

= 276 @. @ 1 pm and c =
445 @. @ 6 pm .

Its usual commercial form is a powder , but this element can be consolidated by pressing and sintering in a vacuum or hydrogen atmosphere . This procedure yields a compact solid having a density above 90 % of the density of the metal . When annealed this metal is very ductile and can be bent , coiled , or rolled . Rhenium @-@ molybdenum alloys are superconductive at 10 K ; tungsten @-@ rhenium alloys are also superconductive around 4 ? 8 K , depending on the alloy . Rhenium metal superconducts at 1 @. @ 697 ± 0 @. @ 006 K.

In bulk form and at room temperature and atmospheric pressure , the element resists alkalis , sulfuric acid , hydrochloric acid , dilute (but not concentrated) nitric acid , and aqua regia .

= = = Isotopes = = =

Rhenium has one stable isotope , rhenium @-@ 185 , which nevertheless occurs in minority abundance , a situation found only in two other elements (indium and tellurium) . Naturally occurring rhenium is only 37 @. @ 4 % ^{185}Re , and 62 @. @ 6 % ^{187}Re , which is unstable but has a very long half @-@ life (? 1010 years) . This lifetime can be greatly affected by the charge state of rhenium atom . The beta decay of ^{187}Re is used for rhenium @-@ osmium dating of ores . The available energy for this beta decay (2 @. @ 6 keV) is one of the lowest known among all radionuclides . The isotope rhenium @-@ 186m is notable as being one of the longest lived metastable isotopes with a half @-@ life of around 200 @, @ 000 years . There are twenty @-@ five other recognized radioactive isotopes of rhenium .

= = = Compounds = = =

Rhenium compounds are known for all the oxidation states between ? 3 and + 7 except ? 2 . The oxidation states + 7 , + 6 , + 4 , and + 2 are the most common . Rhenium is most available commercially as salts of perrhenate , including sodium and ammonium perrhenates . These are white , water @-@ soluble compounds .

= = = Halides and oxyhalides = = =

The most common rhenium chlorides are ReCl_6 , ReCl_5 , ReCl_4 , and ReCl_3 . The structures of these compounds often feature extensive Re @-@ Re bonding , which is characteristic of this metal in oxidation states lower than VII . Salts of [Re_2Cl_8] 2 ? feature a quadruple metal @-@ metal bond . Although the highest rhenium chloride features Re (VI) , fluorine gives the d0 Re (VII) derivative rhenium heptafluoride . Bromides and iodides of rhenium are also well known .

Like tungsten and molybdenum , with which it shares chemical similarities , rhenium forms a variety of oxyhalides . The oxychlorides are most common , and include ReOCl_4 , ReOCl_3 .

= = = Oxides and sulfides = = =

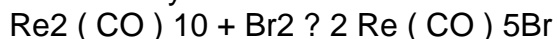
The most common oxide is the volatile colourless Re_2O_7 . Rhenium trioxide ReO_3 adopts a perovskite @-@ like structure . Other oxides include Re_2O_5 , ReO_2 , and Re_2O_3 . The sulfides are ReS_2 and Re_2S_7 . Perrhenate salts can be converted to tetrathioperrhenate by the action of ammonium hydrosulfide .

= = = Other compounds = = =

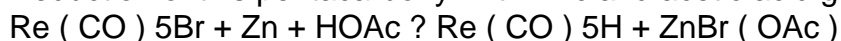
Rhenium diboride (ReB_2) is a hard compound having the hardness similar to that of tungsten carbide , silicon carbide , titanium diboride or zirconium diboride .

