You can find tungsten at work whenever the heat's on. Because no other metal can compare with tungsten when it comes to heat resistance. Tungsten has the highest melting point of all metals and is therefore also suitable for very high-temperature applications. It is also characterized by a uniquely low coefficient of thermal expansion and a very high level of dimensional stability. Tungsten is practically indestructible. For example, we use this material to manufacture high-temperature furnace components, lamp components and components for use in the fields of medical and thin-film technology.
Properties of tungsten

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic number</td>
<td>74</td>
</tr>
<tr>
<td>CAS number</td>
<td>7440-33-7</td>
</tr>
<tr>
<td>Atomic mass</td>
<td>183.84</td>
</tr>
<tr>
<td>Melting point</td>
<td>3,420 °C</td>
</tr>
<tr>
<td>Boiling point</td>
<td>5,555 °C</td>
</tr>
<tr>
<td>Atomic volume</td>
<td>0.0159 [nm³]</td>
</tr>
<tr>
<td>Density at 20 °C</td>
<td>19.25 [g/cm³]</td>
</tr>
<tr>
<td>Crystal structure</td>
<td>body-centred cubic</td>
</tr>
<tr>
<td>Lattice constant</td>
<td>317 [pm]</td>
</tr>
<tr>
<td>Abundance in the Earth's crust</td>
<td>1.25 [g/t]</td>
</tr>
</tbody>
</table>

Guaranteed purity

Are you looking for truly excellent quality? Then you need us. We produce our tungsten products ourselves – from the metal powder right through to the finished product. As our input material, we use only the purest tungsten oxide. This ensures that you benefit from a very high level of material purity. Find out for yourself.

We guarantee that our tungsten has a purity of 99.97 % (Metal purity without Mo). The remaining content consists of the following elements:
<table>
<thead>
<tr>
<th>Element</th>
<th>Typical max. value [µg/g]</th>
<th>Guaranteed max. value [µg/g]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Cr</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>Cu</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Fe</td>
<td>8</td>
<td>30</td>
</tr>
<tr>
<td>K</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Mo</td>
<td>12</td>
<td>100</td>
</tr>
<tr>
<td>Ni</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Si</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td>30</td>
</tr>
<tr>
<td>H</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>N</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>O</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Cd</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Hg*</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Pb</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

*Initial value

Die Anwesenheit von Cr (VI) und organischen Verunreinigungen kann durch den Produktionsprozess ausgeschlossen werden (mehrfache Wärmebehandlung bei Temperaturen über 1,000 °C in H2-Atmosphäre)

A material with special talents

The very special industrial applications in which our tungsten is used reflect the unique properties of the material. We briefly present three of these below:

Outstanding creep resistance and high purity.

Our tungsten is very popular for use in melting and solidification vessels in the field of sapphire crystal growth. Its high level of purity prevents any contamination of the sapphire crystal and its good creep resistance guarantees the product's dimensional stability. Even at extremely high temperatures, the results of the process remain stable.
High purity and good electrical conductivity.

With the lowest coefficient of thermal expansion of all metals and a high level of electrical conductivity, our tungsten is the perfect material for thin-film applications. Its high level of electrical conductivity and low diffusivity to neighboring layers mean that tungsten is an important component in thin-film transistors of the sort that are used in TFT-LCD screens. And, of course, we are also able to supply you with the coating material in the form of ultra-high purity sputtering targets. No other manufacturer is able to supply tungsten targets in larger dimensions.

Long service life and an extremely high melting point.

With their long service lives even at extremely high temperatures, our tungsten melting crucibles and mandrel shafts are able to withstand even quartz glass melts without difficulty. Thanks to the outstanding purity of our tungsten, we can reliably prevent any bubble formation or discoloration of the quartz melts.

Pure tungsten - or maybe an alloy?

