= Tellurium =

Tellurium is a chemical element with symbol Te and atomic number 52 . It is a brittle , mildly toxic , rare , silver @-@ white metalloid . Tellurium is chemically related to selenium and sulfur . It is occasionally found in native form , as elemental crystals . Tellurium is far more common in the universe as a whole than it is on Earth . Its extreme rarity in the Earth 's crust , comparable to that of platinum , is partly due to its high atomic number , but also due to its formation of a volatile hydride which caused the element to be lost to space as a gas during the hot nebular formation of the planet .

Tellurium was discovered in the Habsburg Empire , in 1782 by Franz @-@ Joseph Müller von Reichenstein in a mineral containing tellurium and gold . Martin Heinrich Klaproth named the new element in 1798 after the Latin word for " earth " , tellus . Gold telluride minerals are the most notable natural gold compounds . However , they are not a commercially significant source of tellurium itself , which is normally extracted as a by @-@ product of copper and lead production .

Commercially , the primary use of tellurium is in alloys , foremost in steel and copper to improve machinability . Applications in CdTe solar panels and as a semiconductor material also consume a considerable fraction of tellurium production .

Tellurium has no biological function , although fungi can incorporate it in place of sulfur and selenium into amino acids such as tellurocysteine and telluromethionine . In humans , tellurium is partly metabolized into dimethyl telluride , (CH3) 2Te , a gas with a garlic @-@ like odor which is exhaled in the breath of victims of tellurium toxicity or exposure .

= = Characteristics = =

= = = Physical properties = = =

Tellurium has two allotropes , crystalline and amorphous . When crystalline , tellurium is silvery @-@ white and when it is in pure state it has a metallic luster . It is a brittle and easily pulverized metalloid . Amorphous tellurium is a black @-@ brown powder prepared by precipitating it from a solution of tellurous acid or telluric acid (Te (OH) 6) . Tellurium is a semiconductor that shows a greater electrical conductivity in certain directions which depends on atomic alignment ; the conductivity increases slightly when exposed to light (photoconductivity) . When in its molten state , tellurium is corrosive to copper , iron and stainless steel . Of the chalcogens , tellurium has the highest melting and boiling points , at 722 @.@ 66 K (841 @.@ 12 ° F) and 1 @,@ 261 K (1 @,@ 810 ° F) , respectively .

= = = Chemical properties = = =

Tellurium adopts a polymeric structure , consisting of zig @-@ zag chains of Te atoms . This gray material resists oxidation by air and is nonvolatile .

= = = Isotopes = = =

Naturally occurring tellurium has eight isotopes . Five of those isotopes , 122Te , 123Te , 124Te , 125Te and 126Te , are stable . The other three , 120Te , 128Te and 130Te , have been observed to be radioactive . The stable isotopes make up only 33 @.@ 2 % of the naturally occurring tellurium ; this is possibly due to the long half @-@ lives of the unstable isotopes . They are in the range from 1013 to 2 @.@ 2 × 1024 years (for 128Te) . This makes 128Te the isotope with the longest half life among all radionuclides , which is approximately 160 trillion (1012) times the age of the known universe .

There are 38 known nuclear isomers of tellurium with atomic masses that range from 105 to 142 . Tellurium is among the lightest elements known to undergo alpha decay , with isotopes 106Te to

110Te being able to undergo this mode of decay . The atomic mass of tellurium (127 @.@ 60 g · mol ? 1) exceeds that of the following element iodine (126 @.@ 90 g · mol ? 1) .

= = = Occurrence = = =

With an abundance in the Earth 's crust comparable to that of platinum , tellurium is one of the rarest stable solid elements in the Earth 's crust . Its abundance is about 1 µg / kg . In comparison , even the rarest of the lanthanides have crustal abundances of 500 µg / kg (see Abundance of the chemical elements) .

