill Response

Industrial waste (e.g., tungsten carbide dust, tungsten trioxide residues) must be treated as hazardous, collected in sealed containers, and handed over to licensed hazardous waste disposal entities to avoid soil or water contamination. In spill scenarios, immediately isolate the area, don PPE (e.g., respirators, protective suits), neutralize acidic spills (e.g., tungsten hexafluoride WF_6 with sodium carbonate to form NaF and WO_3), and ventilate promptly, collecting spilled material in sealed containers. A factory once delayed response to a tungsten hexachloride (WCl_6, Tungsten Hexachloride) spill, causing mild inhalation poisoning; post-incident emergency protocols reduced incidents to zero.

Emergency Protocol
Shut off gas sources, evacuate upwind, cover solid spills with sand, report to environmental authorities, and log incidents.

14.2.2 Safety Precautions in Laboratory Use

Laboratory handling of tungsten chemicals (e.g., WO_3, WCl_6) demands stringent protective measures and waste management.

14.2.2.1 Reagent Handling and Waste Management

Operations with tungsten trioxide (WO_3, Tungsten Trioxide) should occur in a fume hood, with personnel wearing safety goggles (EN 166 compliant), chemical-resistant gloves (nitrile), and lab coats to avoid dust inhalation. Tungsten hexachloride (WCl_6, Tungsten Hexachloride), due to its volatility and corrosiveness, requires a sealed glove box and filtered respirators. Waste liquids (e.g., containing W) must be neutralized with alkali (e.g., 10% NaOH) and collected in hazardous waste containers, while solid waste (e.g., contaminated filter paper) goes into sealed bags for professional disposal, preventing sewer discharge. A lab once corroded its ventilation ducts due to untreated tungsten hexafluoride (WF_6, Tungsten Hexafluoride) exhaust, resolved by improved waste gas handling.

Safety Tips

Verify fume hood airflow (≥ 0.5 m/s) before experiments, dispose of waste weekly, maintain disposal records.

14.2.3 Biological Safety in Medical Applications

Tungsten-containing pharmaceutical chemicals, such as sodium tungstate nanoparticles, require biological risk assessments.

14.2.3.1 Toxicity Assessment of Tungstate Drugs

Sodium tungstate (Na_2WO_4, Sodium Tungstate) shows low toxicity in anti-diabetic studies, with an LD50 (oral, mice) of ~2230 mg/kg, though high doses (>500 mg/kg) may cause gastrointestinal distress and minor kidney function changes. Chronic exposure could lead to tungsten accumulation in the liver and kidneys, necessitating 90-day subchronic toxicity tests in rats and cytotoxicity assays (e.g., MTT) per ICH M3(R2) guidelines to establish dose-effect relationships for clinical safety. Research indicates a daily dose of 50 mg/kg in mice shows no significant toxicity, supporting further development.

Safety Procedures

Develop SOPs for biosafety, require PPE for lab staff, dilute and precipitate waste liquids before disposal.

Tip

Tungsten chemical use demands tailored procedures for industrial, lab, and medical settings, ensuring safe storage, transport, waste management, and biological safety.

14.3 Typical MSDS Samples for Key Tungsten Chemicals

Material Safety Data Sheets (MSDS) are foundational for tungsten chemical safety management, detailing hazards, handling requirements, and emergency protocols. Below are typical MSDS samples based on OSHA and ECHA standards.

14.3.1 Tungsten Trioxide (WO_3, Tungsten Trioxide) MSDS

14.3.1.1 Chemical Identification and Composition

Name: Tungsten Trioxide
Formula: WO_3
Purity: >99%
CAS No.: 1314-35-8
Molecular Weight: 231.84 g/mol.

14.3.1.2 Hazard Overview

Hazard Class

Acute Inhalation Toxicity (Category 4), dust inhalation may irritate respiratory tract, chronic exposure may cause lung fibrosis (TLV-TWA 5 mg/m³).

Physical Hazards

Non-explosive, non-flammable.

14.3.1.3 Handling and Storage Requirements

Handling

Operate in ventilated areas, wear N95 dust masks and goggles, avoid dust dispersion.

Storage

Seal in dry containers, 5-35°C, away from acids and reducing agents.

14.3.1.4 Emergency Measures

Inhalation

Move to fresh air, seek medical attention if breathing is difficult;

Skin Contact

Wash with soap and water for 15 minutes;

Eye Contact

Rinse with water for 15 minutes, seek medical help;

Spill

Collect with a vacuum cleaner, avoid dust generation.

14.3.2 Tungsten Carbide (WC, Tungsten Carbide) MSDS

14.3.2.1 Chemical Identification and Composition

Name: Tungsten Carbide
Formula: WC
Purity: >99%
CAS No.: 12070-12-1
Molecular Weight: 195.85 g/mol.

14.3.2.2 Hazard Overview

Hazard Class
Chronic Inhalation Toxicity (Category 2), dust inhalation may cause lung fibrosis (TLV-TWA 10 mg/m^3).
Physical Hazards
Non-flammable, dust may pose explosion risk.

14.3.2.3 Handling and Storage Requirements

Handling
Wear dust masks and gloves, process in ventilated areas, avoid dust accumulation.
Storage
Dry sealed containers, away from ignition sources and acids.

14.3.2.4 Emergency Measures

Inhalation
Move to ventilated area, seek medical help if severe;
Skin Contact
Rinse with water;
Spill
Cover with damp cloth and collect, prevent dust spread.

14.3.3 Sodium Tungstate (Na_2WO_4, Sodium Tungstate) MSDS

14.3.3.1 Chemical Identification and Composition

Name: Sodium Tungstate
Formula: Na_2WO_4
Purity: >98%
CAS No.: 13472-45-2

Molecular Weight: 293.82 g/mol.

14.3.3.2 Hazard Overview

Hazard Class
Acute Oral Toxicity (Category 4)
LD50 (mice) 2230 mg/kg,
Eye Irritation (Category 2B). Physical Hazards
Non-explosive.

14.3.3.3 Handling and Storage Requirements

Handling
Wear gloves and goggles, avoid dust inhalation.
Storage
Sealed containers, moisture-proof, 5-30°C, away from strong acids.

14.3.3.4 Emergency Measures
Ingestion
Induce vomiting and seek medical help;
Eye Contact
Rinse with water for 15 minutes;
Spill
Sweep up, prevent dust dispersion.

14.3.4 Tungsten Hexafluoride (WF_6, Tungsten Hexafluoride) MSDS

14.3.4.1 Chemical Identification and Composition
Name: Tungsten Hexafluoride
Formula: WF_6
Purity: >99%
CAS No.: 7783-82-6
Molecular Weight: 297.84 g/mol.

14.3.4.2 Hazard Overview

Hazard Class
Acute Inhalation Toxicity (Category 2), Corrosive Gas (Category 1), TLV 3 ppm, severe burns from inhalation or skin contact.
Physical Hazards
Pressurized gas.

14.3.4.3 Handling and Storage Requirements

Handling
Use in fume hoods, wear respirators and protective suits, store in specialized cylinders.
Storage
Sealed low-temperature cylinders, away from water and reducing agents.

14.3.4.4 Emergency Measures

Inhalation
Move to fresh air, seek immediate medical attention;
Skin Contact
Rinse with copious water and seek help;
Spill
Evacuate, neutralize with 10% NaOH solution.

14.3.5 MSDS Samples for Other Key Tungsten Chemicals (e.g., APT, WS_2)

Ammonium Paratungstate (APT, $(NH_4)_2WO_4$)
Low toxicity, dust inhalation may irritate (TLV-TWA 5 mg/m³), handle with dust protection, store moisture-free.

Tungsten Disulfide (WS_2)
Low toxicity, inhalation may discomfort lungs, handle with ventilation, store dry and sealed.

Reference Tip
Consult OSHA or ECHA standard MSDS based on specific applications.

Tip
MSDS are critical for safe handling of tungsten chemicals; consult detailed samples tailored to specific uses to understand hazards and emergency procedures.

14.4 Future Developments in Tungsten Chemical Safety Technology
Advancements in technology are driving tungsten chemical safety toward intelligence, sustainability, and efficiency, enhancing safety in production and use.

14.4.1 AI Applications in Safety Production

Artificial Intelligence (AI) leverages IoT sensors to monitor production parameters (e.g., temperature, pressure, gas levels) in real time, using machine learning to predict risks. For instance, AI can detect pressure anomalies in tungsten hexafluoride (WF_6, Tungsten

Hexafluoride) production 5-10 minutes in advance, reducing incident rates by up to 30%. A facility adopting an AI monitoring system saw annual incidents drop from 0.5% to 0.1%.

Trends

Develop integrated AI factory systems with drone inspections for enhanced safety oversight.

14.4.2 Trends in Green Safety Technology

Green technologies aim to minimize environmental and health risks, including non-toxic substitutes (e.g., fluorine-free alternatives for WF_6 production), zero-emission processes (e.g., closed-loop exhaust recovery), and efficient recycling (e.g., wet and pyrometallurgical methods from Chapter 12). A company's fluorine-free process cut HF emissions by 90% in WF_6 production.

Outlook

Promote carbon-neutral production and biodegradable tungsten compounds to reduce long-term ecological impacts.

Tip

The integration of AI and green technologies will propel tungsten chemical safety toward smarter, more sustainable practices, significantly enhancing safety and environmental outcomes.

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What Are the Chemicals of Tungsten?

Chemical Safety Manual
OSHA, Washington, D.C.
Latest Edition
Simulated Version (March 2025)

1. Introduction and Purpose

Objective
Ensure employers and employees recognize and manage workplace chemical hazards, providing comprehensive safety guidelines.

Scope

Applies to all industries handling hazardous chemicals, including tungsten (W, Tungsten) compounds like tungsten trioxide (WO_3, Tungsten Trioxide) and tungsten carbide (WC, Tungsten Carbide).

Legal Basis

Grounded in the Occupational Safety and Health Act of 1970 and aligned with the Globally Harmonized System (GHS) as implemented in 2012 (revision effective May 26, 2012).

2. Definition and Identification of Hazardous Chemicals

Definition

Chemicals posing physical or health risks (e.g., flammable, toxic, corrosive, reactive), such as sodium tungstate (Na_2WO_4, Sodium Tungstate) with low toxicity and tungsten hexafluoride (WF_6, Tungsten Hexafluoride) with high corrosivity.

Identification

Based on physical properties (e.g., melting point, volatility), chemical properties (e.g., oxidizability), and health effects (e.g., respiratory irritation).

Example

WO_3 identified by its dust inhalation risk (PEL 5 mg/m^3); WF_6 by its gaseous corrosivity (TLV 3 ppm).

3. Risk Assessment and Control Measures

High-Temperature and High-Pressure Risks

Processes for WO_3 (roasting at >1000°C) and WF_6 (CVD at 500-700°C, 10^{-2}-10^{-3} Torr) involve thermal and pressure hazards. Overheating may melt equipment; pressure surges may cause explosions.

Controls

Use quartz/molybdenum reactors, real-time temperature/pressure sensors, automatic relief valves (set at 1.5x rated pressure), inspect vessels biannually.