We prepare our tungsten to perform perfectly in its specific applications. We can determine the following properties through the addition of various alloys:

- Physical properties (e.g. melting point, vapor pressure, density, electrical conductivity, thermal conductivity, thermal expansion, heat capacity, electron work function)
- Mechanical properties (e.g. strength, fracture behavior, creep resistance, ductility)
- Chemical properties (corrosion resistance, etchability)
- Machinability (e.g. cutting processes, formability, weldability)
- Microstructure and recrystallization behavior (recrystallization temperature, embrittlement, aging effects)

And there's more: By using our own customized manufacturing processes, we can modulate various other properties of tungsten across a wide range of values. The result: Tungsten alloys with different ranges of properties which are precisely engineered to meet the requirements of each individual application.
<table>
<thead>
<tr>
<th>Name of material</th>
<th>Chemical composition (percentage by weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W (pure)</td>
<td>&gt;99.97 % W</td>
</tr>
<tr>
<td>WK65</td>
<td>60 - 65 ppm K</td>
</tr>
<tr>
<td>WVM</td>
<td>30 - 70 ppm K</td>
</tr>
<tr>
<td>WVMW</td>
<td>15 - 40 ppm K</td>
</tr>
<tr>
<td>S-WVMW</td>
<td>15 - 40 ppm K</td>
</tr>
<tr>
<td>WC</td>
<td>WC20 2.0 % CeO₂</td>
</tr>
<tr>
<td>WL</td>
<td>WL10 1.0 % La₂O₃</td>
</tr>
<tr>
<td></td>
<td>WL15 1.5 % La₂O₃</td>
</tr>
<tr>
<td></td>
<td>WL20 2.0 % La₂O₃</td>
</tr>
<tr>
<td>WL-S</td>
<td>1.0 % La₂O₃</td>
</tr>
<tr>
<td>WLZ</td>
<td>2.5 % La₂O₃/ 0.07 % ZrO₂</td>
</tr>
<tr>
<td>WRe</td>
<td>WRe5 5.0 % Re</td>
</tr>
<tr>
<td></td>
<td>WRe26 26.0 % Re</td>
</tr>
<tr>
<td>WCu</td>
<td>10 - 40 % Cu</td>
</tr>
<tr>
<td>W-High-density tungsten-heavy metal alloys</td>
<td>Densimet® 1.5 % - 10 % Ni, Fe, Mo</td>
</tr>
<tr>
<td></td>
<td>Inermet® 5 % - 9.8 % Ni, Cu</td>
</tr>
<tr>
<td></td>
<td>Denal® 2.5 % - 10 % Ni, Fe, Co</td>
</tr>
</tbody>
</table>

WK65 (Tungsten-potassium).

We dope tungsten with 60 to 65 ppm potassium and form the material to create wire products with an elongated stacked microstructure. This microstructure gives the material excellent high-temperature properties such as good creep resistance and dimensional stability. Special production steps can be used to make WK65 more load-resistant than WVM.

WVM (Wolfram-Vacuum-Metallizing).

WVM is pure tungsten doped with a tiny amount of potassium. We primarily supply our WVM in rod or wire form for use in evaporation coils or heating filaments. This doping, which also interacts with the highly orientation-dependent cold working, creates a stacked microstructure which results in increased dimensional stability at high temperatures.
**WVMW / S-WVMW (WVM-Tungsten).**

WVMW and S-WVMW were developed for use as anode materials for short-arc lamps of diameters greater than 15 mm. To produce both materials, we use pure tungsten doped with aluminum-potassium silicate. S-WVMW is particularly suitable for rod diameters greater than 30 mm. Thanks to the special production process we use to manufacture S-WVMW, we are able to achieve high densities in the rod core.

**WC20 (Tungsten-Cerium Oxide).**

Who needs thorium if they have WC20? WC20 is our non-radioactive material variant and the best possible alternative to WT20. It is used as a material for welding electrodes. We dope tungsten with two percent cerium oxide by weight to obtain a material with a lower electron work function, better ignition characteristics and a longer service life than pure tungsten.

**WL (Tungsten-Lanthanum Oxide).**

We dope our tungsten with between 1.0 and 2.0 percent of lanthanum oxide ($\text{La}_2\text{O}_3$) by weight in order to improve its creep resistance and increase the recrystallization temperature. Our WL is also easier to machine due to the finely distributed oxide particles in its structure. The electron work function of tungsten-lanthanum oxide is significantly lower than that of pure tungsten. Consequently, WL is a popular choice for ion sources, lamp electrodes and welding electrodes.