The extreme rarity of tellurium in the Earth 's crust is not a reflection of its cosmic abundance , which is in fact greater than that of rubidium , even though rubidium is ten thousand times more abundant in the Earth 's crust . The extraordinarily low abundance of tellurium on Earth is rather thought to be due to conditions in the Earth 's formation , when the stable form of certain elements , in the absence of oxygen and water , was controlled by the reductive power of free hydrogen . Under this scenario , certain elements such as tellurium which form volatile hydrides were severely depleted during the formation of the Earth 's crust , through evaporation of these hydrides . Tellurium and selenium are the heavy elements most depleted in the Earth 's crust by this process .

Tellurium is sometimes found in its native (i.e. , elemental) form , but is more often found as the tellurides of gold such as calaverite and krennerite (two different polymorphs of AuTe2) , petzite , Ag3AuTe2 , and sylvanite , AgAuTe4 . The city of Telluride , Colorado was named in hope of a strike of gold telluride (which never materialized , though gold metal ore was found) . Gold itself is usually found uncombined , but when found naturally as a chemical compound , it is most often combined with tellurium .

Although tellurium is found with gold more often than in uncombined form , it is found even more often combined with elements other than gold , as tellurides of more common metals (e.g. melonite , NiTe2) . Natural tellurite and tellurate minerals also occur , formed by oxidation of tellurides near the Earth 's surface . In contrast to selenium , tellurium is not in general able to replace sulfur in its minerals , due to the large difference in ion radius of sulfur and tellurium . In consequence , many common sulfide minerals contain considerable amounts of selenium , but only traces of tellurium .

In the gold rush of 1893 , diggers in Kalgoorlie discarded a pyritic material which got in their way as they searched for pure gold . The Kalgoorlie waste was thus used to fill in potholes or as part of sidewalks . Three years passed before it was realized that this waste was calaverite , a telluride of gold that had not been recognized . This led to a second gold rush in 1896 which included mining the streets .

= = History = =

Tellurium (Latin tellus meaning " earth ") was discovered in the 18th century in a gold ore from the mines in Zlatna , near today 's city of Alba Iulia , Romania . This ore was known as " Faczebajer weißes blättriges Golderz " (white leafy gold ore from Faczebaja , German name of Facebánya , now Fa?a B?ii in Alba County) or antimonalischer Goldkies (antimonic gold pyrite) , and , according to Anton von Rupprecht , was Spießglaskönig (argent molybdique) , containing native antimony . In 1782 Franz @-@ Joseph Müller von Reichenstein , who was then serving as the Austrian chief inspector of mines in Transylvania , concluded that the ore did not contain antimony , but that it was bismuth sulfide . The following year , he reported that this was erroneous and that the ore contained mostly gold and an unknown metal very similar to antimony . After a thorough investigation which lasted for three years and consisted of more than fifty tests , Müller determined the specific gravity of the mineral and noted the radish @-@ like odor of the white smoke which passed off when the new metal was heated , the red color which the metal imparts to sulfuric acid , and the black precipitate which this solution gives when diluted with water . Nevertheless , he was not able to identify this metal and gave it the names aurum paradoxium and metallum problematicum , as it did not show the properties predicted for the expected antimony .

In 1789 , a Hungarian scientist , Pál Kitaibel , also discovered the element independently in an ore

from Deutsch @-@ Pilsen which had been regarded as argentiferous molybdenite , but later he gave the credit to Müller . In 1798 , it was named by Martin Heinrich Klaproth who had earlier isolated it from the mineral calaverite .

The 1960s brought growth in thermoelectric applications for tellurium (as bismuth telluride) , as well as its use in free @-@ machining steel , which became the dominant use .

= = Production = =

The principal source of tellurium is from anode sludges produced during the electrolytic refining of blister copper . It is a component of dusts from blast furnace refining of lead . Treatment of 1000 tons of copper ore typically yields one kilogram (2 @.@ 2 pounds) of tellurium . Tellurium is produced mainly in the United States , Peru , Japan and Canada . For the year 2009 the British Geological Survey gives the following numbers : United States 50 t , Peru 7 t , Japan 40 t and Canada 16 t .