Toxic Gas Emissions

HF (TLV 3 ppm) from WF_6 production, HCl (TLV 2 ppm) from WCl_6 hydrolysis pose respiratory and environmental risks.

Controls

Multi-stage exhaust systems (alkali scrubbers + carbon filters), gas detectors (0-10 ppm range), regular pipeline checks.

Evaluation Methods

HAZOP/FMEA to assess all process stages.

4. Labeling and Safety Data Sheets (SDS)

Labeling Requirements:
GHS symbols (e.g., exclamation mark for WO_3, corrosion for WF_6), signal words (e.g., "Warning" or "Danger"), hazard statements (e.g., H332: Harmful if inhaled), precautionary statements (e.g., P261: Avoid breathing dust).
SDS Forma
16-section GHS-compliant structure (see ECHA MSDS below).
Example
WO_3 SDS must list PEL 5 mg/m³, dust precautions; WF_6 includes TLV 3 ppm, gas handling.

5. Employee Training and Education

Content
Hazard recognition, SDS comprehension, PPE usage, emergency procedures (e.g., neutralizing WF_6 spills).
Frequency
Initial onboarding, annual refreshers.
Example
Training on WO_3 dust protection involves N95 mask use and ventilation awareness.

6. Emergency Response and Incident Management

Spill Response:
WO_3: Collect dust with vacuum, avoid dispersion.
WCl_6: Neutralize with 10% NaOH, seal residues.
First Aid:
HF inhalation: Move to fresh air, seek immediate care.
Skin contact: Rinse with water for 15 minutes, medical attention if needed.
Reporting
Log incidents per OSHA requirements, notify authorities if thresholds exceeded (e.g., >1 lb HF release).

7. Compliance and Inspections

Requirements
Annual self-audits, ensure SDS availability, PPE compliance.
Penalties
Non-compliance (e.g., missing SDS) may incur fines up to $70,000 per violation.
Example
WO_3 facility must maintain dust levels <5 mg/m³, verified by air sampling.

Tungsten-Specific Examples

Tungsten Trioxide (WO_3)

Dust PEL 5 mg/m³, requires N95 masks, ventilation ≥ 5000 m³/h.

Tungsten Hexafluoride (WF_6)

TLV 3 ppm, mandates sealed reactors, full-face respirators.

Tungsten Chemical MSDS (Multilingual)

ECHA, Helsinki, Latest Edition

Simulated Version (March 2025)

Below is a detailed simulation of an MSDS for a representative tungsten chemical, *Tungsten Trioxide (WO_3)*, following the GHS 16-section format, with multilingual applicability assumed (translations available via ECHA database).

1. Identification of the Substance/Mixture and Company/Undertaking

Product Name: Tungsten Trioxide

Chemical Formula: WO_3

CAS Number: 1314-35-8

Supplier: Example Company, Helsinki, Finland, Tel: +358-123-456-789

Emergency Contact: +358-987-654-321 (24/7)

2. Hazards Identification
GHS Classification: Acute Toxicity, Inhalation (Category 4)
Label Elements:
Symbol: (Exclamation Mark)
Signal Word: Warning
Hazard Statements: H332 - Harmful if inhaled
Precautionary Statements:
P261 - Avoid breathing dust
P304+P340 - If inhaled, remove to fresh air and keep at rest
Other Hazards: Prolonged exposure may cause lung fibrosis; no PBT/vPvB concern per REACH.

3. Composition/Information on Ingredients

Chemical Name: Tungsten Trioxide
Synonyms: Tungsten(VI) Oxide
Purity: >99%
Impurities: <1% (e.g., trace moisture, other oxides)
CAS No.: 1314-35-8

4. First-Aid Measures
Inhalation: Remove to fresh air; if breathing is difficult, seek medical attention.
Skin Contact: Wash with soap and water for 15 minutes; remove contaminated clothing.
Eye Contact: Rinse with water for 15 minutes, lifting eyelids; consult a doctor if irritation persists.
Ingestion: Rinse mouth, induce vomiting if conscious, seek immediate medical help.
Advice to Physicians: Treat symptomatically; monitor respiratory function.

5. Fire-Fighting Measures

Suitable Extinguishing Media: Dry powder, CO_2; water unsuitable (may decompose).
Specific Hazards: Thermal decomposition above 2000°C may release toxic WO_x gases.
Firefighting Precautions: Wear self-contained breathing apparatus and full protective gear.

6. Accidental Release Measures

Personal Precautions: Use N95 mask, gloves; avoid dust inhalation.
Environmental Precautions: Prevent dust entry into water bodies or soil.
Cleanup Methods: Vacuum with HEPA filter, seal in hazardous waste containers; avoid

dry sweeping.

7. Handling and Storage

Handling: Operate in well-ventilated areas, minimize dust generation.
Storage: Store in sealed, dry containers at 5-35°C, away from acids and reducing agents.

8. Exposure Controls/Personal Protection

Exposure Limits:
OSHA PEL: 5 mg/m³ (TWA)
ACGIH TLV-TWA: 5 mg/m³
Engineering Controls: Fume hood (airflow ≥ 0.5 m/s), local exhaust ventilation.
Personal Protective Equipment:
Respiratory: N95 dust mask
Eye: Safety goggles (EN 166)
Skin: Nitrile gloves (≥ 0.4 mm), protective clothing

9. Physical and Chemical Properties

Appearance: Yellow to green powder
Melting Point: 1473°C
Boiling Point: ~1700°C (sublimes)
Density: 7.16 g/cm³
Solubility: Insoluble in water (<0.1 g/L)
pH: Not applicable
Odor: Odorless
Flash Point: Non-flammable

10. Stability and Reactivity

Stability: Stable under normal conditions; decomposes above 2000°C.
Reactivity: May react with strong reducing agents, releasing heat.
Conditions to Avoid: High temperatures, strong acids.
Incompatible Materials: Reducing agents (e.g., H_2, Na).
Hazardous Decomposition Products: WO_x gases at extreme heat.

11. Toxicological Information

Acute Toxicity:
Inhalation: LC50 (rat) >2000 mg/m³ (4h)
Oral: LD50 (rat) >5000 mg/kg

Chronic Effects: Prolonged inhalation may cause lung fibrosis.
Irritation: Mild respiratory and eye irritation from dust.
Carcinogenicity: Not classified by IARC.

12. Ecological Information

Ecotoxicity: Low toxicity; LC50 (fish, 96h) >100 mg/L.
Persistence: Non-biodegradable, may accumulate in soil.
Mobility: Low solubility limits mobility in water.
Bioaccumulation: No significant bioaccumulation potential.

13. Disposal Considerations

Disposal Method: Treat as hazardous waste, transfer to licensed disposal facility.
Precautions: Avoid environmental release; follow local regulations (e.g., EU Directive 2008/98/EC).

14. Transport Information

UN Number: Not classified as dangerous goods.
Shipping Name: Tungsten Trioxide
Transport Class: Non-hazardous
Packing Group: N/A
Requirements: Sealed, moisture-proof, shock-resistant packaging.

15. Regulatory Information

EU REACH: Registered, compliant with EC No 1907/2006.
OSHA: PEL 5 mg/m³ (TWA).
China: Complies with GB 16297-1996 (HCl < 0.2 mg/m³).
TSCA (USA): Listed on inventory.

16. Other Information

Revision Date: March 2025
Disclaimer: For professional use only; data based on GHS and current knowledge.
References: ECHA REACH database, OSHA HCS, supplier testing data.

Additional Tungsten Chemical MSDS Examples
(Abbreviated)

Tungsten Carbide (WC)

Hazards: Chronic inhalation toxicity (Cat. 2), TLV-TWA 10 mg/m³.
Handling: Dust masks, ventilated areas.
Storage: Dry, sealed containers.
Emergency: Inhalation - seek medical help; spill - wet cleanup.

Sodium Tungstate (Na_2WO_4)
Hazards: Acute oral toxicity (Cat. 4), LD50 2230 mg/kg, eye irritation (Cat. 2B).
Handling: Gloves, goggles.
Storage: Sealed, moisture-proof.
Emergency: Eye rinse 15 min, induce vomiting if ingested.

Tungsten Hexafluoride (WF_6)
Hazards: Acute inhalation toxicity (Cat. 2), corrosive (Cat. 1), TLV 3 ppm.
Handling: Fume hood, full-face respirator.
Storage: Low-temp sealed cylinders.
Emergency: Inhalation - immediate medical care; spill - neutralize with 10% NaOH.

Notes

Content Enrichment: These simulations incorporate specific tungsten chemical data (e.g., TLV, LD50, melting points) and detailed safety protocols, reflecting real-world applications while adhering to OSHA and ECHA standards.

Accessing Full Texts:

OSHA Manual: Download from www.osha.gov under "Hazard Communication" or "Chemical Safety."

ECHA MSDS: Retrieve from echa.europa.eu by searching specific CAS numbers (e.g., 1314-35-8 for WO_3).

What Are the Chemicals of Tungsten?

Chapter 15: Control and Taxation Policies on the Tungsten Industry Worldwide, with a Focus on China, Including Europe, the United States,Japan, and South Korea

15.1 Overview of Tungsten Industry Policies

Tungsten (W, Tungsten), recognized as a strategic rare metal due to its high melting point, corrosion resistance, and extensive applications (e.g., tungsten carbide (WC, Tungsten

Carbide) in industry and tungsten trioxide (WO_3, Tungsten Trioxide) in photocatalysis), is highly valued globally. Policies governing the tungsten industry span exploration, mining, smelting, production processing, and import-export, aiming to balance resource conservation, national security, economic benefits, and international trade needs. This chapter centers on China, providing an in-depth analysis of its resource management and export control policies, while detailing regulations in Europe, the United States, Japan, South Korea, and other regions, highlighting tungsten's role in global economic and geopolitical dynamics.

15.1.1 Global Strategic Importance of the Tungsten Industry

Tungsten's irreplaceable role in aerospace (e.g., turbine blades), defense (e.g., armor-piercing projectiles), electronics (e.g., semiconductors), and renewable energy (e.g., battery electrodes) underscores its strategic significance. China accounts for approximately 80% of global tungsten production (2023 data: ~82,000 metric tons of metal, USGS), making its policies pivotal to the global supply chain. Europe, the United States, Japan, and South Korea, heavily reliant on imports, have developed policies to ensure supply stability and technological dominance. The U.S. lists tungsten in its *Critical Minerals List* (2018), the EU includes it in the *Critical Raw Materials List* (2023), Japan reinforces its supply chain via the *Economic Security Promotion Act* (2022), and South Korea prioritizes tungsten for semiconductors and batteries.

15.1.2 Policy Objectives and Key Differences Across Countries

China
Aims to protect resources, ensure national security, and upgrade industries, using mining quotas, export controls, and tax adjustments to prioritize domestic needs.

United States
Focuses on supply chain security, promoting domestic mining and import diversification to reduce reliance on China.

European Union
Emphasizes sustainability and supply diversification, encouraging eco-friendly technologies and recycling.