**WL-S (Tungsten-Lanthanum Oxide-Stem).**

This special WL was specifically developed for use in the stems (support rods) of high-pressure discharge lamps. We use a special production process to create a more fine-grained microstructure than is found in standard quality tungsten-lanthanum oxide. Thanks to this special microstructure, the breaking strength of the material is higher than that of standard quality WL and WVM even following exposure to high thermal loads. WL-S is therefore the perfect material for support rods which have to maintain the anode and cathode in precisely the same position throughout the entire lifetime of a high-pressure discharge lamp.
WLZ (Tungsten-Lanthanum Oxide-Zirconium Oxide).

We dope tungsten with lanthanum oxide and zirconium oxide to obtain high creep resistance coupled with a low electron work function. WLZ is an excellent material for cathodes used in high-load environments. WLZ has very good ignition properties and remains stable even at extremely high temperature ranges.

WRe (Tungsten-Rhenium).

To obtain greater ductility and a lower brittle-to-ductile transition temperature, we alloy our tungsten with rhenium. Moreover, tungsten-rhenium has a higher recrystallization temperature and better creep resistance. We use the WRe standard compositions – WRe5 and WRe26 – as material for thermoelements in applications of over 2 000 °C. This material is also used in the aviation and aerospace industries.

WCu (Tungsten-Copper).

WCu composites consist of a porous tungsten matrix infiltrated with approximately 10 - 40 percent by weight of copper. We mostly use our WCu for the construction of high-voltage circuit breakers (marketed under the name Elmet®) and for erosion electrodes (marketed under the name Sparkal®). Our WCu composites are also used as base plates and heat spreaders in radar technology, opto electronics and high frequency electronics. Tungsten-Copper is very resistant to arc erosion, exhibits good electrical conductivity, a high level of thermal conductivity and low thermal expansion.
A good all-rounder. Material properties of tungsten.

Tungsten belongs to the group of refractory metals. Refractory metals are metals that have a higher melting point than platinum (1,772 °C). In refractory metals, the energy binding the individual atoms together is particularly high. Refractory metals have a high melting point coupled with a low vapor pressure, high modulus of elasticity and good thermal stability. Refractory metals are also typically characterized by a low coefficient of thermal expansion and relatively high density.

Tungsten has the highest melting point of all metals as well as a remarkably high modulus of elasticity. In general, its properties are similar to those of molybdenum. The two metals are located in the same group in the periodic table. However, some of the properties of tungsten are more pronounced than they are in molybdenum.

Thanks to its outstanding thermal properties, tungsten can easily withstand even the most intense heat. Find out for yourself:
## Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic number</td>
<td>74</td>
</tr>
<tr>
<td>Atomic mass</td>
<td>183.84</td>
</tr>
<tr>
<td>Melting point</td>
<td>3,420 °C / 3,693 K</td>
</tr>
<tr>
<td>Boiling point</td>
<td>5,555 °C / 5,828 K</td>
</tr>
<tr>
<td>Atomic volume</td>
<td>$1.59 \cdot 10^{-28} \text{[m}^3\text{]}$</td>
</tr>
<tr>
<td>Vapor pressure at 1,800 °C / 2,200 °C</td>
<td>$2 \cdot 10^{-9} \text{[Pa]}$ / $6 \cdot 10^{-6} \text{[Pa]}$</td>
</tr>
<tr>
<td>Density at 20 °C (293 K)</td>
<td>19.25 [g/cm$^3$]</td>
</tr>
<tr>
<td>Crystal structure</td>
<td>body-centred cubic</td>
</tr>
<tr>
<td>Lattice constant</td>
<td>317 [pm]</td>
</tr>
<tr>
<td>Hardness at 20 °C (293 K)</td>
<td>$&gt;460$ [HV30] / $\sim 360$ [HV30]</td>
</tr>
<tr>
<td>Modulus of elasticity at 20 °C (293 K)</td>
<td>405 [GPa]</td>
</tr>
<tr>
<td>Poisson number</td>
<td>0.28</td>
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<tr>
<td>Coefficient of linear thermal expansion at 20 °C (293 K)</td>
<td>$4.4 \cdot 10^{-6}$ [m/(m·K)]</td>
</tr>
<tr>
<td>Thermal conductivity at 20 °C (293 K)</td>
<td>164 [W/(m·K)]</td>
</tr>
<tr>
<td>Specific heat at 20 °C (293 K)</td>
<td>0.13 [J/(g·K)]</td>
</tr>
<tr>
<td>Electrical conductivity at 20 °C (293 K)</td>
<td>$18.2 \cdot 10^6$ [1/(Ω·m)]</td>
</tr>
<tr>
<td>Specific electrical resistance at 20 °C (293 K)</td>
<td>0.055 [(Ω·mm$^2$)/m]</td>
</tr>
<tr>
<td>Sound speed at 20 °C (293 K)</td>
<td>Longitudinal wave 5,180 [m/s] / Transverse wave 2,870 [m/s]</td>
</tr>
<tr>
<td>Electron work function</td>
<td>4.54 [eV]</td>
</tr>
<tr>
<td>Capture cross-section for thermal neutrons</td>
<td>$1.92 \cdot 10^{-27}$ [m$^2$]</td>
</tr>
</tbody>
</table>
We are able to influence the properties of our tungsten and its alloys by varying the type and quantity of alloy elements that we add as well as by the production process we employ.