= = = Organorhenium compounds = = =

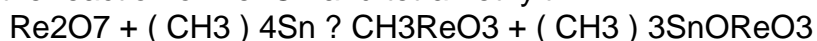
Dirhenium decacarbonyl is the most common entry to organorhenium chemistry . Its reduction with sodium amalgam gives $\text{Na} [\text{Re} (\text{CO})_5]$ with rhenium in the formal oxidation state -1 . Dirhenium decacarbonyl can be oxidised with bromine to bromopentacarbonylrhenium (I) :



Reduction of this pentacarbonyl with zinc and acetic acid gives pentacarbonylhydridorhenium :



Methylrhenium trioxide (" MTO ") , CH_3ReO_3 is a volatile , colourless solid has been used as a catalyst in some laboratory experiments . It can be prepared by many routes , a typical method is the reaction of Re_2O_7 and tetramethyltin :



Analogous alkyl and aryl derivatives are known . MTO catalyses for the oxidations with hydrogen peroxide . Terminal alkynes yield the corresponding acid or ester , internal alkynes yield diketones , and alkenes give epoxides . MTO also catalyses the conversion of aldehydes and diazoalkanes into an alkene .

== Nonahydridorhenate ==

A distinctive derivative of rhenium is nonahydridorhenate , originally thought to be the rhenide anion , Re^- , but actually containing the ReH_2^- 9 anion in which the oxidation state of rhenium is $+7$.

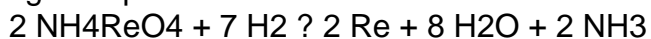
9 anion in which the oxidation state of rhenium is $+7$.

== Occurrence ==

Rhenium is one of the rarest elements in Earth 's crust with an average concentration of 1 ppb ; other sources quote the number of 0 .@ 5 ppb making it the 77th most abundant element in Earth 's crust . Rhenium is probably not found free in nature (its possible natural occurrence is uncertain) , but occurs in amounts up to 0 .@ 2 % in the mineral molybdenite (which is primarily molybdenum disulfide) , the major commercial source , although single molybdenite samples with up to 1 .@ 88 % have been found . Chile has the world 's largest rhenium reserves , part of the copper ore deposits , and was the leading producer as of 2005 . It was only recently that the first rhenium mineral was found and described (in 1994) , a rhenium sulfide mineral (ReS_2) condensing from a fumarole on Russia 's Kudriavyy volcano , Iturup island , in the Kuril Islands . Kudriavyy discharges up to 20 ? 60 kg rhenium per year mostly in the form of rhenium disulfide . Named rheniite , this rare mineral commands high prices among collectors .

== Production ==

Commercial rhenium is extracted from molybdenum roaster @-@ flue gas obtained from copper @-@ sulfide ores . Some molybdenum ores contain 0 .@ 001 % to 0 .@ 2 % rhenium . Rhenium (VII) oxide and perrhenic acid readily dissolve in water ; they are leached from flue dusts and gasses and extracted by precipitating with potassium or ammonium chloride as the perrhenate salts , and purified by recrystallization . Total world production is between 40 and 50 tons / year ; the main producers are in Chile , the United States , Peru , and Poland . Recycling of used Pt @-@ Re catalyst and special alloys allow the recovery of another 10 tons per year . Prices for the metal rose rapidly in early 2008 , from \$ 1000 ? \$ 2000 per kg in 2003 ? 2006 to over \$ 10 @, @ 000 in February 2008 . The metal form is prepared by reducing ammonium perrhenate with hydrogen at high temperatures :



== Applications ==

Rhenium is added to high @-@ temperature superalloys that are used to make jet engine parts ,

using 70 % of the worldwide rhenium production . Another major application is in platinum ? rhenium catalysts , which are primarily used in making lead @-@ free , high @-@ octane gasoline .

= = = Alloys = = =

The nickel @-@ based superalloys have improved creep strength with the addition of rhenium . The alloys normally contain 3 % or 6 % of rhenium . Second @-@ generation alloys contain 3 % ; these alloys were used in the engines for the F @-@ 15 and F @-@ 16 , whereas the newer single @-@ crystal third @-@ generation alloys contain 6 % of rhenium ; they are used in the F @-@ 22 and F @-@ 35 engines . Rhenium is also used in the superalloys , such as CMSX @-@ 4 (2nd gen) and CMSX @-@ 10 (3rd gen) that are used in industrial gas turbine engines like the GE 7FA . Rhenium can cause superalloys to become microstructurally unstable , forming undesirable TCP (topologically close packed) phases . In 4th- and 5th @-@ generation superalloys , ruthenium is used to avoid this effect . Among others the new superalloys are EPM @-@ 102 (with 3 % Ru) and TMS @-@ 162 (with 6 % Ru) , as well as TMS @-@ 138 and TMS @-@ 174 .