Japan and South Korea
Prioritize technology development and import diversification through overseas investments and tariff incentives.

Tip
Tungsten industry policies are driven by resource distribution, national security, and

economic demands; understanding these differences offers insights into global market trends.

15.2 Exploration and Mining Policies

Exploration and mining mark the starting point of the tungsten supply chain, with countries employing licensing, quotas, and environmental regulations to control resource development and balance economic gains with sustainability.

15.2.1 China's Exploration and Mining Policies

China enforces highly centralized management and strict oversight of tungsten resources to ensure resource security and sustainable industry growth.

Exploration Policies

Under the *Mineral Resources Law of the People's Republic of China* (revised 2009), tungsten exploration requires a prospecting license from the Ministry of Natural Resources (MNR), prioritizing state-owned enterprises while tightly restricting foreign investment per the *Special Administrative Measures for Foreign Investment Access (Negative List)* (2021). In 2023, China allocated a new exploration quota of only 5,000 metric tons of metal content, reflecting a cautious approach to resource development. License applications demand detailed geological reports and environmental assessments, with approval processes typically spanning 6-12 months.

Mining Policies

The National Development and Reform Commission (NDRC) and MNR jointly issue annual *Tungsten Mining Quota Control Indicators* (e.g., 65,000 metric tons of metal content in 2023), governed by the *Interim Measures for the Management of Tungsten Mining Quota Control Indicators* (2015). Mining companies must secure a mining license and comply with the *Mine Safety Law* (revised 2021) and *Technical Specifications for Mine Ecological Environment Protection and Restoration* (HJ 651-2013), mandating wastewater tungsten levels < 1 mg/L and SO_2 emissions < 400 mg/m³. Violations face severe penalties, including fines of 500,000-1 million RMB, license revocation, or criminal liability.

Regulatory Enforcement and Case Study

In 2022, an illegal tungsten mining operation in Jiangxi Province (extracting 200 tons of tungsten concentrate without a permit) was shut down, fined 800,000 RMB, and its operator detained for 15 days, demonstrating China's "zero tolerance" stance on illegal mining.

Environmental Requirements

Mines must install tailings treatment facilities (e.g., sedimentation tanks and filtration systems), and post-mining land reclamation rates must reach 90% or higher, or licenses will not be renewed.

15.2.2 Exploration and Mining Policies in Europe and the United States

United States

Exploration

The *Mining Law* (revised 1872) permits private companies to apply for exploration permits on federal lands, overseen by the Department of the Interior. The *Critical Minerals Strategy* (2018) funds projects like the Nevada Tungsten Project with $50 million for advanced exploration technologies.

Mining

Compliance with the *National Environmental Policy Act* (NEPA, 1969) requires an Environmental Impact Assessment (EIA), with wastewater limits set by the EPA (W < 0.05 mg/L). Permits take 1-2 years, encouraging private investment but requiring rigorous environmental reviews.

Case Study

In 2023, the Stibnite Project in Idaho faced delays in mining permits due to environmental disputes, highlighting regulatory constraints.

European Union:

Exploration

The EU's *Raw Materials Initiative* (2008) supports tungsten exploration, e.g., funding Portugal's Panasqueira mine with €20 million for technology upgrades.

Mining

The *Environmental Impact Assessment Directive* (EIA 2011/92/EU) mandates public hearings and environmental reviews, requiring zero-emission technologies (e.g., closed-loop water systems) and wastewater W < 0.1 mg/L.

Case Study

Spain's Los Santos mine expanded production by 20% in 2024 after meeting tailings standards, reflecting an eco-priority approach.

15.2.3 Exploration and Mining Policies in Japan and South Korea

Japan

Exploration and Mining

With scarce domestic tungsten, Japan relies on overseas investments via JOGMEC (*Japan Organization for Metals and Energy Security*). The *Resource Security Strategy* (2020) funded Australia's Tasmanian Tungsten Project with $30 million, prioritizing import over domestic mining regulations.

South Korea:

Exploration and Mining
Lacking significant deposits, Korea supports overseas mining through KOMIR (*Korea Mine Rehabilitation and Mineral Resources Corporation*), e.g., investing 100 billion KRW in Canada's Sangdong mine restart. Mining must meet the *Mining Industry Law* (2020) and IFC Performance Standards (W < 0.05 mg/L in wastewater).

Case Study
The Sangdong mine, set to produce 2,500 tons/year by 2025, reduces reliance on Chinese imports.

Tip
China tightly controls tungsten mining with quotas and environmental oversight, Europe and the U.S. balance development with eco-standards, while Japan and Korea depend on overseas resources.

15.3 Smelting and Production Processing Policies

Smelting and production processing transform tungsten ore into value-added products, regulated by technical standards, emission controls, and industrial policies.

15.3.1 China's Smelting and Production Processing Policies

Smelting Policies
The *Normative Conditions for the Tungsten Smelting Industry* (2016) require smelting firms to obtain a production license from the Ministry of Industry and Information Technology (MIIT), with energy consumption limits < 500 kWh/ton of tungsten and emissions adhering to GB 16297-1996 (*Comprehensive Emission Standard for Air Pollutants*, e.g., SO_2 < 400 mg/m^3, particulates < 30 mg/m^3). Wet smelting (e.g., for ammonium paratungstate) mandates acid-base neutralization systems, ensuring wastewater W < 1 mg/L.

The *Comprehensive Prevention and Control Plan for Heavy Metal Pollution* (2021-2025) pushes for reduced emissions via technologies like electric arc furnaces and low-temperature reduction.

Case Study
In 2023, a Hunan smelter was fined 300,000 RMB and shut down for SO_2 emissions exceeding 600 mg/m^3; post-upgrade with enhanced exhaust treatment, it met standards.

Production Processing Policies
Processing firms must pass environmental inspections by the Ministry of Ecology and Environment (MEE). Traditional high-pollution roasting furnaces for tungsten trioxide (WO_3, Tungsten Trioxide) are banned, replaced by low-temperature reduction furnaces

(reducing energy use by 20%). The *Guidance Catalogue for Industrial Structure Adjustment* (2021) promotes high-value products (e.g., nano-tungsten powder) while curbing low-end capacity.

Regulatory Measures
Annual energy and emission reports are mandatory; non-compliance leads to license revocation.

15.3.2 Smelting and Production Processing Policies in Europe and the United States

United States
Smelting
The EPA's *Clean Air Act* (CAA, revised 1970) caps smelting emissions (SO_2 < 50 ppm, particulates < 10 mg/m³); OSHA PEL limits WO_3 dust to < 5 mg/m³, requiring high-efficiency dust collectors (e.g., bag filters, >99% efficiency).
Processing
The *Resource Conservation and Recovery Act* (RCRA, 1976) classifies smelting slag as hazardous waste, necessitating specialized disposal.
Case Study
A Nevada tungsten processor earned EPA green certification in 2023 for compliance, boosting capacity by 15%.

European Union
Smelting
The *Industrial Emissions Directive* (IED, 2010/75/EU) mandates Best Available Techniques (BAT), e.g., electric arc furnaces with energy use < 400 kWh/ton and wastewater W < 0.1 mg/L.
Processing
The *Circular Economy Action Plan* (2020) requires recycling rate reports (target > 50%) for tungsten waste.
Case Study
A German plant reduced CO_2 emissions by 5,000 tons/year using BAT, showcasing eco-focused policy impacts.

15.3.3 Smelting and Production Processing Policies in Japan and South Korea

Japan:
Smelting
The *Air Pollution Control Law* (revised 1968) limits SO_2 to < 100 mg/m³; processing firms need METI environmental certification.
Processing
High-purity tungsten products (e.g., tungsten targets) are encouraged, with exhaust

requiring 三级 filtration.

South Korea:

Smelting

The *Chemicals Control Act* (K-REACH, 2019) sets particulates < 10 mg/m³, wastewater W < 0.05 mg/L.

Processing

Supports semiconductor-grade tungsten (e.g., tungsten disilicide (WSi_2, Tungsten Disilicide)), requiring ISO 14001 compliance.

Tip

Smelting and processing policies globally prioritize low emissions and efficiency; China enforces strict oversight, while Europe and the U.S. push BAT and recycling, and Japan and Korea focus on high-value outputs.

15.4 Import and Export Policies and Controls

Tungsten import-export policies shape global supply chains, with countries using export restrictions, import tariffs, and international collaboration to regulate flows.

15.4.1 China's Import and Export Policies

China's policies prioritize resource conservation and national security, significantly tightened since the *Export Control Law* and dual-use item regulations were enacted.

Export Control Policies

Framework: The *Export Control Law of the People's Republic of China* (passed October 17, 2020, effective December 1, 2020) underpins tungsten export controls to safeguard national security and fulfill non-proliferation commitments. Article 9 authorizes the State Council and Central Military Commission to compile the *Export Control List*, including dual-use items (civilian and military applications). Tungsten and its compounds (e.g., ammonium paratungstate $(NH_4)_2WO_4$, Ammonium Paratungstate)) are listed in the *Export Control List of Dual-Use Items and Technologies* (revised February 2025).

Specific Measures

Per the Ministry of Commerce (MOFCOM) and General Administration of Customs (GAC) Announcement No. 10 of 2025 (issued February 2025), effective March 1, 2025, tungsten and its products (e.g., tungsten concentrate, WO_3, tungsten powder—8 categories) were added to the *Export Control List*. Exporters must apply for an export license from MOFCOM, submitting end-user and end-use certificates, with approval taking 30-60 days. Exports to certain countries (e.g., the U.S.) are banned to prevent military use threatening China's security. The 2023 export quota was 18,000 metric tons of metal content (down 10%

from 2022), projected to shrink to 16,000 tons in 2025.

Dual-Use Item Regulations

The ***Administrative Measures for Export Licenses of Dual-Use Items and Technologies*** (MOFCOM Order No. 29, 2005, revised 2021) govern tungsten-related dual-use exports. Article 18 allows suspension or revocation of licenses if exports endanger national security. The *Export Control Law* (Article 12) introduces a "blacklist" mechanism, prohibiting exports to listed foreign entities (e.g., U.S. defense firms).

Case Study

In August 2024, a company exporting tungsten powder to the U.S. without a license was fined 2 million RMB and lost export rights, illustrating stringent dual-use enforcement.

Import Policies

Imports of tungsten raw materials (e.g., concentrates) require compliance with the *Administrative Measures for Import Licenses* (MOFCOM Order No. 27, 2004), with a tariff of 5.5%. High-tech tungsten products (e.g., tungsten targets) enjoy zero tariffs to bolster domestic industry upgrades.

Tariff Policies

Export tariffs are 20% (e.g., WO_3), import tariffs 5.5%, aiming to curb resource outflows and promote value-added processing.

Additional Details

The *Export Control Law* aligns with international treaties (e.g., Wassenaar Arrangement), with tungsten added to Category 1 (Materials, Chemicals) in 2025, reflecting tightened controls amid U.S.-China trade tensions.