We primarily use doped tungsten materials. For example, to produce WVM and WK65 we add small quantities of potassium. Potassium has a positive effect on the mechanical properties, in particular at high temperatures. The additives CeO$_2$ and La$_2$O$_3$ ensure a low electron work function and consequently make tungsten suitable for use as cathode material.

WRe and WCu, as well as our heavy metal variants, have a higher alloy content which may reach as much as 40%. They are therefore known as tungsten alloys. We add rhenium in order to increase the ductility of our tungsten. Copper increases the material's electrical conductivity. Thanks to their ease of machinability, you can also use our heavy metal alloys for complex geometries. They can be used, for example, as shielding material or as damping and absorption components.

<table>
<thead>
<tr>
<th>Property</th>
<th>W</th>
<th>WK65</th>
<th>WVM (S-)WVM</th>
<th>WC20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alloy components (percentage by weight)</td>
<td>99.97 % W</td>
<td>60 - 65 ppm K</td>
<td>30 - 70 ppm K</td>
<td>15 - 40 ppm K</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>~</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>Stability at high temperatures, creep resistance</td>
<td>~</td>
<td>++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Recrystallization temperature</td>
<td>~</td>
<td>++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Fineness of grain</td>
<td>~</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Ductility</td>
<td>~</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Machinability/workability</td>
<td>~</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Electron work function</td>
<td>~</td>
<td>~</td>
<td>~</td>
<td>--</td>
</tr>
</tbody>
</table>
### Tungsten

#### Plansee High Performance Materials, info@plansee.com, www.plansee.com

**8/2019, Page 11/25**

<table>
<thead>
<tr>
<th>Property</th>
<th>WL</th>
<th>WL-S</th>
<th>WLZ</th>
<th>WRe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alloy components (percentage by weight)</td>
<td>1.0 % La₂O₃ 1.5 % La₂O₃ 2.0 % La₂O₃</td>
<td>1.0 % La₂O₃ 2.5 % La₂O₃ 0.07 % ZrO₂</td>
<td>5 % / 26 % Re</td>
<td></td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>~</td>
<td>~</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>Stability at high temperatures, creep resistance</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Recrystallization temperature</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Fineness of grain</td>
<td>+</td>
<td>++</td>
<td>+</td>
<td>~</td>
</tr>
<tr>
<td>Ductility</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Machinability/workability</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Electron work function</td>
<td>--</td>
<td>--</td>
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<td>+</td>
</tr>
</tbody>
</table>

#### WCu

<table>
<thead>
<tr>
<th>Property</th>
<th>WCu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alloy components (percentage by weight)</td>
<td>10 - 40 % Cu</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>+</td>
</tr>
<tr>
<td>Stability at high temperatures, creep resistance</td>
<td>--</td>
</tr>
<tr>
<td>Recrystallization temperature</td>
<td></td>
</tr>
<tr>
<td>Fineness of grain</td>
<td></td>
</tr>
<tr>
<td>Ductility</td>
<td>++</td>
</tr>
<tr>
<td>Machinability/workability</td>
<td>++</td>
</tr>
<tr>
<td>Electron work function</td>
<td></td>
</tr>
</tbody>
</table>

~ comparable with pure W + higher than pure W ++ much higher than pure W - lower than pure W -- much lower than pure W
Thermophysical properties

Tungsten has the highest melting point of all the refractory metals, a low coefficient of thermal expansion and a relatively high density. Tungsten’s good electrical conductivity and excellent thermal conductivity are further valuable properties. The values of all these properties are higher for tungsten than they are in the case of molybdenum. Although it is in the same group in the periodic table, tungsten is located a period lower than molybdenum.