The anode sludges contain the selenides and tellurides of the noble metals in compounds with the formula M2Se or M2Te (M = Cu , Ag , Au) . At temperatures of 500 ° C the anode sludges are roasted with sodium carbonate under air . The metal ions are reduced to the metals , while the telluride is converted to sodium tellurite .

M2Te + O2 + Na2CO3 ? Na2TeO3 + 2 M + CO2

Tellurites can be leached from the mixture with water and are normally present as hydrotellurites HTeO3 ? in solution . Selenites are also formed during this process , but they can be separated by adding sulfuric acid . The hydrotellurites are converted into the insoluble tellurium dioxide while the selenites stay in solution .

HTeO ?
3 + OH ? + H2SO4 ? TeO2 + SO2 ?
4 + 2 H2O

The reduction to the metal is done either by electrolysis or by reacting the tellurium dioxide with sulfur dioxide in sulfuric acid .

TeO2 + 2 SO2 + 2H2O ? Te + 2 SO2 ?
4 + 4 H +

Commercial @-@ grade tellurium is usually marketed as 200 @-@ mesh powder but is also available as slabs , ingots , sticks , or lumps . The year @-@ end price for tellurium in 2000 was US $ 14 per pound . In recent years , the tellurium price was driven up by increased demand and limited supply , reaching as high as US $ 100 per pound in 2006 . Despite an expected doubling in production due to improved extraction methods , the United States Department of Energy (DoE) anticipates a supply shortfall of tellurium by 2025 .

= = Compounds = =

Tellurium belongs to the same chemical family as oxygen , sulfur , selenium and polonium : the chalcogen family . Tellurium and selenium compounds are similar . It exhibits the oxidation states ? 2 , + 2 , + 4 and + 6 , with the + 4 state being most common .

Tellurides

Reduction of Te metal produces the tellurides and polytellurides , Ten2 ? . The ? 2 oxidation state is exhibited in binary compounds with many metals , such as zinc telluride , ZnTe , formed by heating tellurium with zinc . Decomposition of ZnTe with hydrochloric acid yields hydrogen telluride (H
2Te) , a highly unstable analogue of the other chalcogen hydrides , H
2O , H
2S and H
2Se :
ZnTe + 2 HCl ? ZnCl
2 + H
2Te

H
2Te is unstable , whereas salts of its conjugate base [TeH] ? are stable .
Halides
The + 2 oxidation state is exhibited by the dihalides , TeCl
2 , TeBr
2 and TeI
2 . The dihalides have not been obtained in pure form , although they are known decomposition products of the tetrahalides in organic solvents , and their derived tetrahalotellurates are well @-@ characterized :
Te + X
2 + 2 X ? ? TeX2 ?
4
where X is Cl , Br , or I. These anions are square planar in geometry . Polynuclear anionic species also exist , such as the dark brown Te
2I2 ?
6 , and the black Te
4I2 ?
14 .
Fluorine forms two halides with tellurium : the mixed @-@ valence Te
2F
4 and TeF
6 . In the + 6 oxidation state , the ? OTeF
5 structural group occurs in a number of compounds such as HOTeF
5 , B (OTeF
5)
3 , Xe (OTeF
5)
2 , Te (OTeF
5)
4 and Te (OTeF
5)
6 . The square antiprismatic anion TeF2 ?
8 is also attested . The other halogens do not form halides with tellurium in the + 6 oxidation state , but only tetrahalides (TeCl
4 , TeBr
4 and TeI
4) in the + 4 state , and other lower halides (Te
3Cl
2 , Te
2Cl
2 , Te
2Br
2 , Te
2I and two forms of TeI) . In the + 4 oxidation state , halotellurate anions are known , such as TeCl2 ?
6 and Te
2Cl2 ?
10 . Halotellurium cations are also attested , including TeI +
3 , found in TeI
3AsF
6 .
Oxocompounds
Tellurium monoxide was first reported in 1883 as a black amorphous solid formed by the heat