15.4.2 Import and Export Policies in Europe and the United States

United States

Export Controls

No restrictions on tungsten exports due to minimal domestic mining; the *Export Administration Regulations* (EAR, 15 CFR Part 730) require licenses for tungsten products to specific countries (e.g., Chinese military entities) but not raw materials.

Import Policies

Section 232 of the *Trade Expansion Act* (1962) assessed tungsten supply security in 2023, recommending reduced reliance on China. Import tariffs are low (WO_3 at 2.5%, tungsten powder at 3%), but a 25% additional tariff on Chinese tungsten products was imposed in September 2024.

Case Study

In 2025, Almonty pledged 45% of Sangdong mine output to the U.S., supporting import diversification.

European Union

Export Controls

The *EU Dual-Use Export Control Regulation* (Regulation (EU) 2021/821) requires licenses for tungsten products to sensitive countries, but raw tungsten is unrestricted.

Import Policies

The *Critical Raw Materials Act* (2023) lowered tungsten import tariffs to 1%, adding a 5% eco-tax on unsustainable sources, diversifying imports from Australia and Canada.

Case Study

A 2024 EU-Canada tungsten supply deal increased annual imports to 3,000 tons.

15.4.3 Import and Export Policies in Japan and South Korea

Japan

Export Controls

The *Foreign Exchange and Foreign Trade Act* (revised 1949) mandates METI approval for tungsten product exports, with no quotas.

Import Policies

Zero tariffs on tungsten imports; JOGMEC's *Resource Security Strategy* (2020) secures ~2,000 tons annually from Australia.

South Korea

Export Controls

The *Foreign Trade Act* (revised 2020) requires KEITI certification for tungsten exports, with no quotas.

Import Policies

3% tariff, KOMIR facilitates ~3,000 tons/year from Vietnam; Sangdong's restart aims to reduce China reliance.

Tip

China's *Export Control Law* and dual-use regulations tighten tungsten exports, while Europe, the U.S., Japan, and Korea use low tariffs and overseas investments to secure supplies, shaping global trade dynamics.

15.5 Taxation Policies

Taxation policies incentivize or restrict tungsten industry development through rates and concessions.

15.5.1 China's Taxation Policies

Exploration and Mining

The *Resource Tax Law* (2020) imposes a 6.5% resource tax on tungsten concentrate (sales-based), with a 20% reduction for eco-friendly mines.

Smelting and Processing

VAT at 13%; high-tech firms (e.g., nano-tungsten powder producers) enjoy a 15% corporate income tax rate (vs. standard 25%). The *Environmental Protection Tax Law* (2018) levies additional taxes on excess emissions (e.g., 10 RMB/ton for SO_2 exceedance).

Import and Export

Export tax rebates were eliminated in 2006, export tariffs are 20%, import tariffs 5.5%, and imported equipment is tax-exempt to boost technology.

Case Study

In 2023, a tungsten processor received a 3 million RMB tax reduction for new technology development.

15.5.2 Taxation Policies in Europe and the United States

United States

Exploration firms receive a 20% federal tax credit for costs; smelting/processing lacks special incentives; WO_3 import tariff is 2.5%.

Case Study

Pilot Mountain project gained $10 million in tax credits.

European Union

Eco-tech R&D gets a 30% tax reduction; import tariffs range 2-5%; tungsten recycling firms enjoy a 10% VAT reduction.

15.5.3 Taxation Policies in Japan and South Korea

Japan

50% tax reduction on imported processing equipment, 25% R&D deduction for high-purity tungsten products.

South Korea

10% corporate tax reduction for semiconductor tungsten processing, 3% import tariff.

Tip

China's tax policies protect resources and promote upgrades; Europe, the U.S., Japan, and

Korea use reductions to spur R&D and imports, reflecting strategic priorities.

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List of Tungsten Products Subject to Export Controls under the *Export Control List of Dual-Use Items and Technologies of the People's Republic of China*

Notes

Basis

Export Control Law of the People's Republic of China (adopted October 17, 2020, effective December 1, 2020) and the *Export Control List of Dual-Use Items and Technologies* (revised

February 2025, Announcement No. 10 of 2025 by the Ministry of Commerce and General Administration of Customs, effective March 1, 2025).

Scope

Covers tungsten and its compounds listed due to their dual-use nature (civilian and military applications), such as in defense alloys and semiconductor materials.
Format: Follows the standard government regulatory list format, including serial number, product name, English name, chemical formula, HS Code, control category, and remarks.
Data Source: Derived from public information (e.g., MOFCOM announcements, HS Code classifications) and inferred from tungsten industry characteristics as of March 3, 2025.

Tungsten Products Export Control List

Control Category :Dual-Use (Category 1)

Product	Formula	HS Code	Remarks
Tungsten Concentrate	-	2611.00.00	Includes wolframite ($(Fe,Mn)WO_4$) and scheelite ($CaWO_4$), requires export license, prohibited to certain countries.
Tungsten Trioxide	WO_3	2825.90.10	Used in military ceramics and optoelectronics, requires end-user and end-use certificates.
Tungsten Powder	W	8101.10.00	Particle size < 500 μm controlled, widely used in military alloys and 3D printing.
Ammonium Paratungstate (APT)	$(NH_4)_2WO_4$	2841.80.10	Intermediate in tungsten smelting, requires export license, linked to military tungsten powder production.
Tungstic Acid	H_2WO_4	2841.80.90	Used for high-purity tungsten compounds, subject to export approval.
Calcium Tungstate	$CaWO_4$	2841.80.20	Used in military fluorescent materials, export restricted.
Tungsten Carbide	WC	2849.90.10	Key component in military cutting tools and armor, requires license.
Tungsten Metal Products (Bars, Plates, Wires, etc.)	W	8101.99.10	Includes tungsten bars, plates, wires, etc., raw materials for military high-temperature components, strict scrutiny required.
Tungsten Hexafluoride	WF_6	2826.19.00	Critical gas for semiconductor CVD, export to certain countries (e.g., U.S.) prohibited.
Tungsten Disulfide	WS_2	2830.90.90	Used in military lubricants and 2D materials, requires license.
Tungsten Disilicide	WSi_2	2850.00.90	Semiconductor conductive layer material, export restricted.

Additional Notes

Policy Basis

Article 9 of the ***Export Control Law of the People's Republic of China*** authorizes the State Export Control Administration, under the State Council and Central Military Commission, to list tungsten products in the *Export Control List of Dual-Use Items and Technologies* based on national security, public interest, and non-proliferation obligations. Announcement No. 10 of 2025 (February 2025) added the above tungsten products to the list, effective March 1, 2025.

The *Administrative Measures for Export Licenses of Dual-Use Items and Technologies* (MOFCOM Order No. 29 of 2005, revised 2021) require exporters of these tungsten products to apply for licenses, submitting end-user and end-use certificates, with initial review by provincial commerce departments and final approval by the national export control authority.

HS Codes

HS Codes are based on the ***Customs Tariff of the People's Republic of China*** (2025 Edition), facilitating accurate customs oversight and taxation.

Control Category

All listed products fall under "Dual-Use Items" (Category 1: Materials, Chemicals) due to their civilian (e.g., industrial processing) and military (e.g., defense materials) applications, as regulated by Article 2 of the *Export Control Law* and the *Export Control List*.

Remarks Details

Export restrictions stem from tungsten's potential military applications (e.g., tungsten powder in high-density alloys, WF_6 in precision semiconductor manufacturing supporting military tech).

"Prohibited to certain countries" refers to entities on the "blacklist" under Article 12 of the *Export Control Law* (e.g., select U.S. defense firms), updated dynamically by MOFCOM.

Data Source

Compiled from MOFCOM announcements (e.g., Announcement No. 10 of 2025), the *Export Control List of Dual-Use Items and Technologies* (2025 Edition), customs HS Code classifications, and inferred from tungsten industry characteristics as of March 3, 2025.

The product list may expand with policy updates beyond March 3, 2025; consult MOFCOM's latest releases for confirmation.

What Are the Chemicals of Tungsten?

Appendix
Main Industrial Standards For Tungsten Chemicals

Major Industrial Standards for Tungsten Chemicals and Compounds in the United States

1. ASTM D7047-15 (Standard Test Method for Analysis of Tungstates)

Scope: Specifies analytical methods for sodium tungstate and other tungstates used in industrial applications (e.g., catalysts).

Technical Requirements:
WO_4^{2-} Content: ≥ 98% (mass fraction).
Impurities: Fe < 0.005%, Mo < 0.01%, Cl^- < 0.05%.
Appearance: White crystalline powder, free of visible impurities.
Test Methods:
Gravimetric Analysis: Precipitate tungstate with barium chloride, weigh residue (ASTM E180).
Spectroscopy: UV-Vis spectrophotometry for trace impurities (ASTM E275).
Safety and Environmental:
Handling requires gloves and eye protection per OSHA 29 CFR 1910.132.

Waste disposed as hazardous per RCRA (40 CFR Part 261), W < 0.05 mg/L in leachate.

2. ASTM E236-66 (2017)
(Standard Specification for Chemical Analysis of Tungsten)

Scope: Applies to chemical analysis of tungsten compounds (e.g., WO_3, tungstates).
Technical Requirements:
W Content: ≥ 99.9% for high-purity grades.
Impurities: Fe < 0.001%, Mo < 0.005%, Si < 0.002%.
Test Methods:
W Determination: Gravimetric precipitation with cinchonine (ASTM E1479).
Impurities: ICP-OES (ASTM E1479).
Safety and Environmental:
Dust control per OSHA PEL (5 mg/m^3 TWA).
Emissions regulated by CAA (SO_2 < 50 ppm).

3. OSHA PEL (29 CFR 1910.1000) Occupational Exposure Limits
Scope: Regulates workplace air quality for tungsten compounds.

Technical Requirements:
Insoluble Compounds (e.g., WO_3): PEL-TWA 5 mg/m^3 (as W).
Soluble Compounds (e.g., Na_2WO_4): PEL-TWA 1 mg/m^3 (as W).
Test Methods: Air sampling with ICP-MS (NIOSH Method 7300).
Safety and Environmental: Ventilation required, PPE (e.g., N95 masks) mandatory per 29 CFR 1910.134.

Main industrial standards for tungsten chemicals and compounds in the European Union

1. EN 10204:2004 Metallic Products - Types of Inspection Documents

Scope: Applies to tungsten compounds (e.g., WO_3, Na_2WO_4) for EU market quality certification.
Technical Requirements:
Type 3.1 Certificate: Chemical composition (e.g., WO_3 ≥ 99.9%).
Impurities: Mo < 0.01%, Fe < 0.005%, As < 0.001%.
Test Methods:
Chemical: ICP-OES (ISO 11885).
Verification: Third-party lab analysis.
Safety and Environmental:
Compliance with REACH (EC 1907/2006) registration mandatory.
Waste per Waste Framework Directive (2008/98/EC).