The thermophysical properties of tungsten change with temperature. The diagrams below indicate the curves of the most important variables in comparison:

![Vapour pressure of refractory metals](image)
Coefficient of linear thermal expansion of tungsten and molybdenum

Heat capacity of tungsten and molybdenum
Specific electrical resistance of tungsten and molybdenum

Thermal conductivity of tungsten and molybdenum
The graphic summarizes the temperature-dependent values of emissivity of tungsten (shown as blue scatter band). Experimentally measured values of Plansee samples in typical as-delivered condition can be found on the upper end of the scatter band.

**Mechanical properties**

We optimize the purity of the material, determine the type and quantity of alloy components and modify the microstructure of our tungsten through heat treatment (annealing) and specially adapted forming processes. The result: customized mechanical properties for the most diverse applications. The mechanical properties of tungsten are similar to those of molybdenum. As in the case of molybdenum, these properties are dependent on the temperature at which they are tested. At 3420 °C, tungsten has the highest melting point of all metals. The material's high thermal stability coupled with its high modulus of elasticity give tungsten its high creep resistance.
Like molybdenum, tungsten has a body-centered cubic lattice and therefore the same characteristic brittle-to-ductile transition. The brittle-to-ductile transition temperature can be reduced by means of cold working and alloying. The strength of the material increases with increasing cold working. However, unlike other metals, this also increases the ductility of tungsten. The main alloy element used to improve the overall ductility of tungsten is rhenium.

The term "doping" come from the Latin "dotare" and means "provide with". In the world of metallurgy, doping refers to the introduction of one or more alloy elements in levels measured in ppm. The term "microalloying" is also often used. The alloy content introduced during doping may reach several hundred ppm. The abbreviation ppm stands for "parts per million", i.e. $10^{-6}$.

If you are intending to use tungsten at high temperatures, you should take account of the material's recrystallization temperature. The mechanical properties of the material – such as its ductility and fracture toughness – decrease as the level of recrystallization rises. Doping with small oxide particles (e.g. lanthanum oxide or cerium oxide) increases the recrystallization level and creep resistance of tungsten. And there's more. Reducing the size of the oxide particles by cold working the material further increases its recrystallization temperature.

The table indicates the recrystallization temperatures of our tungsten-based materials at different levels of deformation.
<table>
<thead>
<tr>
<th>Material</th>
<th>Temperature [°C] for 100 % recrystallization (annealing time: 1 hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Deformation level = 90 %</td>
</tr>
<tr>
<td>W (pure)</td>
<td>1350</td>
</tr>
<tr>
<td>WVM</td>
<td>-</td>
</tr>
<tr>
<td>WC20</td>
<td>1550</td>
</tr>
<tr>
<td>WL10</td>
<td>1500</td>
</tr>
<tr>
<td>WL15</td>
<td>1550</td>
</tr>
<tr>
<td>WRe5</td>
<td>1700</td>
</tr>
<tr>
<td>WRe26</td>
<td>1750</td>
</tr>
</tbody>
</table>

Typical 0.2% yield strength for W and Mo sheet material in the stress relieved and recrystallized condition respectively (thickness of the sheet: W = 1 mm / Mo = 2 mm)
Typical ultimate tensile strength for W and Mo sheet material in the stress relieved and recrystallized condition respectively (thickness of the sheet: W = 1 mm / Mo = 2 mm)

Typical 0.2% yield strength for W and Mo rod material in the stress relieved and recrystallized condition respectively (diameter: 25 mm)
Typical ultimate tensile strength for W and Mo rod material in the stress relieved and recrystallized condition respectively (diameter: 25 mm)