For 2006 , the consumption is given as 28 % for General Electric , 28 % Rolls @-@ Royce plc and 12 % Pratt & Whitney , all for superalloys , whereas the use for catalysts only accounts for 14 % and the remaining applications use 18 % . In 2006 , 77 % of the rhenium consumption in the United States was in alloys . The rising demand for military jet engines and the constant supply made it necessary to develop superalloys with a lower rhenium content . For example , the newer CFM International CFM56 high @-@ pressure turbine (HPT) blades will use Rene N515 with a rhenium content of 1 @-@ 5 % instead of Rene N5 with 3 % .

Rhenium improves the properties of tungsten . Tungsten @-@ rhenium alloys are more ductile at low temperature , allowing them to be more easily machined . The high @-@ temperature stability is also improved . The effect increases with the rhenium concentration , and therefore tungsten alloys are produced with up to 27 % of Re , which is the solubility limit . One application for the tungsten @-@ rhenium alloys is X @-@ ray sources . The high melting point of both compounds , together with the high atomic mass , makes them stable against the prolonged electron impact . Rhenium tungsten alloys are also applied as thermocouples to measure temperatures up to 2200 ° C.

The high temperature stability , low vapor pressure , good wear resistance and ability to withstand arc corrosion of rhenium are useful in self @-@ cleaning electrical contacts . In particular , the discharge occurring during the switching oxidizes the contacts . However , rhenium oxide Re_2O_7 has poor stability (sublimates at ~ 360 ° C) and therefore is removed during the discharge .

Rhenium has a high melting point and a low vapor pressure similar to tantalum and tungsten . Therefore , rhenium filaments exhibit a higher stability if the filament is operated not in vacuum , but in oxygen @-@ containing atmosphere . Those filaments are widely used in mass spectrometers , in ion gauges and in photoflash lamps in photography .

= = = Catalysts = = =

Rhenium in the form of rhenium @-@ platinum alloy is used as catalyst for catalytic reforming , which is a chemical process to convert petroleum refinery naphthas with low octane ratings into high @-@ octane liquid products . Worldwide , 30 % of catalysts used for this process contain rhenium . The olefin metathesis is the other reaction for which rhenium is used as catalyst . Normally Re_2O_7 on alumina is used for this process . Rhenium catalysts are very resistant to chemical poisoning from nitrogen , sulfur and phosphorus , and so are used in certain kinds of hydrogenation reactions .

= = = Other uses = = =

The isotopes ^{188}Re and ^{186}Re are radioactive and are used for treatment of liver cancer . They both have similar penetration depth in tissue (5 mm for ^{186}Re and 11 mm for ^{188}Re) , but ^{186}Re has advantage of longer lifetime (90 hours vs. 17 hours) .

^{188}Re is also being used experimentally in a novel treatment of pancreatic cancer where it is delivered by means of the bacterium *Listeria monocytogenes* .

Related by periodic trends , rhenium has a similar chemistry to that of technetium ; work done to label rhenium onto target compounds can often be translated to technetium . This is useful for radiopharmacy , where it is difficult to work with technetium ? especially the $^{99\text{m}}$ isotope used in medicine ? due to its expense and short half @-@ life .

= = Precautions = =

Very little is known about the toxicity of rhenium and its compounds because they are used in very small amounts . Soluble salts , such as the rhenium halides or perrhenates , could be hazardous due to elements other than rhenium or due to rhenium itself . Only a few compounds of rhenium have been tested for their acute toxicity ; two examples are potassium perrhenate and rhenium trichloride , which were injected as a solution into rats . The perrhenate had an LD50 value of 2800 mg / kg after seven days (this is very low toxicity , similar to that of table salt) and the rhenium trichloride showed LD50 of 280 mg / kg .