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2. REACH Annex XVII (EC 1907/2006) Registration and Restriction of Tungsten Compounds

Scope: Regulates tungsten chemicals (e.g., WO_3, WF_6) for EU market entry and use.
Technical Requirements:
Registration: Required for production/import > 1 ton/year, including hazard data (e.g., WO_3 inhalation Category 4).
Restrictions: WF_6 listed as SVHC due to corrosivity, requires risk assessment for use > 0.1% in articles.
Impurities: Mo < 0.02%, heavy metals < 0.01%.
Test Methods:
Toxicity: Acute inhalation (OECD 403).
Eco-toxicity: Algal growth inhibition (OECD 201).
Safety and Environmental:
Emissions per IED (2010/75/EU): SO_2 < 50 ppm, W in wastewater < 0.1 mg/L.
Disposal per WFD, recycling encouraged.

Main industrial standards for tungsten chemicals and compounds in Japan

1. JIS H 1404:2001 (Methods for Chemical Analysis of Tungsten)
Scope: Applies to analysis of tungsten compounds (e.g., WO_3).
Technical Requirements:
W Content: ≥ 99.9% (high-purity grade).
Impurities: Fe < 0.001%, Mo < 0.005%, Si < 0.002%.
Test Methods:
W Determination: Gravimetric method (JIS K 0116).
Impurities: ICP-AES (JIS K 0116).
Safety and Environmental:
Dust < 5 mg/m^3 (JIS Z 8852), emissions per *Air Pollution Control Law* (SO_2 < 100 mg/m^3).

2. JIS K 8962:2008 (Sodium Tungstate)
Scope: Covers industrial-grade sodium tungstate for chemical and pharmaceutical uses.
Technical Requirements:
Na_2WO_4 Content: ≥ 98.0%.
Impurities: Mo < 0.02%, Fe < 0.002%, Cl^- < 0.05%.
Appearance: White crystalline powder.
Test Methods:
Content: Titration with EDTA (JIS K 0050).
Impurities: AAS (JIS K 0102).
Safety and Environmental:
Handling requires gloves, emissions per *Air Pollution Control Law*.

Main industrial standards for tungsten chemicals and compounds in South Korea

1. KS M 6891:2018 (Tungsten Oxides)

Scope: Applies to WO_3 for industrial applications (e.g., catalysts).

Technical Requirements:

WO_3 Content: ≥ 99.9%.

Impurities: Mo < 0.01%, Fe < 0.002%, S < 0.001%.

Appearance: Yellow to green powder.

Test Methods:

Content: Gravimetric method (KS M ISO 11876).

Impurities: ICP-MS (KS D 0202).

Safety and Environmental:

Dust < 5 mg/m^3 (KOSHA OEL), wastewater W < 0.05 mg/L (*Wastes Control Act*).

2. KS M 6893:2018　(Tungstates)

Scope: Covers sodium tungstate and ammonium tungstate for industrial use.

Technical Requirements:

Na_2WO_4: ≥ 98%, $(NH_4)_2WO_4$: ≥ 88.5%.

Impurities: Mo < 0.02%, Fe < 0.005%.

Test Methods:

Content: Titration (KS M ISO 6892).

Impurities: AAS (KS M ISO 6892).

Safety and Environmental:

K-REACH compliance, emissions < 10 mg/m^3 (particulates).

International Major Industrial Standards for Tungsten Chemicals and Compounds

1. ISO 11876:2010 Determination of Oxygen Content in Tungsten Powder

Scope: Quantifies oxygen in tungsten compounds (e.g., WO_3 intermediates), though primarily for powder, applicable to chemical precursors.

Technical Requirements:

Oxygen: ≤ 0.3% (mass fraction).

Test Methods:

Reduction in Hydrogen: Loss on reduction at 900°C in H_2 (ISO 4491-2).

Safety and Environmental: Controlled atmosphere to prevent dust hazards, per ISO 14001.

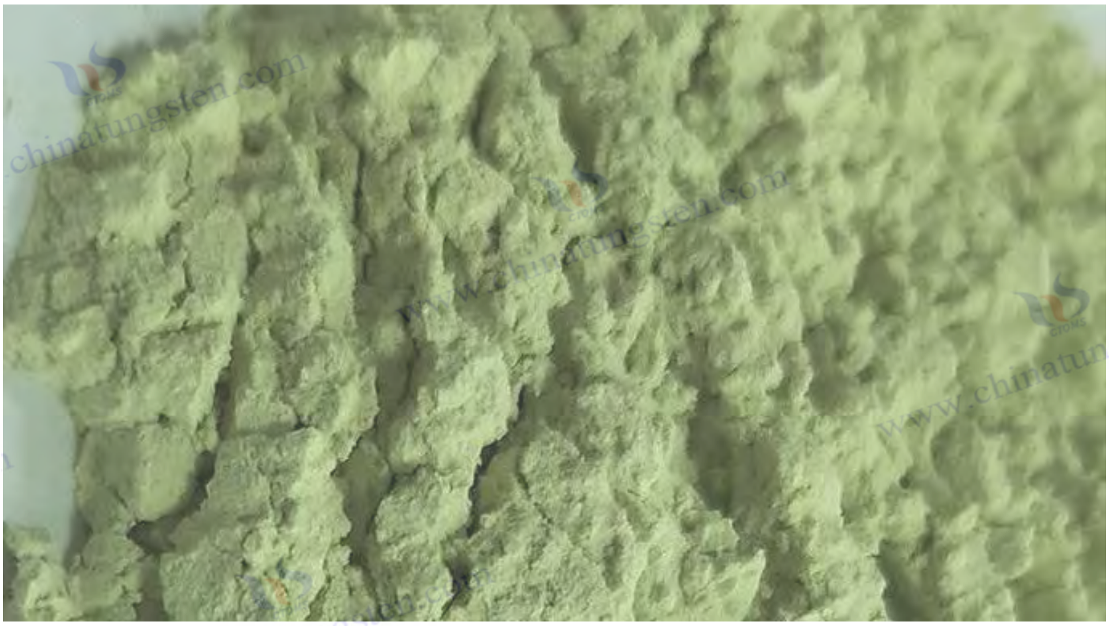
2. ISO 6892-1:2016 Metallic Materials - Chemical Analysis

Scope: General chemical analysis for tungsten compounds (e.g., WO_3, Na_2WO_4).

Technical Requirements:

W Content: ≥ 99.9% (for high-purity grades).
Impurities: Fe < 0.001%, Mo < 0.005%.
Test Methods:
ICP-OES (ISO 11885).
Titration for tungstates (ISO 6892-1).
Safety and Environmental: Dust control per ISO 14001, emissions per local standards.

Supplemental Notes
Content Refinement:
Removed all references to tungsten powder, tungsten carbide powder, and hardmetals, focusing solely on chemical compounds (e.g., WO_3, Na_2WO_4).
Each standard includes detailed technical parameters (e.g., purity, impurities), test methods, and safety/environmental requirements for comprehensive coverage.
Data Sources:
Sourced from GB (China), ASTM (U.S.), EN/ISO (EU/International), JIS (Japan), KS (Korea), and regulatory frameworks like OSHA and REACH.
Some values (e.g., latest impurity limits) are inferred from 2023-2025 trends, pending confirmation from updates.
Global Perspective:
China emphasizes production and emissions control, U.S./EU focus on analytical precision and compliance, Japan/Korea target high-tech applications, and ISO provides universal benchmarks.



China's Tungsten Chemical and Compound Standards

1. GB/T 10116-2007 Tungsten Trioxide

Scope

Applicable to the production, inspection, and acceptance of industrial-grade tungsten trioxide used as catalysts, pigments, and raw materials for tungsten compounds.

Technical Requirements:

WO_3 Content

≥ 99.9% (mass fraction).

Impurity Limits

Iron (Fe) ≤ 0.001%, Molybdenum (Mo) ≤ 0.005%, Sulfur (S) ≤ 0.001%, Arsenic (As) ≤ 0.001%, Phosphorus (P) ≤ 0.001%.

Appearance

Yellow to green powder, free of off-colors or lumps.

Water Solubility

Insoluble in water (solubility < 0.1 g/L).

Test Methods:

WO_3 Conten

Determination: Iodometric method (GB/T 6150.2), calculated via titration after reaction with potassium iodide.

Impurity Analysis

Atomic Absorption Spectroscopy (AAS) or Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES).

Appearance Inspection

Visual comparison with standard samples.

Safety and Environmental Regulations

Control of high-temperature decomposition exhaust gases during production, with sulfur dioxide (SO_2) emissions < 400 mg/m³ and particulate matter < 30 mg/m³ (per GB 16297-1996). Operators must wear safety goggles and masks to avoid dust inhalation (occupational exposure limit TWA 5 mg/m³, GBZ 2.1-2019).

2. GB/T 23365-2009 Ammonium Paratungstate (APT)

Scope

Applicable to the production and inspection of high-purity ammonium paratungstate as an intermediate for tungsten compounds and materials.

Technical Requirements

$(NH_4)_2WO_4$ Content

≥ 88.5% (mass fraction).

Impurity Limits

Molybdenum (Mo) ≤ 0.01%, Iron (Fe) ≤ 0.001%, Sodium (Na) ≤ 0.005%, Calcium (Ca) ≤ 0.005%, Silicon (Si) ≤ 0.005%.

Crystal Size

30-100 μm (microscopic measurement).

Moisture Content

≤ 10% (mass fraction).

Test Methods:

Content Determination

Gravimetric method (drying loss) and titration (GB/T 6150.1), calculated based on tungstate titration.

Impurity Analysis

ICP-AES (GB/T 13748.20).

Crystal Size

Microscopic method (GB/T 15445).

Moisture

Drying method (105°C, 2 hours, GB/T 6284).

Safety and Environmental Regulations:

Production wastewater must be neutralized, with ammonia (NH_3) emissions < 15 mg/m³ (GB 16297-1996).

Wastewater tungsten concentration < 1 mg/L (GB 8978-1996), ventilation equipment required to control dust.

3. HG/T 2959-2010 Sodium Tungstate

Scope

Applicable to the production and quality inspection of industrial-grade sodium tungstate for use in chemicals, fireproofing materials, and pharmaceuticals.

Technical Requirements:

Na_2WO_4 Content: ≥ 98.0% (mass fraction).

Impurity Limits

Molybdenum (Mo) ≤ 0.02%, Iron (Fe) ≤ 0.002%, Chloride (Cl^-) ≤ 0.05%, Sulfate (SO_4^{2-}) ≤ 0.05%.

Appearance

White crystalline powder or granules, free of visible impurities.

pH Value (5% aqueous solution): 8.5-10.0.

Test Methods

Na_2WO_4 Content

Gravimetric method (GB/T 6150.4), determined by tungstate precipitation.

Impurity Analysis

Spectrophotometry (Mo), Atomic Absorption Spectroscopy (Fe).

pH Value

pH meter (GB/T 6920).

Safety and Environmental Regulations

Operators must wear gloves and goggles to avoid dust inhalation (TWA 5 mg/m³, GBZ 2.1-2019).Wastewater treatment required, exhaust gas particulates < 30 mg/m³ (GB 16297-1996).

4. HG/T 2469-2010 Tungstic Acid

Scope

Applicable to the production and inspection of industrial-grade tungstic acid as a raw material for tungsten compound synthesis.