Optical micrograph of a tungsten sheets (stress relieved)
The machining of tungsten requires a real feeling for the material. Forming processes such as bending or folding must generally be applied at above the brittle-to-ductile transition temperature. In the case of tungsten, this temperature is higher than for molybdenum. The thicker the sheets that are to be processed, the higher the required preheating temperature. The sheets need a higher preheating temperature for cutting and punching than for folding operations. It is very difficult to use machining processes with tungsten. Our tungsten alloys using cerium oxide or lanthanum oxide are somewhat easier to cut. However, the level of tool wear is still very considerable and chipping may occur. If you have any special questions relating to the forming and machining of refractory metals, we would be glad to assist you with our many years of experience.
At relative humidity of under 60 %, tungsten is corrosion-resistant. In moister air, discoloration starts to occur. However, this is less pronounced than in molybdenum. Even at very high temperatures, glass melts, hydrogen, nitrogen, noble gases, metallic melts and oxide ceramic melts are largely unaggressive to tungsten provided that they do not also contain oxidants.

The table below indicates the corrosion resistance of tungsten. Unless indicated to the contrary, the specifications relate to pure solutions not mixed with air or nitrogen. Tiny concentrations of extraneous chemically active substances can significantly affect the corrosion resistance. Do you have any questions regarding complex corrosion-related topics? We would be delighted to help you with our experience and our in-house corrosion laboratory.

<table>
<thead>
<tr>
<th>Corrosion resistance of tungsten</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water</strong></td>
</tr>
<tr>
<td>Cold and warm water &lt; 80 °C (353 K)</td>
</tr>
<tr>
<td>Hot water &gt; 80 °C (353 K)</td>
</tr>
<tr>
<td>Hot water with nitrogen gassing or inhibitor</td>
</tr>
<tr>
<td>Hydrofluoric acid &lt; 100 °C (373 K)</td>
</tr>
<tr>
<td>Nitrohydrochloric acid, cold</td>
</tr>
<tr>
<td>Orthophosphoric acid up to 270 °C (543 K)</td>
</tr>
<tr>
<td>Nitric acid, cold and warm</td>
</tr>
<tr>
<td>Hydrochloric acid, cold and warm</td>
</tr>
<tr>
<td>Sulfuric acid &lt; 70 % up to 190 °C (463 K)</td>
</tr>
<tr>
<td>Chromosulfuric acid</td>
</tr>
<tr>
<td><strong>Inorganic acids</strong></td>
</tr>
<tr>
<td>Ammonia solution</td>
</tr>
<tr>
<td>Potassium hydroxide (KOH &lt; 50 %) up to 100 °C (373 K)</td>
</tr>
<tr>
<td>Potassium hydroxide (KOH &gt; 50 %)</td>
</tr>
<tr>
<td>Sodium hydroxide (NaOH &lt; 50 %) up to 100 °C (373 K)</td>
</tr>
<tr>
<td>Sodium hydroxide (NaOH &gt; 50 %)</td>
</tr>
<tr>
<td>Sodium hypochlorite solution, cold and warm</td>
</tr>
<tr>
<td><strong>Lyes</strong></td>
</tr>
<tr>
<td>Formic acid, room temperature</td>
</tr>
<tr>
<td>Acetic acid up to 100 °C (373 K)</td>
</tr>
</tbody>
</table>
### Organic acids

<table>
<thead>
<tr>
<th>Organic acid</th>
<th>Concentrated lactic acid, room temperature</th>
<th>resistant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boron</td>
<td>up to 1800 °C (2073 K)</td>
<td>resistant</td>
</tr>
<tr>
<td>Oxalic acid, room temperature</td>
<td>resistant</td>
<td></td>
</tr>
<tr>
<td>Tartaric acid, room temperature</td>
<td>resistant</td>
<td></td>
</tr>
<tr>
<td>Phosphorous up to 800 °C (1073 K)</td>
<td>resistant</td>
<td></td>
</tr>
</tbody>
</table>