decomposition of TeSO
3 in vacuum , disproportionating into tellurium dioxide , TeO
2 and elemental tellurium upon heating . Since then , however , some doubt has been cast on its existence in the solid phase , although it is known as a vapor phase fragment ; the black solid may be merely an equimolar mixture of elemental tellurium and tellurium dioxide .
Tellurium dioxide is formed by heating tellurium in air , causing it to burn with a blue flame . Tellurium trioxide , ? @-@ TeO
3 , is obtained by thermal decomposition of Te (OH)
6 . The other two forms of trioxide reported in the literature , the ?- and ?- forms , were found not to be true oxides of tellurium in the + 6 oxidation state , but a mixture of Te4 + , OH ? and O ?
2 . Tellurium also exhibits mixed @-@ valence oxides , Te
2O
5 and Te
4O
9 .
The tellurium oxides and hydrated oxides form a series of acids , including tellurous acid (H
2TeO
3) , orthotelluric acid (Te (OH)
6) and metatelluric acid ((H
2TeO
4) n) . The two forms of telluric acid form tellurate salts containing the TeO2 ?
4 and TeO6 ?
6 anions , respectively . Tellurous acid forms tellurite salts containing the anion TeO2 ?
3 . Other tellurium cations include TeF2 +
8 , which consists of two fused tellurium rings and the polymeric TeF2 +
7 .
Zintl cations
When tellurium is treated with concentrated sulfuric acid , it forms red solutions containing the Zintl ion , Te2 +
4 . The oxidation of tellurium by AsF
5 in liquid SO
2 also produces this square planar cation , as well as with the trigonal prismatic , yellow @-@ orange Te4 +
6 :
4 Te + 3 AsF
5 ? Te2 +
4 (AsF ?
6)
2 + AsF
3
6 Te + 6 AsF
5 ? Te4 +
6 (AsF ?
6)
4 + 2 AsF
3
Other tellurium Zintl cations include the polymeric Te2 +
7 and the blue @-@ black Te2 +
8 , which consists of two fused 5 @-@ membered tellurium rings . The latter cation is formed by the reaction of tellurium with tungsten hexachloride :
8 Te + 2 WCl
6 ? Te2 +
8 (WCl ?

6)
2
Interchalcogen cations also exist , such as Te
2Se2 +
6 (distorted cubic geometry) and Te
2Se2 +
8 . These are formed by oxidizing mixtures of tellurium and selenium with AsF
5 or SbF
5 .
Organotellurium compounds
Tellurium does not readily form analogues of alcohols and thiols , with the functional group ? TeH and are called tellurols . The ? TeH functional group is also attributed to using the prefix tellanyl- . Like H2Te , these species are unstable with respect to loss of hydrogen . Telluraethers (R @-@ Te @-@ R) are more stable as are telluroxides .

= = Applications = =

= = = Metallurgy = = =

The largest consumer of tellurium is metallurgy , where it is used in iron , copper and lead alloys . When added to stainless steel and copper it makes these metals more machinable . It is alloyed into cast iron for promoting chill for spectroscopic purposes , as the presence of electrically conductive free graphite tends to deleteriously affect spark emission testing results . In lead it improves strength and durability and decreases the corrosive action of sulfuric acid .