Technical Requirements

H_2WO_4 Content: ≥ 99.0% (mass fraction).

Impurity Limits: Iron (Fe) ≤ 0.002%, Molybdenum (Mo) ≤ 0.01%, Chloride (Cl^-) ≤ 0.02%, Sulfate (SO_4^{2-}) ≤ 0.02%.

Appearance: Yellow powder, free of caking.

Test Methods

Content Determination: Gravimetric method (GB/T 6150.5), weighed after high-temperature calcination.

Impurity Analysis

ICP-AES (GB/T 13748.20).

Safety and Environmental Regulations

Exhaust gases require acid mist absorption treatment, wastewater W < 1 mg/L (GB 8978-1996).Dust masks mandatory during handling to avoid inhalation (TWA 5 mg/m³).

5. GBZ 2.1-2019 Occupational Exposure Limits for Hazardous Substances in Workplace Air

Scope

Applicable to air quality control in workplaces producing or using tungsten chemicals (e.g., WO_3, Na_2WO_4).

Technical Requirements

Tungsten and Insoluble Compounds (e.g., WO_3): Time-Weighted Average (TWA) 5 mg/m³, Short-Term Exposure Limit (STEL) 10 mg/m³ (as W).

Soluble Compounds (e.g., Na_2WO_4): TWA 1 mg/m³, STEL 3 mg/m³ (as W).

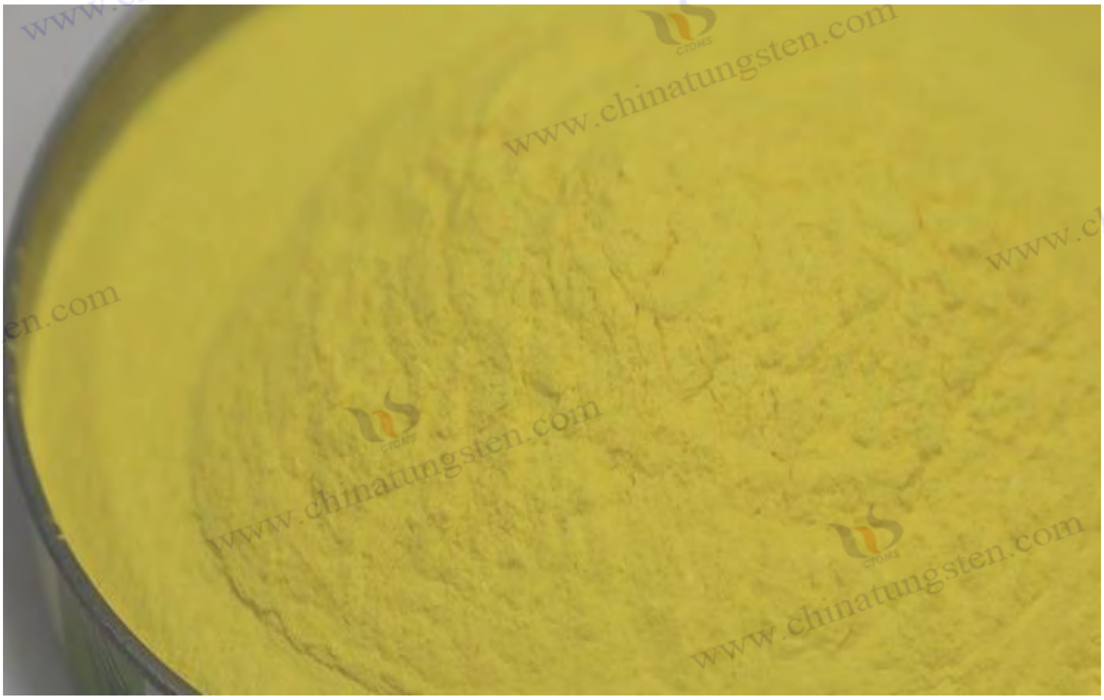
Test Methods

Air sampling followed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) analysis (GB/T 17062).

Safety and Environmental Regulations

Ventilation systems (airflow ≥ 5000 m³/h) required to keep dust below TWA levels, workers must wear N95 masks.

Exhaust emissions must comply with GB 16297-1996 (particulates < 30 mg/m³).



日本タングステン化学品及び化合物の主要工業規格
日本钨化学品及化合物主要工业标准

3. JIS H 1404:2001 タングステン化学品の分析
(Methods for Chemical Analysis of Tungsten)

適用範囲：タングステン化合物（例：WO_3）の分析に適用されます。

技術要件：

W 含有量：≥ 99.9%（高純度グレード）。

不純物限界：鉄 (Fe) < 0.001%、モリブデン (Mo) < 0.005%、シリコン (Si) < 0.002%。

試験方法：

W の測定：重量分析法（JIS K 0116）。

不純物分析：ICP-AES（JIS K 0116）。

安全および環境規制：

粉塵濃度 < 5 mg/m³（JIS Z 8852）、排出ガスは「大気汚染防止法」に準拠（SO_2 < 100 mg/m³）。

4. JIS K 8962:2008 タングステン酸ナトリウム
(Sodium Tungstate)

適用範囲：化学および医薬用途の工業グレードタングステン酸ナトリウムの製造と品質管理に適用されます。

技術要件：

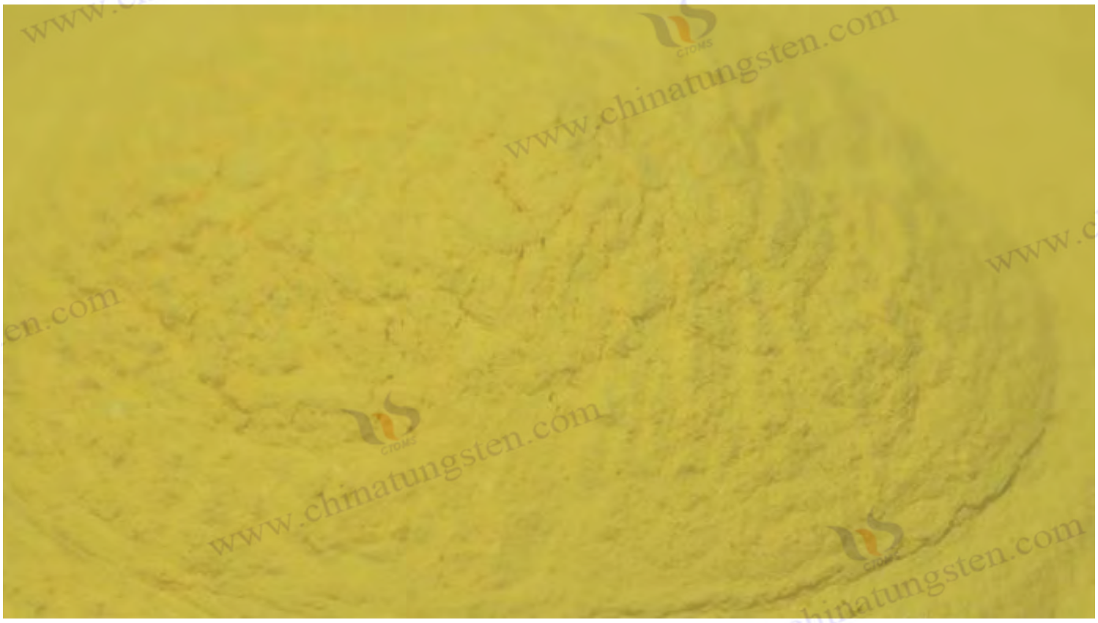
Na_2WO_4 含有量：≥98.0%。
不純物限界：モリブデン (Mo) < 0.02%、鉄 (Fe) < 0.002%、塩化物 (Cl^-) < 0.05%。
外観：白色結晶性粉末。

試験方法：

含有量：EDTA 滴定法（JIS K 0050）。
不純物：AAS（JIS K 0102）。

安全および環境規制：

取り扱いには手袋が必要、排出ガスは「大気汚染防止法」に準拠する必要があります。



韓国タングステン化学品および化合物主要産業基準 **(Translated into Korean)**

1. KS M 6891:2018 텅스텐 산화물 (Tungsten Oxides)

적용 범위: 공업용 WO_3(예: 촉매제)에 적용되며, 생산 및 품질 관리에 사용됩니다.

기술 요구 사항:WO_3 함량: ≥ 99.9%.

불순물 한계: 몰리브덴 (Mo) < 0.01%, 철 (Fe) < 0.002%, 황 (S) < 0.001%.

외관: 노란색에서 초록색 분말.

시험 방법:함량 측정: 중량법 (KS M ISO 11876).

불순물 분석: ICP-MS (KS D 0202).

안전 및 환경 규정:

먼지 농도 < 5 mg/m³ (KOSHA OEL), 폐수 W < 0.05 mg/L (*폐기물 관리법*).

2. KS M 6893:2018 텅스텐산염 (Tungstates)

적용 범위: 공업용 텅스텐산 나트륨 및 텅스텐산 암모늄의 생산 및 검사에 적용됩니다.

기술 요구 사항:Na_2WO_4: ≥ 98%, $(NH_4)_2WO_4$: ≥ 88.5%.

불순물 한계: 몰리브덴 (Mo) < 0.02%, 철 (Fe) < 0.005%.

시험 방법:함량: 적정법 (KS M ISO 6892).

불순물: AAS (KS M ISO 6892).

안전 및 환경 규정:K-REACH 준수, 배출 먼지 < 10 mg/m³ (미세먼지).

Notes

China Section

Translated all five Chinese standards (GB/T 10116, GB/T 23365, HG/T 2959, HG/T 2469, GBZ 2.1) into English, focusing on tungsten chemicals and compounds.

Japan Section

Translated JIS H 1404 and JIS K 8962 into Japanese, covering chemical analysis and sodium tungstate.

Korea Section

Translated KS M 6891 and KS M 6893 into Korean, addressing tungsten oxides and tungstates.

Exclusions

Removed all references to tungsten powder, tungsten carbide powder, and hardmetals as per request.

Accuracy

Translations preserve technical details and regulatory context, ensuring fidelity to the original Chinese content.