### Non-metals

<table>
<thead>
<tr>
<th>Non-metal</th>
<th>Temperature</th>
<th>resistant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boron</td>
<td>up to 1800 °C (2073 K)</td>
<td>resistant</td>
</tr>
<tr>
<td>Carbon</td>
<td>up to 1200 °C (1473 K)</td>
<td>resistant</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>up to 800 °C (1073 K)</td>
<td>resistant</td>
</tr>
<tr>
<td>Sulfur up to 500 °C</td>
<td>(773 K)</td>
<td>resistant</td>
</tr>
<tr>
<td>Silicon up to 900 °C</td>
<td>(1173 K)</td>
<td>resistant</td>
</tr>
<tr>
<td>Fluorine at room temperature</td>
<td>not resistant</td>
<td></td>
</tr>
<tr>
<td>Chlorine up to 250 °C</td>
<td>(523 K)</td>
<td>resistant</td>
</tr>
<tr>
<td>Bromine up to 450 °C</td>
<td>(723 K)</td>
<td>resistant</td>
</tr>
<tr>
<td>Iodine up to 450 °C</td>
<td>(723 K)</td>
<td>resistant</td>
</tr>
</tbody>
</table>

### Glass melts*

<table>
<thead>
<tr>
<th>Glass melts</th>
<th>Temperature</th>
<th>resistant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 1700 °C (1973 K)</td>
<td></td>
<td>resistant</td>
</tr>
</tbody>
</table>

* Excluding glasses containing oxidants (e.g. lead glass)

### Corrosion resistance against gases

<table>
<thead>
<tr>
<th>Gas</th>
<th>Temperature</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia gas</td>
<td>resistant at &lt; 1000 °C</td>
<td>Air and oxygen resistant at &lt; 500 °C</td>
</tr>
<tr>
<td>Noble gases</td>
<td>no reaction</td>
<td>Nitrogen no reaction</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>resistant at &lt; 1200 °C</td>
<td>Hydrogen no reaction</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>resistant at &lt; 1400 °C</td>
<td>Water vapor resistant at &lt; 700 °C</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>resistant at &lt; 1200 °C</td>
<td></td>
</tr>
</tbody>
</table>

### Corrosion resistance against ceramic furnace construction materials

<table>
<thead>
<tr>
<th>Ceramic</th>
<th>Temperature</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum oxide</td>
<td>resistant at &lt; 1900 °C</td>
<td>Magnesium oxide resistant at &lt; 1600 °C</td>
</tr>
<tr>
<td>Beryllium oxide</td>
<td>resistant at &lt; 2000 °C</td>
<td>Silicon carbide resistant at &lt; 1300 °C</td>
</tr>
<tr>
<td>Graphite</td>
<td>resistant at &lt; 1200 °C</td>
<td>Zirconium oxide resistant at &lt; 1900 °C</td>
</tr>
<tr>
<td>Magnesite bricks</td>
<td>resistant at &lt; 1600 °C</td>
<td></td>
</tr>
</tbody>
</table>

In particular, tungsten is more resistant than molybdenum to zinc and tin melts.
## Corrosion resistance against metal melts

<table>
<thead>
<tr>
<th>Metal</th>
<th>Resistance</th>
<th>Metal</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>resistant at &lt; 700 °C</td>
<td>Sodium</td>
<td>resistant at &lt; 600 °C</td>
</tr>
<tr>
<td>Beryllium</td>
<td>not resistant</td>
<td>Nickel</td>
<td>not resistant</td>
</tr>
<tr>
<td>Lead</td>
<td>resistant at &lt; 1100 °C</td>
<td>Plutonium</td>
<td>resistant at &lt; 700 °C</td>
</tr>
<tr>
<td>Oxygen-containing lead</td>
<td>resistant at &lt; 500 °C</td>
<td>Mercury</td>
<td>resistant at &lt; 600 °C</td>
</tr>
<tr>
<td>Caesium</td>
<td>resistant at &lt; 1200 °C</td>
<td>Rubidium</td>
<td>resistant at &lt; 1200 °C</td>
</tr>
<tr>
<td>Iron</td>
<td>not resistant</td>
<td>Scandium</td>
<td>resistant at &lt; 1400 °C</td>
</tr>
<tr>
<td>Gallium</td>
<td>resistant at &lt; 1000 °C</td>
<td>Rare earths</td>
<td>resistant at &lt; 800 °C</td>
</tr>
<tr>
<td>Potassium</td>
<td>resistant at &lt; 1200 °C</td>
<td>Silver</td>
<td>resistant</td>
</tr>
<tr>
<td>Copper</td>
<td>resistant at &lt; 1300 °C</td>
<td>Uranium</td>
<td>resistant at &lt; 900 °C</td>
</tr>
<tr>
<td>Gold</td>
<td>resistant at &lt; 1100 °C</td>
<td>Bismuth</td>
<td>resistant at &lt; 1400 °C</td>
</tr>
<tr>
<td>Lithium</td>
<td>resistant at &lt; 1 600 °C</td>
<td>Zinc</td>
<td>resistant at &lt; 750 °C</td>
</tr>
<tr>
<td>Magnesium</td>
<td>resistant at &lt; 1000 °C</td>
<td>Tin</td>
<td>resistant at &lt; 980 °C</td>
</tr>
</tbody>
</table>
Natural occurrence and preparation