= = = Semiconductor and electronic industry uses = = =

Tellurium is used in cadmium telluride (CdTe) solar panels . National Renewable Energy Laboratory lab tests using this material achieved some of the highest efficiencies for solar cell electric power generation . Massive commercial production of CdTe solar panels by First Solar in recent years has significantly increased tellurium demand . If some of the cadmium in CdTe is replaced by zinc then (Cd , Zn) Te is formed which is used in solid @-@ state X @-@ ray detectors .
Alloyed with both cadmium and mercury , to form mercury cadmium telluride , an infrared sensitive semiconductor material is formed . Organotellurium compounds such as dimethyl telluride , diethyl telluride , diisopropyl telluride , diallyl telluride and methyl allyl telluride are used as precursors for metalorganic vapor phase epitaxy growth of II @-@ VI compound semiconductors . Diisopropyl telluride (DIPTe) is employed as the preferred precursor for achieving the low @-@ temperature growth of CdHgTe by MOVPE . For these processes highest purity metalorganics of both selenium and tellurium are used . The compounds for semiconductor industry and are prepared by adduct purification .
Tellurium as a tellurium suboxide is used in the media layer of several types of rewritable optical discs , including ReWritable Compact Discs (CD @-@ RW) , ReWritable Digital Video Discs (DVD @-@ RW) and ReWritable Blu @-@ ray Discs .
Tellurium dioxide is used to create acousto @-@ optic modulators (AOTFs and AOBSs) for confocal microscropy .
Tellurium is used in the new phase change memory chips developed by Intel . Bismuth telluride (Bi2Te3) and lead telluride are working elements of thermoelectric devices . Lead telluride is used in far @-@ infrared detectors .

= = = Other uses = = =

Used to color ceramics .

The strong increase in optical refraction upon the addition of selenides and tellurides into glass is used in the production of glass fibers for telecommunications . These chalcogenide glasses are widely used .

Mixtures of selenium and tellurium are used with barium peroxide as oxidizer in the delay powder of electric blasting caps .

Organic tellurides have been employed as initiators for living radical polymerization and electron @-@ rich mono- and di @-@ tellurides possess antioxidant activity .

Rubber can be vulcanized with tellurium instead of sulfur or selenium . The rubber produced in this way shows improved heat resistance .

Tellurite agar is used to identify members of the corynebacterium genus , most typically Corynebacterium diphtheriae , the pathogen responsible for diphtheria .

The tellurium is a key constituent of high performing mixed oxide catalysts for the heterogeneous catalytic selective oxidation of propane to acrylic acid . The surface elemental composition changes dynamically and reversibly with the reaction conditions . In the presence of steam the surface of the catalyst is enriched in tellurium and vanadium which translates into the enhancement of the acrylic acid production .

= = Biological role = =

Tellurium has no known biological function , although fungi can incorporate it in place of sulfur and selenium into amino acids such as telluro @-@ cysteine and telluro @-@ methionine . Organisms have shown a highly variable tolerance to tellurium compounds . Many cells , such as Pseudomonas aeruginosa take up tellurite and reduce it to elemental tellurium , which accumulates and causes a characteristic and often dramatic darkening of cells . In yeast , this reduction is mediated by the sulfate assimilation pathway . Tellurium accumulation seems to account for a major part of the toxicity effects . Many organisms also metabolize tellurium partly to form dimethyl telluride , although dimethyl ditelluride is also formed by some species . Dimethyl telluride has been observed in hot springs at very low concentrations .

= = Precautions = =

Tellurium and tellurium compounds are considered to be mildly toxic and need to be handled with care , although acute poisoning is rare . Tellurium poisoning is particularly difficult to treat as many chelation agents used in the treatment of metal toxicities will increase the toxicity of tellurium . Tellurium is not reported to be carcinogenic .

Humans exposed to as little as 0 @.@ 01 mg / m3 or less in air exude a foul garlic @-@ like odor known as " tellurium breath . " This is caused from the tellurium being metabolized by the body , converting it from any oxidation state to dimethyl telluride , (CH3) 2Te . This is a volatile compound with a highly pungent garlic @-@ like smell . Even though the metabolic pathways of tellurium are not known , it is generally assumed that they resemble those of the more extensively studied selenium , because the final methylated metabolic products of the two elements are similar .

People can be exposed to tellurium in the workplace by breathing it in , swallowing it , skin contact , and eye contact . The Occupational Safety and Health Administration (OSHA) has set the legal limit (Permissible exposure limit) for tellurium exposure in the workplace as 0 @.@ 1 mg / m3 over an 8 @-@ hour workday . The National Institute for Occupational Safety and Health (NIOSH) has set a recommended exposure limit (REL) of 0 @.@ 1 mg / m3 over an 8 @-@ hour workday . At levels of 25 mg / m3 , tellurium is immediately dangerous to life and health .