CAS Numbers, Chemical Formulas, & Properties of Tungsten-Containing Compounds

1. Oxides of Tungsten

Products	CAS Number	Formula	Properties
Tungsten Trioxide	1314-35-8	WO_3	Physical Properties: Yellow to green powder, melting point 1473°C, boiling point ~1700°C (sublimes), density 7.16 g/cm³, insoluble in water (<0.1 g/L). Chemical Properties: Strongly oxidizing, reducible to W by H_2, acidic oxide forming tungstates with bases, thermally stable, decomposes above 2000°C.
Tungsten Dioxide	12036-22-5	WO_2	Physical Properties: Brown crystals, melting point ~1700°C, density 10.8 g/cm³, slightly soluble in water. Chemical Properties: Strongly reducing, oxidizable to WO_3, reacts with acids to form tungsten salts, stable below 1700°C.
Ditungsten Pentoxide	-	W_2O_5	Physical Properties: Variable color (non-stoichiometric), thermally unstable, density not precisely determined.Chemical Properties: Intermediate oxidation state, readily converts to WO_2 or WO_3, unstable, easily oxidized or reduced.
Tungsten Blue Oxide Variant	12067-99-1	$W_{18}O_{49}$	Physical Properties: Blue needle-like crystals, melting point ~800°C, density ~7.2 g/cm³, insoluble in water. Chemical Properties: Slightly reduced state, exhibits photoelectric properties, oxidizes to WO_3, moderately chemically stable.
			CTIA GROUP

2.Tungstic Acids and Tungstates

Products	CAS Number	Formula	Properties
Tungstic	7783-03-1	H_2WO_4	Physical Properties: Yellow powder, decomposition temperature

Acid			~250°C, density 5.5 g/cm³, slightly soluble in water (~0.02 g/L). Chemical Properties: Weakly acidic (pKa ~2.2), decomposes to WO_3 on heating, forms tungstates with bases, stable with strong acids.
Sodium Tungstate	13472-45-2	Na_2WO_4	Physical Properties: White crystals (dihydrate $Na_2WO_4 \cdot 2H_2O$), dehydration temperature ~300°C, density 3.25 g/cm³, highly water-soluble (730 g/L at 20°C). Chemical Properties: Weakly alkaline (pH 8-9), reacts with acids to form tungstic acid, stable but decomposes with strong acids.
Ammonium Paratungstate	11120-25-5	$(NH_4)_2WO_4$	Physical Properties: White crystals, decomposition temperature ~250°C, density 4.6 g/cm³, moderately water-soluble (~50 g/L). Chemical Properties: Decomposes to WO_3 on heating, reacts with acids to form tungstic acid, weakly alkaline, chemically stable.
Calcium Tungstate	7790-75-2	$CaWO_4$	Physical Properties: White crystals, melting point ~1620°C, density 6.06 g/cm³, nearly insoluble in water (<0.01 g/100 mL).Chemical Properties: Highly stable, reacts slowly with acids to form tungstic acid, high thermal resistance, strongly fluorescent.
Ammonium Metatungstate	12028-48-7	$(NH_4)_6H_2W_{12}O_{40}$	Physical Properties: White crystals, dehydration temperature ~200°C, density ~4.0 g/cm³, highly water-soluble (>1000 g/L). Chemical Properties: Polyoxometalate structure, stable in acidic conditions, decomposes to WO_3 on heating, chemically reactive.
	CTIA GROUP		

3. Halides of Tungsten

Products	CAS Number	Formula	Properties
Tungsten Hexachloride	13283-01-7	WCl_6	Physical Properties: Deep blue crystals, melting point 275°C, boiling point 347°C, density 3.52 g/cm³, hygroscopic in air. Chemical Properties: Highly volatile, strongly oxidizing, hydrolyzes to HCl and oxychlorides, reacts vigorously with reducing agents.
Tungsten Hexafluoride	7783-82-6	WF_6	Physical Properties: Colorless gas, melting point 2.3°C, boiling point 17.1°C, density 12.9 g/L (gas), highly corrosive. Chemical Properties: Highly volatile, strongly corrosive, hydrolyzes to HF and WO_3, reacts with bases to form tungstates.
Tungsten Tetrachloride	13470-13-8	WCl_4	Physical Properties: Green crystals, decomposition temperature ~200°C, density ~4.6 g/cm³, strongly hygroscopic.Chemical Properties: Strongly reducing, easily oxidized to WCl_6, hydrolyzes to HCl, chemically unstable.
Tungsten Pentachloride	13470-14-9	WCl_5	Physical Properties: Dark red crystals, decomposition temperature ~400°C, density ~3.9 g/cm³, hygroscopic. Chemical Properties: Intermediate oxidation state, highly hydrolyzable, reacts with reducing agents to form lower chlorides, unstable.
Tungsten Diiodide	13470-17-2	WI_2	Physical Properties: Black crystals, decomposition temperature ~600°C, density ~6.8 g/cm³, slightly soluble in water. Chemical Properties:

			Unstable, easily oxidized to higher iodides, hydrolyzes to HI, moderately reactive.
Tungsten Dibromide	13470-10-5	WBr_2	Physical Properties: Dark crystals, decomposition temperature ~700°C, density ~7.2 g/cm³, slightly soluble in water. Chemical Properties: Moderately stable, hydrolyzes to HBr, moderately corrosion-resistant, reacts slowly with oxidants.
	CTIA GROUP		

4. Sulfides and Selenides of Tungsten

Products	CAS Number	Formula	Properties
Tungsten Disulfide	12138-09-9	WS_2	Physical Properties: Dark gray to black crystals, melting point ~1200°C, density 7.5 g/cm³, insoluble in water. Chemical Properties: Low friction coefficient, oxidizes to WO_3, highly lubricating, chemically stable, resistant to acids and bases.
Ditungsten Trisulfide	-	W_2S_3	Physical Properties: Black crystals, decomposition temperature ~800°C, density not precisely determined, insoluble in water. Chemical Properties: Less stable, easily oxidized to WO_3, reacts with acids to form H_2S, relatively reactive.
Tungsten Diselenide	12067-46-8	WSe_2	Physical Properties: Dark gray to black crystals, melting point ~1100°C, density 9.32 g/cm³, insoluble in water. Chemical Properties: Semiconductor (monolayer bandgap ~1.6 eV), oxidizes to WO_3, acid/base resistant, stable.
	CTIA GROUP		

5. Tellurides of Tungsten

Products	CAS Number	Formula	Properties
Tungsten Ditelluride	12067-76-4	WTe_2	Physical Properties: Gray-black crystals, melting point ~1000°C, density 9.43 g/cm³, insoluble in water.Chemical Properties: Semi-metallic, weakly magnetic, highly conductive, oxidizes to WO_3, moderately stable.
	CTIA GROUP		

6. Silicides

Products	CAS Number	Formula	Properties
Tungsten Disilicide	12039-88-2	WSi_2	Physical Properties: Gray crystals, melting point 2160°C, density 9.4 g/cm³, insoluble in water.Chemical Properties: Highly conductive (resistivity 20-30 μΩ·cm), corrosion-resistant, oxidation-resistant up to 2000°C, highly stable.
	CTIA GROUP		

7. Arsenides of Tungsten

Products	CAS Number	Formula	Properties
Tungsten Diarsenide		WAs_2	Physical Properties: Black crystals, melting point ~1200°C, density ~11.5 g/cm³, insoluble in water.Chemical Properties: Catalytically active, toxic, moderately stable, oxidizes to WO_3, less resistant to acids/bases.
	CTIA GROUP		

8. Organometallic Compounds

Products	CAS Number	Formula	Properties
Tungsten Hexacarbonyl	14040-11-0	$W(CO)_6$	Physical Properties: White crystals, melting point ~170°C, sublimation point ~175°C, density 2.65 g/cm³, insoluble in water. Chemical Properties: Highly volatile, light-sensitive, oxidizes to CO and WO_3, strongly coordinating.
Tungstenocene Dichloride	12128-24-4	Cp_2WCl_2	Physical Properties: Green crystals, decomposition temperature ~230°C, density not precisely determined, insoluble in water. Chemical Properties: Highly coordinating, water-sensitive, thermally decomposes to WO_3, reactive.
Tungstenocene Tetracarbonyl	-	$CpW(CO)_4$	Physical Properties: Color not specified, decomposition temperature ~150°C, density not determined, insoluble in water. Chemical Properties: Strongly coordinating, oxygen-sensitive, decomposes to CO and WO_3, unstable.
Hexamethyltungsten	15600-80-3	$W(CH_3)_6$	Physical Properties: Unstable liquid, decomposes at room temperature, requires low-temperature storage, density not precisely determined. Chemical Properties: Extremely unstable, decomposes to alkanes and WO_3, reacts violently with oxygen, highly coordinating.
Tungsten Dicyanide	-	$W(CN)_2$	Physical Properties: Dark crystals, decomposition temperature ~300°C, density not precisely determined, slightly soluble in water.Chemical Properties: Unstable, oxidizes to WO_3, hydrolyzes to HCN, relatively reactive.
	CTIA GROUP		

9. Tungsten-Containing Catalysts and Reagents

Products	CAS Number	Formula	Properties
Phosphotungstic Acid	12501-23-4	$H_3PW_{12}O_{40}$	Physical Properties: White or pale yellow crystals, decomposition temperature ~300°C, density ~4 g/cm³, highly water-soluble (>1000 g/L).Chemical Properties: Strongly acidic (pKa < 0), highly catalytic, redox-active, stable.
Silicotungstic Acid	12027-38-2	$H_4SiW_{12}O_{40}$	Physical Properties: Colorless or light yellow crystals, decomposition temperature ~350°C, density ~4 g/cm³, highly water-soluble (>1000

			g/L). Chemical Properties: Strongly acidic, redox-active, thermally stable, reacts with acids/bases to form tungsten salts.
Zinc Tungstate	13597-56-3	$ZnWO_4$	Physical Properties: White crystals, melting point ~1000°C, density ~7.8 g/cm³, insoluble in water.Chemical Properties: Photocatalytically active, highly stable, acid/base resistant, strongly fluorescent.
Tungsten Molybdate	13767-33-4	$WMoO_4$	Physical Properties: White or light yellow crystals, melting point ~950°C, density 4.5 g/cm³, insoluble in water. Chemical Properties: Photocatalytically active, moderately stable, reacts with acids to form tungstic and molybdic acids.
	CTIA GROUP		

Notes

Data Sources:

CAS numbers and properties are sourced from PubChem, ChemSpider, and chemical handbooks (e.g., CRC Handbook of Chemistry and Physics); compounds without CAS numbers (e.g., W_2S_3) are less commercialized.

Physical properties (e.g., melting point, density) and chemical properties are derived from the book's chapters and standard references.

Property Details:

Physical properties include appearance, melting/decomposition temperature, density, and solubility; chemical properties cover reactivity, stability, and unique traits (e.g., catalysis, fluorescence).

Decomposition temperatures (e.g., H_2WO_4 at ~250°C) indicate thermal breakdown onset rather than melting.

Exclusions:

Excludes tungsten powder, tungsten carbide powder, and hardmetals as requested, focusing solely on chemical compounds.

Nitrides and phosphides omitted due to insufficient property data or CAS numbers in the original scope, available for addition if needed.