Tungsten was first found in the Ore Mountains of Central Europe in the Middle Ages during the process of tin reduction. However, at that time it was considered to be an unwanted accompanying element. The tungsten ore facilitated slag formation during the reduction of tin and consequently impaired the yield. The German name for tungsten (Wolfram = "wolf's drool") comes from its reputation as a tin-devouring ore "It consumes tin as a wolf eats sheep".

In 1752, the chemist Axel Fredrik Cronstedt discovered a heavy metal which he named "Tung Sten", Swedish for "heavy stone". It was not until 30 years later that Carl Wilhelm Scheele succeeded in producing tungstic acid from the ore. And just two years after that, Scheele's two assistants, the brothers Juan Jose and Fausto de Elhuyar, reduced tungsten trioxide to produce tungsten. Nowadays, these two brothers are considered to be the true discoverers of tungsten. The name "Wolframium" and the accompanying symbol W were proposed by Jöns Jakob Berzelius.

Tungsten ore occurs most frequently naturally in the form of wolframite ((Fe/Mn)WO$_4$) and scheelite (CaWO$_4$). The largest deposits of tungsten are found in China, Russia and the USA. In Austria, there is also a scheelite deposit in Mittersill in the Felbertauern district.

Depending on the deposit, these tungsten ores have a WO$_3$ content of between 0.3 and 2.5 percentage by weight. Commination, grinding, flotation and roasting processes can be employed to increase the WO$_3$ content to approximately 60 %. The remaining impurities are mostly eliminated by means of digestion with sodium hydroxide. The sodium tungstate that is obtained is transformed into APT (ammonium paratungstate) using a so-called ion exchange extraction process.

Reduction is performed in a hydrogen atmosphere at temperatures between 500 and 1000 °C:

$$WO_3 + 3H_2 \rightarrow W + 3H_2O$$

Our sister company GTP specializes in the preparation, extraction and reduction of APT. GTP supplies us with exceptionally pure metallic tungsten of a uniformly high quality.
How do we do it? With powder metallurgy!

So what is powder metallurgy? It is well known that nowadays most industrial metals and alloys, such as steels, aluminum and copper, are produced by melting and casting in a mold. In contrast, powder metallurgy does away with the melting operation and the products are manufactured by compacting metal powders which are then subjected to a heat treatment (sintering) below the melting temperature of the material. The three most important factors in the field of powder metallurgy are the metal powder itself as well as the compacting and sintering operations. We are able to control and optimize all these factors in-house.

Why do we use powder metallurgy? Powder metallurgy allows us to produce materials with melting points of well over 2 000 °C. The procedure is particularly economical even when only small quantities are produced. In addition, by using tailor-made powder mixes, we can produce a range of extremely homogeneous materials endowed with specific properties.

The molybdenum powder is mixed with the possible alloy elements and then filled into molds. The mixture is then compacted at pressures of up to 2 000 bars. The resulting pressed part (also known as a "green compact") is then sintered in special furnaces at temperatures of over 2000 °C. During this process, the part acquires its density and its microstructure forms. The very special properties of our materials - such as their excellent thermal stability, their hardness or their flow characteristics - are due to the use of the appropriate forming methods, for example forging, rolling or drawing. Only when all these steps dovetail perfectly can we achieve our exacting quality demands and manufacture products of outstanding purity and quality.