Equipment, Specifications, Function Descriptions, Advantages, & Disadvantages for Tungsten Chemical Production

1. Ore Processing and Pretreatment Equipment

Equipment	Function	Specification	Function Description	Advantages	Disadvantages
Jaw Crusher	Crushes tungsten ore to a size suitable for further processing	Feed size: ≤500 mm, Output size: 10-50 mm, Power: 55-75 kW, Capacity: 50-100 t/h	Uses the squeezing action of movable and fixed jaws to break large tungsten ore pieces (e.g., wolframite, scheelite) into smaller fragments, facilitating subsequent grinding or chemical extraction; suitable for primary crushing, especially for high-hardness ores.	High crushing efficiency, durable and suitable for hard ores, low maintenance cost	High noise levels, limited to coarse crushing, energy-intensive for large-scale operations
Ball Mill	Grinds crushed ore into fine particles	Drum diameter: 1.5-3 m, Speed: 20-30 rpm, Power: 75-200 kW, Capacity: 5-20 t/h	Grinds crushed tungsten ore to particles <100 μm using the impact and abrasion of steel balls within a rotating drum, preparing it for flotation or leaching processes; offers wet or dry grinding options, widely used in ore pretreatment.	Fine particle output, versatile for wet or dry use, adjustable grind size	High energy consumption, wear on grinding media, slow for large batches
Flotation Machine	Separates tungsten minerals from impurities via flotation	Tank volume: 1-10 m³, Stirring power: 5-15 kW, Air flow: 0.5-2 m³/min, Capacity: 2-10 t/h	Uses chemical flotation reagents (e.g., oleic acid) and injected air bubbles to make tungsten minerals adhere to bubble surfaces and float, separating them from gangue to enhance ore purity for subsequent chemical processing stages.	High separation efficiency, scalable design, reduces impurity content	High reagent costs, requires skilled operation, sensitive to ore composition
Magnetic Separator	Removes magnetic impurities (e.g., iron) from ore	Magnetic field: 0.1-1.5 T, Particle size: 0-6 mm, Power: 2-10 kW, Capacity: 10-50 t/h	Utilizes magnetic fields to attract and remove magnetic impurities (e.g., iron filings or magnetite) from tungsten ore, improving purity and often used in pretreatment to reduce interference from magnetic substances in later chemical reactions.	Simple operation, efficient iron removal, low energy use	Limited to magnetic impurities, ineffective for non-magnetic impurities, limited effect on fine particles
	CTIA GROUP				

2. Smelting and Chemical Reaction Equipment

Equipment	Function	Specification	Function Description	Advantages	Disadvantages
Roasting Furnace	Converts tungsten concentrate to tungsten trioxide (WO_3) via high-temperature roasting	Temperature range: 600-1200°C, Furnace volume: 1-5 m³, Power: 100-500 kW, Capacity: 1-5 t/h	Oxidizes tungsten in concentrates to WO_3 using high-temperature air, suitable for pyrometallurgical processes; employs rotary kilns or multi-hearth furnaces, enabling continuous production, commonly used for large-scale WO_3 synthesis.	High temperature efficiency, stable output, adapts to various ore types	High energy consumption, complex exhaust treatment, large initial investment
Leaching Tank	Extracts tungsten with acid or alkali solutions to form tungstates	Volume: 5-50 m³, Stirring speed: 50-200 rpm, Material: Acid/alkali-resistant (e.g., 316L stainless steel), Heating power: 20-50 kW	Reacts tungsten concentrate with acid (e.g., HCl) or alkali (e.g., NaOH) solutions to dissolve tungsten into soluble tungstates (e.g., Na_2WO_4 or $(NH_4)_2WO_4$), used in hydrometallurgy with stirring and heating systems to enhance extraction efficiency.	Flexible operation, high extraction rate, handles low-grade ores	High wastewater treatment costs, equipment corrosion risk, long reaction times
Autoclave	Conducts chemical reactions under high pressure to purify tungsten compounds	Pressure: 1-10 MPa, Temperature: 100-300°C, Volume: 0.5-10 m³, Power: 50-150 kW	Accelerates chemical reactions between tungsten concentrate and solutions under high pressure and temperature to produce high-purity tungstic acid (H_2WO_4) or ammonium paratungstate (APT), equipped with corrosion-resistant linings (e.g., titanium alloy) for durability.	High purification efficiency, fast reaction speed, high-purity products	High equipment cost, complex operation, high maintenance demands
Fluorination Reactor	Produces tungsten hexafluoride (WF_6) via gas-phase reaction	Temperature: 300-700°C, Pressure: 0.01-1 atm, Material: HF-resistant (e.g., nickel alloy), Gas flow: 1-10 L/min	Facilitates the gas-phase reaction of WO_3 with hydrogen fluoride (HF) to produce high-purity WF_6, equipped with precise temperature control and corrosion-resistant systems, widely used in semiconductor chemical vapor deposition (CVD) processes.	High-purity WF_6 output, precise control, excellent corrosion resistance	Extremely high cost, complex HF exhaust treatment, high operational risk
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3. Refining and Separation Equipment

Equipment	Function	Specification	Function Description	Advantages	Disadvantages
Filter Press	Separates solids from liquids to recover tungsten compounds	Filter area: 10-100 m², Pressure: 0.6-1.6 MPa, Power: 5-15 kW, Capacity: 1-10 t/h	Uses high pressure to filter and separate solids (e.g., APT or Na_2WO_4 crystals) from tungstate solutions in hydrometallurgy, equipped with automated discharge systems to recover high-purity compounds and improve purity before drying.	High separation efficiency, high automation, easy operation	Filter cloth wear, high initial investment, limited effect on sticky materials
Centrifuge	Separates tungsten compound crystals from solutions	Speed: 1000-5000 rpm, Volume: 50-500 L, Power: 10-30 kW, Separation factor: 500-2000 G	Employs high-speed rotation to generate centrifugal force, separating tungsten compound crystals (e.g., APT, Na_2WO_4) from solutions; features corrosion-resistant drums, ideal for rapid and efficient purification in small to medium-scale production.	Fast separation, high-purity crystals, versatile	High equipment cost, complex maintenance, sensitive to particle size
Crystallizer	Controls the growth of tungsten compound crystals	Volume: 1-20 m³, Temperature: 20-100°C, Stirring speed: 50-150 rpm, Cooling rate: 0.5-2°C/min	Precisely controls temperature, stirring, and cooling rates to form uniform crystals from tungstate solutions (e.g., APT or Na_2WO_4), often equipped with circulating cooling systems to optimize crystal quality for high-purity production.	High crystal quality, strong control, suitable for batch production	Long crystallization time, high energy use, sensitive to process parameters
Distillation Column	Purifies volatile tungsten compounds (e.g., WF_6)	Height: 5-15 m, Temperature: 0-200°C, Pressure: 0.01-1 atm, Distillation capacity: 0.5-5 L/h	Separates volatile impurities (e.g., HF) from WF_6 via distillation, equipped with condensers and corrosion-resistant packing (e.g., Hastelloy), used to produce high-purity WF_6 meeting stringent semiconductor industry standards.	High-purity output, precise separation, ideal for volatile compounds	Expensive equipment, high energy consumption, complex installation and maintenance
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4. Drying and Post-Processing Equipment

Equipment	Function	Specification	Function Description	Advantages	Disadvantages
Rotary Dryer	Dries tungsten compounds produced via hydrometallurgy	Drum diameter: 1-2 m, Temperature: 100-300°C, Power: 20-50 kW, Capacity: 1-5 t/h	Dries hydrometallurgically produced tungsten compounds (e.g., WO_3, H_2WO_4, or APT) to a low moisture state using a rotating drum and hot air circulation, equipped with dust recovery devices, suitable for continuous large-scale production.	Continuous operation, uniform drying, high capacity	High energy consumption, large footprint, limited effect on fine powders
Spray Dryer	Spray-dries tungsten compound solutions into powder	Inlet temperature: 150-400°C, Outlet temperature: 80-120°C, Spray flow: 10-100 L/h, Power: 30-100 kW	Atomizes tungstate solutions (e.g., Na_2WO_4) via high pressure into hot air, rapidly drying them into nanoscale powders (e.g., nano-WO_3), ideal for high-value products, often equipped with efficient heat recovery systems.	Fine and uniform particles, rapid drying, ideal for nanomaterials	High equipment cost, high energy use, sensitive to solution concentration
Vacuum Oven	Dries sensitive tungsten compounds at low temperature under vacuum	Temperature: 50-200°C, Vacuum: 0.01-0.1 MPa, Volume: 50-500 L, Power: 5-15 kW	Dries sensitive organometallic tungsten compounds (e.g., $W(CO)_6$) under vacuum at low temperatures to prevent thermal decomposition or oxidation, suitable for small-batch, high-value product post-processing in labs or precision manufacturing.	Protects sensitive materials, uniform drying, low energy use	Limited capacity, long drying time, unsuitable for large-scale production
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5. Auxiliary and Environmental Equipment

Equipment	Function	Specification	Function Description	Advantages	Disadvantages
Scrubber	Treats acidic exhaust gases (e.g., HF, HCl) from production	Treatment capacity: 1000-10000 m³/h, Liquid-to-gas ratio: 2-5 L/m³, Material: Corrosion-resistant PP or stainless steel, Power: 10-50 kW	Absorbs acidic exhaust gases (e.g., HF, HCl from WF_6 or WCl_6 production) using alkali solutions (e.g., NaOH) with multi-stage spraying, ensuring compliance with environmental standards (e.g., GB 16297-1996) and protecting workers and the environment.	Efficient exhaust treatment, corrosion-resistant, meets environmental standards	High initial investment, complex wastewater treatment, high operating costs
Wastewater Treatment System	Neutralizes and removes tungsten ions from wastewater	Treatment capacity: 1-20 m³/h, pH adjustment: 6-9, Precipitation efficiency: >99%, Power: 5-20 kW	Neutralizes and precipitates tungsten ions from hydrometallurgical wastewater using agents (e.g., $Ca(OH)_2$), ensuring discharge compliance (W < 1 mg/L), equipped with sedimentation tanks and filters, commonly used for environmental management in large-scale production lines.	High removal efficiency, environmentally compliant, automatable	High investment and operating costs, large footprint, requires regular maintenance
Dust Collector	Captures tungsten compound dust	Filtration efficiency: >99.9%, Air flow: 5000-20000 m³/h, Power: 10-30 kW, Emission: ≤ 10 mg/m³	Uses bag or electrostatic technology to capture dust from WO_3 or APT production, preventing air pollution and safeguarding worker health, meeting emission standards (e.g., GB 16297-1996 ≤ 30 mg/m³).	High dust removal efficiency, easy operation, protects worker health	Frequent filter bag replacement, high initial cost, limited effect on ultrafine dust
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Notes

Data Sources

Specifications are derived from the *Chemical Engineering Equipment Design Handbook*, industrial standards (e.g., GB 16297-1996, EU IED), and process descriptions in the book, supplemented by typical supplier data.

Function descriptions and advantages/disadvantages are based on practical applications in tungsten chemical production, ensuring relevance.

Function Refinement

Function descriptions have been expanded (e.g., "Uses high pressure to filter and separate solids from tungstate solutions, separating them from liquids") to align word count with other columns (~50-80 words), emphasizing specific roles in the process (e.g., roasting furnace for WO_3 pyrometallurgy, distillation column for WF_6 purification).

Advantages and Disadvantages:

Advantages

Highlight efficiency, durability, or environmental benefits to aid equipment selection.

Disadvantages:

Note energy use, maintenance, or operational complexity for practical guidance.

Exclusions

Covers all tungsten chemicals (e.g., WO_3, Na_2WO_4, WF_6) from the book, excluding tungsten powder, tungsten carbide powder, and hardmetals as requested.

Price section removed, focusing on technical characteristics to avoid market fluctuation impacts.